International Council on Systems Engineering

A better world through a systems approach

Rally the Troops!
The Secret Energies Driving All Innovation Ecosystems

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V1.2.1

Abstract

- Can “innovation systems” deliver faster, while also earning confidence in the face of risk?
- Limitations on capabilities of an engineered aircraft, bridge, or car are ultimately constrained, through their designs, by underlying first principles phenomena.
- Does this also apply to phenomena of the socio-technical innovation ecosystem itself?
- Verification and validation (V&V) are more than “checks on the main work”.
- Instead, they highlight consistency gaps which define the potential energy framework of the innovation ecosystem’s Hamiltonian, driving the entire innovation ecosystem.
- Foundational limits don’t just tell us what is impossible—they also tell us what future may be possible, including for hybrid human-AI ecosystems.
- Following is a partial tour of the descriptive landscape, to provoke thought . . . .

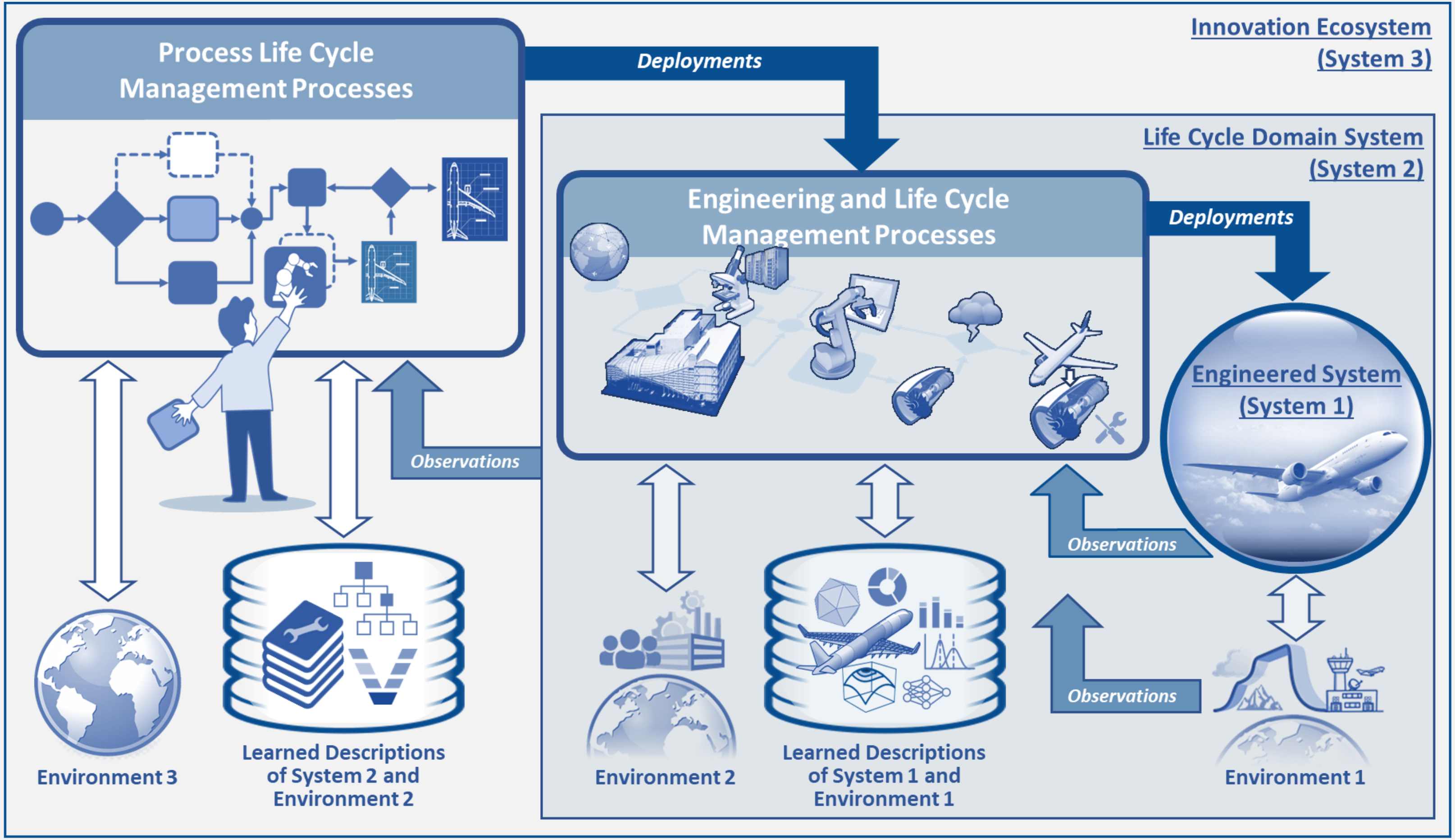
Contents

- Innovation ecosystem performance: ASELCM Reference Pattern
- Learning as ecosystem state trajectory
- VVUQ standards situation: The Rosetta Stone Project
- How to quantify inconsistency across all model & artifact types (MBSE, etc.)
- Vector spaces describe the landscape
- Inconsistency and ecosystem energy
- Questions, discussion

- References

Innovation ecosystem performance: ASELCM Reference Pattern

- INCOSE ASELCM (Agile Systems Engineering Life Cycle Mgmt) Pattern [1,2]
  - AKA The Innovation Ecosystem Pattern
- A configurable reference model used to represent ecosystem learning in particular, independent of methodology and effectiveness
- Descriptive, not prescriptive – used to study anyone’s innovation ecosystem
- Especially information artifacts themselves (models or otherwise), not just the processes that consume and produce them

