What is a system and what is systems engineering?

A presentation to INCOSE-LA
7 August 2018

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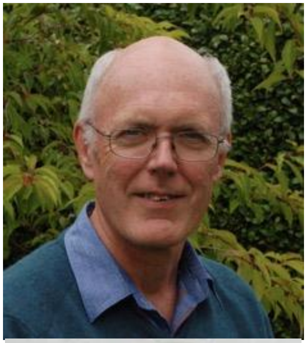
Fellows’ Initiative - Task statement (Dorothy McKinney, May 2016)



- *A Task Team of INCOSE Fellows to write a white paper that contains a definition of systems engineering that reflects the consensus for INCOSE Fellows.*
- *The purpose of this white paper is to distill the discussion of the definition of systems engineering so it is constructive and helpful to both systems engineering practitioners, and to those INCOSE is reaching out to educate about the value of systems engineering.*

- Project launched at IS16, Edinburgh,
- Sponsored by INCOSE President and President Elect
- Agreed we needed to look at definitions of “System” as well as “Systems Engineering”
- This presentation is based on team’s draft recommendations plus outputs of IFSR Conversation in Linz last week.






Part 1 – What is a system?

Headlines and conclusions

- **INCOSE definition of SYSTEM needs to widen**
- **Include system types excluded by current definition, notably**
  - **Naturally occurring systems (involved in and/or affected by many engineered systems)**
  - **Systems whose properties cannot be fully controlled by design – complex, viable, autonomous, eco-systems…**
- **Three motivations:**
  - **Define what we do**
  - **Learn to do better**
  - **Facilitate cross-fertilization with Systems Sciences, other system domains**
- **At least 7 Different system worldviews in INCOSE**
  - **these correspond to different system types with different characteristics.**

The presentation will discuss:

- INCOSE's current definition of "system"
- Review of SYSTEM definitions
- Seven System Worldviews in the INCOSE community
- Our System taxonomy
- Taxonomy vs the seven worldviews
- The complex system challenge for INCOSE – "systems with minds of their own"
- Current challenges and proposed direction of travel towards
    - (a) new definition(s)
    - a "system ontology

INCOSE’s current definition of “system”

and why it needs to change to accommodate the wider vision for SE presented in INCOSE’s Vision 2025

Current INCOSE definition of "SYSTEM"

…an integrated set of elements, subsystems and assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements. -- INCOSE SE Handbook 4th Edition

Critique

- **Couched in terms of "real" systems**
- **Restricted to purposeful human-made systems, excludes naturally occurring systems**
  - **since these don't have an 'a priori' defined objective**
- **Does not include naturally occurring elements**
- **Does not recognize that system is an open system which accomplishes its defined objective by interacting with wider context or environment**
- **Does not recognize that unintended consequences may arise from unintended interactions.**
- **Not compatible with wider system science definitions – limits knowledge transfer**

NB INCOSE also offers another, wider, definition of SYSTEM:

A Consensus of the INCOSE Fellows

Definition of a System

A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected (Rechtin, 2000).

https://www.incose.org/AboutSE/WhatIsSE

Our review of SYSTEM definitions

What else is out there?

- We reviewed literally hundreds of definitions of system.
- These tend to cover one or more of three aspects:
    - System IS: structure
        - e.g. multiple interacting or inter-related elements
    - System DOES: function/behavior
        - e.g. does things the parts can’t do on their own
    - WHY: e.g. purpose
        - NB purpose can only be safely attributed to deliberately constructed “artificial” systems
- Definitions tend to be grounded, usually implicitly, in specific worldviews
    - Systems occur in the “real” (physical) world
    - Systems are mental constructs
    - Systems may consist of pure information
    - System boundaries are observer designated
    - System boundaries are discoverable based on objective criteria
    - Systems are "parts standing in relation”
    - Systems have complex dynamic properties
- Most definitions refer, usually implicitly, to specific system subtypes

The seven different worldviews on “system” within the INCOSE community

We don't agree on what is and is not a system!

System Worldviews Survey issued to Fellows and SSWG Dec 16 / Jan 17

Seven different worldviews identified.

1. **A formal minimalist view based on mathematics and logic;**
2. **Constructivist -** systems are purely a mental construct;
3. **Moderate realist –** systems exist in physical and mental "worlds";
4. **Strong and Extreme Realists –** systems only exist in physical world;
5. **Complex, viable and living systems** - Miller, 1978; CAS, etc.
6. **Systems as a Mode of Description** – Aslaksen, 2013;
7. **System as a process –** process, rather than object/structure, is the essence of systems: Blockley, 2010, also "Process Philosophy".

"Systemicity"

- Generally the more complex the system, the more of the properties (listed below) it exhibits. The properties are sorted according to the frequency of responses in the SSWG survey on "system definition, January 2017 – sample size 33. Similar in Fellows' responses (26)
- Many of these properties:
  - are not present in the current generation of systems-engineered "product systems";
  - are present in naturally occurring and "viable" systems;
  - are seen as desirable or essential in future intelligent systems.

Essence of our definition.

relationships between the parts	29
interactions between the parts	28
more than one part	27
"emergent properties", properties of the whole system not possessed by the individual parts acting separately	27
a boundary separating or distinguishing the system from its environment	24
systems occur at multiple levels of integration with new properties emerging at each level	22
internal communication between parts	19
input / output behavior	19
have dynamic and integrity limits	16
The characteristic of being "whole" or "complete"	16
"homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external changes	15
adaptive control using internal feedback	14
internal decision making processes	13
cohesiveness, the ability to or characteristic of clustering as a group	13
when deployed into their operational environment, systems both change and adapt to their environment	12
a defined "purpose" or "goal"	10
viability, the ability to survive in a non-benign environment	10
resilience, the ability to absorb and recover from major disruption	10

