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Dean Beale, **Dorothy McKinny**, Rudolph Oosthuizen, Gary Smith, **Michael Watson**

SE Heuristics for Complex Systems

Motivation

- Connectivity is leading to exponential increases in complexity
- Complexity means that when we make changes we no longer have SUFFICIENT confidence in the effect
  - As we can not see or understand all the connections
  - We can not predict all the consequences!
- This leads to a paradigm shift

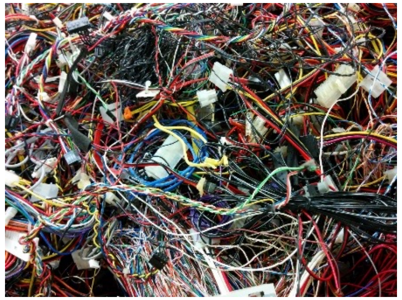
Complex vs complicated systems

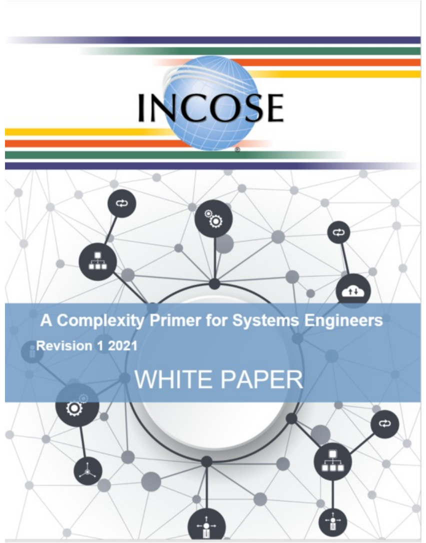
INCOSE Complexity Primer for SE's –Review 1

- *A **complicated system** has elements, the relationship between the states of which can be unfolded and comprehended, leading to sufficient certainty between cause and effect.*

- *A **complex system** has elements, the relationship between the states of which are weaved together so that they are not fully comprehended, leading to insufficient certainty between cause and effect*

- This difference leads to a knowledge gap
- Experience in complex problems yields heuristics to help us handle COMPLEX systems





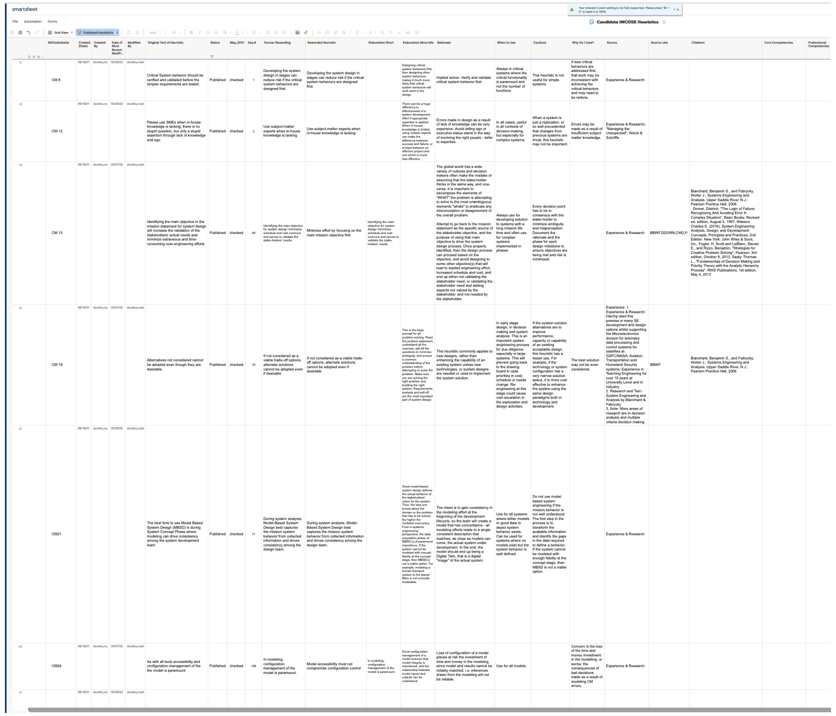
INCOSE Complex Systems Working Group . (2021). *A Complexity Primer for Systems Engineers Revision 1 2021, INCOSE-TP-2021-007-01*. INCOSE.

Why Heuristics

- Focussed on helping others to discover how to act
- Based on experience
- Correct an otherwise typical error
- Memorable – mental short cuts
- Simple way to encapsulate difficult concepts
- First step towards Principles
- INCOSE Fellows leading SE heuristic push, & asking for Working Group input

Approach

- Search INCOSE Fellows Heuristic database for, complex and complexity related heuristics
- Focus Group method:
  - Assembly of people in an in-depth interview
  - Different backgrounds, experiences and knowledge
  - To review, simplify, expand, redo or ignore
  - Document details: Elaboration, Rationale, When to use, Cautions & Why we care
- Individual Heuristic suitability test
  1. Derived from experience
  2. Memorable (short and pithy)
  3. Simple to understand
  4. Easy to apply
  5. Significant impact - changes an action that would otherwise occurred
  6. Applicable across a range of domains



Approach

- **Set** of Heuristic suitability test
  1. Internally coherent
  2. Collectively greater than the sum of the parts
  3. Presented in away that aids memorability
  4. Mutually Exclusive Collectively Exhaustive (MECE)
  5. Sufficient coverage of application area

EXAMPLES

1	**Iterate to evolve complex systems**
Elaboration	Apply iterative approaches to developing or evolving a complex system. These approaches include Agile, Spiral, Lean Start-Up etc., to incrementally deliver and evolve a complex system.
Rationale	You cannot develop a complex system right the first time, because we discover so much new information, and stakeholders often have to co-create new knowledge to be successful. Sense and iterate frequently, adjusting at a pace that is at a higher frequency than the change (Boyd, 2018). Being within the decision loop enables you to influence the environment. If you are in a high change environment you need to sequence the work to minimise overall risk ASAP. A slower pace of change than the external decision loop implies firefighting. Choosing the right pace of change is critical for complex systems (Senge, 1990). Complex systems should be engaged in a manner that they support change, via identifying suitable leverage points (Meadows, 2008).
When to use	When considering any complex system.
Cautions	Change needs to be planned and well thought through to minimise unintended consequences (Griffin, 2010). If you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good. Use feedback to ensure the impact of change is as expected. Don't change for the sake of change. Unnecessary change can be a major source of added complexity.
Why do I care	You cannot develop a complex system right the first time.

