A Model of Systems Engineering in a System of Systems Context

Conference on Systems Engineering Research
Redondo Beach, CA
4-5 April 2008

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Introduction

- Systems engineers are increasingly called upon to
  - Implement SE in networked environments
  - Evolve existing and new systems to meet changing user needs
- Challenge is to leverage SE processes developed and applied for SE of new systems
  - Individual systems are no longer considered as individual bounded entities and are evolved based on extant capabilities
  - Constituents in larger, more variable, ensembles of interdependent systems which interact based on end-to-end business processes and networked information exchange
- A new set of conditions for their SE processes calls for a new SE framework that reflects the
  - Dynamics and uncertainty of SoS
  - Added complexity of operating in an SoS environment

DoD System of Systems SE Guide

SoS Guide Version 1.0

- Effort led by the Office of the Secretary of Defense
- Collaborative approach with DoD, Industry, Academia
- Purpose
  - 6 month effort addressing areas of agreement across the community
  - Focus on technical aspects of SE applicable across SoS management constructs
  - Vehicle to *capture* and *debate* current SoS experience
- Audience
  - SoS and Program Managers and Lead/Chief Engineers

Pilot

- Pilot effort 'Boots on the Ground' basis for
  - Structured reviews with practitioners
  - Refine early draft guide content, identify areas for future study
  - Update findings and release Version 1.0

Definitions

System: *A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole.* (JP 1-02 & JP 3-0)

SoS: *A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities* [DoD Defense Acquisition Guide, 2004].

Taxonomy of SoS

- Directed
  - SoS objectives, management, funding and authority; systems are subordinated to SoS
- Acknowledged
  - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
- Collaborative
  - No objectives, management, authority, responsibility, or funding at the SoS level; Systems voluntarily work together to address shared or common interest
- Virtual
  - Like collaborative, but systems don't know about each other

Active SoS SE Practitioners

Name	Acronym	Owner	Approach
Army Battle Command System	**ABCS**	Army	Acquisition Program
Air Operations Center	**AOC**	Air Force	Acquisition Program
Ballistic Missile Defense System	**BMDS**	Joint	Acquisition Program
USCG Command & Control Convergence	**C2 Convergence**	Coast Guard	Strategy
Common Aviation Command & Control System	**CAC2S**	Marine Corps	Acquisition Program
Distributed Common Ground Station	**DCGS-AF**	Air Force	Program Office
DoD Intelligence Information System	**DoDIIS**	Intel	DIA CIO Initiative
Future Combat Systems	**FCS**	Army	Program Office
Ground Combat Systems	**GCS**	Army	Program Executive Office PEO
Military Satellite Communications	**MILSATCOM**	Joint	AF Wing
Naval Integrated Fire Control – Counter Air	**NIFC-CA**	Navy	SE Integrator in PEO
National Security Agency	**NSA**	Intel	Agency
Naval Surface Warfare Center Dahlgren	**NSWC**	Navy	Warfare Center
Single Integrated Air Picture	**SIAP**	Joint	Acquisition Program
Space and Missile Systems Center	**SMC**	Air Force	SE Authority
Space Radar	**SR**	Joint	Acquisition Program
Theater Joint Tactical Networks	**TJTN**	Joint	PEO
Theater Medical Information Systems – Joint	**TMIP**	Joint	Acquisition Program