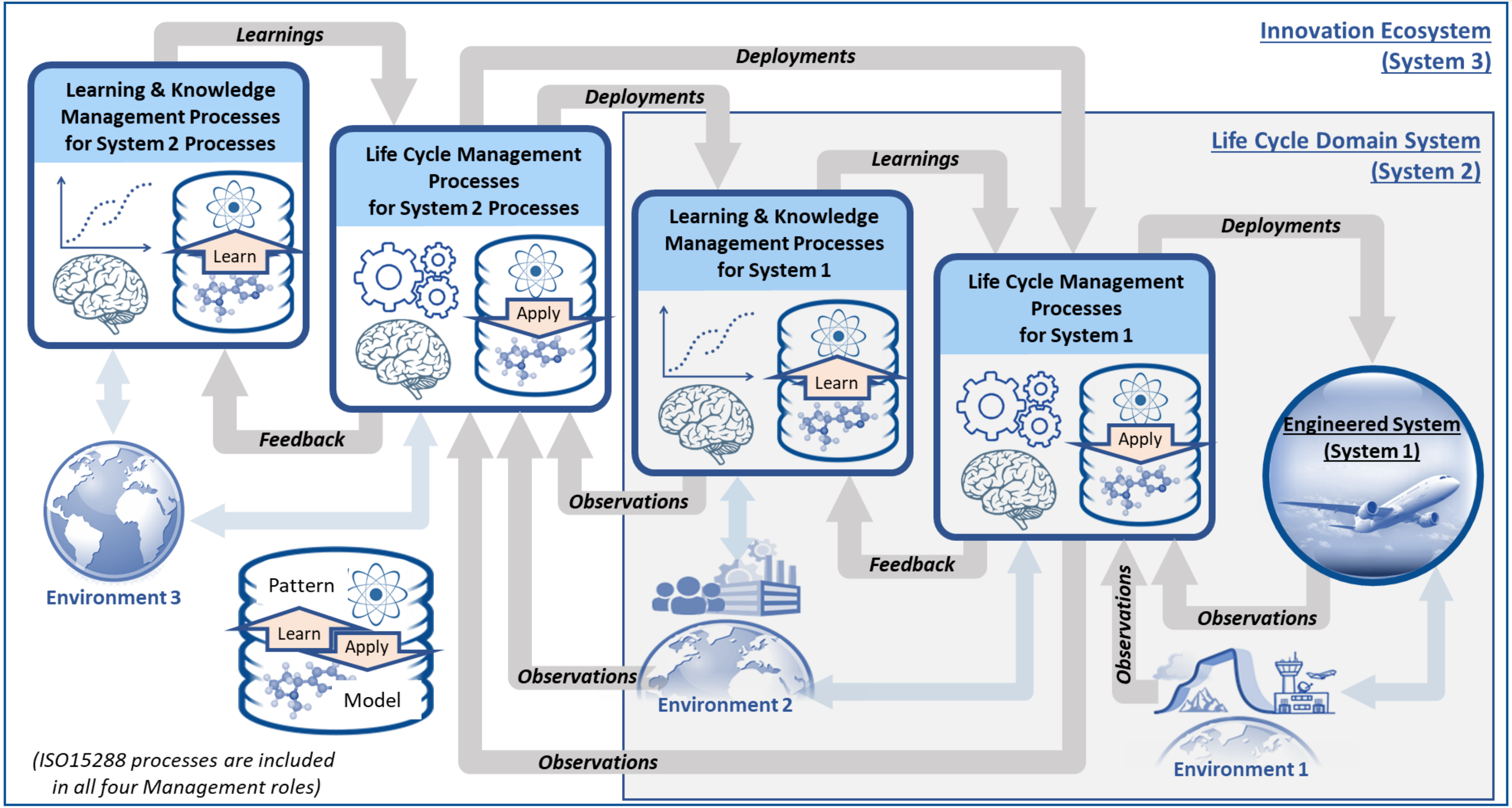


INCOSE ASELCM Level 0 Reference Model

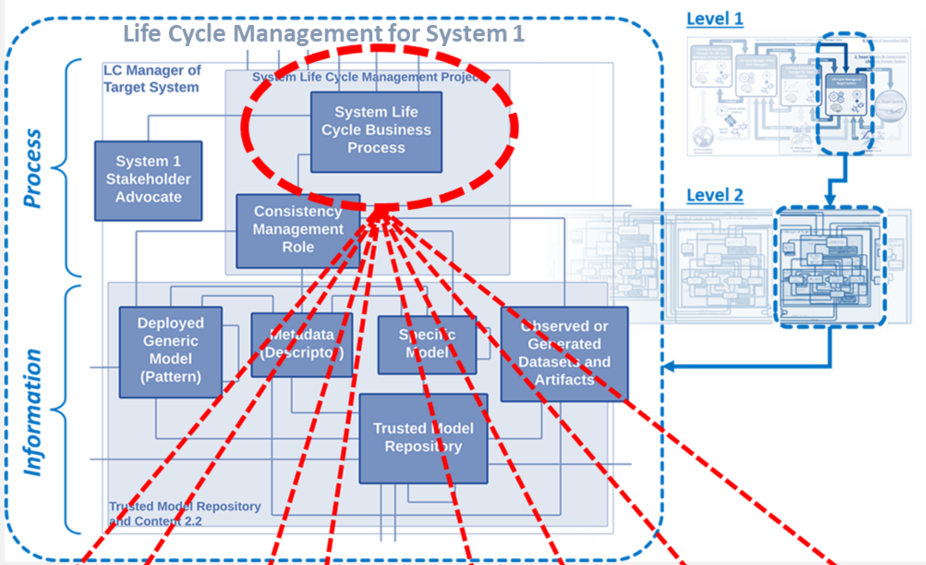
System 3: Process definition, advancement

