**NAVAL RESEARCH ADVISORY COMMITTEE**

# Science and Technology for Modular Systems

**Presentation to**
**The Honorable John J. Young, Jr.**
**ASN (RD&A)**
**5 August 2004**

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# Panel Membership

**Ms. Teresa B. Smith – Chair**
(Northrop Grumman)

**Dr. Walt Williamson – Vice-Chair**
(Texas Christian University)

**Dr. A. Michael Andrews, II**
(L-3 Communications, former DASA R&T)

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(Georgia Institute of Technology)

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(Consultant)

**RDML Lewis A. Felton, USN (Ret.)**
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(Microsoft)

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(Consultant, former PD USD A&T)

**Mr. Joseph Y. Rodriguez**
(Raytheon)

**Mr. Richard L. Rumpf**
(Rumpf Associates, former PDASN)

**Dr. John C. Sommerer**
(Johns Hopkins University-APL)

**Mr. William D. Whiddon**
(Northrop Grumman)

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(BearingPoint)

***RDML Charles S. Hamilton, USN***
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***Dr. Richard Vogelsong – Executive Secretary***
(Office of Naval Research)

# *Terms of Reference*

- Review and assess ***Navy systems engineering*** efforts on programs of record and the extent to which ***modular open systems, provisions for spiral upgrades, and S&T are factors in the requirements definition and acquisition processes.***

- Identify candidate ***high-payoff S&T areas for modular development and horizontal integration***; and assess the opportunities for S&T engagement with systems engineering efforts.

- Where appropriate, recommend ***guidelines for structuring modular S&T*** initiatives that would enable utilization of results in multiple platforms/missions packages.

- Recommend changes required to improve ***the interface between Navy's S&T planning and acquisition processes.***

# *Approach*

- Reviewed selected ***programs of record*** for modularity implementation
  - *Types* of modularity and drivers
  - *Degree* of modularity versus integration
  - *Methodology* (systems engineering and procurement requirements) used to define modularity
  - *Spirals* – provisions to incorporate future capabilities (S&T)
  - *Benefits* – business and operational cases
- Baselined ***commercial and defense industry*** (U.S. and International) for modularity drivers, business models, implementation methodologies and benefits
- Reviewed ***systems engineering practices***, especially regarding modularity
- Surveyed ***literature*** for implementation methodologies, business drivers, metrics for measuring success and prior Government/Industry studies

# Briefings Received

**Programs**
- Virginia Class Subs
- SSGN Conversion
- ARCI
- CVN-21
- DD(X)
- MMA
- J-UCAS
- JTRS
- ONR FNC
- LCS Seaframe
- LCS Mission Modules
- Integrated Deepwater System
- FCS System Analysis (Sandia)
- HSV-2
- X-Craft

**Systems Engineering/Other**
- NAVSEA 05
- ASN RDA Deputy CHENG
- Total Open System Architecture
- PEO IWS Open System Architecture
- Navy Acquisition Management
- NPS/Meyer Institute of Systems Eng.
- MIT Lean Initiative
- AF Systems Engineering Forum
- OSD Open Systems Joint Task Force
- OUSD (AT&L) – Defense Systems

**Guidance**
- CNR
- DASN (RDT&E)
- PEO Ships

**Industry**
- Boeing
- IBM
- L3 Communications
- Lockheed Martin
- Microsoft
- Northrop Grumman
- Rockwell Collins

**International**
- Ericsson
- HDW
- Naval Team Denmark
- Thales

# *Executive Summary*

- Modularity concepts are intuitively simple, but multi-faceted, complex to implement effectively.

- Navy programs delegate modularity implementation to primes/LSIs without guidelines - resulting in questionable benefits and contractor stovepipes.

- Navy should perform systems engineering and set procurement guidelines to effectively implement modularity horizontally; ***the Navy should not abdicate the systems engineering responsibility*****.**

- Navy S&T Community should support the introduction of modular systems into Navy programs by developing capabilities to decompose complex systems, experimenting with modular concepts to support acquisition spirals, and developing M&S tools to enable system of systems engineering analysis.

# *Bottom Line, Up Front*

**The real issue is a lack of a Navy-wide Systems Engineering & Analysis Process**

Systems Engineering & Analysis applied horizontally across programs enables determination of appropriate modularity

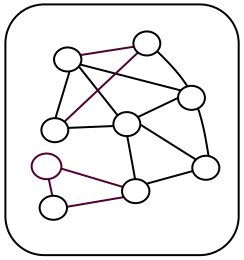
# Background
## Definitions

**Systems Engineering**

Is a top-down, comprehensive, interactive and recursive system synthesis & analysis process; applied through all stages of development and sustainment

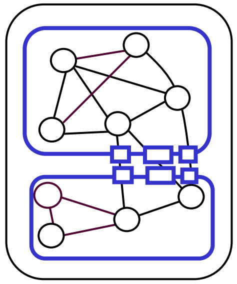
**Integrated**

An architectural framework where most system functions are mapped to single components. Components have high degrees of interdependency and non-standard interfaces.



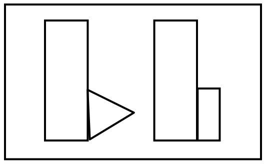
**Modular**

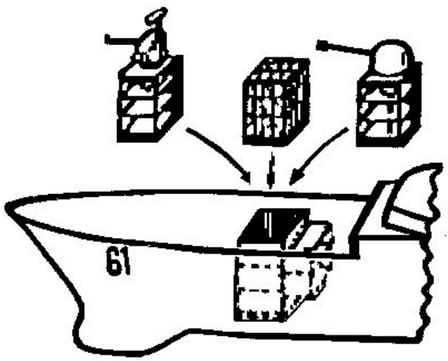
An architecture where system functions are partitioned into elements consisting of various components. These elements have standard/defined interfaces and minimal interdependencies in the overall system.