2	**Multiple perspectives identify complexity**
Elaboration	Observe a system from multiple perspectives to determine complex characteristics. Different perspectives include levels of abstraction, stakeholder perspectives, familiarity levels, and a range of boundary choices etc. If you cannot access expertise or training to determine or identify th[illegible] the system is complicated, treat it as complex.
Rationale	Since single perspective on a system virtually guarantees that you will not see all relevant information. you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good.
When to use	Continuously as part of reflective practise.
Cautions	Familiarity with problem space and the solution space both need to be considered.
Why do I care	Identifying aspects of complexity in systems prevents failure.

3	**Complex systems are not homogeneous**
Elaboration	It is counterproductive to merely label a system as complex or not complex. Always identify and assess where the types of complexity are within the system.
Rationale	Seek to understand and capture the type, location, characteristics and scale of complexity exhibited in the SOI and the WSOI throughout the lifecycle and respond accordingly. Consider treating complex elements of system differently to complicated or simply system elements
When to use	When determining what part of a system is complex and therefore requires special attention. Using a Complexity Assessment Tool (Beale & Young, Initial thoughts on measuring and managing complexity, 2016) (Beale, Tryfonas, & Young, Evaluating approaches for the next generation of difficulty and complexity assessment tools, 2017) or by reviewing the Characteristics of the task. (Watson, McKinney, Anway, Rosser, & MacCarthy, 2019) The SOI represents the aspects that you can act on and manage or lead. The WSOI may only be influenced at best.

4	**Do not assume complicated pegs fit in complex holes**
Elaboration	Do not assume successful techniques for complicated systems will be helpful with a complex system. Do not assume that a Systems Engineering technique that has worked well in the past, even in past complex challenges, will be successful for this complex challenge.
Rationale	Complicated systems assume stable systems that work well with static structural or semantic modelling. Complex systems are fundamentally different and suggest the need "to change everything" - mindset as well as techniques (Boulton, Allen, & Bowman, 2015). Complicated systems are well understood using partitioning and reductive techniques, while complex systems are not.
When to use	When choosing an approach for a complex problem, be careful in applying past successful approaches. Apply experimental, incremental and/or iterative approaches to test suitability.
Cautions	Do not hesitate to use applicable proven approaches for complicated portions of a complex system.
Why do I care	Techniques useful for complicated systems typically use partitioning and reductionism; these techniques often obscure the very inter-relationships which make a system or environment complex.

5	**For every complex problem, there is an answer that is clear, simple, and wrong** (Mencken, 2022)
Elaboration	As we learn, do not be overly attracted to potentially simple problems or solutions without due diligence. Avoid jumping to solutions that have not been carefully analysed, especially in terms of unintended consequences. These are like Fixes that fail and Shifting the Burden system archetypes (Braun, 2021) (Wolstenholme, 2003).
Rationale	Popular communication often uses "sound bites" which make it seem obvious that a simple solution will work. The quick fix may have unintended consequences that may not be immediately apparent. Do not assume an answer is right, while the problem is not well understood. A complex system is required to solve a complex problem (Ashby, 1958).
W[illegible]en t[illegible]	When [illegible]ou are cur[illegible] in [illegible] a simple approach, a sound bite approach seems attrac-t[illegible] b[illegible] still needs [illegible] be checked. [illegible]owever, it is the job of systems engineering to fully understand [illegible] sit[illegible]ation, and [illegible] solution will not work. In complex problems, remove as ma[illegible] unnecessa[illegible] dependencies as you [illegible]an, but no necessary ones.
C[illegible]tion[illegible]	Do no[illegible] assume sim[illegible]le solutions [illegible] not po[illegible]ible. Elegant solutions are optimal when they can be realised, [illegible] if it is [illegible] simple or elegant.
Why do I care	Popular communication often uses "sound bites" which make it seem obvious that a simple solution will work. However, it is the job of systems engineering to fully understand the situation, and why an overly simplistic solution will not work.

6	**Complexity understanding should precede action**
Elaboration	It is important to understand, recognize and characterize complexity as a first step before you engineer or deal with complex systems. This is likely to require effort through learning and/or suitable experience.
Rationale	Understanding and recognizing complexity in the environment and system to be developed will enable the creation of more suitable solutions.
When to use	Anytime complexity or a breakdown between cause and effect, is likely in the system or the environment. This is often sensed when you feel uncomfortable with current methods for handling the task.
Cautions	Consulting an expert can be helpful to distinguish between complex or complicated. Sometimes experimentation is required to understand the complexity in the system or the environment. Expertise required: Requires knowledge of Systems Thinking and supporting techniques.
Why do I care	Not understanding complexity means you may treat a complex task as a complicated task. Misclassifying or treating a complex system as complicated is a major source of project failure (Cavanagh, 2013).

18 Heuristics Assessed

		Experience	Memorable	Simple	Easy to apply	Impact	Applicable	Source
1	Apply iterative approaches to developing or evolving a complex system.				for teams			Database
2	Observe a system from multiple perspectives to determine complex characteristics.							Database
3	Complex systems are not homogeneous.				with CATs			Database
4	Do not assume successful techniques for complicated systems will be helpful with a complex system.							Database
5	For every complex problem, there is an answer that is clear, simple, and wrong (Mencken)							Database
6	Before you system engineer complex systems, first develop the ability to recognize and understand complexity.							New
7	Engineers can aggregate and iterate more rapidly with stable intermediate forms of the design, within an overall architecture, to develop a complex system.				For SE architect			Database
8	Organisational culture and structure must adapt and adjust to develop complex solutions, or even to cope in complex environments.				Hard to change culture			Database
9	Think big, assess all, but start small and continuously evolve when handling complexity.							Database

