CCSDS

Architecture Working Group

Tools for Describing Space Data Systems Reference Architecture

19 May 2004

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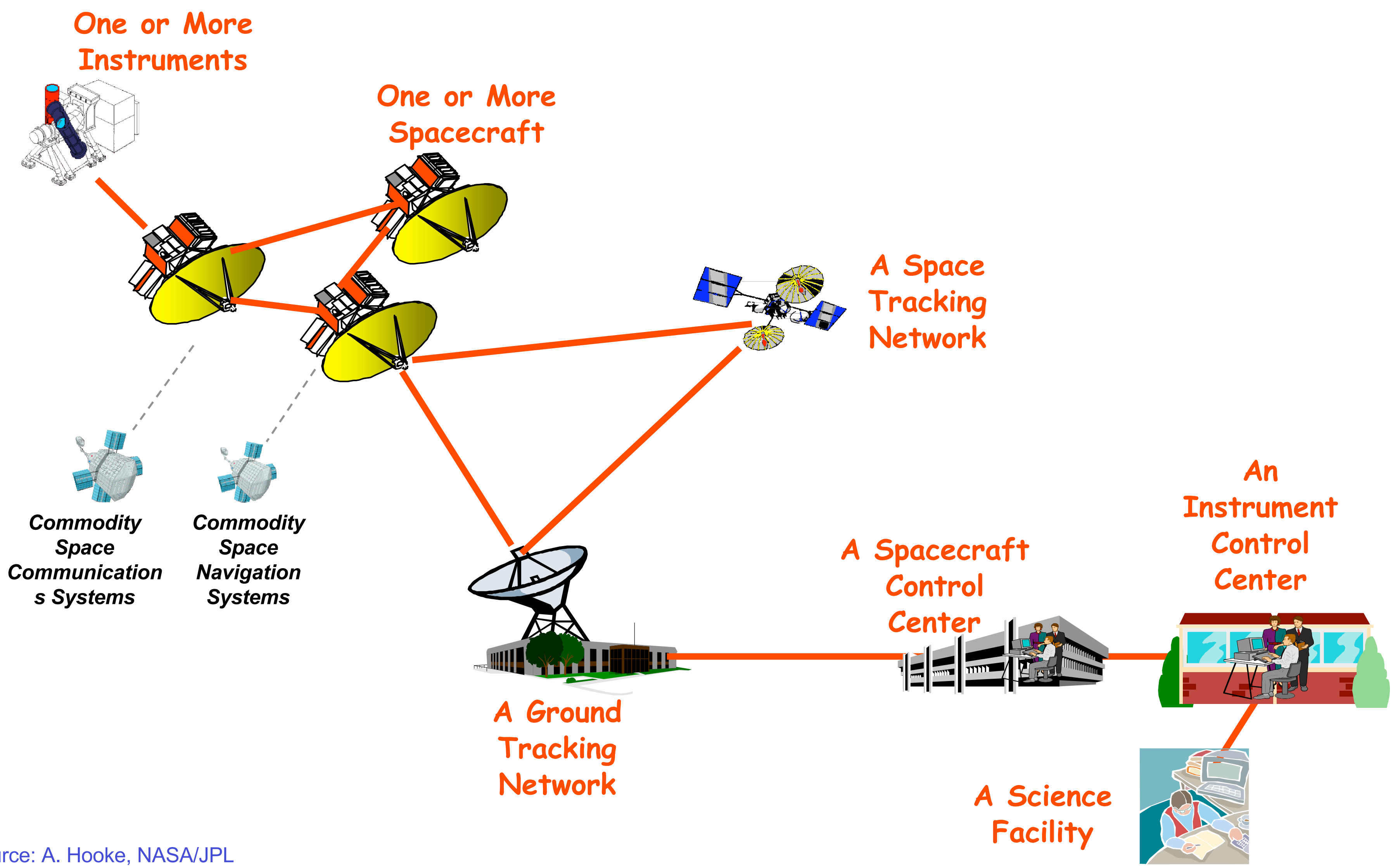
Agenda

- Introduce the Reference Architecture for Space Data Systems (RASDS)
- Show some examples of how it can be used to model space data systems
- Define the RASDS requirements on formal methodologies & tools
- Describe our analysis of using SysML to provide the means to formally describe RASDS models

A Physical View of a Space Data System



Source: A. Hooke, NASA/JPL

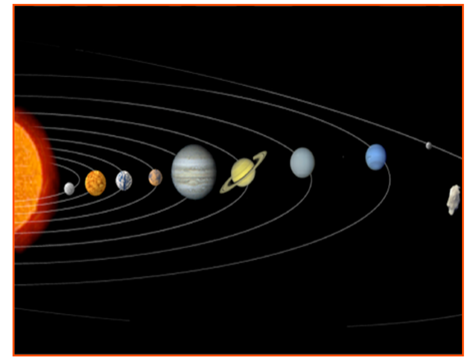
Reference Architecture Purpose

- Establish an overall CCSDS approach to architecting and to developing domain specific architectures
- Define common language and representation so that challenges, requirements, and solutions in the area of space data systems can be readily communicated
- Provide a kit of architect's tools that domain experts will use to construct many different complex space system architectures
- Facilitate development of standards in a consistent way so that any standard can be used with other appropriate standards in a system
- Present the standards developed by CCSDS in a systematic way so that their functionality, applicability, and interoperability may be clearly understood