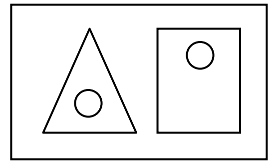
# Background
# Types of Modularity

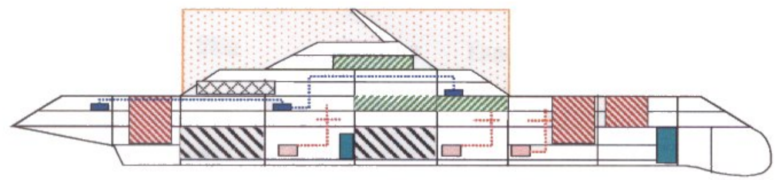
## Capability Swapping Modularity - Mission Packages



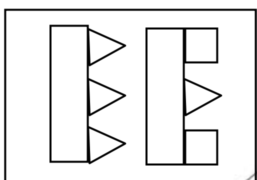


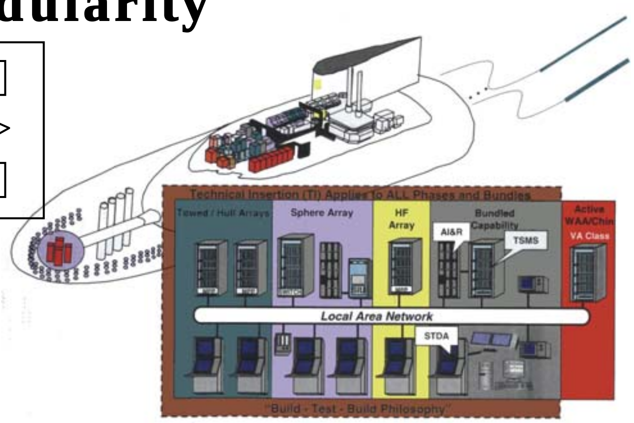

## Component Sharing Modularity



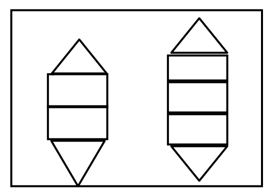


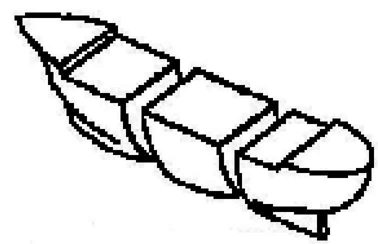
## Bus Modularity






## Construction/Design Modularity





# Background
# Modularity: Why or Why Not?

**Drivers**

- Technology Refresh
- Interoperability
- Increased Readiness
- Mission Reconfiguration
- Capability Upgrades
- Construction/Manufacturing
- Design Re-use & Qualification
- Logistics & Maintainability
- Training
- Navy Total Ownership Cost

**Tradeoffs**

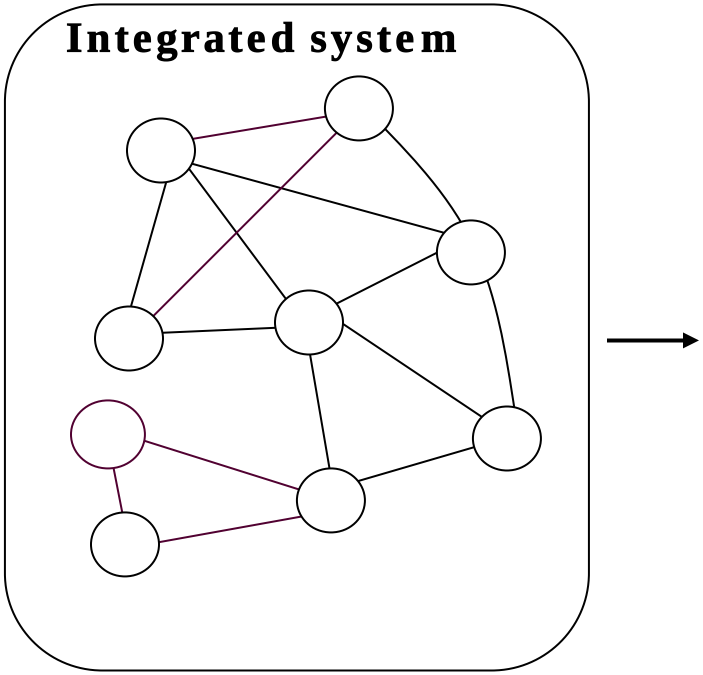
- Performance
- Development Risk
- Flexible & Enhanced Operational Capabilities
- Manpower & Skills
- Schedule/Time
- Economies of Scale
- Best of Breed Technology
- Acquisition Cost
- Physical (size, weight, power)

