

NAVAL RESEARCH ADVISORY COMMITTEE

Science and Technology for Modular Systems

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

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 05 AUG 2004		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Science and Technology for Modular Systems				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Advisory Committee 800 North Quincy Street Arlington, VA 22217-5660				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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Panel Membership

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(Texas Christian University)

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(Georgia Institute of Technology)

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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

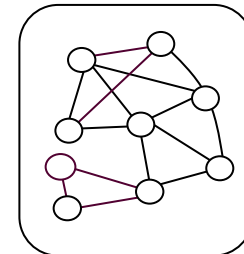
Systems Engineering & Analysis applied horizontally across programs enables determination of appropriate modularity

Systems Engineering

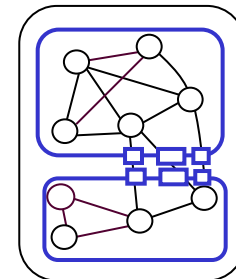
Is a top-down, comprehensive, interactive and recursive system synthesis & analysis process; applied through all stages of development and sustainment

Integrated

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

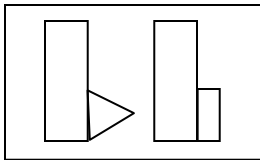
**Modular**

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.

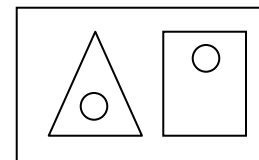
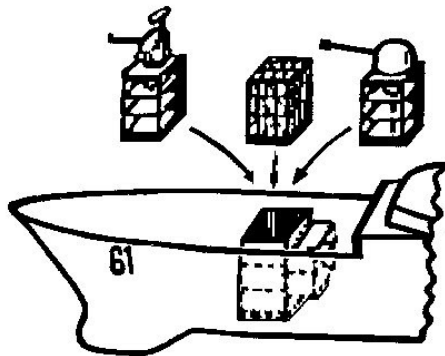


Background

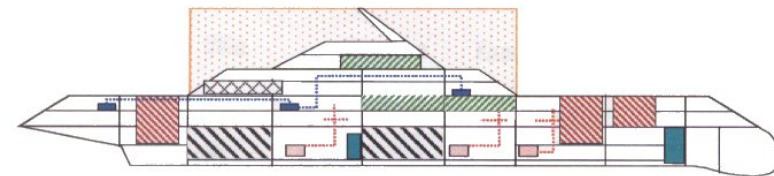
Types of Modularity



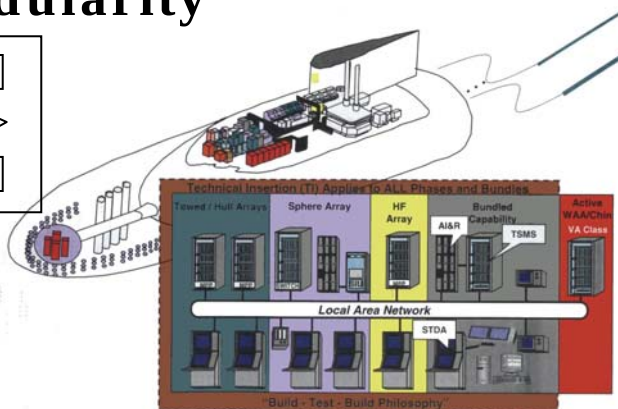
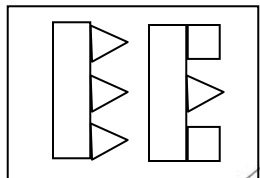
**Capability Swapping
Modularity -
Mission Packages**



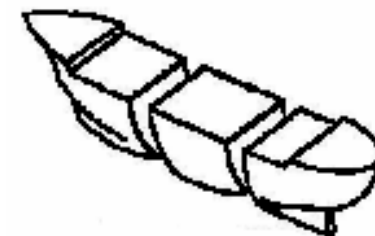
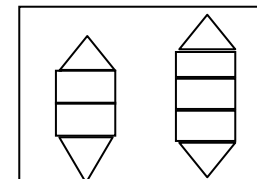
**Component
Sharing
Modularity**



