Leveraging Software Development Approaches in Systems Engineering

Rick Steiner

Engineering Fellow

Raytheon Integrated Defense Systems

fsteiner@raytheon.com

6 May 2004

Naval Postgraduate School SI4000 Project Seminar

We're going to talk about:

Raytheon

- Why Software Tools exist, why Systems Engineers should care
- Software vs. SE as a discipline – key differences
- The importance of requirements
  - Different requirement/system development approaches
  - Pros & cons of each, and how they relate to software approaches
- How Use Cases relate to Requirements
  - Hints on how to manage use case development
- How Object Oriented Design relates to Functional Analysis
  - or not!
- What graphical languages can help (UML, SysML)
- The promise of Model Driven Architecture (MDA)

Software Development Crisis

- In the 1980's, software development underwent a crisis:
  - Software was RAPIDLY proliferating
  - Software was becoming very complex
    - Software on top of Software (OS, Application)
    - Software talking to Software (interfaces)
  - Software development delays were holding up system delivery
  - Software was becoming very expensive to develop and maintain
  - Software development effort was becoming very hard to estimate
  - Software reliability was becoming problematic
  - Existing techniques were proving inadequate to manage the problem
- Reasons:
  - Economics
    - Processing hardware (silicon) got cheap
      - Easy way to add capability
    - Cheaper to modify product through software than hardware

Response to the Software Crisis

Raytheon

- In the ’90’s, software development changed:
  - New methods
    - Scalability – Structured Analysis – Coad/Yourdon
    - Reuse – Object Oriented Design
  - <u>Model based</u> tools & techniques
    - CASE tools – Excellerator, TeamWork, Software through Pictures
    - Software modeling languages & techniques
      - Unified Modeling Language (UML)
        - Object Modeling Technique (OMT) - Rumbaugh
        - Use Cases - Jacobsen
        - Sequence Diagrams – Booch
      - Specific techniques (ROOM, RUP, 4+1, etc.)
    - Estimating models & tools: COCOMO, SEER, Price-S, etc.
- When appropriately applied, these changes dramatically improved the predictability, productivity, and quality of software development!
  - Software began to play a progressively larger role in the product system.

Differences between SW and Systems

Raytheon

	Software Engineering	Systems Engineering
Mission	Efficiently develop software that meets requirements	1) Ensure requirements correct 2) Ensure system works
Product	Software ready for integration	1) Specifications 2) Integrated, usable system
Lifecycle	Development (design, code, test)	1) Concept -> Requirements 2) Integration -> Acceptance 3) Disposal
Focus	Source code, diagrams	Requirements, tests, reports
Done when	Code compiles error free, unit test complete	1) Requirements balanced 2) System accepted

Systems Development Problem

Raytheon

- In the ’90’s, system development underwent a crisis:
  - Systems were becoming very complex
    - Systems on top of Systems (SoS)
    - Systems talking to Systems (system level interfaces)
  - Systems Engineering delays were holding up software development
  - Systems were becoming very expensive to develop and maintain
  - Systems development effort was becoming very hard to estimate
  - Systems reliability was becoming problematic
  - Existing techniques were proving inadequate to manage the problem
- Reasons:
  - Demand for increased capability
  - Systems becoming software intensive (embedded processing)
  - Decreased manning driving increased automation
  - Reliability of manned systems and weapon systems cannot be compromised, in spite of rising complexity

Systems Engineering Response to the Problem

Raytheon

- In the ’00’s, system development is changing:
  - More rigorous approaches to Requirements
  - Use of Models to specify systems
  - Adoption of successful software modeling methods
    - Model Driven Development
    - Hatley-Pirbhai
    - Object Oriented Techniques
  - Adaptation of software modeling languages & techniques to systems engineering
    - System Modeling Language (SysML)
  - Estimating models & tools: COSYSMO
  - Development of new methods
    - Systems Architecting

Characteristics of a Good System Development Approach

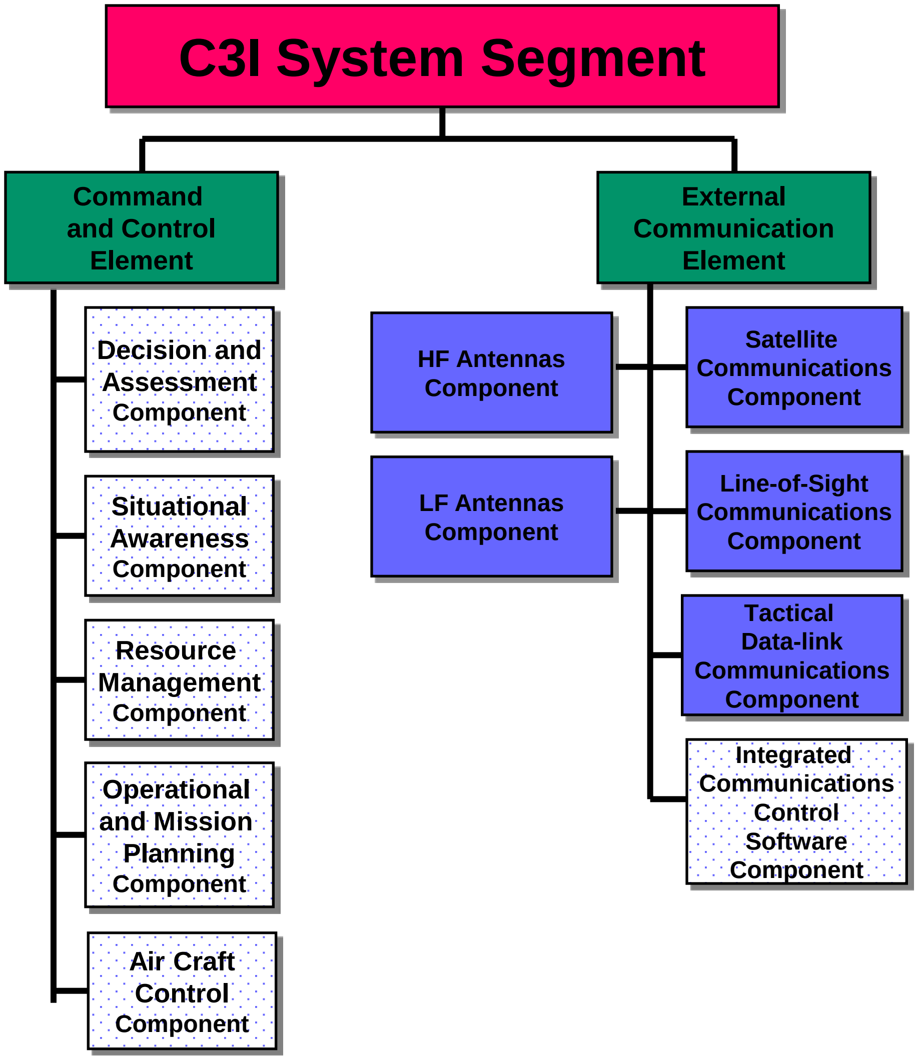
- Sort wants from needs
  - Identify and relay imperatives
  - Track and tradeoff everything else
- Validate imperatives
- Manage/control level of abstraction
  - Segregate requirements from design at each level of abstraction
- Keep track of Form vs. Functional imperatives
- Provide a framework for assessing completeness of all requirements & design
- Provide a framework for assessing consistency across all requirements & design
- Provide a framework for verifying product meets the requirements

