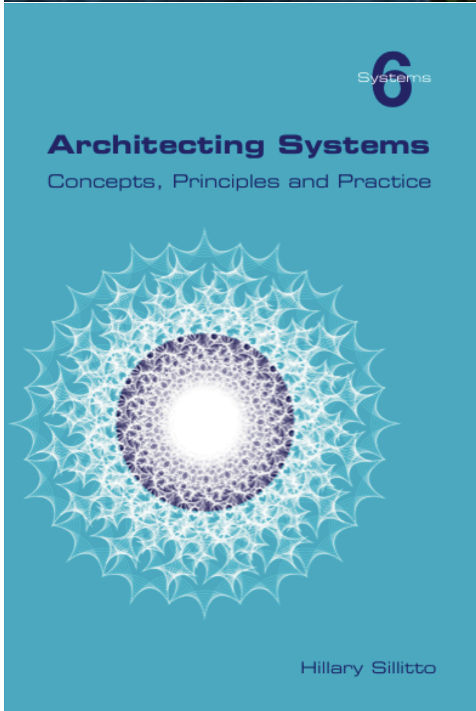
What is a system?

April 2018

Hillary Sillitto - ESEP, INCOSE Fellow, etc…

Author of “Architecting Systems – Concepts, Principles and Practice”, College Publications, 2014



SILLITTO ENTERPRISES

ENGINEERING SUCCESS IN A COMPLEX WORLD

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



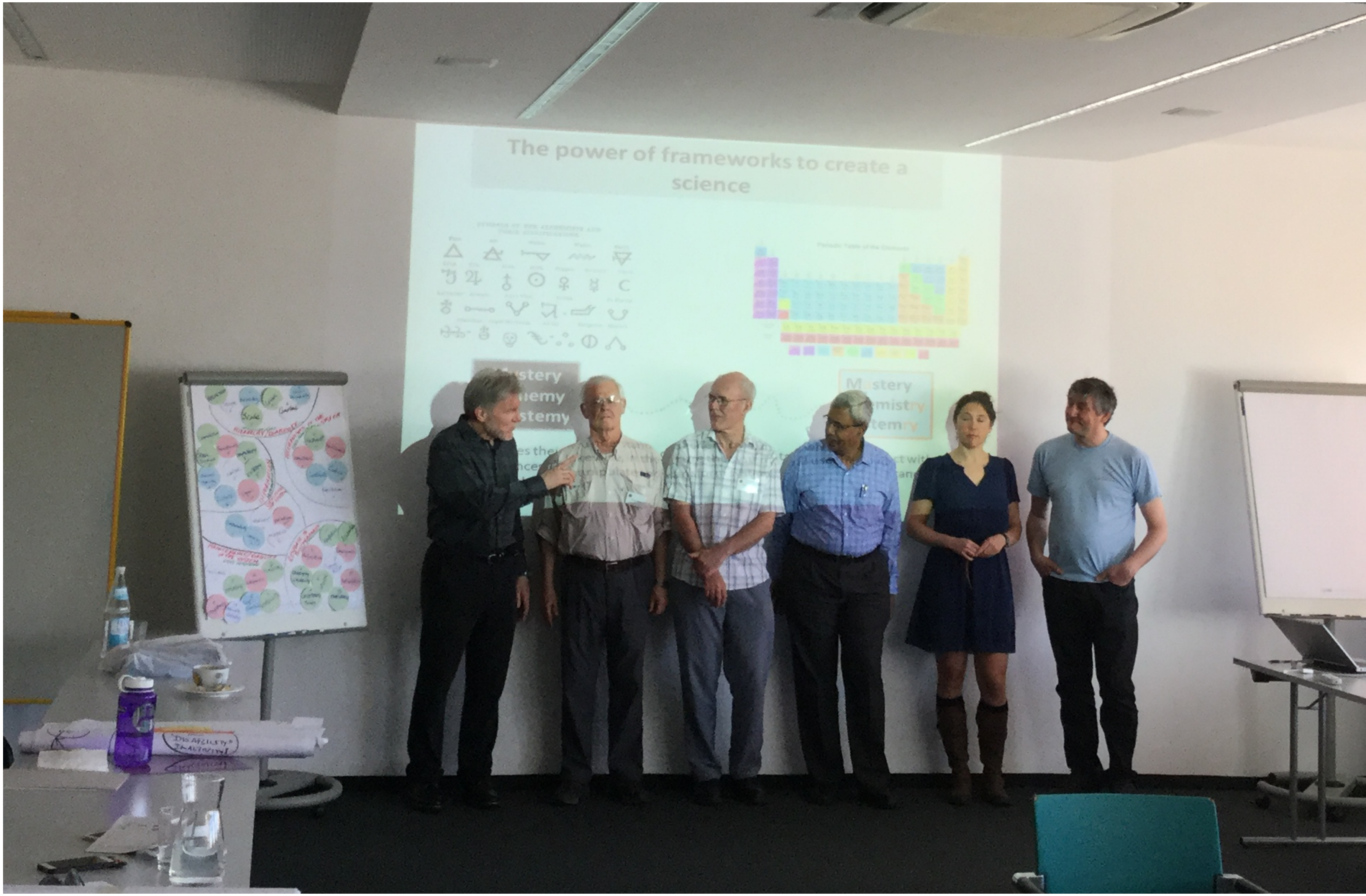
- *A Task Team of INCOSE Fellows to write a white paper that contains a definition of systems engineering that reflects the consensus for INCOSE Fellows.*
- *The purpose of this white paper is to distill the discussion of the definition of systems engineering so it is constructive and helpful to both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






The disrupters – IFSR Conversation, Linz, 2018 – Team 2



The webinar 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"
- Disruption and synthesis – an 8th worldview identified in IFSR "conversation" April 2018

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 recognise that system is an open system which accomplishes its defined objective by interacting with wider context or environment
- Does not recognise that unintended consequences may arise from unintended interactions.
- Not compatible with wider system science definitions – limits knowledge transfer

NB we do offer 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

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 characteristics.
  - We found an 8th during the IFSR Conversation in Linz last week!

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/behaviour
    - 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

ID This is the ID that will be used to uniquely identify this definition of System. It should be unique and short.	**Source** The short ID of one of the identified references; or create the appropriate reference, allocate a short ID, and then use the short ID in this column to identify the source.	**Date, details**	**Text definition** This should be a concise and precise definition of the form "a system is...", not a discussion. If the source is a discussion, please put this in the "elaboration" column and use key phrases in the discussion to create a short definition.	**Elaborations:** Additional discussion adding
Rechtin_S_1	Rechtin (1991)	1991,p.28	1. A system is a complex set of dissimilar elements or parts so connected or related as to form an organic whole. 2. The whole is greater in some sense than the sum of the parts, that is, the system has properties beyond those of the parts. Indeed the purpose of building systems is to gain those properties.	"Relationships among the el
Rechtin_S_2	Rechtin (1999)	1999, p 5	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	Cited in Bahill et al, "INCOSE
Sillitto_S_1	Sillitto (2014)	2014 p. 16	A system is a collection of interacting parts, in which the interactions result in system-level properties and behaviours not attributable to the individual parts (so we call them emergent properties and behaviours).	When I talk about a "system" people, organisations, proce embracing socio-technical a
Sillitto_S_2	Sillitto (2014)	2014 p 16	A system's behaviour is due to the processes the parts perform, so another useful definition of a system is "a network of processes"....	Most of this book is about "re There are also "conceptual s real world.
Bertalanffy_S_1	Bertalanffy (1968)	1968 p.55	A system can be defined as a set of elements standing in inter-relations.	Real systems (e.g. galaxy, d (Preface to revised edition, p
Hyberstons_S_1	Hybertson (2009)	2009 p 59	Informal concepts: A system is an entity that is of interest as a whole and as a set of two or more connected parts, where connection can be due to structural relations or dynamic interactions	An open system is a system
Hybertson_S_2	Hybertson (2009)	2009 p 59-60	A designation by an observer of a group of entities that exist in some world - as a single whole system, with logical boundary (kown or uncertain), with at least two related or interacting parts, closed or open...	More formal definition, parap interacting entities.
Hitchins_S_1	Hitchins (2007)	2007 p 28	A system is 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.	The definition encompasses
Checkland_S_1	Checkland (1999)	1999 p. 317	A system is a model of whole entity.	This is the mental model vie
Checkland as interpeted by Wastell	Wastell (2012) http://www.managingbydesign.net/my_library/systems_think... .pdf	page 2	Crudely, a system has the following characteristics: it is goal driven, purposefully transforming inputs to desired outputs, and feed-back loops are present (performance measures) to ensure that goals are achieved. Systems also operate in a defined ...	
Hall_S_1	Hall (1962)			
APDS&T_S_1	Academic Press Dictionary of Scien... & Technology			

Free_Dict_S_45	The Free Dictionary: http://www.thefreedictionary.com/system	2016	8. system - the living body considered as made **up of interdependent components forming a unifie**d whole; "exercise helped him get the alcohol out of his system"
Free_Dict_S_46	The Free Dictionary: http://www.thefreedictionary.com/system	2016	9. system - **an ordered manner; orderliness by virtue of being methodical and well organized;** "his compulsive organization was not an endearing quality"; "we can't do it unless we establish some system around here"
Free_Dict_S_47	The Free Dictionary: http://www.thefreedictionary.com/system	2016	1. arrangement, structure, organization, scheme, combination, classification, coordination, setup (informal) a multi-party system of government 2. network, organization, web, grid, set of channels a news channel on a local cable system 3. method, practice, technique, procedure, routine, theory, usage, methodology, frame of reference, modus operandi, fixed order the decimal system of metric weights and measures 4. establishment, the authorities, established order, the system, ruling class, the powers that be, institutionalized authority He wants to be a tough rebel who bucks the system.
Free_Dict_S_48	The Free Dictionary: http://www.thefreedictionary.com/system	2016	1. An organized array of individual elements and parts forming and working as a unit:
Free_Dict_S_49	The Free Dictionary: http://www.thefreedictionary.com/system	2016	2. A usually large entity composed of interconnected parts:
Free_Dict_S_50	The Free Dictionary: http://www.thefreedictionary.com/system	2016	3. Systematic arrangement and design:
Free_Dict_S_51	The Free Dictionary: http://www.thefreedictionary.com/system	2016	4. The approach used to do something:
OED_S_3	Oxford Dictionary	2016	1 **A set of things working together as parts of a mechanism or an interconnecting network; a complex whole:** the state railway system fluid is pushed through a system of pipes or channels
OED_S_4	Oxford Dictionary	2016	2 **A set of principles or procedures according to which something is done; an organized scheme or method:** a multiparty system of government the public-school system
OED_S_5	Oxford Dictionary	2016	3 (the system) The prevailing political or social order, especially when regarded as oppressive and intransigent: don't try bucking the system

The seven different worldviews on "system" within the INCOSE community

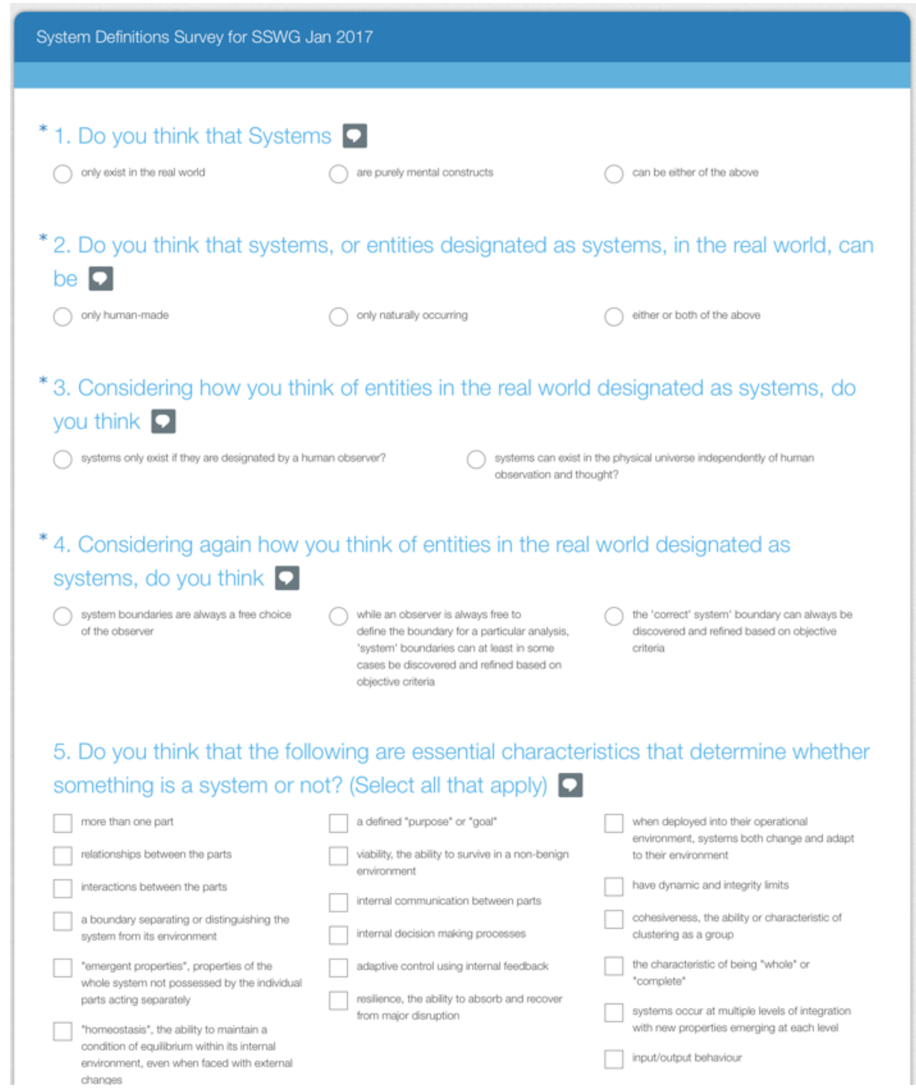
System Worldviews in INCOSE community

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 –** only in physical world
5. **Complex, viable and living systems -** Miller, 1978; CAS, etc
6. **Systems as a Mode of Description**
7. **System as a process**


System Definitions Survey for SSWG Jan 2017

* 1. Do you think that Systems

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

* 2. 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

* 3. 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 independently of human observation and thought?