18 Heuristics Assessed

		Experience	Memorable	Simple	Easy to apply	Impact	Applicable	Source
10	Understanding your organisation as a complex adaptive system is critical to incorporating improved systems engineering: implement change by observing, orienting, deciding, and then acting in a continuous loop.							New
11	Optimization of complex systems is less important than understanding all the different perspectives.				New SE Focus			Database
12	Keep as many options as possible open during the development and evolution of complex systems.				Need skill			Database
13	Complex systems should be made as simple as possible to deliver all needed system outputs, but not simpler.				Need skill			Database
14	An element good enough in a previous system needs careful analysis before being applied to another complex system.				Need insight			Database
15	For complex problems, focus on holistic utility, not optimization of any single objective.							New
16	Strategically assess the areas of complexity to select handling approaches thoughtfully.				Need skill			New
17	Proactively and holistically manage the unexpected emergent health issues within a complex system to mitigate failure.				Need skill			Database
18	Proactively and holistically manage unexpected emergence within complex sociotechnical system to mitigate failure and realise opportunity.				Need skill			New

Observations:

- Not memorable!
- Not easy to apply

Challenges

- Why memorable
  - Heuristics are more about being useful than accurate
  - If they can not be remembered they are not useful
  - Memorable and right enough to encourage further consideration
- What is memorable:
  - Simple words
  - A few words - The Magic Number - 7+/- 2
  - Or play on a well known phrase
- Easy to apply
  - Many SE tools are hard to apply – but they are worth the effort!
  - The term “Easy to apply” is wrong – changed to “Possible to apply”

Initial vs Final Set

	Initial Heuristics	Final Heuristics	Experience	Memorable	Simple	POSSIBLE to apply	Impact	Applicable
1	Apply iterative approaches to developing or evolving a complex system.	Iterate to evolve complex systems						
2	Observe a system from multiple perspectives to determine complex characteristics.	Multiple perspectives identify complexity						
3	Complex systems are not homogeneous.	Complex systems are not homogeneous.						
4	Do not assume successful techniques for complicated systems will be helpful with a complex system.	Do not assume complicated pegs fit in complex holes						
5	For every complex problem, there is an answer that is clear, simple, and wrong (Mencken)	For every complex problem, there is an answer that is clear, simple, and wrong						
6	Before you system engineer complex systems, first develop the ability to recognize and understand complexity.	Complexity understanding should precede action						
7	Engineers can aggregate and iterate more rapidly with stable intermediate forms of the design, within an overall architecture, to develop a complex system.	Iterate and/or aggregate with stable system steps						
8	Organisational culture and structure must adapt and adjust to develop complex solutions, or even to cope in complex environments.	Culture mismatch kills complex systems						
9	Think big, assess all, but start small and continuously evolve when handling complexity.	Think big, evolve from small						

Initial vs Final Set

	Initial Heuristics	Final Heuristics	Experience	Memorable	Simple	POSSIBLE to apply	Impact	Applicable
10	Understanding your organisation as a complex adaptive system is critical to incorporating improved systems engineering: implement change by observing, orienting, deciding, and then acting in a continuous loop.	Complexity necessitates continuous learning and adaptation						
11	Optimization of complex systems is less important than understanding all the different perspectives.	Deprioritize optimization, prioritize perspectives						
12	Keep as many options as possible open during the development and evolution of complex systems.	Keep options open to evolve						
13	Complex systems should be made as simple as possible to deliver all needed system outputs, but not simpler.	Complex Systems: As simple as possible, but no simpler!						
14	An element good enough in a previous system needs careful analysis before being applied to another complex system.	Reuse with extreme care						
15	For complex problems, focus on holistic utility, not optimization of any single objective.	Focus on holistic utility						
16	Strategically assess the areas of complexity to select handling approaches thoughtfully.	Complex problems call for strategic thinking						
17	Proactively and holistically manage the unexpected emergent health issues within a complex system to mitigate failure.	Holistic system health avoids complex system failures						
18	Proactively and holistically manage unexpected emergence within complex sociotechnical system to mitigate failure and realise opportunity.	Manage emergence holistically						

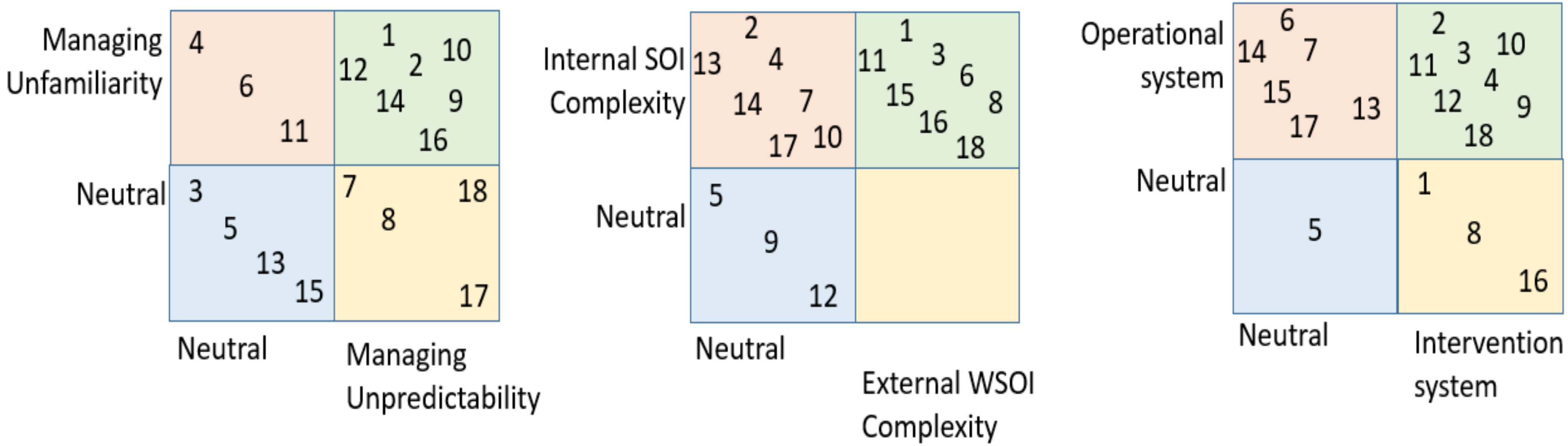
Suitability as a set

1. Internally coherent
2. Collectively greater than the sum of the parts
3. Presented in away that aids memorability
4. Mutually Exclusive Collectively Exhaustive
5. Sufficient coverage of application area (Next slides)