Document Driven Approach

Raytheon

The *traditional* approach:

- Characterized by textual specifications
- Specifications created and managed as documents
- Specifications provided in a hierarchical tree
- Specifications may be parsed and requirements linked in a database



Document Driven Pros & Cons

Raytheon

Advantages:

- Easy to understand, traditional approach
- Clear, straightforward hierarchy of specifications quickly defines levels of abstraction
- In precedented systems, can rapidly partition requirements development task
- Allows loose coupling between requirements developers
  - Can make rapid progress early in program, compared to other methods

Disadvantages:

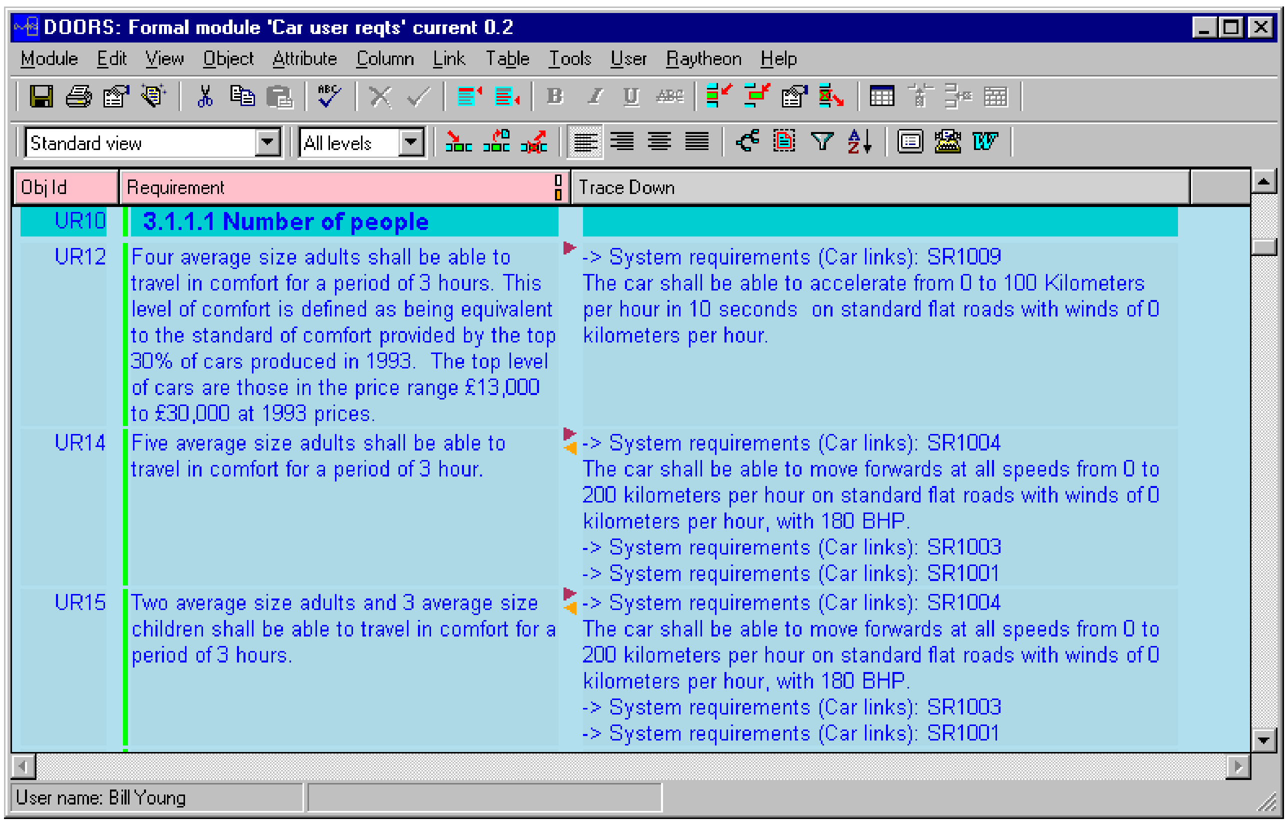
- Consistency of requirements hard to assess
  - must read many documents, manually link related requirements
- Large “chunks” of requirements unwieldy
  - latencies associated with specification updates are significant
  - need for reparsing/retracing of requirements after each update
- Product tree needs to be defined in advance
  - not amenable to unprecedented systems
- Requirement definition can outpace analysis & design
  - lower level requirements defined before impact at higher level design is understood
- Focus can easily revert to quantity, rather than quality of requirements

Database Driven Approach

Raytheon

Becoming more commonplace in Systems Engineering:

- **characterized by integrated requirements/design databases**
  - **requirements are records in relational database**
  - **relations between requirements, attributes of requirements emphasized**
- **“specifications” are views into database**
- **requirements hierarchy very flexible**



Database Driven Pros & Cons

Raytheon

Advantages:

- Difficult to defer rigor
  - need thorough analysis of requirements up front
  - difficult to "cheat" to save time
- Benefits of clear linkage
  - on-demand consistency checking
  - facilitated completeness checking
  - on-demand verification
- flexible hierarchy
  - can easily move requirements to appropriate level of detail
- rapid cycle time for updates
  - on-demand change impact assessment
  - clear ownership control
- unambiguous linkage to design tools

Disadvantages:

- Difficult to defer rigor
  - need thorough analysis of requirements up front
  - difficult to "cheat" to save time
- Slow startup… many decisions need to be made up front
  - requirements heirarchy, multiple heirarchy - need <u>CLEAR vision</u> of what to do!
  - guidelines for requirements attributes
  - specification scripts
  - linkage to design tools
  - training, training, and relevant training
- Investment in resources
  - experienced toolsmith
  - experienced process owner