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

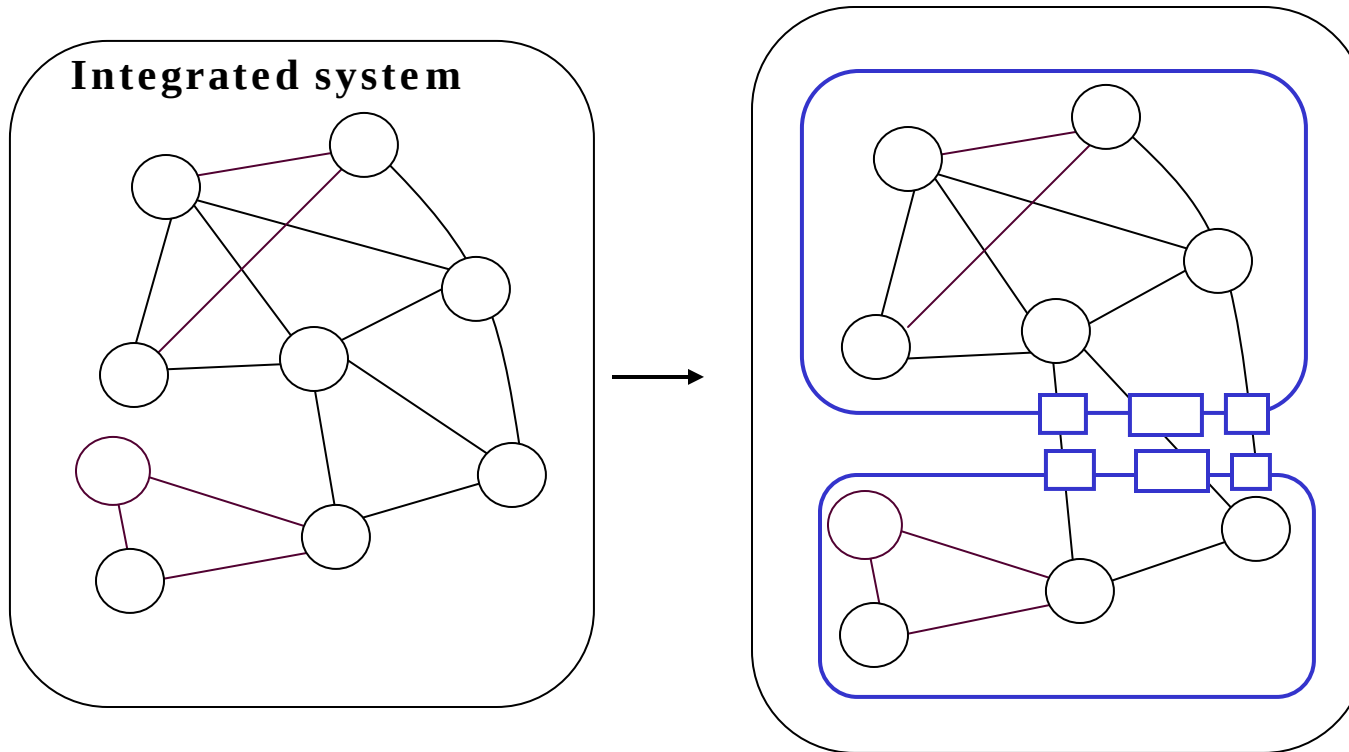
Background

Evaluating Modularity Tradeoffs

- **What are good decompositions?**

- Introduction of multiple considerations
- Understanding tradeoffs

“Minimize interface complexity for ease of mission reconfiguration”