Final Heuristics			
1	Iterate to evolve complex systems	10	Complexity necessitates continuous l earning and adaptation
2	Multiple perspectives identify complexity	11	Deprioritize optimization, prioritize perspectives
3	Complex systems are not homogeneous.	12	Keep options open to evolve
4	Do not assume complicated pegs fit in complex holes	13	Complex Systems: As simple as possible, but no simpler!
5	For every complex problem, there is an answer that is clear, simple, and wrong	14	Reuse with extreme care
6	Complexity understanding should precede action	15	Focus on holistic utility
7	Iterate and/or aggregate with stable system steps	16	Complex problems call for strategic thinking
8	Culture mismatch kills complex systems	17	Holistic system health avoids complex system failures
9	Think big, evolve from small	18	Manage emergence holistically

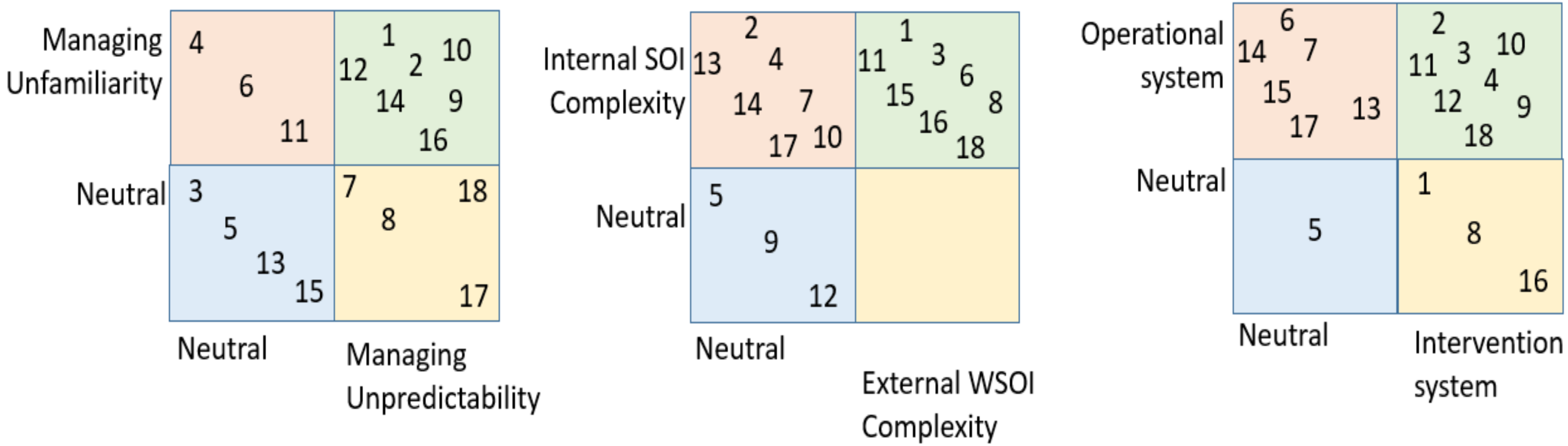
Sufficient coverage?

- Assessed:
  - Unfamiliarity (Novelty) and Unpredictability coverage
  - Wider System Of Interest (WSOI) and System Of Interest (SOI) coverage
  - Intervention and operational system coverage



Sufficient coverage?

- Results:
  - Insufficient coverage of Wide System Of Interest
  - Light coverage of intervention system



Sufficient Coverage?

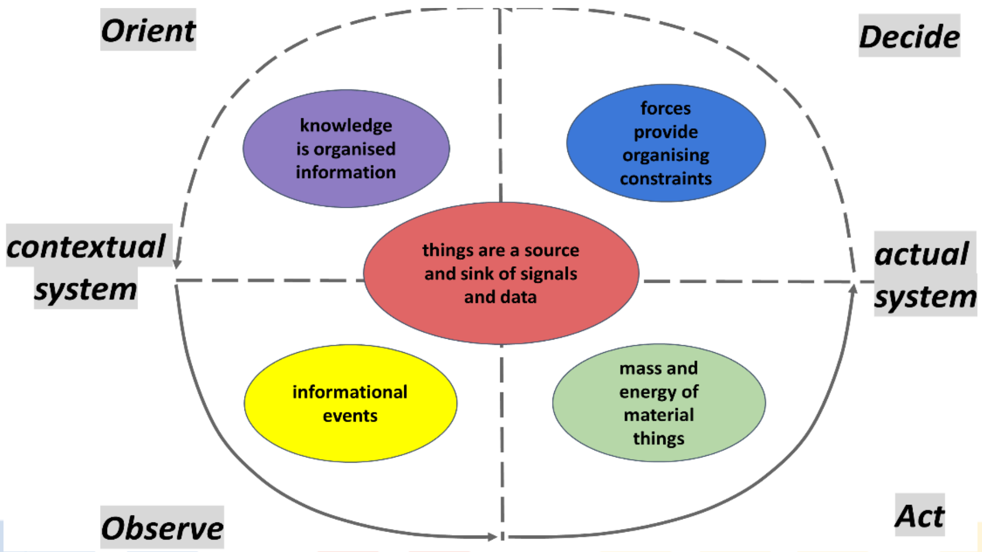
- Against Top-Down developed Heuristics (Beale & Tryfonas)
- Light coverage of culture/ team aspects

