System of Systems Characteristics and Interoperability in Joint Command and Control

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Topics

- JV 2010 and 2020 System of Systems Needs and Current Composition
- Spectrum of Systems to System of Systems
- System of Systems Definitions and Characteristics
- Interoperability Enabler
- Levels of Interoperability

Systems Engineering for Large Scale System of Systems

- **A Department of Defense perspective….**

- Autonomous, semi-autonomous, and stand-alone systems
- Legacy systems
- Coalition systems
- Omnipresent protocols

System of Systems DoD Example

Ballistic Missile Defense

- Autonomous, semi-autonomous, and stand-alone systems
- Interoperable systems
- Legacy and new systems
- Future coalition systems

System of Systems NASA Example

Project Constellation

- **Autonomous systems**
- **Interoperable systems**
- **“Future legacy” and new systems**
- **Protocols withstanding time**

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System of Systems in Joint C2

- **Joint Vision 2010 and 2020**
  - Independent agencies and multinational systems dynamically merge
  - SoS bridge between legacy and new systems
  - JV 2010 - Innovation of Technology
  - JV 2020 - Innovation of Technology, Organizations, Concepts
  - Require SoS to have coalition operations – changing central control
- **Experiences from Operations Joint Endeavor in Bosnia and Desert Shield/Desert Storm**
  - Need for common and open standards
  - Interface systems never imagined to have the need to communicate
  - Integration leads to what you get vs. what you need
- **Interoperability must result in capabilities greater than the sum of constituent systems**

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System of Systems Spectrum

- **System of Systems (SoS) Definition (DoD):**
  - **Arrangement of interdependent systems connected to provide a capability greater than sum of the member systems**
  - **Definition is augmented by characteristics**

  [GAO "Defense Acquisitions DoD Management Approach and Processes Not-Well Suited to Support Development of Global Information Grid," January 2006.]

- **Family of Systems (FoS) Definition (DoD):**
  - **Capability is summation of member systems**
  - **Grouping of systems with common characteristics**
  - **Does not acquire new properties or capabilities as a result of grouping**

  [http://akss.dau.mil/dag/Guidebook/IG_c4.2.6.asp]

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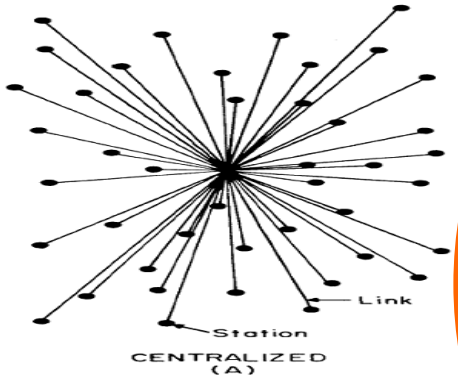
Comparing a System with an SoS

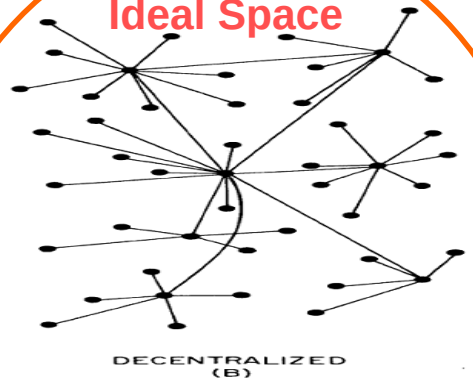
Element	System	System of Systems
Autonomy	Autonomy is ceded by parts in order to grant autonomy to the system	Autonomy is exercised by constituent systems in order to fulfill the purpose of the SoS
Belonging	Parts are akin to family members; they did not chose themselves but came from parents. Belonging of parts is in their nature.	Constituent systems choose to belong on a cost/benefits basis; also in order to cause greater fulfillment of their own purposes, and because of belief in the SoS supra purpose.
Connectivity	Prescient design, along with parts, with high connectivity hidden in elements, and minimum connectivity among major subsystems.	Dynamically supplied by constituent systems with every possibility of myriad connections between constituent systems, possibly via a net-centric architecture, to enhance SoS capability.
Diversity	Managed i.e. reduced or minimized by modular hierarchy; parts' diversity encapsulated to create a known discrete module whose nature is to project simplicity into the next level of the hierarchy	Increased diversity in SoS capability achieved by released autonomy, committed belonging, and open connectivity
Emergence	Foreseen, both good and bad behavior, and designed in or tested out as appropriate	Enhanced by deliberately not being foreseen, though its crucial importance is, and by creating an emergence capability climate, that will support early detection and elimination of bad behaviors.