* 4. 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 define 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

5. Do you think that the following are essential characteristics that determine whether something is a system or not? (Select all that apply)

- 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 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 behaviour

Paper on “System Worldviews” offered to IS 18

System Worldviews in INCOSE community

Survey responses:

Distinct patterns and clustering discernible in responses.
Clusters led to postulation of the different worldviews.

Fellows

	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											

SSWG

	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	

Paper on "System Worldviews" offered to IS 18

Some significant differences between Fellows and SSWG responses

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%			

"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.

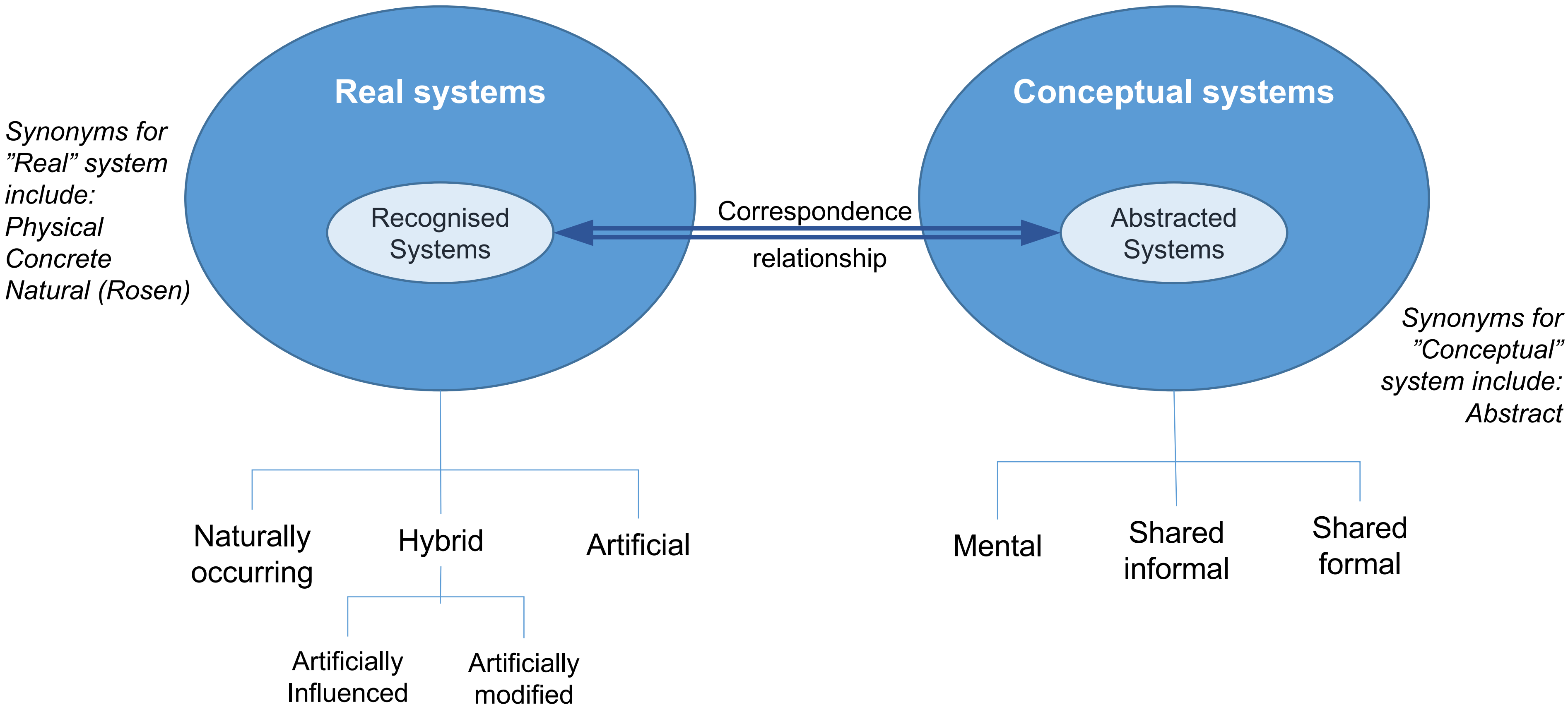
There are strong and mutually inconsistent patterns and clustering in the data.

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

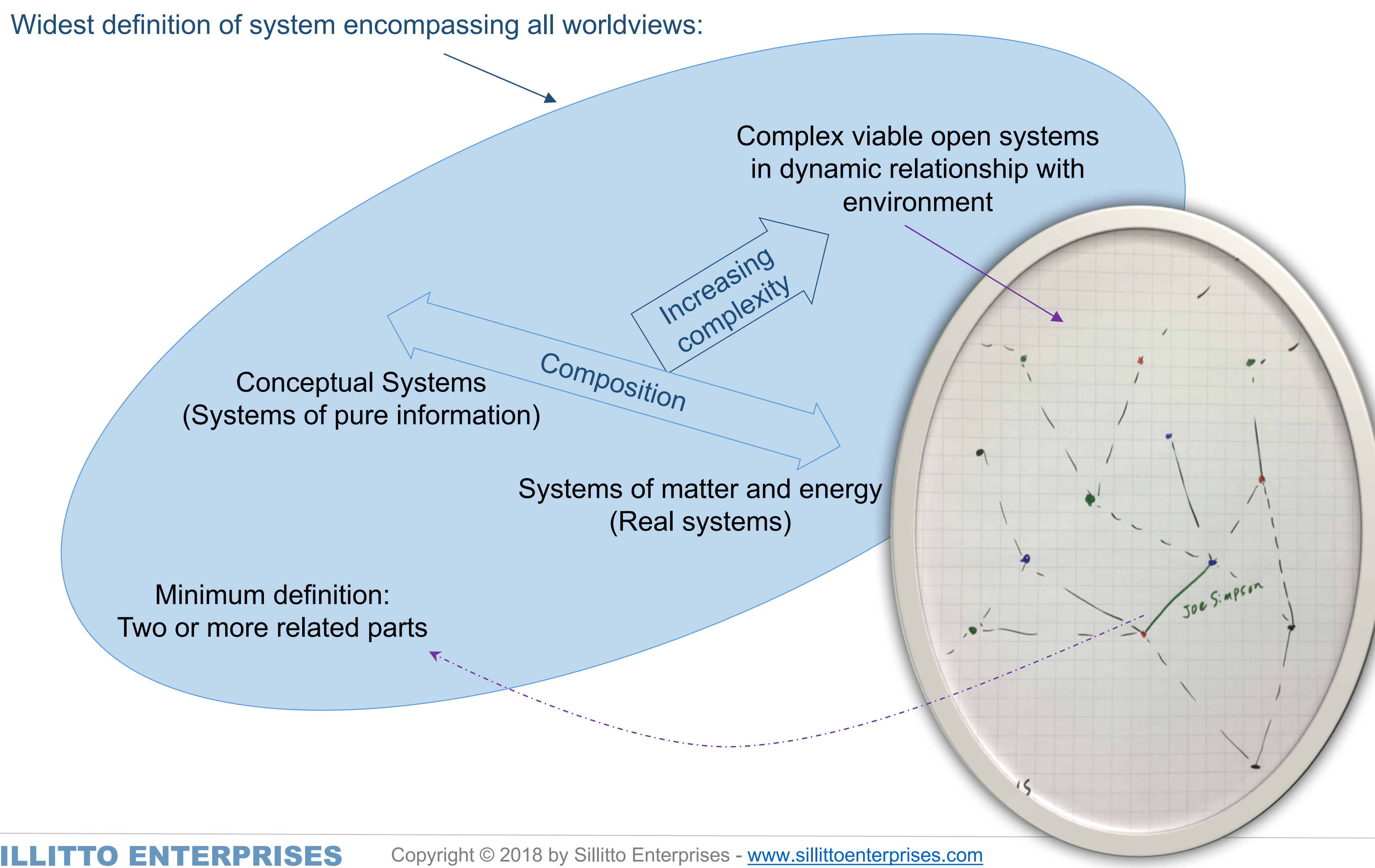
Language, and primary distinction of real/conceptual, follow Hall /Fagen (1956) and von Bertalanffy (1968)



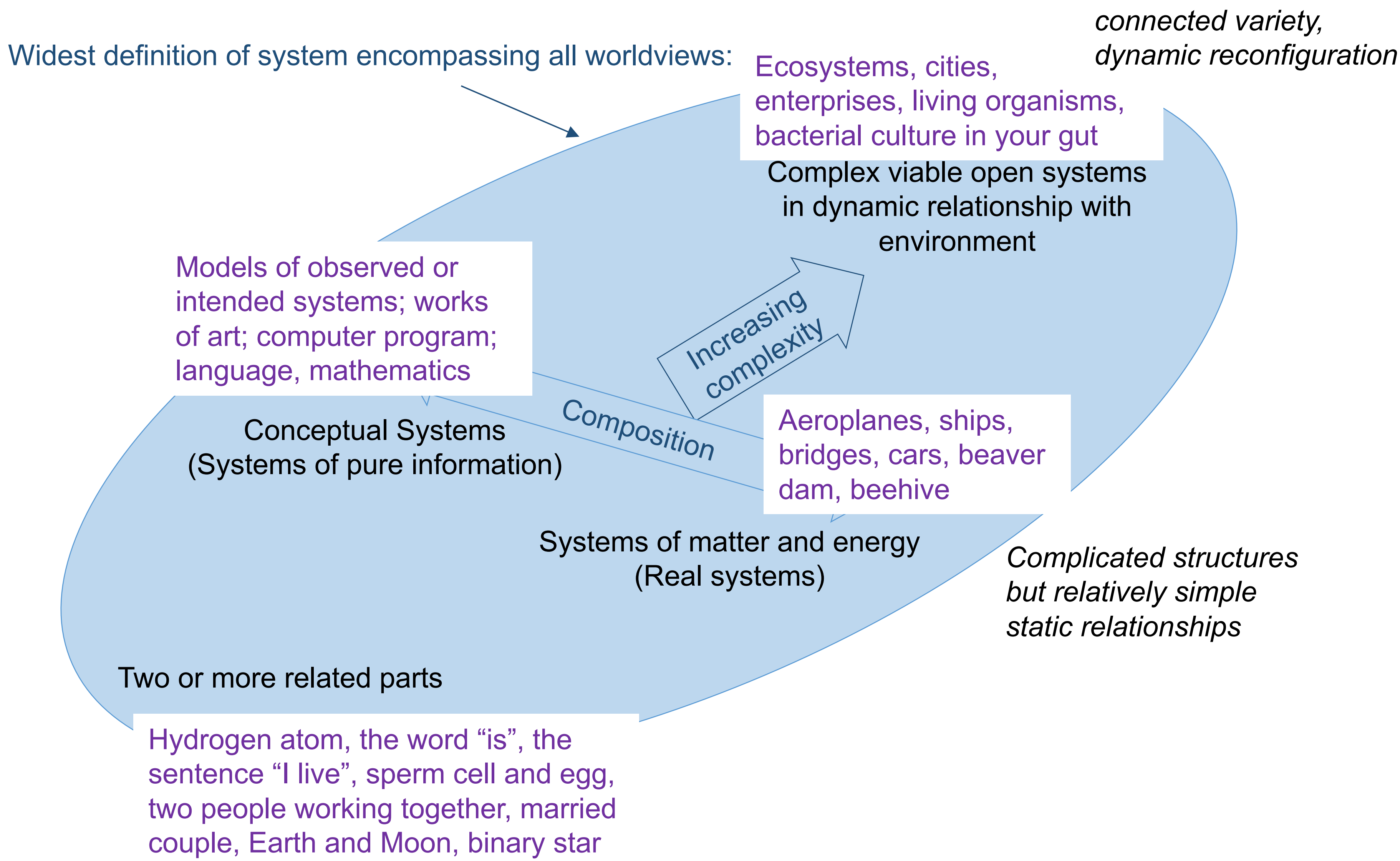
Bertalanffy, L v: General Systems Theory, 1968 edition
Hall & Fagen,1956, "Definition of System", Arthur Hall with Robert E. Fagen, in: *General Systems*, 1 (1956), p18
Dori and Sillitto, *What is a System? An Ontological Framework*, Systems Engineering, Vol 20, Issue 3, May 2017
Sillitto et al, *Defining “System”: a Comprehensive Approach*, INCOSE IS2017, Adelaide, July 2017

