A Conceptual Model of Systems Engineering

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MOTIVATION

Enable integration between system model and domain-specific models

- Currently we have difficulty integrating domain-specific models: Point integrations
- Bridge across vocabularies and viewpoints
- Conceptual basis for viewpoint generation & reconciliation

Provide semantic basis for system modelling

- Currently models have semantics only for the representation
- Need semantic model of how the model fits together to describe system and its behaviour
- Content needed for reasoning

Theoretical foundations for systems engineering

- Currently viewed as empirical discipline
- Explicate conceptual foundations underlying current practice
- Enable reasoning about practice

Linking Systems science and systems engineering

- Currently each has its own worldview
- Systems science is clearly the foundation for engineering, but the relationship needs to be explicated

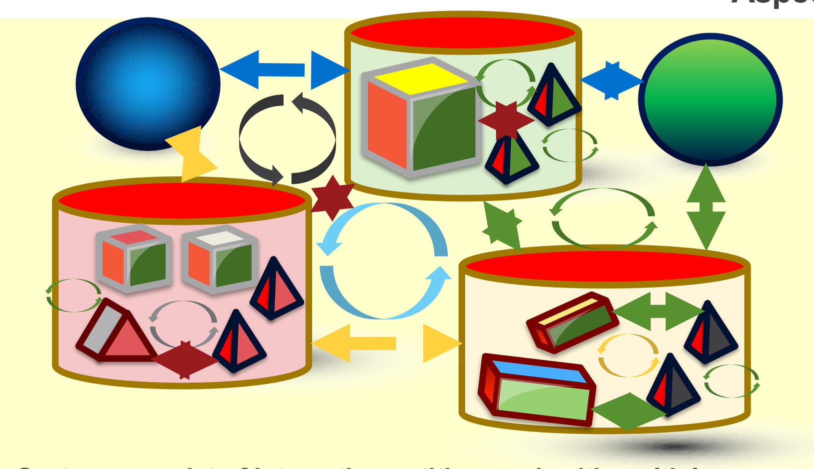
Key insight

Systems and software engineering depend on knowledge in other domains. Understanding how knowledge domains come together in systems is central to building conceptual foundations for systems engineering.
→ Need a theoretical model of how knowledge domains fit together in systems

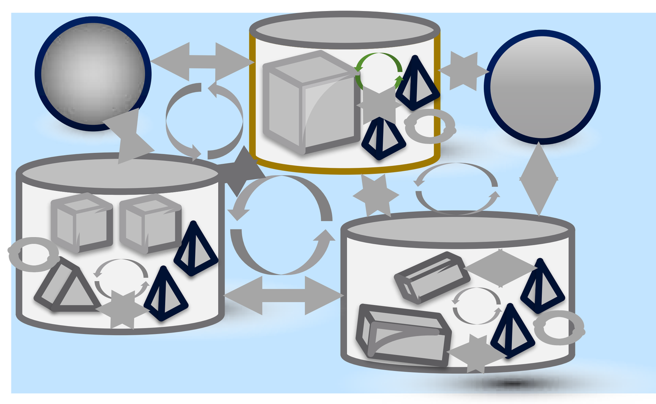
WHOLES & ASPECTS

Whole: Assemblage or collection of parts regarded as a single entity. Entities can be modelled as wholes by capturing context assumptions in the form of **context roles** with **role profiles**

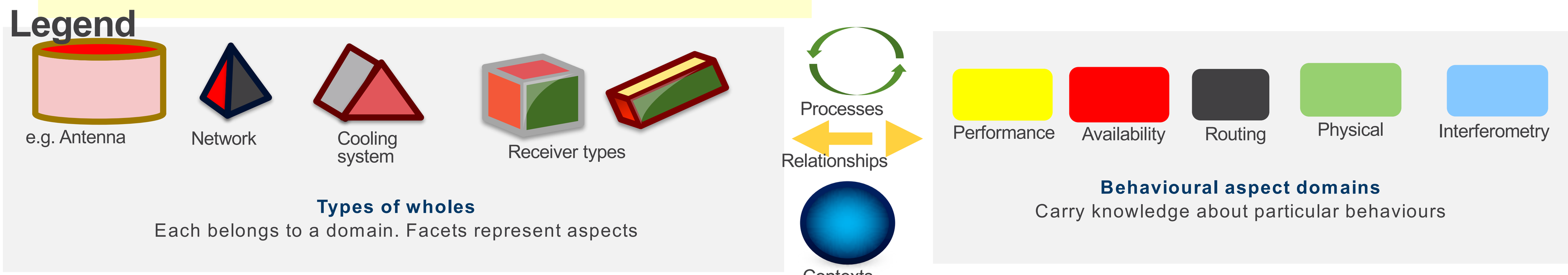
Aspect: set of properties or characteristics of interest.