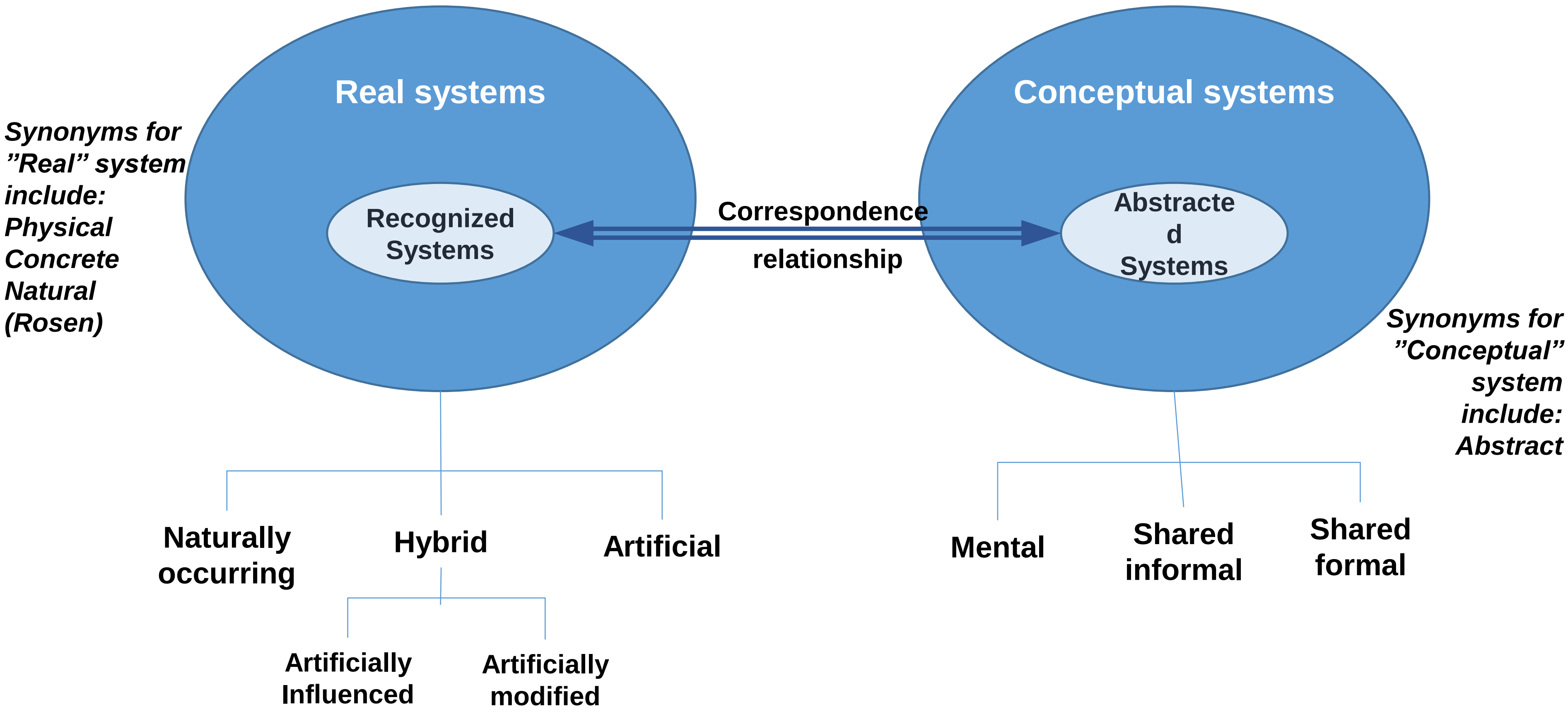
Selection or not of these additional criteria is highly dependent on worldview.

There are strong and mutually inconsistent patterns and clustering in the data.

That's why we need:
- a minimalist universal definition
- specific definitions for each system type

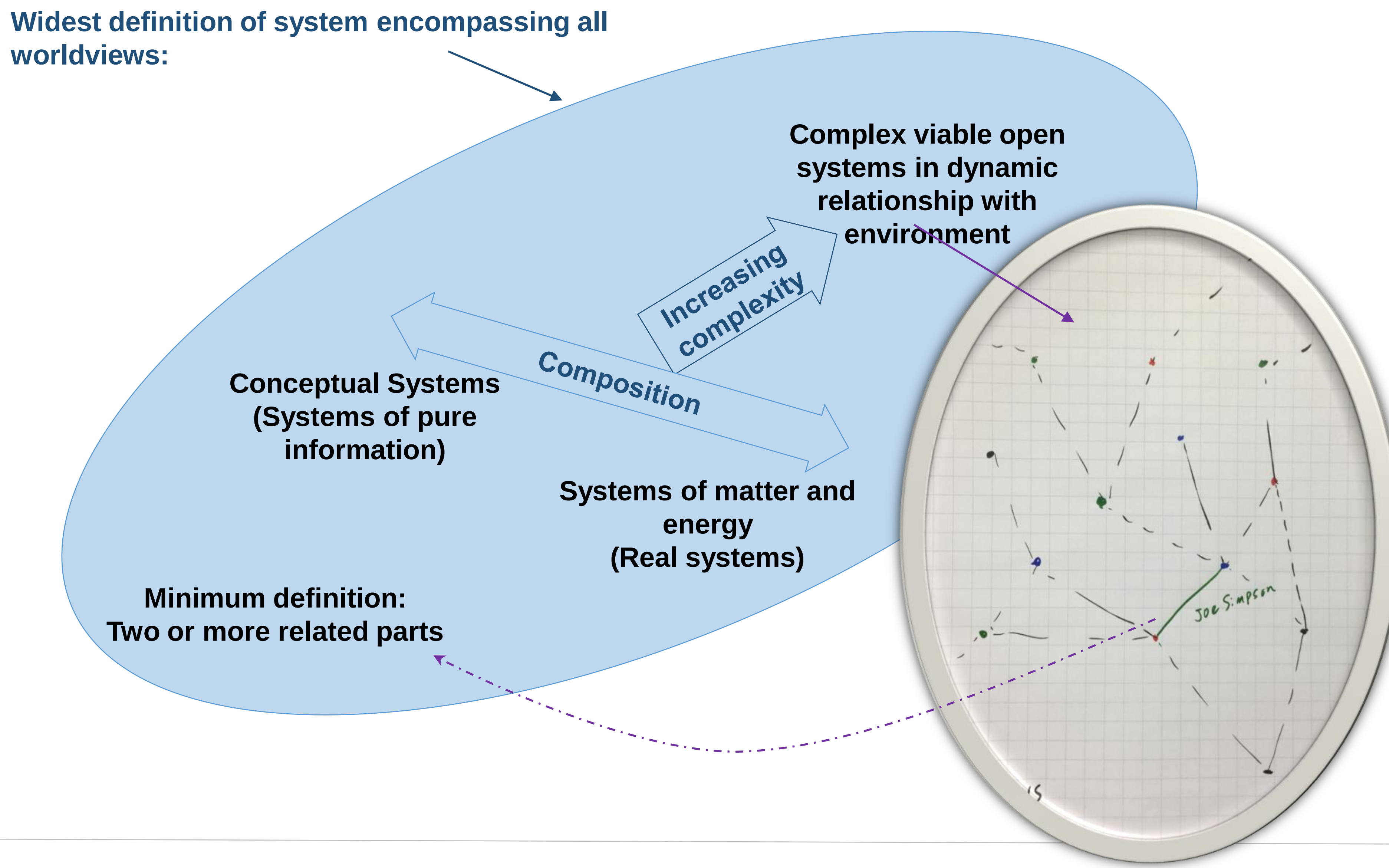
A taxonomy summarizing the range of system types we identified in the literature