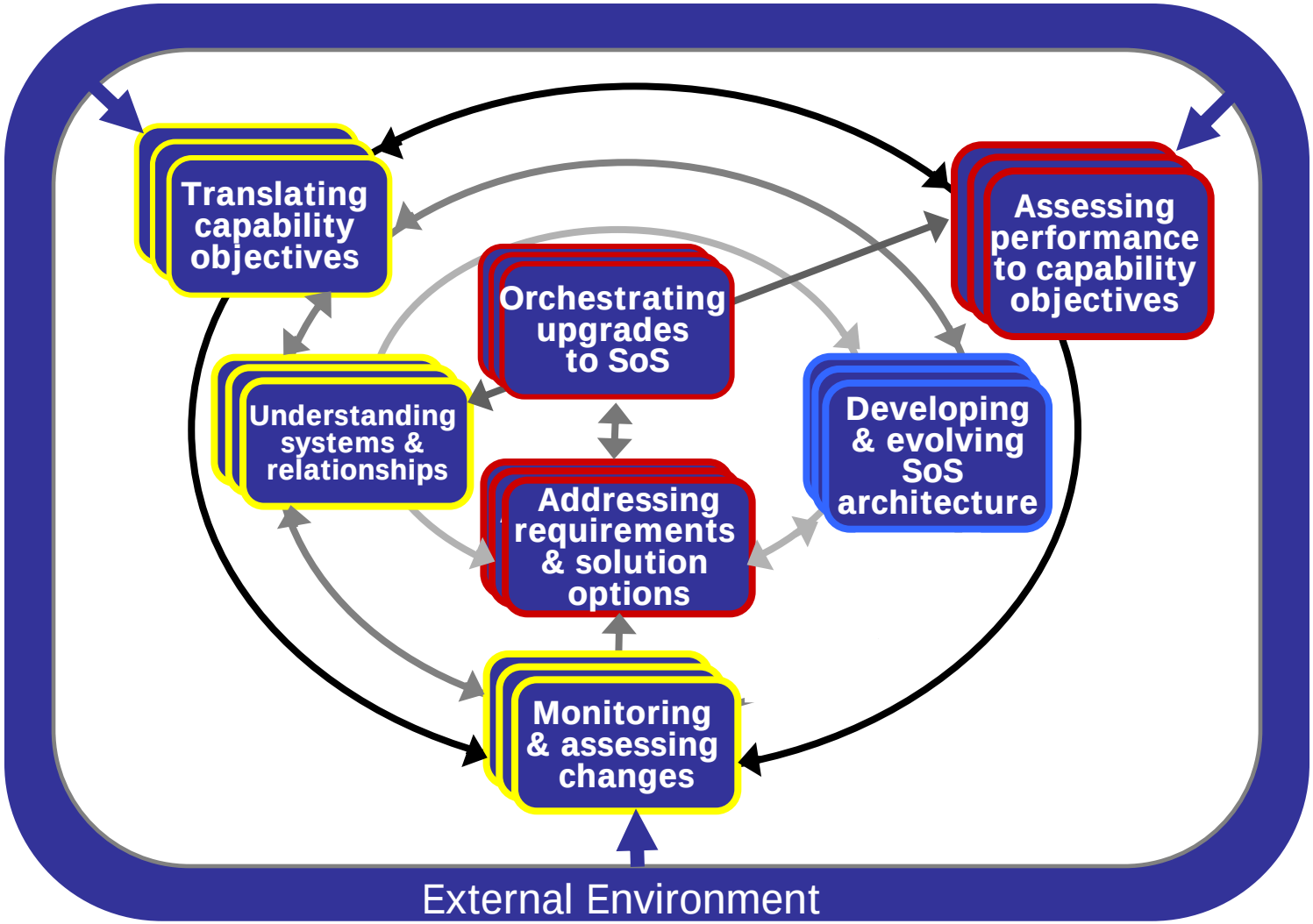
Provided a basis for understanding SoS in DoD Today

Focus on Acknowledged SoS

- Increased US DoD emphasis on war fighter capabilities
  - Typically require multiple systems to meet end-to-end capability needs
  - Approach has been to leverage current systems to meet new capability needs
- However, current systems are still needed for original use
  - And since most systems are developed and managed by the Military Services, responsibility for systems often differs from responsibility for capabilities or SoS
  - Consequently, there are increasing instances of acknowledged SoS in the US DoD
- Characterized by dual management, funding and technical authorities
  - Source of management issues which impact SE
- V1 of the guide provides an initial resource for SE teams working in this environment

