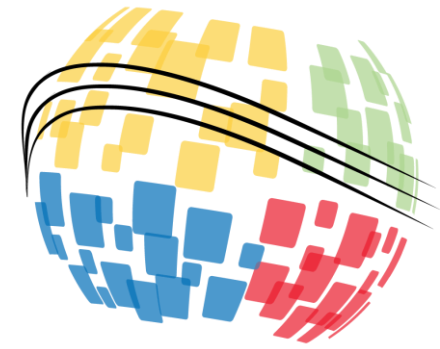# System Revisited- Again

A review of the foundational definitions of 'system' and 'systems engineering' in the INCOSE Systems Engineering Handbook, V5, 2023

Anthony Quayle

Part 1: Introduction to the Concept of 'System'

What is a System?

«a set of elements standing in inter-relations»

von Bertalanffy, 'General System Theory' 1968

«a structure composed of distinct parts so constituted that the functioning of the parts and their relation to one and other are governed by their relation to the whole...to achieve some designed purpose»

SAGE Air Defense System (1950s) in Thomas Hughes 'Rescuing Prometheus' 1998
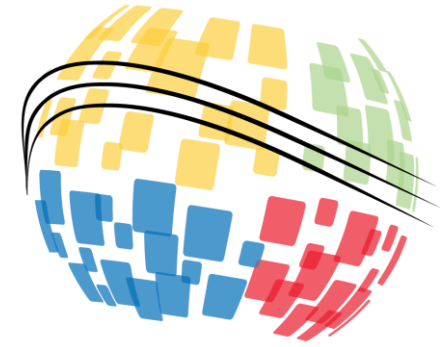
Wholes, Parts and Emergence…

- Systems are 'wholes' made up of parts in a 'whole-part' organization

- The dynamic relationship between the parts produces non-reductive emergent behavior that belongs to the whole

- Wholes have boundaries across which the system interacts with its environment or 'domain'

- The parts and their relationships form the system's architecture -- its structure and behavior to achieve its 'functions' (F-B-S)

System Function

- In a dynamic system, function derives from behavior and not directly from structure (F-B-S)

- Function is contextually determined by the designer: it is not part of system architecture (F-(B-S))

- A system is 'complex' if the way function emerges from architecture cannot be grasped coherently.
  - Complexity: something one cannot get one's head around
  - System modeling to simplify complexity

SYSTEM: a Summary – but not a Definition

An (open) system is a bounded whole, within an environmental domain, that is organized into a complex architecture of parts and inter-relationships (a persistent causal structure) that causes emergent non-reductive system behavior, as flows of energy, materials or information, that implement its designed or implied function.

Part 2: INCOSE Definitions of the Concept of 'System'

INCOSE 'System' Definitions

"An integrated set of elements, sub-systems, or assemblies that accomplish a defined objective".

INCOSE Systems Engineering Handbook V4, 2015

"An arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not".

INCOSE Systems Engineering and System Definitions, 2019

INCOSE (2019): What Stands Out?

1. No reference to emergence, holism, architecture, or function.

2. The curious contrast of behavior and meaning.

   - Behavior is a property of a <u>physical</u> system (of matter and energy).

   - Meaning is a property of a <u>conceptual</u> system (of information or knowledge).

3. The false binary distinction between physical and conceptual systems.

Concrete/Real & Abstract

"One doesn't go far in the study of what there is without encountering the view that every entity falls into one of two categories: concrete or abstract. The distinction is supposed to be of fundamental importance significance for metaphysics, epistemology, the formal sciences, the philosophy of language, the philosophy of mind, and the philosophy of the empirical sciences".

Abstract Objects, Stanford Encyclopedia of Philosophy, 2021
https://plato.stanford.edu/entries/abstract-objects/#AbouAbstDist

- Concrete/Real: existing in the real world

- Abstract: not existing in the real world

What is a Concept?