System typology proposed in 2017

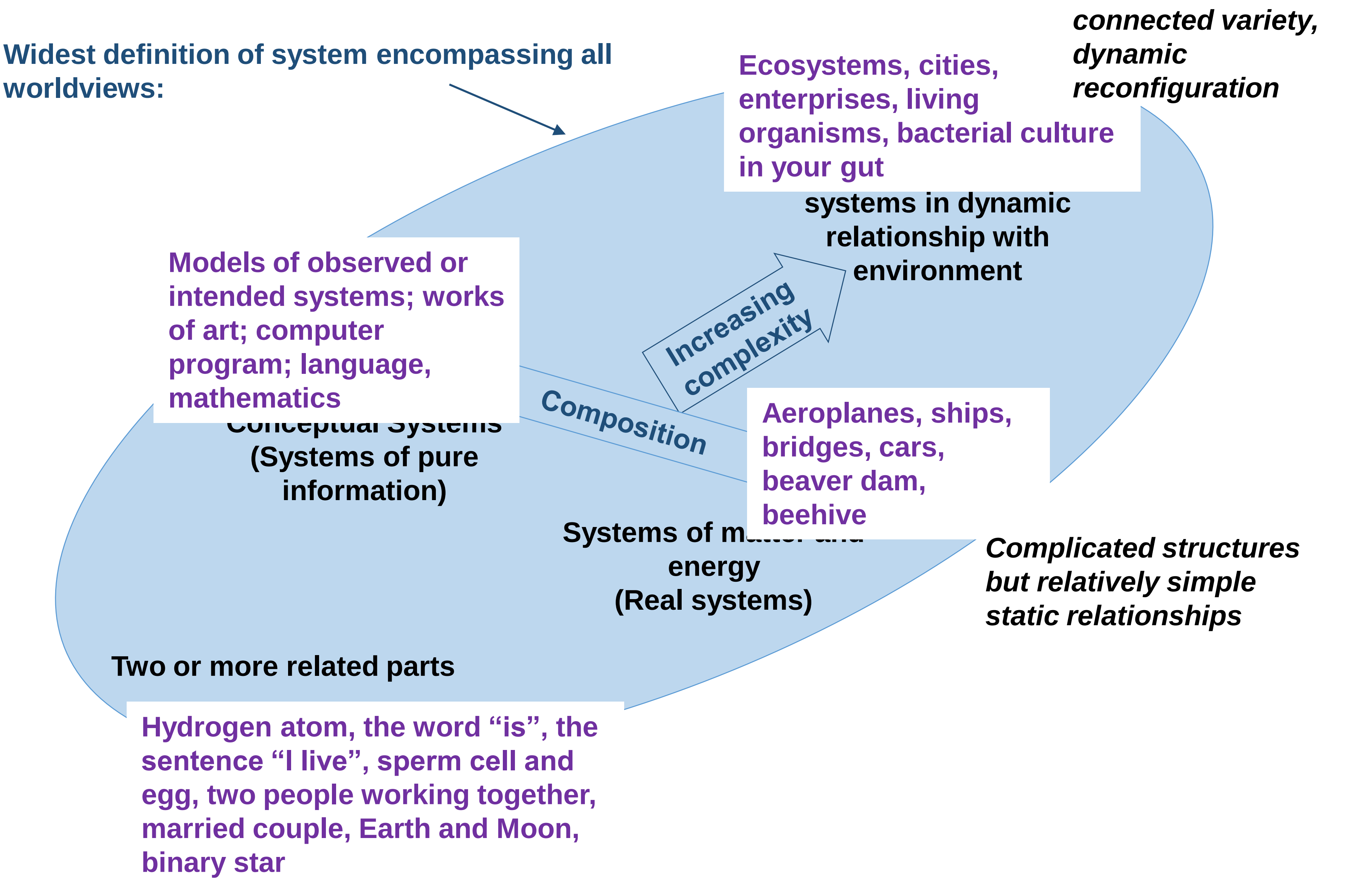


How this taxonomy relates to the seven worldviews

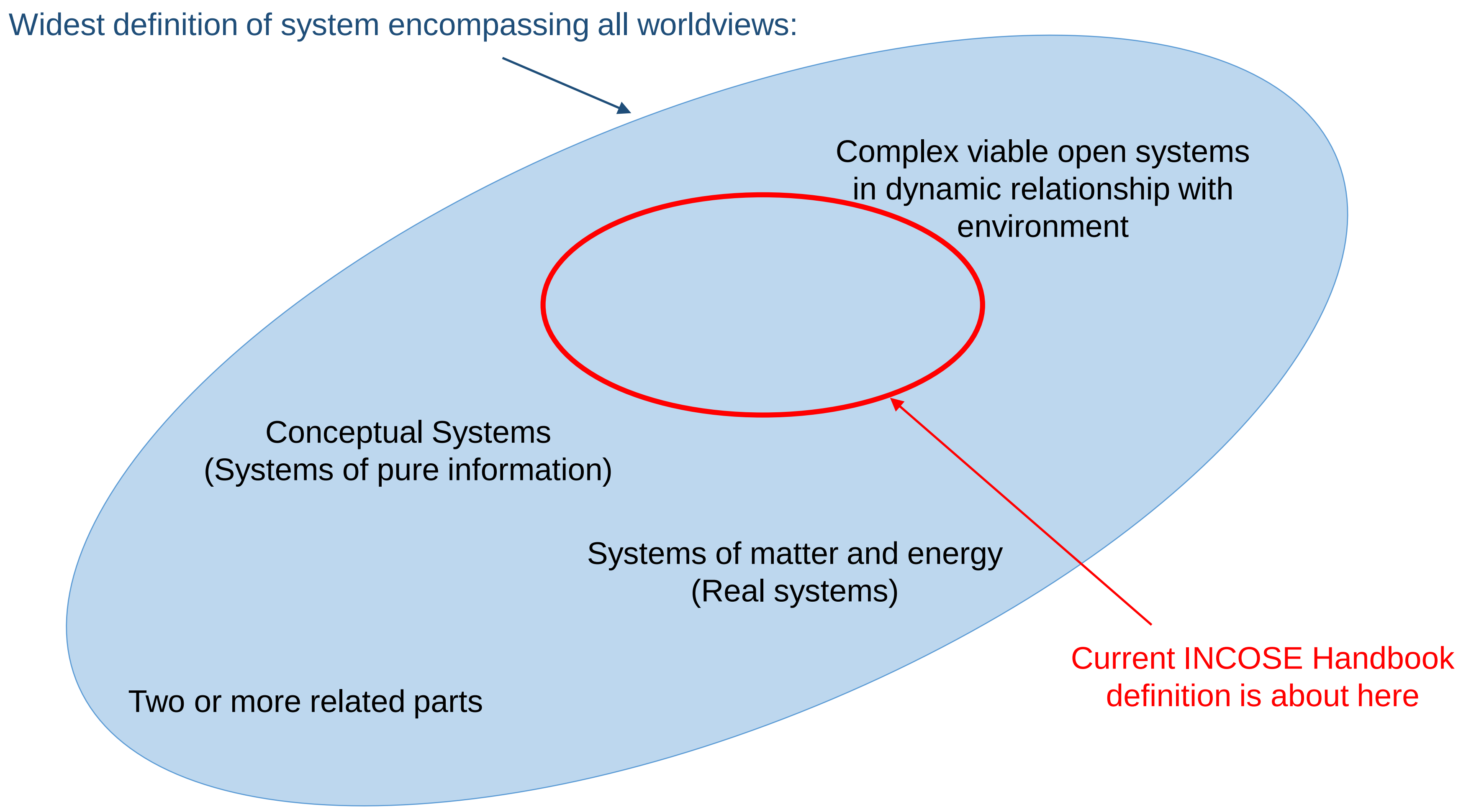
Impact of different worldviews on definition(s)