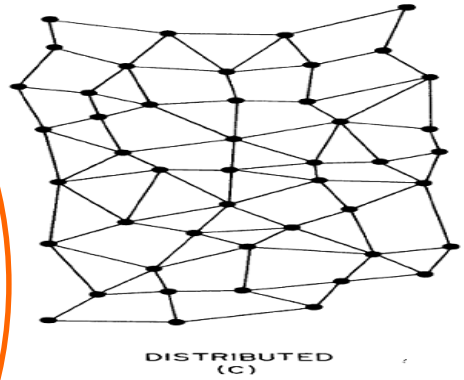
Paul Baran Distributed Networks and SoS Characteristics Spectrum

Janus Effect – Your System Is My SoS



DoD JC2
Ideal Space

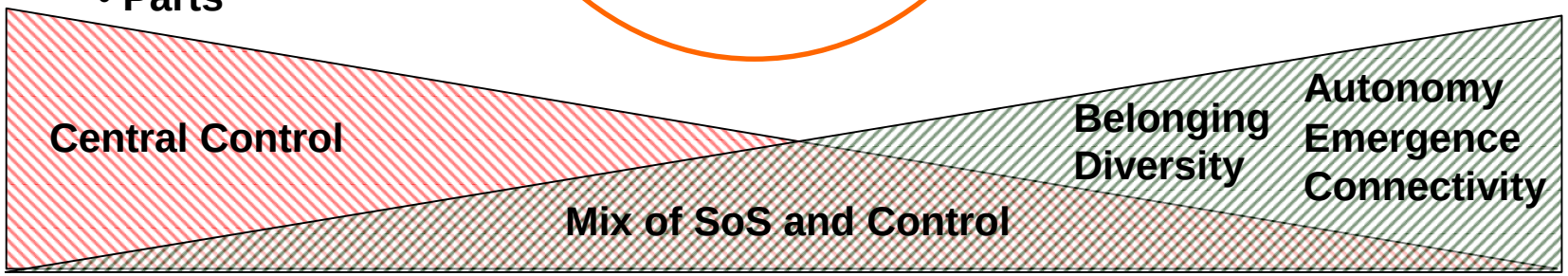




- System
- Assemblies
- Modules
- Parts

- System of Systems
- Family of Systems
- System

- Enterprise System of Systems
- System of Systems



SoS Spectrum Characteristics Implications

- **Centralized Network**
  - **Central control**
  - **Defined and clear authority**
- **Decentralized Network**
  - **Varying degrees of net-centricity**
    - Open-ended (convergent protocol) asymmetric communication across traditional systems and enterprise boundaries
  - **Varying levels of SoS characteristics**
  - **Mixed levels of control and authority**
  - **Changing authority and control**
  - **Varying degrees of complex adaptive systems**
- **Distributed Network**
  - **No central control**
  - **No defined or clear authority**
  - **High net-centricity**
  - **High levels of SoS characteristics**
  - **Complex adaptive systems**
  - **Enterprise system - evolved**

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Command & Control vs. Emergence