How this taxonomy relates to the seven worldviews

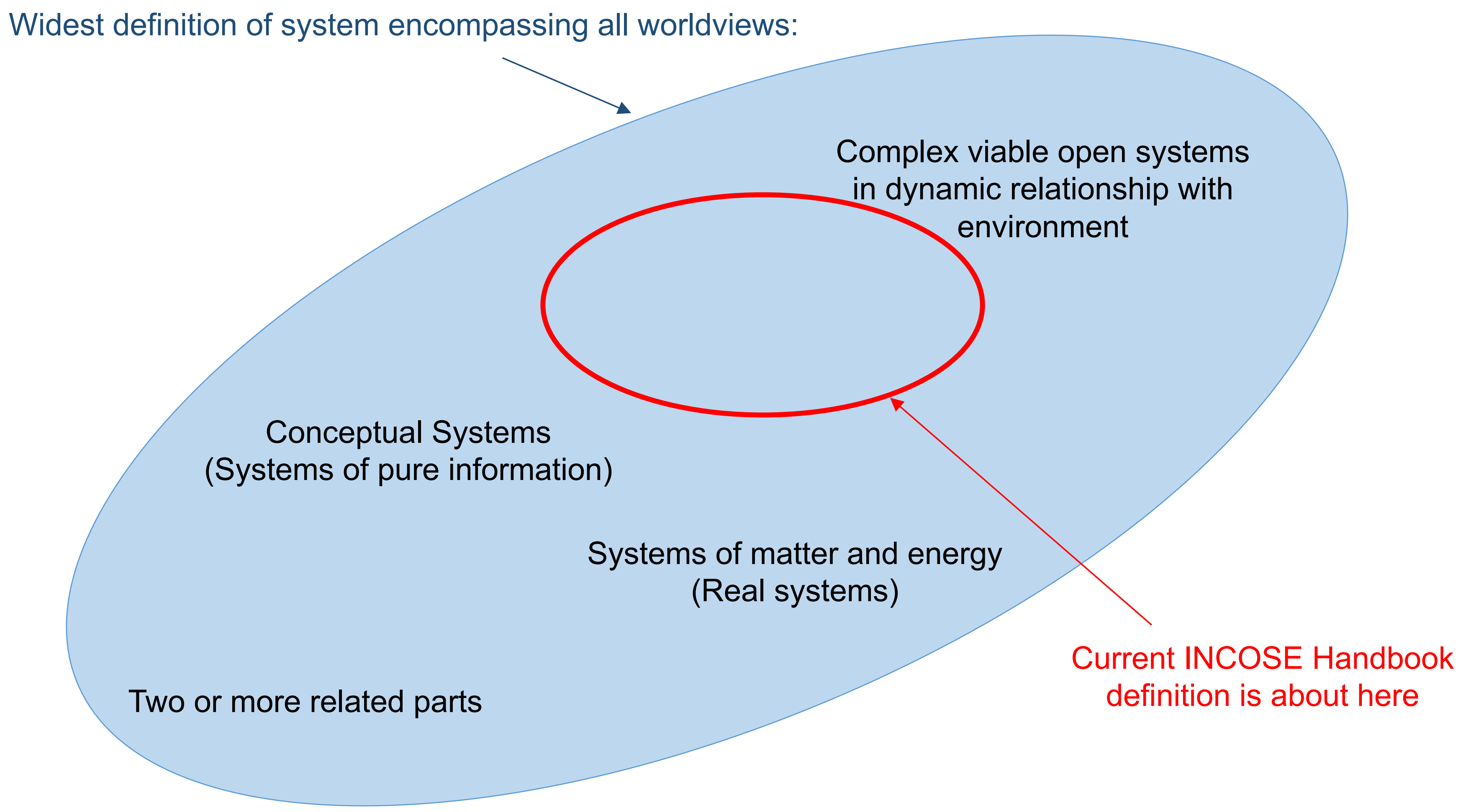
Impact of different worldviews on definition(s)



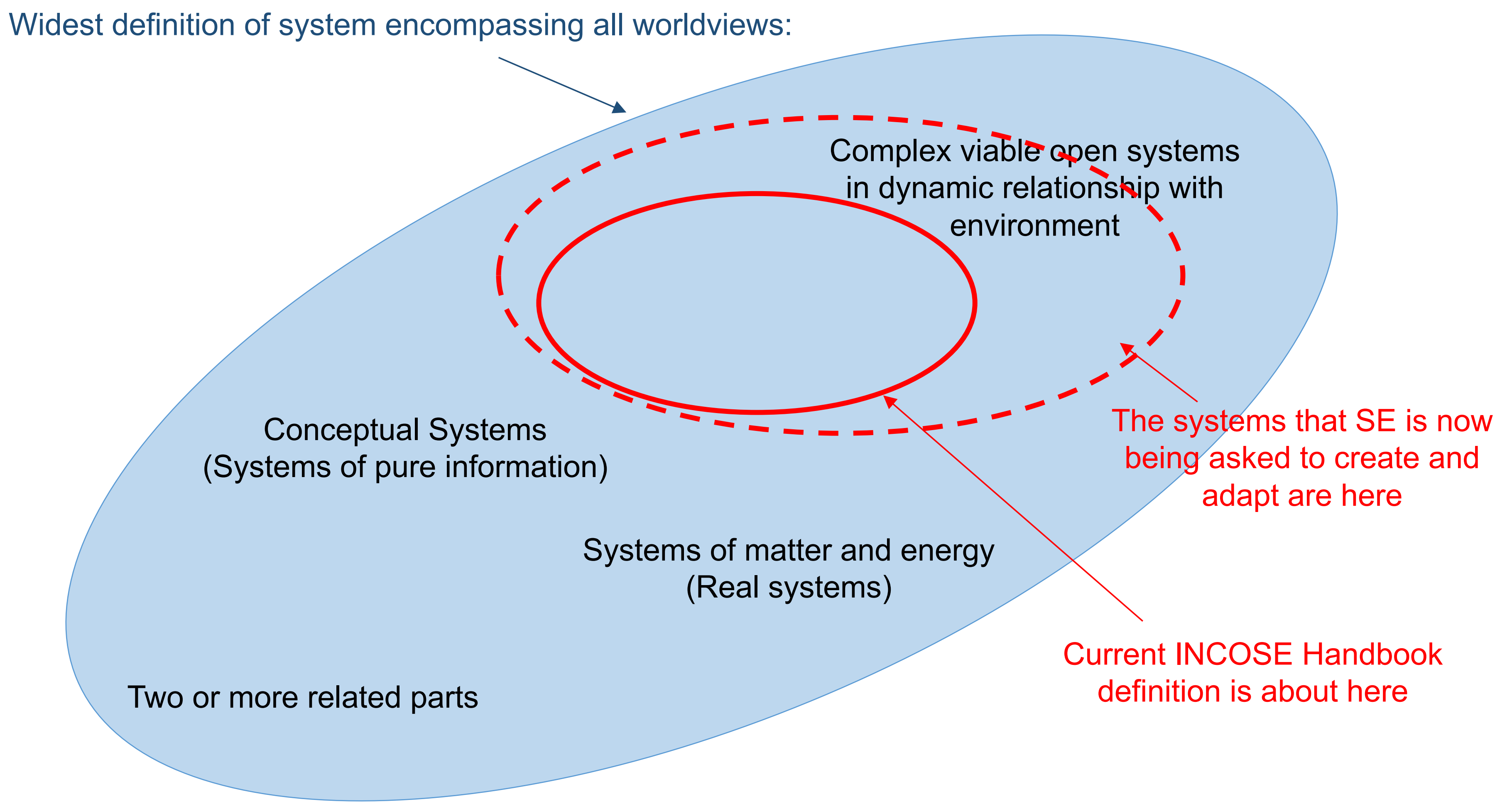
Examples of different system types – type has NO relation to scale



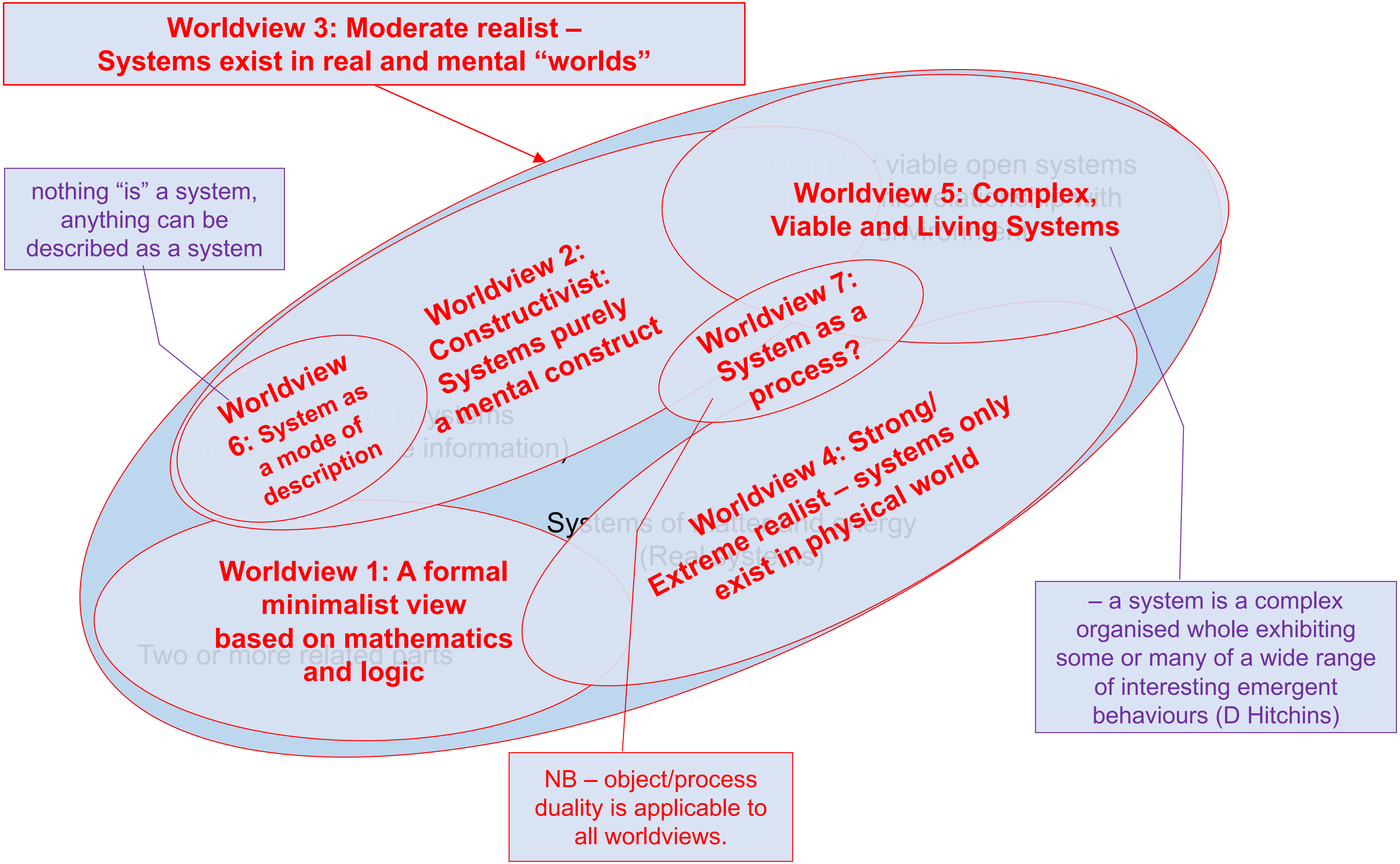
Impact of different worldviews on definition(s)



Impact of different worldviews on definition(s)



Mapping the different worldviews



The boundary challenge

System Boundary: 3 types

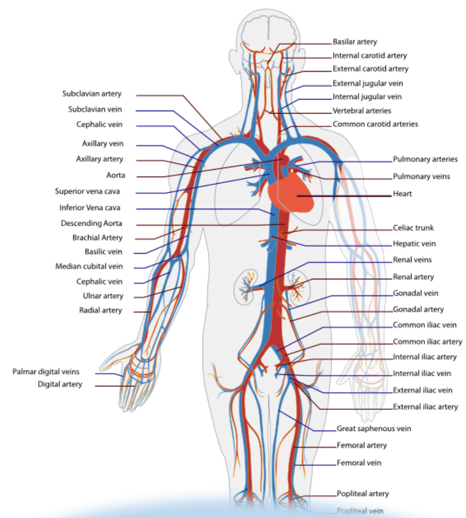
Physical or conceptual surface that

- *encloses the parts of the system of interest*
- *separates them from the environment*
- *allows them to exchange material, energy and information with it*

Physical

All parts of system move together, as one, through the environment: can define a continuous boundary surface

Functional



System is completely embedded in its containing system or environment: boundary "surface" is fractal and almost impossible to identify

arwick.

Behavioural

System is distributed, transient and dynamically reconfigurable, runs on information: no continuous boundary surface

Thinking about information and entropy…

- Two kinds of system organisation can exhibit low entropy/ high organisation:

- Complicated - variety suppressed
  - Connections are limited to make system controllable
  - Low self-organisation, low resilience

- Complex - variety exploited
  - Connections encouraged to create opportunities
  - High self organisation, high resilience

Rice paddy: artificially modified naturally occurring system
High organisation, low variety, pseudo-deterministic.

Non-complex – variety suppressed

– viability depends on external inputs and human management

- crops selectively bred to maximise food output at expense of resilience

Temple: artificial structure – static organisation, decays over time
Jungle: natural ecosystem – connected variety, dynamic reconfiguration
Jungle is winning!

