Cross-Scale Resilience:
Relating Systems of Systems to Individual System Analysis and Back Again

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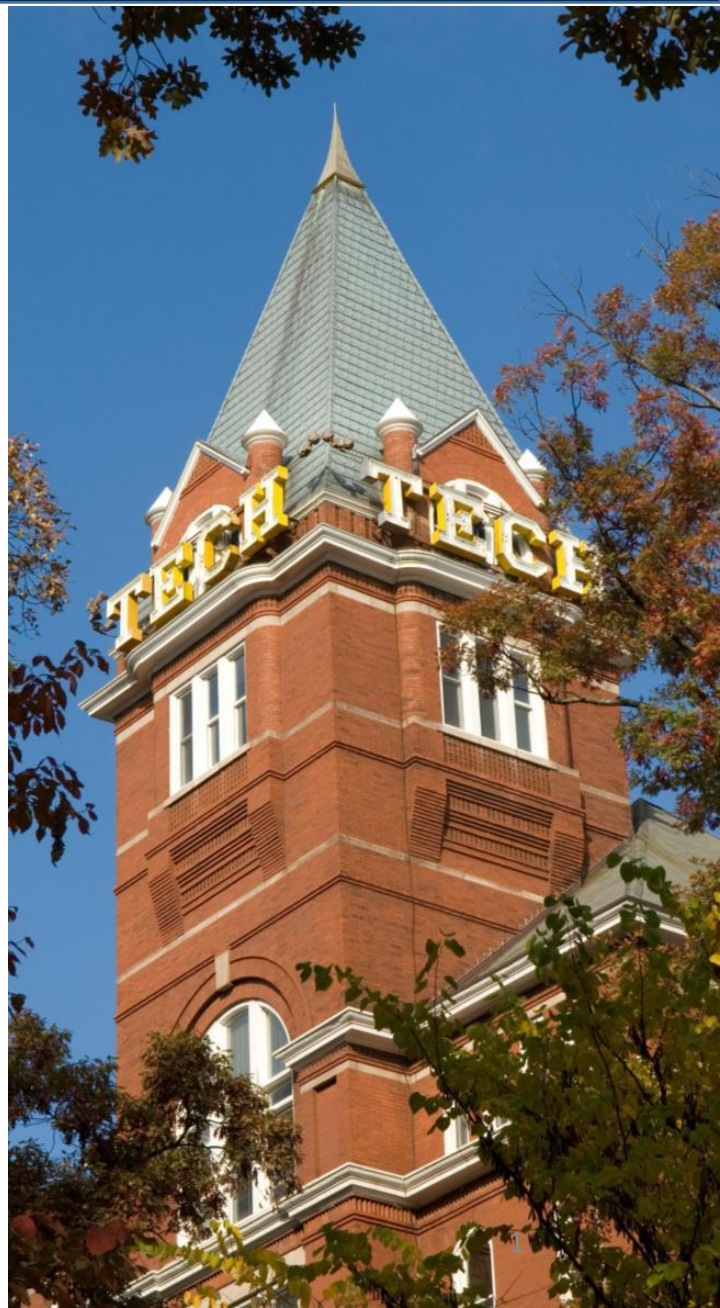

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bridging system of systems and
constituent system engineering and analysis

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From System of Systems Engineering…

To support the higher needs of a System of Systems, constituent systems should be developed to be:

- Interoperable
- Reconfigurable
- Adaptable to meet current and future operational needs

True and Necessary …

but not sufficient to create and understand SoS operational resilience.

… To Engineering a System of Systems

A different perspective.