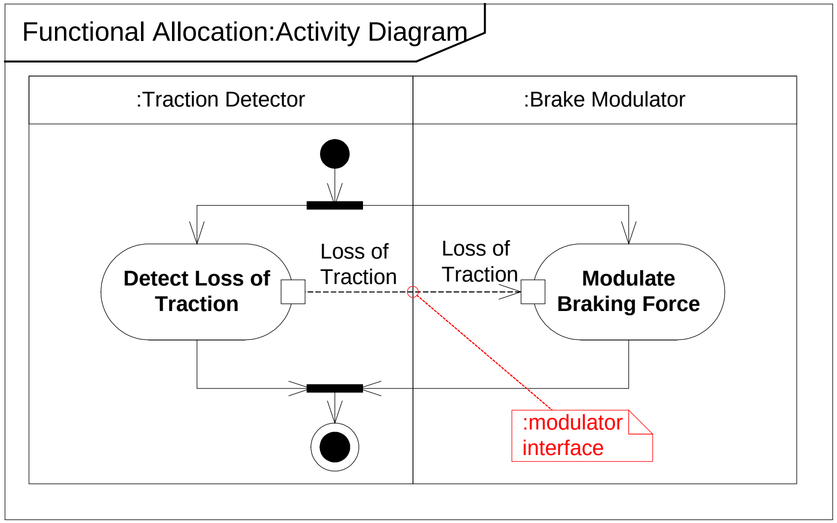
Model Driven Approaches

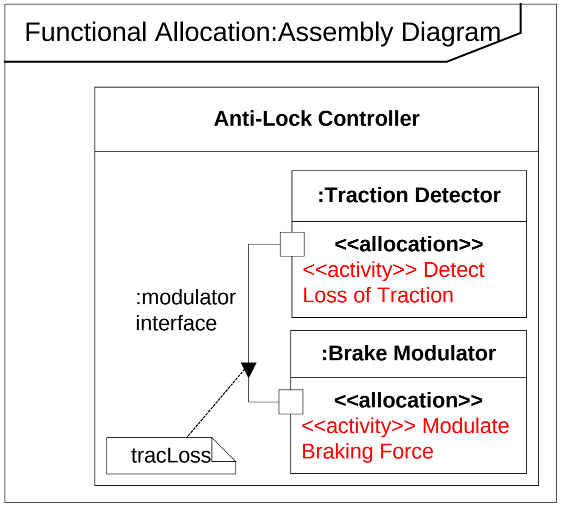
Raytheon

Becoming more common in Software development

Rarely implemented at Systems Engineering level - high risk, high payoff

- **characterized by integrated model that represents both design and requirements**
- **“specifications” are views into model**
- **“requirements hierarchy” doesn’t exist by itself**
  - **“requirements” are simply characteristics of the model**





Model Driven Pros & Cons

Raytheon

Advantages:

- Strong enforcement of rigor
  - need thorough analysis of requirements up front
  - impossible to "cheat" to save time
- Clear, unambiguous system definition
  - clear allocation of function onto form
- Benefits of clear linkage
  - on-demand consistency checking
  - facilitated completeness checking
  - on-demand verification
- Possible to eliminate "shalls" altogether
  - "firmness" becomes an attribute of model elements
- Very rapid cycle time for updates
  - on-demand change impact assessment
  - clear ownership control
- Unambiguous linkage to design tools

Disadvantages:

- Impossible to defer rigor
  - impossible to "cheat" to save time
- Slow startup… many decisions need to be made up front
  - syntax and relationship of proposed models must be crystal clear!
  - guidelines for model attributes
  - linkage to design tools
  - training, training, training, experience, and relevant training
- Significant up front investment in resources
  - Very experienced toolsmith
  - Very experienced process owner
- The model can become as complex as the product itself

