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What do we mean by "system"? - System Beliefs and Worldviews in the INCOSE Community

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Abstract. The System Definition Survey issued to INCOSE Fellows in December 2016 revealed at least five radically distinct worldviews on Systems within a relatively small, but moderately representative, part of the INCOSE community. We describe and analyse the survey results, and comment on differences between the responses from the Fellows and the responses to a similar survey issued to the System Science Working Group a month later. Then we discuss how the different worldviews on "system" revealed by the surveys map onto different areas of the set of system definitions described in a previous paper. We conclude that all the worldviews identified offer useful perspectives for systems engineering, and that Systems Engineers need the flexibility to adopt different worldviews for different situations, or at least to act "as if" different worldviews are true in different situations.

Introduction

A special initiative was started by the INCOSE Fellows in summer 2016 at the request of the INCOSE president and President Elect, to review INCOSE's definitions of 'system' and 'systems engineering', and if necessary improve them to ensure they are fit for purpose, both now and looking forward towards the aspirations expressed in INCOSE's Systems Engineering Vision 2025.

As a crude generalisation, most system practitioners have a view on systems that lies somewhere on the spectrum from strictly constructivist (systems are a mental construct that human create to explain aspects of how the world works) to extreme realist (systems exist only in the real world). Within that spectrum there are many nuances: systems exist purely in the mind, or purely in reality, or both; systems are human-made, or naturally occurring, or both; systems are "a mode of description" of any aspect of reality, or a formal model of certain types of current or intended reality.

Sillitto et al (2017) describe how the team elicited inputs from the INCOSE Fellows (a population of about 60 respected senior SE practitioners and researchers) in the form of an extensive email correspondence, reviewed over 100 definitions of 'system', and formed some assumptions and hypotheses about the different worldviews represented by different groups of definitions. The team then used online surveys to gather data from different subsets of the systems community both within and outside INCOSE. The aim was to understand the range of worldviews about system and assess how widely the various worldviews are held through different parts of the community. A survey was issued to the Fellows in December 2016 and a slightly modified version to the Systems Science Working Group (SSWG) in January 2017.

This paper presents an analysis of the survey responses and relates these to prior literature. Five distinct worldviews are identified from the survey responses, and two more are identified from subsequent correspondence.

Background –system worldviews in philosophy and practice

Figure 1 shows a summary map of some key influences in systems as applied to science and engineering. In the 4th Century BCE, Aristotle made the famous proposition that "the whole is something over and above its parts and not just the sum of them all". Two thousand years later, Descarte's "reductionism" (*the practice* of *analysing and describing a complex phenomenon in terms of its simple or fundamental components*) led to rapid progress in Europe in experimental physics, biology and medicine from the 17th Century.

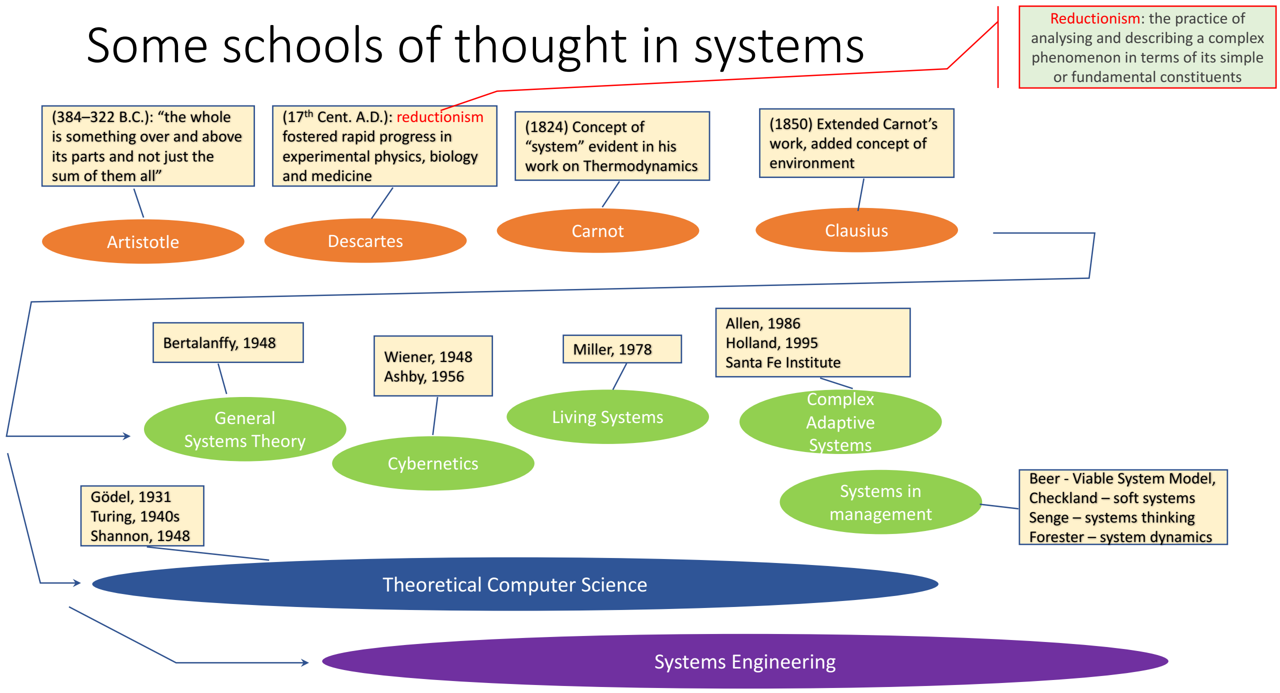


Fig 1: Some Schools of Thought in Systems

The concept of "system" is prominent in Adam Smith's philosophical treatises written around 1750, and evident in Carnot's work on thermodynamics, published in 1824. Clausius extended Carnot's work, adding the notion of environment in 1850. In the 1930s, Gödel launched what was to become theoretical computer science, leading to Turing's foundational work in the 1940s, and Shannon's seminal work on information theory published in 1948. Bertalanffy's work on General Systems

Theory was also first published in 1948, as was Wiener's work on Cybernetics. Ashby built on the latter in the 1950s.

Systems Engineering became recognised in the 1950s and 1960s, initially in the context of applying cybernetics principles to the design of complex engineered technological systems - though with the benefit of hindsight it can be recognised much earlier in history (Hitchins, 2007) and notably during WW2. Miller built on the biological aspects of Bertalanffy's work to develop his Living Systems Theory, published in 1978.