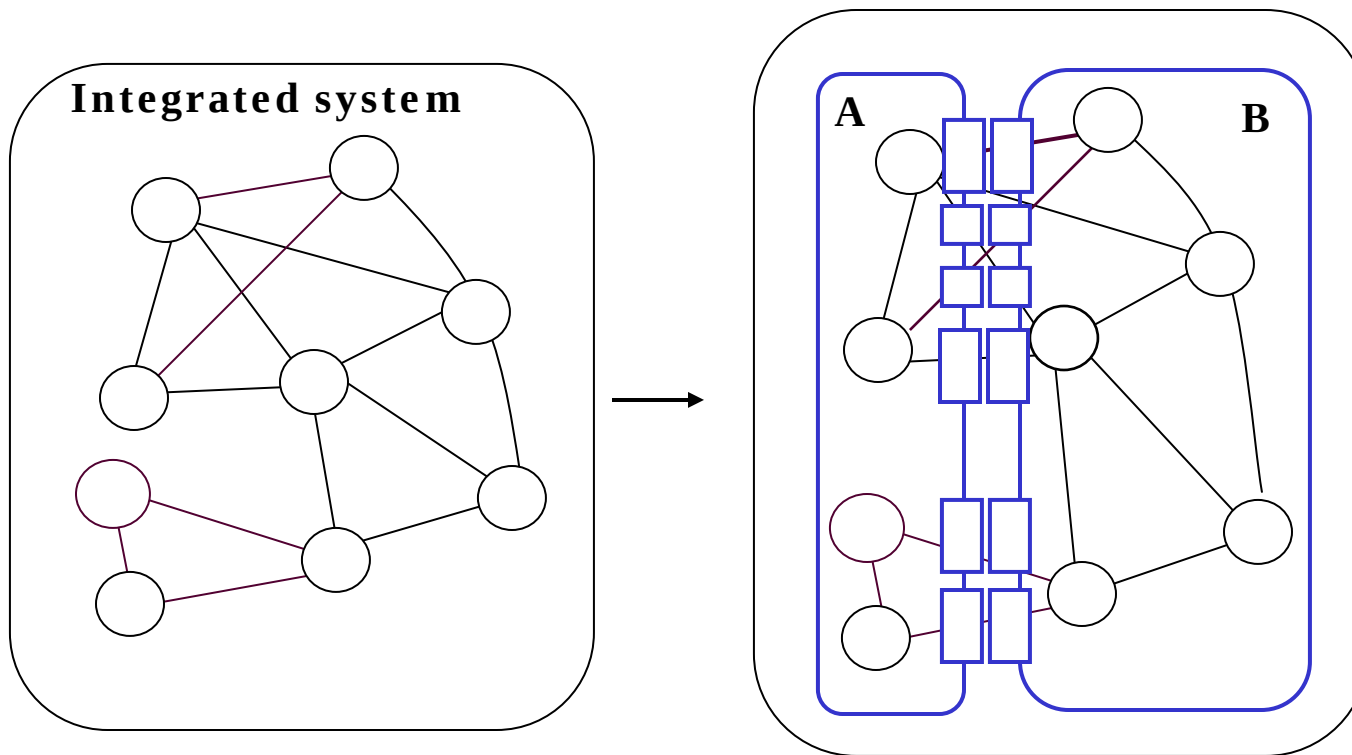


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Evaluating Modularity Tradeoffs

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“Prepare for technical refresh of A”



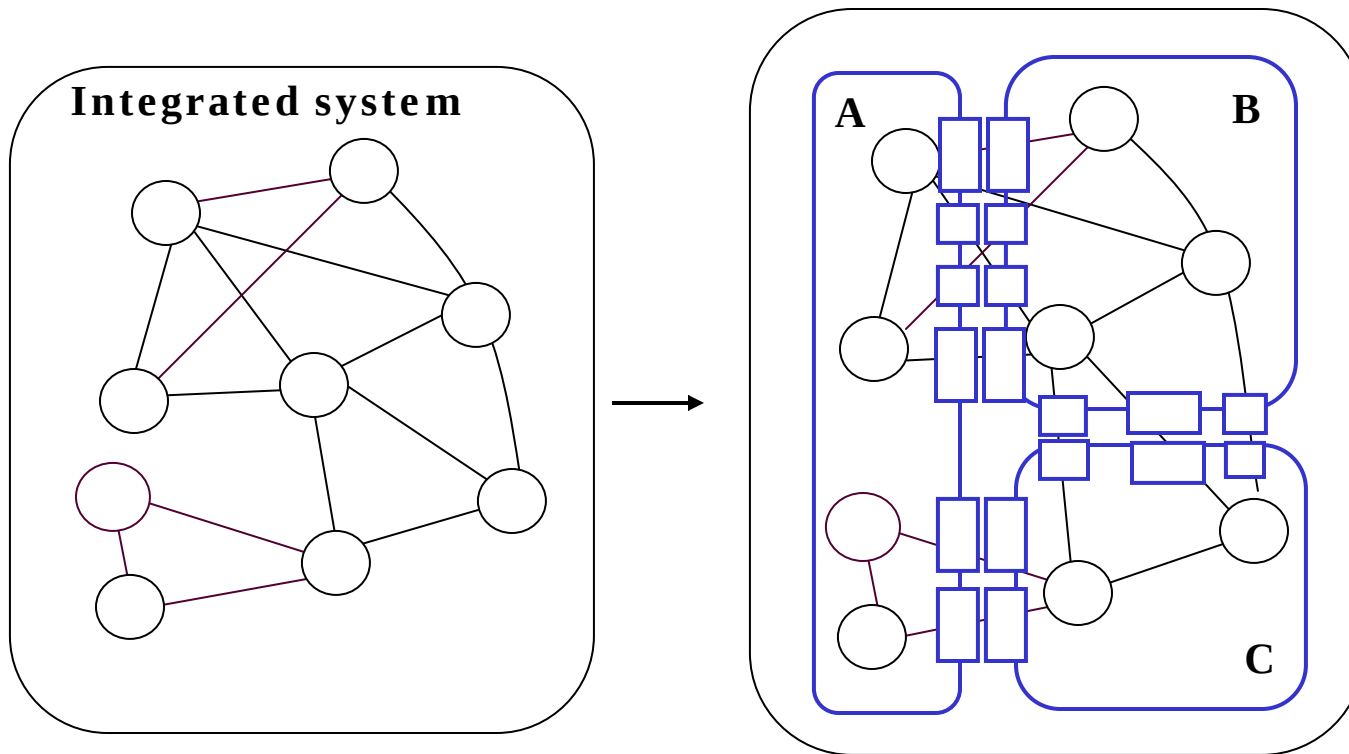
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Evaluating Modularity Tradeoffs