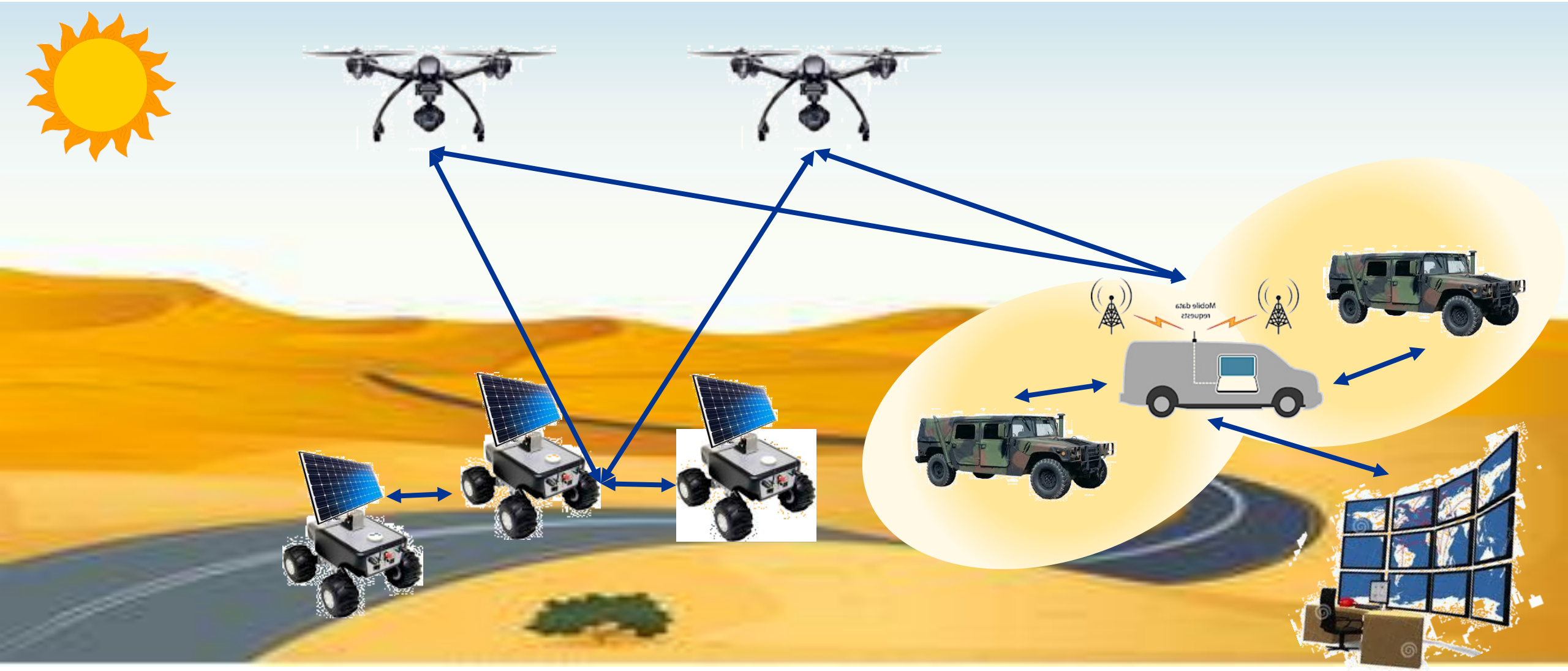
- Cross-scale understanding and evaluation of operational capability

Under what conditions will my SoS fail?

