INCOSE
A better world through a systems approach
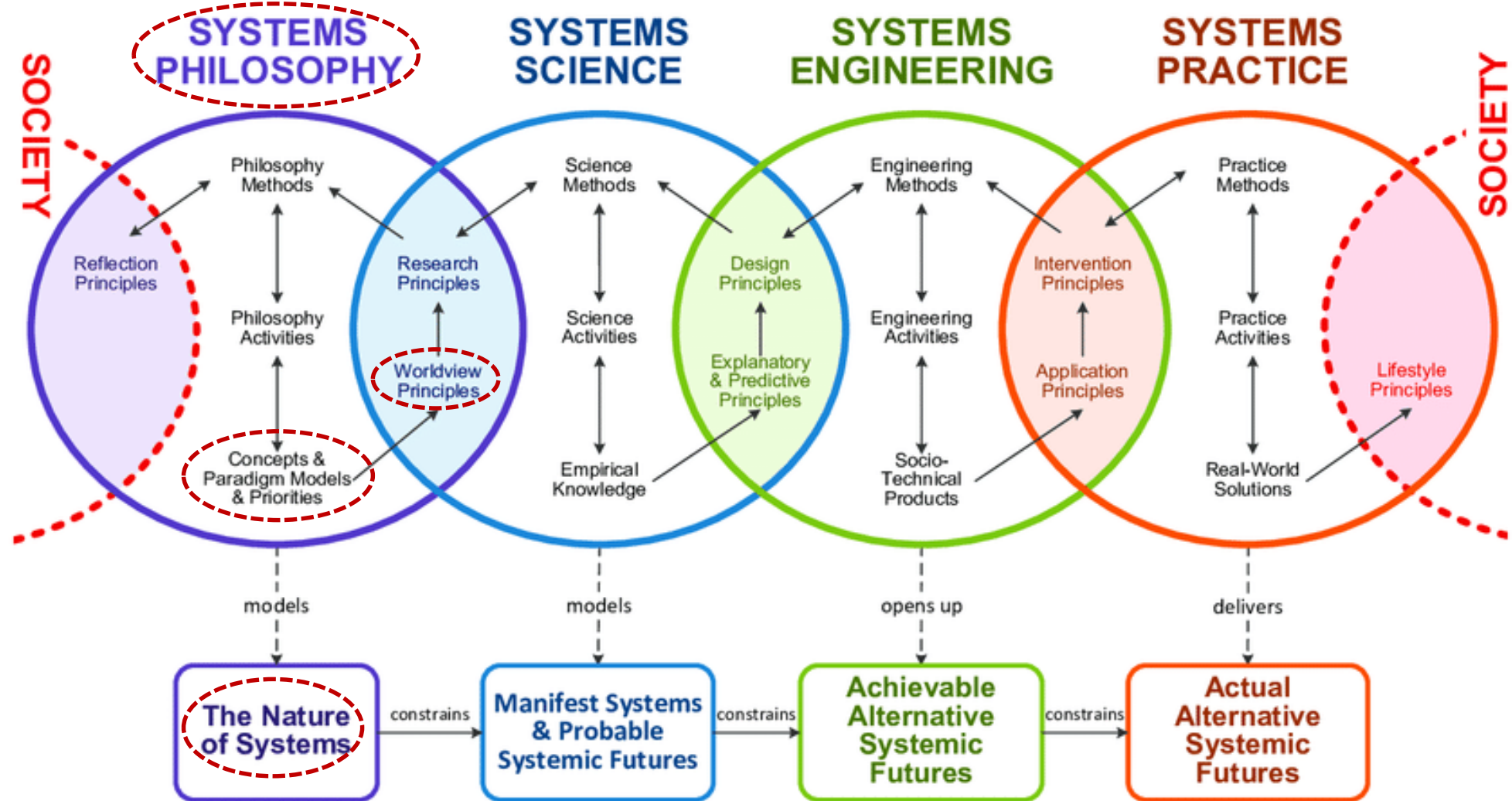
Systems Engineering the Conditions of the Possibility

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David Rousseau's Systemology Architecture

Immanuel Kant's Philosophy

- **Conditions of the Possibility**
  - A *necessary* framework for the *possible* appearance of a given list of entities

    Necessary… gotta have the framework to get the results.
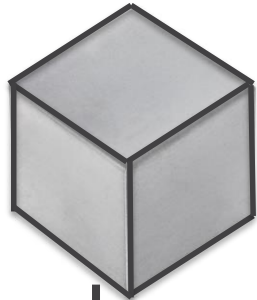
    Possible appearance… framework does not cause a result.