Technical Approach

- Develop a methodology for describing systems, and systems of systems from several viewpoints
  - Initial focus was CCSDS, but it is more generally applicable to space data systems
  - Derived from Reference Model of Open Distributed processing (RM-ODP), which is ISO 10746
  - Adapted to meet requirements and constraints of space data systems
- Define the needed viewpoints for space data system architecture description
  - Does not specifically include all elements of RM-ODP engineering and technology views, assume use of RM-ODP for these
  - Does not encompass all aspects of Space Systems, i.e. power, propulsion, thermal, structure, does not preclude them either
- Define a representational methodology
  - Applicable throughout design & development lifecycle
  - Capture architecture & design artifacts in a machinable form, able to support analysis and even simulation of performance
  - Validate methodology by applying it to several existing CCSDS reference models and existing systems
- Identify relevant existing commercial methodologies
  - Evaluate UML 2.0 and SysML, now in progress
  - Explore applicability of selected methodology & tools to RASDS

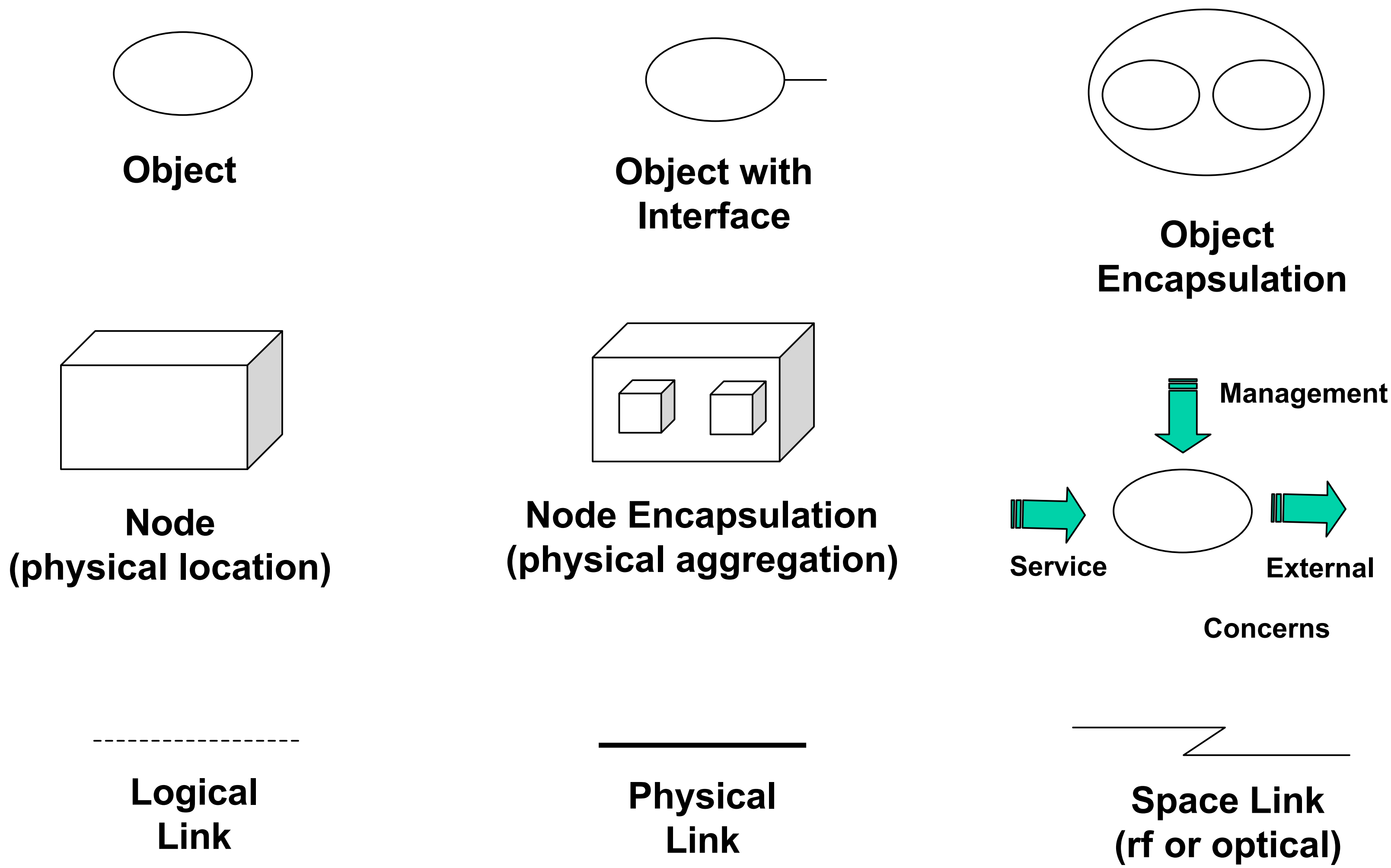
Space Data System
Several Architectural Viewpoints



Viewpoint	Concerns
Enterprise	**Business Concerns** **Organizational perspective**
Connectivity	**Physical Concerns** **Node & Link perspective**
Functional	**Computational Concerns** **Functional composition**
Information	**Data Concerns** **Relationships and transformations**
Communications	**Protocol Concerns** **Communications stack perspective**