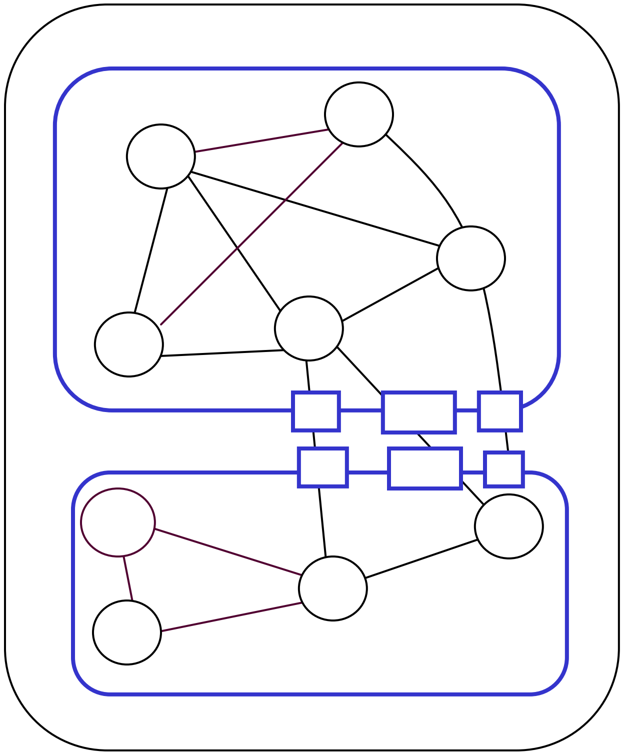
Decisions for modularity require understanding operational/business drivers and tradeoffs

# Background
## Evaluating Modularity Tradeoffs

- **What are good decompositions?**
  - **Introduction of multiple considerations**
  - **Understanding tradeoffs**

**"Minimize interface complexity for ease of mission reconfiguration"**



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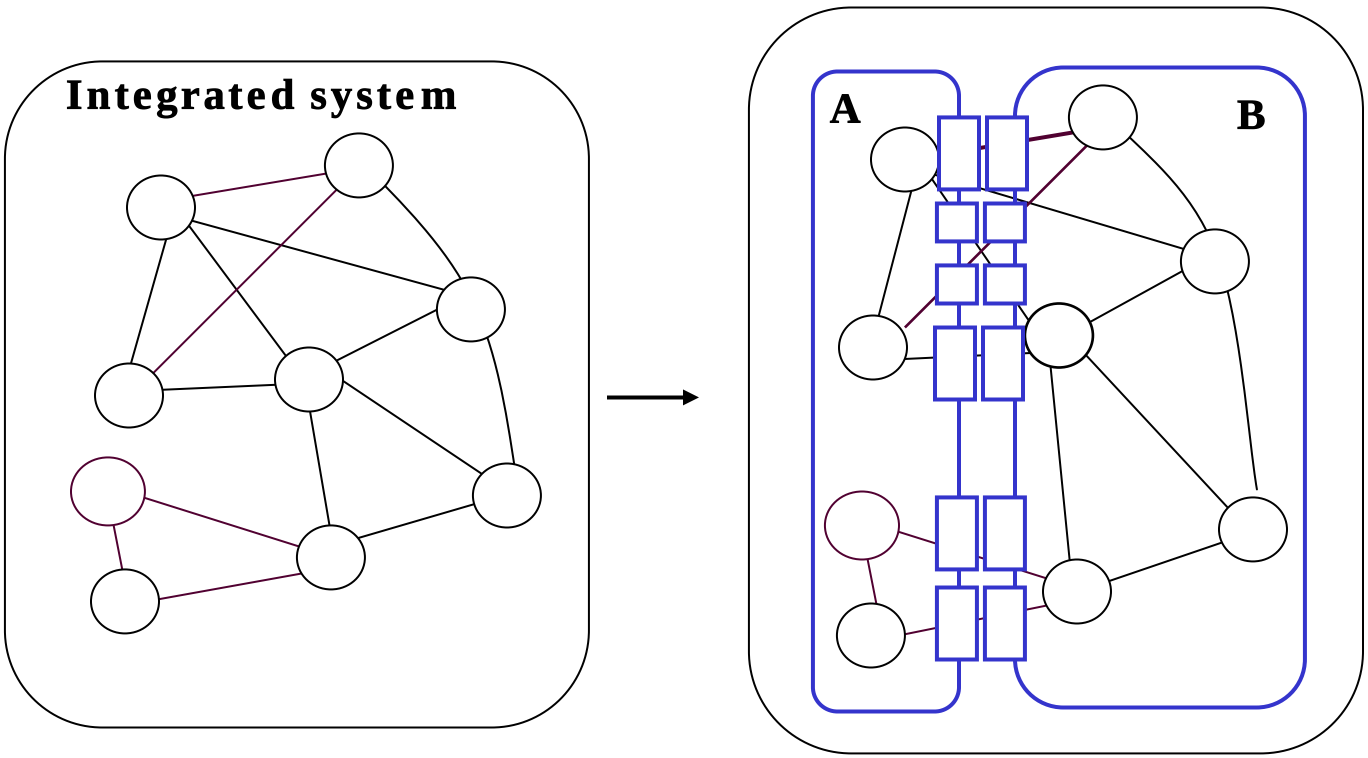
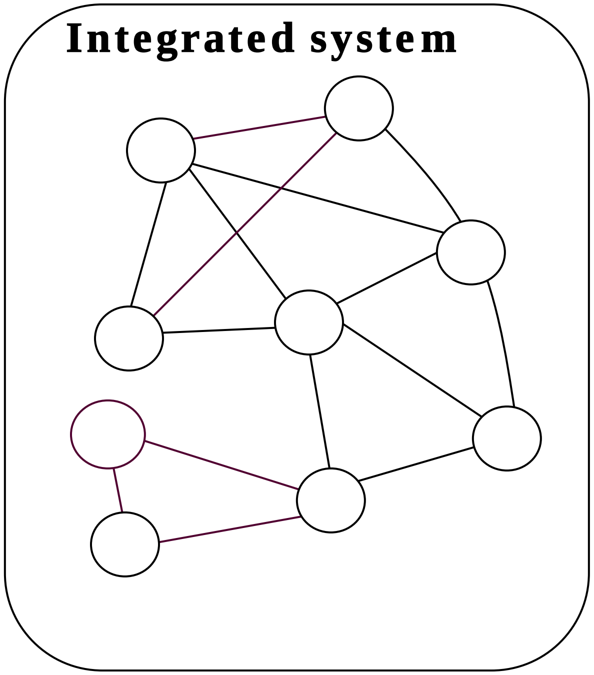
**"Prepare for technical refresh of A"**

