



# System of Systems (SoS) Engineering & Architecture Challenges in a Net Centric Environment

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**Advanced Concepts/Net Centric Integration**

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# Agenda

- **SoS & FoS**
- **NCO and NCW – Implications on SoS Engineering**
- **Some Observations on Architecting SoS in a NetCentric Environment**
- **Concluding comments on SoS Engineering**

# Tiered Hierarchy of Architectures

TIER 0

## National / Int'l Architectures

US, NATO, Other Countries

TIER 1

## Department / Federal Architectures

DOD, IC, HLS, DOC, DOT, ...

TIER 2

## Cmd/Service/Agency Architectures

Air Force, Army, Navy, ...

TIER 3

## Mission Area / X-MA Architectures

Space, Wx, Combat Ops, Mobility, ...

TIER 4

## Program / Node Architectures

MILSTAR, AFSCN, AOC, ...

Enterprise Architectures

Architectures for Mission Areas, Programs & Nodes & "Systems"

Source: "Modeling and Architecture Considerations for Systems of Systems", James Martin (Aerospace Corp), 11 May 2004

# Systems Exist at Different Levels

TIER 0

## National / Int'l Architectures

US, NATO, Other Countries

Unified Cryptologic Architecture

National Security Space

Environmental Monitoring System

TIER 1

## Department / Federal Architectures

DOD, IC, HLS, DOC, DOT, ...

DOD Global Information Grid (GIG)

Federal Enterprise Architecture (FEA)

TIER 2

## Cmd/Service/Agency Architectures

Air Force, Army, Navy, ...

NSA Enterprise Architecture

Air Force Enterprise Architecture

TIER 3

## Mission Area / X-MA Architectures

Space, Wx, Combat Ops, Mobility, ...

Space Mission Area

NOAA Observing System Architecture (NOSA)

TIER 4

## Program / Node Architectures

MILSTAR, AFSCN, AOC, ...

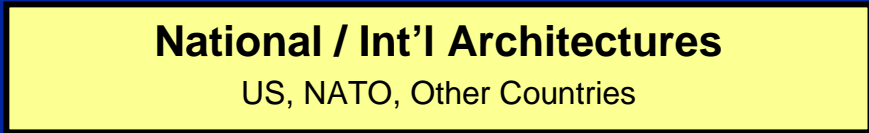
Integrated Overhead Sigint Architecture (IOSA)

Future Imagery Architecture (FIA)

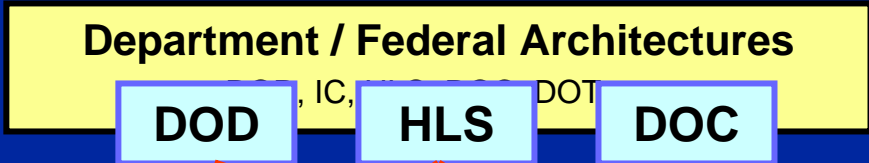
Source: "Modeling and Architecture Considerations for Systems of Systems", James Martin (Aerospace Corp), 11 May 2004