Summary of current understanding

- Conceptual systems – boundary is observer designated
- **Some** real systems – boundary has clear identity – e.g. membrane of cell
- Other real systems – entropy gradient is assymptotic, belongingness is shared…

Current view:

- Boundary
  - **is** a key concept of "how we perceive and interact with systems"
  - **is not** a primary observable of real systems, only a derivative

More on this later

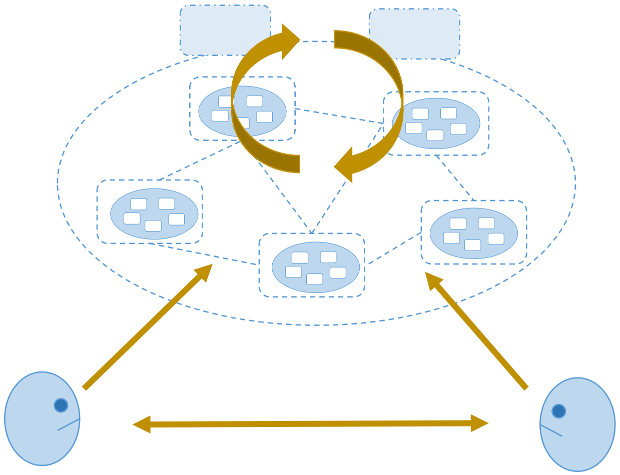
The Complex System Challenge

City: high energy low entropy:
Complex – connected variety, dynamic reconfiguration
Organisation discernible at **many different scales**

Three aspects of complexity

We need to think about complexity in three ways, from three different perspectives. These are:

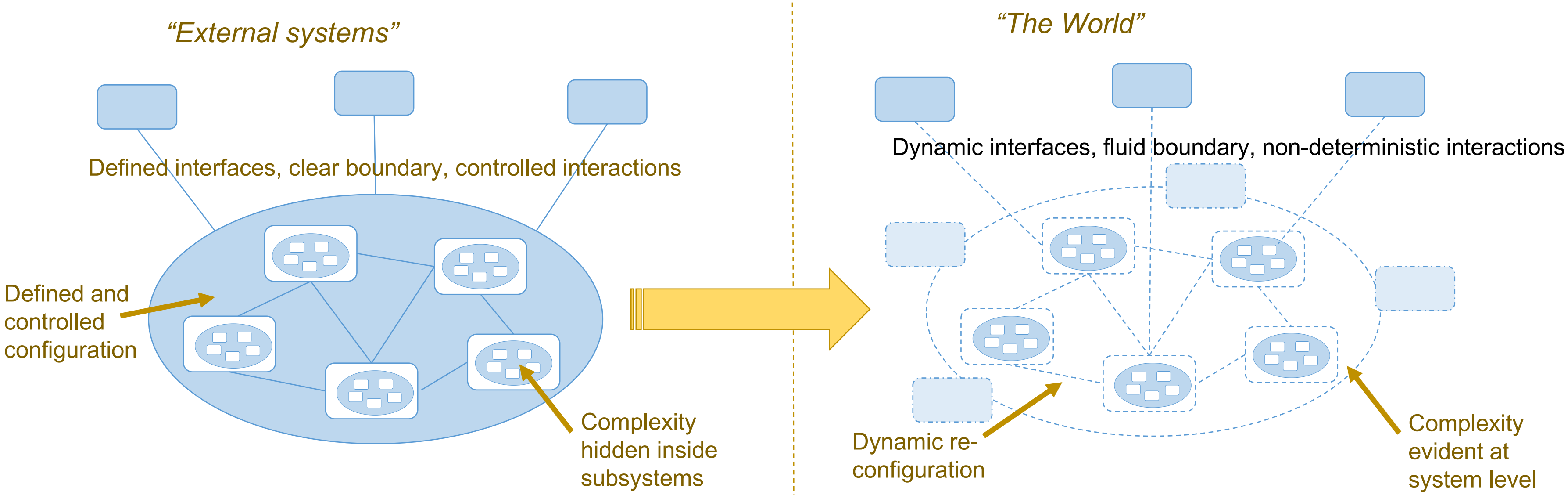
- Complexity in the system –
  - Non-linear interactions – dynamic reconfiguration - agency in the system – fuzzy boundary ->> non-determinism
  - "System" = system of interest **in its operating environment**;
- Complexity in the relationship between system and observer –
  - most people observing and trying to understand a complex system can only see part of it,
  - their understanding of it is further limited by their perceptions and biases;
  - a complex system may be too much for any single observer to comprehend even if they have access to all the necessary information – the problem is "more than one headful";
  - and, hence:
- Complexity in the relationship between the stakeholders –
  - As a result of two or more observers having different perceptions of the system, the problem situation, and how the system works
  - - they are unlikely to agree on what to do next!



“Non-Complex” vs Complex Systems

“Non-complex” System -
“does what it’s told”

“Complex” System –
“mind of its own”



Design paradigm is “control”

Design paradigm is “influence”

The complex/non complex divide

Do what they're told

- An aeroplane
- A car
- A ship
- Air defence system elements
  - sensors,
  - software,
  - comms networks,
  - effectors,…
- Medical equipment
- A proper old fashioned telephone

Mind of their own

- Aeroplane or car or ship with
  - crew,
  - fuel,
  - delegated authority
- Integrated air defence system
  - human and organisation actors
  - technical elements
  - required resources
  - …
- A surgical team, first responders…
- My mobile phone…!

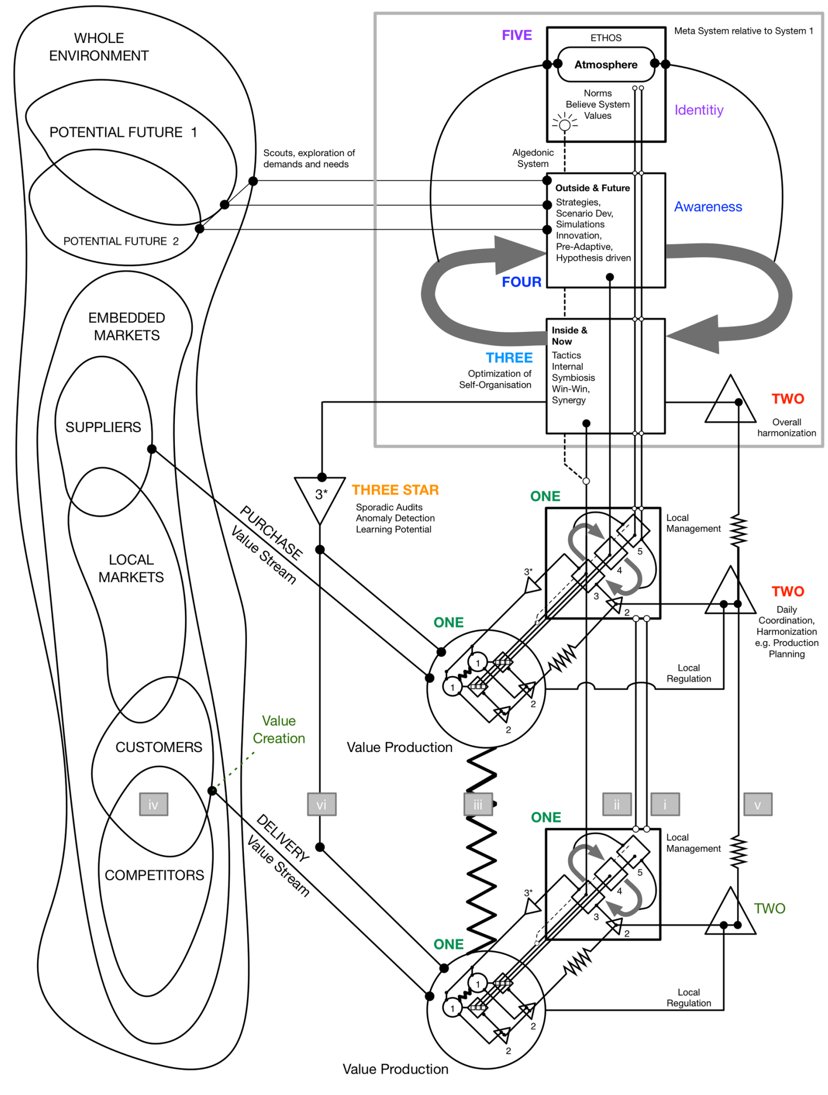
What's in a system? - Systems with a mind of their own: General paradigms for autonomous viable systems

- Beer's Viable System Model
- Hitchin's Generic System Reference Model
- Mobus's system reference model
- Rosen's Anticipatory Systems
- Complex Adaptive and Self Organising Systems
- Is there a synthesis?

General paradigms for “viable autonomous systems” - 1

Beer’s Viable System Model
System 5: Identity
System 4: Strategy and Futures
System 3: Management
System 2: Co-ordination
System 1: Operations

Comments/critique:
Recursive
VERY top-down.
Variety in system to match variety in environment.
Emphasises Need for enough communication bandwidth to allow informed and timely decision making.
Has been known to encourage illusion of perfect control at the expense of delegation!



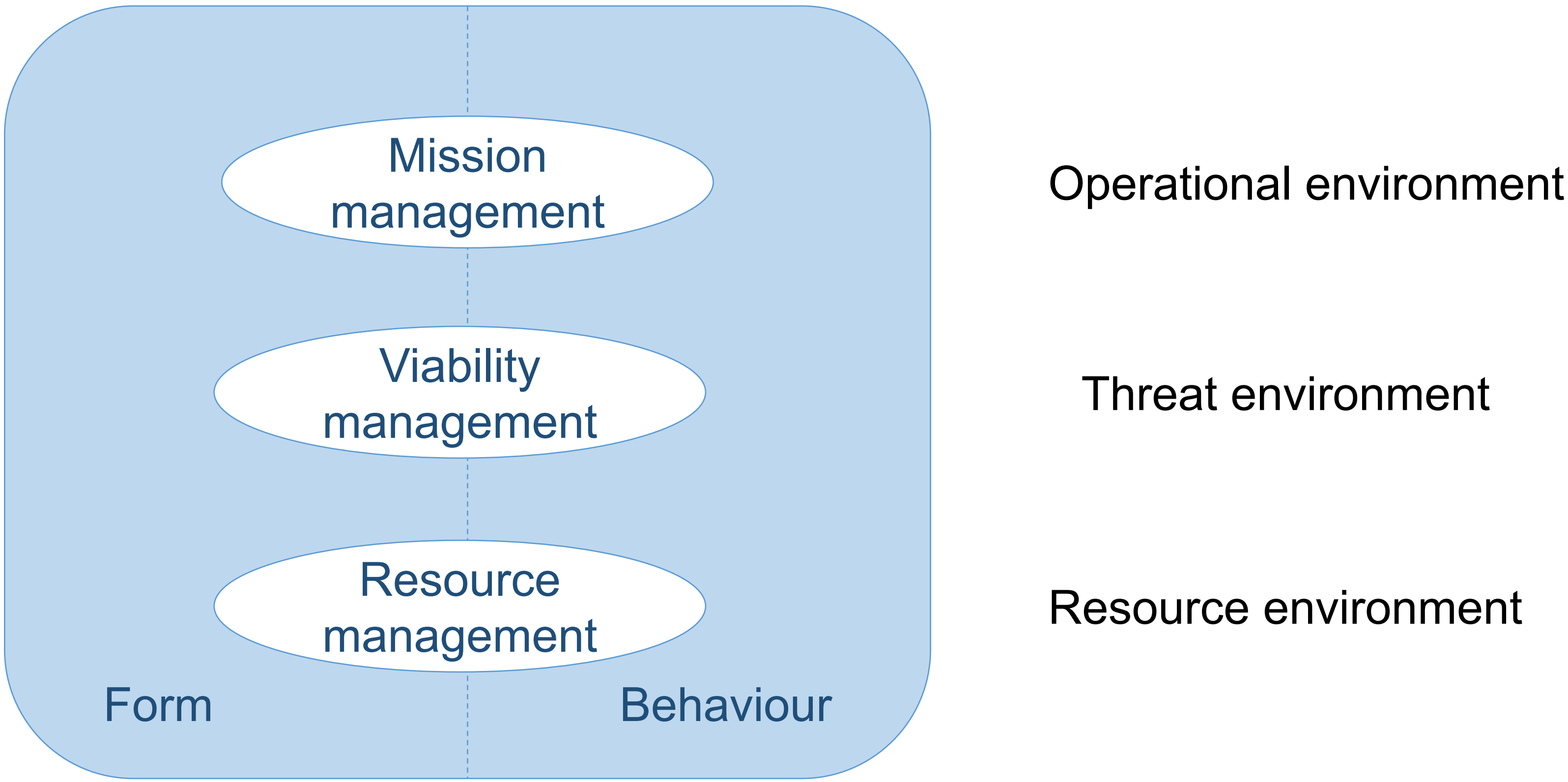
Viable System Model
Stafford Beer

Transducer
Each ● represents an interface between each subsystem

Channels:
i Interventions & Rules
ii Ressource Bargain
iii Operational Linkages
iv Overlapping Sub-Environments
v Anti-Oscillation, autonomous
vi Sporadic Audits