Derived from: RM-ODP

Space Data System Architectural Notation



Unified Object Representation

Management Interfaces:
How objects are configured controlled, and reported upon

Object

Service Interfaces:
How services are requested & supplied

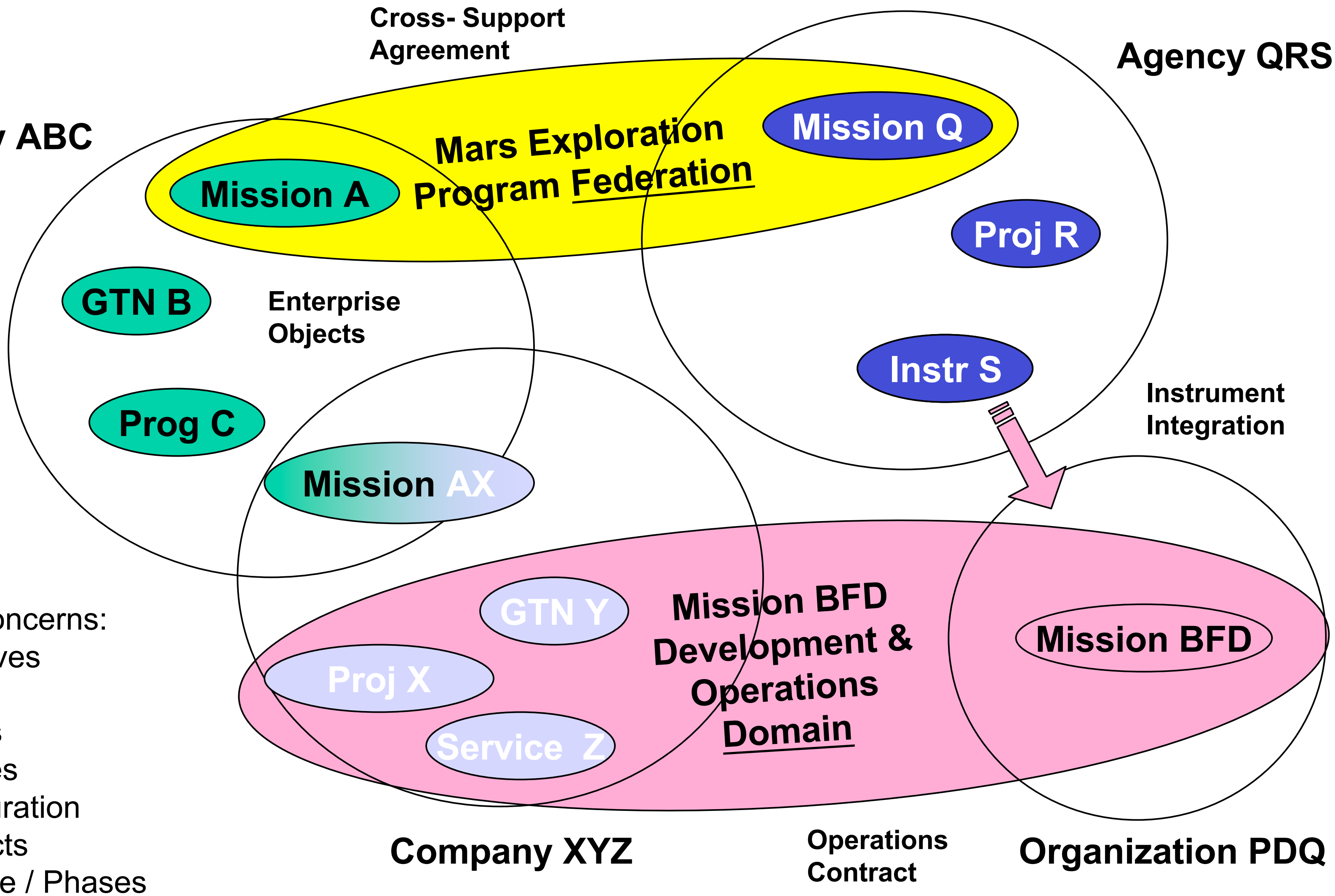
Core Functions
What the object does

External Interfaces:
How external elements are controlled