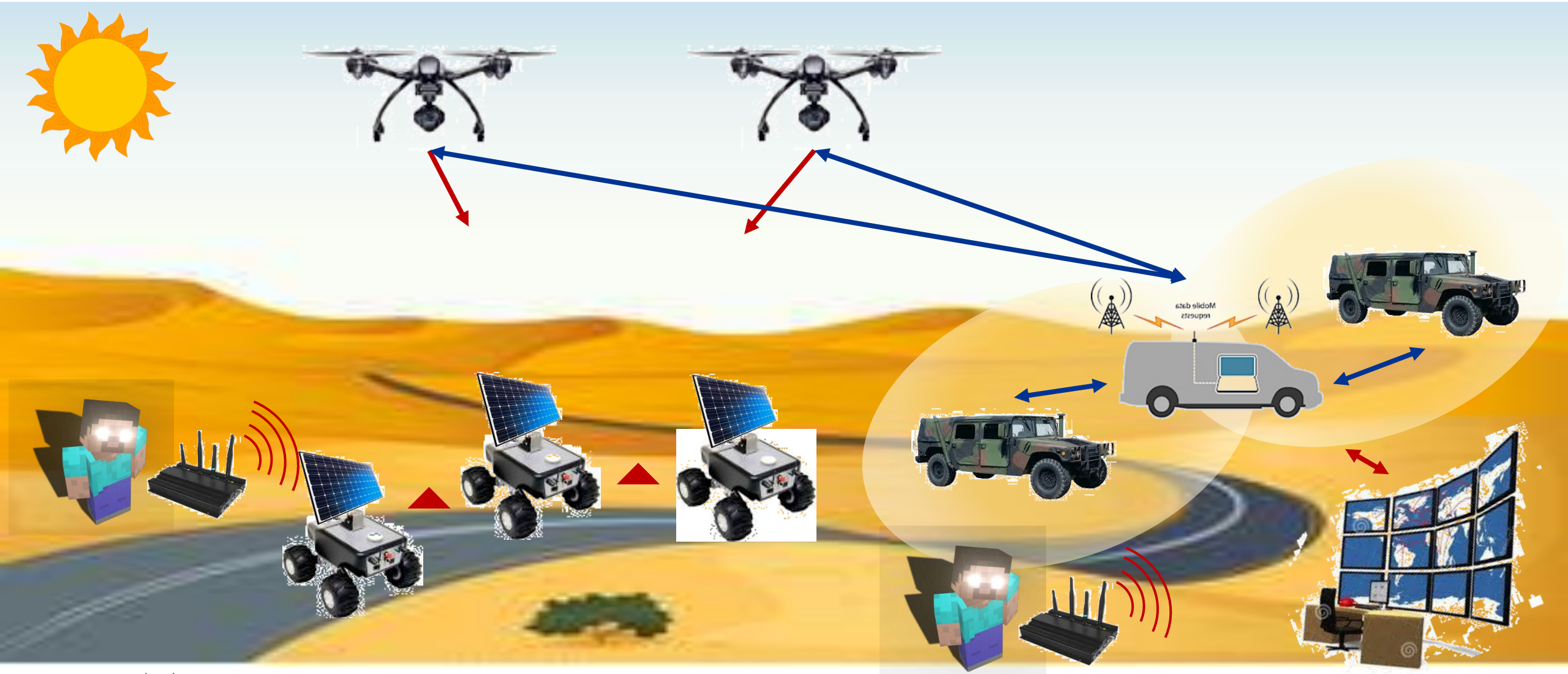
Scale = level of granularity

Cross-scale analyses use purposefully look for interactions across multiple scales to enhance overall fidelity and better inform decisions at each scale

Is my system resilient?



What about now?



What about now?