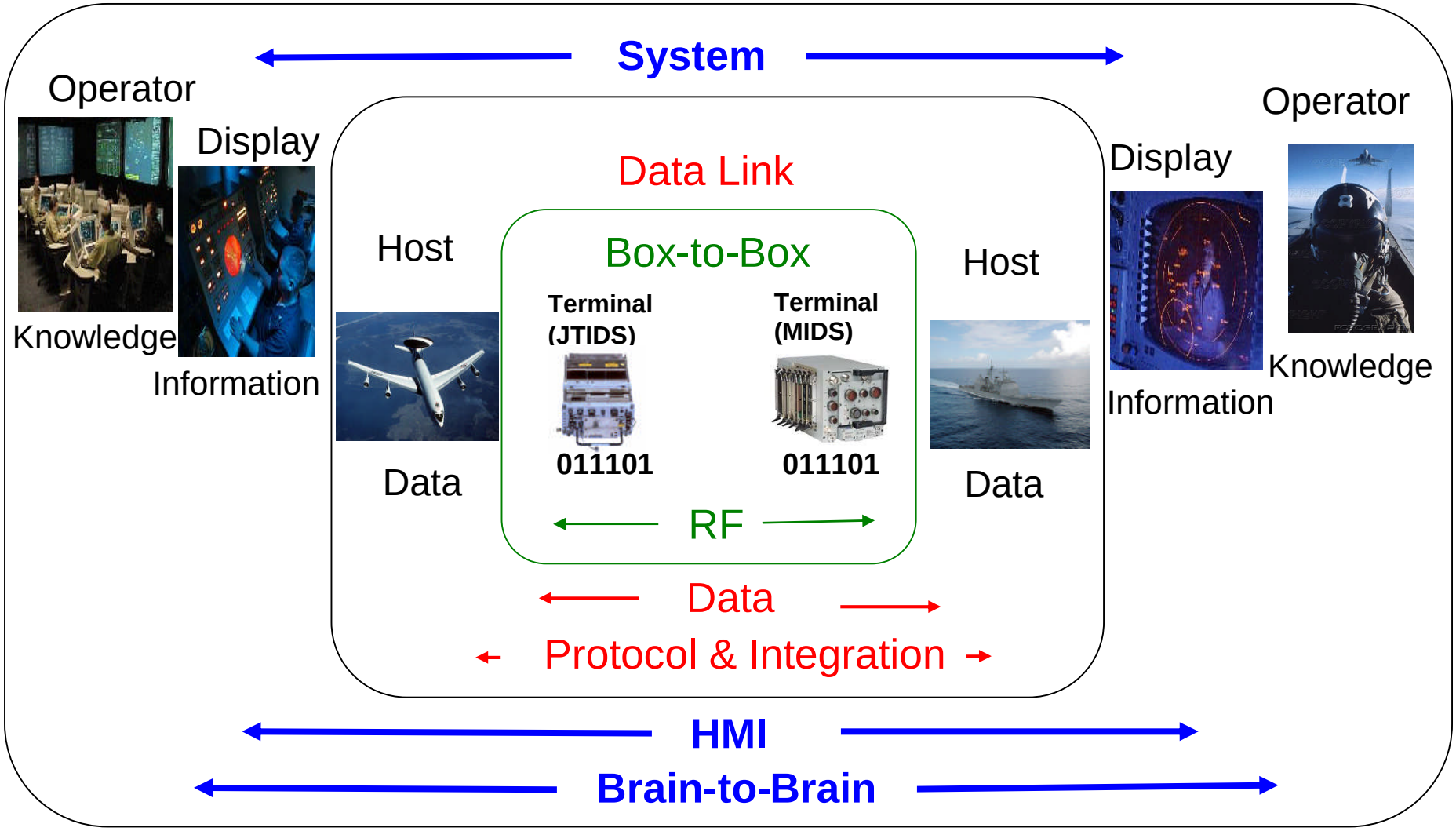
Command & Control Characteristic	Emergent SoS Characteristic
Functional silos	Build connectivity
Conformity	Encourage diversity
Manage communication initiatives	Have conversations in corridors
Blame people for failures	Learn from events
Defined authority	Everyone has leadership and authority
Tell people what to do	Tell people what not to do
Set objectives	Agree clear goals
Keep busy	Wait expectantly

From http://www.new-paradigm.co.uk/emergence-human.htm, accessed June 4, 2006

Never Experience the Same SoS Twice

- Different missions require different aggregation of systems
  - Aggregation of systems used in Bosnia Joint Endeavor are different for desert operations in Desert Shield/Desert Storm
    - Terrain is a factor in surveillance capabilities – what works well in the dessert will not work in the jungle or urban environment
    - Require different combinations of systems concurrently
- Interoperability enables relationships among systems
  - Integration enables the relationship and ensures synergy of the participant systems – syntactic and semantic interoperability
  - Unifies the participant systems to achieve desired holistic behavior
  - Syntactic – ability to exchange data
  - Semantic – ability to use and understand the data

Interoperability
Syntactic to Semantic



Source: Integrated Architecture Development and Fielding, CAPT Jeff Wilson, USN, INCOSE, South Maryland Chapter, April 30, 2004.