# Not Strictly a “Decomposition” Hierarchy

TIER 0



TIER 1



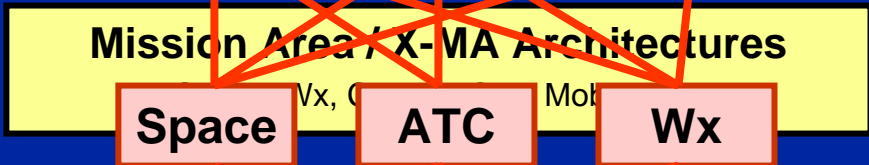
Department / Federal

TIER 2



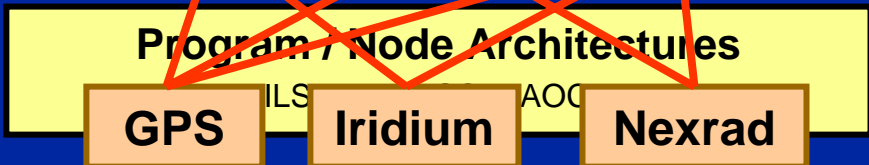
Cmd / Service / Agency

TIER 3



Mission Area / X-MA

TIER 4



Program / Node

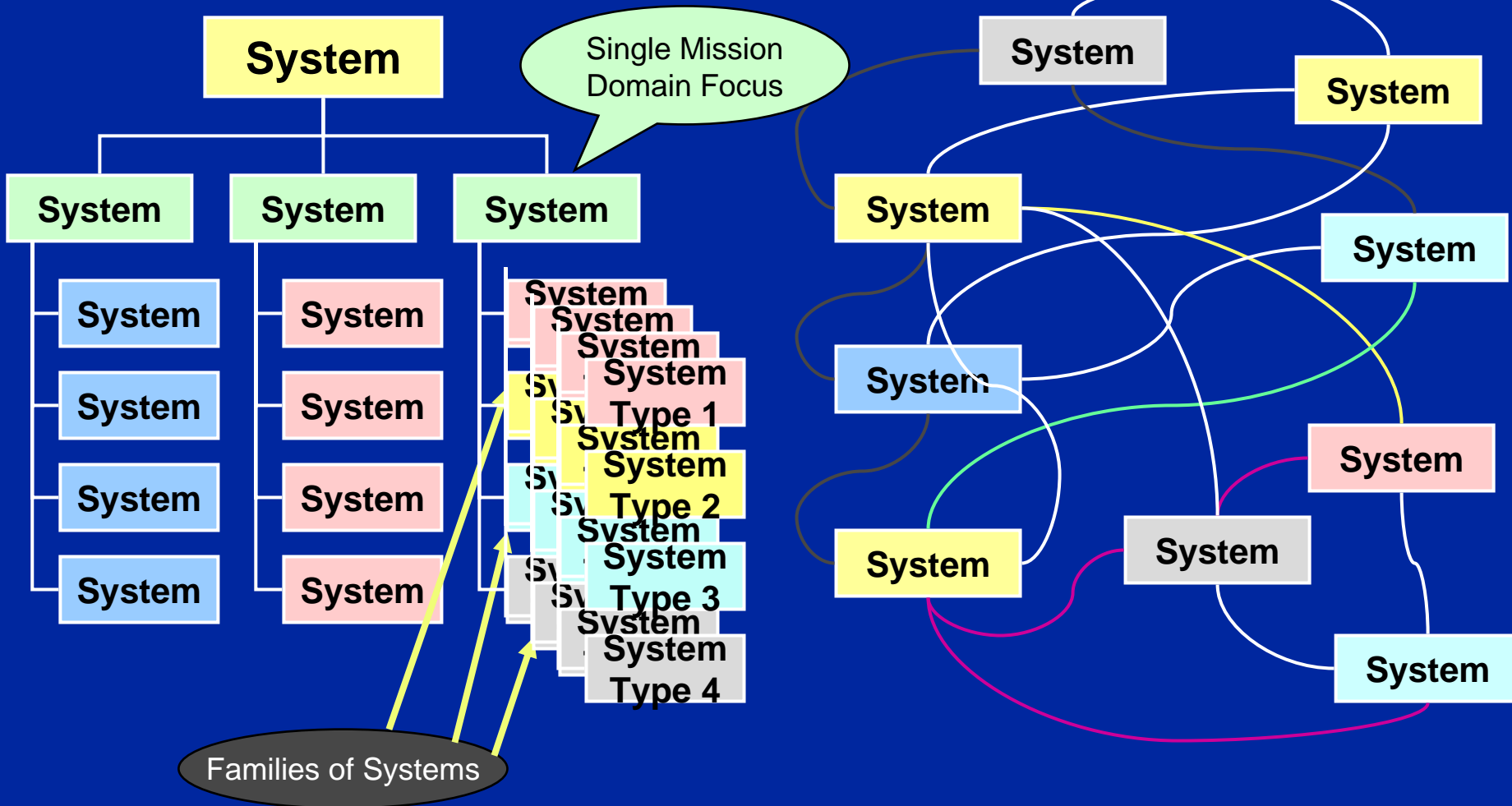
Source: “Modeling and Architecture Considerations for Systems of Systems” , James Martin (Aerospace Corp) , 11 May 2004

# SoS & FoS

NetCentric Design A (FoS/SoS)