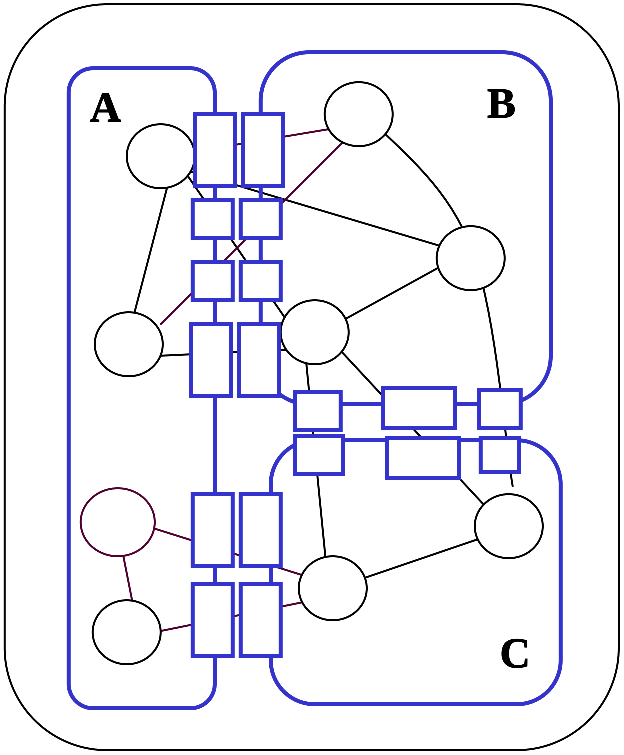


# Background
## Evaluating Modularity Tradeoffs

- **What are good decompositions?**
  - Introduction of multiple considerations
  - Understanding tradeoffs