- **What are good decompositions?**

- Introduction of multiple considerations
- Understanding tradeoffs

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



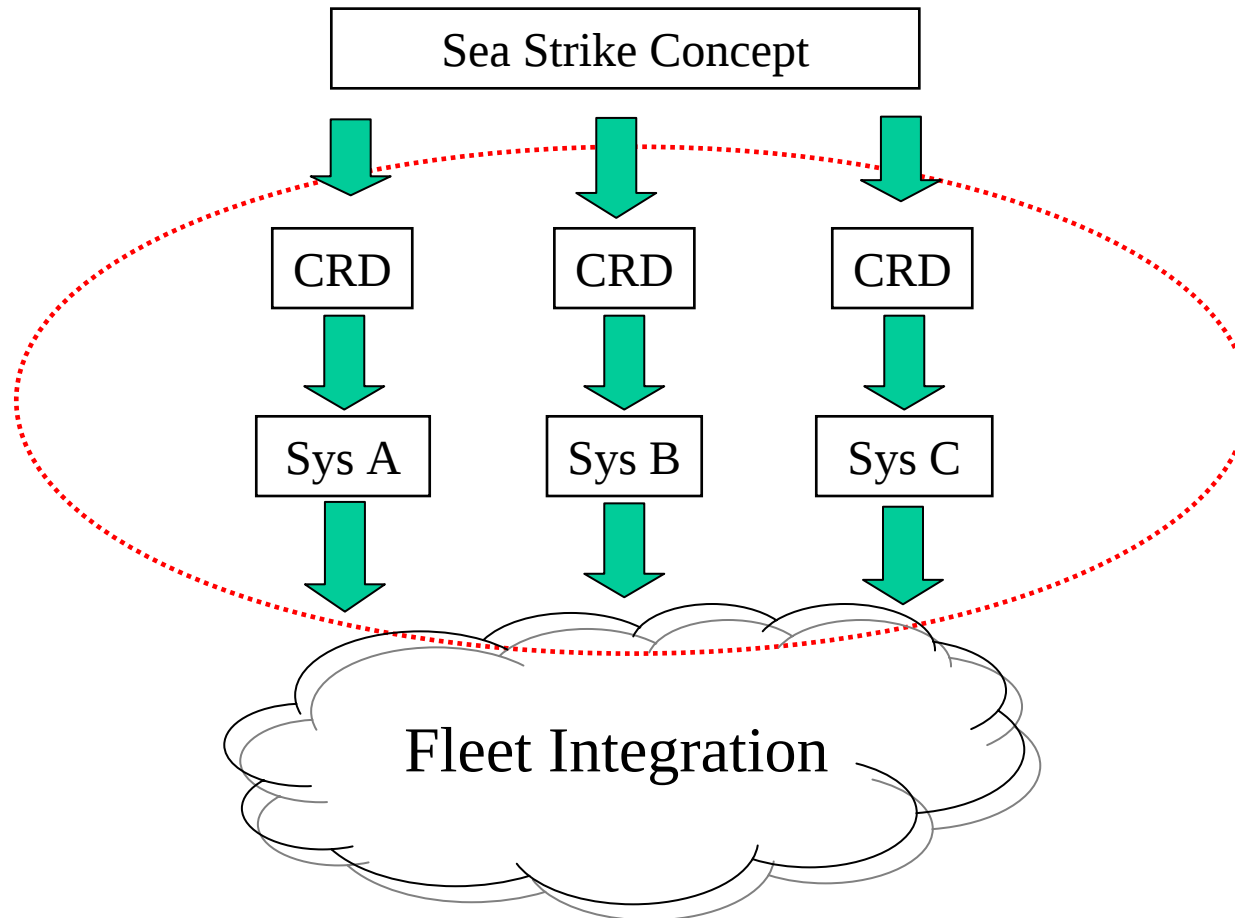
Pillars of Modular Systems