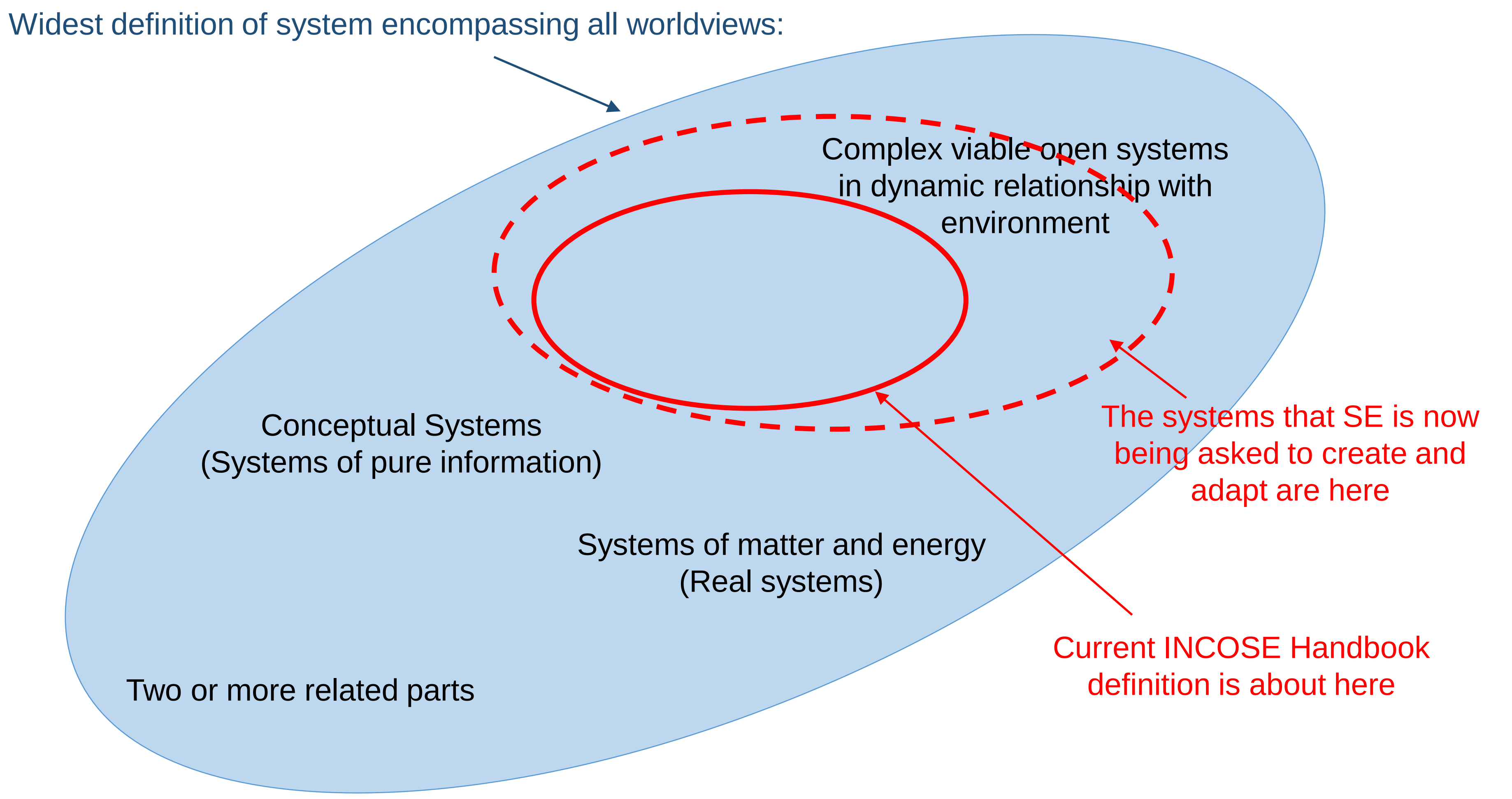
Examples of different system types – not to scale



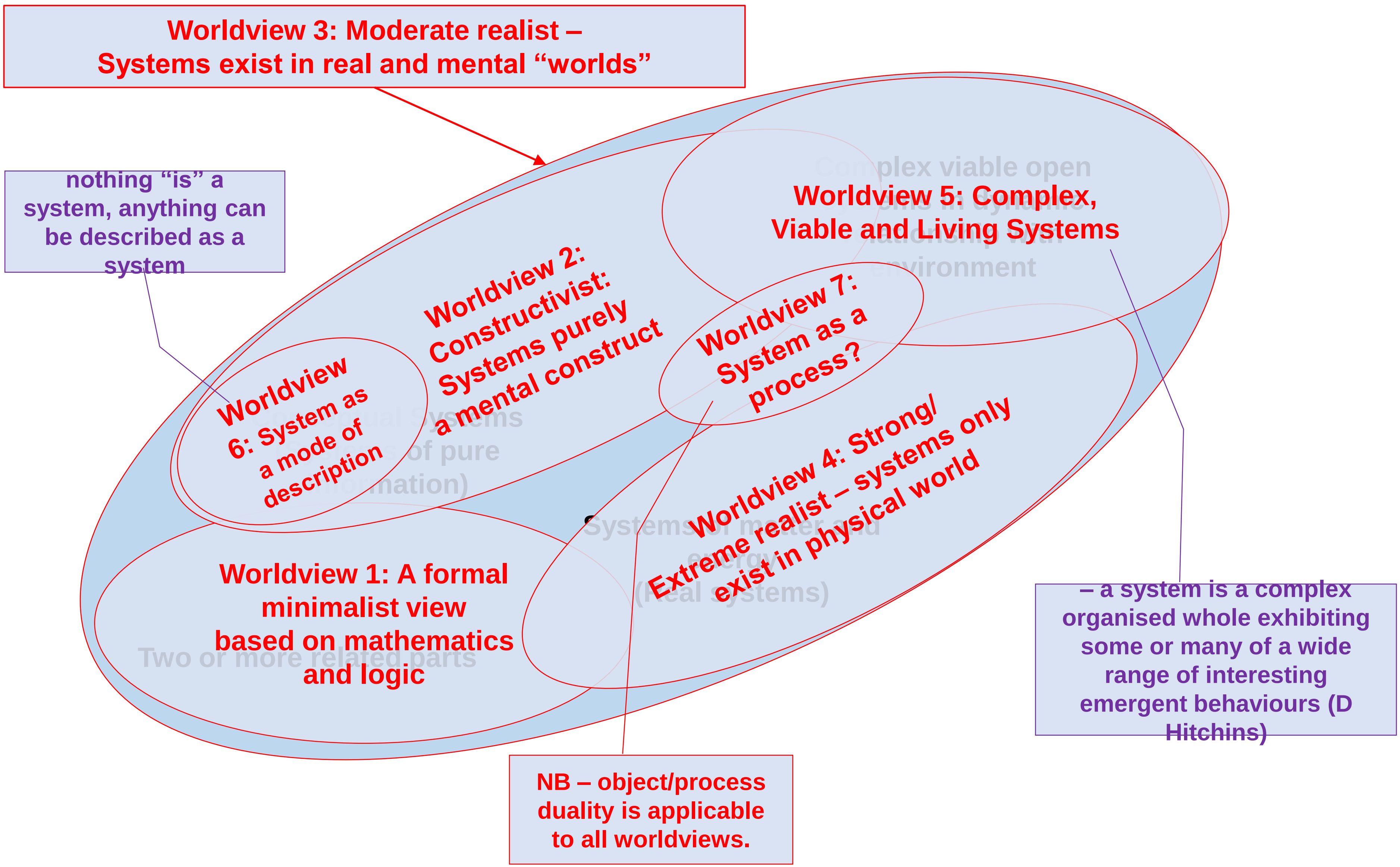
Impact of different worldviews on definition(s)