Resilience is Inherent and Contextual

Resilience is an inherent system quality

created through design choices

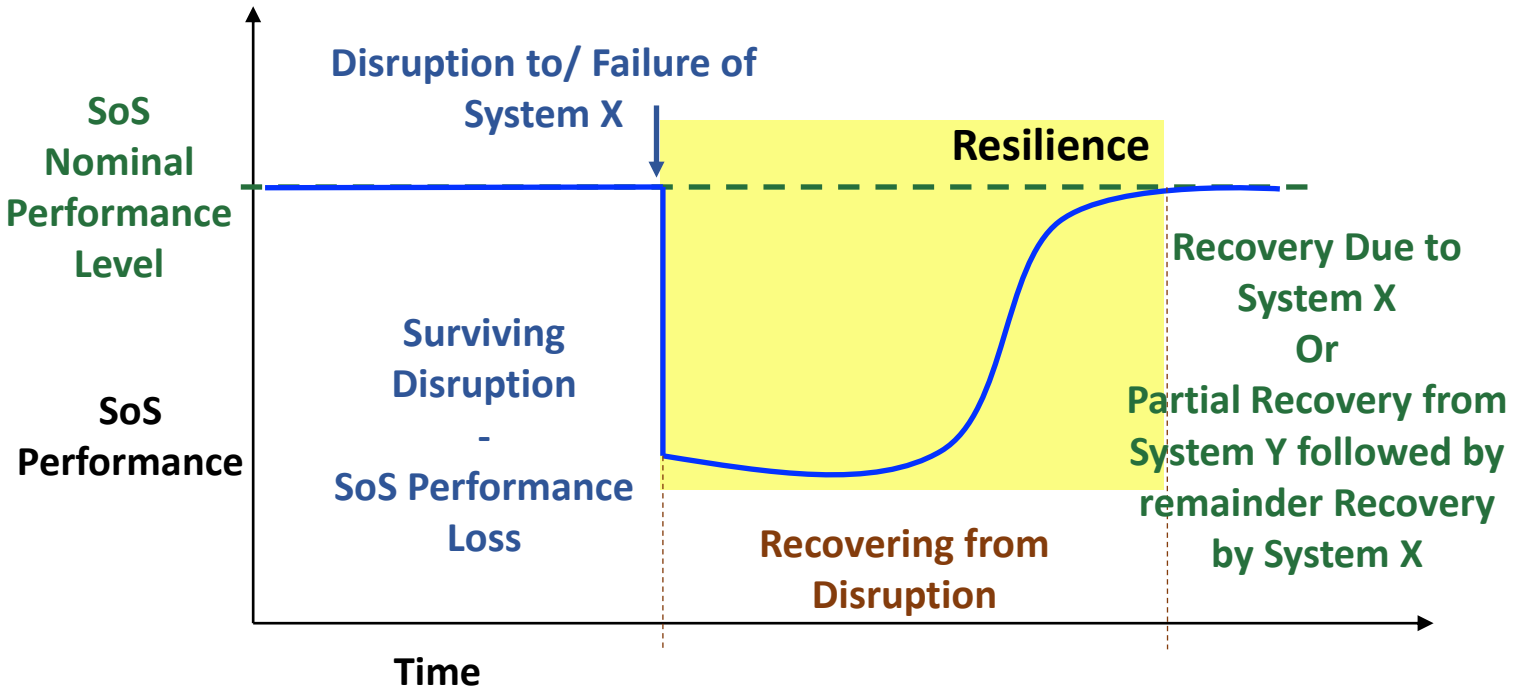
that enable a system to maintain its performance objectives in the face of diverse operational challenges,

in either a preparative or recovery sense,

within acceptable time and cost parameters.

Like Complexity…
Resilience is dynamic and emergent.

Traditional SoS Approaches



SoS evaluations of resilience:

1. Disruptions are function of individual system reliability (frequently abstract). Propagate these measures through SoS network representation.

   Requires many recovery assumptions.

2. Graph theoretic measures

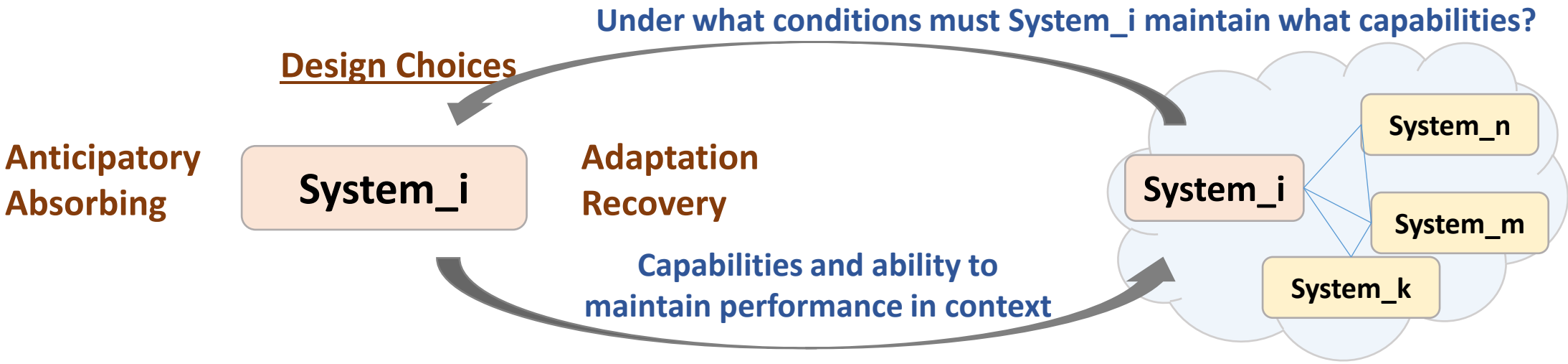
   Blends concepts of structure with very low-level concepts of function.