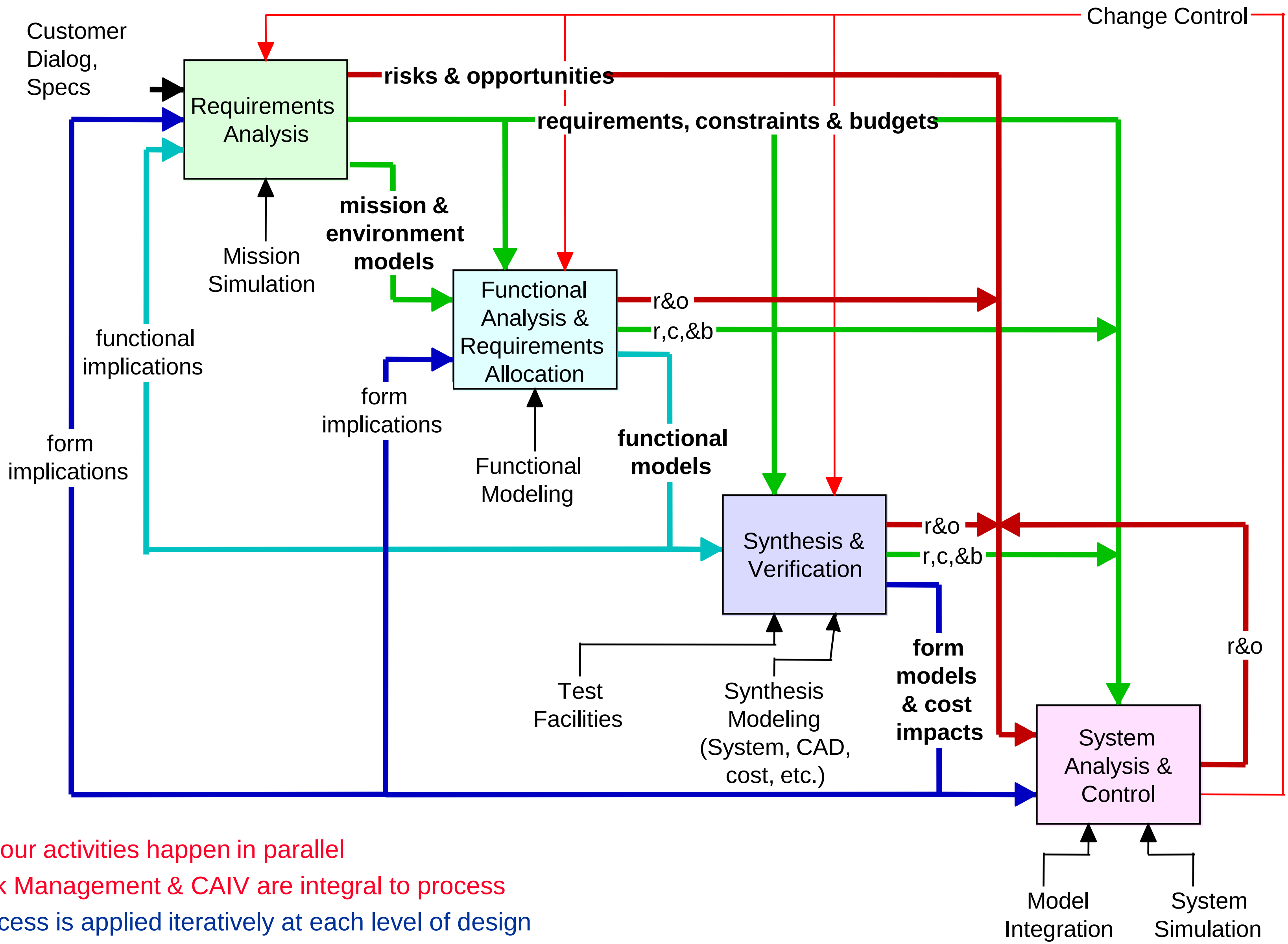
Development Approach Scorecard

Raytheon

Characteristic	Document Driven	Database Driven	Model Driven
Sort wants from needs	“Shall” statements	Attributes, link to CONOPS	Attributes of model elements
Validate imperatives	Manual only	Link to analyses	Model execution, links to analyses
Manage/control level of abstraction	Spec tree: specification vs. design description	Hierarchy, requirement tree	Product hierarchy, consistency checks
Form vs. functional imperatives	Typically poor segregation	Attributes, scripts, filters	Separate form, function, and allocation
Framework completeness	All top level requirements traced to lower level	Vertical linkage, hierarchy	Vertical linkage
Framework consistency	Typically poor – some peer to peer requirements tracing	Horizontal linkage	Horizontal linkage
Framework for meeting the requirements	System Requirements Verification Matrix	Link to verification database	Development and verification scenarios
Semantics captured	Low	Medium	High
Design iteration time	Long	Medium	Short

EIA 632 SE Process IDEFØ w/ Models

Raytheon



- All four activities happen in parallel
- Risk Management & CAIV are integral to process
- Process is applied iteratively at each level of design

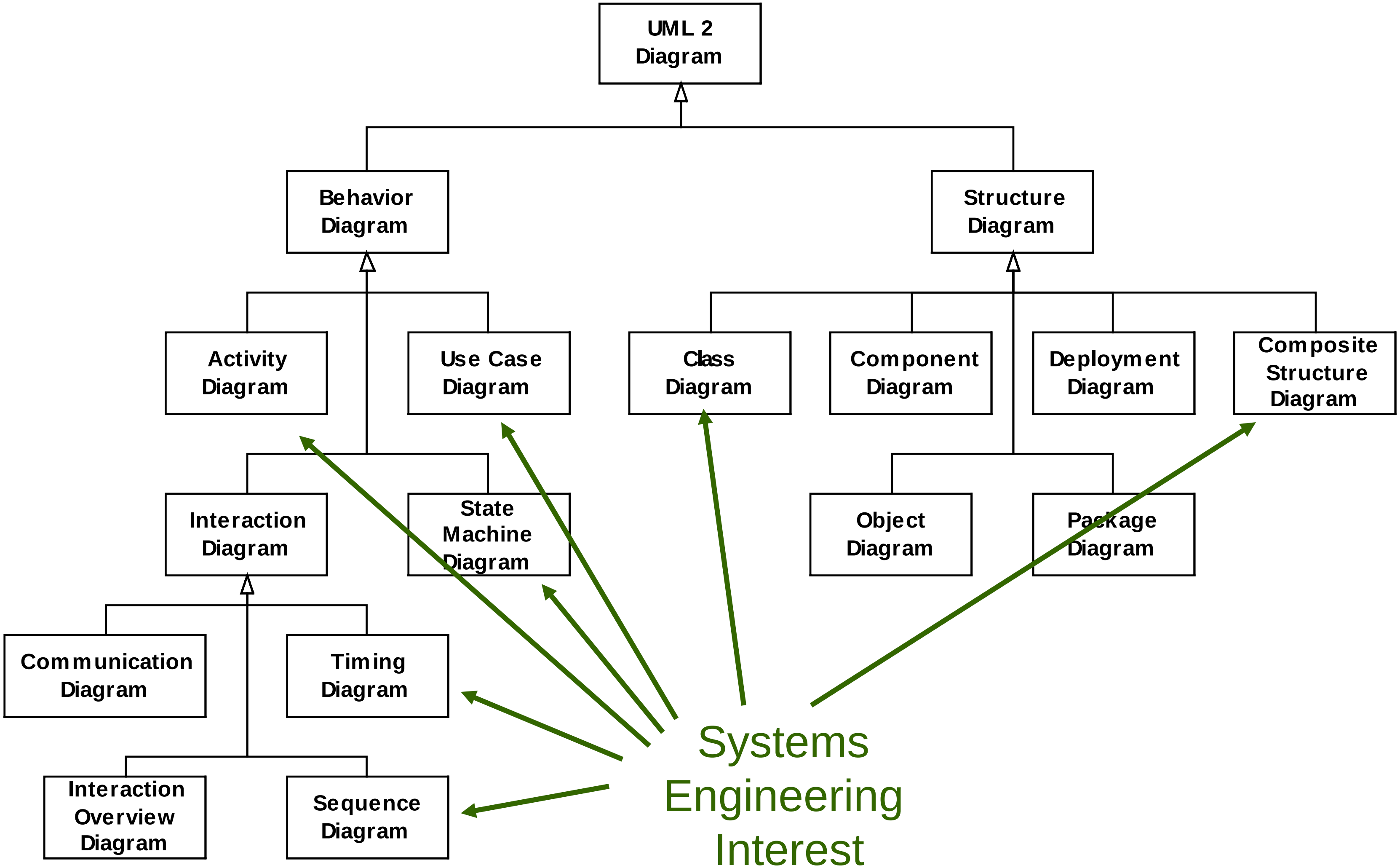
Unified Modeling Language (UML)

Raytheon

- UML is maintained by the Object Management Group (OMG)
- The Unified Modeling Language (UML) is
  - a ***graphical*** language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system. (from the OMG UML 1.4 specification, emphasis added)
  - the industry standard for expressing and communicating object-oriented software designs
- Has undergone several revisions
  - 1.0 Original submittal - Never released
  - 1.1 UML Partners final submittal - First approved standard
  - 1.2 Editorial clean-up - Document changes, no technical changes
  - 1.3 Revisions, not enhancements - Clarifications and corrections
  - 1.4 Revisions to UML extensions - Released late 2001
  - 2.0 Major revisions to Behavior and Structure
    - Approval August 2003, release expected soon.
- So what does that mean to the systems engineering community
  - The OMG, in cooperation with INCOSE and ISO are exploring ways to expand the role of UML into the realm of systems engineering