Systems thinking was applied to management from the 1970s (Beer, 1972), and Complex Adaptive Systems emerged and developed in the same era.

Scottish philosopher and polymath Adam Smith, writing his Essay on Astronomy in 1750, clearly positioned system as "**a mode of description**" when he writes: *a system is an imaginary machine invented to connect together in the fancy those different movements and effects which are already in reality performed.* In the same paragraph he appears also to adopt a **realist** perspective, writing: "*a machine is a little system, created to perform, as well as to connect together, in reality, those different movements and effects which the artist has occasion for.*" In his collected works published posthumously (Smith, 1869) the word "system" appears 327 times.

In the early 20th Century, we see systems defined as existing both in the real world and as mental constructs. For example, Müller-Freienfels (1922) describes a system as:

- objectively: a coherent whole of things and their relations, of processes (e.g. of the world system or the 'closed system' of mechanics),
- Logical, ideal: a unified [whole], in accordance with principles arranged, internally connected and articulated whole of insights.

By the 1950s, more definitions adopted an explicitly "realist" position, signifying that systems were considered to exist in the real world:

- "*A system is a set of objects together with relationships between the objects and between their attributes*." (Arthur David Hall, Robert E. Fagen, 1956 Definition of System. General Systems 1 (1956), 18)
- "*A system is a set of interacting units with relationships among them*." (Ludwig von Bertalanffy: General Systems Theory. General Systems 1.3, 1956)

Ackoff (1960) explicitly embraces both "physical and conceptual" systems:

- System: "*any entity, conceptual or physical, which consists of interdependent parts*"

From 1968 onwards, many sources are explicit about the duality between real or physical, and abstract or conceptual, systems. Davis (1997) makes the following assertions.

Systems can be abstract or physical.

An abstract system is an orderly arrangement of interdependent ideas or constructs. For example, a system of theology is an orderly arrangement of ideas about God and the relationship of humans to God.

A physical system is a set of elements that operate together to accomplish an objective. Examples of physical systems are the circulatory system of a body, a school system (with building, teachers, administrators, and textbooks), and a computer system (the hardware and software that function together to accomplish computer processing).

The examples illustrate that a system is not a randomly assembled set of elements; it consists of elements that can be identified as belonging together because of a common purpose, goal, or objective.

Physical systems are more than conceptual constructs; they display activity or behavior. The parts interact to achieve an objective.

A general model of a physical system comprises inputs, process, and outputs. The features that define and delineate a system form its boundary. The system is inside the boundary; the environment is outside the boundary. In some cases, it is fairly simple to define what is part of the system and what is not; in other cases, the person studying the system may arbitrarily define the boundaries.

Ossimitz (1997), quoted in www.sebokwiki.org, says that "*Systems thinking requires the consciousness of the fact that we deal with models of our reality and not with the reality itself.*" There are many different "schools" of systems thinking: most or all adopt this position, that their system models are mental constructs used to abstract and reason about the world rather than claiming to be explicitly representative. For example, in Soft Systems Methodology (Checkland, 1981), *"A human activity system is a notional system which expresses some purposeful human activity. The systems are notional in the sense that they are intellectual constructs and not descriptions of actual real-world activity."*

Aslaksen (2013) and Blockley and Godfrey (2017), prominent Civil Engineers in or close to the INCOSE community, applying systems engineering to their domain, adhere to the "system as a mode of description" worldview.

Many systems engineers adopt the moderate realist worldview that systems can be abstract/conceptual, or physical/real, or both. Increasingly, systems engineering depends on use of models that correspond to, and allow us to make predictions about, real systems, either actual or intended. Rosen (2005) is explicit about the "modelling relationship" between real and conceptual (or in his language "natural" and "formal") systems.

Many systems engineers and systems scientists regard "emergence", the ability of the system to do something its separate parts cannot, as a defining property of systems. Hitchins (2007) defines a system as *an open set of complementary interacting parts, with properties, capabilities and behaviours emerging, both from the parts and their interactions, to synthesise a unified whole.* Rechtin (1991), Dickerson (2008), and Sillitto (2014) propose similar definitions along the lines of: *[a system comprises] parts interacting to create properties of the whole not possessed or exhibited by any of the parts on its own*.

The notion of "interacting" parts leads on to the notion that a system might be primarily defined, not in terms of its composition and structure, but in terms of the process(es) it performs. The notions of system/process duality and even of process primacy are evident for example in Blockley's (2010) discussion of "the importance of being process", and Ruhm's (2010) discussion of system/process duality. This notion is reflected in the Object Process Methodology (Dori, 2002), Sillitto's (2016) discussion of how an observable process provides evidence for the existence of a real system, and the emphasis of the process perspective in the logical architecture view of many model based systems engineering methods, as described for example by Voirin (2008).

Ruhm (2010) expresses his frustration at the current state of affairs. "*Is every configuration of items a system? Searching definitions of the term system is really amazing. If we exaggerate, we could claim that they differ altogether and in many respects. This fills whole books and leaves us disoriented and inclined to abandon the topic*".

The current INCOSE definition is couched in terms of real systems, and further restricts its scope to artificial (human-made) technology-based systems:

…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)

Later in this paper we argue that this definition needs to be widened to enable transdisciplinary integration across the different schools of thought, if INCOSE's 2025 Vision (INCOSE 2014) is to be realised. In support of this aspiration, Sillitto et al (2017) and Dori & Sillitto (2017) set out a family of systems definitions that, taken together, provide a framework that is claimed to encompass the full range of worldviews discussed in this paper.

Design of the System Definition Survey

Analysis of the existing definitions and the extensive email correspondence among the Fellows suggested that although INCOSE has a single definition of System, the individual Fellows use a wide range of different, and apparently mutually incompatible, definitions. The survey questions were designed to quantify the range and relative popularity of the different beliefs, and to get a better understanding of the specific assumptions behind each.

Realist or constructivist?

The first question was intended to elicit the respondents' position on the basic realist/constructivist spectrum:

Do you think that Systems

- *only exist in the real world?*
- *are purely mental constructs*
- *can be either of the above*

Human-made or naturally occurring

The second question probed beliefs about whether systems are human-made, occur in nature, or both. To avoid excluding constructivists from the conversation, the question was couched in terms of "*systems, or entities designated as systems*".