    Entities… abstract reference to schtuff or people.

Immanuel Kant's Philosophy

- **Conditions of the Possibility Example**
  - Space is a *condition* for the existence of cubes

    … no space… no possibility of cubes

  - Space does not *cause* cubes
  - Space is *distinct* from cubes
  - Space does not *define* cubes
  - Cubes *depend* on the existence of space

Systems Engineering Focus and Need

- Focus

  concept – **Complex adaptive socio-technical systems of systems**

    - System itself (combinations of people, technology)
    - Environment (current order, containing whole)

- Need

  paradigm – **Continual dynamic adaptability**

SE Conditions of the Possibility

- A design *framework* for the *possible* <u>appearance</u> and <u>variation</u> of predictable and unpredictable:
  - **Structures**: organization of parts, states
  - **Behaviors**: functions, functional exchanges
  - **Resources**: inputs (raw material, energy/fuel)
  - **Content**: virtual (data), real (people, cargo)
  - **Results**: outputs; impact, effect, consequence
  - **Environments**: current order, containing whole
  - **Value-delivery**: customer/beneficiary needs

SE CoP Philosophy

- **Design for *continual dynamic adaptability***
  - Goal 1: *provide* value-delivery under nominal conditions
  - Goal 2: *sustain* value-delivery under adverse conditions

SE CoP Philosophy

- **Design for expected and unexpected**

deterministic   *non-deterministic*

… we design for the possibility of cubes (expected)
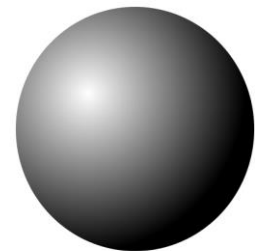
… we get spheres instead (unexpected); however, our engineered conditions are successful

Current – Traditional SE (or SE v1.0)

- Cause-Effect
- Rules-Based
- Deterministic
- Well-bounded
- Finite
- Predominantly static
- Deviation from expected
  - Simple systemic structures
  - Simple rules
- Humans provide intelligence & intervention for dynamic adjustment

SE CoP (SE v2.0) Intent

- Transcend cause-effect to embrace…
  - Non-deterministic
  - Flexibly defined
  - Blurred boundaries
  - Highly combinatorial, if not infinite
  - Adaptable

adaptable
- development
- systems
- workflows
- workforce
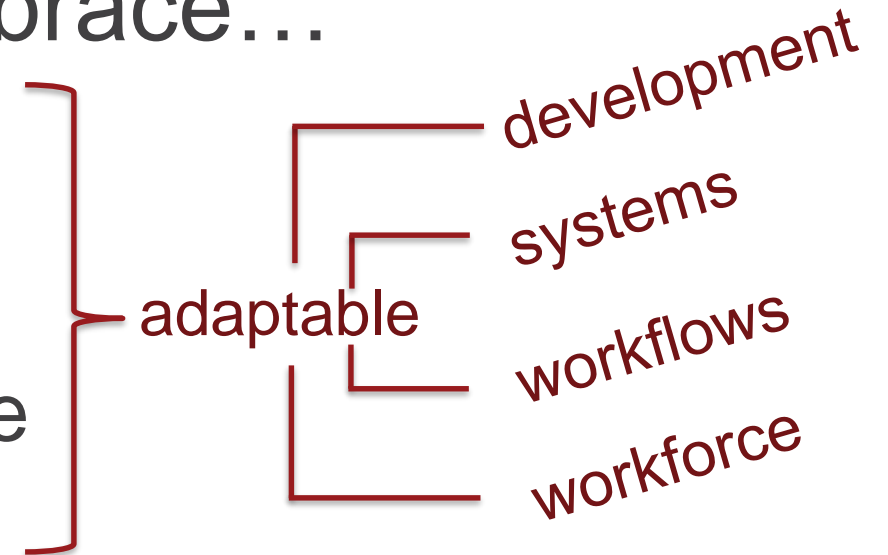
- Produce *complex adaptive socio-technical-physical systems of systems*
  - Facilitate **continual dynamic adaptation**

System of Interest (SoI)

