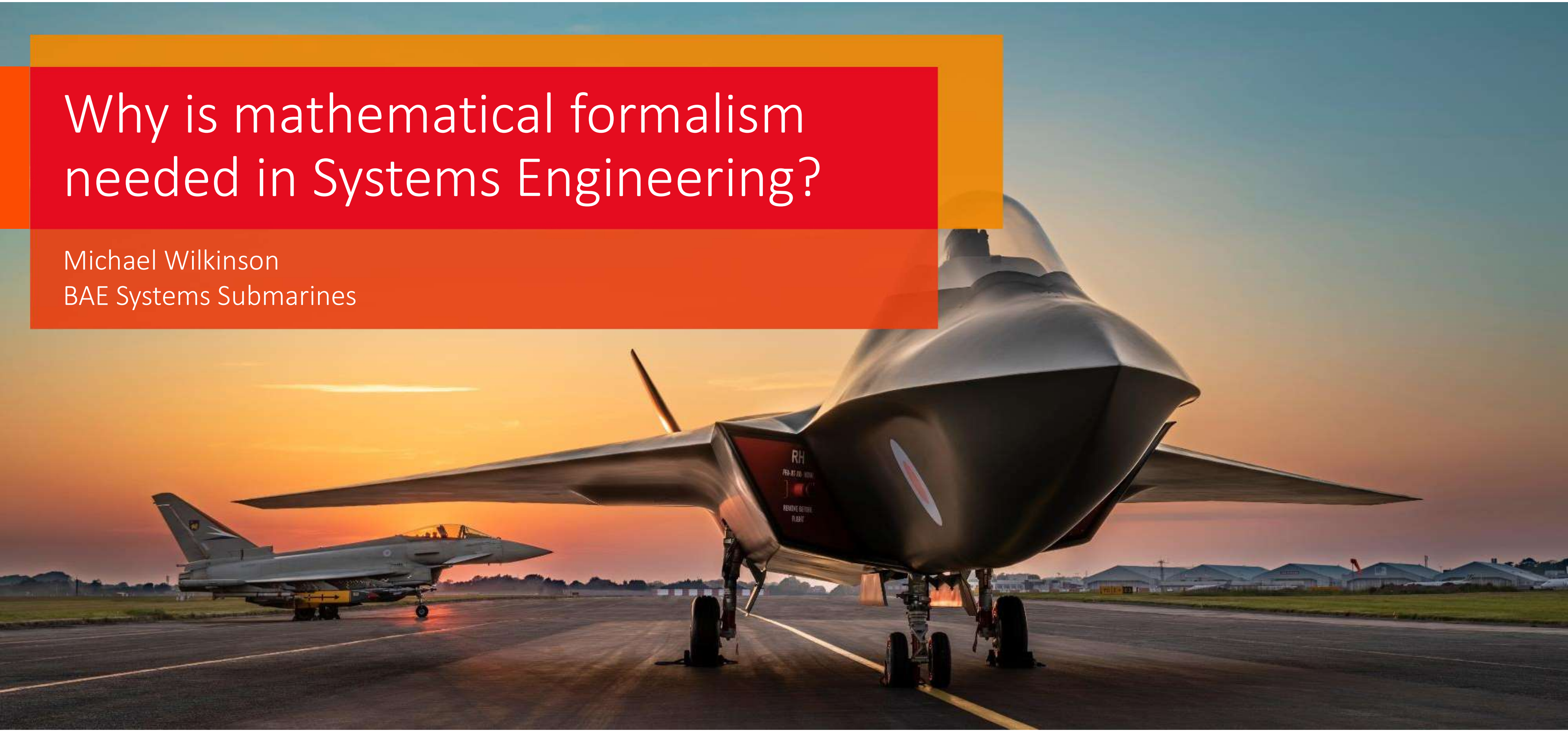
Why is mathematical formalism needed in Systems Engineering?

Michael Wilkinson
BAE Systems Submarines



OMG Document Number mathsig/2022-12-01

What are the problems?

- Imprecision over concepts and terminology
- Handling of system diversity and scale
- Methods for highly complex systems
- Methods for structuring different types of system

The response to these problems needs to be a set of robust methods drawing on a practical but precise mathematical framework and supported by OMG tools

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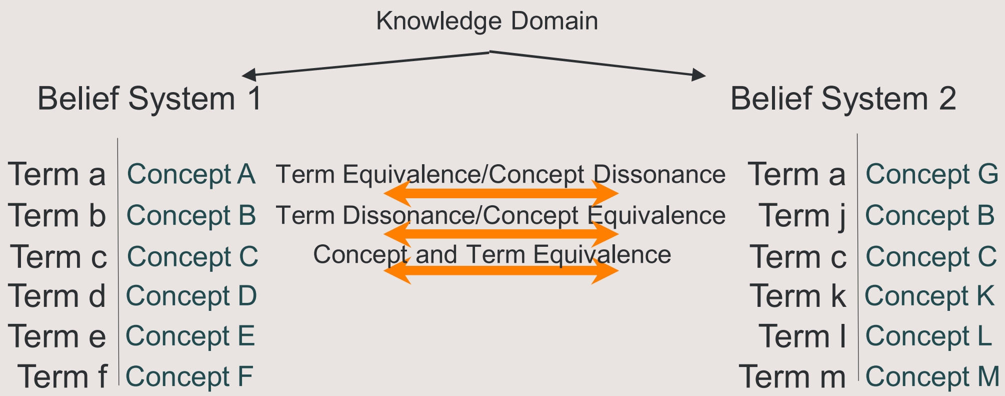
Imprecision over terms and concepts leads to divergent beliefs and practices