Source: Wikipedia
Author: Mark Lamberz

Derek Hitchin's Generic System Reference Model



Rosen's Anticipatory Systems

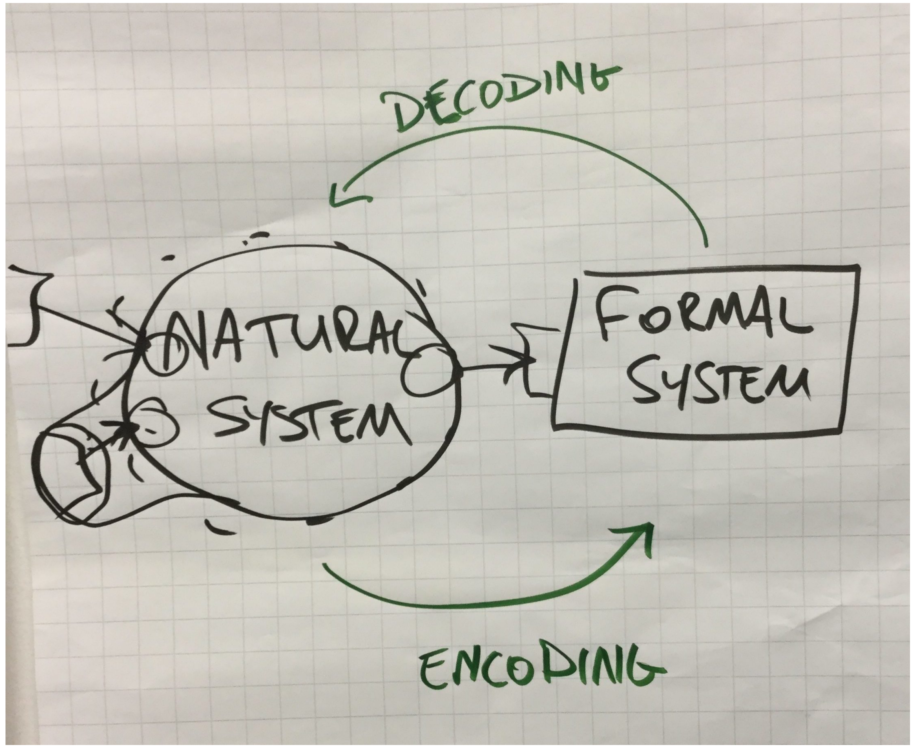
- Anticipatory system:
  - a system that acts **in anticipation of** how the environment **will** or **may** change in a way that will affect it in the future
  - contains a **model** of their environment that allows them to relate **what is happening now** to **what is likely to happen in the future**

- Examples:
  - You and me… some of the time
  - Squirrels storing food for winter
  - Trees shedding leaves in autumn (the fall)
  - Take a torch on a walk because you know it will be dark before you get home
  - An organisation hiring in expectation of an upturn

Anticipation
- is based on a **good world model with predictive power**.
- is **essential** for successful autonomous systems

Critical concepts from Rosen (1)

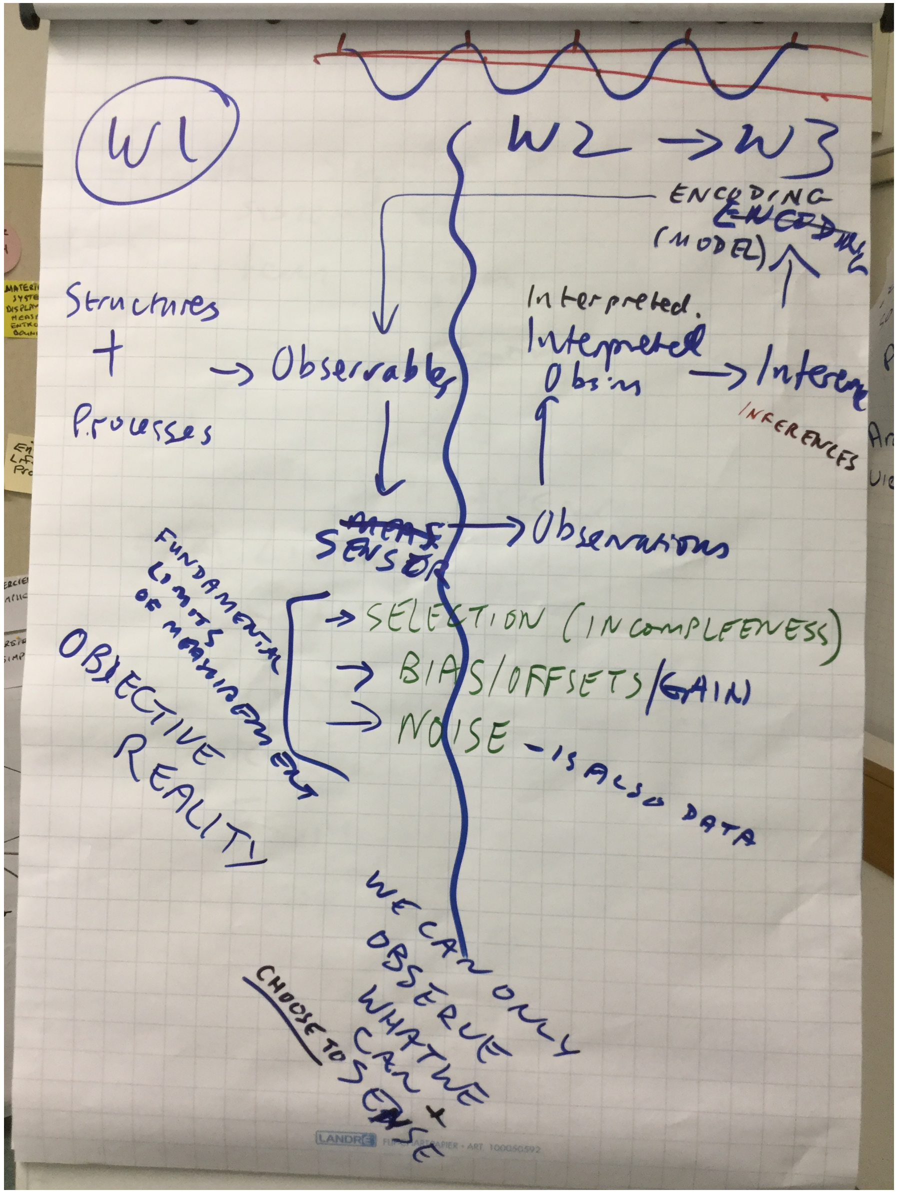
Real world



Human knowledge

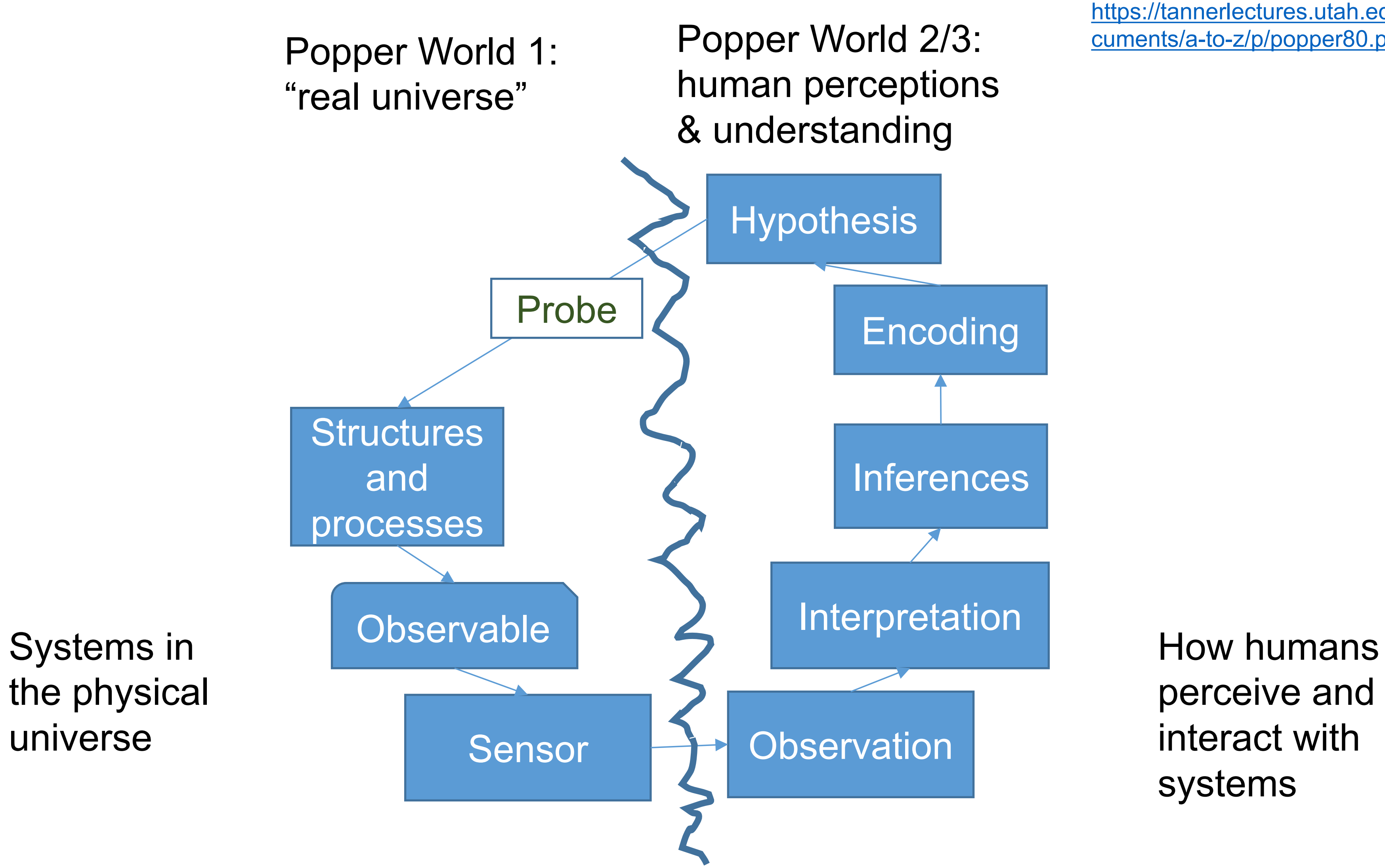
Critical concepts from Rosen (2)

”Observables” are the interface between real and perceived worlds



Integrating Rosen, Popper and Scientific method

Karl Popper "Three Worlds", The Tanner Lecture on Human Values, Univ. of Michigan, April 7 1978 - https://tannerlectures.utah.edu/_documents/a-to-z/p/popper80.pdf



Current challenges and postulated direction of travel towards

- new definition(s)
- “system ontology”

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!!!!

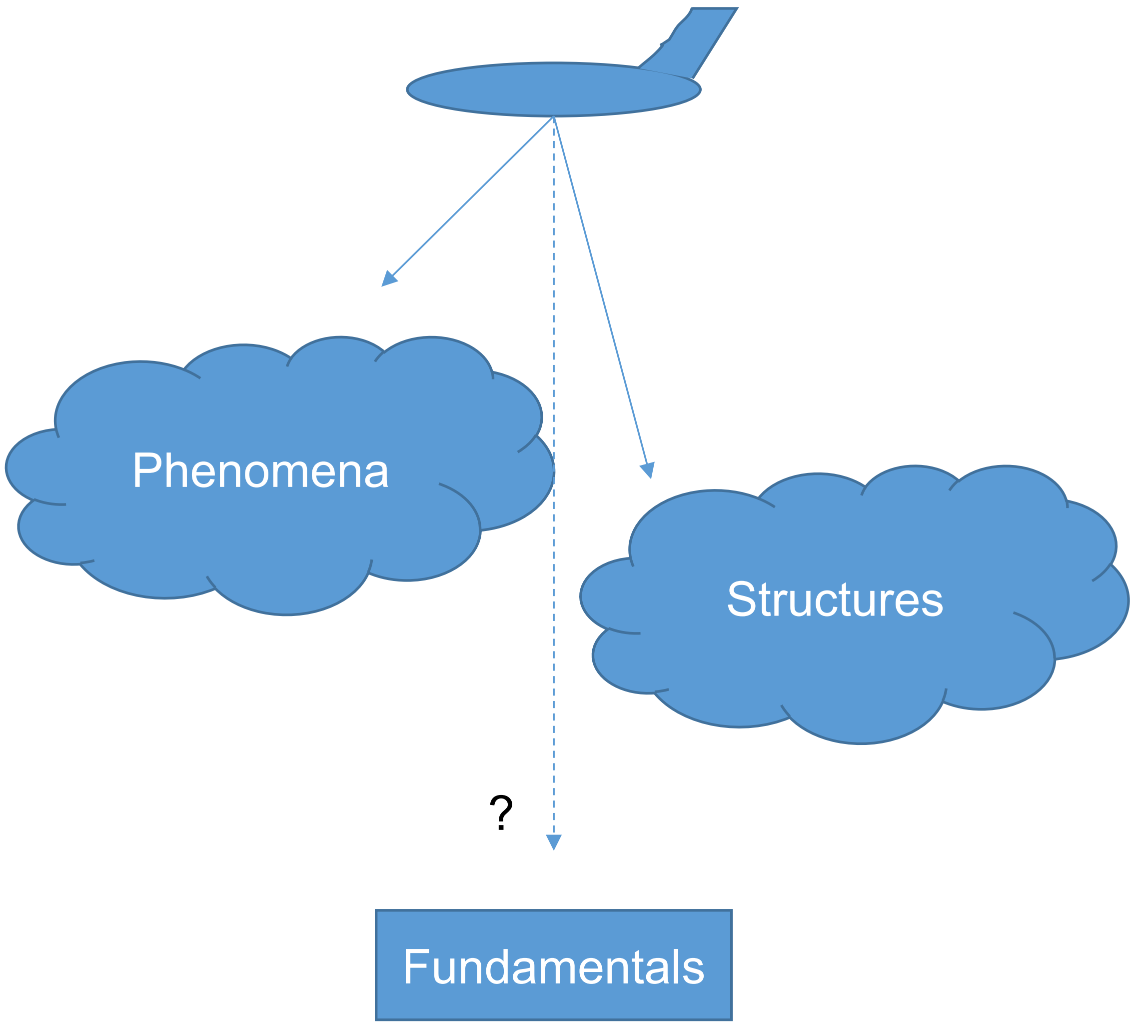
……and that we won't change each others' minds by telling people they are wrong!!!