"a concept is a (real or abstract) basic unit of thought, defined by its intension, an abstract description of its common properties or attributes that are shared by its extension, the concrete (or real) examples of the concept". Margolis E & Laurence S (eds.), <u>Concepts: Core Readings</u>, 3-81, MIT Press,1999

"it seems wrong to designate as concepts mental representations of any size whatsoever. Representations at the level of complete thoughts…are too big to be concepts".

Lawrence, S & Margolis, E, The Conceptual Mind, MIT Press, 2015

Is a scientific definition of 'system' possible? (1)

- INCOSE Fellows had obvious difficulties: the physical/ conceptual distinction is not consistent with the basic metaphysical real/abstract distinction. Beyond this:

"It is unlikely that a topic as complicated as emergence will submit meekly to a concise definition".

Holland J, Emergence: From Chaos to Order, Addison-Wesley, 1998

- Like emergence, the concept of 'system' is not rooted in a single science which supplies a dominant definition in an exemplar domain.

Is a scientific definition of 'system' possible? (2)

- The concept of 'system' is so abstract (removed from specificity of domain), the INCOSE Fellows' definition leads only to another dictionary definition. Other recent efforts can do no better...

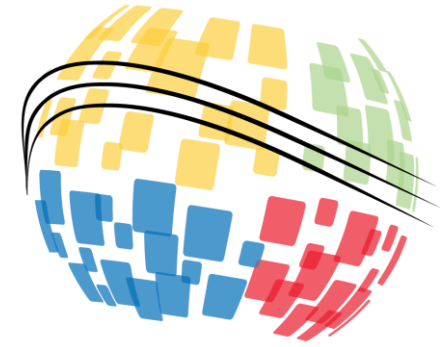*"A system is a collection of objects among which relations hold".*

Humphreys, P, Emergence, Oxford UP, 2016

«A set of elements standing in inter-relations».

von Bertalanffy, General System Theory 1968

Conclusions I: The Concept of 'System'

- Despite the efforts of INCOSE over many years, the concept of 'system' cannot be defined scientifically – it is too abstract (removed from domain specificity).

- INCOSE could focus on more domain-based definitions of engineered/artificial systems at lower levels of abstraction.

Part 3: Systems Engineering

Systems Engineering: INCOSE Definitions

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems……It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem…Systems Engineering integrates all the disciplines and specialty groups [to] form a structured process…from concept to production to operation".

INCOSE, System Engineering Handbook, 2016

"Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts."

INCOSE, Systems Engineering and System Definitions, 2019

So what is Systems Engineering?

- Systems engineering is the essential first stage of the engineering design process that is wholly in the <u>abstract</u> and precedes the necessity or practicality of real representation.

- Abstraction: freedom from representational qualities [of the real]