>> Run time SoS – Mission 1

## Hierarchy (SoS)

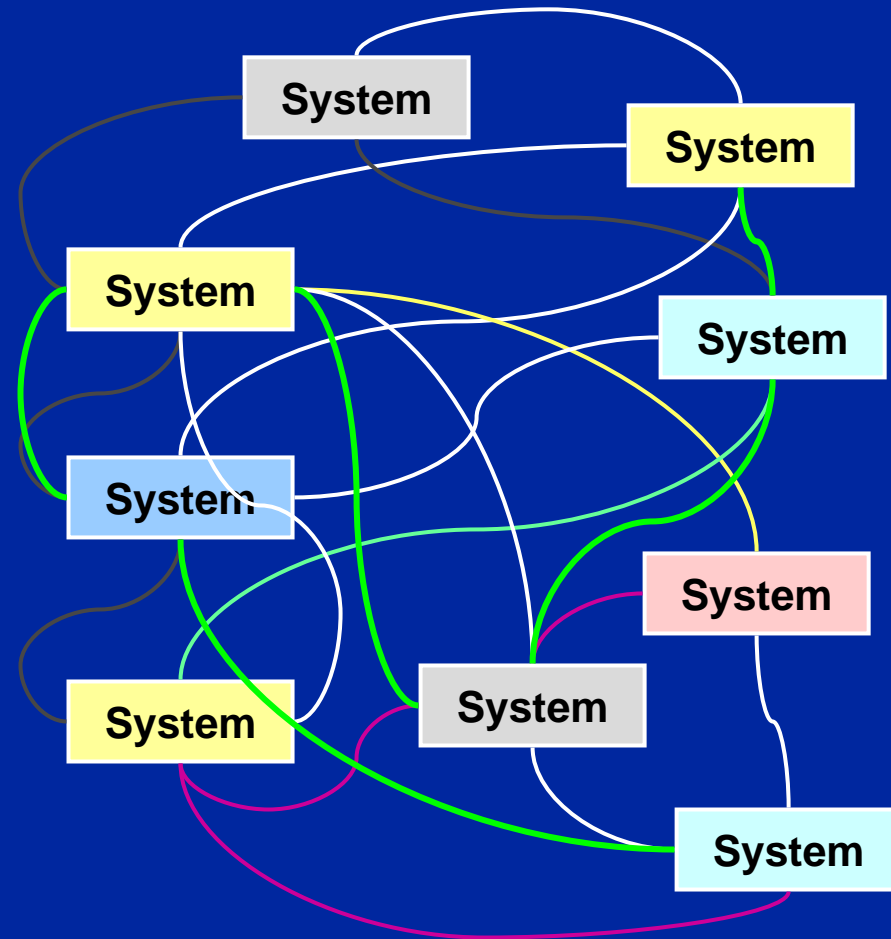
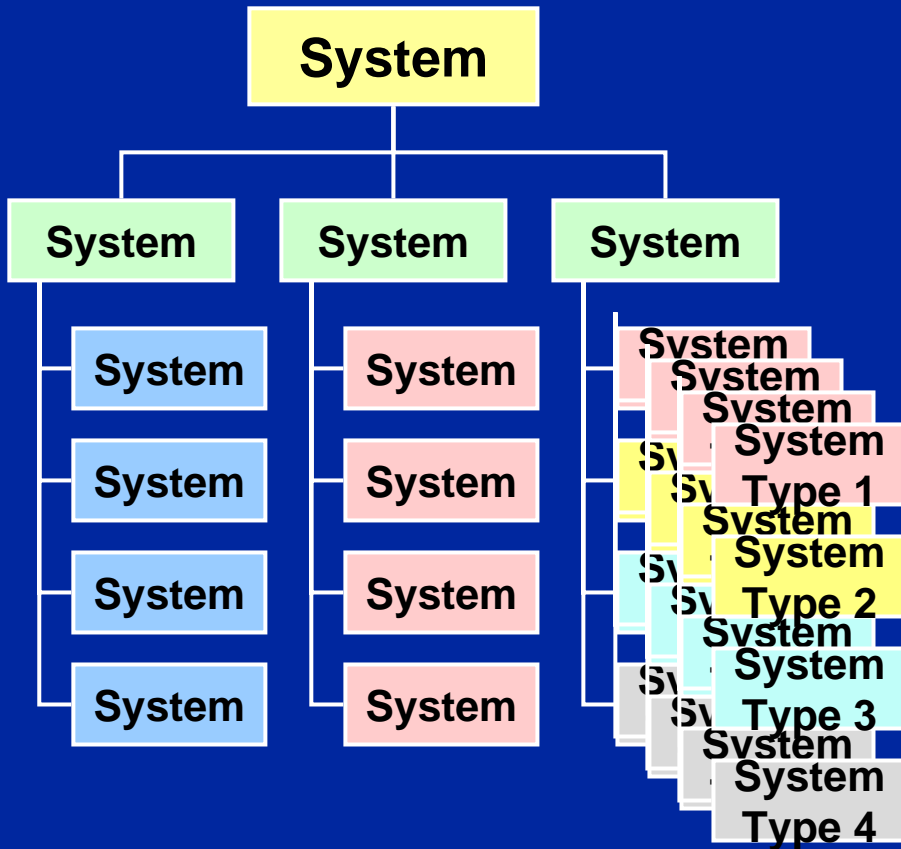