Do you think that systems, or entities designated as systems, in the real world, can be

- *only human made*
- *only naturally occurring*
- *either or both of the above?*

Do systems only exist if an observer designates them as such?

The third question probes respondents' beliefs on a major source of debate - whether systems only exist because someone calls them that, or if they have objective properties that mean they exist whether or not they are observed.

Considering how you think of entities in the real world designated as systems, do you think

- *systems only exist if they are designated by a human observer?*
- *systems can exist in the physical universe independent of human observation and thought?*

System Boundaries – observer designated or intrinsic?

The fourth question is about whether respondents believe that system boundaries are designated by the observer or can be located based on objective criteria.

Considering again how you think of entities in the real world designated as systems, do you think

- *system boundaries are always a free choice of the observer*

- *while an observer is always free to designate the boundary for a particular analysis, 'system' boundaries can at least in some cases be discovered and refined based on objective criteria*
- *the 'correct' system' boundary can always be discovered and refined based on objective criteria?*

Exploring "systemicity"

The fifth question offered a considerable number of characteristics often asserted to be essential or defining properties of "system". Respondents could choose as few or as many as they liked, and this question turned out to be a very strong discriminator between different groups of respondents, and yielded additional and unexpected information about the range of worldviews held by respondents.

Do you think that the following are essential characteristics of "systems"?

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

The last five of this list were offered as "other" responses in the survey issued to the Fellows, and included as options in the modified survey issued to SSWG members.

Demographic information

The other questions in the survey collected demographic information, including age band, institution membership, native language, and geographical area.

Analysis of INCOSE Fellows' System Definition Survey responses

The summarised and clustered results of the Fellows' survey are shown in Figure 2. (Note: the figures can be zoomed so as to be readable in the electronic version of the paper.)

The salient points emerging from the survey responses include the following.

1. About 20% of the respondents are "constructivists", who consider that systems are a human mental construct. Almost all the others are "moderate realists" who hold that systems can be

mental constructs but also entities in the real world. One of these respondents considers that systems only exist in the real world.

2. One respondent considers that “systems” can only be human-made. All the others hold that systems, or, for the constructivists, entities humans choose to designate as systems, can be both human-made and naturally occurring.
3. About ¾ of the respondents considered that systems can exist in the real world independent of human observation or thought. A similar percentage considered that the “correct” or most appropriate system boundary can at least sometimes be established based on objective criteria. One respondent considered that the system boundary can always be established based on objective criteria.
4. About 2/3 considered that a boundary is an essential characteristic of “systems”, whereas 1/3, all of whom were characterized as adhering broadly to the “realist consensus”, did not.

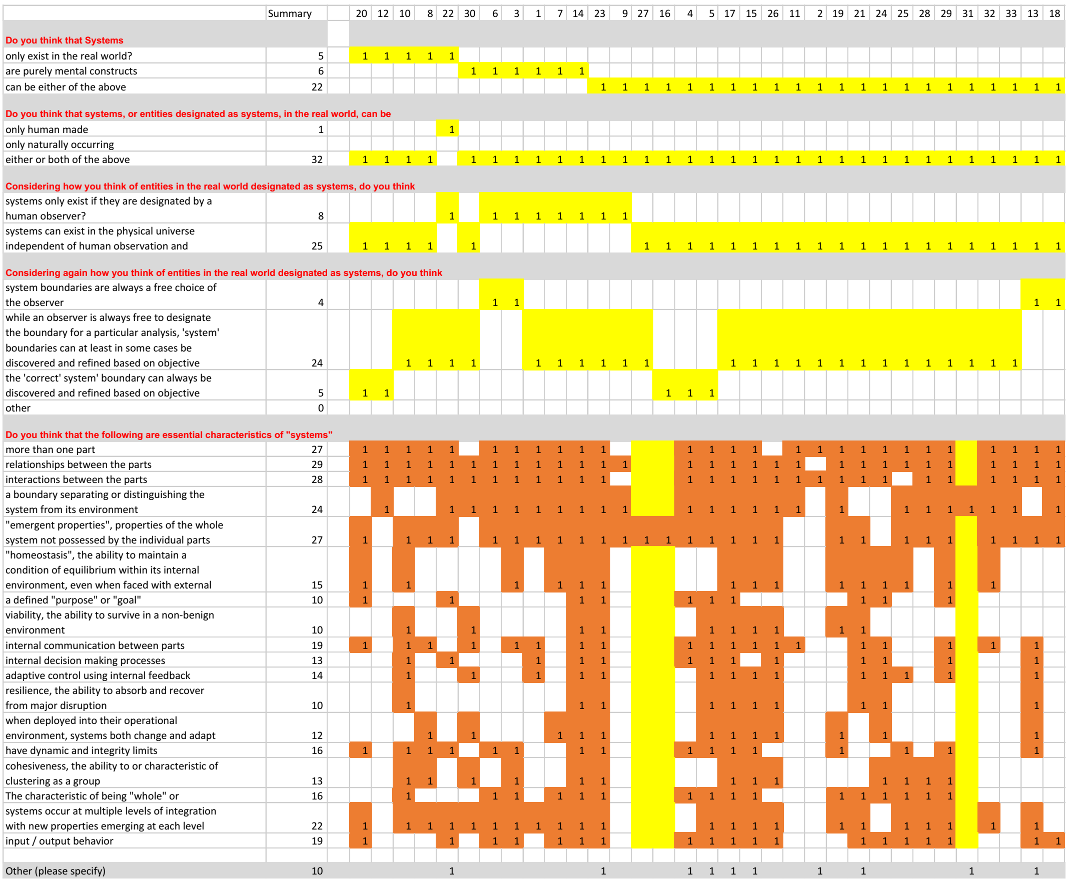
	Summary	13	16	8	9	22	25	3	18	7	17	2	4	24	6	19	26	10	14	15	20	1	5	23	12	11	21
Do you think that Systems		Constructivists								"realist consensus"																	
exist (only) in the real world?	1																										1
are a mental construct	4	1	1	1	1																						
can be both of the above	21					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Do you think that systems, or entities designated as systems, in the real world, can be																											
human made	1							1																			
naturally occurring	0																										
either or both of the above	25	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Considering how you think of entities in the real world described as systems, do you think																											
systems only exist if they are designated by a human observer?	6	1	1	1	1	1	1																				
systems can exist in the physical universe independent of human observation and thought?	19							1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1
Considering again how you think of entities in the real world described as systems, do you think																											
system boundaries are always a free choice of the observer	5		1	1	1			1	1																		
while an observer is always free to designate the boundary for a particular analysis, 'system' boundaries can at least in some cases be discovered and refined based on objective criteria	20	1				1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
the 'correct' system' boundary can always be discovered and refined based on objective criteria	1																									1	
other	0																										
Do you think that the following are essential characteristics of "systems"																											
more than one part or element	24	1	1	1	1	1	1		1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
relationships between the parts	24	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
interactions between the parts	22	1	1	1	1	1			1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1
a boundary (physical or logical) separating the system from its environment	18	1	1	1	1	1	1								1	1	1	1	1	1		1	1	1	1	1	1
"emergent properties", properties of the whole system not possessed by the individual parts acting separately	22	1	1	1		1	1		1	1	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1
"homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external changes	6																				1	1	1	1	1	1	
a defined "purpose" or "goal"	7		1	1																		1		1	1	1	1
viability, the ability to survive in a non-benign environment	6																			1	1		1	1	1	1	
internal communication between parts	11					1					1	1					1		1	1			1	1	1	1	1
internal decision making processes	3																							1	1	1	
adaptive control using internal feedback	5													1						1				1	1	1	
resilience, the ability to absorb and recover from major disruption	4																			1				1	1	1	
when deployed into their operational environment, systems both change and adapt to their environment	10									1							1		1	1	1	1	1	1	1	1	
Total no. of attributes selected from all 5 q's		9	10	10	8	10		4	8	9	9	9	8		8	8		7	11	14	11	11	13	17	17	17	11
Other (please specify)	10																										
have dynamic and integrity limits	1																									1	
cohesiveness, the ability to cluster as a group	1																						1				
input / output behavior	1							1																			
"human-engineered systems" have goals; "natural systems" only have goals or purpose as imputed or inferred by humans.	2											1						1									
Not all required but may be desired	1																								1		
Marked are essential, others relevant for some	1			1																							
a role defined by a perspective associated with a particular viewpoint	1																							1			
Systems are wholes, complete	2						1														1						
interactions are not necessary in that some kinds of systems only have relationships between parts that do not necessarily involved "interactions" if you define interaction as a "flow" of data, info, material, energy, etc between the parts.	1															1											

