



**Carnegie Mellon
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System of Systems Integration Cost Driver Research

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Overview

Research Effort Background

- Collaborators
- Schedule

Initial Model and Hypotheses

- Definitions
- Implications
- Solutions

Next Steps and Opportunities for Participation



Research Background

Collaboration:

- OSD PA&E multi-year funding
- SEI and UNC primary researchers
- DAU and others affiliated

Schedule

Year 1: Literature review, case studies and interviews to identify potential diagnostic factors

Year 2: Initial quantitative model and revised diagnostic factors

Year 3: Longitudinal validation of model and diagnostic factors



Our Approach

Starting with a view of the end in mind

- Understanding the characteristics and relationships among the integrated and interoperating systems and organizations
- Leads us to study the implications of interorganizational relationships and complexity for the integration effort
- First to identify diagnostic and risk factors
- Later to identify mitigation tasks
- Finally to develop cost and schedule estimation approaches for the mitigation tasks



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Definitions¹

Complex Systems

- Used to address unstructured problems
- Self regulated and adaptive
- Permeable boundaries that are difficult to control
- Interdisciplinary- requires the reconciliation of multiple disciplines
- High degree of uncertainty regarding system performance – no one solution can be proved to be the best
- Emergent – small perturbations can result in large scale changes, nonlinear
- Multiple recursive feedback loops
- Multidimensional



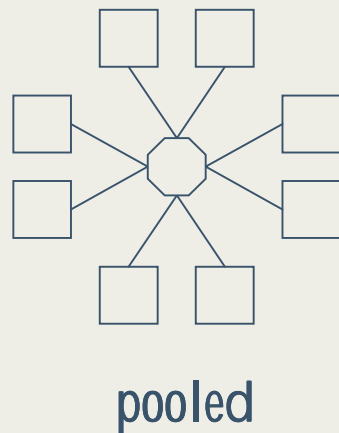
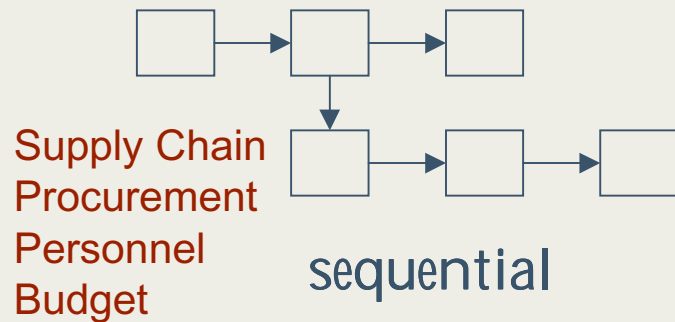
Definitions²

System of Systems

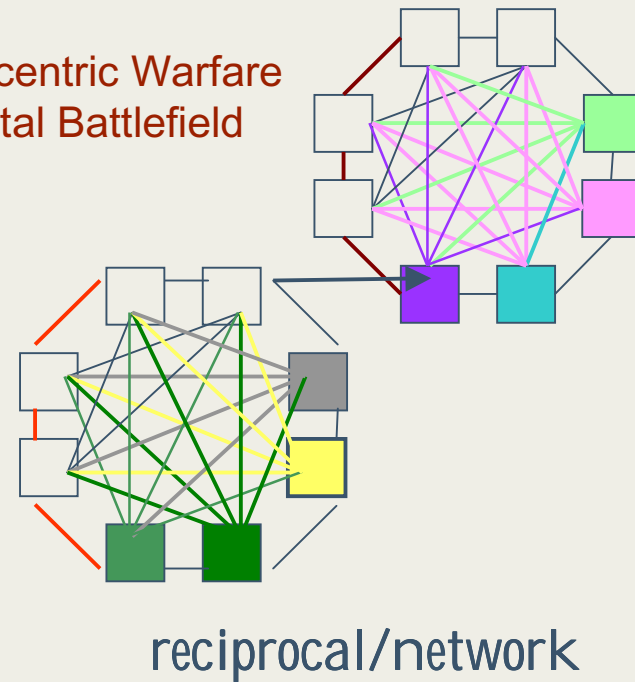
- Integration of multiple systems to achieve desired capabilities or performance level not realized by the constituent systems such as reduce transaction costs, adapt to new situations, and exchange resources (e.g., information)
- An approach to achieving JOINT CAPABILITIES
- Address missions, goals, and objectives of previously independent stakeholders
- SoS tend to establish 3 types of interoperational relationships among the systems : sequential, pooled, and reciprocal