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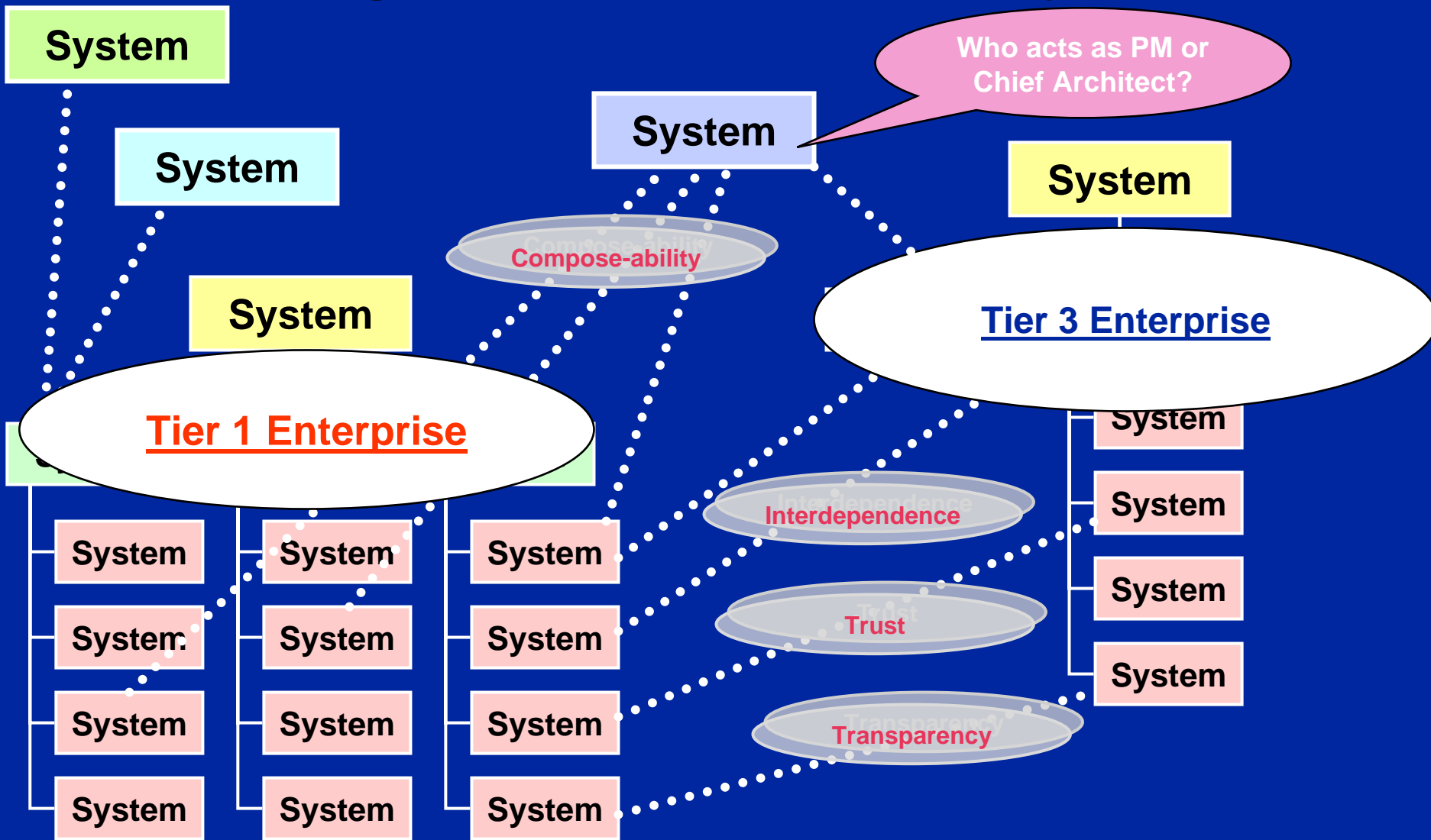
# SoS & FoS