Figure 2: Clustered summary of INCOSE fellows’ responses to System Definition Survey: yellow highlights apparently significant clustering

5. The large majority considered that "interactions between the parts" are an essential characteristic of a system. The few who did not point out that certain kinds of conceptual system are composed purely of abstract information elements which can't "interact" unless placed in a host "real system" such as a computer (in the case of computer code), a human brain (in the case of ideas), a biological system (in the case of the information stored in DNA) or a social system (in the case of laws, policies, religious and political belief systems, etc)
6. One or two respondents did not consider that "more than one part" was an essential characteristic. One of these respondents is explicit with their set of responses that a system is viewed as a "black box", a function-carrying object with input-output behavior and no assertions about internal structure or content. We will see in the SSWG responses that a small set of respondents in that group take a very formal approach to defining a system and end up with quite a different set of criteria for "what is a system" compared with the majority.
7. Nearly 90% considered that "emergent properties", properties of the whole system not possessed by individual parts or subsets, were essential characteristics of systems.
8. About 25% considered that "a defined purpose or goal" was an essential characteristic.
9. Most respondents took a modest or even a minimalist approach to the essential attributes defining a system. By contrast, a small group – about 1/8 – consider that all the "systemic" characteristics listed were essential for something to be considered a system.

Comparison with SSWG survey

A similar survey was issued to the INCOSE Systems Science Working Group (SSWG). Some of the "other" criteria suggested in responses to the first survey were added as options in this second survey. Most SSWG respondents were members of both INCOSE and ISSS.



	Summary		20	12	10	8	22	30	6	3	1	7	14	23	9	27	16	4	5	17	15	26	11	2	19	21	24	25	28	29	31	32	33	13	18
Do you think that Systems																																			
only exist in the real world?	5		1	1	1	1	1																												
are purely mental constructs	6							1	1	1	1	1	1																						
can be either of the above	22													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Do you think that systems, or entities designated as systems, in the real world, can be																																			
only human made	1						1																												
only naturally occurring																																			
either or both of the above	32		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Considering how you think of entities in the real world designated as systems, do you think																																			
systems only exist if they are designated by a human observer?	8						1		1	1	1	1	1	1	1																				
systems can exist in the physical universe independent of human observation and	25		1	1	1	1		1								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Considering again how you think of entities in the real world designated as systems, do you think																																			
system boundaries are always a free choice of the observer	4								1	1																								1	1
while an observer is always free to designate the boundary for a particular analysis, 'system' boundaries can at least in some cases be discovered and refined based on objective	24				1	1	1	1			1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1	1	1	1	1		
the 'correct' system' boundary can always be discovered and refined based on objective	5		1	1													1	1	1																
other	0																																		
Do you think that the following are essential characteristics of "systems"																																			
more than one part	27		1	1	1	1	1		1	1	1	1	1	1				1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1
relationships between the parts	29		1	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1		1	1	1	1	1	1		1	1	1	1
interactions between the parts	28		1	1	1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1
a boundary separating or distinguishing the system from its environment	24			1			1	1	1	1	1	1	1	1	1			1	1	1	1	1	1		1			1	1	1	1	1	1		1
"emergent properties", properties of the whole system not possessed by the individual parts	27		1		1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1		1	1	1		1	1	1	1
"homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external	15		1		1					1		1	1	1						1	1	1			1	1	1	1		1		1			
a defined "purpose" or "goal"	10		1				1						1	1				1	1	1						1	1			1					
viability, the ability to survive in a non-benign environment	10				1			1					1	1					1	1	1	1			1	1									
internal communication between parts	19		1		1	1		1		1	1		1	1				1	1	1	1	1	1			1	1			1		1		1	
internal decision making processes	13				1		1				1		1	1				1	1	1		1				1	1			1				1	
adaptive control using internal feedback	14				1			1			1		1	1					1	1	1	1				1	1	1		1				1	
resilience, the ability to absorb and recover from major disruption	10				1								1	1					1	1	1	1				1	1							1	
when deployed into their operational environment, systems both change and adapt	12					1		1				1	1	1					1	1	1	1			1		1							1	
have dynamic and integrity limits	16		1		1	1	1		1	1			1	1				1	1	1	1				1			1		1				1	
cohesiveness, the ability to or characteristic of clustering as a group	13				1	1		1		1			1	1						1	1	1					1	1	1	1					
The characteristic of being "whole" or	16				1				1	1		1	1	1				1	1	1	1				1	1	1	1	1	1					
systems occur at multiple levels of integration with new properties emerging at each level	22		1		1	1	1	1	1	1	1	1	1	1					1	1	1	1			1	1		1	1	1		1		1	
input / output behavior	19		1				1		1	1		1	1	1				1	1	1	1	1				1	1	1	1	1				1	1
Other (please specify)	10						1							1				1	1	1	1			1		1					1			1	

Figure 3: Responses from Systems Science Working Group to updated survey, January 2017: yellow and orange indicate and contrast significant clusters.