Concerns:
- Issues
- Resources
- Policies

Enterprise View

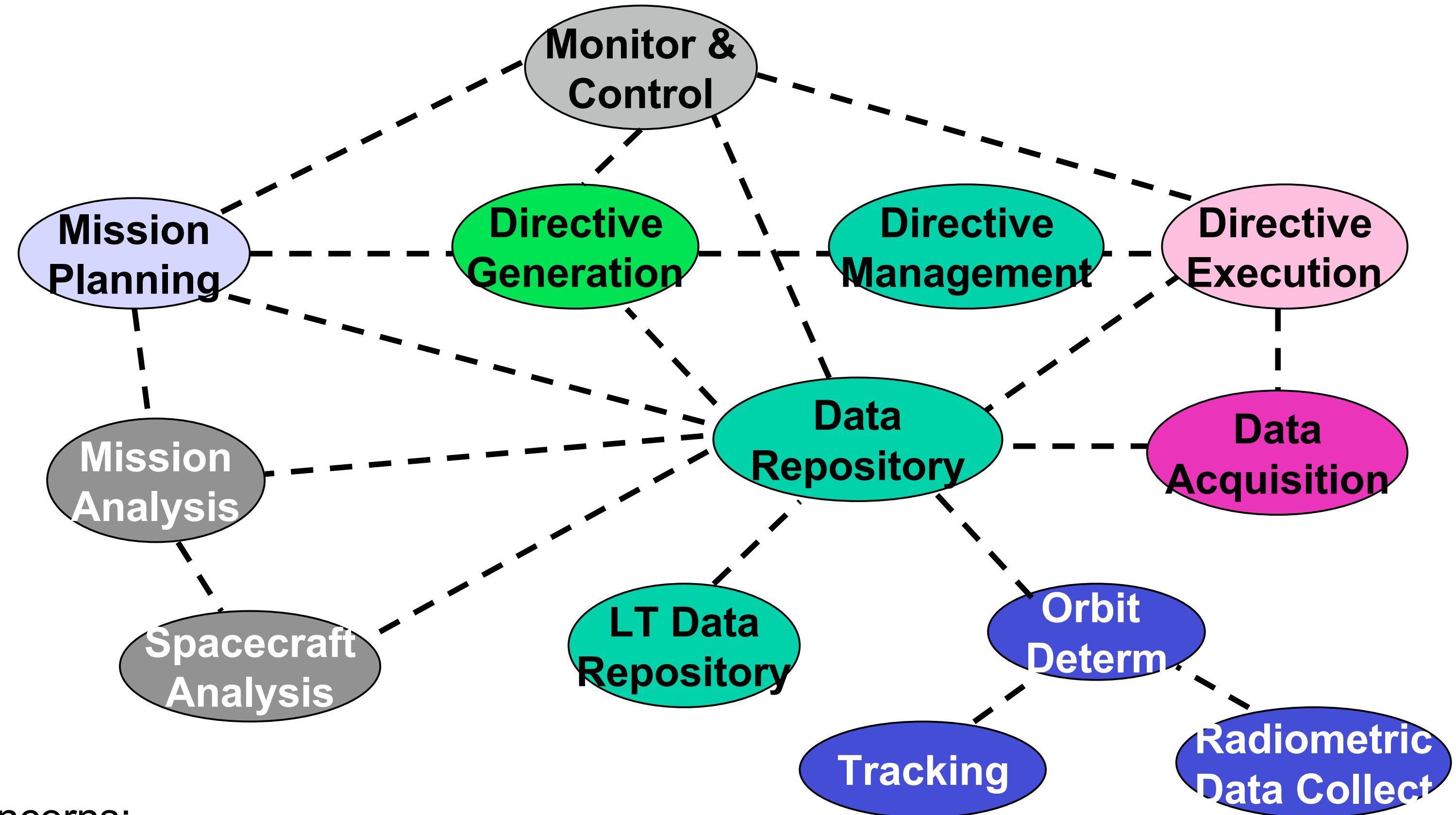
Federated Enterprises with Enterprise Objects



Enterprise Concerns:
- Objectives
- Roles
- Policies
- Activities
- Configuration
- Contracts
- Lifecycle / Phases

Functional View

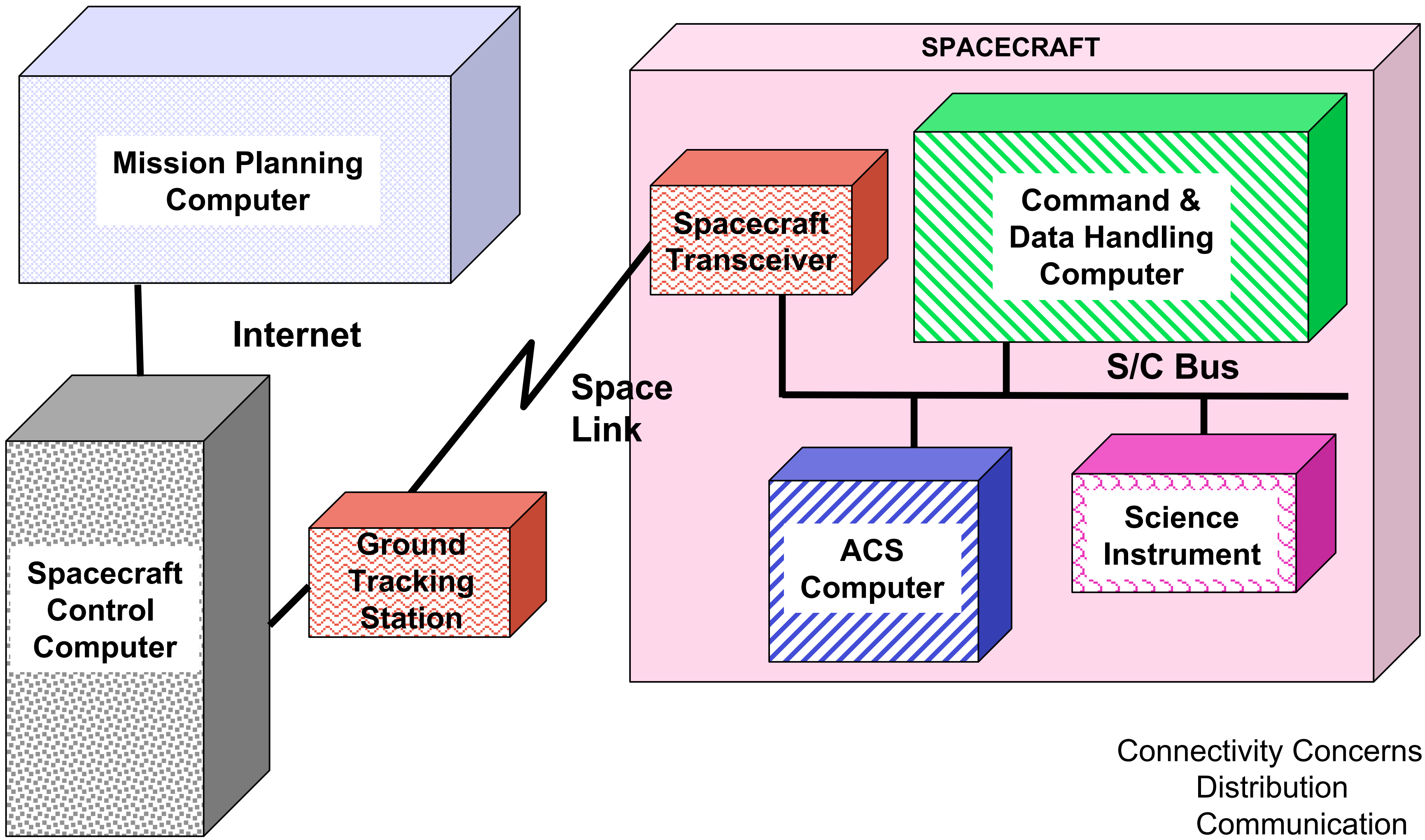
Example Functional Objects & Interactions