Impact of different worldviews on definition(s)



Mapping the different worldviews



What’s in a system?

We need to agree that we disagree…???!!!

Before we can come up with a definition, or set of definitions, that the whole INCOSE community can agree with –

……we all need to realise that we disagree with each other!!!!

……and that we won’t change each others’ minds by telling people they are wrong!!!

So:

We need

1. **A very fundamental definition that applies to “all systems”**
   - **that means it has to work for anybody’s type of system, not just mine or yours**
2. **More specific definition(s) applicable to the types of system we are interested in**
3. **Preferably, definitions that are shared with other system communities**

Key distinctions in the systems universe

- **“Observables” vs “Concepts”**

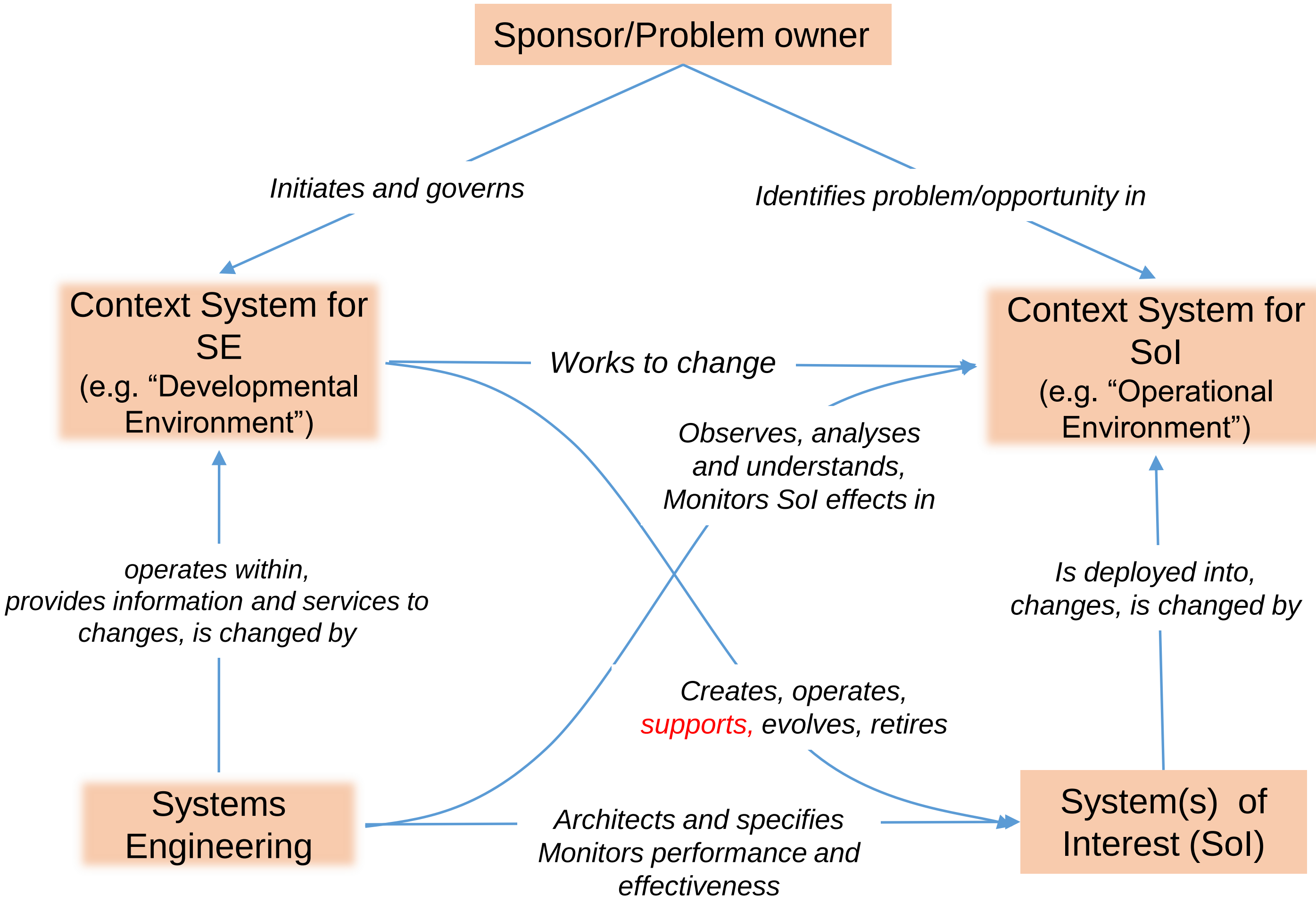
- **Real (matter-energy) vs Conceptual (abstract informatic objects)**

- **Statics (parts, relationships, connections, “qualities”, material, energy)**
  - **vs**
- **Dynamics (processes, interactions, flows, transactions, performance, history)**