- **Social**
  - Individual, couple, group, organization, nation, coalitions, …
- **Technical**
  - Manufacturing equipment, computer, car, airplane, naval ship, …
- **Process**
  - E.g., systems engineering…
- **Natural**
  - Non-human made
- **Engineered**
  - Human made
- **Intangible**
  - E.g., system of mathematics
- **Coupling of the SoI and its**:
  - *Containing whole*: system of systems (SoS)
  - *Environment*: that within which the SoI or SoS resides
  - *Context*: that which facilitates the expression of meaning and value
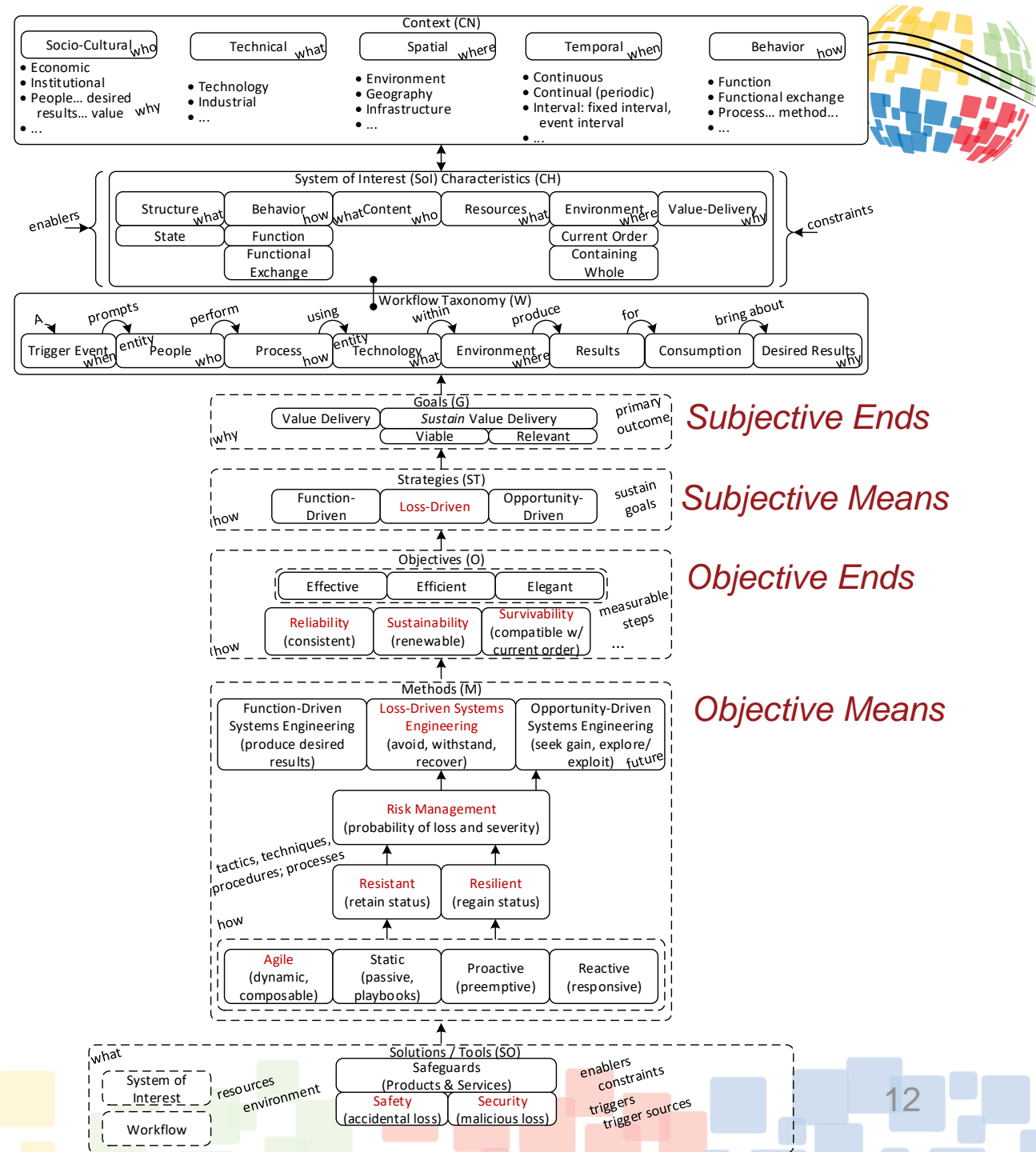
SE CoP Framework