System 2: Engineering, production, support, science

System 1: Products



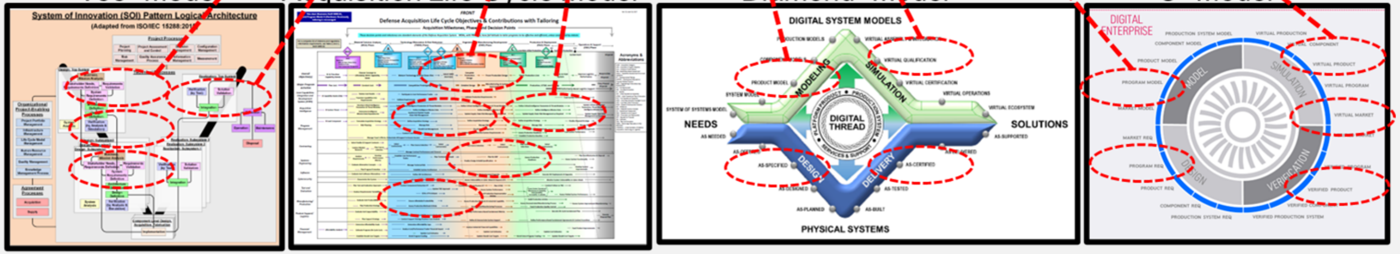
INCOSE ASELCM Level 1 Reference Model



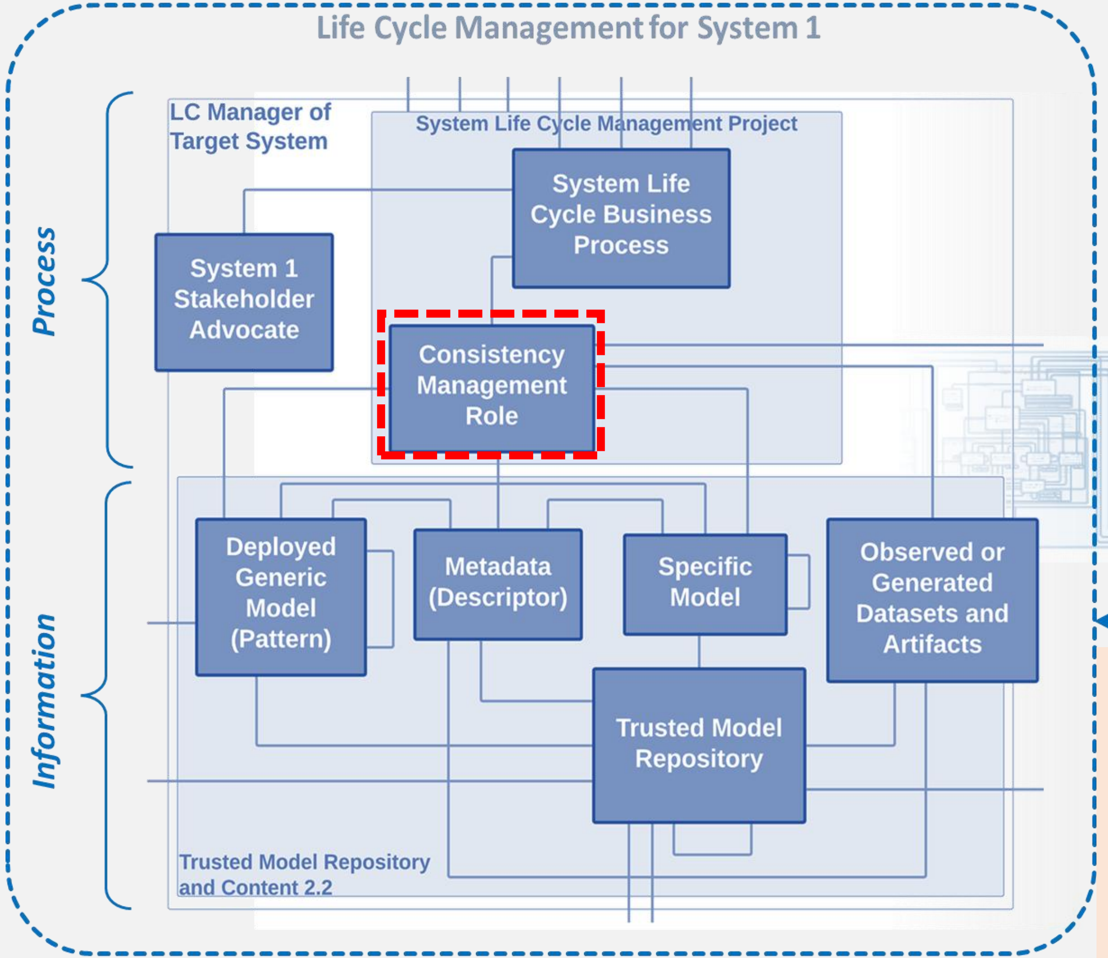
ASELCM Level 2 Roles

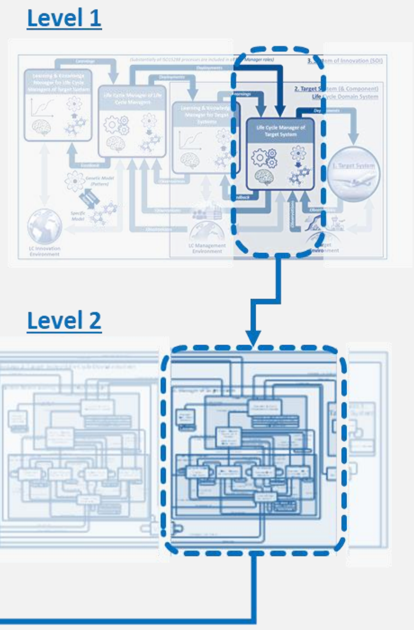
Configurable to specific life cycle management models---

ISO15288 Life Cycle "Vee" Model[1] | DoD 5000 Defense Acquisition Life Cycle Model[2] | Boeing "Diamond" Model[3] | Rolls-Royce "O" Model[4]



Excerpted or adapted from: (1) ISO15288 and INCOSE SE Handbook; (2) DoD5000 Wall Chart; (3) AIAA Sci Tech, 01.2020, J. Hatakeyama; (4) AIAA DEIC Digital Twin Subcommittee, 04.08.19 Donaldson, Flay, French, Matlik, Myer, Pond, Randjelovic