Functional Concerns:

- Behaviors
- Interactions
- Interfaces
- Constraints

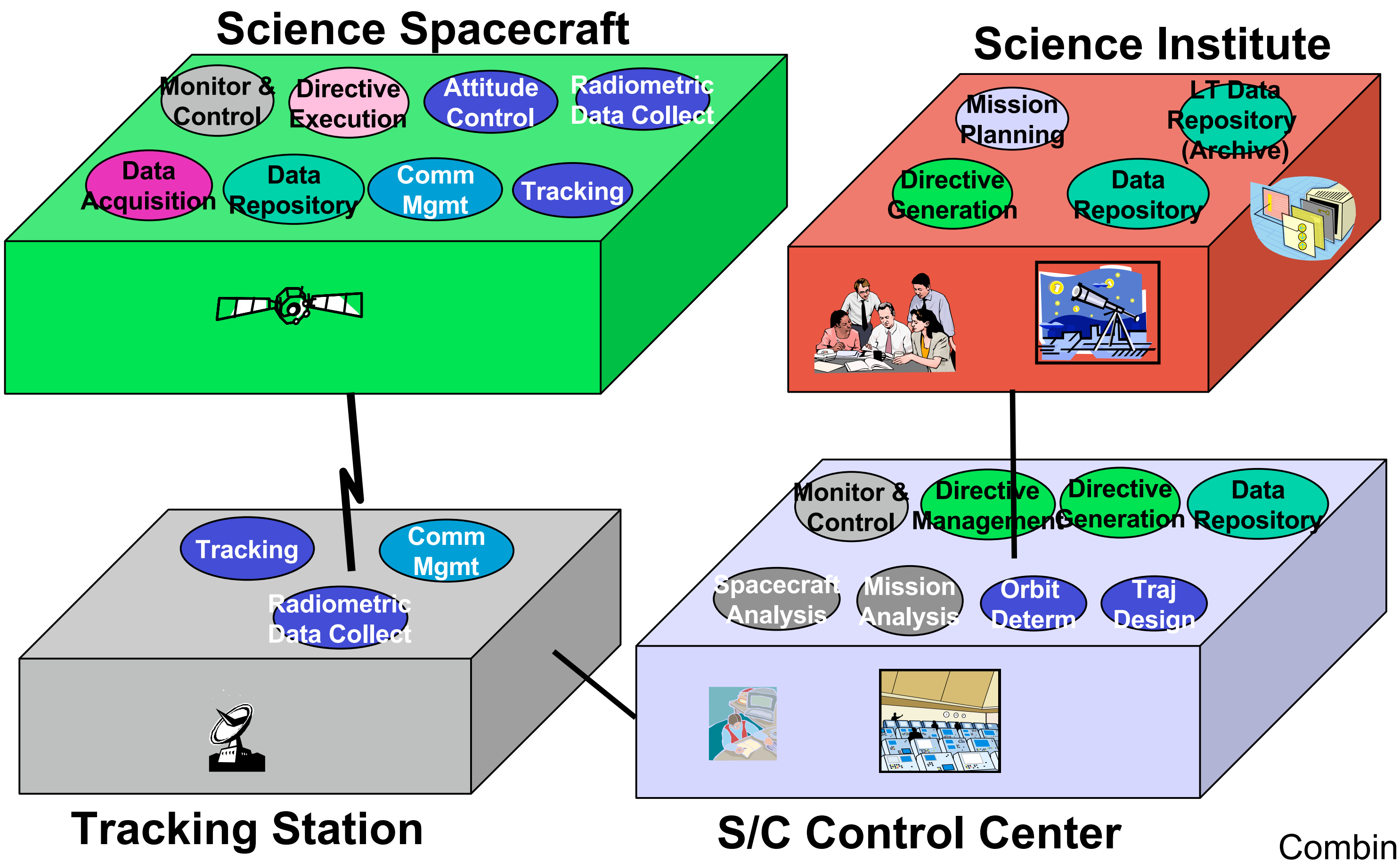
Connectivity View
Nodes & Links



Connectivity Concerns:
- Distribution
- Communication
- Physical Environment
- Behaviors
- Constraints
- Configuration