NetCentric Design **A** (FoS/SoS) >>  
Run time SoS – Mission **2**

## Hierarchy (SoS)



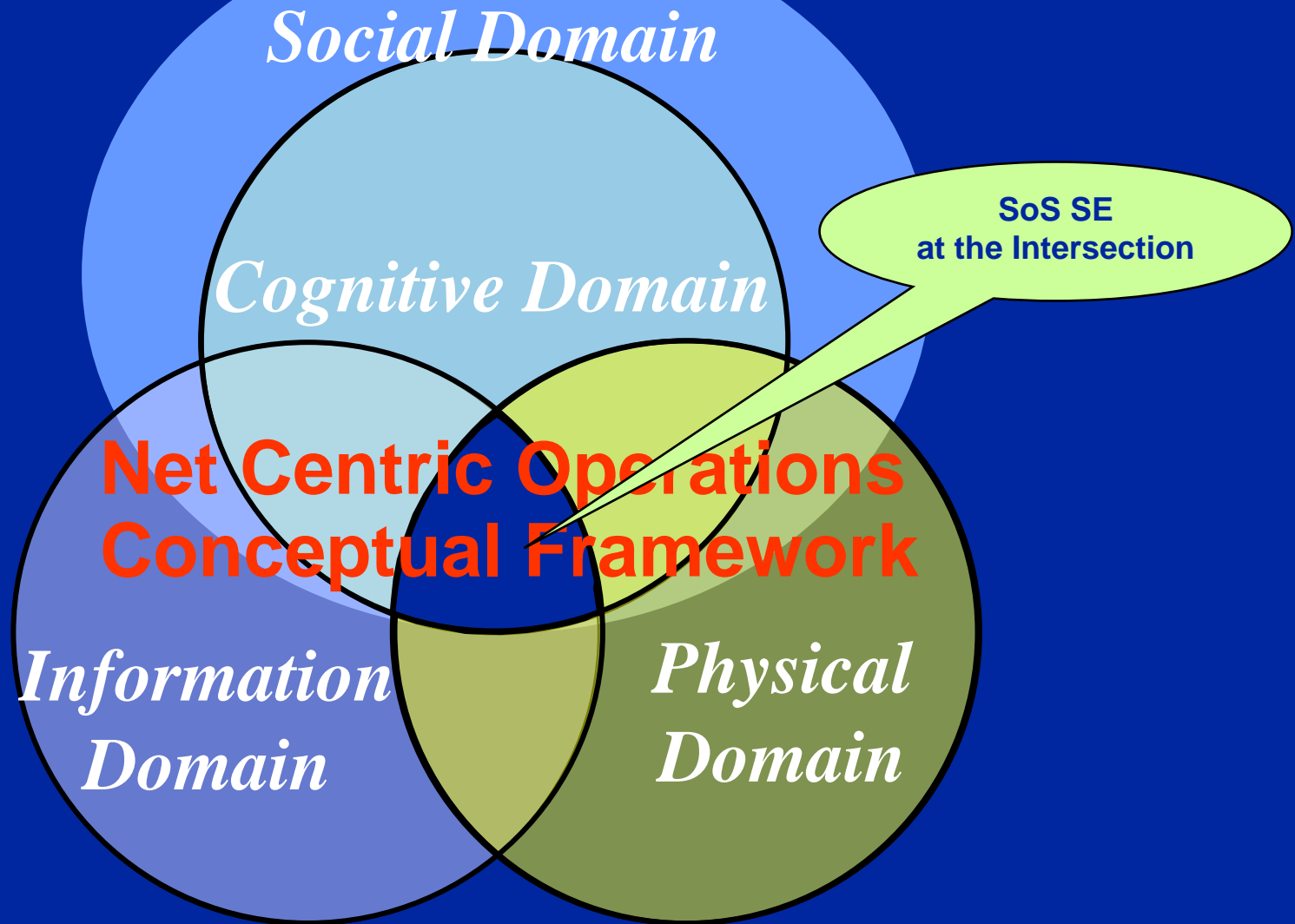
# In a NetCentric Environment >> Some Systems May "Belong" to More than One Parent System