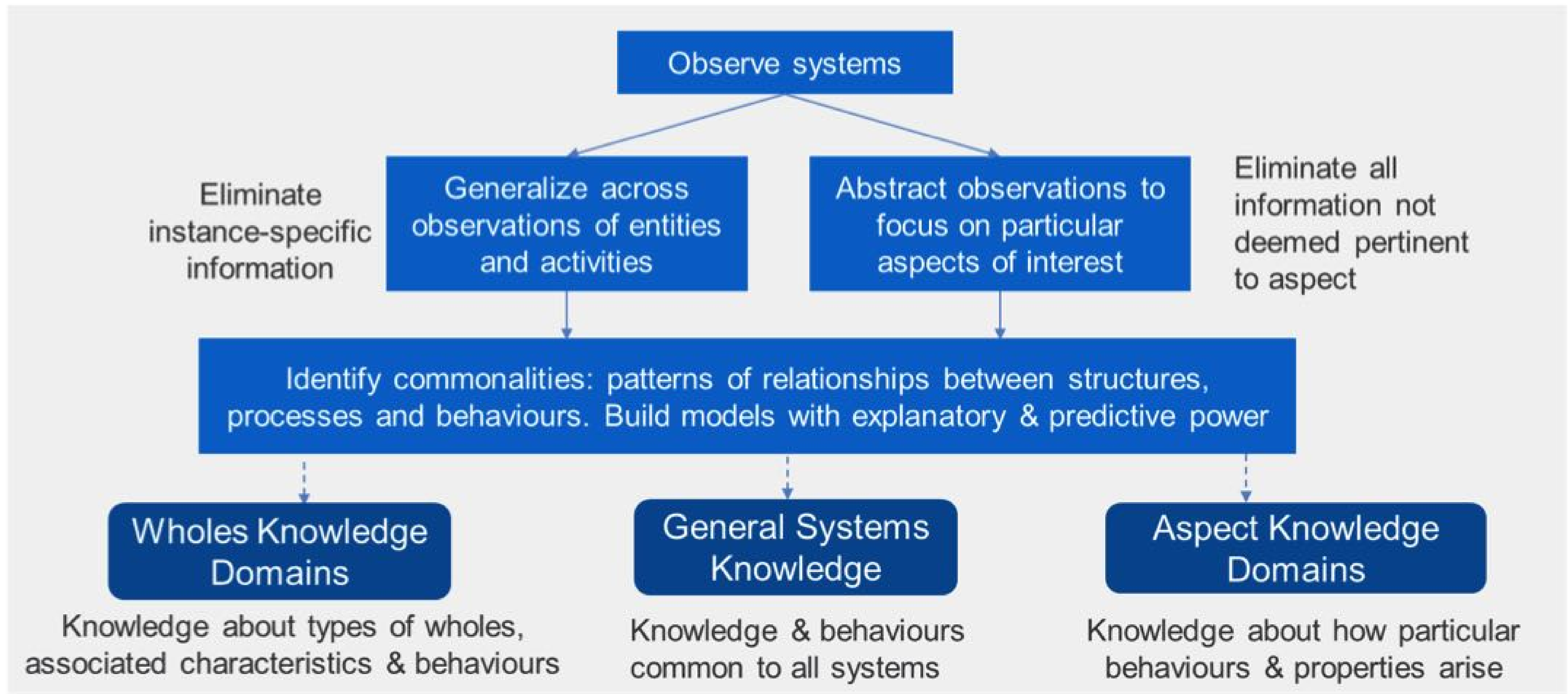
Systems consist of interacting entities, each with multiple concerns that can be grouped into aspects e.g. availability.