Network Centric SoS Example
Require Syntactic and Semantic Interoperability

Single Integrated Air Picture (SIAP)
- Common and Complete Pictures
- One Track per Air Object
- Continuous Track

Combat Identification (CID)
- Long Range
- Wide Area
- Improve Shooter Confidence

Integrated Fire Control (IFC)
- Employ independent of organic radar
- Overcome Radar Horizon Limitation

Automated Battle Management Aids (ABMA)
- Determine Optimum Weapons and Sensors
- Efficient Weapon and Sensor Management

Autonomous and Interdependent Systems To Form Holistic Capabilities

GiG and CEC Interoperability Challenges

- Navy Cooperative Engagement Capability (CEC)
  - JV 2010 Contributor at > $3.5B
  - Major fielding issues due to syntactic ship centric focus vs. a SoSI or Battle Group Semantic Focus
  - Lessons Learned: Required Programmatic and Constructive Interoperability
- Global Information Grid (GiG) - January 2006 GAO Report
  - Developed in a “stove-piped” manner
  - Perpetuates the problem it is intended to solve

Warrior Component
- Networked planes, ships, vehicles, missiles, ground troops, platforms

Global Applications
- Mission/functional automated information systems

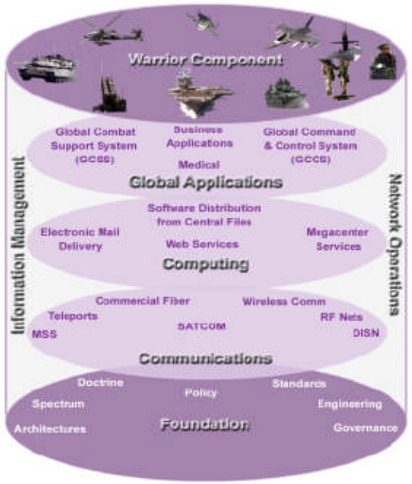
Computing
- Common user processing services

Communications
- Bandwidth on demand

Network Operations
- Network Management, Information Dissemination Management, Information Assurance

Information Management
- Information on demand
- Life cycle management

Foundation
- Doctrine, Architecture, Standards, Policies, Organization, Resourcing, Training, Testing, Governance

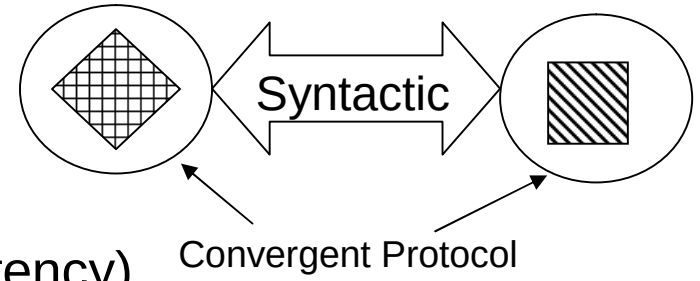


SoS and Interoperability Challenges

- Systems operational requirements documents pre-date current understanding of joint needs
- Detailed information about system members in a dynamic environment to select a proper mix of assets quickly
- Require a means to codify options to ensure consistency and quality of decision support information
- Distributed SoS require large data pipes
- Interoperability process at programmatic and constructive levels need to be defined via the DoD acquisition process
- Requirements for “SoS Enabled” systems
- Operational field tactics must evolve as joint capabilities evolve