**"Prepare for technical refresh of A, and ready for failure of B"**



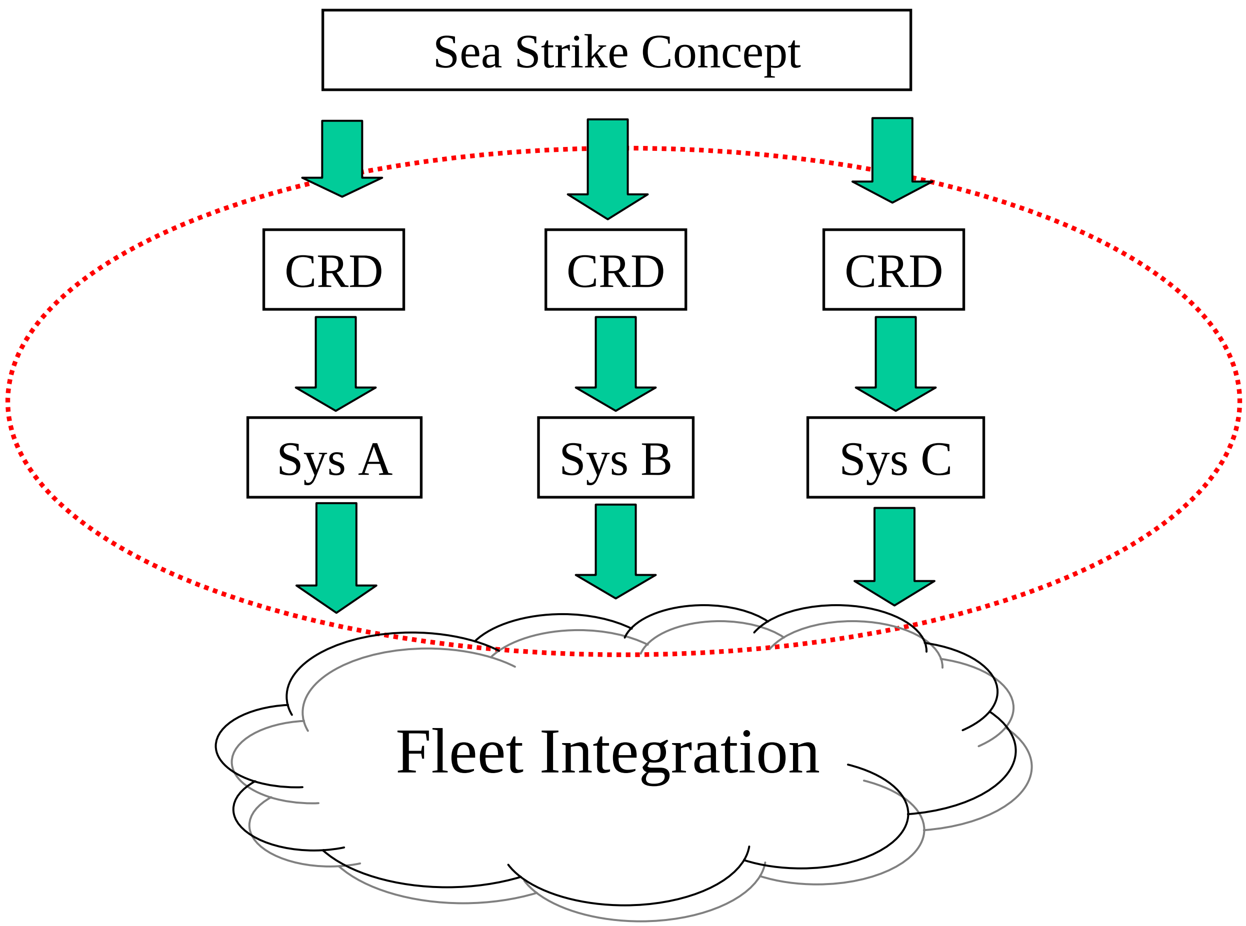
# *Pillars of Modular Systems*

- **Systems Engineering**
- **Standard Interfaces**
- **Open System Architecture**

**Systems Engineering Drives Standards and Open System Architecture**

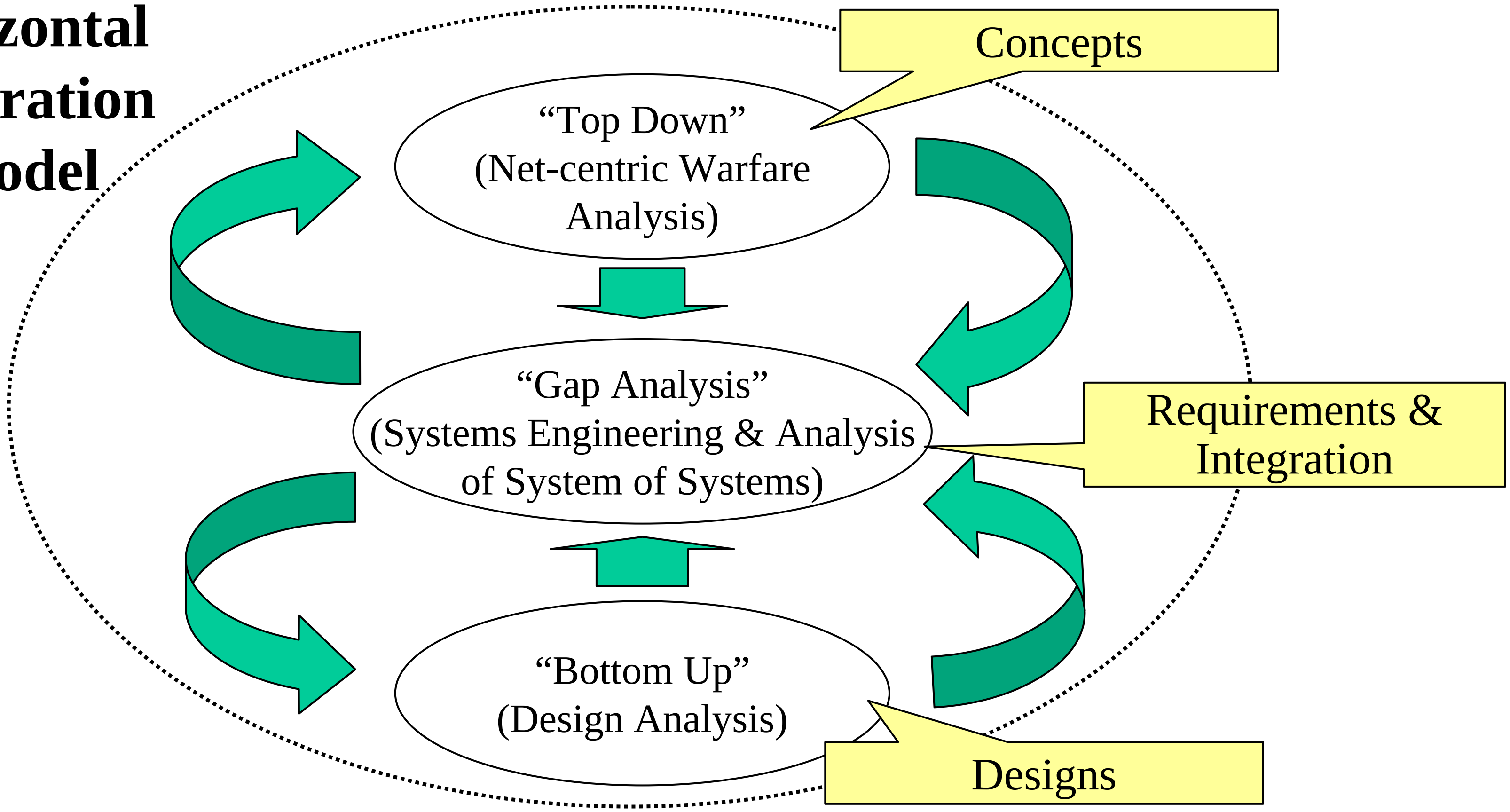
# Background
# Systems Engineering

## Platform/Program Model



# *Background*
# *Systems Engineering*

**Horizontal Integration Model**




**Modularity for System-of-Systems Require Horizontal Approach to SE**

# Findings

# *Navy Program Findings*

- No actionable ***policy, guidance, definitions, or principles*** for modularity
- Shortage of ***systems engineers*** and lack of experience with modularity

**Decision Process**

- ***Motivators*** for modularity not understood or articulated
- Inconsistent ***system analysis*** (if any), program/platform centric, done by primes