Modelling this purely in terms of systems concepts (entities, relationships, properties) is like reducing it to 2-D B&W (domain & aspect semantics abstracted out).



NATURE OF KNOWLEDGE CREATION

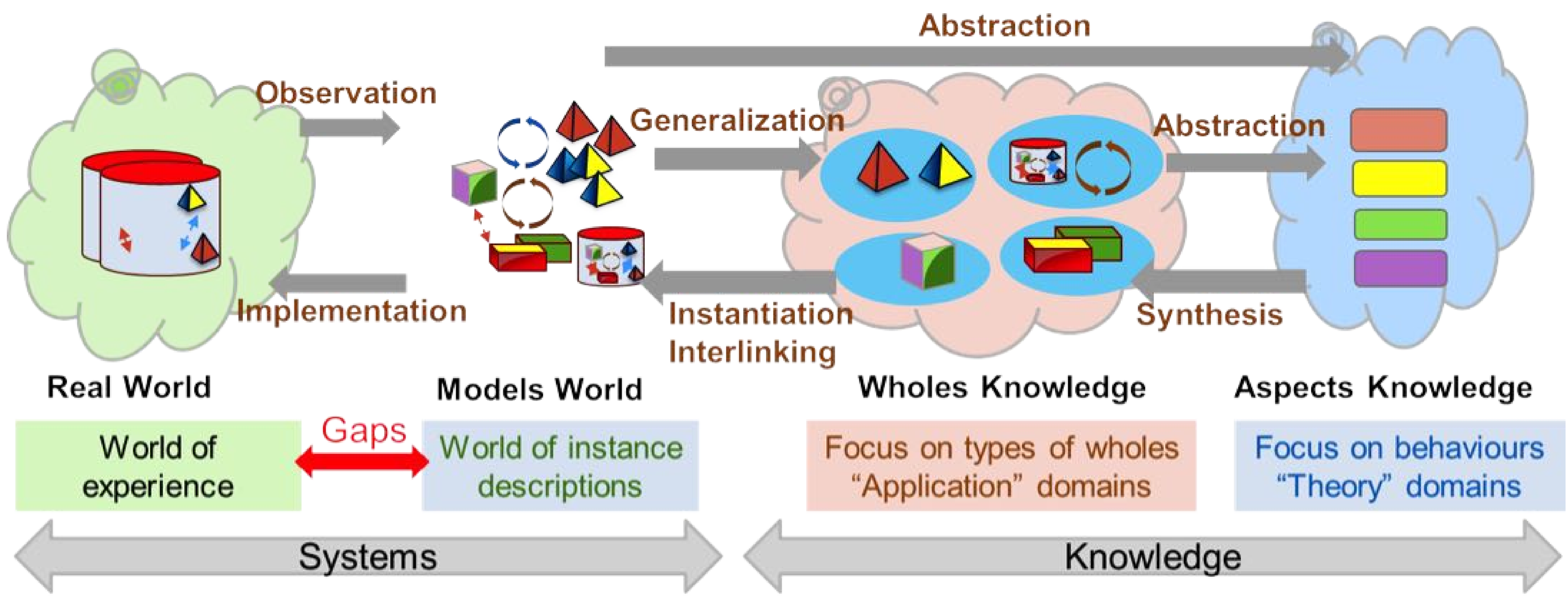


Systems knowledge includes all knowledge that relates to systems and causal understanding of their behavior: science knowledge, engineering knowledge, People systems knowledge: Education, sociology, management, banking…

Systems knowledge identifies patterns of relationships between structures, processes and behaviours that hold across observations of systems

Systems axiom: **Behaviours arise from processes operating over structures in particular contexts**

FOUR WORLDS MODEL: RELATING SYSTEMS & KNOWLEDGE



Wholes Knowledge Domains

- Radiotelescopes
- Network routers
- Signal processing systems
- Banks
- Educational institutions
- Cell biology
- Geography