Context

SoI Characteristics

Workflow Taxonomy

Goals

Strategies

Objectives

Methods

Solutions / Tools

Context (CN)

Socio-Cultural *who*	Technical *what*	Spatial *where*	Temporal *when*	Behavior *how*
• Economic • Institutional • People… desired results… value *why* • …	• Technology • Industrial • …	• Environment • Geography • Infrastructure • …	• Continuous • Continual (periodic) • Interval: fixed interval, event interval • …	• Function • Functional exchange • Process… method… • …

System of Interest (SoI) Characteristics (CH)

enablers → ← constraints

Structure *what*	Behavior *how*	*what* Content *who*	Resources *what*	Environment *where*	Value-Delivery *why*
State	Function			Current Order	
	Functional Exchange			Containing Whole	

Workflow Taxonomy (W)

A → prompts → Trigger Event *when* → *entity* perform → People *who* → using → Process *how* → *entity* within → Technology *What* → produce → Environment *where* → for → Results → bring about → Consumption → Desired Results *why*

Goals (G)   *Subjective Ends*

why

Value Delivery	*Sustain* Value Delivery	primary outcome
	Viable	Relevant

Strategies (ST)   *Subjective Means*

how

Function-Driven	Loss-Driven	Opportunity-Driven	sustain goals

Objectives (O)   *Objective Ends*

how

Effective	Efficient	Elegant
Reliability (consistent)	Sustainability (renewable)	Survivability (compatible w/ current order)

measurable steps …

Methods (M)   *Objective Means*

tactics, techniques, procedures; processes

how

Function-Driven Systems Engineering (produce desired results)	Loss-Driven Systems Engineering (avoid, withstand, recover)	Opportunity-Driven Systems Engineering (seek gain, explore/exploit) future

Risk Management (probability of loss and severity)

Resistant (retain status)	Resilient (regain status)

Agile (dynamic, composable)	Static (passive, playbooks)	Proactive (preemptive)	Reactive (responsive)

Solutions / Tools (SO)

what

System of Interest		Safeguards (Products & Services)	enablers constraints
Workflow	resources environment	Safety (accidental loss) / Security (malicious loss)	triggers trigger sources

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Context [Ontology]

- **Socio-Culture** (who)
  - People… desired results, value-delivery (why)
  - Economic, institutional (political, religious, education)…
- **Technical** (what)
  - Technology, industrial…
- **Spatial** (where)
  - Environment, geography, infrastructure, facilities…
- **Temporal** (when)
  - Continuous, continual (periodic), interval…
- **Behavior** (how)
  - Function, functional exchange; process, TTPs…
- **Expected Value** (why)
- *Extensible*
  - *Ethics… others…*

Context ←→ SoI

- **Context provides for:**
  - Expression of SoI *role*, *fit*, *function*, *impact*
  - Expression of SoI *meaning* and *value*

SoI Characteristics

- **Structure** (what)
    - Organization of parts
    - State
- **Behavior** (how)
    - Function
    - Functional exchange
- **Content** (what, who)
    - That which the SoI contains, bears, or conveys
    - Virtual (data); real (cargo, people)
- **Resources** (what)
    - Inputs: raw materials
    - Energy: fuel
- **Environment** (where)
    - Current order: that to which the system must conform to remain *viable* and *relevant*
    - Containing whole: the system of systems of which the SoI is a part
- **Value-Delivery** (why)
    - Provide desired results under nominal and adverse conditions
        - Sustain value-delivery

SoI ⟷ Workflow Taxonomy

- ## **SoI is a subset of:**
  - – People, process, technology, environment
    - • Constituent parts within the dynamic that produces desired results
  - – *SoI may be a complex adaptive socio-technical system of systems*

Workflow Taxonomy

- **Trigger event** (when)
- **people** (who)
- **processes** (how)
- **technology** (what)
- **environment** (where)
- **results**
- **consumption**
- **desired outcome** (why).

prompts
to perform
using
within an
to produce
for
to bring about a

Workflow Taxonomy ←→ Goals

- **Goals provide:**
  - A reason for the workflow
  - That which the workflow seeks to accomplish
    - … ambition… aim… desire…
    - … incognizant need satisfaction…
    - … provision of an incognizant benefit…

Goals

- **Value-Delivery**
  - – Under nominal and adverse conditions
- *Sustain* **Value-Delivery**
  - – **Viable**: capable of producing results
  - – **Relevant**: compatible with current order