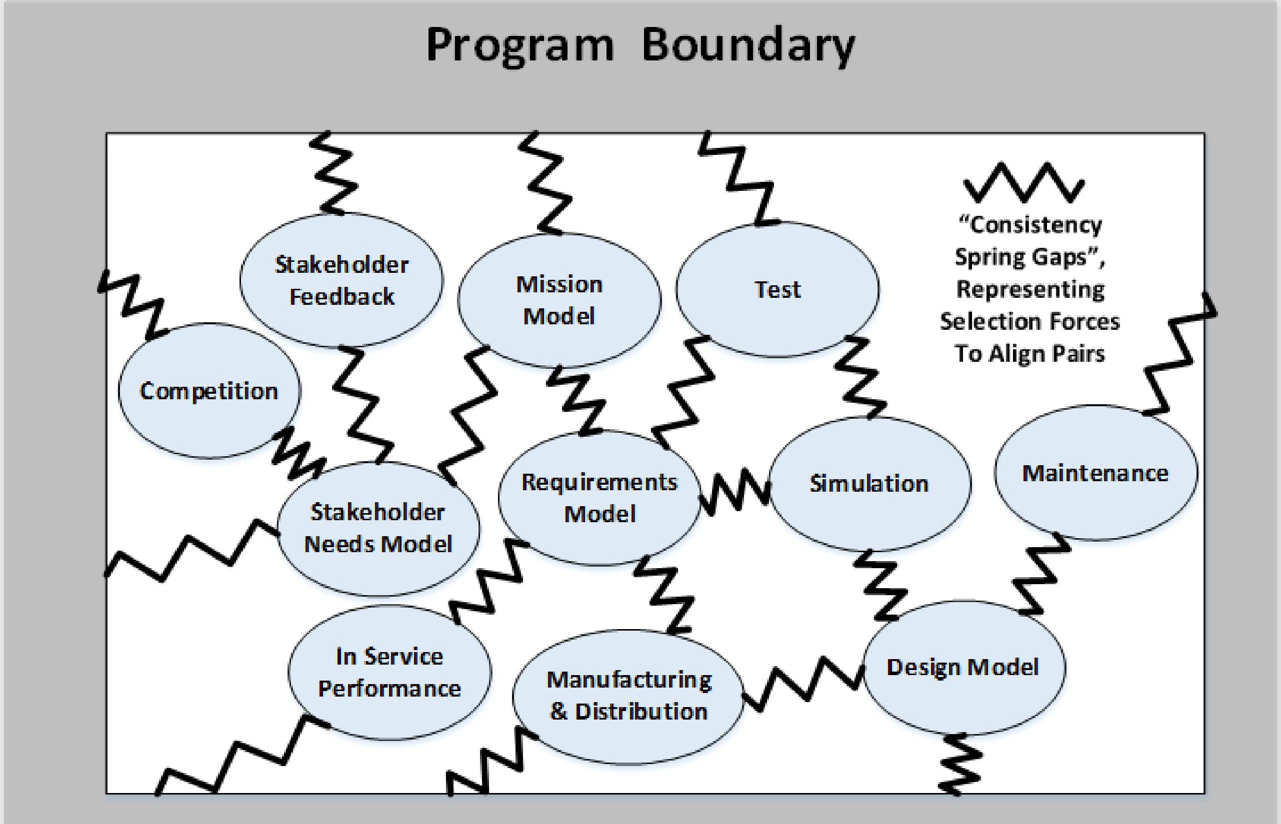
INCOSE ASELCM Level 2 Reference Model

- “Semantic interoperability” is not the central dynamics issue of achieving inter-artifact <u>content</u> consistency.

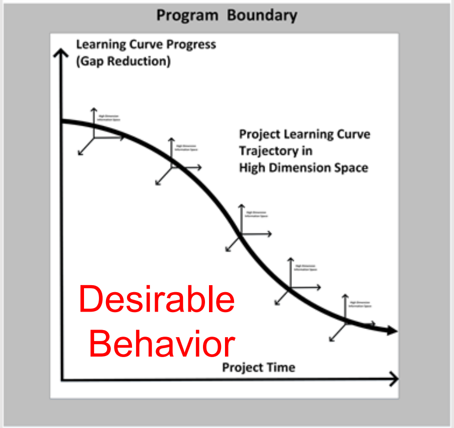
Examples:

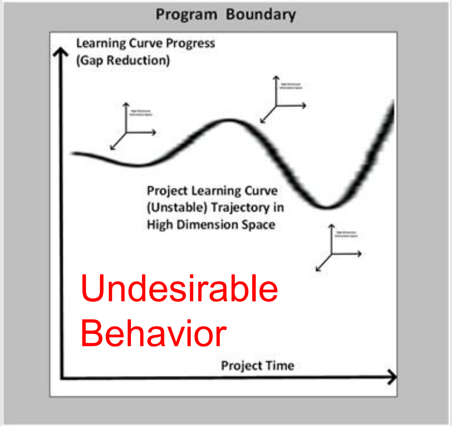
- Design not meeting Requirements
- Production Recipe inconsistent with Design

Learning as Innovation Ecosystem state trajectory



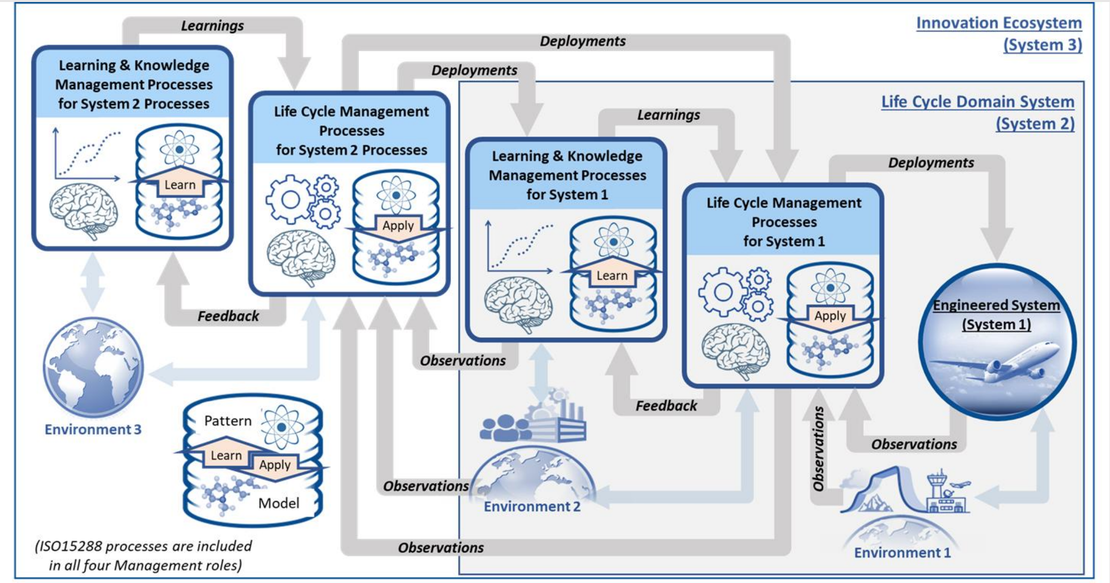
From [3]