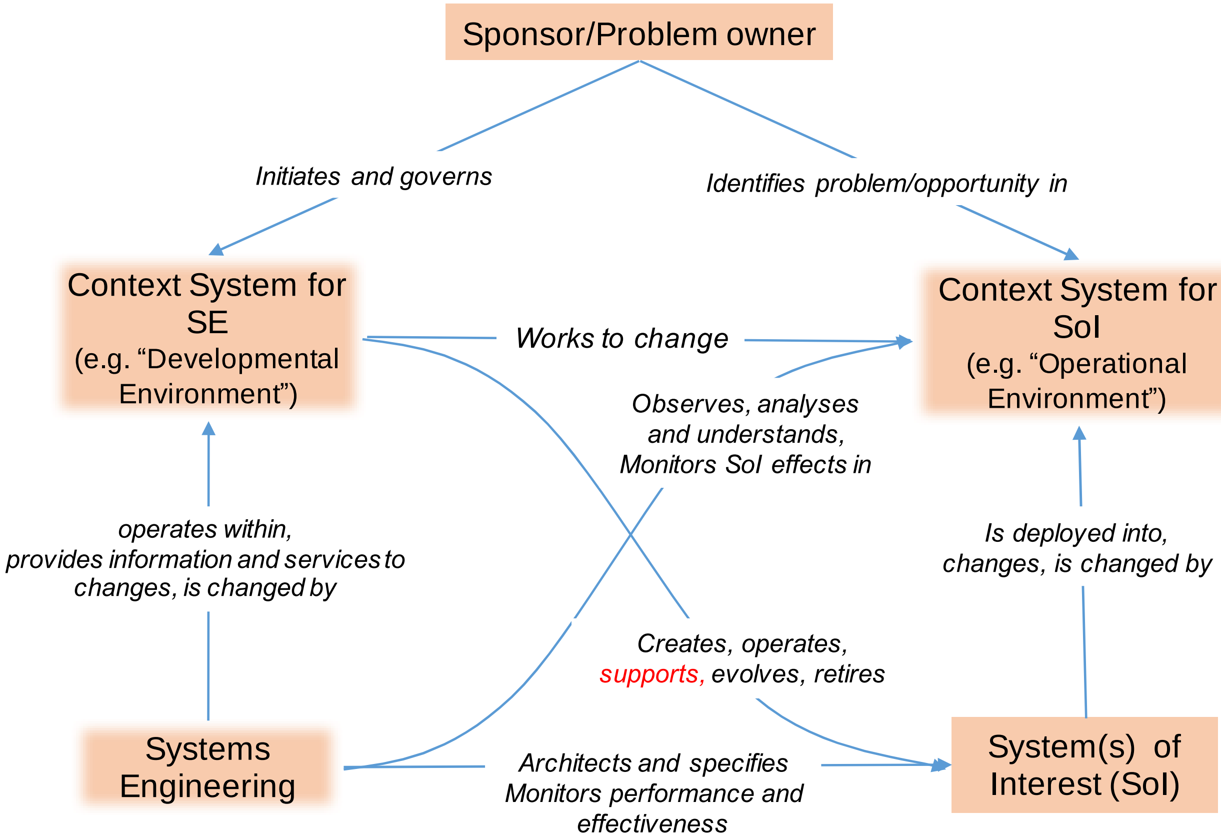
- **In real systems –**
  - **essential ingredients of all systems, vs**
  - **properties and behaviors of all systems, vs**
  - **properties and behaviors of some classes or types or combinations of system**

Part 2 – A fresh look at systems engineering

Fig 1: Conceptual model for SE in context



Conceptual model for SE



A system becomes part of a bigger system when placed in its operating environment.

Thus, we must analyse the current problem situation **as a system**, and understand how the proposed **new or improved system** will interact with and change the rest of the "**problem system**" to predict its effectiveness.

We need to think of multiple layers or levels of system, with new properties and capabilities emerging at each level.

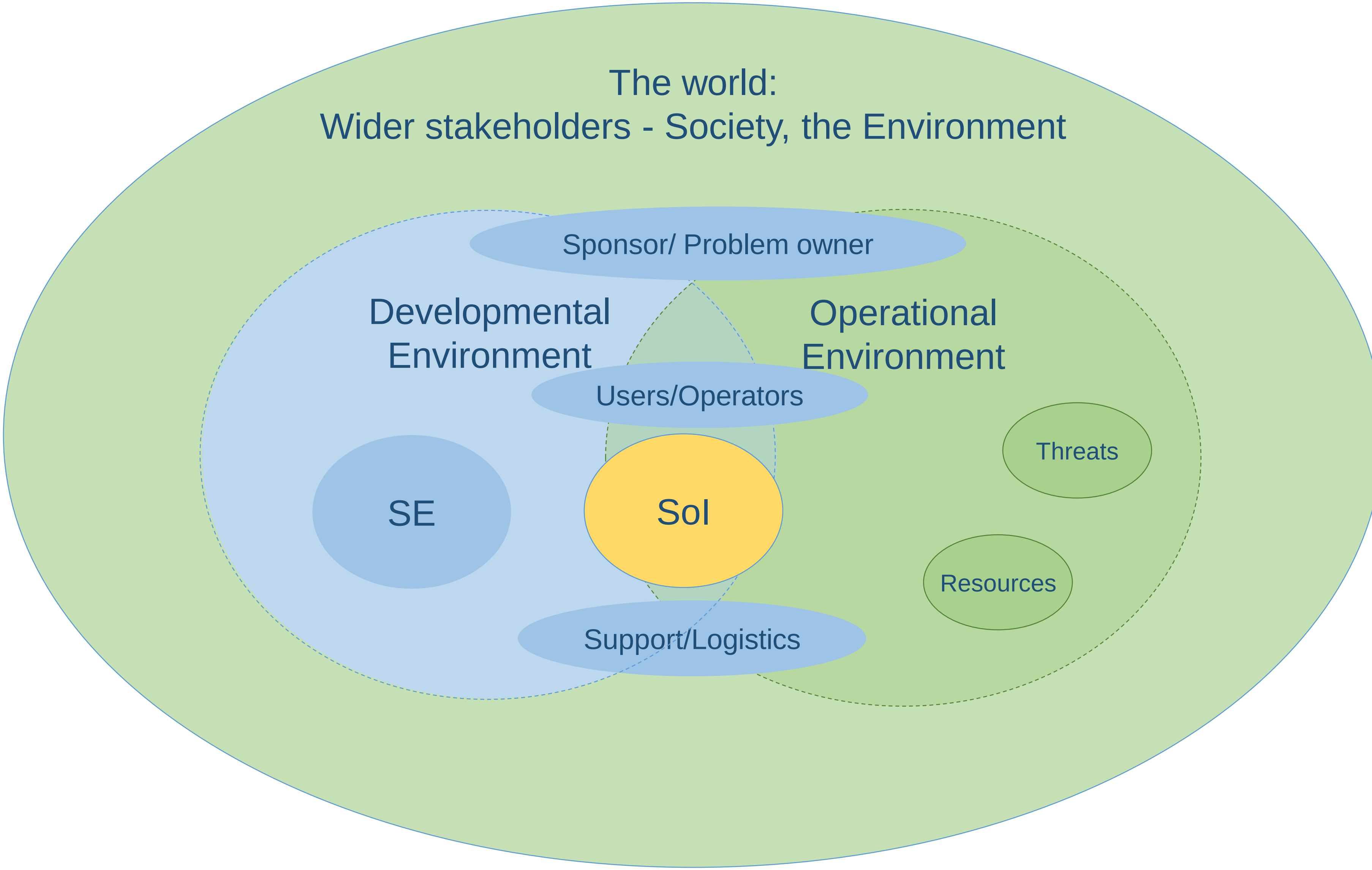
We need to apply systems engineering at multiple interacting levels in a complex systems endeavour.