Interoperational Relationships

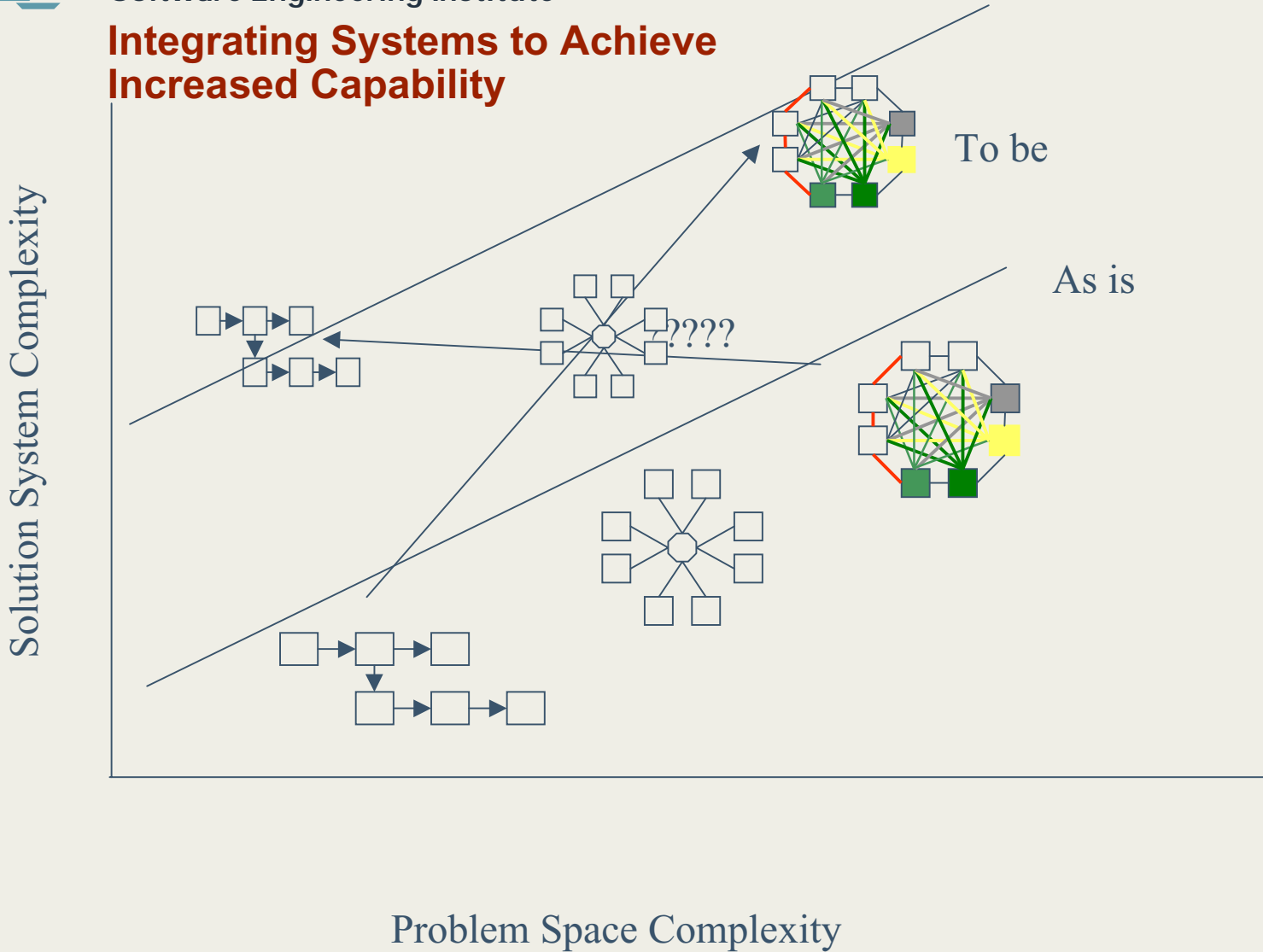


Netcentric Warfare
Digital Battlefield





Integrating Systems to Achieve Increased Capability





Implications of Complexity

Self regulation implies autonomy

Adaptive implies local prioritization

Interdependency implies uncertainty and risk

Interdisciplinary implies multiple cultures, terminologies,
and values

Permeability implies subject to external forces both
positive and negative

Emergence implies inability to predict behavior and
system needs



System of Systems – What's Different?

Tensions among stakeholders arising from:

- Diminished Autonomy
- Increased Interdependency
- Increased Permeability
- Increased Cultural/Organizational Diversity
- Reduced Local Adaptation in favor of Global Adaptation

Traditional cost estimation approaches have not considered the implications of organization complexity on development/integration costs.