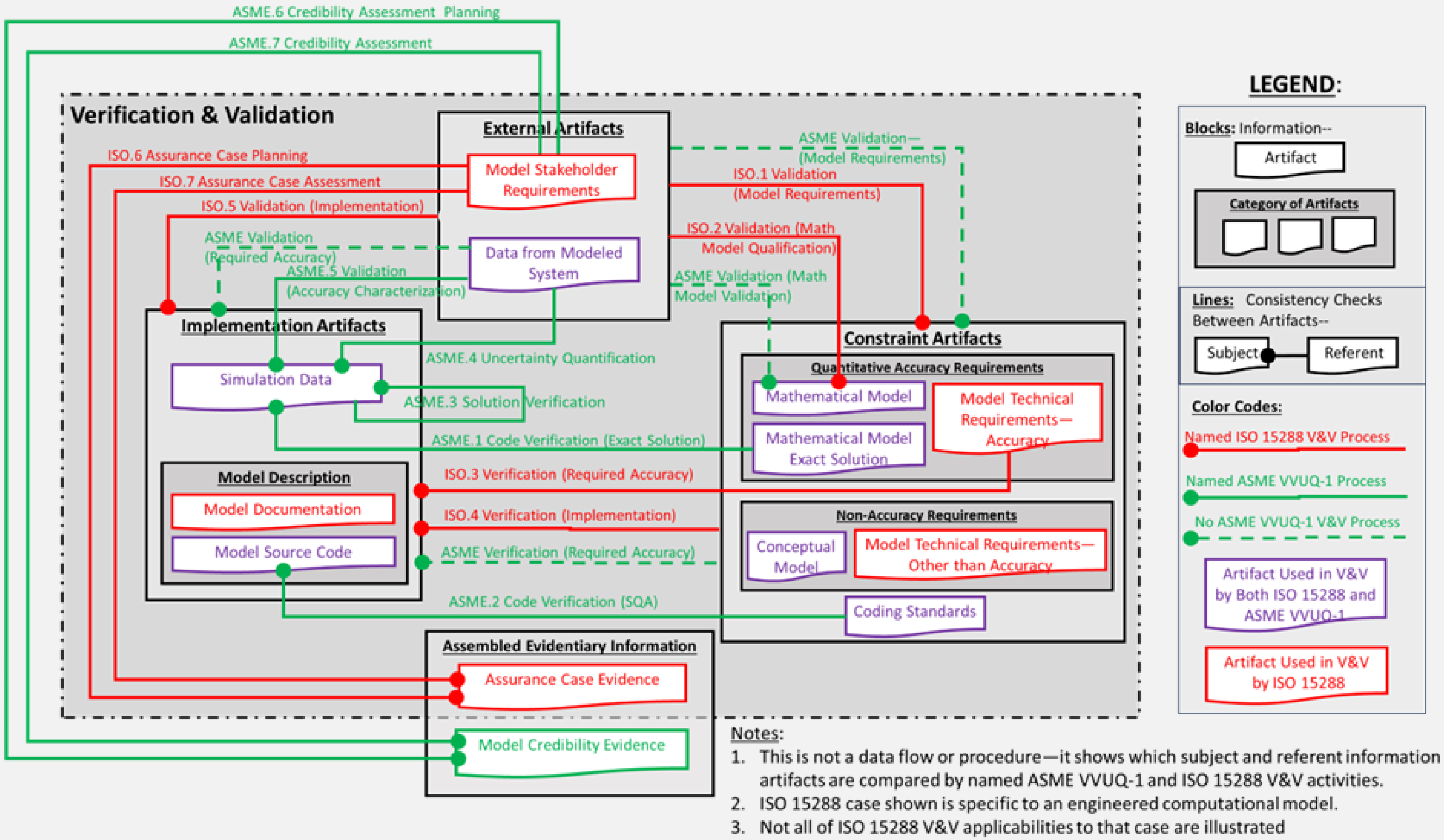
Learning as Innovation Ecosystem state trajectory

- So, what foundational laws govern the learning trajectory?
- What are the "state variables"?
- What is the "energy"?
- Insights from V&V . . . .