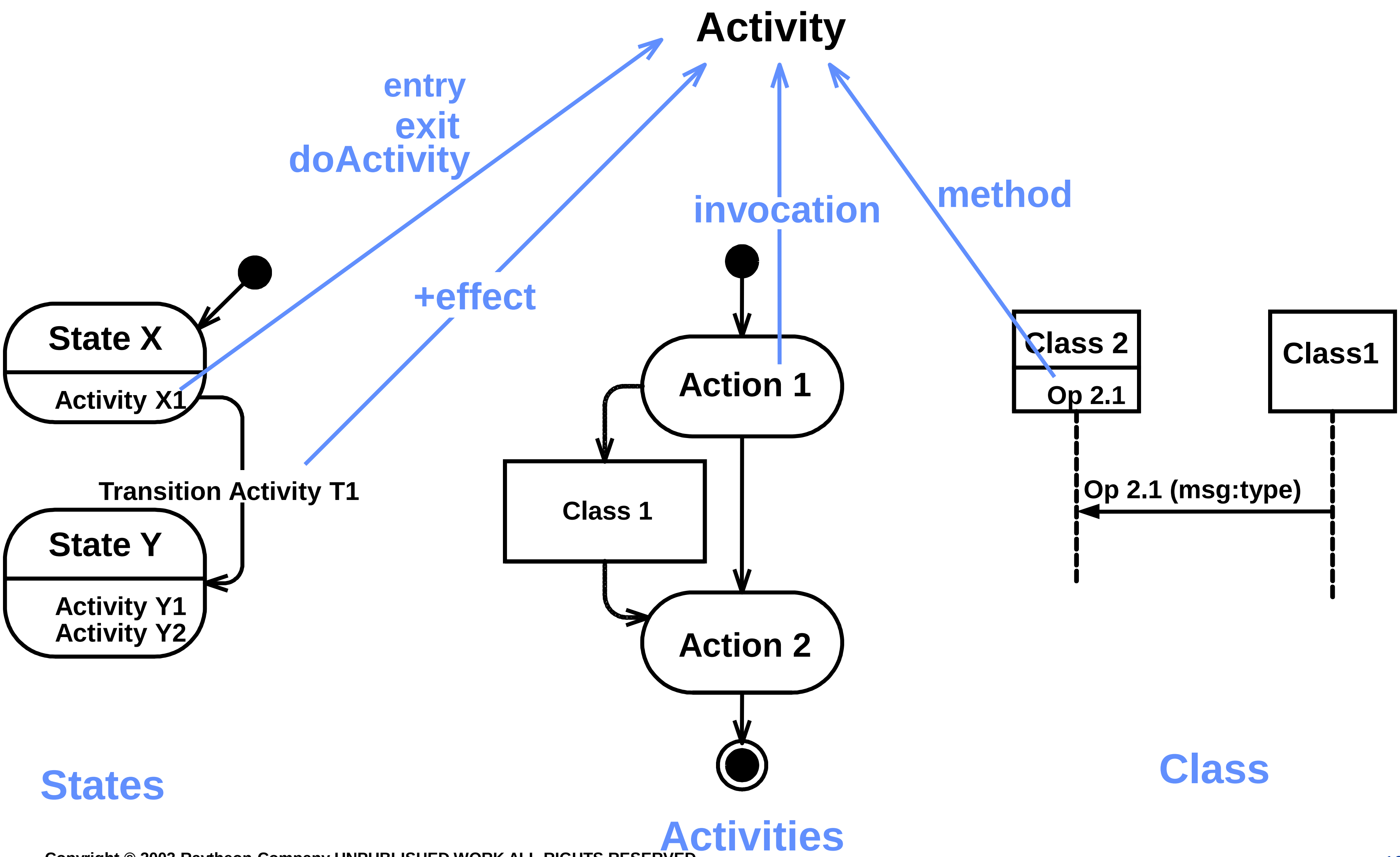
UML 2 Diagram Taxonomy

Raytheon



Behavior in UML 2

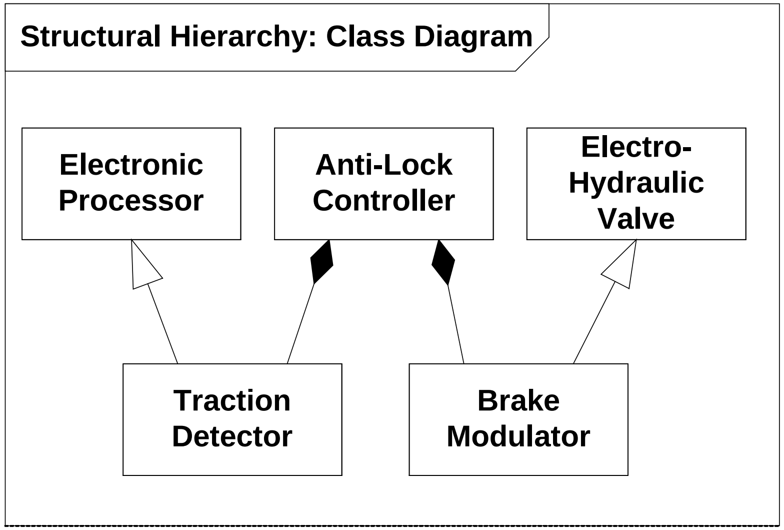
Raytheon



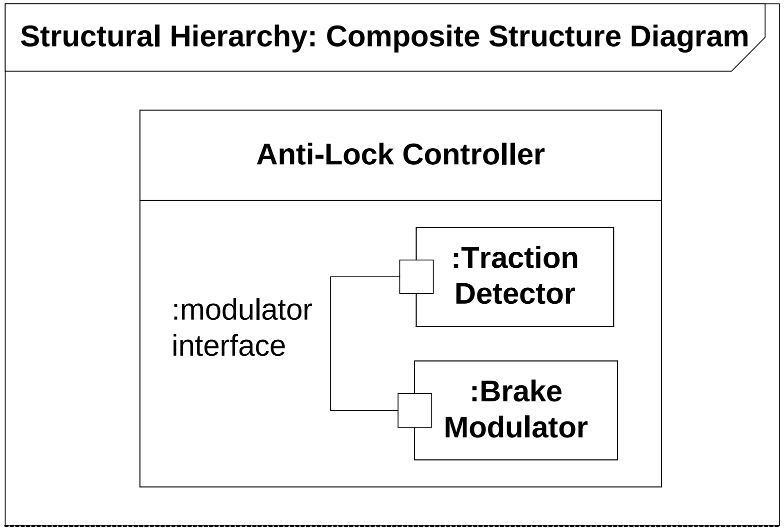
Structure in UML 2

Raytheon

Definition
(Class Diagram)



Use
(Composite Structure Diagram)