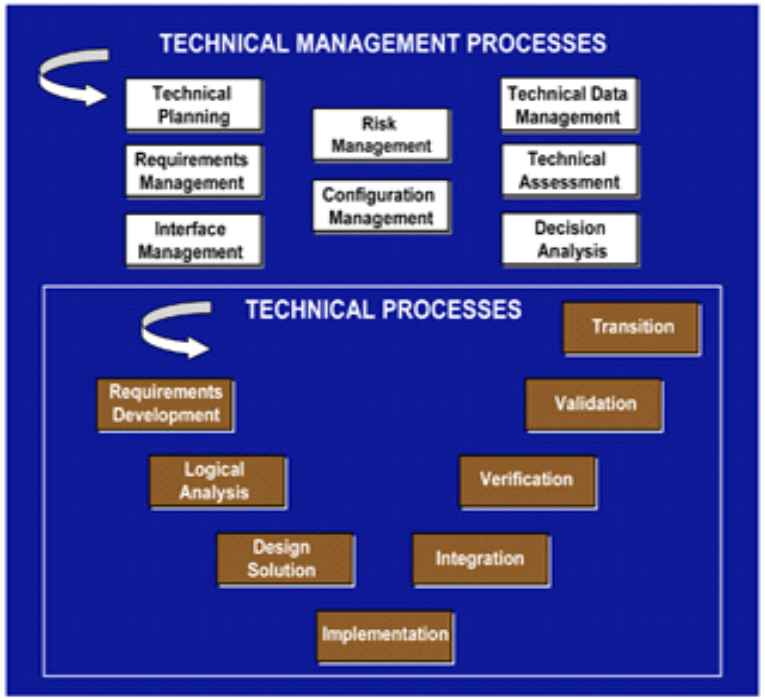
Acknowledged SoS growing in the US DoD
They have received little attention to date

SE Model for SoS Based on 7 Core Elements of SoS SE



SE Processes Support Core Elements

- DoD Defense Acquisition Guide presents 16 basic SE processes
- In an SoS, SE team adapts these processes to execute core SE elements
- Focus for SoS SE is on technical management since implementation is in systems



SoS SE Core Elements	Technical Processes								Technical Management Processes							
	Rqts Devel	Logical Analysis	Design Solution	Implement	Integrate	Verify	Validate	Transition	Decision Analysis	Tech Planning	Tech Assess	Rqts Mgt	Risk Mgt	Config Mgt	Data Mgt	Interface Mgt
Translating Capability Objectives	X											X		X	X	
Understanding Systems & Relationships		X							X				X		X	X
Assessing Performance to Capability Objectives		X					X		X		X		X		X	
Developing & Evolving an SoS Architecture	X	X	X						X	X		X	X	X	X	X
Monitoring and Assessing Changes									X				X		X	X
Address Requirements & Solution Options	X		X						X	X		X	X	X	X	X
Orchestrating Upgrades				X	X	X	X	X	X	X	X	X	X	X	X	X

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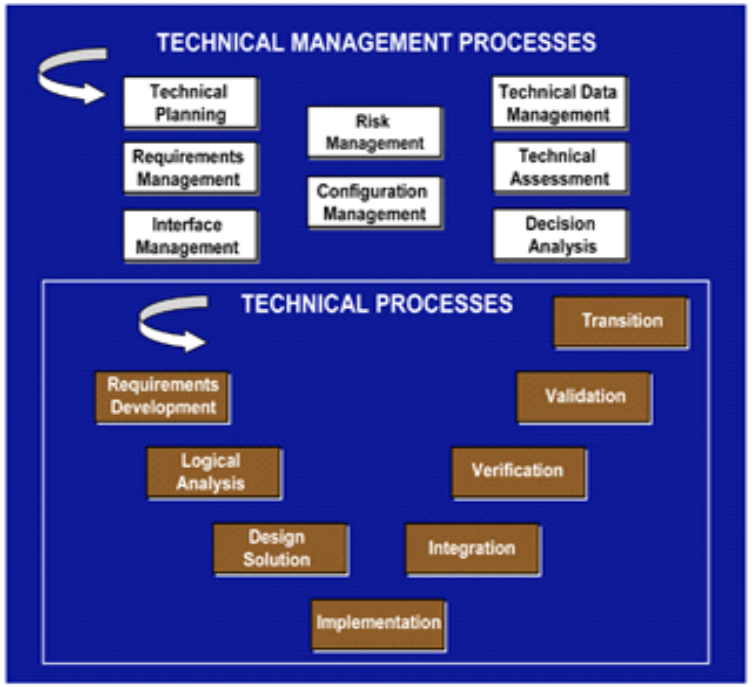

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	Rqts Devel	Logical Analysis	Design Solution	Implement	Integrate	Verify	Validate	Transition	Decision Analysis	Tech Planning	Tech Assess	Rqts Mgt	Risk Mgt	Config Mgt	Data Mgt	Interface Mgt
Translating capability objectives	X											X		X	X	
Understanding systems & relationships		X							X				X		X	X
Assessing performance To capability objectives		X					X		X		X		X		X	
Developing & evolving SoS architecture	X	X	X						X	X		X	X	X	X	X
Monitoring & assessing changes									X				X		X	X
Addressing requirements and solution options	X		X						X	X		X	X	X	X	X
Orchestrating upgrades to SoS				X	X	X	X	X	X	X	X	X	X	X	X	X