Most systems interact with their environment by exchanging material, energy, force and information. Thus, systems change, and are changed by, their environment.

A system's effectiveness, delivered value, and fitness for purpose depend on what the system actually does, and how the system actually works, in its real-world context.

This applies both to the SoI and to the "system that does the SE"

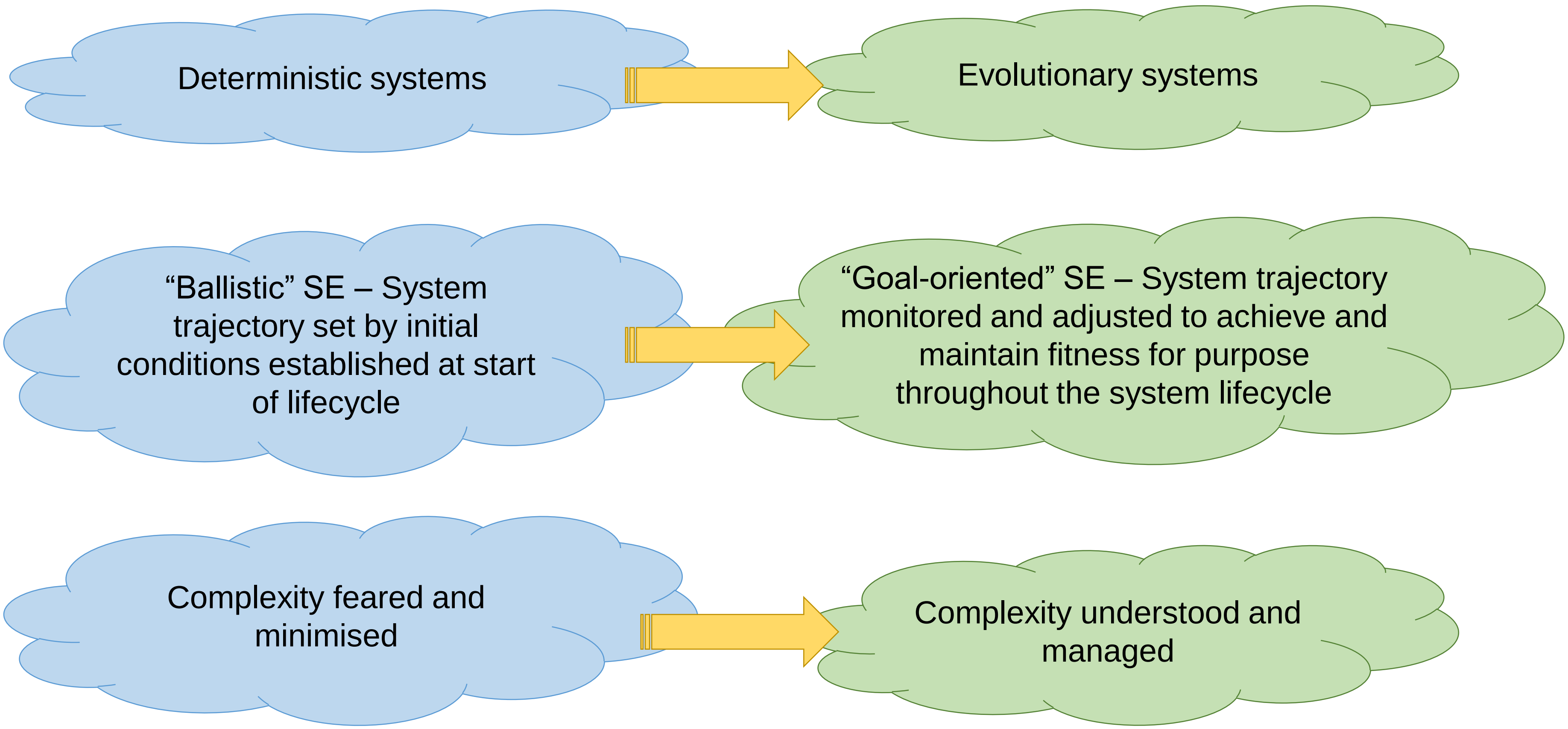
Fig 3: SE in context in context – poached egg diagram



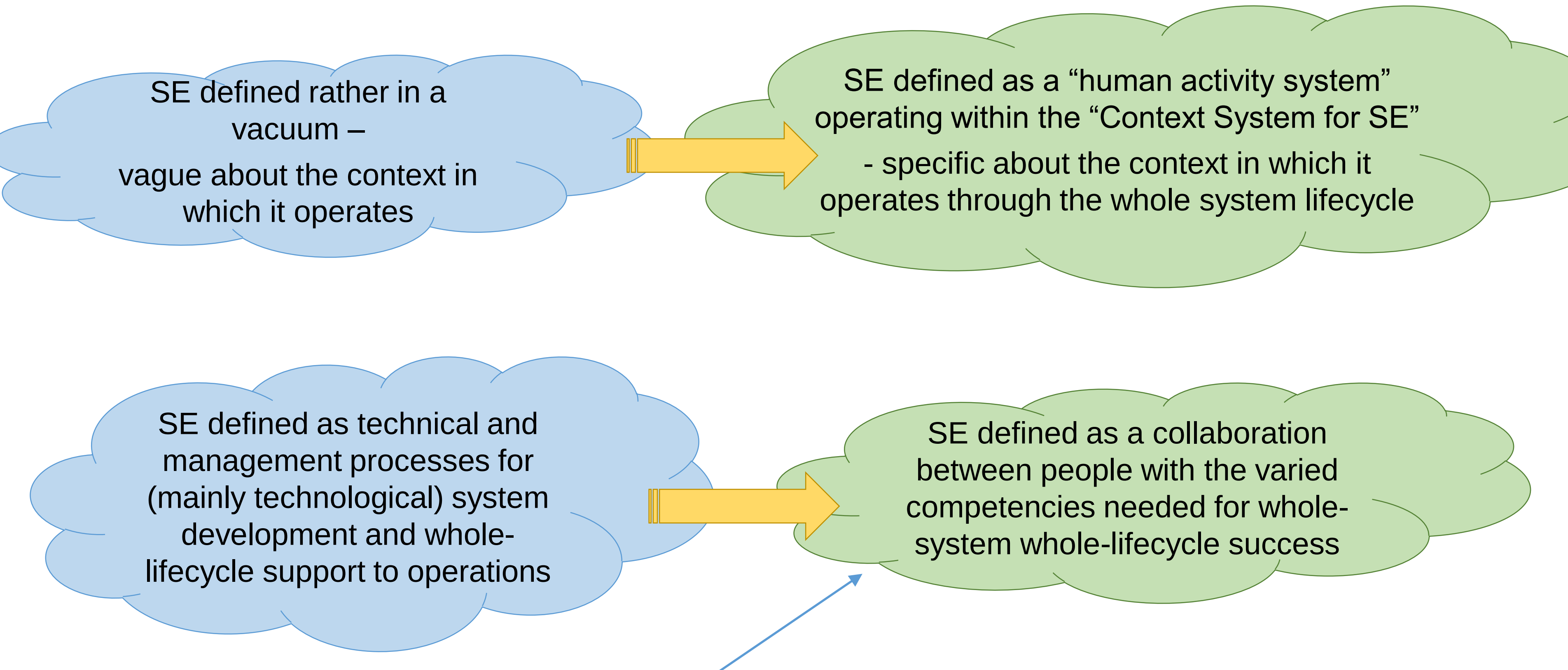
SE 2025 Vision demands PARADIGM SHIFT IN SE -> NEED FOR CHANGE!!!