"Architecture Panel: Concepts, Terminology & Principles", INCOSE IS08, M K Wilkinson (2008)

Example: (Bendz 2008) Over 130 ISO standards have the term *Architecture* in their title or abstract – with a multiplicity of interpretations

J. Bendz, Presentation to INCOSE Special Architecture Workshop, IW08, Albuquerque, NM, 2008.

Example: (Emes et al 2012) identify six different conceptual models for the relationship between the related processes of System Engineering and System Architecting

"Interpreting 'Systems Architecting'". M R Emes, P A Bryant, M K Wilkinson, P King, A M James and S Arnold. Syst. Eng. **15**, 2012, 369–395.

Caveat: there is no single ontology

Formalised **ontologies** provide a means of managing ambiguities within a knowledge domain

Complex systems exhibit diverse system properties

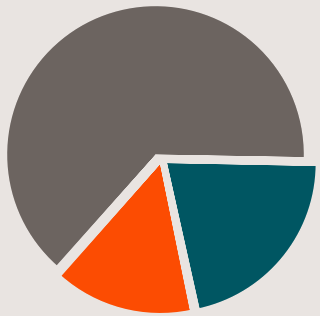
Complex system properties: scale, intensity, technology, diversity, coupling…

Functionally driven systems

Typically functionally rich and built on abstracted hardware platforms.

Performance driven systems

Typically functionally simple but required to operate close to physical limits. May involve novel optimisations.



Constraint driven systems

Typically constrained by the need to use previous designs, to comply with standards or re-use OTS components.

Multiply driven systems

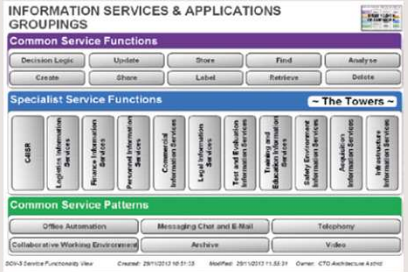
Typically products used within a broader enterprise system or system of systems to provide a capability.

M. Wilkinson, "A Systems Journey: From Theory to Practice and Back Again, Keynote Address, INCOSE Conference on Systems Engineering Research (CSER), 2022.

Methodologies are required based on matching approaches to the driving system properties

Add NAF reference

Different types of structure & process are useful for different purposes



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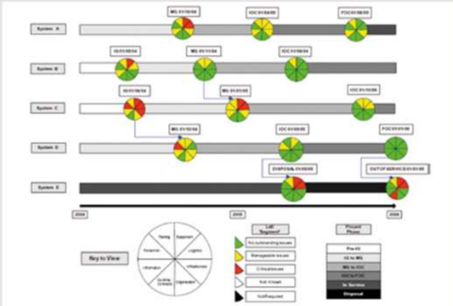
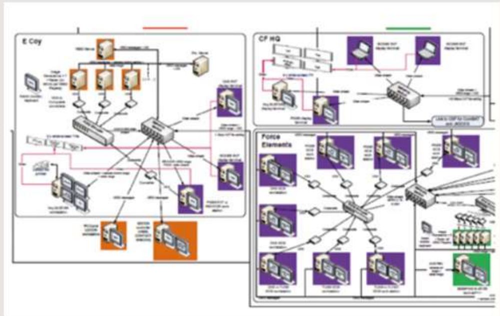


Coordinative

Supportive



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We need to match problem types to types of structure and order of properties addressed – styles of architecting