Limits of SoS M&S.

Interdependence does not equate to interaction.

Must understand performance impacts across scales

We can identify design principles that – if well integrated and supported – support resilience of systems



But how can we use cross-scale resilience concepts to better support

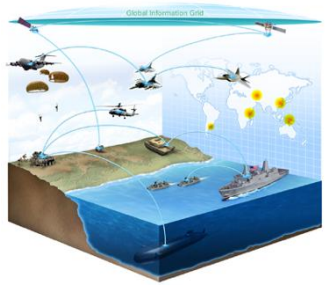
Constituent and SoS design and evaluation

and thereby co-evolve more operationally relevant capabilities and mutually derived requirements?

What use are requirements?

Operational Need

Capability Gap



Operational Requirements

System Requirements

Bridge from operational requirements to engineering interpretation

Not just a dirty word…

Requirements help define the problem.

- What Stakeholders need
- Consequently – what they value
- Basis for tradespace generation
- Foundation for objective hierarchy

Link AoA to Operational Needs.

Aim for a unification guided by decision theory

Unify executable model-based systems engineering (MBSE), requirements analysis, and decision theory

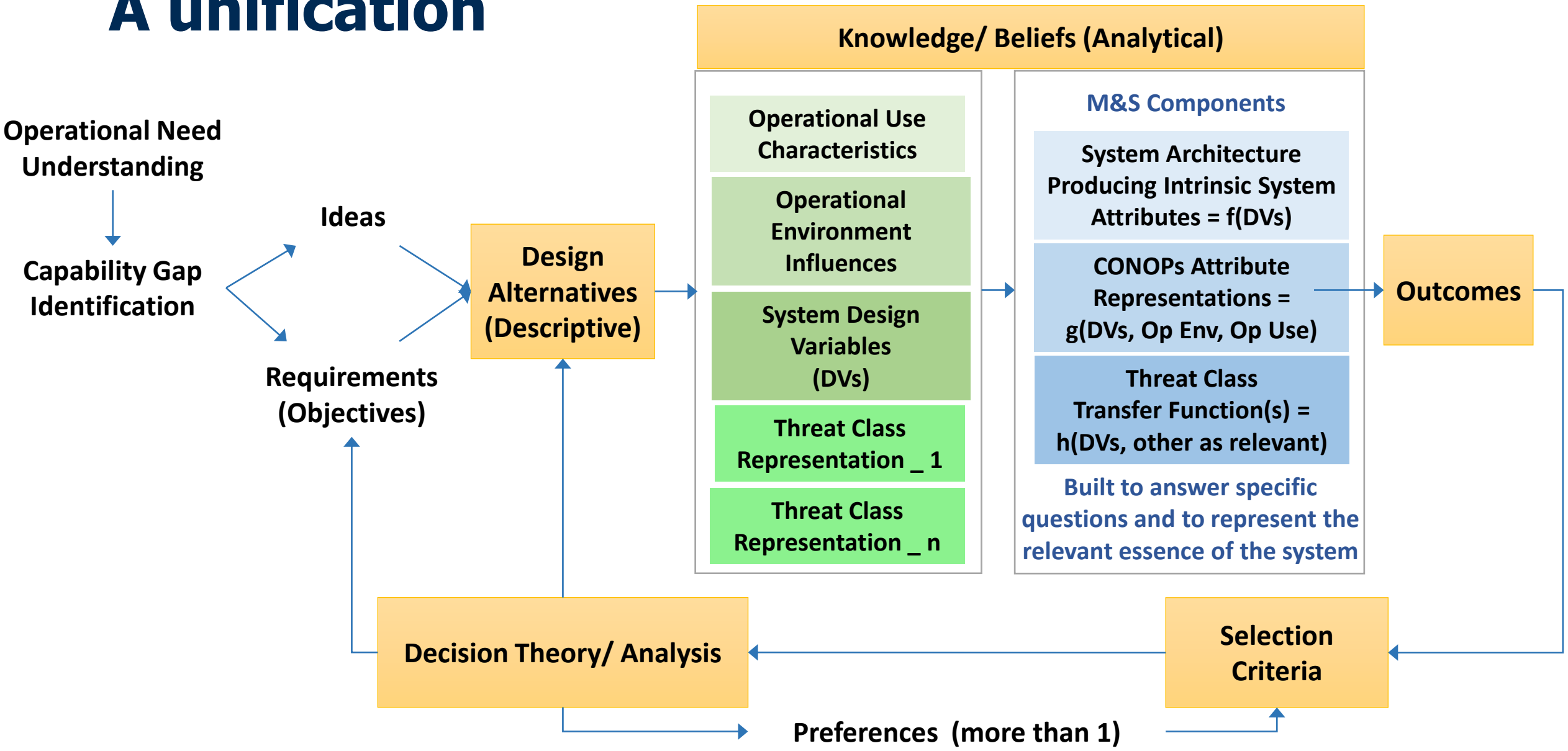
through an operational lens enabled by M&S