Aspect Knowledge Domains

- Interferometry
- Network routing
- Signal processing
- Banking
- Developmental theory
- Mechanics
- Cartography

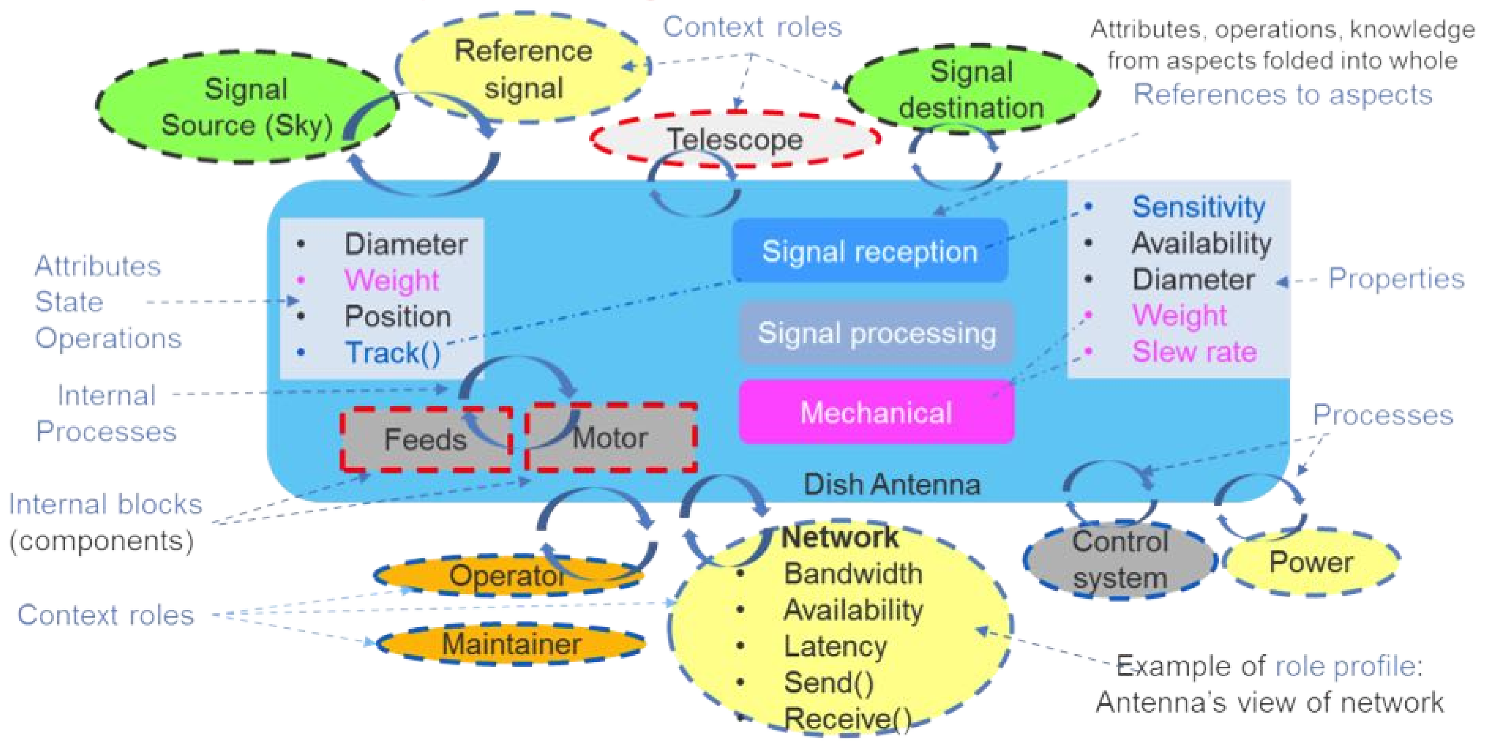
Wholes knowledge is about types of wholes ("common nouns")

Aspects knowledge is about how particular behaviours arise (fundamental causal knowledge) or focusing on specific commonalities