Connectivity & Functional View

Mapping Functions to Nodes

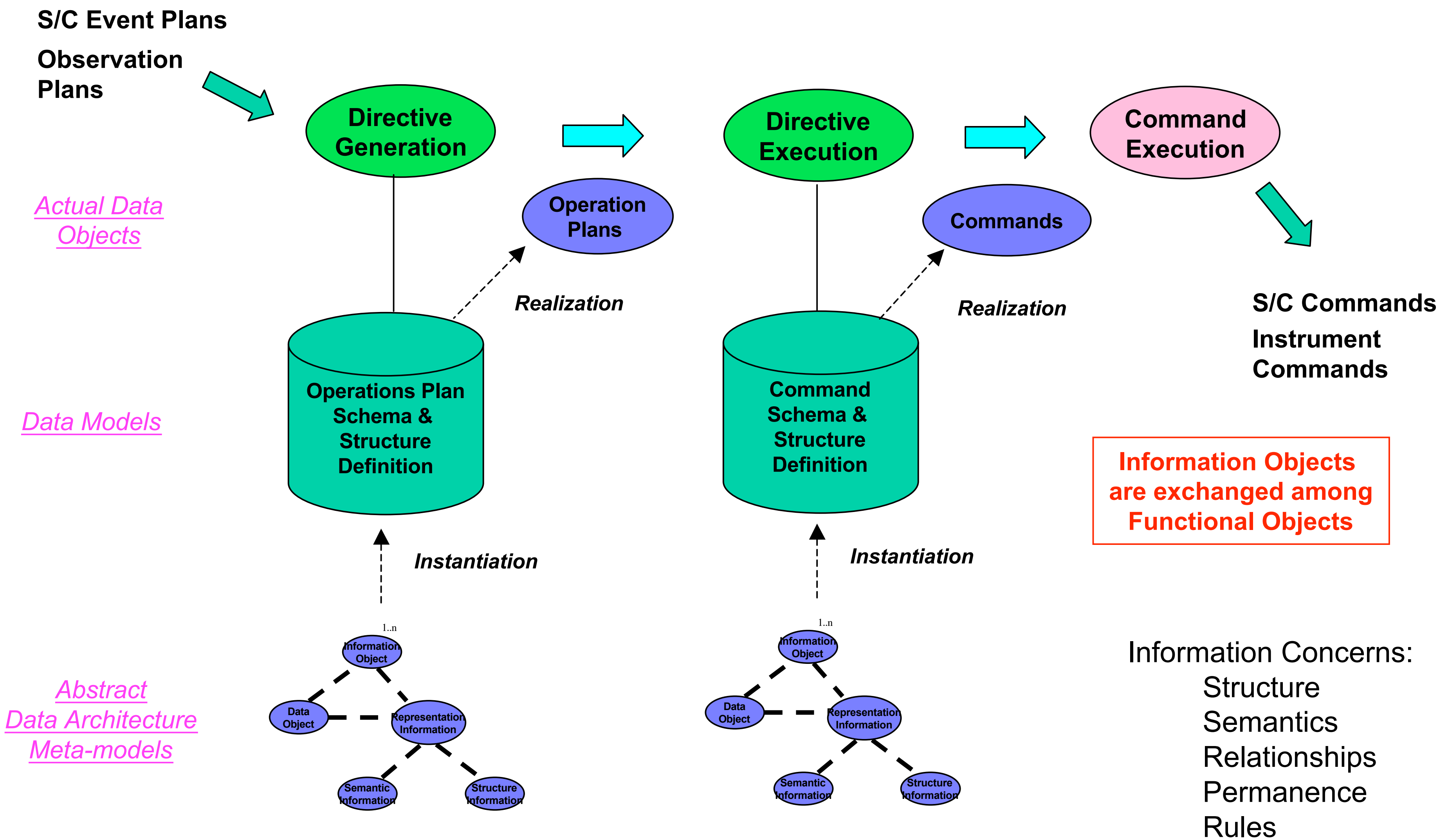


Combined View:

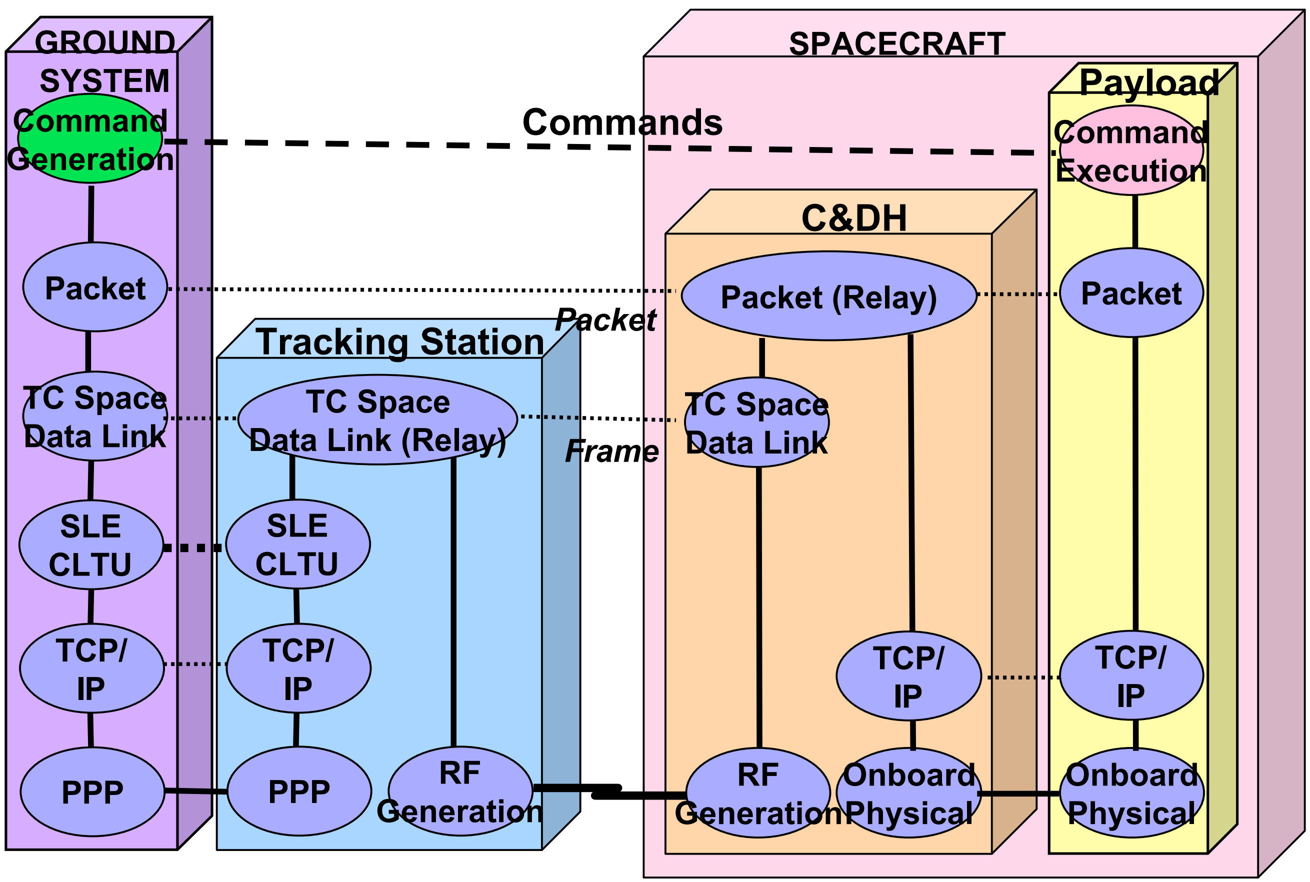
- End to End Behavior
- Performance
- Throughput
- Trade studies