Core Elements of SoS SE (1 of 3)

- Translating SoS capability objectives into high level requirements over time
  - SoS objectives based on broad capability objectives
  - SE team plays strong role in establishing requirements and understanding dynamics of the environment

- Identifying and understanding the systems that impact SoS objectives
  - Focus on components and dynamics vs boundaries
  - Extends beyond technical to broader context of management, organizational, development plans, funding, etc.

- Anticipating and assessing impacts of potential changes on SoS performance
  - Given scope of SoS authority, key to SoS SE is identifying and addressing changes in systems and other areas (e.g. threat) which may impact the SoS

Core Elements of SoS SE (2 of 3)

- Developing and evolving SoS architecture
  - This includes
    - Concept of operations
    - Systems, functions and relationships and dependencies, both internal and external
    - End-to-end functionality, data flow and communications within the SoS.
  - Provides the technical framework for assessing options and implications for meeting requirements over time
    - Persistence, tolerance for change

- An **architecture** is the structure of components, their relationships, and the principles and guidelines governing their design evolution over time (IEEE Std 610.12 and DoDAF).
- The architecture of an SoS is a persistent technical framework for governing the evolution of an SoS over time.

Core Elements of SoS SE (3 of 3)

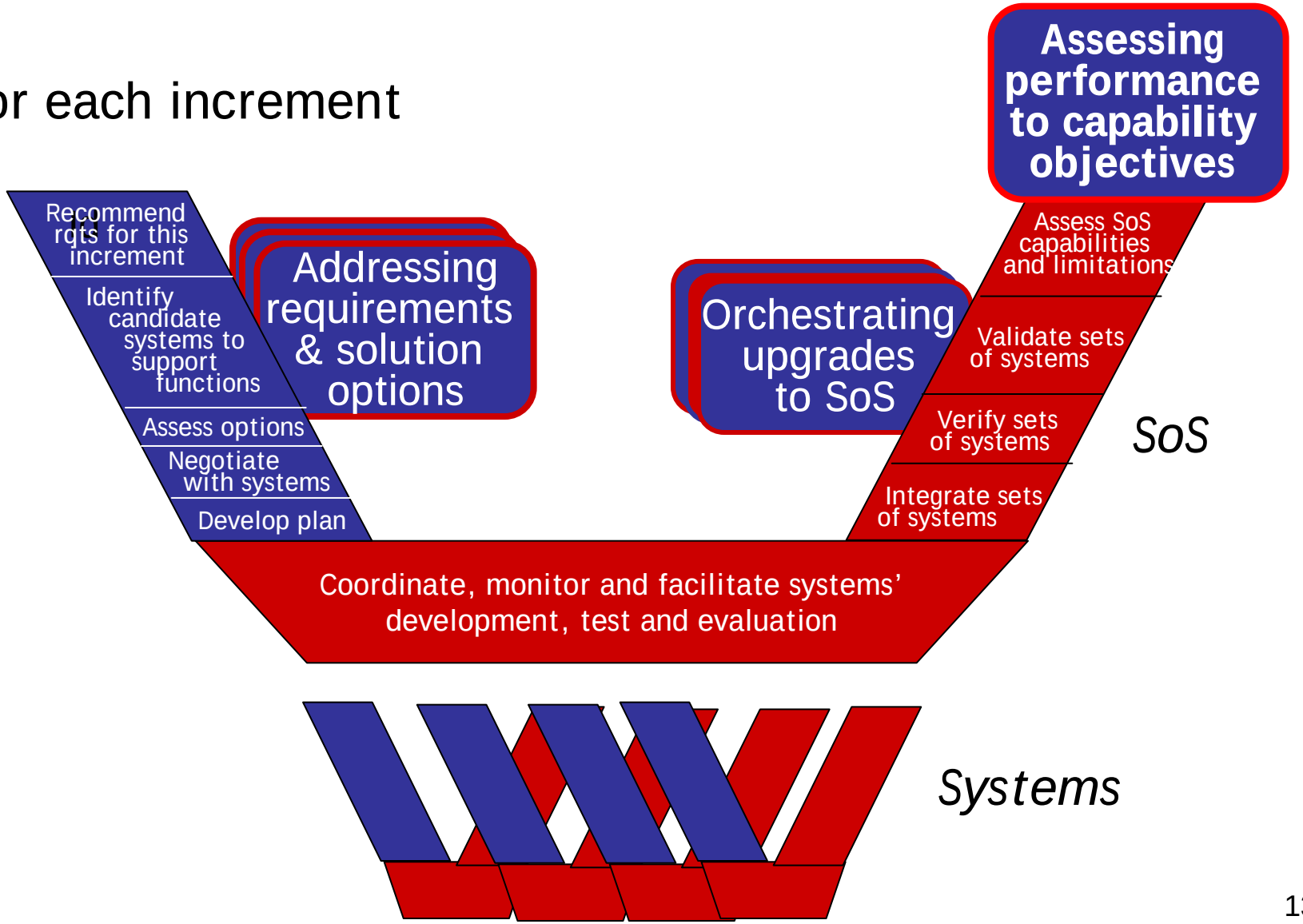
- SoS requirements and solution options
  - Requirements addressed at both SoS & systems
  - Recommend SoS requirements based on both priority and practicality
  - SoS and system SE teams identify and assess options
  - Result is plan for development for next increment