Salient differences between SSWG responses to this survey and Fellows' responses to the previous one included the following.

1. A significantly higher percentage of respondents (15% instead of 4%) believe that systems only exist in the real world.
2. A significantly higher percentage (15% instead of 4%) believe that the system boundary can always be discovered and refined by objective criteria.
3. Some characteristics proposed by one or more of the fellows in their responses were added to the SSWG survey and attracted many positive responses – including "dynamic and integrity limits", input/output behavior, and the characteristics of being "whole" or "complete".
4. Again there are "extreme" positions. One respondent, a realist, gave emergent properties as the only essential characteristic of a system, while another considered that "more than one part" and "interactions" were the only essential characteristics, adding that the behavior of each interacting system component depends on its state.
5. More respondents checked many characteristics as "essential" in the SSWG survey than the Fellows' one

SSWG: sample size = 33	Summary	%	Fellows: Sample size = 26	Fellows Summary	Fellows % (26)	SSWG Summary	SSWG % (33)	Total % (59)	Difference SSWG-Fellows	Significant?
Do you think that Systems			**Do you think that Systems**							
only exist in the real world?	5	15%	exist in the real world?	1	4%	5	15%	10%	11%	
are purely mental constructs	6	18%	are a mental construct	4	15%	6	18%	17%	3%	
can be either of the above	22	67%	can be both of the above	21	81%	22	67%	73%	-14%	
Do you think that systems, or entities designated as systems, in the real world, can be			**Do you think that systems, or entities designated as systems, in the real world, can be**							
only human made	1	3%	human made	1	4%	1	3%	3%	-1%	
only naturally occurring		0%	naturally occurring	0	0%		0%	0%	0%	
either or both of the above	32	97%	either or both of the above	25	96%	32	97%	97%	1%	
Considering how you think of entities in the real world designated as systems, do you think			**Considering how you think of entities in the real world described as systems, do you think**							
systems only exist if they are designated by a human	8	24%	systems only exist if they are designated by a human	6	23%	8	24%	24%	1%	
systems can exist in the physical universe independent of human observation and thought?	25	76%	systems can exist in the physical universe independent of human observation and thought?	19	73%	25	76%	75%	3%	
Considering again how you think of entities in the real world designated as systems, do you t			**Considering again how you think of entities in the real world described as systems, do you think**							
system boundaries are always a free choice of the	4	12%	system boundaries are always a free choice of the	5	19%	4	12%	15%	-7%	
while an observer is always free to designate the boundary for a particular analysis, 'system' boundaries can at least in some cases be discovered and refined	24	73%	while an observer is always free to designate the boundary for a particular analysis, 'system' boundaries can at least in some cases be discovered and refined	20	77%	24	73%	75%	-4%	
the 'correct' system' boundary can always be discovered and refined based on objective criteria	5	15%	the 'correct' system' boundary can always be discovered and refined based on objective criteria	1	4%	5	15%	10%	11%	
other	0	0%	other			0		0%		
Do you think that the following are essential characteristics of "systems"			**Do you think that the following are essential characteristics of "systems"**							
more than one part	27	82%	more than one part or element	24	92%	27	82%	86%	-10%	
relationships between the parts	29	88%	relationships between the parts	24	92%	29	88%	90%	-4%	
interactions between the parts	28	85%	interactions between the parts	22	85%	28	85%	85%	0%	
a boundary separating or distinguishing the system from its environment	24	73%	a boundary (physical or logical) separating the system from its environment	18	69%	24	73%	71%	3%	
"emergent properties", properties of the whole system not possessed by the individual parts acting separately	27	82%	"emergent properties", properties of the whole system not possessed by the individual parts acting separately	22	85%	27	82%	83%	-3%	
"homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external changes	15	45%	"homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external changes	6	23%	15	45%	36%	22%	
a defined "purpose" or "goal"	10	30%	a defined "purpose" or "goal"	7	27%	10	30%	29%	3%	
viability, the ability to survive in a non-benign	10	30%	viability, the ability to survive in a non-benign	6	23%	10	30%	27%	7%	
internal communication between parts	19	58%	internal communication between parts	11	42%	19	58%	51%	15%	
internal decision making processes	13	39%	internal decision making processes	3	12%	13	39%	27%	28%	
adaptive control using internal feedback	14	42%	adaptive control using internal feedback	5	19%	14	42%	32%	23%	
resilience, the ability to absorb and recover from major disruption	10	30%	resilience, the ability to absorb and recover from major disruption	4	15%	10	30%	24%	15%	
when deployed into their operational environment, systems both change and adapt to their environment	12	36%	when deployed into their operational environment, systems both change and adapt to their environment	10	38%	12	36%	37%	-2%	
			Other (please specify)	10	10					
have dynamic and integrity limits	16	48%	have dynamic and integrity limits	1	4%	16	48%			
cohesiveness, the ability to or characteristic of clustering as a group	13	39%	cohesiveness, the ability to cluster as a group	1	4%	13	39%			
The characteristic of being "whole" or "complete"	16	48%	Systems are wholes, complete. a w(?)	2	8%	16	48%			
input / output behavior	19	58%	input / output behavior	1	4%	19	58%			

Figure 4: Summary of SSWG responses and comparison with Fellows' responses: green in the right-hand column means similar, yellow somewhat different, pink significantly different.