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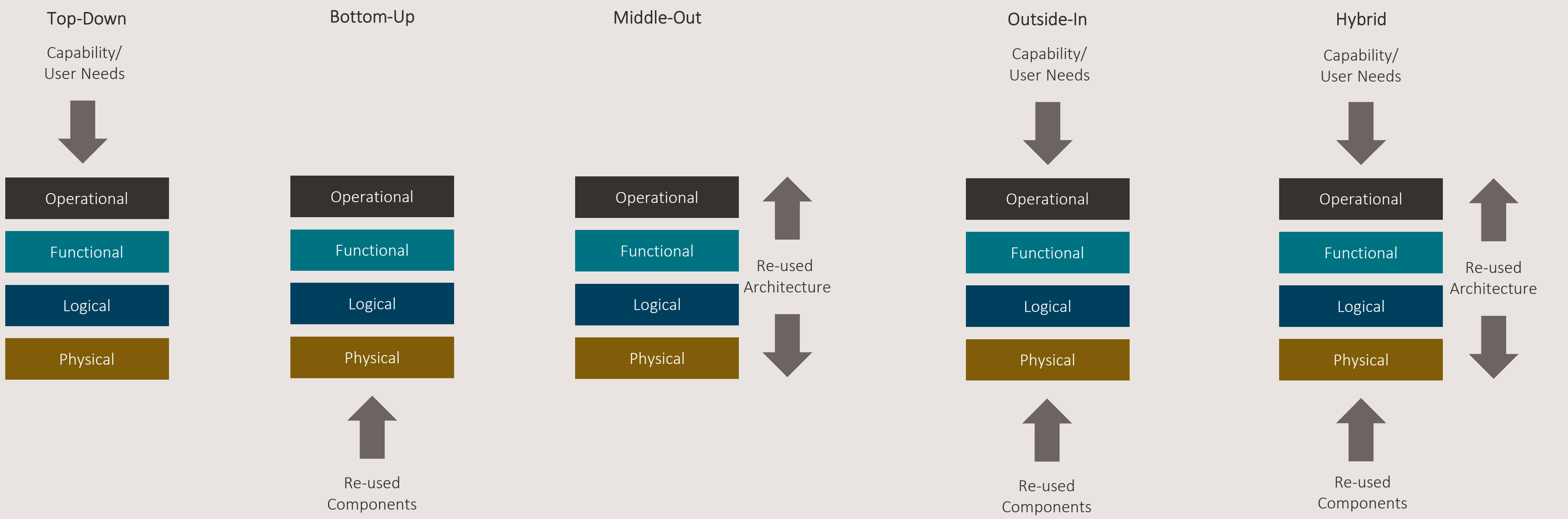
Tactics for solving complex systems problems



M. Wilkinson, "A Systems Journey: From Theory to Practice and Back Again, Keynote Address, INCOSE Conference on Systems Engineering Research (CSER), 2022.

Realistic large scale systems methods could be based on concurrent engineering and iterative model 'synchronisation'

Historical perspective: a new generation of formalism is needed

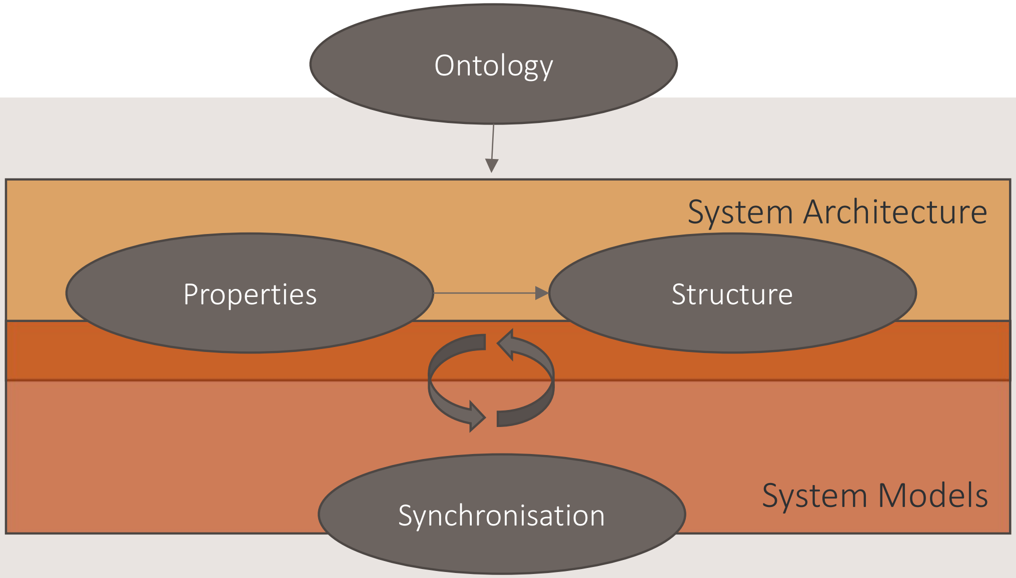
- Early attempts to formalise systems and software engineering were found to be impractical except for application by specialists
  - Surviving approaches include the Tarski Model Theory and Graphical Predicate Calculus standardised in ISO/IEC 24707
  - These are mathematical formalisms

- Graphical object oriented languages (UML, SysML) have since become predominant
  - SysML 2.0 is built on a more formal foundational language (KerML)
  - Facilitates constraint modelling and mathematical computation

- Opportunity now exists to revisit formality, building on two decades of modelling experience
  - Formalise the underlying concepts
  - Apply within a joint cognitive paradigm

Possible response

- A rigorously founded framework based on mathematics and incorporating
  - Ontology
  - Properties
  - Structure
  - Synchronisation
- OMG tools incorporating the above framework



"Ontology" is the definition of acknowledged concepts, their properties and relations

"Architecture" is structural type with compatible properties (Dickerson et al)

"Model" is (relational) structure for which interpretation of a sentence in the predicate calculus is true (Tarski)

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