to provide the basis for cross-scale convergence.

Not a traditional waterfall approach but an iterative, cyclic ebb and flow between:

- Mission engineering needs at the SoS level
- Individual system evaluation needs
- Generation of new knowledge via data-driven analyses

A unification



Needs

- **End-to-end capability founded on open framework**
  - Enable SEs to specify, orchestrate, generate, and explore across these dimensions
  - Much of the metadata will be contextual and should be defined in structures that enable it to be carried through and executed upon dynamically

- **New techniques to intelligently create data needed to answer these questions**
  - Multi-contextual concepts require SEs to go beyond Pareto Frontiers
  - Exploit the duality of physics and value dimensions

Specify

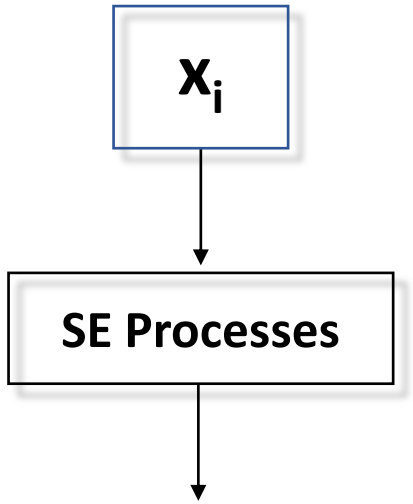
Design variables, capabilities, requirements, value hierarchies, models, data tables, etc.