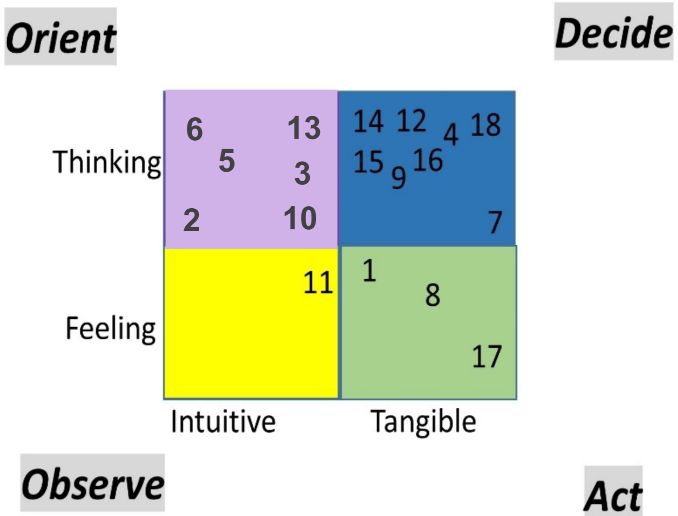
	Principle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Equality Mind-set		X						X			X							
Culture	Robust Relations								X										
	Generous leadership								X				X	X			X		
	Compelling Vision					X		X	X	X						X	X		
	Living Systems	X						X	X	X	X		X					X	X
Adaptive	Proactive Observation	X	X	X	X	X	X			X		X		X	X	X	X	X	X
	Continuous Learning	X				X	X				X	X	X		X				

Beale, D., & Tryfonas, T. (2021). An Initial Set of Heuristics for Handling Organizational Compleixty. *IEEE Internaional Systems Conference (SYSCON)* (pp. 1-8). IEEE Xplore.

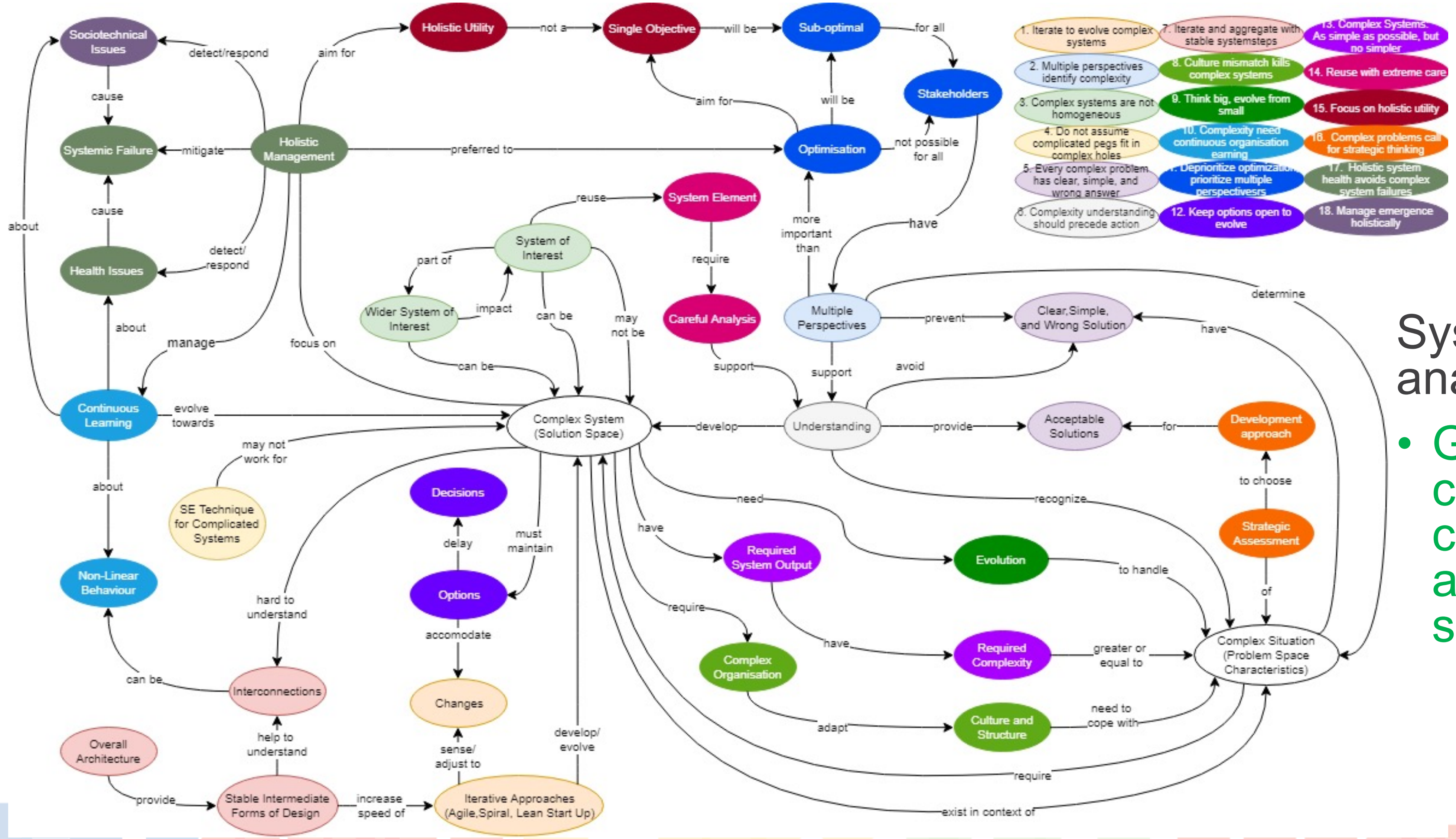
Sufficient coverage?

- Against Relational Theory Models
- Light coverage of feelings, especially intuition.





Sufficient coverage?



Systemigram analysis

- Good coverage, connectivity & coherence across system space

Discussion

- **The 18 Heuristics, individually are potentially useful to SE**
  - The updated wording needs to be validated through usage
  - The Heuristics are not yet a complete set for complex systems
- They do not fully cover:
    - Implementation systems
    - Socio-technical system elements
    - Environmental or culture issues
    - Soft skills, intuition or feelings
  - They appear to reflect our SE history!!
- Questions:
  - Will they ever be a good set of bottom-up Heuristics?
    - Mutually Exclusive Collectively Exhaustive?
  - Do we need to combine with Top down approaches?
  - Can we find or develop Heuristics that can fill the gaps?
- But we know we can only test and improve the Heuristics by consciously using them

Conclusions and Further Work

- The Heuristics developed are useful individually (use them!)
- They are not a complete set of Heuristics (yet):
  - Coverage gaps
  - Mutually Exclusive Collectively Exhaustive (MECE)
  - Memorability

Further Work

  - SE Practitioners need to use and provide feedback
  - Repeat the approach by increasing search terms on INCOSE database – Emergence, culture, environment etc.
  - To ask INCOSE Corporate Advisory Board (CAB) to indicate what Heuristics they use for handling complexity
  - To consider Top-Down approaches in combination with bottom-up
  - To check how the Heuristics translate into other languages!!