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

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

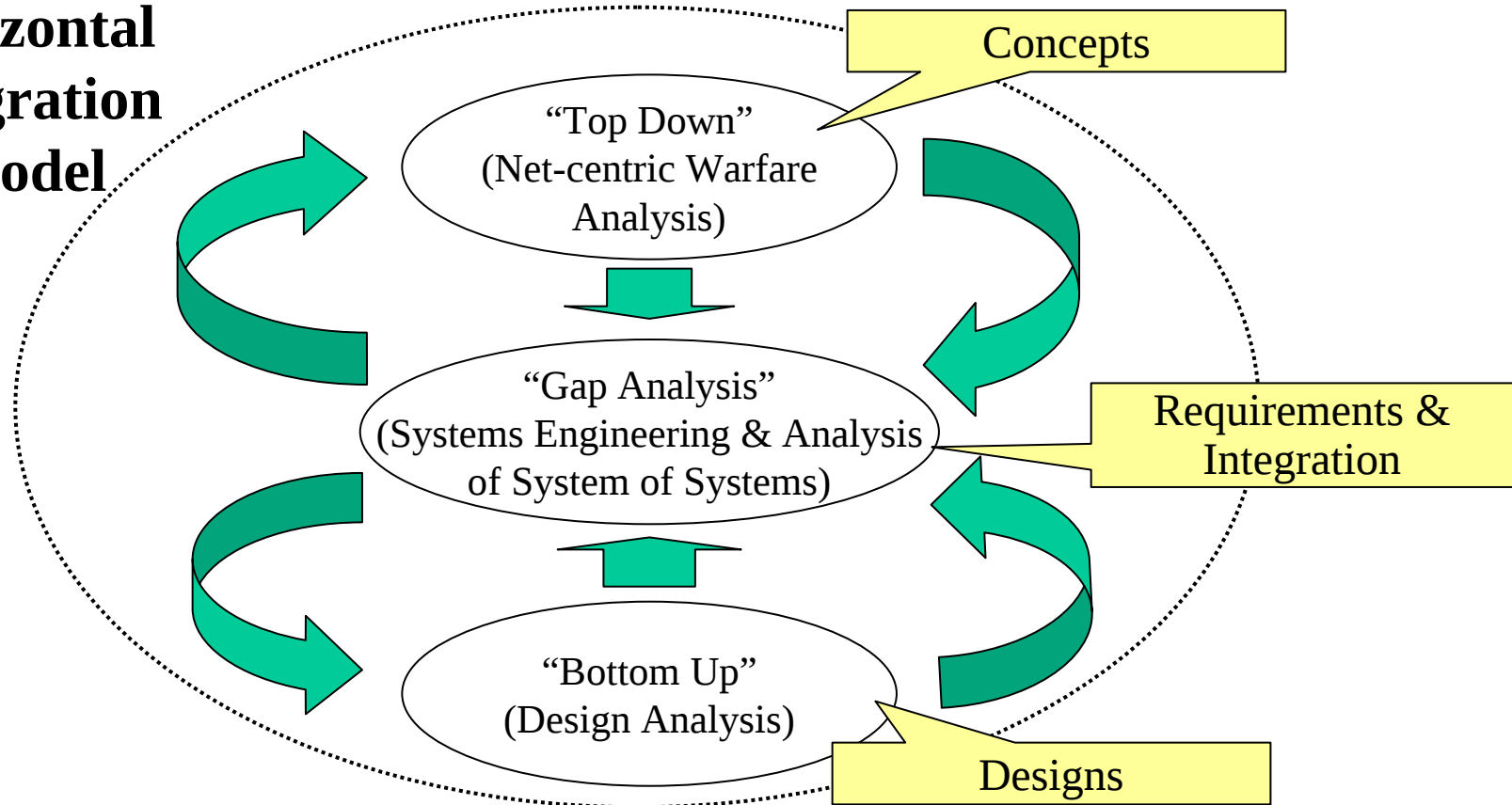
Background Systems Engineering

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*)