**Acquisition Implementation**

- LCS, SSGN, and ARCI reflect transformational use of modularity
- In general, programs have delegated decision responsibility for modularity to primes without guidelines or incentives
- No serious commitment to spiral development observed; S&T community largely decoupled
- Impact of modularity on T&E, training, and logistics not well understood

# *Navy Program Findings*

**Examples of Best Practices**

- LCS, SSGN: Navy taking responsibility for upfront SE
- ARCI: good use of modularity, spiral development, commercial standards, & technology to enhance capability
- Virginia Class: good example of benefits of modular construction
- X-Craft and HSV2 potential test beds for SE and operational mission module evaluations

**Areas for Improvement**

- UUVs (approximately 70 types): lack of modularity, policy, guidance, and standards
- MMA: program office and prime have different visions
- MMA, ACS, BAMS, J-UCAS: minimal horizontal systems engineering
- LCS and Deepwater: MOU in place; questionable commitment
- DD(X), CG(X), CVN21: technology sharing opportunity
- FORCEnet: System of Systems Engineering an absolute requirement

# *U.S. Industry Findings*

- No common definitions or standards for modularity (***Defense***)
- Company interests dominate modularity decisions (***Defense***)
- Need for Systems Engineering recognized, not uniformly implemented, and shortage of expertise (***Defense & Commercial***)
- Software an enabler for open-system architectures and modularity (***Defense & Commercial***)
- Low percentage of software re-use; high opportunity for cost savings (***Defense & Commercial***)

**Defense Industry Specifics**

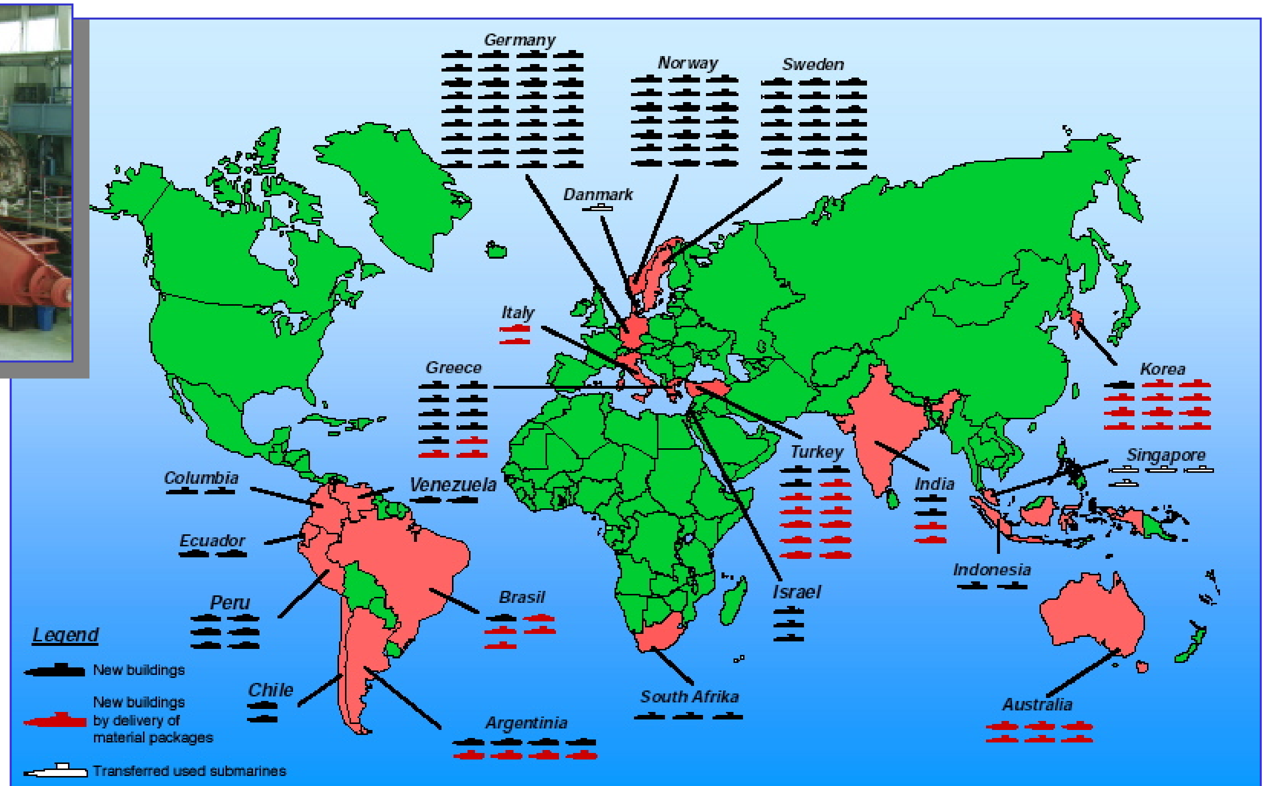
- ***Capability Swapping Modularity/Mission Packages -*** industry not developing unless directed by government
- ***Construction/Design Modularity*** – both government and industry in harmony
- ***Bus Modularity*** - commercial companies ahead of defense in implementation
- ***Component Sharing Modularity*** - defined by company business models not by customer

# *International Findings*

- Global Market Drives Business Behavior
- Effective Joint Government-Industry Collaborations
  - Naval Team Denmark
- European defense products reviewed incorporate more modularity than U.S.
  - Systems Engineering used to determine type and degree of modularity

# International Findings

| Specific Examples | Primary Motivation | Approach |
|---|---|---|
| HDW / small submarines<br>(*Construction Modularity*) | • Custom offerings to diverse market (design reuse)<br>• Construction efficiency | • Modular hull sections<br>• Optional capabilities |