Questions?

Appendix of Heuristics’ fields

1	Iterate to evolve complex systems
Elaboration	Apply iterative approaches to developing or evolving a complex system. These approaches include Agile, Spiral, Lean Start-Up etc., to incrementally deliver and evolve a complex system.
Rationale	You cannot develop a complex system right the first time, because we discover so much new information, and stakeholders often have to co-create new knowledge to be successful. Sense and iterate frequently, adjusting at a pace that is at a higher frequency than the change (Boyd, 2018). Being within the decision loop enables you to influence the environment. If you are in a high change environment you need to sequence the work to minimise overall risk ASAP. A slower pace of change than the external decision loop implies firefighting. Choosing the right pace of change is critical for complex systems (Senge, 1990). Complex systems should be engaged in a manner that they support change, via identifying suitable leverage points (Meadows, 2008).
When to use	When considering any complex system.
Cautions	Change needs to be planned and well thought through to minimise unintended consequences (Griffin, 2010). If you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good. Use feedback to ensure the impact of change is as expected. Don't change for the sake of change. Unnecessary change can be a major source of added complexity.
Why do I care	You cannot develop a complex system right the first time.

2	Multiple perspectives identify complexity
Elaboration	Observe a system from multiple perspectives to determine complex characteristics. Different perspectives include levels of abstraction, stakeholder perspectives, familiarity levels, and a range of boundary choices etc. If you cannot access expertise or training to determine or identify that the system is complicated, treat it as complex.
Rationale	Since single perspective on a system virtually guarantees that you will not see all relevant information. you do not fully understand the system or the environment you must act cautiously to ensure you do not cause more harm than good.
When to use	Continuously as part of reflective practise.
Cautions	Familiarity with problem space and the solution space both need to be considered.
Why do I care	Identifying aspects of complexity in systems prevents failure.

3	Complex systems are not homogeneous
Elaboration	It is counterproductive to merely label a system as complex or not complex. Always identify and assess where the types of complexity are within the system.
Rationale	Seek to understand and capture the type, location, characteristics and scale of complexity exhibited in the SOI and the WSOI throughout the lifecycle and respond accordingly. Consider treating complex elements of system differently to complicated or simply system elements
When to use	When determining what part of a system is complex and therefore requires special attention. Using a Complexity Assessment Tool (Beale & Young, Initial thoughts on measuring and managing complexity, 2016) (Beale, Tryfonas, & Young, Evaluating approaches for the next generation of difficulty and complexity assessment tools, 2017) or by reviewing the Characteristics of the task. (Watson, McKinney, Anway, Rosser, & MacCarthy, 2019) The SOI represents the aspects that you can act on and manage or lead. The WSOI may only be influenced at best.
Cautions	Do not use only one approach for dealing with all types of complexity. Complexity is multi-dimensional and varied.
Why do I care	Even if a system is simple, the environment in which it is intended to be used, and/or stakeholder interactions may well be complex. There is no “one size fits all” way to address complexity; instead, it is imperative to identify specific characteristics and types of complexity, and address each individually.

4	Do not assume complicated pegs fit in complex holes
Elaboration	Do not assume successful techniques for complicated systems will be helpful with a complex system. Do not assume that a Systems Engineering technique that has worked well in the past, even in past complex challenges, will be successful for this complex challenge.
Rationale	Complicated systems assume stable systems that work well with static structural or semantic modelling. Complex systems are fundamentally different and suggest the need “to change everything” - mindset as well as techniques (Boulton, Allen, & Bowman, 2015). Complicated systems are well understood using partitioning and reductive techniques, while complex systems are not.
When to use	When choosing an approach for a complex problem, be careful in applying past successful approaches. Apply experimental, incremental and/or iterative approaches to test suitability.
Cautions	Do not hesitate to use applicable proven approaches for complicated portions of a complex system.
Why do I care	Techniques useful for complicated systems typically use partitioning and reductionism; these techniques often obscure the very inter-relationships which make a system or environment complex.

5	For every complex problem, there is an answer that is clear, simple, and wrong (Mencken, 2022)
Elaboration	As we learn, do not be overly attracted to potentially simple problems or solutions without due diligence. Avoid jumping to solutions that have not been carefully analysed, especially in terms of unintended consequences. These are like Fixes that fail and Shifting the Burden system archetypes (Braun, 2021) (Wolstenholme, 2003).
Rationale	Popular communication often uses “sound bites” which make it seem obvious that a simple solution will work. The quick fix may have unintended consequences that may not be immediately apparent. Do not assume an answer is right, while the problem is not well understood. A complex system is required to solve a complex problem (Ashby, 1958).
When to use	When you are currently failing in applying a simple approach, a sound bite approach seems attractive but still needs to be checked. However, it is the job of systems engineering to fully understand the situation, and why an overly simplistic solution will not work. In complex problems, remove as many unnecessary dependencies as you can, but no necessary ones.
Cautions	Do not assume simple solutions are not possible. Elegant solutions are optimal when they can be realised, so we need to check if it is overly simple or elegant.
Why do I care	Popular communication often uses “sound bites” which make it seem obvious that a simple solution will work. However, it is the job of systems engineering to fully understand the situation, and why an overly simplistic solution will not work.

6	Complexity understanding should precede action
Elaboration	It is important to understand, recognize and characterize complexity as a first step before you engineer or deal with complex systems. This is likely to require effort through learning and/or suitable experience.
Rationale	Understanding and recognizing complexity in the environment and system to be developed will enable the creation of more suitable solutions.
When to use	Anytime complexity or a breakdown between cause and effect, is likely in the system or the environment. This is often sensed when you feel uncomfortable with current methods for handling the task.
Cautions	Consulting an expert can be helpful to distinguish between complex or complicated. Sometimes experimentation is required to understand the complexity in the system or the environment. Expertise required: Requires knowledge of Systems Thinking and supporting techniques.
Why do I care	Not understanding complexity means you may treat a complex task as a complicated task. Misclassifying or treating a complex system as complicated is a major source of project failure (Cavanagh, 2013).