VVUQ standards situation: The Rosetta Stone Project

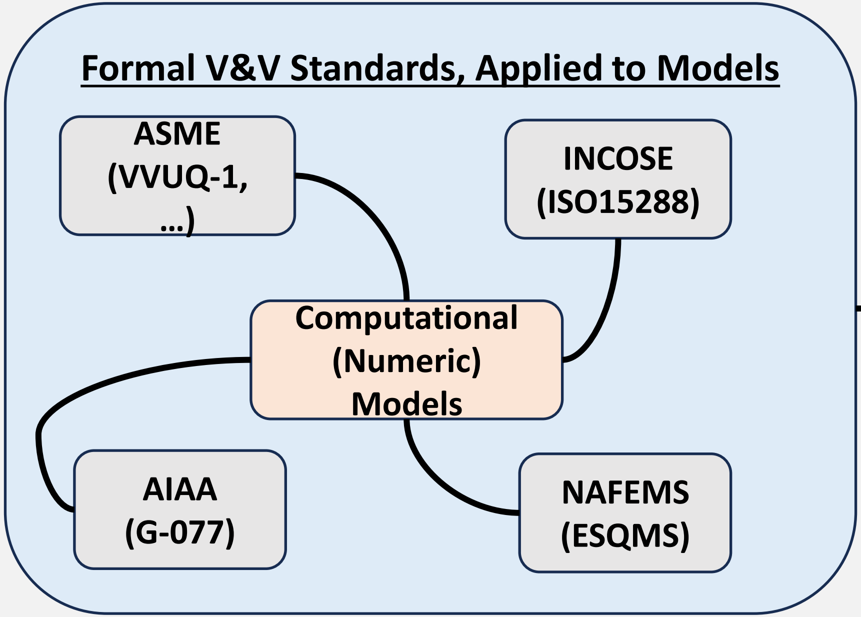
- **<u>An ASME VVUQ50 Standards Working Group Task (c. 2016)</u>**: Write a standard for managing the credibility of computational models for advanced manufacturing, across their full life cycles.
- Initial effort blended ISO-15288 V&V and ASME VVUQ-1 V&V. [4,5]
- Learned these are profoundly inconsistent views of V&V.
- Rewrote initial draft to incorporate an explicit comparison of the standards, based on use of differing "consistency pairs".
- Draft standard ASME 50.1 passed ASME VVUQ Standards Committee balloting in 2025, based on that . . . .



V&V Standards—Comparing Different “Consistency Pairs” of ISO15288 V&V versus ASME VVUQ-1 V&V. [4,5,6,7]

VVUQ standards situation: The Rosetta Stone Project

- That standards authoring journey also spawned the (separate) Rosetta Stone Project. [6]
- A joint activity of members of related committees in ASME, AIAA, INCOSE, and NAFEMS.
- Generated formal comparisons of those four societies' related V&V standards, based on consistency pairs.
- Rosetta Stone Report was published in Jan, 2025 . . .



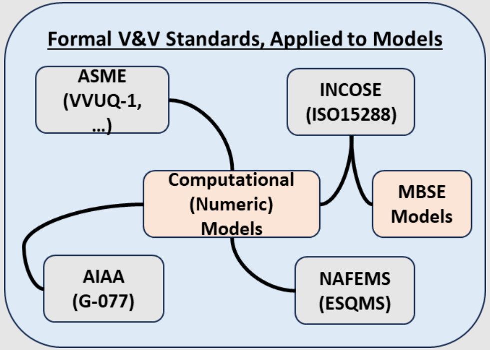
Formal V&V Standards, Applied to Models
ASME (VVUQ-1, …)
INCOSE (ISO15288)
Computational (Numeric) Models
AIAA (G-077)
NAFEMS (ESQMS)

Results of the 2024 Rosetta Stone Project—
A Cross-Societies Collaboration
ASME
VVUQ 2025
Verification, Validation, and Uncertainty Quantification Symposium
Olivia Fischer 1, Mat French 1,2
Joe Hightower 3, Alex Karl 4
John Matlik 1, Laura Pullum 3
Bill Schindel 1,2,3, Guodong Shao 3
Nigel Taylor 1,3
1 – AIAA Digital Engineering Integration Committee
2 – INCOSE/OMG MBSE Patterns Working Group
3 – ASME VV50 Model Life Cycle Working Group
4 – NAFEMS Simulation Governance Working Group
A Cross-Society Collaboration Project:
Mapping Consistency Confirmation Frameworks
of Different Communities
Phase 1 Project Report
Rosetta Stone
ASME
V1.8.5
The American Society of Mechanical Engineers

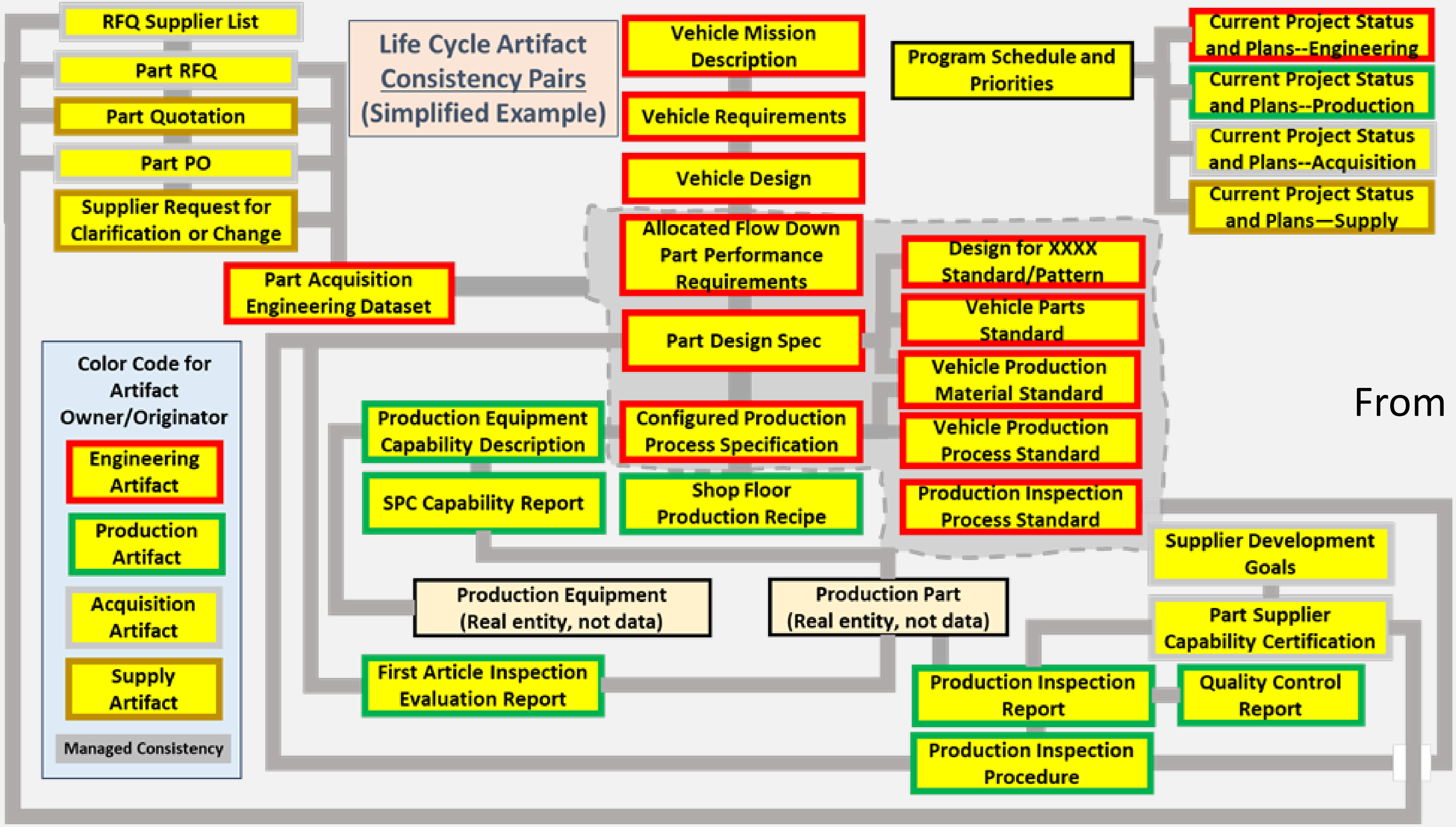
From [6]