So:

We need

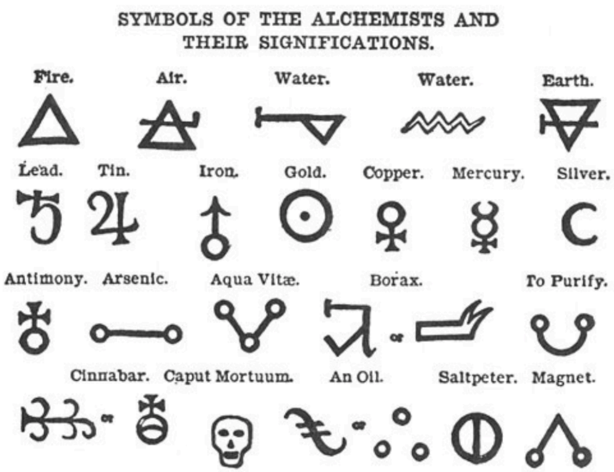
1. A very fundamental definition that applies to "all systems"
   - that means it has to work for anybody's type of system, not just mine or yours
2. More specific definition(s) applicable to the types of system we are interested in
3. Preferably, definitions that are shared with other system communities

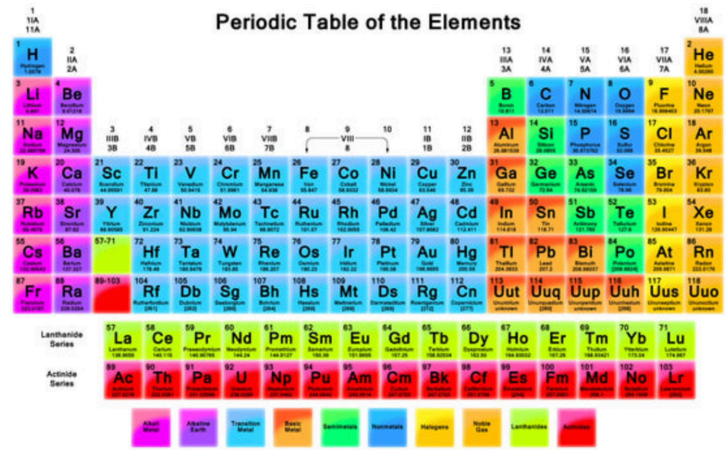
This is how it feels like now…



This is what we want to get to …

Compounds, alloys and crystals…





Mystery
Al-chemy
Al-systemy

→

Mastery
Chemistry
Systemry

"The chemist uses their understanding of chemical elements when they interact with chemical substances. Likewise, in the future the systemist will use their understanding of systemics when they manipulate and transform systems"

Key distinctions in the systems universe

- “Observables” vs “Concepts”

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

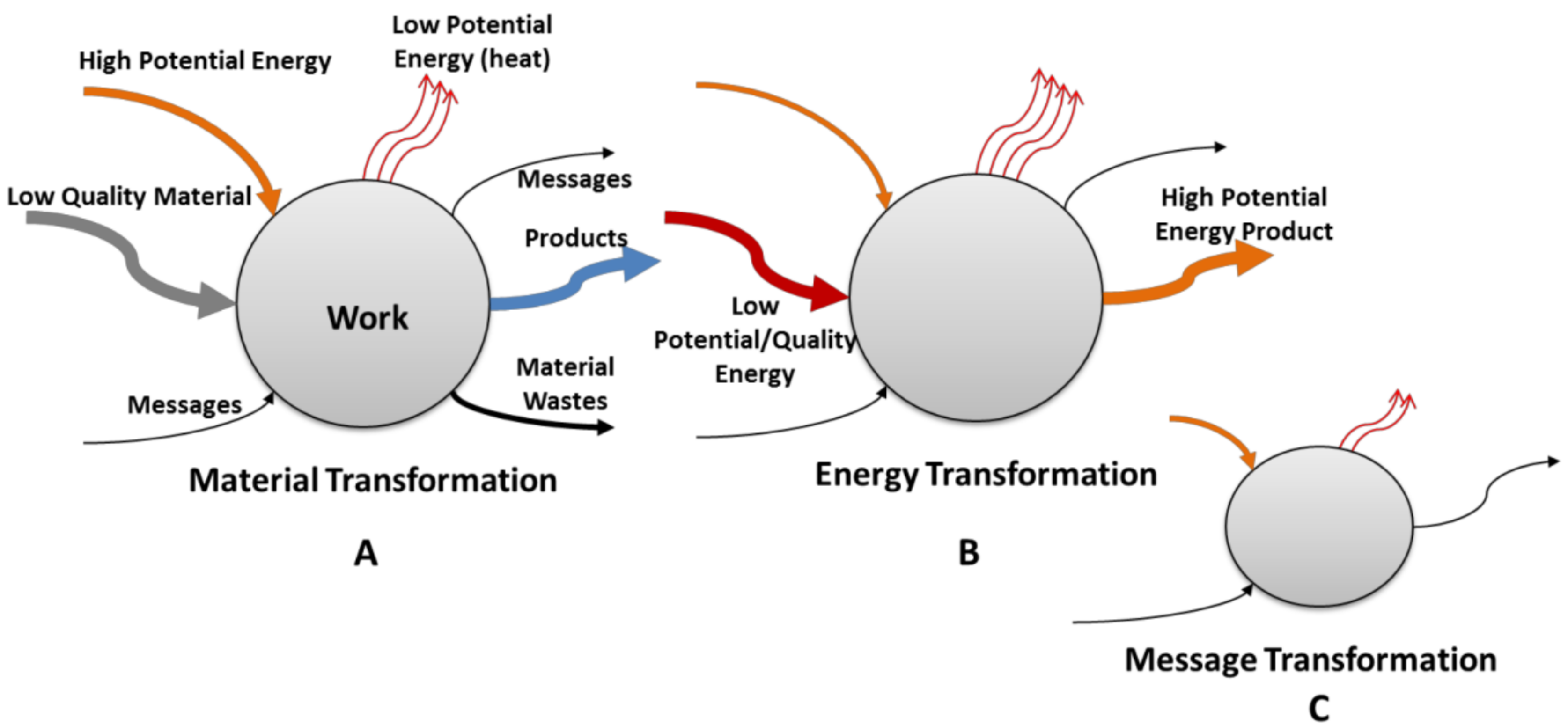
- Statics (parts, relationships, connections, “qualities”, material, energy)
  - vs
- Dynamics (processes, interactions, flows, transactions, performance, history)

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

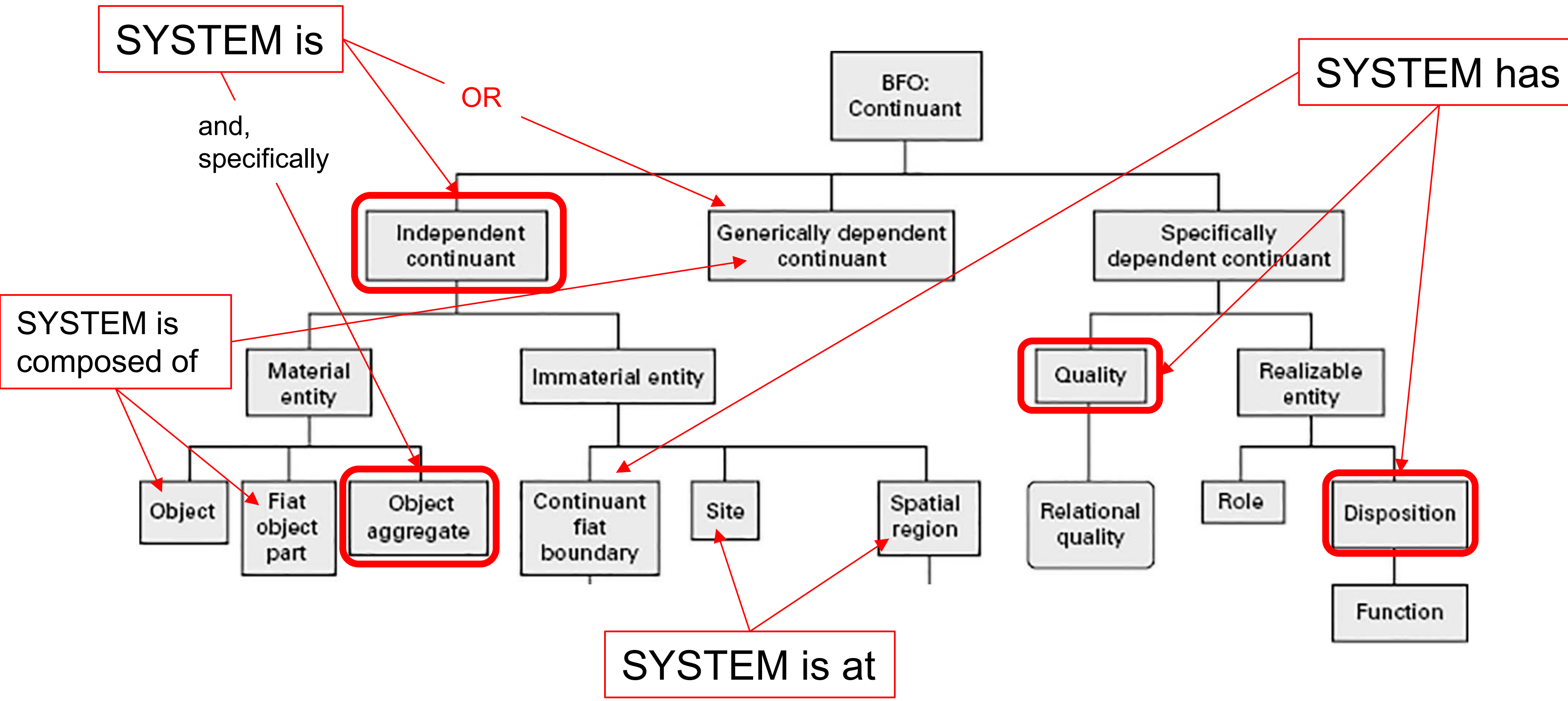
Current challenges and possible direction of travel towards a "system ontology"

George Mobus system ontology reference model – used with permission

2 System Ontology



Basic Formal Ontology (BFO) - 1



Universals vs Particulars:

Systems engineers talk about systems such as "Boeing 787" in two ways: as the TYPE of aircraft (**Universal**); and as a particular "instance" or "example" or "tail number" (**Particular**). The universal would be associated with the design definition, while the particulars would be the physical examples built to the design definition.

Translations from Onto-speak to SE-speak:

Continuant fiat boundary	– boundary
Quality	– property (or quality)
Disposition	– capability (ability to do something) or affordance (potential for interaction)
Function	– function (with associated performance)

Diagram from "Building ontologies with basic formal ontology", Arp, Smith and Spear, MIT Press, 2015

BFO – 2 - Informatic entities

- Information entities are "generically dependent continuants"
  - can be considered in the abstract
  - must have at least one instance in a physical host at any time
    - e.g. in a person's memory, or computer storage, or marks on a piece of paper or stone…
  - can have many different representations of the same information –
    - e.g. a book can exist on paper and in computer memory, as a hardback, paperback, e-book.
  - When the last instance is destroyed the generically dependent continuant ceases to exist.