7	Iterate and/or aggregate with stable system steps
Elaboration	Engineers can aggregate and iterate more rapidly with stable intermediate forms (increments) of the design, within an overall architecture, to develop a complex system. The architecture accommodates the system's complexity in the context of its environment. It provides constraints and requirements for the design. Intermediate forms of the system design facilitate learning to better understand the interdependencies for the next increment or iteration (Scaled Agile Inc, 2022).
Rationale	Engineers iterate and learn from each iteration before progressing to the next stage or increment. Baselines established an increasing level of learning, confidence and willingness to proceed. Expertise required: To implement this task successfully the SE architect skill is required.
When to use	When designing a large complex system with uncertainty and high risk. This also applies to the implementation system (the system that makes the system). This also applies to organisational evolution.
Cautions	The amount of documentation or modelling required for intermediate forms should scale to the size of the team to ensure a common understanding. The time allocated to baseline the intermediate forms of the design needs to be sufficiently short to allow for all iterations or increments required to complete the design. When evolving a complex system which is in use, intermediate versions need to be considered carefully.
Why do I care	Complex systems contain many unknown unknowns, intermediate steps help you to identify and understand them. Failure to iterate with stable system steps can lead to whole system failure, a big bang approach is highly unlikely to work with complex systems.

8	Culture mismatch kills complex systems
Elaboration	Organisational culture and structure must adapt and adjust to deal with complex systems or environments. Organizational preparedness is necessary to handle complex systems. See Principle 3 (Watson, et al., 2021).
Rationale	Organisational culture will hinder the development of complex systems if the organisation cannot accommodate the uncertainty and reduction of control required to produce complex systems (Cameron & Quinn, 2011).
When to use	Culture and organizational change take time (years). You can use it for a team to create separate cultures if required using Bi-model (Gartner, 2019) or multi-modal approaches (Christensen, 2016). Organizational preparedness includes for example: culture change, training in systems thinking and other complexity techniques, changing reward structures, breaking organisational silos, awareness of complexity principles and heuristics, and servant leadership.
Cautions	An organization needs complicated and complex (innovative) parts with their different cultures for success (Bi model or multi-model working, Principle 13). There are many different views on the definition of culture that need to be considered.
Why do I care	Organisations successful in implement complicated systems is highly unlikely to be good at creating complex systems, without culture change.

9	Think big, evolve from small
Elaboration	Think big, assess all, but start small and continuously evolve when handling complexity. Invest in conceptualisation and exploration with small prototyping exercises before embarking on larger investments. Start development in small increments, test your assumptions and wait until sufficient uncertainty has been removed to make the time investment fruitful. Applies to both the operational and intervention systems.
Rationale	Big compelling visions help align behaviors, but big steps cause avoidable risk. Building on the lessons learnt from the prototyping exercises in a safe to fail environment makes it possible to test key assumptions and eliminate uncertainties. Small evolutionary steps enable beneficial emergent outcomes that adapt where possible to changes in the external environment.
When to use	For all unprecedented systems and for all potentially complex systems, especially when being developed with tight time constraints. The more unknowns in a complex system, the more opportunity thinking big starting small will offer. Using this heuristic at the start of a new initiative is helpful.
Cautions	Starting small will lead to concerns on progress, so reassurance will be required. Be careful to ensure that approach scales in time. Be careful not to get stuck in apparent safety of small. Using this heuristic mid-initiative can be disruptive, which will often be a good thing!
Why do I care	Dealing with complexity requires both a big picture view and attention to details at lower levels and getting the foundation right. Using smaller steps to test assumptions with rapid feedback will reduce risk.

10	Complexity necessitates continuous organisational learning and adaptation
Elaboration	Understanding your organisation as a complex adaptive system is critical to incorporating improved systems engineering: implement change by observing, orienting, deciding, and then acting in a continuous loop (Boyd, 2018). All social systems are complex adaptive systems. If leaders do not see their organisation as a complex adaptive system, that learns, then it is hard to recognize the benefits of systems engineering (Senge, 1990).
Rationale	Systems Engineering is an essential element of any complex adaptive organisation (system).
When to use	When helping an organisation deal more effectively with complexity.
Cautions	While learning and adapting the organisation needs to maintain focus, continuity and momentum in the system development and evolution project. Do not stop the learning process when you finish an activity or make a decision, organisational learning needs to be continuous in anticipation of future challenges.
Why do I care	Any organisation that seeks to be successful in handling complexity needs to include within it a systems engineering capability. Systems Engineering benefits will not be fully realised unless organisations see themselves as complex adaptive systems.

11	Deprioritize optimization, prioritize multiple perspectives.
Elaboration	Optimization of any single function constrains accommodating all the different perspectives. Understanding the many and varied perspectives of a complex system is essential to inform balanced system-wide optimisation. As examples, different stakeholders, levels of abstraction, systems behaviors, and systems structures provide different perspectives. No complex system can be optimized to all parties concerned, nor all functions optimized while maintaining the flexibility to adapt. Try to achieve an acceptable "optimal" balance across all the different perspectives, including current and future needs.
Rationale	Accommodating multiple perspectives is more important than optimisation in dealing with complex systems. Optimizing a system for overall benefit across the multi-perspectives of complex systems means that we need to accept that specific benefits will be sub-optimised.
When to use	When developing success criteria for a complex system. Helping others to realise that balancing all perspectives saves money in the complex domain, as efficiency saves money in simple and complicated domains.
Cautions	Pursuing optimization and efficiency in a complex world may lead to failure if all the perspectives are not considered. Incorporating all perspectives is expected to save money, but may increase costs in the short-term.
Why do I care	Pursuing optimization without understanding all perspectives will lead at worst to system failure and at best to lots of rework.