Goals⟵⟶ Strategies

- **Strategies:**
  - Support goals
    - Strategies to *provide* value-delivery
    - Strategies to *sustain* value-delivery
      - Strategies for *viability*
      - Strategies for *relevance*

Strategies

- **Function-Driven**
  - Traditional SE focus
- **Loss-Driven**
  - Collective consideration of all loss-oriented functions (viability)
    - Reliability, sustainability, survivability
    - Risk management (negative side): resistance, resilience
    - Safety, security
- **Opportunity-Driven**
  - Collective consideration of all gain-oriented functions (relevance)
    - TBD… area mostly unexplored
    - Continuity, compatibility, contingency, preempt, proactive, TBD
    - Risk management (positive side): revisit, revise

Strategies ←→ Objectives

- **Objectives:**
  - Measurable steps within strategies

Objectives

- **Effective**: produce desired results
- **Efficient**: produce desired results within specified performance parameters
- **Elegant**: produce desired results with minimal resource expenditure
- **Reliability**: consistent, dependable
- **Sustainability**: renewable
- **Survivability**: compatible with *current order*
- Et al… TBD

Objectives ←→ Methods

- **Methods:**
  - Tactics, techniques, procedures (TTP's), and processes to achieve objectives

Methods

- **Function-Driven**
- **Loss-Driven**
  - **Risk Management**
    - **Resistance:** retain status
    - **Resilience:** regain status
- **Opportunity-Driven**
  - **Risk Management**
    - **Revisit**: continual optimization; contingencies
    - **Revise**: adapt
- **Agile:** dynamic, adaptable, composable
- **Static**: passive, playbooks
- **Proactive:** preemptive
- **Reactive:** responsive

Methods ←→ Solutions

- **Methods:**
  - Invoke solutions

Solutions

- **System of Interest (SoI)**
  – Person, people
  – Technology
  – Socio-technical
  – A *thing* (solution) or *process* (systems engineering)
  – Natural or engineered
  – Tangible or intangible (e.g., system of mathematics)
- **Operations**
  – Workflow
- **Enablers**
- **Constraints**
- **Safeguards**
  – **Safety**: accidental loss
  – **Security**: malicious loss

Solution Design: *Modular Perspective*

- *Develop* system modules
  - *Compose* systems
  - *Adapt* systems via dynamic composition
- *Develop* operational modules
  - *Compose* workflows
  - *Adapt* workflows via dynamic composition

SE v2.0 Patterns (Towards Modules)

- System Archetypes
- Architecture Patterns
- Design Patterns
- Decision Patterns
- Ecosystem Patterns
- Anti-Patterns

System Archetypes

- Recurrent motifs in *system dynamics*

Fixes that Fail

Shifting the Burden

Limits to Success

Growth and Underinvestment

Success to the Successful

Escalation

Tragedy of the Commons

Architecture Patterns

- Capture and reuse *system* modules to *compose systems*

- Capture and reuse *operational* modules to *compose workflows*

Design Patterns

- Capture and reuse *development* knowledge

Decision Patterns

- Capture and reuse *operational* knowledge

Ecosystem Patterns

- Capture and reuse *knowledge of a community of entities* existing within a physical or logical boundary interacting as a system
  - Structure (organization of entities), states (to be), and behaviors (to do)
    - Triggers for action
    - Triggers for change

Anti-Patterns

- Capture ways known not to work

Don't go that way!
There be dragons!

Next Steps

- Dozens of areas open for research
- Algorithmic design research for **continual dynamic adaptation**
  - Set-Based Design (enumerated options readily available)
  - Category Theory (set relationships)
  - Compositionality Theory (compose vs. develop)
  - Combinatorics (manage compositional options/variations)
  - Quantum cognition (modeling human decisions; socio-)
  - AI and machine learning (adaptable systems; techno-)
  - Distributed ledger technology (techno-social contracts)
  - Bayesian Belief Networks (quantifying dependency & causality)
  - Uncertainty Quantification (quantifying degrees of accuracy)
  - Portfolio Theory (maximize return for given level of risk)
  - Network Theory (safeguarding against weaponizing interconnectedness)
  - Viable Systems Theory (evolution of dynamic systems)
- Axiomatic influence research
  - Design and operate to principles for when algorithms fail or are unprepared
    - E.g., do no harm vs. minimize unintentional harm vs. minimize intentional harm
  - Culturally adaptive systems

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