- Orchestrating SoS Upgrades
  - Upgrades implements by systems under system SE teams
  - SoS SE team plans, facilitates, integrates and tests upgrades to the SoS
  - Development based on approaches (bus stop, wave) which accommodate asynchronous system developments

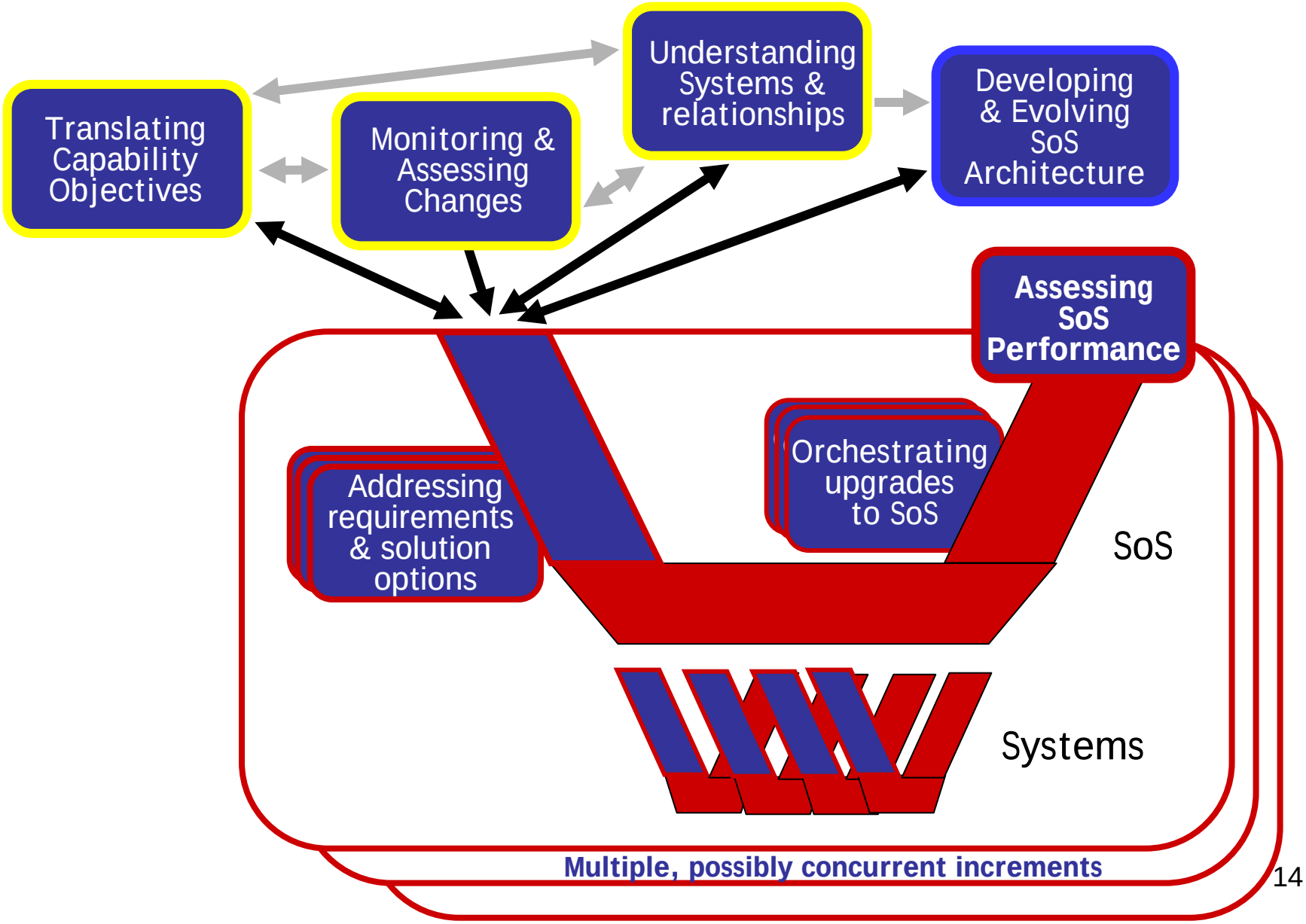
- Assessing SoS Performance
  - Based on measures of SoS user results applied in different settings (test, exercises, M&S, operations)
  - Opportunity to identify changes and emergent behavior