Achieving Desired Capability

SoS View

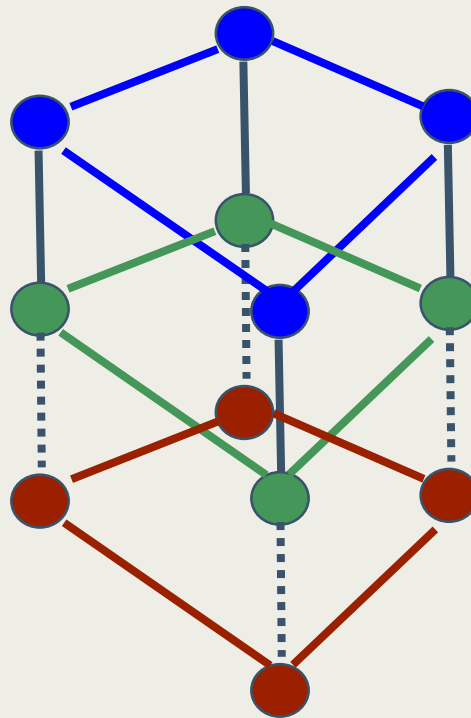
System level
interoperability

requires

Standardized
Business Rules

and coordinated

Business Practices



Single System View

System level

implements

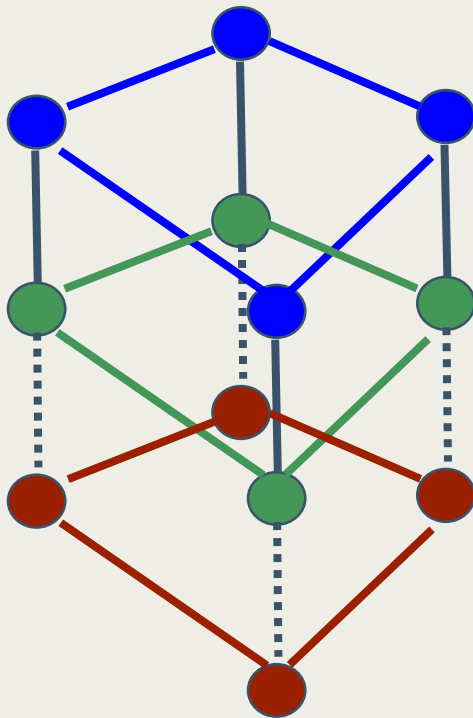
Explicit Business Rules

represent

Actual Business Practices



Manifestations in SoS Integration¹



Technical System Level Issues:

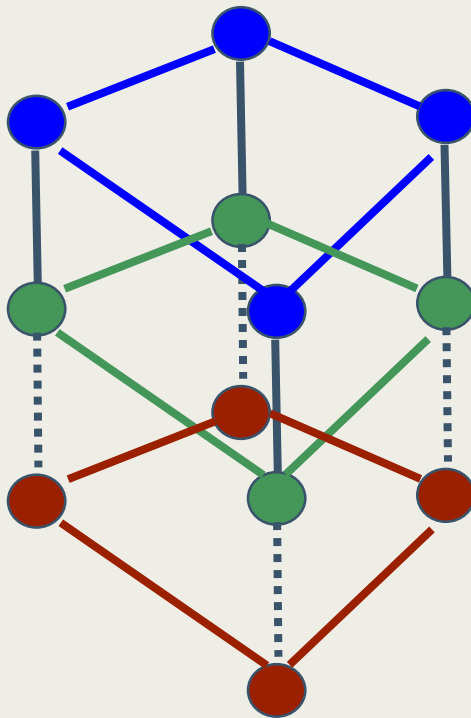
- Interface
- Semantic
- Data
- Timing/performance

SoS Mission Issues:

- Conflicting priorities
- Differing values
- Lack of common terminology
- Lack of compatible business practices
- Implicit rules and expectations
- Overlapping responsibilities



Manifestations in SoS Integration²



SoS Mission Issues:

- Decision paralysis
- Stalemates
- Gaming
- Whitewashing
- Resource hogging
- Resource shifting
- Communication impediments
- Tragedy of commons/unfunded mandate
- Lack of clear and effective authority and accountability
- Scope creep



Implications for Cost and Schedule of SoS Integration

Cost and Schedule Risk increased by

- By definition SoS are complex
 - Migration from current/legacy to SoS involves many new challenges
- Sole focus on technical interoperability to the exclusions of explicit and implicit business rules and practices
- Lack of coordination and attention to reconciling organization mission, values, and motivations



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Potential Solutions to the Implications of SoS Complexity

Simplification and decomposition of system

- Must be done to match the complexity of the problem space

Coordination

- Aligning mission, values, and funding
- Clearly defined authority and responsibilities
- Common business rules, policies, standards
- Shared processes and communications
- Training

Making implicit practices known



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Next Steps/Opportunities for Collaboration

Experiences with SoS Integration and achieving
Interoperability

- Case Studies
- Interviews
- Focus Groups

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