Write-in responses to the "systemness" question included the following:

- Many of the above are the same and so redundant.
- If the phrase had been "a defined 'function' instead of purpose/goal I would have checked it.
- [Systems] exhibit recursive patterns
- Distinction should be made between simple and complex (adaptive) systems
- Some other attributes are associated with some kinds of systems but not all.
- Behaviour of each interacting System Component depends on its State; States in turn depend on past Interactions; Overall System combinatorial State depends on Hamilton's Principle. (Refer to Schindel, 2016)
- System acts as a whole

- interaction and internal communication: both are same but two different perspectives; adaptive control and resilience are one and the same, they both mean the system is striving for its existence; systems changing in an environment is only for natural systems not for man made systems unless we build a mind into it
- counter-intuitive', also the mentioned are essential in a 'normative way', I think.
- There are no "essential" characteristics. Almost anything can be a system.

In summary, the SSWG sample shows a higher diversity of views, ranging from a very formal, possibly mathematical, perspective to a very practical and realist view of systems as a mode of organization of nature, with complex properties associated with viability and persistence (the only systems in nature we know about are the viable ones that have persisted long enough for us to recognize them as systems). We didn't feel we had to make any structural changes to our Systems Definition Framework because of this extra input, but we did feel the need to ensure the full range and scope of the various belief systems were properly considered.

Worldviews revealed by the surveys

Our aim is to use all the data from these and subsequent surveys to make sure the system definition(s) used by INCOSE cover(s) the full range of worldviews of the interested parties within and outside INCOSE. The survey and discussions around it reveal a rich and diverse spectrum of beliefs about systems. The following worldview definitions should be considered as interesting and fairly stable points on a continuous belief spectrum, rather than separate distinct "islands" of belief. It is doubtful that many respondents would identify unreservedly with any one worldview set out below.

Worldview S1: A formal minimalist view based on mathematics and logic

Through discussions and email correspondence it was apparent that a small number of respondents to both surveys hold this very formal and minimalist worldview, though it is not explicitly or easily identifiable from the survey responses. This very formal view, with roots in theoretical computer science, holds that the way to give a rigorous scientific basis to the concept of system is to define abstractly the concept of a "conceptual" system, and then say that a real system is anything that can be modelled by a conceptual system. Complex properties can be developed from even a minimalist definition, such as Bertalanffy's description of a system as an entity that can be mathematically modelled as a dynamical system. This leads to a view of complex systems built up from basic elements. Those who adhere to this worldview are seeking to improve mathematical and scientific tools for systems practice, in a way that seems consistent with an aim of generating real systems from mathematical models. Since the mathematical model comes first, the focus of this worldview seems to be very much on model based generation of artificial systems.

The implication of this worldview is that if we can't model it we can't call it a system, a concept which would trouble many practitioners. The limiting case of this worldview considers systems to be abstracted systems based on formal models, which are used to generate "artificial real" systems.

Worldview S2: Constructivist - systems are purely a mental construct

A substantial minority (about 20%) of both groups espouse a more conventional and less formal constructivist view, in which systems are purely a mental construct. Most constructivist responses agreed that a system comprises more than one part, with relationships and interactions between the parts, has a boundary, and exhibits emergent properties of the whole not possessed by the parts but arising from the relationships and interactions between the parts. Proponents of this worldview are divided on whether systems must have a purpose or goal. The majority consider the system boundary to be a free choice of the observer.

In this worldview, the concept of system is reserved for the conceptual world. When conceptual systems are considered to represent parts of the real world - so they are what Sillitto et al (2017), following Bertalanffy (1968), defined as "abstracted systems" - there is a mapping relationship from the abstracted system to those parts of the real world that the abstracted system represents. The real world configurations represented by the abstracted system are not, IN THIS WORLDVIEW, considered to be "systems". Hybertson (2009) articulates this distinction very clearly. He describes the ensemble of relevant parts of the real world as "the mosaic", and defines systems in terms of a model of parts of the mosaic considered relevant to the purpose or of interest to the observer. This is consistent with Checkland's (1981) view of Human Activity Systems which he describes as *a notional system which expresses some purposeful human activity. The systems are notional in the sense that they are intellectual constructs and not descriptions of actual real-world activity.*

Worldview S3: Moderate realist

The "consensus" moderate realist worldview holds that systems can exist as purely mental constructs, or in the real world, or both, as discussed in Dori & Sillitto (2017); and exist in both the natural and human-made worlds. As Rousseau et al (2016) point out, this worldview (or a view that we act "as if" this worldview applies) seems to be the most appropriate for the practice of systems engineering, and this is reflected by the large majority of responses from the INCOSE Fellows that espouse some variant of this worldview. Within that group there are significant variations in the number of subsidiary characteristics that are considered "essential" aspects of being a system.

This worldview is consistent with Rosen's (1985) "modelling relation" between models and real-world systems, and with Bertalanffy's (1968) identification of "abstracted systems" that are conceptual systems corresponding to, or "abstracted from", real systems. It also allows for pure information systems that don't correspond directly to real world systems. And it fits the notion that systems engineering first produces models of reality and of the proposed intervention system, and then generates the real intervention system from the model.

Many adherents to this worldview do not consider that a boundary is an essential part of a system – they think the boundary can be discovered during investigation of the system, rather than being the starting point; and a minority don't consider emergent properties to be a defining characteristic of systems. Some adherents of this worldview, and some of the next category (strong and extreme realists) maintain that the system boundary can always be discovered and refined based on objective criteria. Intriguingly, there is no obvious correlation between this belief and the number of characteristics deemed "essential" for an entity to be a system.

Worldview S4: Strong and Extreme Realists

One response to the Fellows' survey, and several to the SSWG survey, maintained that systems only exist in the real world. Looking at the Fellows' survey it was tempting to conclude that this worldview corresponded to a belief that many or all the listed characteristics were essential for an entity to be considered a system. This assumption is negated by the SSWG data, in which (on a small sample of five) there is no correlation between "systems only exist in the real world" and the attributes deemed necessary for an entity to be considered as a system.

Worldview S5 – complex, viable and living systems

This worldview appears to be compatible with any of Worldviews S2, S3 and S4, tending to correlate with strong realist positions (Worldview S4), but in terms of its "criteria for systemness" is diametrically opposed to the formal mathematics-based Worldview S1. It refers to those who deemed most or all of the following to be essential and defining attributes of systems:

- "homeostasis", the ability to maintain a condition of equilibrium within its internal environment, even when faced with external changes;
- viability, the ability to survive in a non-benign environment;
- internal communication between parts;

- internal decision making processes;
- adaptive control using internal feedback;
- resilience, the ability to absorb and recover from major disruption;
- when deployed into their operational environment, systems both change and adapt to their environment;
- have dynamic and integrity limits;
- cohesiveness, the ability to or characteristic of clustering as a group;
- The characteristic of being "whole" or "complete";
- systems occur at multiple levels of integration with new properties emerging at each level.