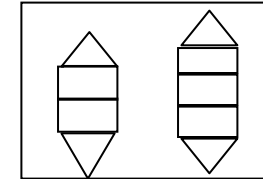
Defense Industry Specifics

- ***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

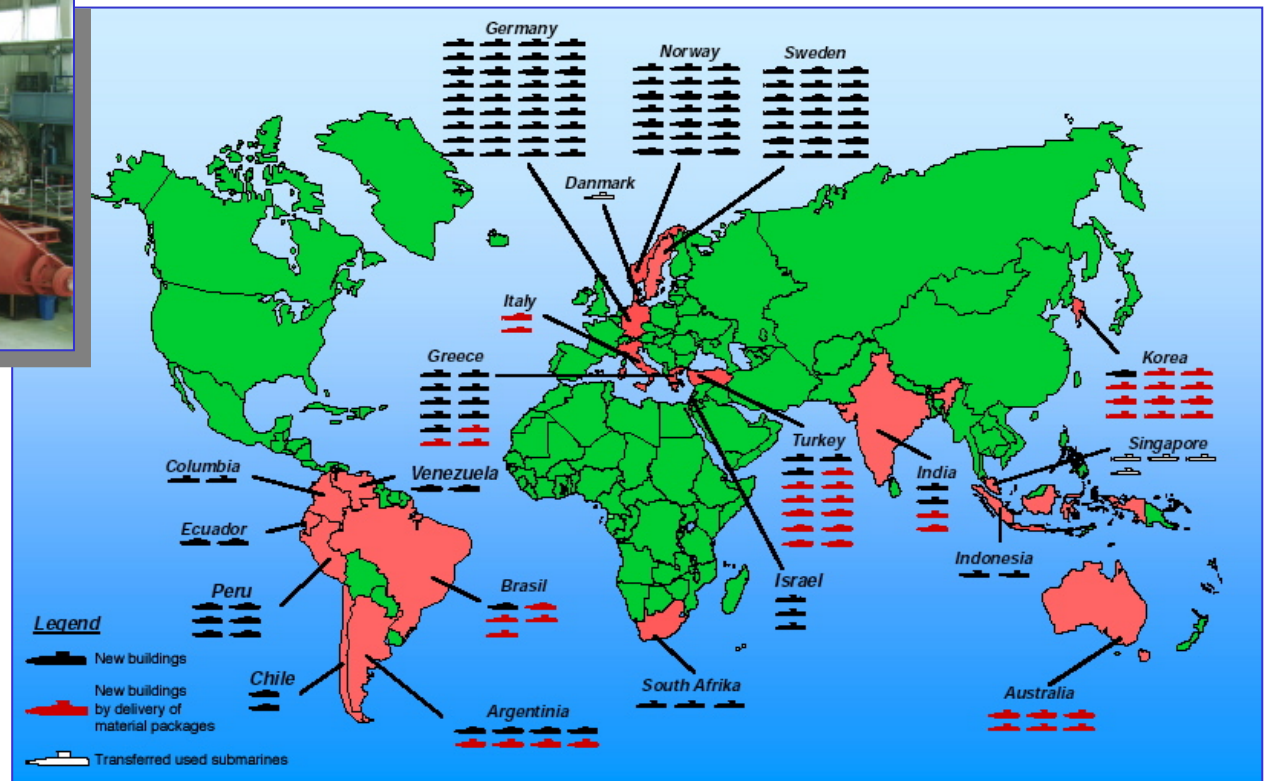
International Findings

- 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

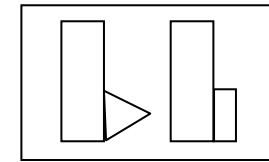
International Findings



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



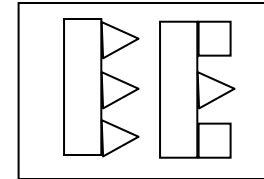
International Findings



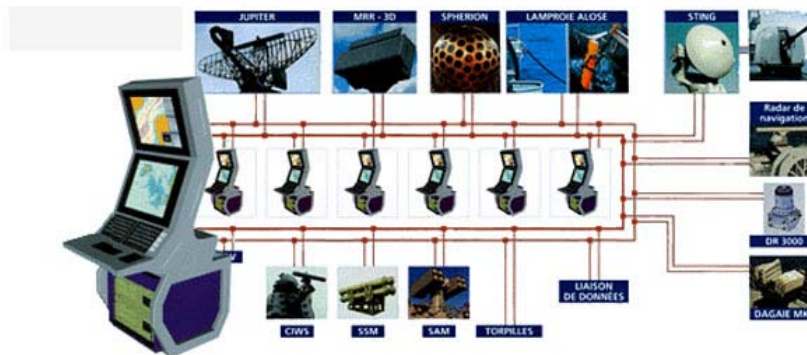
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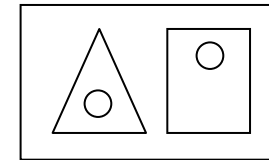
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Thales / TACTICOS TERMA / T-Core ® Thales / UBMS (<i>Bus Modularity</i>)	• Capability upgrades • Enable market penetration • Design reuse • Scalability	• Open Architecture infrastructure



International Findings



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