View of SoS Upgrade (1 of 2)

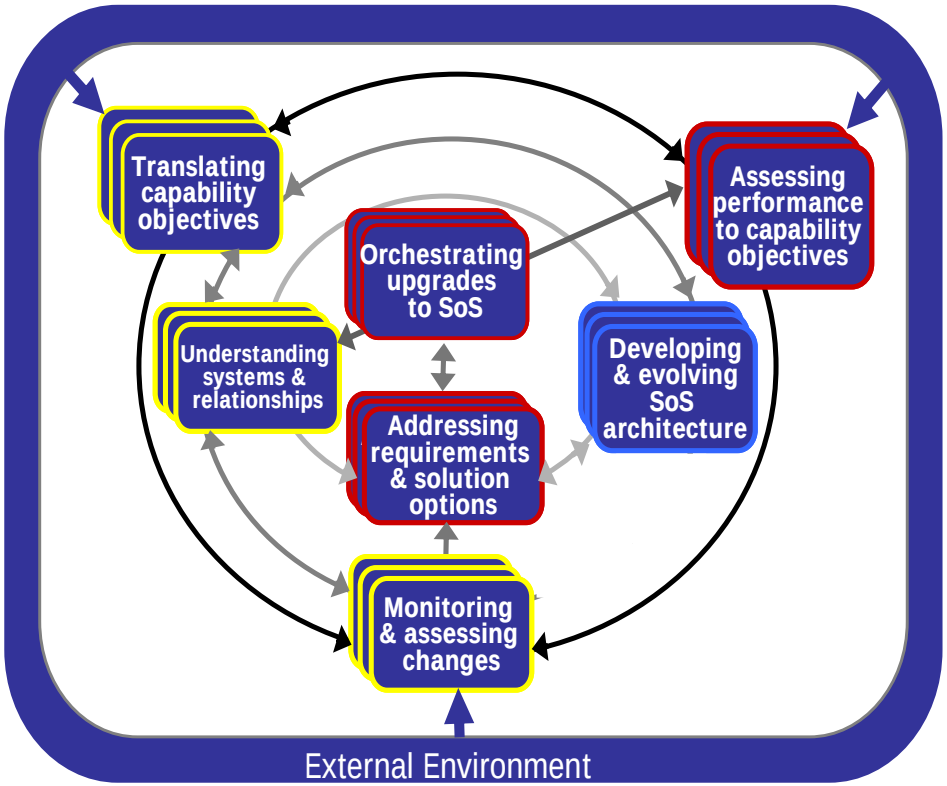
For each increment



View of SoS Upgrade (2 of 2)



In Conclusion



- 'Acknowledged' SoS, challenge the practice of SE
- Research supporting the DoD SoS SE Guide have identified seven core elements of SoS SE and their relations
- This model of SE for SoS
  - Offers initial guidance for SE teams operating in an SoS
  - Provides a framework for leveraging current basic SE processes