Irrespective of which entity gives rise to that behavior or commonalities

THE NATURE OF KNOWLEDGE ABOUT WHOLES

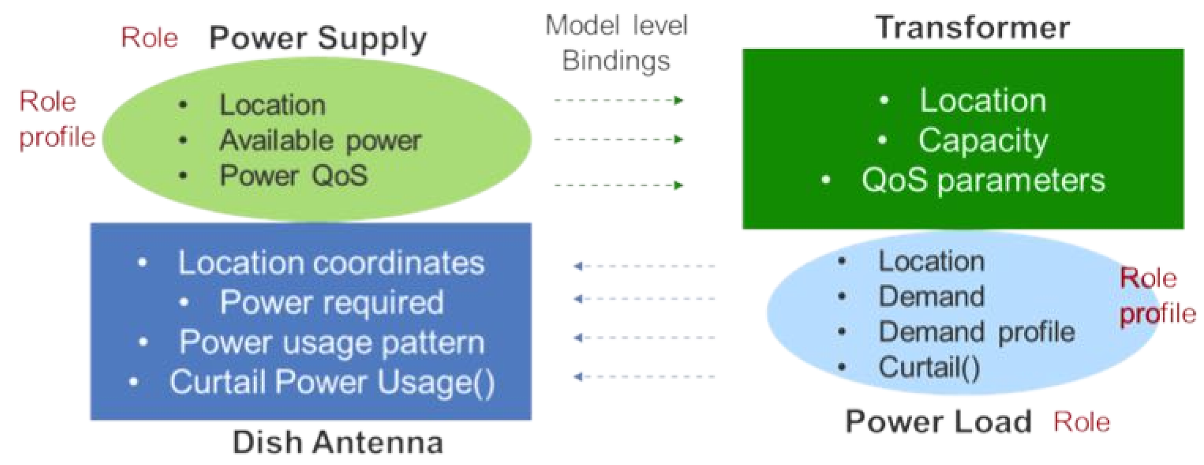
Example: Knowledge about dish antennas



Key idea: Model of whole should include its assumptions about its environment in the form of context roles & role profiles

This approach to modelling blocks is modular & internally complete w.r.t. knowledge & behavioural reasoning