Systems Engineering Findings

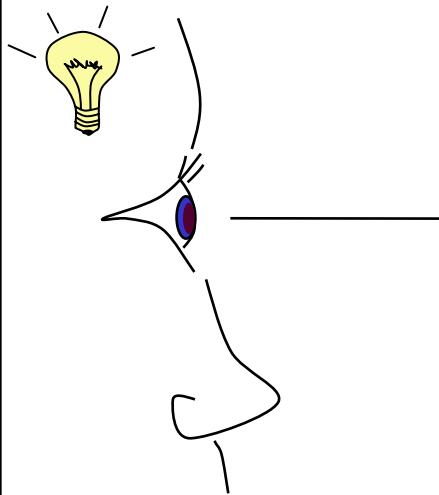
- ***Processes*** - poorly defined, inconsistently implemented
- ***Systems Engineers*** - significant deficiencies in numbers, education and experience – Government & Defense Industry
- ***No horizontal integration*** - Systems engineering, when performed, at platform/program level and stove-piped
- ***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

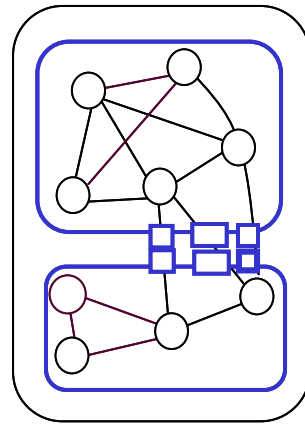
- Limited information on DoD implementations of modularity
 - Critical military factors (e.g. mission flexibility, acquisition tradeoffs) not considered in modularity optimization
 - Some studies related to systems engineering and modularity to Navy ships
 - No formal DoD analysis with explicit focus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

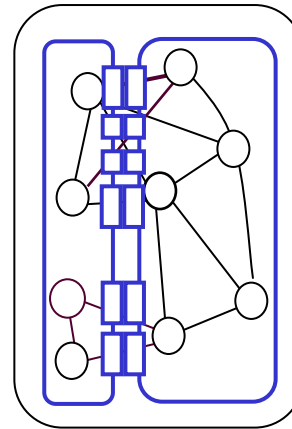


“Minimize interface complexity for reconfig.”