Extending UML to Systems Engineering

Raytheon

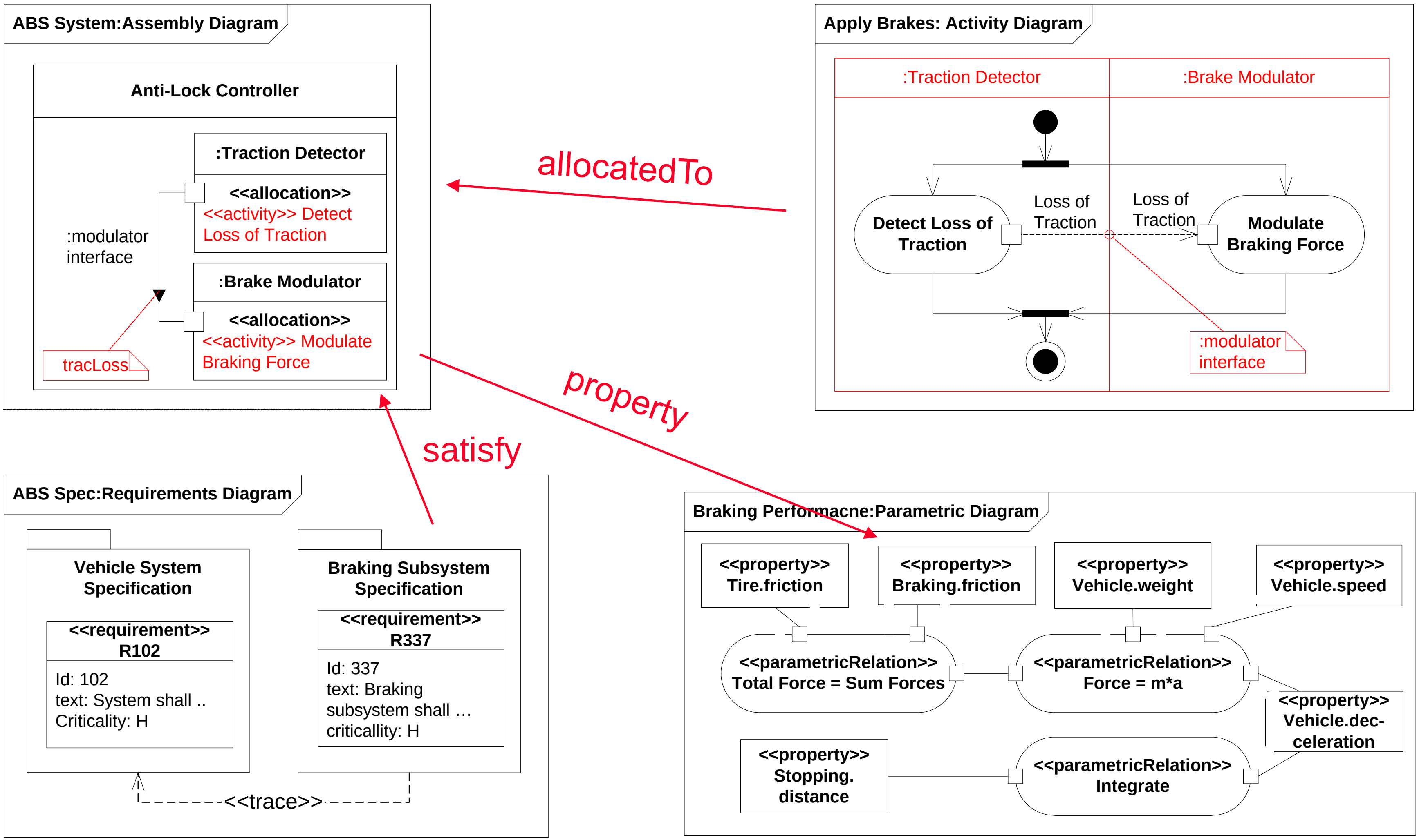
- **OMG Systems Engineering Domain Special Interest Group - http://syseng.omg.org**
  - joint INCOSE-OMG initiative chartered in 2001- collaborated with UML2
  - drafted UML for SE RFP, issued by the OMG in March 2003
- **Systems Modeling Language (SysML) – http://www.sysml.org**
  - SysML Partners organized in May 2003 to respond to RFP
    - Industry - BAE SYSTEMS, Deere & Company, IBM, Lockheed Martin, Motorola, Northrop Grumman, Raytheon, Thales
    - Government - NASA/JPL, NIST, OSD
    - Tool Vendors - Artisan, Gentleware, IBM/Rational, I-Logix, Telelogic, Vitech
    - Liaisons - AP-233, INCOSE, Rosetta, EAST, Ptolemy
  - SysML will customize UML 2.0 to support the specification, analysis, design, verification & validation of complex systems.
  - SysML Draft spec presented to INCOSE in January, OMG in February 04
  - SysML 1.0 spec will be submitted to OMG in August 04, expect release in early ‘05