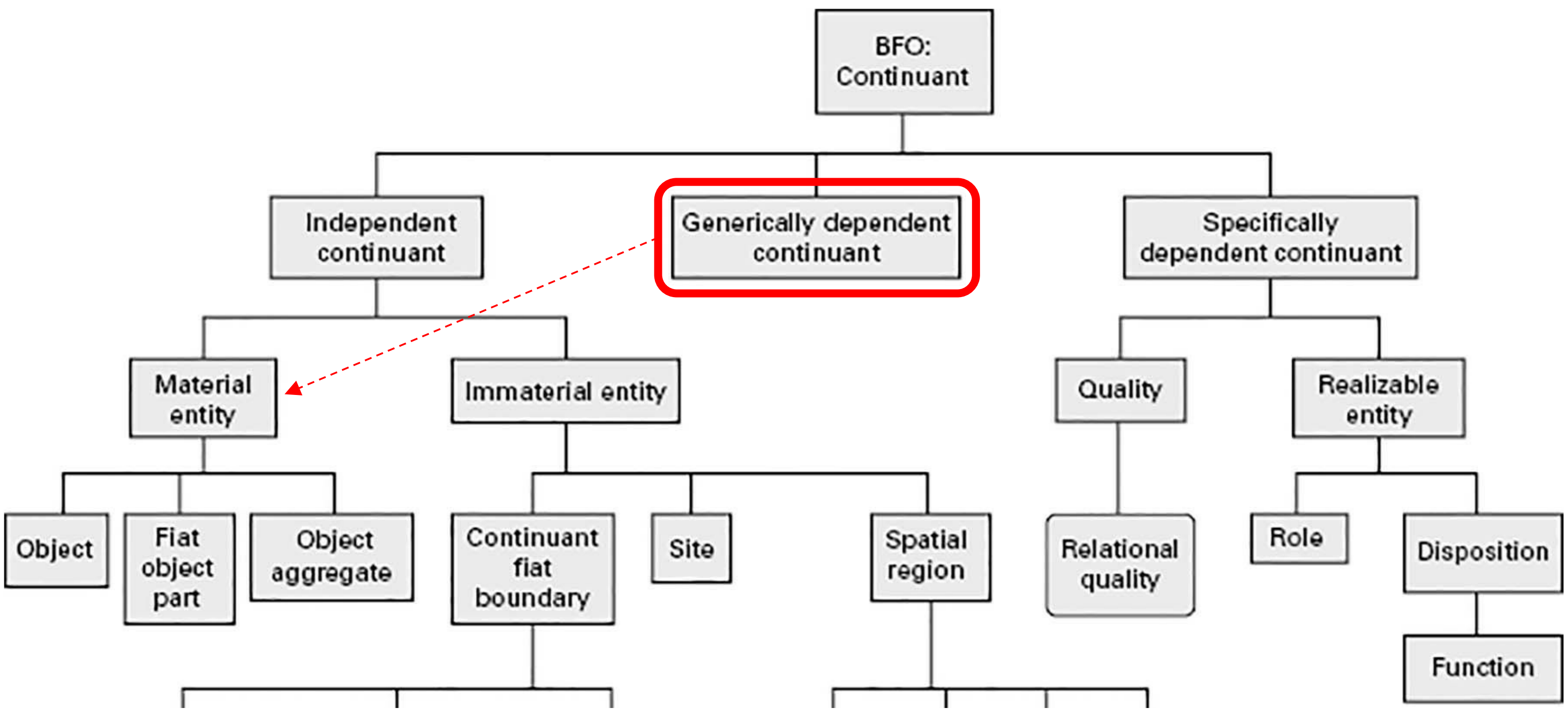
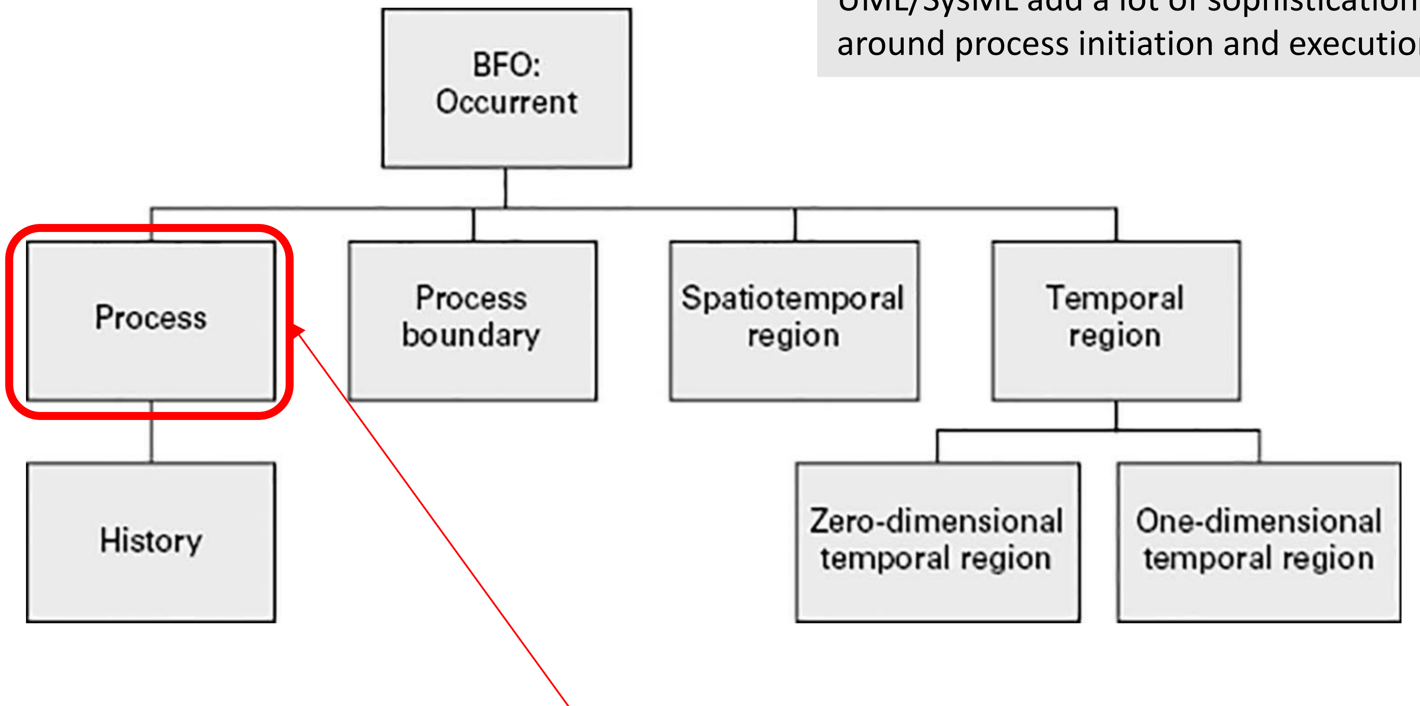


Diagram from "Building ontologies with basic formal ontology", Arp, Smith and Spear, MIT Press, 2015

BFO – 3 - Occurrents

The other occurrent concepts are relevant to system modelling.
System modelling languages such as UML/SysML add a lot of sophistication around process initiation and execution.



1. System performs process
2. Process invokes system or subsystem function
3. System is produced using a set of system lifecycle processes
4. Whole system lifecycle is a process.

Thus – the lifecycle is a process (occurrent) which lasts longer then the system (continuant)

5. The system lifecycle is managed by the “systems engineering system”

Diagram from “Building ontologies with basic formal ontology”, Arp, Smith and Spear, MIT Press, 2015

BFO – 4 - Putting it all together: NB everything is recursive!

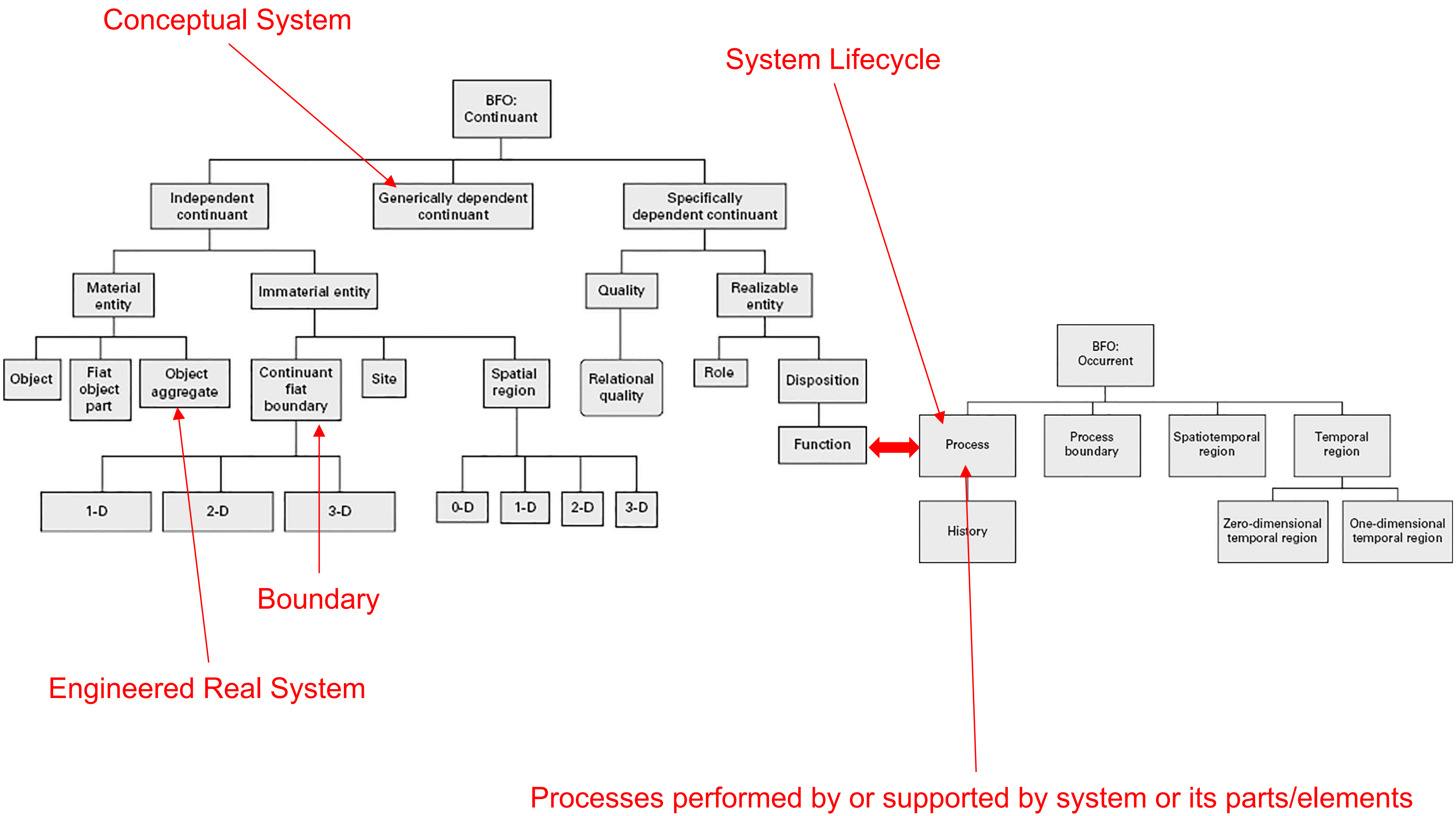
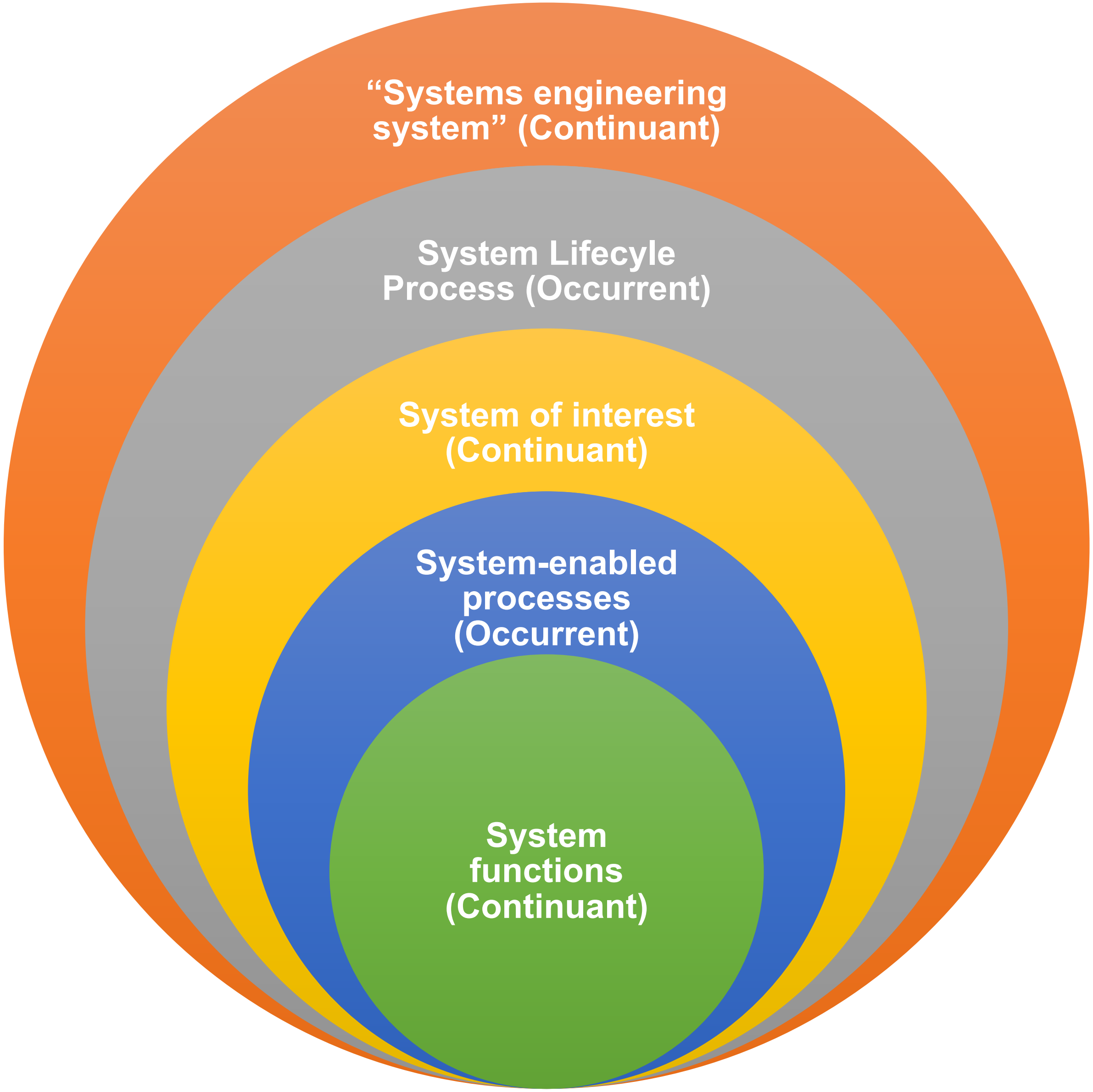


Diagram from "Building ontologies with basic formal ontology", Arp, Smith and Spear, MIT Press, 2015

Process and object recursion – "Hard systems exist inside soft systems"



Key conclusions

1. Basic Formal Ontology handles key system and SE concepts

2. The process of expressing our thinking in the BFO frame was useful
    - Validated some of our ideas
    - Clarified others

3. It seems that we can construct an ontology that respects and integrates the different worldviews as long as we cast the net wide enough and don't impose to much "belief".