How can inconsistency be quantified across all artifact types (MBSE included)?

- The Rosetta Stone Project also begged the question of how to measure inconsistency when the subject models are not just numerical quantitative simulations, as in computational models:
- For example, MBSE models, as well as non-model artifacts:



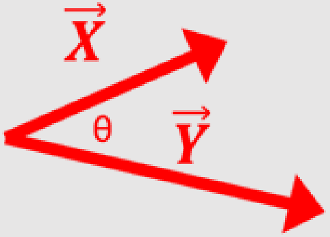
- Use of "artifact proxy models" improves consistency checking and generalizes its framework.


Life Cycle Artifact Consistency Pairs (Simplified Example)
RFQ Supplier List
Part RFQ
Part Quotation
Part PO
Supplier Request for Clarification or Change
Part Acquisition Engineering Dataset
Vehicle Mission Description
Vehicle Requirements
Vehicle Design
Allocated Flow Down Part Performance Requirements
Part Design Spec
Configured Production Process Specification
Shop Floor Production Recipe
Program Schedule and Priorities
Current Project Status and Plans--Engineering
Current Project Status and Plans--Production
Current Project Status and Plans--Acquisition
Current Project Status and Plans—Supply
Design for XXXX Standard/Pattern
Vehicle Parts Standard
Vehicle Production Material Standard
Vehicle Production Process Standard
Production Inspection Process Standard
Color Code for Artifact Owner/Originator
Engineering Artifact
Production Artifact
Acquisition Artifact
Supply Artifact
Managed Consistency
Production Equipment Capability Description
SPC Capability Report
Production Equipment (Real entity, not data)
Production Part (Real entity, not data)
First Article Inspection Evaluation Report
Supplier Development Goals
Part Supplier Capability Certification
Production Inspection Report
Quality Control Report
Production Inspection Procedure

From [8]

Vector spaces describe the landscape

- Established long ago in mathematics, and long applied by engineers: Vector spaces, metric spaces, Hilbert spaces. [9, 10, 11]
- It is also how contemporary AI does internal representation and distance calculation, *for entities in general*, although not so much in the current public AI discourse. [12, 13]
- It is also what the newer hardware is good at computing very fast, especially thanks to NVIDA GPUs, NPUs.



Systems Engineering Evolution: Hilbert Space Enables Mathematical Comparison of MBSE Model "Nearness"

Definitions [2]

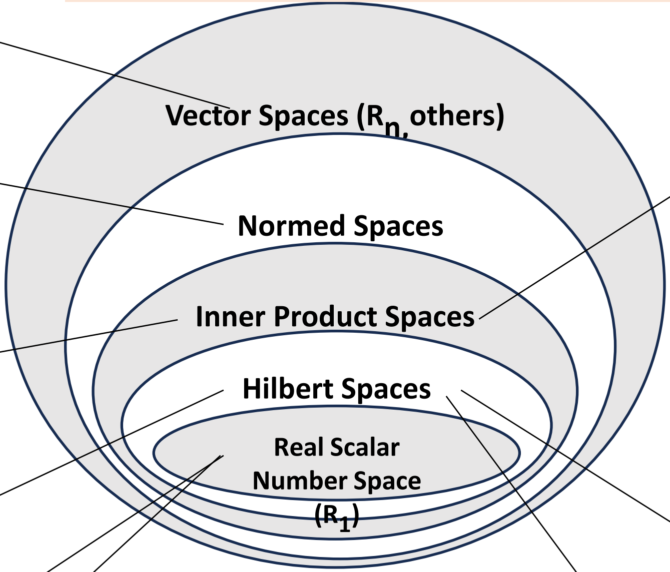
Spaces of multi-dimensional vector (V) entities, that can be added (V1+V2) and scalar multiplied (cV1).

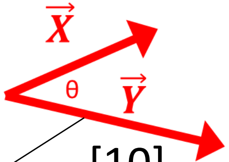
Vector spaces with norms on vectors |V1|, describing their "size".

Normed spaces with inner products <V1,V2> that express "relative orientation" of vectors, and for which $|V1|^2 = \langle V1,V1 \rangle$.

Inner product spaces that are complete (closed for limit sequences).

Simple one-dimensional numeric quantities.