Adapted from Source: "Modeling and Architecture Considerations for Systems of Systems", James Martin (Aerospace Corp), 11 May 2004

# Competing in the Information-Age

*...the power of Network-Centric Operations*



# Some Observations on Architecting SoS

- **“SoS [engineering] may not turn out to be primarily an engineering field.”<sup>1</sup>**
  - **Biology metaphor?**
  - **Network metaphor?**
- **“Systems engineering is based on the assumption that if given the requirements the engineer will give you the system.”<sup>1</sup>**
  - **But requirements continue to change?**
  - **Requirements as a contract versus Darwinian approach?**

<sup>1</sup>Source: *“System of Systems Symposium: Report on a Summer Conversation”*, November 2004, Potomac Institute for Policy Studies.

# NetCentric Principles and SOSE

- **Challenges to system engineers applying NetCentric principles - Although network engineering as a discipline applies SE, classical SE focuses on hierarchy and decomposition as opposed to compose-ability and Net-Friendliness**
- **The crux of the issue for SE is the dynamics of the design environment, i.e., the system to system ( or service to service) interaction and its organizational scope at run time rather than at system development time.**
  - **Organizational Scope dimension: the political/social dynamics of organizations and their supporting information technology systems, and challenges to information model assumptions and frames of reference.**
  - **Runtime Environment: changes the technical approach to system architectures and generally makes them more autonomic and adaptive (and complex).**

# NetCentric Principles and SOSE

- **NetCentric System Engineering turns SE and requirements generation on its ears!**
  - **Capabilities are desired – requirements will only become a “part of” the new acquisition contracts ( e.g., in the DOD)**
  - **Evaluation of NetCentric dimensions desired is a suggested approach to requirements generation**
    - » **NCOIC leading the way**
      - Degrees of Net-Friendliness versus old interoperability maturity models  
NetCentric checklists – NCAT/SCOPE)
      - Adaptation to support unanticipated interactions (protocols and patterns)
  - **Need for systems (or services) in a NetCentric environment is now, but funding/acquisition/governance approaches not mature in present DOD Acquisition models**

# NetCentric Principles and SOSE

- **The operative question is: How Net-Friendly are you?**
  - **How open are they to interacting with previously unspecified systems and organizations over a network, and how rapidly and thoroughly can they adapt to doing so?**
  - **The degree of net-centricity that is appropriate for any given system, collection of systems, or organizations, depends on what the organization wants to be able to accomplish or have the ability to accomplish within its chosen ecosystem<sup>1</sup>.**
- **The Net Centric Operations Industry Consortium (NCOIC) SCOPE Model is in process of exploring these relationships** *[Systems, Capabilities, Operations, Programs, and Enterprises (SCOPE) Model]*

<sup>1</sup>"The Essence of NetCentricity", Hans Polzer, Internal LMC Whitepaper, 2006

# NetCentric Principles and SOSE

- **Years ago Prediction:**
  - **Programmers >> Programmer analyst>>System Engineers (today's reality)**
- **NetCentric Future:**
  - **Systems engineers/architects >> SOS engineers architects (design time) >> Services/systems infrastructure engineers/architects and dynamic SE (support compose-ability)**
  - **User/Operators >> systems evaluation and planning >> mission level SOS engineers/architects (run time, dynamic service orchestration, testing and execution) >> dynamic Service Oriented Systems Engineering (institutionalize compose-ability)**