4 Pillars of SysML

Raytheon

Structure

Behavior



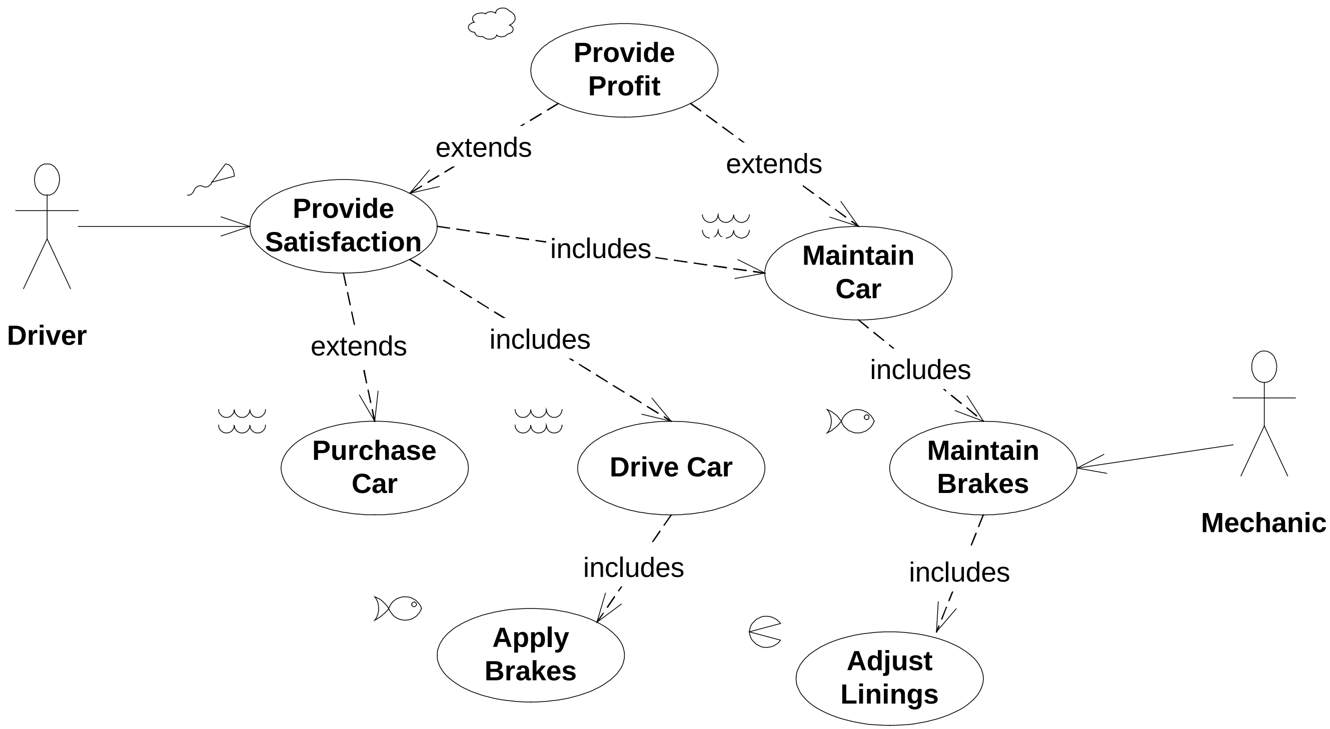
Requirements

Parametrics

Object Oriented Analysis (OOA) & Use Cases

Raytheon

- **OOA focuses on SERVICES the system is to provide, rather than functions the system performs**
- **Use Cases are *textual* descriptions of scenarios**
  - **They usually follow a standard format or template**
  - **They address sequences - “happy path” and alternate paths**
  - **They can include diagrams to show sequences/behavior**
  - **They can address various levels of detail**
  - **The relationships between Use Cases can be represented in a diagram**



Use Case Pros & Cons

Raytheon

Advantages:

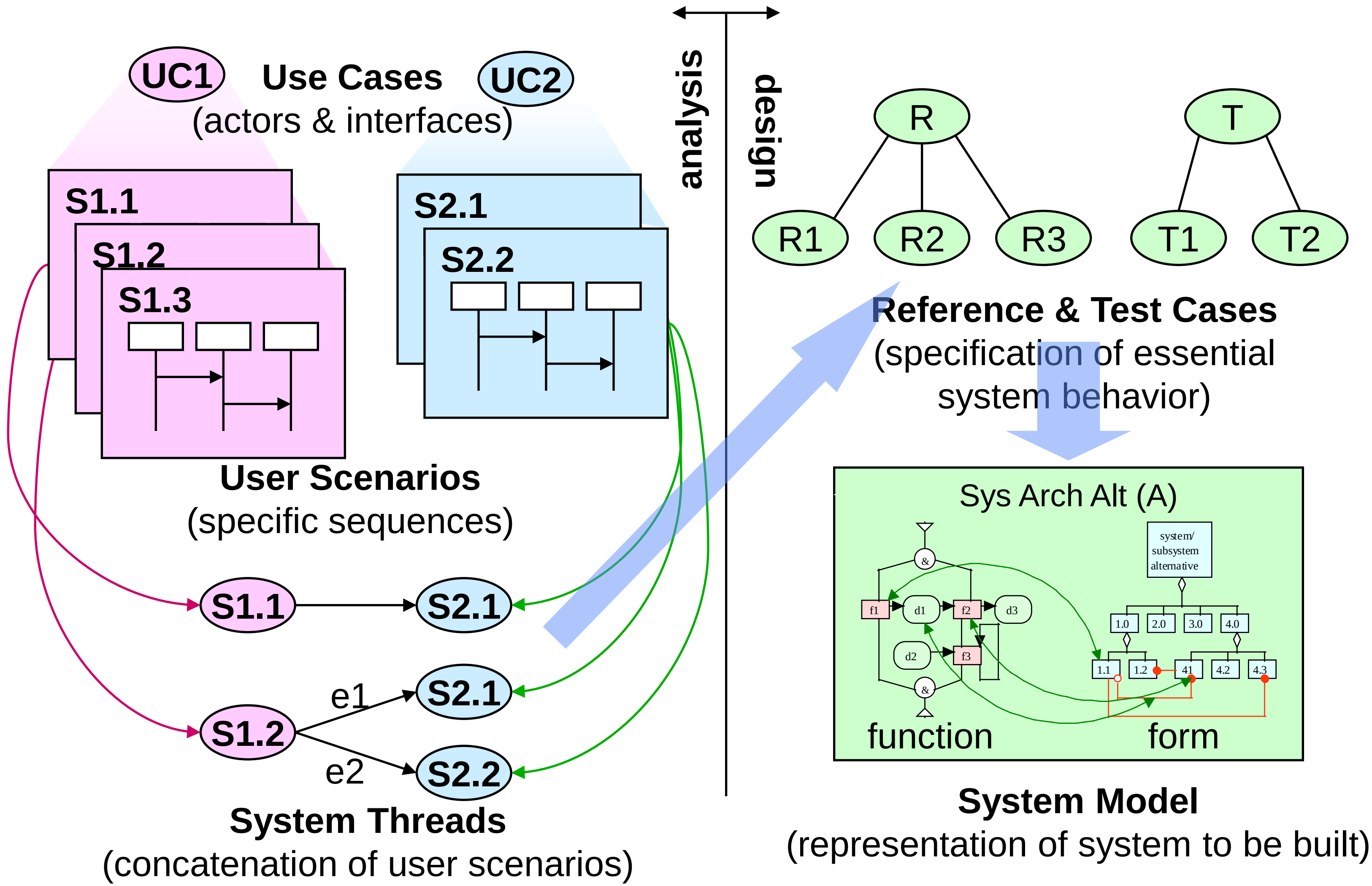
- Help segregate problem from solution
  - Services aren't functions
- Help focus on most important aspects of system
- Used throughout design process, and into testing
  - Basis for test planning
- Vehicle for dialog with customer
- Vehicle for dialog with software developers
- Can be used in conjunction with requirements database to generate specification
  - This is an extension to OOA

Pitfalls:

- Difficult to estimate in advance
- Incomplete
  - Only relate to functional requirements
  - Not performance or non-functional requirements
- Explosion of Use Cases for complex systems
  - Difficult to manage
  - When are you finished?
- Confusion/overlap with functional analysis
  - Services aren't functions

Managing Use Cases

Raytheon



Object Oriented Development (OOD)