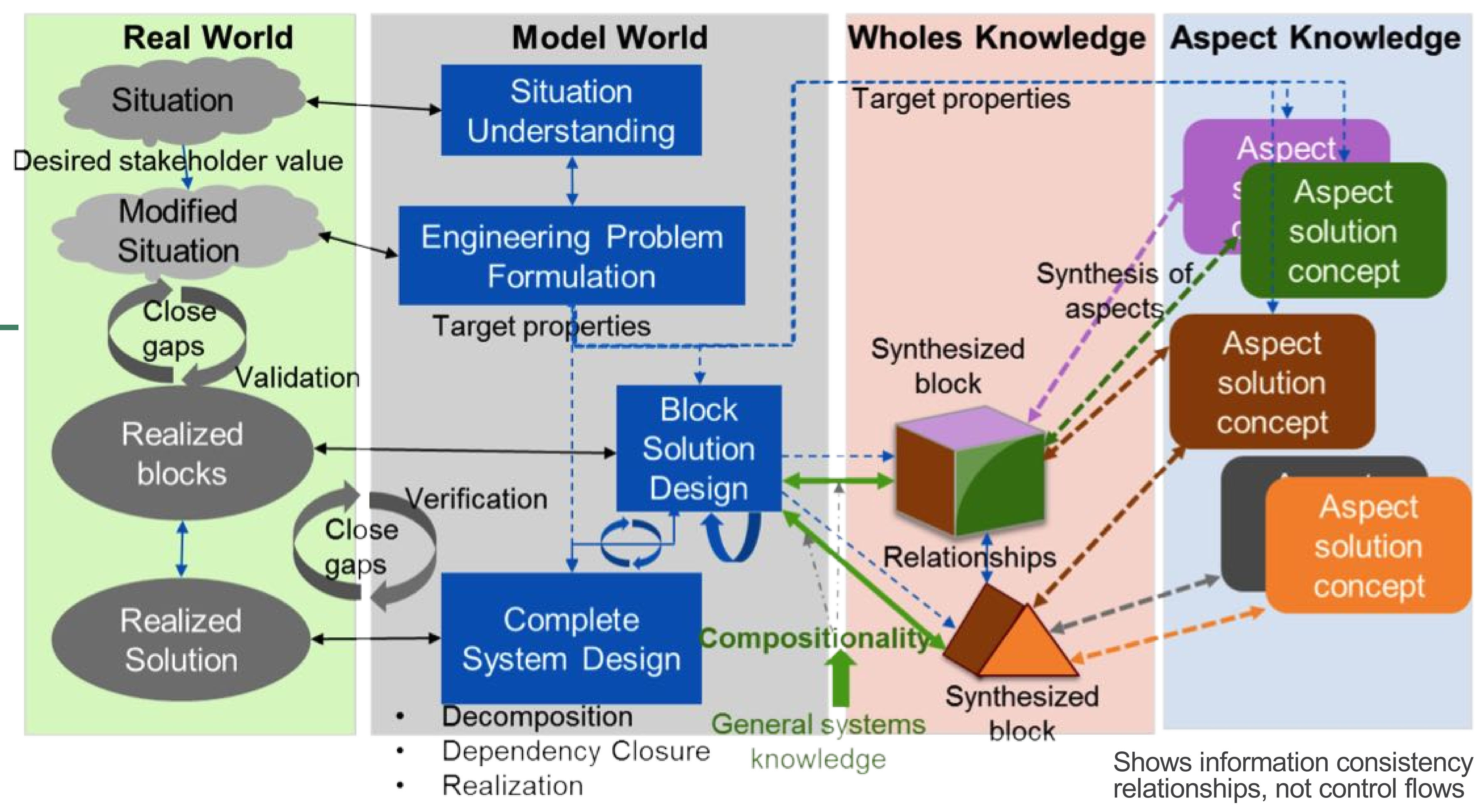
BRIDGING ACROSS DOMAINS: VIEW MAPPINGS



Each whole has associated context roles along various dimensions: behaviour, resource dependencies, life cycle, structural, technology realization, value. Each of these roles should be bound to other wholes in the system or context.

When wholes are bound to each other, each must match the role profile expected by the other (we need to rework the model of the whole until this holds). View mappings capture the resulting relationships among the wholes, and the associated knowledge domains.

A CONCEPTUAL MODEL OF SYSTEMS ENGINEERING



Compositionality Concerns

- **Basic compositionality:** Consistent synthesis of aspects
- **Spatial & temporal concurrency:** Interleaving of multiple streams of activity
- **Multi-dimensionality:** Interplay among dimensions – behaviour, dependencies, life cycle, business
- **Variety:** Scenarios corresponding to combinations of inputs (including variety in dependencies)
- **Unintended behaviour:** Spontaneous processes, undesired inputs / influences / outputs / outcomes
- **Dynamics:** Short-term dynamics (networks of processes), long-term dynamics (structural changes)

SUMMARY

- Systems knowledge is based on the systems axiom: behaviors arise from processes operating over structures, in particular contexts
  - Systems knowledge is at the heart of science, engineering & people systems disciplines
  - We can define an upper ontology based on systems concepts, to facilitate bridging across knowledge domains for systems engineering purposes
- Distinction between wholes knowledge domains and aspect knowledge domains
  - Wholes knowledge is not only about internals, but also context roles & associated assumptions
  - Wholes build on aspect domains, and are complete with respect to prospects reasoning
  - View mappings bridge across domain ontological models in the context of a particular system
  - Wholes are multi-dimensional: include behavioural, dependency, life cycle, value relationships. Modelling systems as networks of wholes enables integrated modelling of complex systems.
- Four worlds model of the relationship between knowledge, systems and engineering
  - First principles model of systems engineering, maps well to current practice
  - Systems science concepts indicate how systems engineering involves combining patterns from different knowledge domains to form a systems solution
    - And the need to close gaps between model (knowledge) and practice

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INCOSE Systems Science Working Group
SE Conceptual Model project

Participation welcome!