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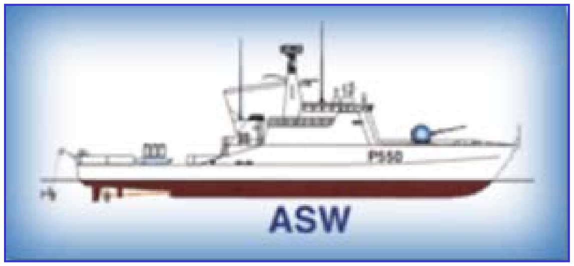


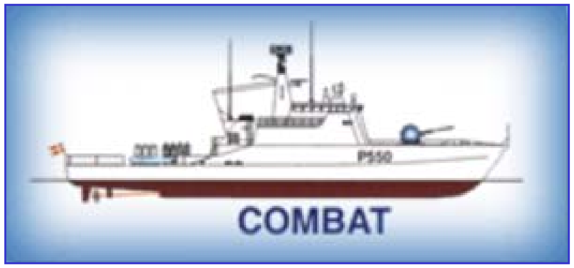





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| Thales / TACTICOS<br>TERMA / T-Core ®<br>Thales / UBMS<br>(*Bus Modularity*) | • Capability upgrades<br>• Enable market penetration<br>• Design reuse<br>• Scalability | • Open Architecture infrastructure |

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| Thales / Sea Guardian<br>(*Component Modularity*) | • Fixed & mobile implementations | • Sensor subsystem modularity<br>• Integration at combat system level |

# *Systems Engineering Findings*

- ***Processes*** **-** poorly defined, inconsistently implemented
- ***Systems Engineers*** - significant deficiencies in numbers, education and experience – Government & Defense Industry
- ***No horizontal integration*** - Systems engineering, when performed, at platform/program level and stove-piped
- ***Systems engineering tools*** - no comprehensive, standard set
- ***S&T*** - decoupled from systems engineering enterprise
- ***NPS*** - has systems engineering curriculum, performs military oriented systems engineering studies; Navy needs more thoughtful process to determine future assignments of graduates

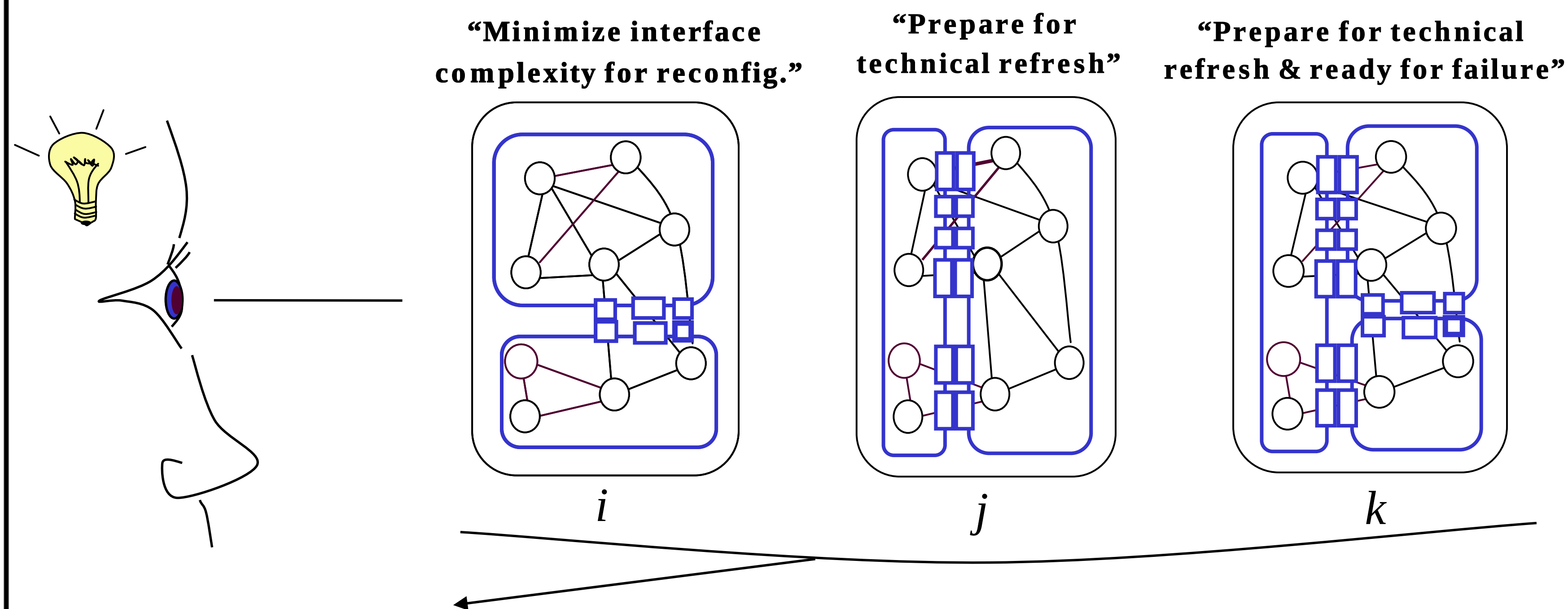
# *Literature Survey Findings*

- Limited information on DoD implementations of modularity
  - Critical military factors (e.g. mission flexibility, acquisition tradeoffs) not considered in modularity optimization
  - Some studies related to systems engineering and modularity to Navy ships
  - No formal DoD analysis with explicit focus on S&T for modularity and systems engineering