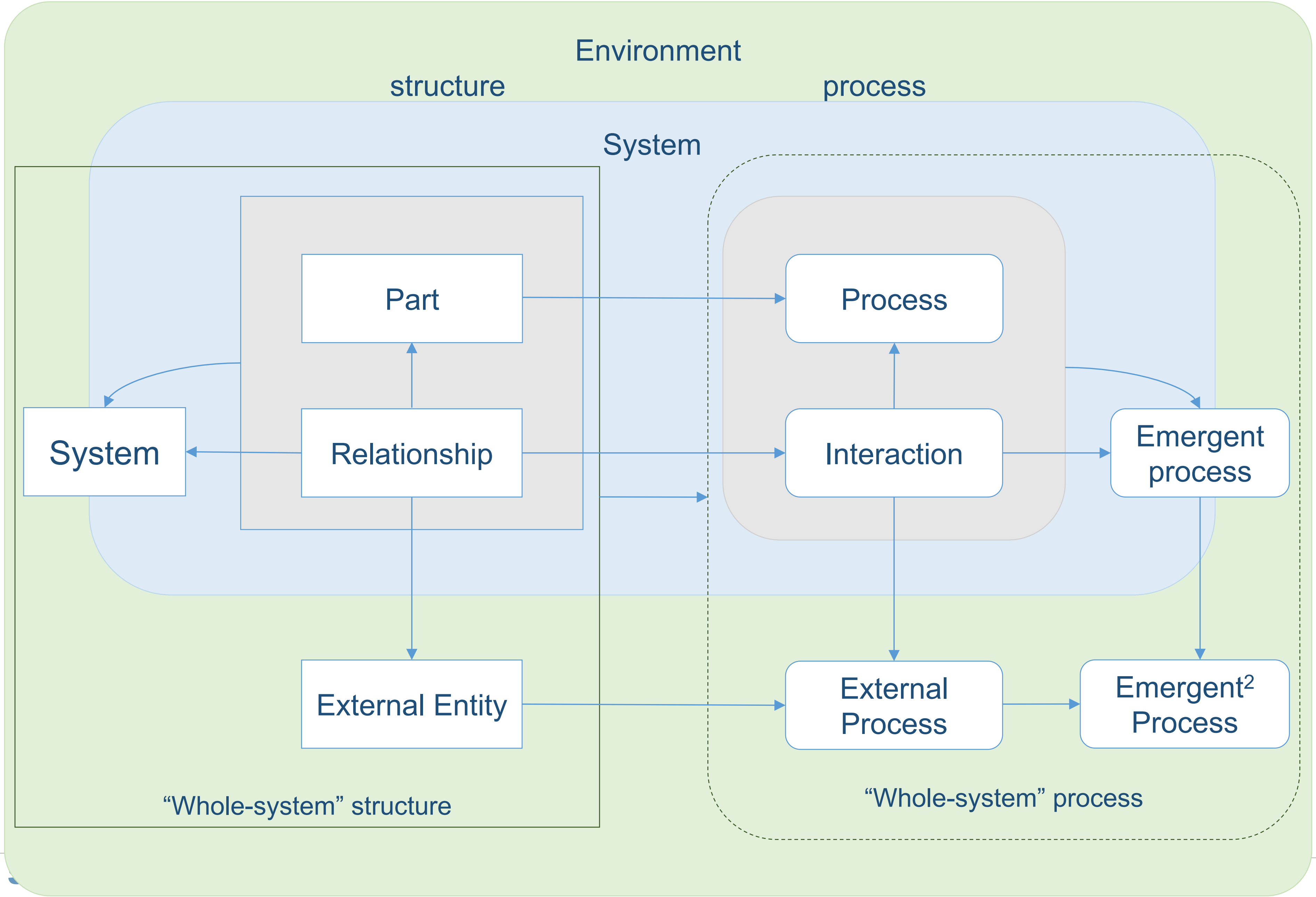
NB:

- The real world is what it is, not what we think it should be.
- It is VERY important not to shoehorn the real world into a "should-be" template.

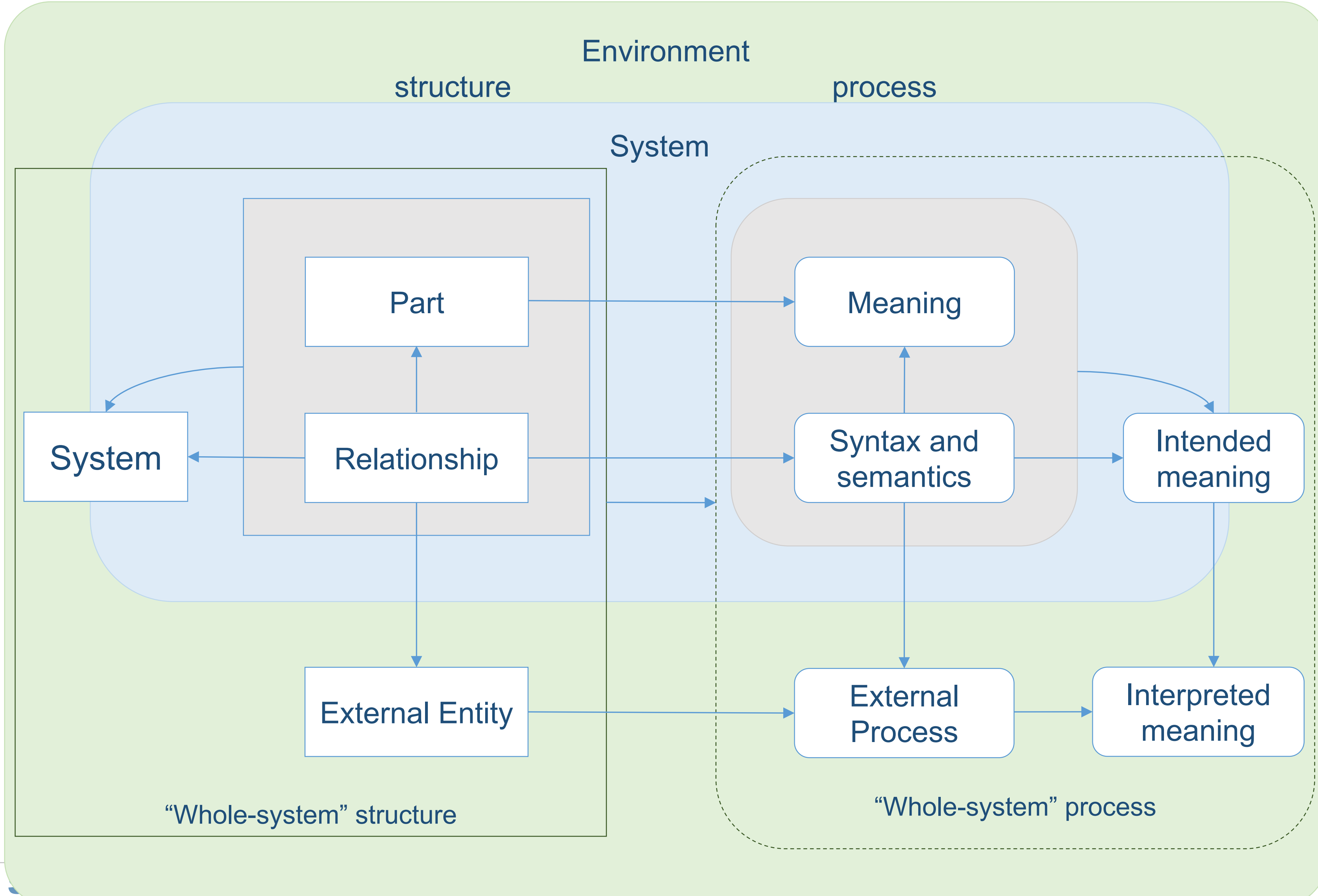
Conclusion – so what IS a system?

Worldview 8 - disruption and Synthesis!

Basic Ontology – of physical or biological system



Basic System Ontology – conceptual system



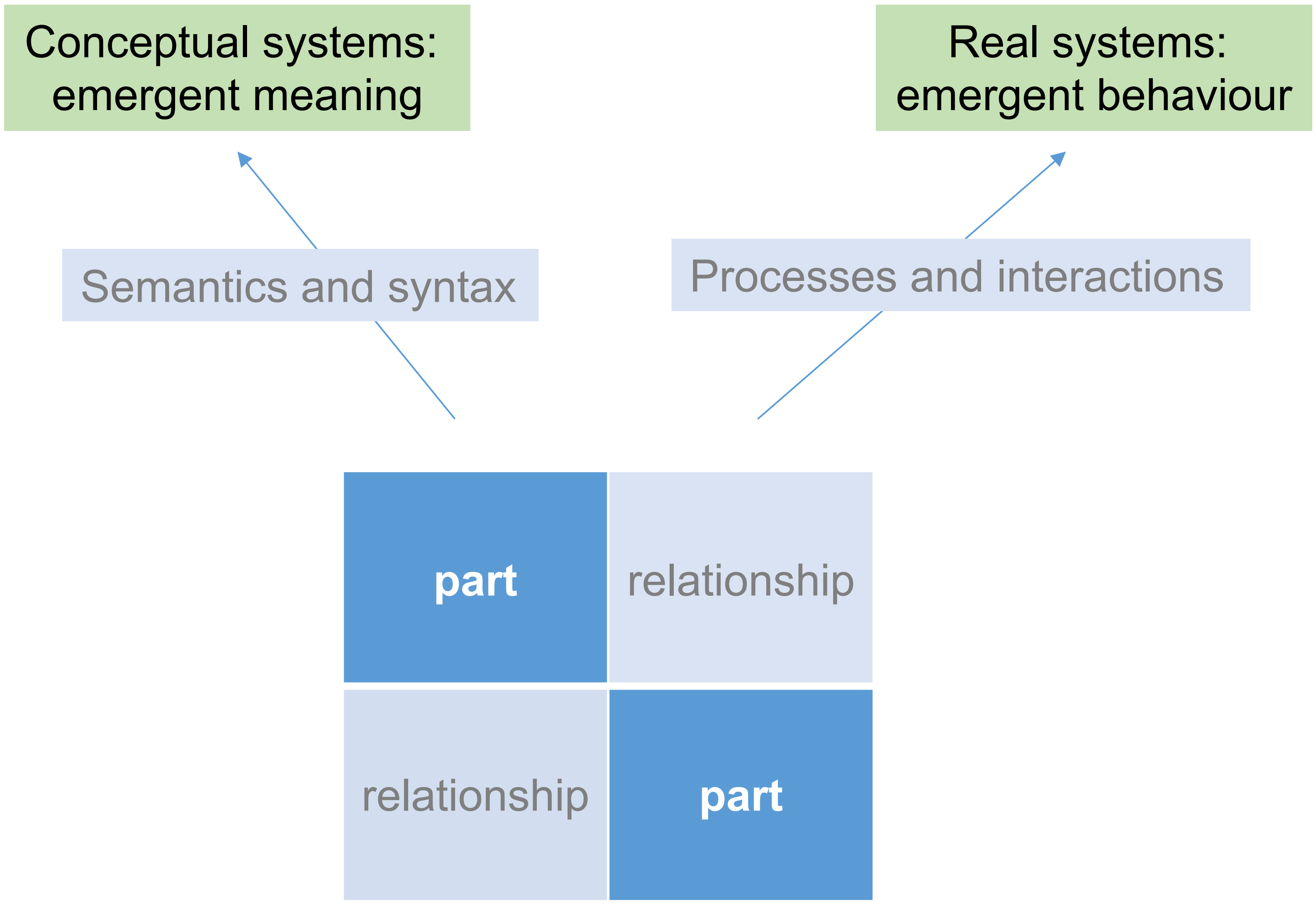
THE DISRUPTION – Worldview 8 offers several fundamental conjectures about systems

- System is a persistent region of low entropy (= organisation) in physical or conceptual space-time.
- Systemness is a fundamental organising principle of nature.
  - "We see systems everywhere because they are everywhere".
  - Systemness is the phenomenon that allows regions of organisation in the material world to exist in a dissipative universe.
- Humans are hardwired to recognise "systems" because it has high survival value
- The universe is the only known closed real system.
  - (NB many conceptual systems, including all system models, are models of closed systems!!!)
- System practice and systems science involve two key aspects:
  - Understanding systems
  - Understanding how we perceive and interact with systems

If we build on these ideas we think we can develop an approach that respects, integrates and builds upon all of the identified worldviews

Based on discussions among Team 2, IFSR Conversation Linz, April 2018

Basics of systemness: "The whole is more than the sum of the parts"



Thank you for your attention

Any questions?