<p align="right">Oxford English Dictionary</p>

- It is essentially <u>abstract engineering</u>

  - abstract functional, behavioral, and structural (F-B-S) models

  - abstract performance, cost, and other parametric models.
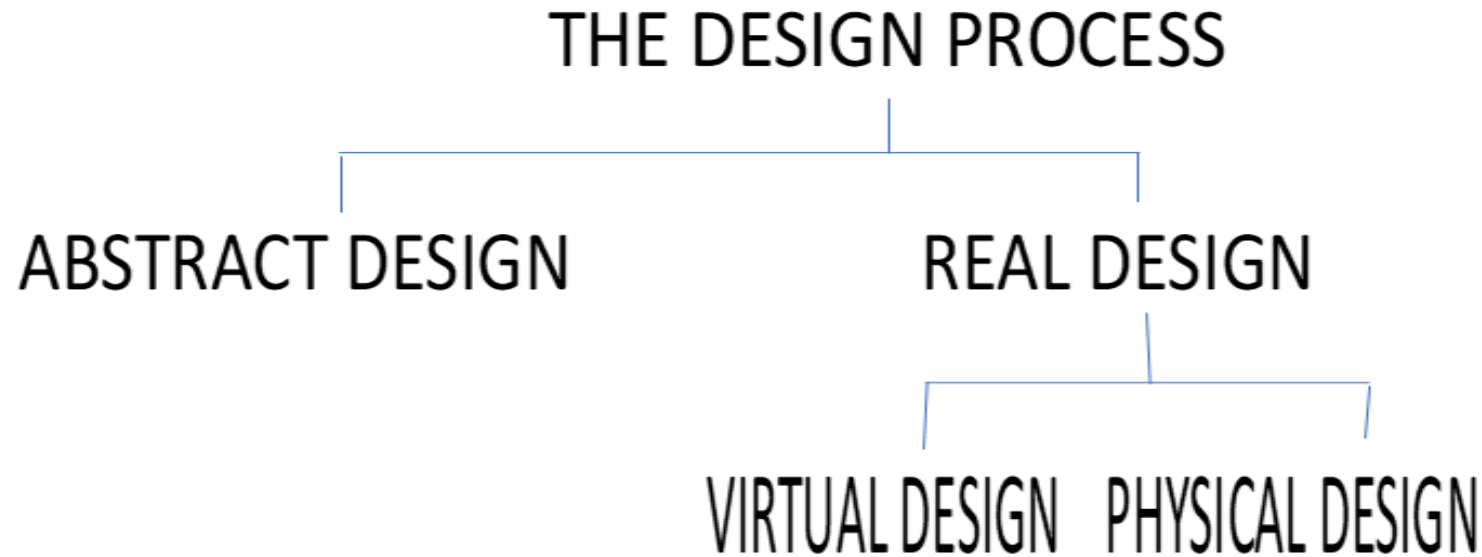
Design: from Abstract to Real (Virtual)

- Abstract (or systems) models are selectively simplified symbolic representations to enable design of the (complex) real.

- Firstly as a virtual design…

  – Virtual: a representation of something not existing physically but made to appear so (software or drawings in a CAD system)…memory, machine, reality

  – Digital twin: a virtual representation that mimics the structure, context, and behavior of a physical counterpart to provide feedback to the real-world component

  Foundational Research Gaps for Digital Twins, National Academies, 2023

- …and then, where relevant, as a physical reality

Design: from Virtual to Real (Physical)

- Because a virtual representation is something not existing physically but made to appear so…it provides an executable basis

  for the production stage or realization of the physical elements…
(and their integration with the software elements that remain virtual)

- …within a three-phase abstract (system) – virtual – (physical) design process

The 3-Phase Engineering Design Process: Abstract-Virtual-Physical

Conclusions 2: Systems Engineering

1. Building on accepted metaphysical distinctions, the engineering design process comprises three stages of:

abstract-real (virtual-physical).

2. The essence of systems engineering is abstraction.   Systems engineering is that part of the engineering design process that is wholly in the abstract – before it is either necessary or possible to design in the real (virtual and then physical).

Better foundational definitions will not directly impact systems engineering practice but do provide a guiding high-level conceptual rigor.

Recommendations

The Concept of 'System'

- INCOSE could explore more domain-based definitions of engineered/ artificial systems at lower levels of abstraction BUT: a more scientific definition may not be possible today even at a lower level of abstraction.

Systems Engineering

- Conceptualizing systems engineering as the abstract phase of a three-stage abstract-real (virtual-physical) engineering design process allows INCOSE to move way from a purely functional definition (what systems engineers do) to define systems engineering within the total (and evolving) engineering design process.

INCOSE IS24 Dublin: Paper 84 «System Revisited – Again»

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Biographical note: Anthony Quayle is an engineer and graduate of the Massachusetts Institute of Technology.   After an early career in the power engineering industry, he became president of Alvis (now part of BAE Systems), a major UK-based defense land systems prime contractor, founded a post-experience Masters' program for engineers in research and innovation at Chalmers University of Technology in Gothenburg, SE and was a Senior Lecturer on the System Design and Management (SDM) program at MIT.   He is retired and lives in Switzerland.