- Several recent articles and reports have explored ***methodologies for design and evaluation of modular systems***
  - Some preliminary work defining degrees and types of modularity
  - Focus on *commercial applications*
  - More mature for software than hardware – but still largely heuristic

# *Needed: Tools and Methodologies for Evaluating System Decompositions*

- **Capture, represent, analyze *multiple concurrent objectives***
- **Optimization for benefits—*quantitative* or *qualitative***

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# *Summary Findings*

- ***Navy Programs*** – implementation of modularity delegated to primes; no horizontal systems engineering
- ***U.S. Defense Industry*** – systems engineering and modularity not uniformly applied within programs
- ***International industry*** - ahead of the U.S. defense industry in judicious use of modularity
- ***Systems Engineering*** – systems engineering fundamental to implementing modularity but current practice inadequate
- ***Literature Survey*** – early work on methodologies for decomposition of systems

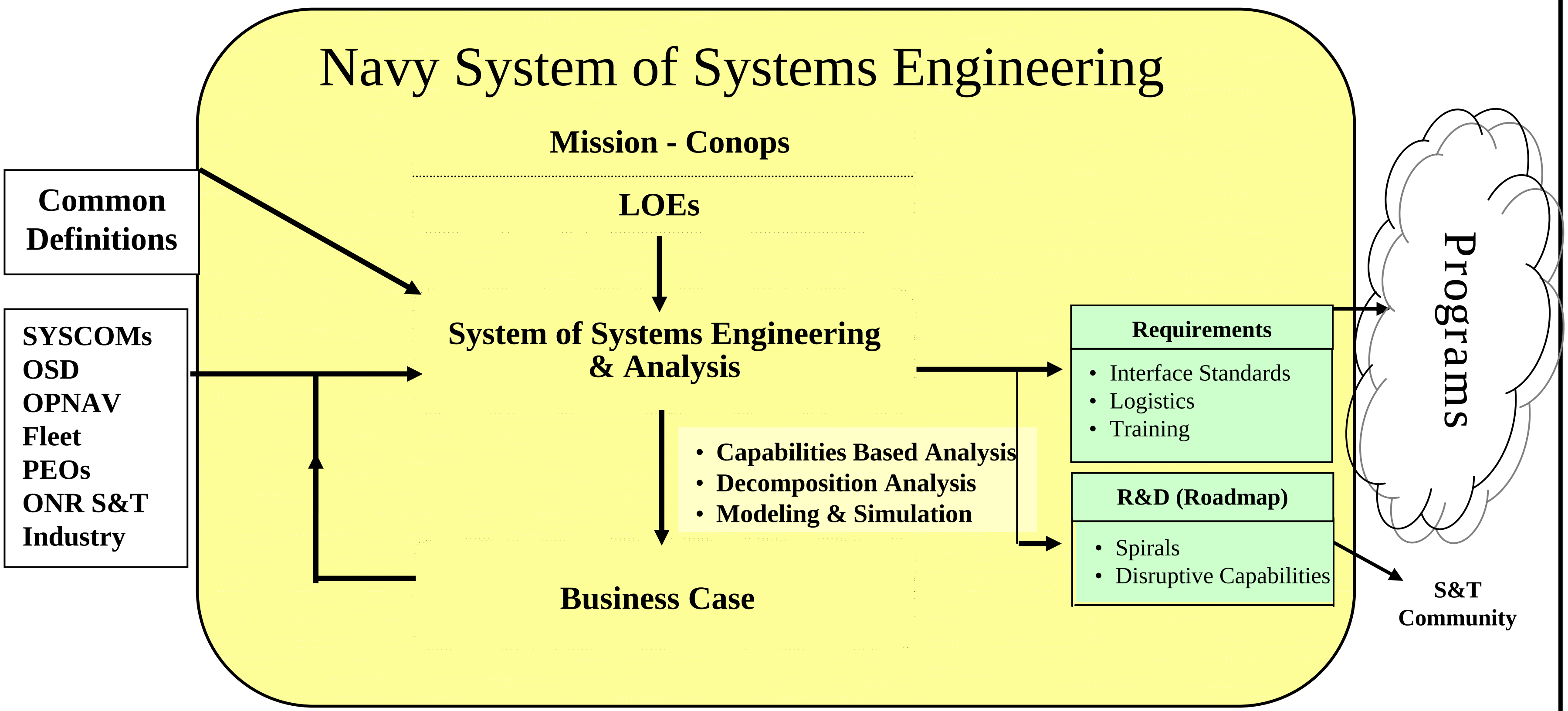
# *Recommendations*

- ASN (RD&A), with VCNO and ACMC, take lead in ***developing a Naval-wide System-of-Systems Engineering function*** that follows a top-down, interactive, and recursive system synthesis & analysis process to define requirements.

- CNO & CMC ***identify driving factors*** for modularity and develop Naval policy and guidance for implementing modularity.

- CNR ***lead as technology change agent*** for (1) development of methodologies for understanding complex systems, enabling modular design; (2) experimentation with modular systems to support acquisition spirals (starting with LCS); (3) development of M&S tools to enable system of systems engineering analysis; and (4) development of advanced concepts & tools for software optimization & re-use.

# Requirements Community Needs to Drive Modularity Guidelines Horizontally




Establish Navy Systems Engineering & Analysis Function

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# *Conclusions*

**The time is right to harvest value from modularity through disciplined Systems Engineering**

**Implementing System of Systems Engineering and adopting modularity effectively can result in:**

- Flexible and interoperable warfighting systems that can better address an uncertain future
- Ability to cope with limited resources

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