# NetCentric Principles and SOSE

- **Is SOA a solution?**

- **But do they work across Enterprise boundaries?**

- » In non-NetCentric development, we are so accustomed to having this enterprise context relationship defined for us that we tend to become unaware of these context and scope assumptions we make.
- » We tend to assume that service requestors will inherently and implicitly understand the scope of applicability of any services and data we advertise/register/expose

- **What about real-time requirements?**

# Implications for NCW SoS Systems Engineering

- It is suggested that SoS Engineering is a consolidated discipline that borrows from:
  - System Engineering (Physical and Information Domain; and Structured management of other disciplines)
  - Operational Analysis (All Domains)
  - Decision Analysis (Physical, Information, and Cognitive Domains)
  - Modeling and Simulation (All Domains)
  - Value Engineering (All Domains)
  - Cognitive Modeling (Cognitive Domain)
  - Collaboration Theory (Social Domain)

**Implication: Training, competency, and domain knowledge beyond present common application of these disciplines**

# Some Observations on Architecting SoS

- Optimality and efficiency is not as important as run-time interoperability with services that were not envisioned at design time - flexibility, compose-ability, extensibility are now much more important
- Will architecture frameworks like DODAF be sufficient to help us do this?
  - Growing recognition that DODAF (in its present form) is insufficient to capture SoS emergent behavior, SOA, or NetCentric principles
- The dynamics of cognitive and social processes do not obey static representations and rules of architecture
  - Networks contain people and agents which exhibit emergent behavior in SoS contexts

# Some Observations on Architecting SoS

- **Human performance as a system parameter takes on more significance and dominance in SOSE, as event-driven phenomena highlight the emergent impact of effects on political, economic, organizational environments**
- **The principles that are used to facilitate M&S between legacy and new systems or services (i.e., interoperability) can be leveraged to build the actual operational capabilities**
  - **Should we somehow combine the M&S and SOSE competencies to evolve the SoSE or NetCentric SE discipline?**

# Looking in the Crystal Ball

- We are entering new era in understanding how to design and, more importantly, leverage systems (i.e., hardware, software, people, data, etc.) in a SoS context
- In the 21<sup>st</sup> century, the complexity of how we go to war has increased
- The definition of war (e.g., traditionally waged against a sovereign) is changing and what it means (e.g., what and who are we fighting against? It changes its form continuously) will increasingly drive SoS definition
- The effects which our warfighting creates have increased their political impacts in new ways not addressed by past wars and in the context of the cultures and countries unfamiliar to us – the education of our warfighters takes on new dimensions
- Effects use to be limited to national boundaries, now they must be considered for their trans-national impacts as religion and other cultural identity factors know no national boundaries and must be considered on a global scale

# What does it Mean for Systems Engineering?

- **The evolution of complexity science is now starting to meet the study of system-of-systems science**
- **System engineering needs to be extended (or maybe transformed?) to capture the new variables influencing system (in the large) designs**
- **The extended application of system science, system dynamics, and leveraging experimentation will be keys to effective solutions to SoS challenges**
- **The war of attrition is giving way to the war against networks ( e.g., Al Queda, etc.)**
  - » **Our understanding of the convergence of network theories [we are not talking IT infrastructure here] and complexity theory, and how we research and experiment with potential solutions to these problems, will be our measure of success\***

\* **“The Agile Organization”, Atkinson & Moffat, CCRP Publications, 2005**

# Closing

- **Challenges to Integration of FoS into SOS architectures**
  - **Complexity**
  - **Dependency**
  - **Emergent Behavior**
    - » tradeoff flexibility and compose-ability (notional training) versus predictability (discipline an doctrine)
  - **Collaboration**
- **The key to implementation success**
  - **New and evolved services must be easy to use and very quick to train – change is the constant in this equation**
  - **Quickly discoverable services on the GIG - the Operator will require time-sensitive information superiority on the battlefields of the future**
  - **Leveraging information in a changing world means: Agility is the preferred MOE - the challenge will be to create and measure these metrics**

**Goal: Embrace, Manage, and Hide Complexity of SoS –  
Maximize Flexibility and Ease of Use for the User**