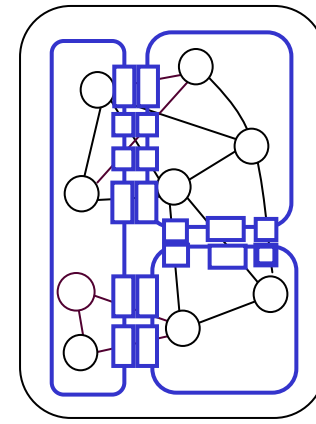
i

“Prepare for technical refresh”



j

“Prepare for technical refresh & ready for failure”



k

Utility(Partition *i*)=

$$f [\text{cost}^{\$}(\text{refresh}), \text{cost}^{\$}(\text{interfaces}), \text{cost}^{\$}(\text{failure}), \text{cost}^{\text{avail}}(\text{failure}), \dots]$$

Summary Findings

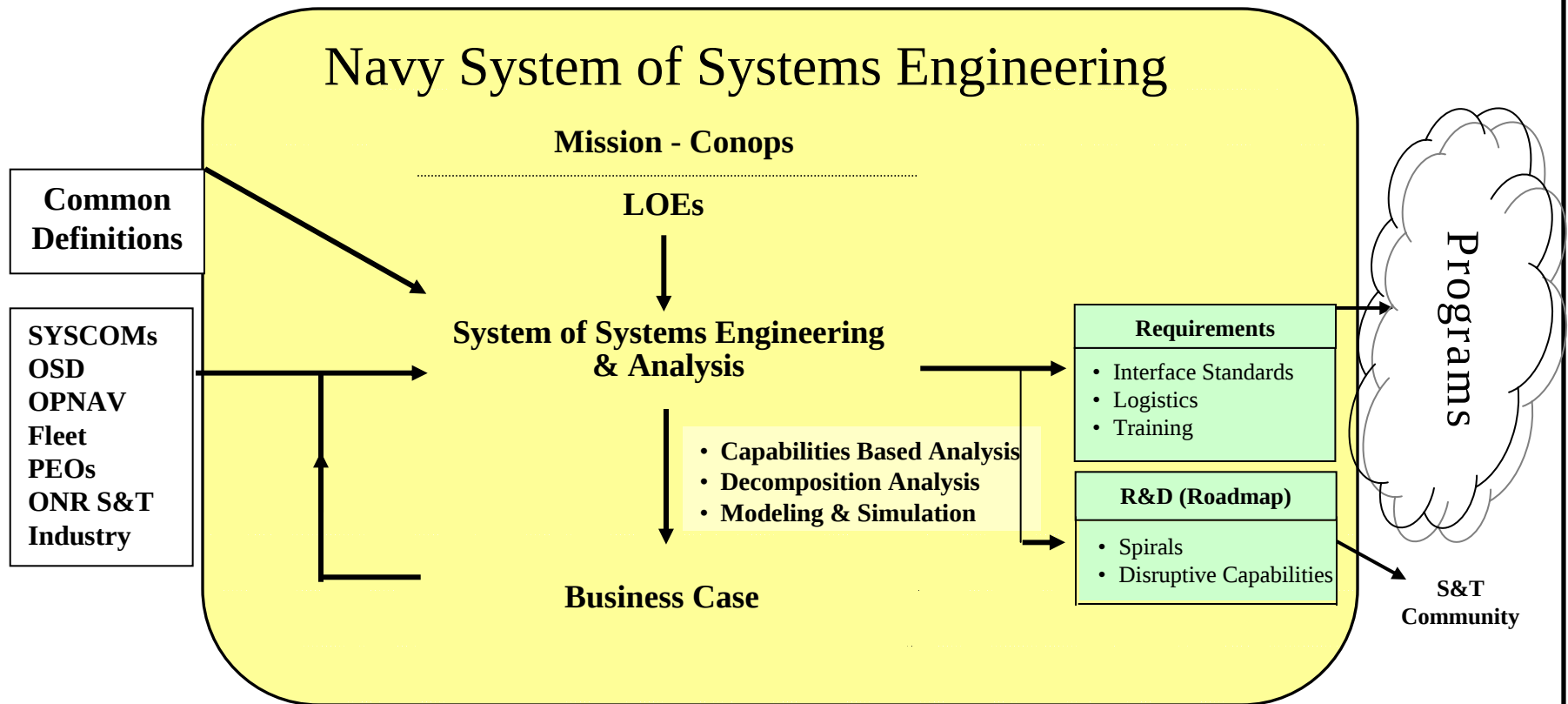
- ***Navy Programs*** – implementation of modularity delegated to primes; no horizontal systems engineering
- ***U.S. Defense Industry*** – systems engineering and modularity not uniformly applied within programs
- ***International industry*** - ahead of the U.S. defense industry in judicious use of 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

Summary Findings

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