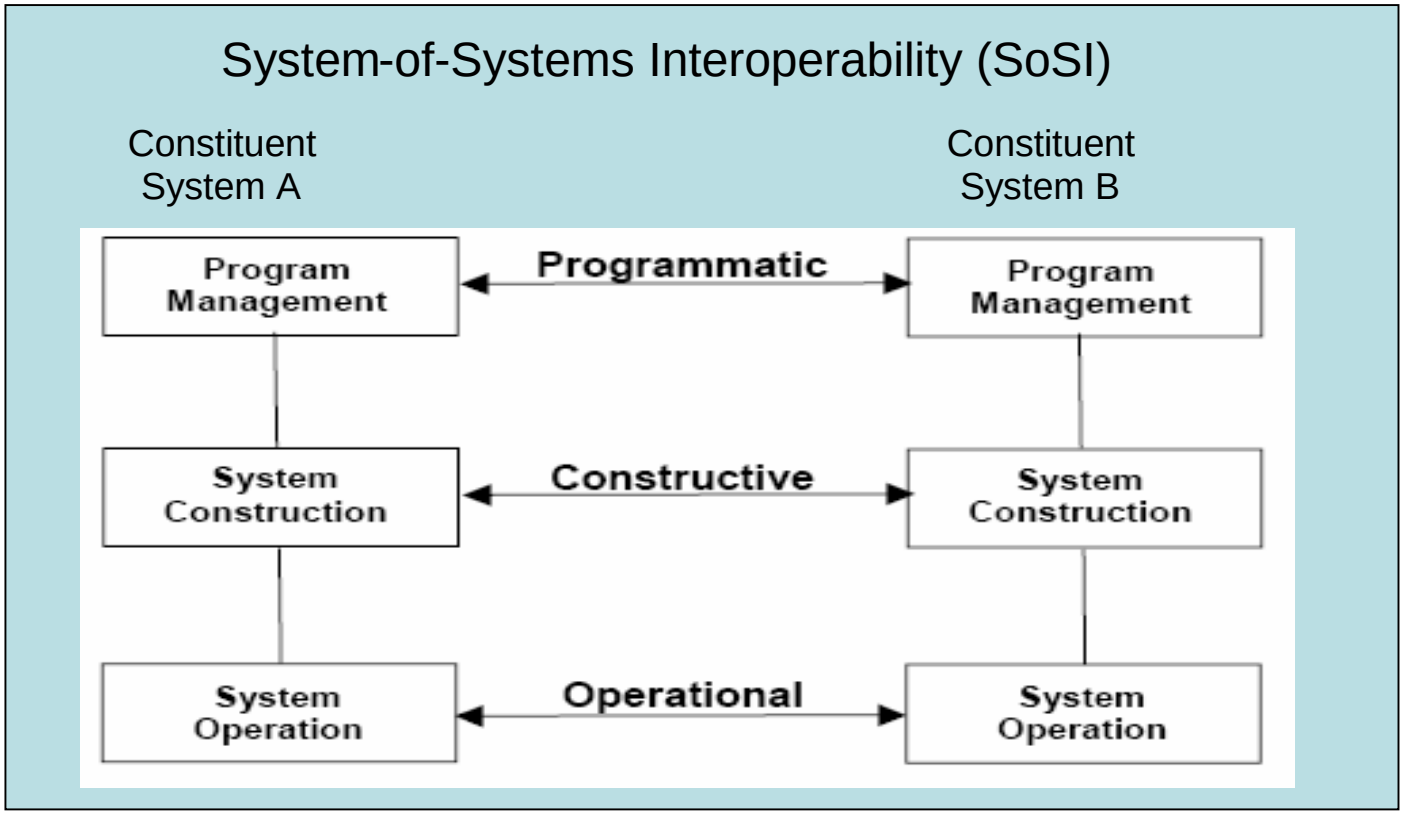
Interoperability Requirements

- Data correctness
  - Time and geospatial alignment
  - Properly characterized
- Data Availability
  - Publish and subscribe
  - Quality of service (e.g., throughput, latency)
- Data processing
  - Common processing (behavior) required to achieve common performance results, minimize life-cycle costs, and reduce time to field new and modified capability
- Interoperability
  - Systems possess a convergent protocol
    - Systems are “SoS Enabled”
    - Omnipresent protocols
      - Mobile Adhoc Network (MANET) (syntactic)
      - Joint SIAP Systems Engineering Organization (JSSEO) IABM (semantic)
  - Passing and fusing of disparate types of information
  - Asymmetric systems



Interoperability Execution

- Interoperability begins at systems acquisition
- Three Levels of Interoperability



JC2 SoSI and Program Success

- Success of JV 2010 and 2020 is dependent on interoperability processes
  - Programmatic
  - Constructive
  - Operational
- Recommend DoD consider changes to acquisition process to reflect SoS and interoperability (SoSI)
- SoSI is fundamental to the SoS complex
- Transition thinking and processes from systems to SoS centricity
- SoSI challenge is an increase in complexity without increase in hierarchy, control, or acquisition cost

BACKUP AND FUTHER REFERENCE

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Complex Adaptive Systems

- **Complex system: a system with multiple agents dynamically interacting in multiple ways, following local rules and oblivious to any higher-level instructions.**
- **Emergence: the movement from lower-level rules to higher-level sophistication; when local interactions result in some kind of discernable macro behavior.**
- **Adaptive: when the system uses local rules between interacting agents to create higher-level behavior well suited to its (macro level) environment.**
- **Complex adaptive system: has a large number of – possibly indistinguishable – elements, which interact in multiple ways, or have a myriad of interactions, thereby producing emergent behavior that makes the entire system self-sustaining in any environment.**