By contrast, many other respondents recognised many of these as common but not essential characteristics of systems.

The Worldview S5 group is quite distinct in the Fellows' survey, comprising about 10% of the sample, and larger but more diffuse in the SSWG responses. We speculate that this group includes, and may be limited to, those who are mainly interested in viable autonomous systems capable of reproducing themselves, such as "living" biological systems as described by Miller (1978), and "viable" organisational systems as described by Beer (1972). Importantly, many of these attributes (except the ability to reproduce themselves!) are increasingly being expected of engineered systems.

Worldview S6: Systems as a Mode of Description

This worldview was not identified from the survey data, but emerged from prior and subsequent discussion – and, as we noted earlier, has long historical precedent, being described by Adam Smith as early as 1750. In email correspondence quoted with permission, Aslaksen explained that the **system concept** is a *mode of description*. Any aspect of an entity can be described in terms of three sets:

- a set of elements;
- a set of interactions between these element; and
- a set of interactions with the outside world (which may be simply an observer).

[In this worldview] nothing *is* a system, and everything can be *described* as a system; ontologically a system is not a thing, descriptions are a separate ontological class. The purpose of describing something as a system is to handle its complexity, and in order to fulfil this purpose, the elements (i.e. the partitioning) must be chosen so that the complexity of the interactions is considerably less than the complexity of the elements (which remains hidden). The application of the concept takes place in a step-by-step, top-down fashion, each step revealing more of the complexity of the entity in the form of sub-system, sub-sub-systems, etc. To an entity there can correspond a number of systems (i.e. descriptions), depending on what aspect of the entity we are interested in, such as cost, reliability, performance, etc.

Worldview S7: System as a process

Similarly, this worldview was not identified from the survey data but through correspondence. As we noted previously, there is a substantial body of literature related to the concept of object/process or system/process duality or correspondence, and several of our sources argue that a system is primarily defined not by its structure but by its ability as a whole system to do things or perform process(es) that cannot be performed by its parts acting independently. Ring (2015-16) argues that "a system" is only a system when it is "doing". Blockley (2010) maintains that "a system is a process", pointing out that while conventionally we think of structure as being persistent and behavior transient, the structure goes through a lifecycle, so is also transient if we consider a sufficiently long timescale.

Consequences for systems engineering as we know it

Looking at the results presented in this paper and considering their implications for systems engineering, the two obvious observations are that

1. there is divergence in worldviews within the SE and Systems Sciences community;
2. there is an important divergence between the way the concept of "system" is used and viewed by system-oriented theoretical computer scientists and all other systems practitioners.

To explore the implications of these observations, we consider five domains of application of the systems sciences and systems engineering, to illustrate how the worldviews we discuss above may influence both current practice and the prospects for improvement.

Domain 1 - Software systems and formal models of engineered technological systems –At the risk of oversimplification, we suggest that practice in this area is divided between, at the one extreme, empiricists who "hack code", and at the other, theory-based practitioners working at model level and drawing on theoretical computer science. The goals of the latter include:

- developing and operationalizing theory-based approaches to Improve the determinism and efficiency of those engineered systems that can be deterministic and efficient;
- extending the dynamic and integrity envelopes of systems to reduce the incidence of behaviour becoming non-deterministic and counter intuitive as integrity limits are approached and breached;
- developing theory to underpin and apply deep learning to allow automated and autonomous systems to respond to non-deterministic situations in non-deterministic ways that are none-the-less appropriate to the situation and acceptable to humans.

We associate this domain with worldviews S1 and S2. It has a very important contribution to make to systems engineering practice, both in the development of autonomous systems, and in the improvement of modeling tools and practice in systems engineering. The challenge is that, as we have seen, there is a radical difference between Worldview S1, governing the thinking of those who develop tools for software and model based engineering, and Worldview S3, moderate realism, which (we agree with Rousseau & Wilby, 2014) governs the outlook of most systems engineering practitioners. This radical difference is a barrier to effective take-up of model based SE methods.

Domain 2: Traditional deterministic technological engineered systems - in this domain, which Hybertson (2009) refers to as Traditional Systems Engineering, the focus is on technology-based "product systems" using components that are essentially deterministic, and seeking to achieve deterministic behavior at system level also. These systems typically include a diverse range of disciplines and technologies whose individual engineering practices are often model-based, but where system level integration may still depend on traditional document centric and 3-D CAD methods focusing on the physical architecture. Practice and process are largely empirical based on currently perceived "best practice", or on "what worked last time". "Traditional SE" practices are derived from those used on successful mainly-hardware systems with software components embedded in physical subsystems, even though increasing percentages of functionality and behaviour are now software and network-based, using layered architecture principles. Systems in this domain are expected to be deterministic within defined environment and scenarios. Their performance and behaviour are typically undefined outside the specified envelope, and the systems may unexpectedly fail, or behave in unpredictable and counter intuitive ways, if dynamic and integrity limits are exceeded. We associate this domain with worldviews S3 and S4.

Domain 3: Enterprise and Organisational systems - Enterprise and Organisational Systems are non-deterministic at microscale due to human actors with "agency", the ability to make independent and not necessarily rational decisions. They are also subject to non-deterministic behaviour at macro scale, though in principle they should be goal-seeking and capable of being adaptive and resilient at "enterprise" scale. They typically evolve and adapt to deal with progressive change, but may go through drastic and unpredictable state changes if affected by disruptive change – and these changes may be at the expense of viability of participants in the system, or of the system itself. Organisational and enterprise systems can collapse unexpectedly if dynamic and integrity limits are exceeded, to the extent that their adaptive capacity is saturated.

Pragmatic practice for project organisations is set out in the Bodies of Knowledge of the various project management associations, but like "traditional systems engineering", these approaches are limited in their ability to deal with unknown or unknowable situations (Snowden and Boone's (2007) "complex" and "chaotic", Obeng's (1995) "quest" and "foggy" quadrants), and very complex tasks with much feedback and iteration between work activities. Current "good practice" methods for more complex situations and larger, more diffuse and decentralized enterprises draw on "learning organisation" and "social network" theory, leavened by Economics, Management Theory, Systems Thinking, Behavioural Psychology, Beer's (1972) Viable Systems Model, and the new field of Enterprise Systems Engineering.