How

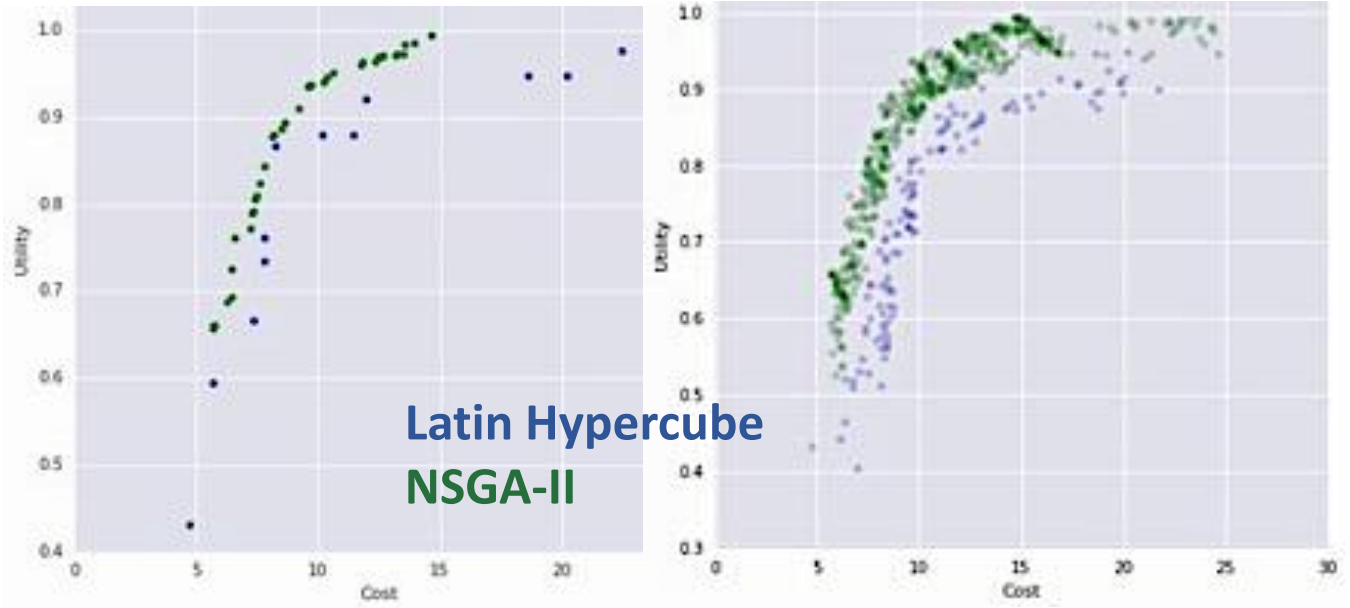
As data structures that enable them to be executed upon and carried through from the defining stage to the exploratory stage for dynamic analyses

Extending traditional views to support multi-contextual understanding

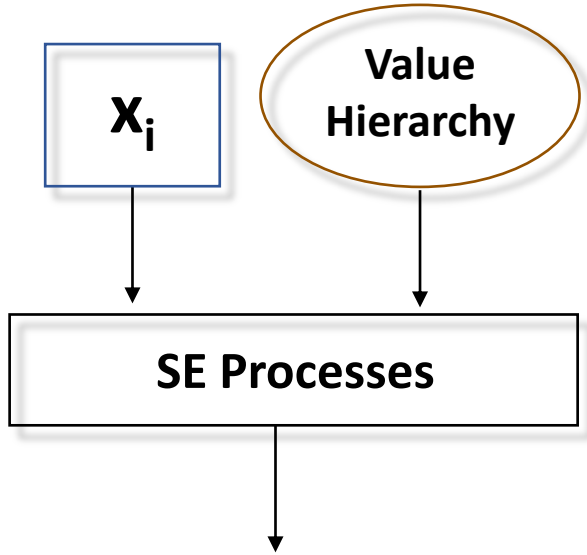
Traditional



"Best" Designs



Adaptive to Needs of Analysis



Answers to SE questions that promote more insightful Decision Analysis

New paradigms and new perspectives

The penultimate goal of the materiel development process is to produce a robust, adaptable, flexible, and affordable capability (or, in the case of an SoS or capability portfolio, a capability set) that is best suited across multiple, plausible, and yet uncertain futures.

- A 'red team' perspective bridges the operational and engineering viewpoints
- Cross-scale guidance regarding levels of abstraction, relevant contexts of evaluation, and impact of value hierarchies at each stage of the design process
- Offers foundation to help harmonize V&V activities through co-evolution of requirements and value models

Does this solve everything? No. But…

- Adds more operational relevance to materiel development
  - Enables deeper understanding of the complex, cross-scale relationships
  - Promotes SoS and mission-relevant exploration of the tradeoffs at the system level
- Initial effort to realize this paradigm may be greater – participatory development!
  - Recoup through understanding of M&S ecosystem and associated constructs that we can reuse and apply at different stages of the process
  - SoS may still evolve but improve evaluation through reuse of contextual outputs from constituent analyses
- Decision theory guides and focuses throughout process
  - Helps identify where data may be needed from other sources ranging from an ecosystem of integrated testbeds, historical projection, training efforts, performance studies, T&E data, etc.

Acknowledgements

"one-size-fits-all definitions … present hindrances to effective interdisciplinary collaboration"

~ Boehm & Kukreja (2015)

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