12	Keep options open to evolve
Elaboration	During the development and evolution of complex systems, create options and keep them open for as long as possible. Resist the temptation to close options prematurely because any improvements in certainty and cost are likely to be illusionary. Useful tools include Systems Thinking, and iterative methods such as Lean Start-Up, SaFE etc.
Rationale	Conventional wisdom says that keeping options open causes cost increases and delays development. But when change is inevitable, it is cheaper to have a system that is sufficiently flexible, than one that is brittle to change.
When to use	In complex situations, especially when the environment is unpredictable.
Cautions	Sometimes it is cheaper to throw away an unsuitable iteration and start again (fail fast) than maintain system options. This heuristic is specifically not suitable for complicated systems.
Why do I care	Ideal timings for making many architectural and design decisions in complex systems is typically a lot later than making similar decisions for complicated systems.

13	Complex Systems: As simple as possible, but no simpler!
Elaboration	Complex systems should be made as simple as possible to deliver all needed system outputs, but not simpler (reflection of a phrase attributed to Albert Einstein). System complexity ideally should match the ideal complexity for fulfilling all system outputs, but often it is somewhat greater. If it is less, it is often because sufficient perspectives have not been taken into account. Design system elements so that they are as independent (modular) as possible; low external complexity (low coupling) and high internal cohesion. E.g. Service Orientated Architecture.
Rationale	In each operational context and decision timeframe, the minimum system complexity required to fulfil all the system outputs is the optimal system complexity.
When to use	In architecting and designing complex systems.
Cautions	A more complex system solution than the optimum can fulfil the system requirements, but not as elegantly, while an overly simple system will fail.
Why do I care	Customers and stakeholders want simple, even elegant solutions. For complex challenges it is tempting to over simplify the design, by ignoring or scoping out aspects of the complexity. This approach will often lead to system failure.

14	Reuse with extreme care
Elaboration	An element good enough in a previous system needs careful analysis before being applied to another complex system. The previous system element (inc. COTS and MOTS) is unlikely to be good enough in coping with new or different complexity.
Rationale	We need to ensure we abide by fit form and function when we are considering system elements in a new context. A little change, even in the fine details of the system, can cause disproportionate effects in the overall system. Existing system elements embody design decisions that are not always explicitly described, making it difficult for engineers to understand their potential effects on a new system.
When to use	When considering re-use of a system element.
Cautions	Small scale modifications can result in radical changes, either in the magnitude of an individual change or the cumulative effects of many changes.
Why do I care	Reuse of parts and subsystems which can work well in other systems can be disastrous in complex systems if done without full insight.

15	Focus on holistic utility
Elaboration	For complex problems, focus on holistic utility, not optimization of any single objective. Removing flexibility to reduce costs is inefficient in complex domains.
Rationale	Optimisation can be counterproductive with complex system development as objective functions are difficult to define. Solution flexibility is required to adjust and adapt when uncertainty in the system, environment, or both causes a new issue to be resolved. Insufficient agility and flexibility are a major source of failure in complex systems.
When to use	During the whole lifecycle. Though special attention during the scoping phases is required.
Cautions	Holistic is the opposite to reductionists approaches. Efficiency should include agility and flexibility across the whole, not optimizing for a single use.
Why do I care	If organisations handling complexity continue to focus on reducing flexibility to achieve efficiency rather than adaptability they will fail.

16	Complex problems call for strategic thinking
Elaboration	Strategically assess the areas of complexity to select handling approaches thoughtfully. Different areas of complexity may require different strategies. Acquire a broad overview and look for synergies to bound the complexity areas. Do not assume one successful approach to handling complexity will handle other complexity types effectively.
Rationale	Decide what is worth doing strategically by exploring the unknown and uncertain as profitably as you can. “If I had only one hour to save the world, I would spend fifty-five minutes defining the problem, and only five minutes finding the solution” (Quote attributed to Albert Einstein).
When to use	When complexity is encountered. Especially at the start of an activity and at phase or transition boundaries during the system lifecycle (i.e. key decisions points).
Cautions	High re-work costs are likely to be incurred if this heuristic is not applied. Be careful not to get lost in the details.
Why do I care	Lack of complexity appreciate can lead to missed risks and opportunities.

17	Holistic system health avoids complex system failures
Elaboration	Proactively and holistically manage the unexpected emergent health issues within a complex system to mitigate failure. The resilience and health of the system will be high if the complexity has been sufficiently addressed. Chances for recovery from a single failure or flaw, even with complex consequences, are fairly good if system health is managed holistically. The likely recovery from two or more independent failures will also increase with holistic system health management. .
Rationale	Holistically manage the health of a complex system to mitigate failure. Traditional health management consists of designing out failures so they cannot occur. Complex system designs require proactive monitoring and elegant response to prevent symptoms escalating into failure.
When to use	For safety critical or expensive systems when resilience is particularly important.
Cautions	Do not measure too much, unnecessary measurement can overuse system resources diminishing the system benefit. Ensure you understand the system state before changing the system. Take care that the response to unhealthy signs does not exacerbate the underlying health problem by causing an overreaction with unintended consequences.
Why do I care	Given the inevitable emergence of unexpected behavior in a complex system, it is necessary to design for health monitoring to enable recovery to a state which supports continuing operation.

18	Manage emergence holistically
Elaboration	Proactively and holistically manage unexpected emergence within complex systems to mitigate failure and realise opportunity. Complex systems can lead to emergent opportunities as well as threats. Spotting opportunities and threats require proactive observation and sampling of the system to monitor the design boundaries to help them to be identified. Complex sociotechnical systems are confounded by social complexity which much be accounted in the management of emergence properties, both social and technical.
Rationale	Unexpected emergence is difficult to predict and can affect the system performance from many perspectives and at many scales. Managing emergence holistically allows for the consideration of all levels of impact. Social systems are inherently complex, compounding any systems complexity, with opportunities and threats frequently occurring. The inability to detect emergent events can lead to missed opportunities and threats. Partial or singular perspective management of emergence can lead to a failure to understand the system operation and a failure of system performance.
When to use	In complex system should have emergence managed holistically. Sociotechnical systems that confound the system technical complexity are more challenging, requiring more care in design and understanding.
Cautions	Take care that the response to emergence does not exacerbate the problem by causing an overreaction or unintended consequences. Especially important to identify the facts, independent of confounding factors (such as biases, social structures, power structures, politics, competence or autonomous system actions), to enable well informed conversations.

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