We associate this domain with System Worldviews S3 and S5, because systems of this nature involve elements from all parts of the System Definition Framework, but are fundamentally complex.

Domain 4: Naturally occurring systems - Naturally occurring systems are deterministic at microscale (though not at nanoscale where quantum effects come into play), and are complex, adaptive, and resilient at "human" and planetary scales. They evolve and adapt to deal with progressive change, and may go through drastic state changes if affected by disruptive change – these changes may be at the expense of viability of participants in the system. Naturally occurring systems can collapse unexpectedly and catastrophically because of cascading failure modes if dynamic and integrity limits are grossly exceeded to the extent that their adaptive capacity is saturated.

Current practice concerning naturally occurring systems draws on Living Systems theory, leaning heavily on such concepts as homeostasis (the ability to maintain internal equilibrium in a changing environment). The focus in this field is scientific understanding and guardianship, considering biological and ecological systems at all scales from molecular to planetary. We associate this domain with Worldviews S4 and S5. However, increasingly we need to consider, integrate and manage such systems in conjunction with engineered socio-technological systems – involving the more inclusive perspective of Worldview S3.

Domain 5: Autonomous adaptive technological systems – these systems are the new challenge facing systems engineering and all the specific disciplines contributing to the field. The goal is to design systems that will be able to adapt to situations that are unforeseen and in detail unforeseeable, while behaving in a way not inconsistent with human value systems, including when dynamic and integrity limits are violated.

The challenge is that in these systems the decision processes are non-deterministic, and are required to deal with non-deterministic scenarios. A "linear" or incremental response to developing such systems, based on deterministic engineering paradigms, would be essentially a brute force attack: to define more and more scenarios, and more and more rules for recognising and dealing with different scenarios. An alternative (or perhaps complementary) approach is offered by Artificial Intelligence (AI), including the disruptive concept of "deep learning". This is a modern implementation, benefiting from more computer processing power, of what used to be called "neural nets", and aims to allow autonomous systems to learn for themselves, and to share their learning with other systems of the same type. This approach shows promise but leads to fundamental conceptual problems regarding validation, not to mention integration with existing pseudo-deterministic systems. It is probably fair to say that in this domain, at system level, practice is ahead of the theory!

We consider that while the core technology for autonomous systems is being successfully developed using worldview S1, the development of successful and trusted autonomous systems is not merely a technical challenge. Complex technical systems such as these invariably exist within a wider socio-technical context. Considering the scale of legal, ethical, regulatory and environmental challenges and issues of societal perception, success will depend on improved collaboration across a wide range of activities and disciplines, spanning the full range of engineering activity but also extending well beyond.

To achieve this, we believe it will be necessary to integrate system worldviews S1 and S3 with concepts from S5, and with new or emerging worldviews on systems engineering. Currently this is not happening, except perhaps in some organisations in private, and in some small fora (such as our project) in professional societies.

Synthesis: Table 1, below, summarises the mappings we suggested above between the different system worldviews and the SE domains we discussed. Our belief is that successful practitioners are able to act "as if" they hold worldviews appropriate to a particular problem or domain, even if their core worldview is different. This belief is based on the observation (Sillitto, 2016) that people who hold quite different worldviews are able to collaborate successfully on real-world problems.

Table 1: Suggested mapping (as discussed above) between System Worldviews and SE Domains

<table>
<tr><th>Worldview</th><th>Domain 1</th><th>Domain 2</th><th>Domain 3</th><th>Domain 4</th><th>Domain 5</th></tr>
<tr><td>S1</td><td style="background:grey"></td><td></td><td></td><td></td><td style="background:grey"></td></tr>
<tr><td>S2</td><td style="background:grey"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>S3</td><td></td><td style="background:grey"></td><td style="background:grey"></td><td style="background:grey"></td><td style="background:grey"></td></tr>
<tr><td>S4</td><td></td><td style="background:grey"></td><td></td><td style="background:grey"></td><td></td></tr>
<tr><td>S5</td><td></td><td></td><td style="background:grey"></td><td style="background:grey"></td><td style="background:grey"></td></tr>
</table>

Summary and Conclusions

We have shown that at least seven quite different worldviews about systems are held by senior and experienced members of the INCOSE community.

We believe that widening INCOSE's view of systems to explicitly accommodate this range of worldviews is part of the transdisciplinary integration challenge faced by INCOSE and other groups (Rousseau & Wilby, 2014) if SE Vision 2025 is to be achieved. We believe our prior work on system definition (Dori & Sillitto, 2017; Sillitto et al, 2017) recognises and provides space for all of the worldviews found in the systems engineering community, allows them to be understood in context with each other, and therefore provides an effective basis for their integration.

This work will inform recommendations to INCOSE for an updated set of definitions for "system" and "systems engineering".

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Biography

Hillary Sillitto held senior systems engineering and architecting positions in Thales and the UK MoD, and is now pursuing various academic and professional interests. His book "Architecting systems – concepts, principles and practice" was published in October 2014. He contributed to the INCOSE SE Handbook and the SEBOK. He is an INCOSE Fellow, and Omega Alpha Association member.

James Martin is an enterprise architect and systems engineer affiliated with The Aerospace Corporation. He was a key author for the SE Body of Knowledge (SEBOK), led the working group developing ANSI/EIA 632, and the INCOSE Standards Technical Committee. He previously worked for Raytheon Systems Company and AT&T Bell Labs. His book, Systems Engineering Guidebook, was published by CRC Press. Dr. Martin is an INCOSE Fellow and received the Founders Award.

Dorothy McKinney is an INCOSE Fellow, serving on the INCOSE Definition Team. She has over 45 years of aerospace and research experience, working over 34 years at Lockheed Martin and heritage companies. She served as an adjunct professor at San Jose and Portland State Universities. She now heads ConsideredThoughtfully Inc., providing online mentoring for professionals.

Professor Dov Dori heads the Enterprise System Modeling Laboratory at the Faculty of Industrial Engineering and Management, Technion, Israel. He is Fellow of IEEE, INCOSE, and IAPR and a Visiting Professor at MIT. His research interests include MBSE and conceptual modeling of complex systems, and systems biology. He invented and developed Object-Process Methodology (OPM), adopted as ISO 19450, authored over 300 publications and mentored over 50 graduate students.

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