Raytheon

- OOD focuses on maximizing cohesion and minimizing coupling
  - Maximizing Cohesion: grouping objects together that tightly interrelate
  - Minimizing Coupling: simplifying interfaces between groups of objects, making them as independent as possible
- This makes objects reusable
  - Aids in the “definition – usage” pattern discussed earlier
  - Isolates the behavior and data of each object from every other object

Advantages:

- Reusable objects, each self contained
  - Significantly reduces subsequent development time
- Strong interface management
- Proven value on non-realtime software development

Pitfalls:

- Extra bulk, overhead that doesn’t add capability in execution
- Cannot separate Form and Function
  - Not amenable to functional specification
- Data is internalized
  - Not amenable to data engineering

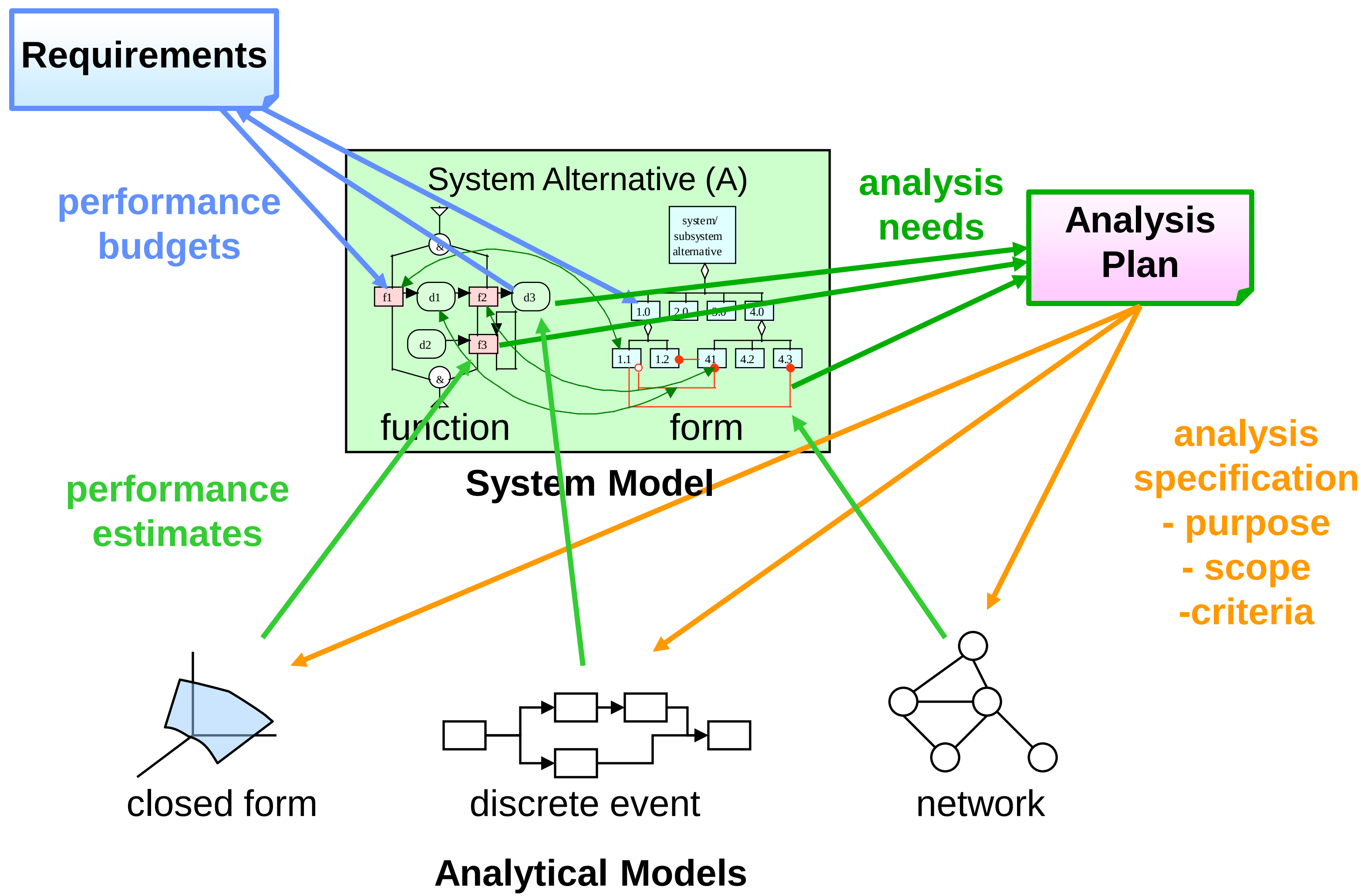
Model Driven Architecture (MDA)

Raytheon

- MDA has been developed & promoted by the OMG
  - See also “Executable UML” – Steve Mellor
- Agreement that existing OOD techniques can be too restrictive
  - Need to model patterns, abstract architecture
  - I see this as a way of segregating form (what) from function (how)
- MDA uses two DIFFERENT modeling levels:
  - Platform Independent Model (PIM)
    - All abstract (non-instantiable) classes, no language dependency
    - Focus on grouping of behavior, data, interfaces
    - I call this “logical architecture”
  - Platform Specific Model
    - Specific languages (Java, C++, etc) and compilers
    - Implementation details
  - One PIM can have many compliant PSMs

System Model & Performance Analysis

Raytheon



Summary

Raytheon

- Systems Engineering needs help to manage development of today's complex systems
- Software Engineering has a variety of tools and techniques which have proven successful
- Applying Software Engineering techniques to SE needs to be done with a full understanding of the scope of SE objectives
- While advanced model driven techniques are appropriate for complex, unprecidented, ultra-quality systems, these techniques require
  - Training
  - Tools
  - Startup time
- These advanced techniques aren't ALWAYS appropriate, especially for highly precedented or legacy systems.

Bibliography

Raytheon

- http://syseng.omg.org (OMG SEDSIG site)
- http://www.sysml.org (SysML Partners site)
- Writing Effective Use Cases, A. Cockburn, Addison-Wesley, 2000, ISBN 0201702258
- UML Distilled, M. Fowler et. al. Addison-Wesley, 1999, ISBN 020165783X
- "Topics in Modern Requirements Development", R. Steiner and J.M. Green, San Diego INCOSE tutorial
- "System "Late Binding" of Function to Form using UML", R. Steiner, San Diego INCOSE 2003 mini-conference
- "Threads, Reference Cases, and System Models: Adapting OOA to Complex System Specification", R. Steiner, Proceedings of INCOSE Symposium 2001
- ""Shoot the Modelers & Begin Design"; Focusing Analysis on Design Using a System Model", R. Steiner, Proceedings of INCOSE Symposium 2001