[10]

David Hilbert
1862 - 1943

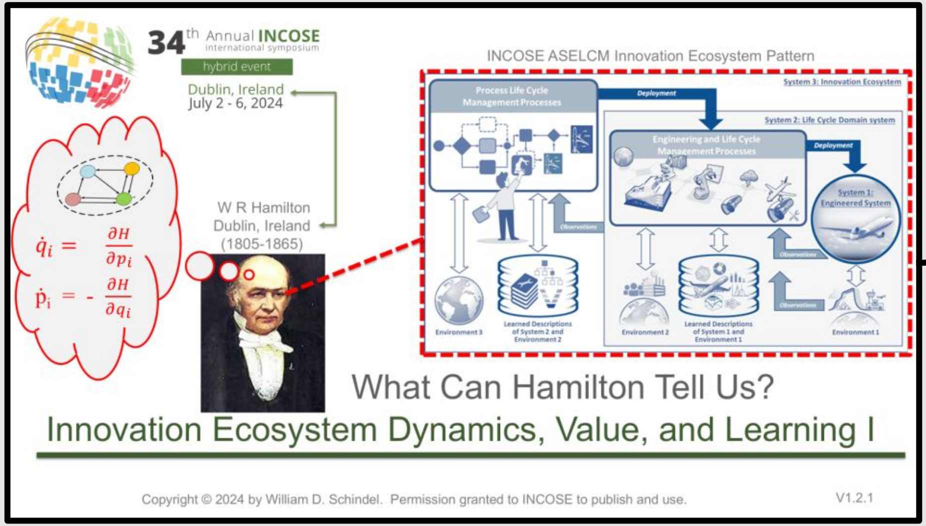
3. "Vector Embedding" software can currently embed MBSE Models in this space, quantifying their "nearness" & "gaps".

1. We express Computational Model numerical output in this space.

2. "Area Metric" expresses Computational Model "nearness" in this space.

Inconsistency and ecosystem energy

- If <u>inter-artifact consistencies</u> are the state variables of ASELCM dynamics, what is the "energy" governing ASELCM dynamics?
- Hamilton's "characteristic function" (now Hamiltonian) also applies to information systems and socio-technical systems [3].



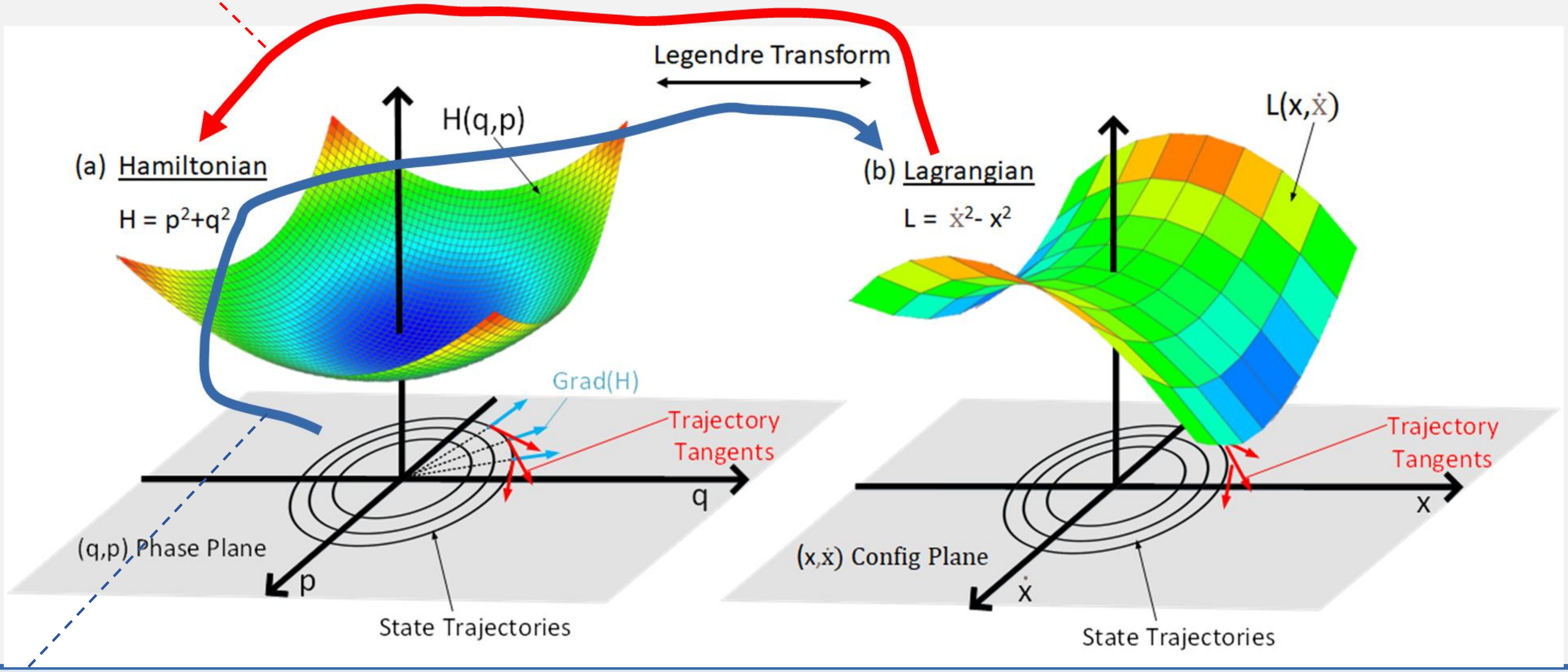
Inconsistency and ecosystem energy

- It may seem strange to apply Hamiltonians, which originated in mechanics, to socio-technical and information systems—but consider that the 2024 Nobel Prize ***in Physics*** was awarded to John Hopfield and Geoffrey Hinton for their related work in neural networks.

- Hopfield's famous 1972 neural net paper was explicitly built on physics; energy-based ANN methods have since grown. [14,15]

Traditional Reasoning Sequence: Assumes energy concept and leads to Hamiltonian [16,17]

The historical path assumed we already had a Lagrangian and familiar mechanical or other energies. The alternate path does not require those, and teaches us about "energies" of different systems.



Alternate Reasoning Sequence: Assumes only States, Trajectories; leads directly to Hamiltonian and "energy". Examining Grad(H) leads to invariance (conservation) of H along trajectories; variational/Lagrangian insight. [3,18]

Questions and discussion

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