Now (present paradigm)	Next (future paradigm)
robust, dependable, mainly-technological, “deterministic systems”	resilient, adaptive, “evolutionary” systems and systems-of-systems - encompassing products, services and enterprises - integrating technological, social and environmental elements
implicitly, a command and control view of how SE works	explicitly, a collaborative view of how SE works

Some aspects of the upcoming paradigm shift in SE



More aspects of the paradigm shift needed in SE



including

- **systemic** and **systematic** "SE" knowledge and leadership
- domain and discipline knowledge (societal, environmental & technical) relevant to the problem space and solution options
- cognitive, behavioural and psychological skills applied to both SE and SoI

Change in focus of SE

Focus of SE "was"

interdisciplinary

dependable, robust, pseudo-deterministic, mainly technological systems

requirements and operational concepts can be established early in the lifecycle and are not expected to change (much) through life

Focus of SE "is" opened out to

transdisciplinary

resilient, adaptive whole-system solutions - systems and SoS - that may be in a state of continual evolution, at least in their operational environment, and probably the solution system as well

systems of interest may be autonomous, possibly involving Artificial Intelligence, probably involving environmental aspects, and certainly involving social aspects as well as engineering and technology.

to address societal grand challenges related inter alia to the Sustainable Development Goals (SDGs)

Such systems will still need dependable robust technological building blocks (which is why we say the focus "opens out" rather than "shifts").

SYSTEMS ENGINEERING definition

Headlines – SE definition

- Many definitions of SE
  - most describe different aspects of the same thing, and at different levels of abstraction, rather than different things
- SE Worldviews Survey
  - distribution Gaussian(ish) rather than Multimodal
  - variation in worldviews on SE much less than in worldviews on *system*
  - Poster paper describing this in IS18 – tomorrow!
- We analysed Deficiencies and Drivers for Change in current INCOSE SE Definition
  - new straw man proposed
  - described in this paper (IS18)
- Future vision for Systems Engineering as a Transdiscipline conceived & described
  - described in paper at IS18
- Current proposal moves on from these

PARADIGM SHIFT IN SE

Now (present paradigm)		Next (future paradigm)
robust, dependable, mainly-technological, "deterministic systems"	→	resilient, adaptive, "evolutionary" systems and systems-of-systems - encompassing products, services and enterprises - integrating technological, social and environmental elements
implicitly, a command and control view of how SE works and systems are controlled	→	explicitly, a collaborative view of how SE works and an influence view of how systems are controlled
projects	→	ecosystems

Current proposal

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:

- *Operations, Cost & Schedule, Performance,*
- *Manufacturing, Test, Training & Support,*
- *Disposal*

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs

Definition augmented by extensive Notes: on four slides later in pack; include all key points from "SIMILAR" model

- *Systems Engineering is a transdisciplinary approach[1] that applies systems principles and concepts to enable the successful realization and use of engineered systems and whole-system solutions.*

Need to add "retirement" to cover whole lifecycle

1. APPROACH noun: a way of dealing with a situation or problem – first hit on internet search!

The up-coming paradigm shift for Systems Engineering

from "Ballistic" SE – trajectory set by initial conditions

to "Goal-oriented" SE – trajectory adjusted to achieve and maintain fitness for purpose throughout the system lifecycle

SE defined as

- technical and management process activities associated with (mainly technological) system development and whole-lifecycle support to operations,
- vague about the context in which it operates
- defined rather in a vacuum

Complexity is feared and minimised

SE defined as

- a collaboration between people with a variety of competencies needed for whole-system whole-lifecycle success, including
  - **systemic** and **systematic** "SE" knowledge, and
  - domain and discipline knowledge (societal and environmental as well as technical) relevant to the problem space and solution options
- specific about the context in which it operates through whole system lifecycle
- a "human activity system" operating within the context of a "system lifecycle extended enterprise"

Complexity is understood and optimised

Focus of SE is : "Deterministic" systems

- to engineer dependable, robust, pseudo-deterministic, mainly technological systems
- requirements and operational concepts that
  - can be established early in the lifecycle
  - are not expected to change (much) through life

Focus of SE is opened out: "Evolutionary" systems

- to address resilient, adaptive systems and systems-of-systems that may be in a state of continual evolution (at least their operational environment, and probably the system as well),
- systems of interest may be autonomous, possibly involving Artificial Intelligence, probably involving environmental aspects, and certainly involving social aspects as well as engineering and technology.
- to address societal grand challenges identified by national academies and funding organisations – e.g. NAE, EPSRC,
- Such systems will still need dependable robust building blocks, which is why we say the focus "opens out" rather than "shifts".

Headlines and conclusions

- INCOSE definition of SYSTEM needs to widen
- Include system types excluded by current definition, notably
  - Naturally occurring systems (involved in and/or affected by many engineered systems)
  - Systems whose properties cannot be fully controlled by design – complex, viable, autonomous, eco-systems…
- Three motivations:
  - Define what we do
  - Learn to do better
  - Facilitate cross-fertilisation with Systems Sciences, other system domains
- At least 7 Different system worldviews in INCOSE
  - these correspond to different system types with different characterist

** IFSR = International Federation for Systems Reasearch*

Final thought

In order to support the transition to model based SE

we need to shift emphasis

from PROCESS

to INFORMATION