Information Objects

Relationship to Functional View

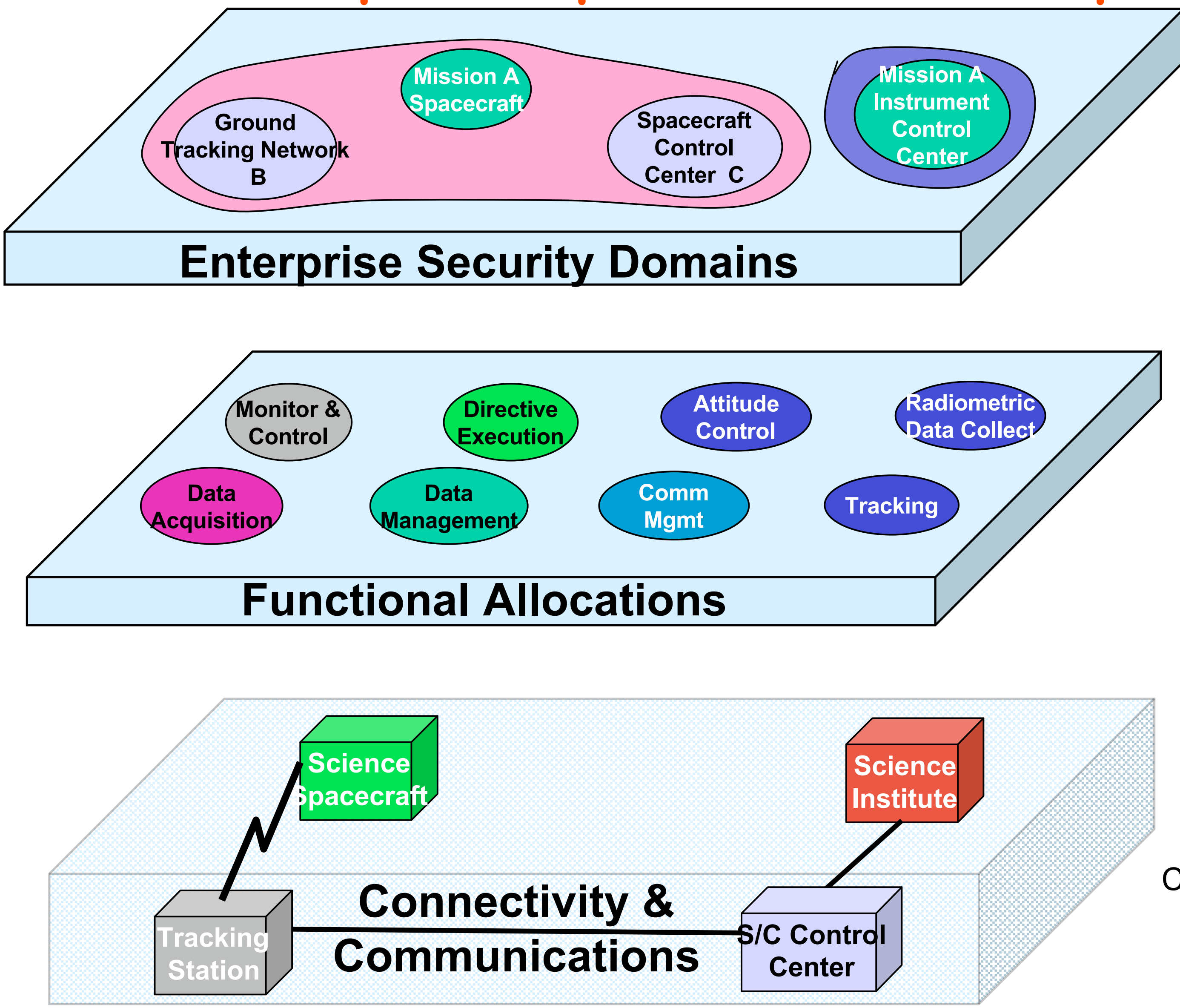


Communications Viewpoint
Protocol Objects
End-To-End Command Processing



Communications Concerns:
- Standards
  - Interfaces
  - Protocols
- Technology
- Interoperability
- Suitability

Security Analyses
Multiple Viewpoints & Relationships



Trust relationships
Policies
Privacy / proprietary issues

Access control
Authentication

Firewalls
Encryption
Boundary access points

Combined View:
- Relationships
- Allocations
- Performance
- Trade studies

High Level RASDS Methodology / Tool Requirements

- Meta-model and model language that is independent of specific tool environments and implementations
  - Models can be exchanged and imported into other tool suites
- Tool suite with a graphical interface that enables creation, manipulation, display, archiving, and versioning of meta-models, component and connector type templates, and instance models
- Support development of machine readable, portable architecture meta-model for RASDS
- Support development of instance models for specific space systems deployments
- Provide a framework that supports coarse grained simulation of behavior and performance characteristics instance models

Formal Method Evaluation

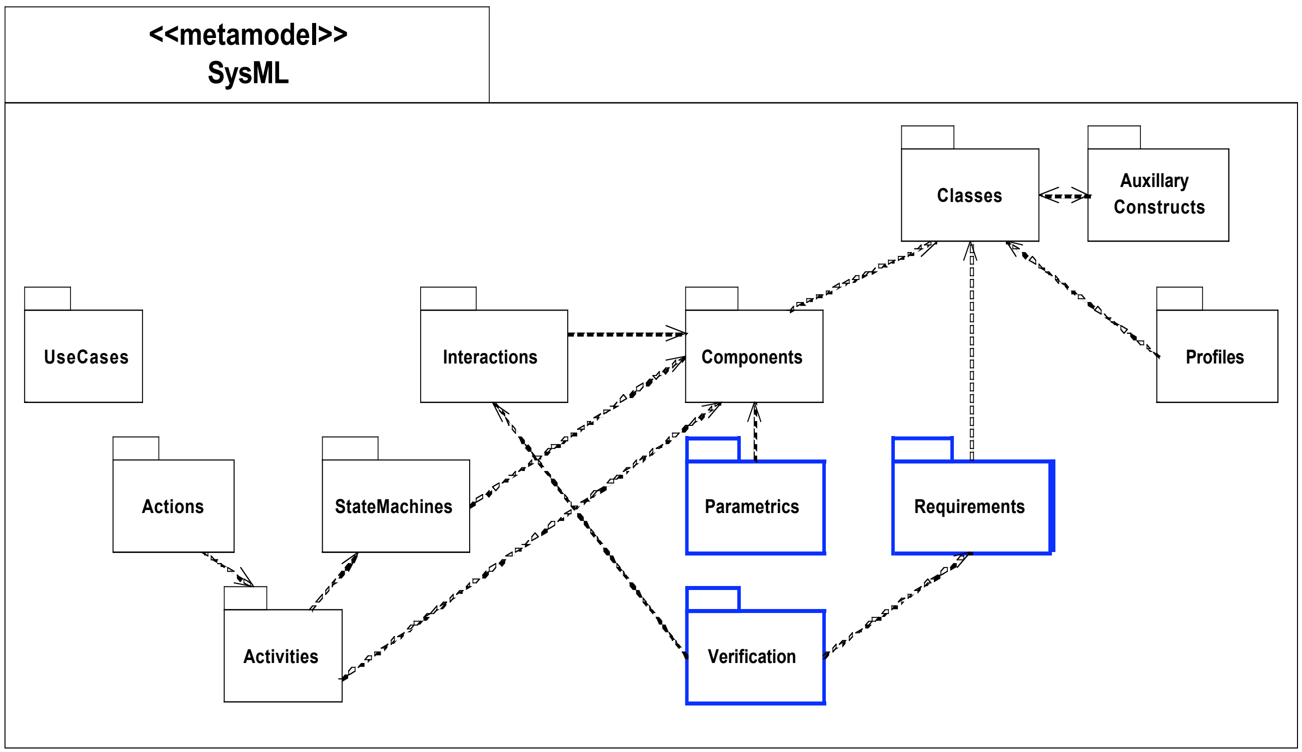
- Studied UML 2.0, SysML, xADL
- Unified Modeling Language (UML 2.0)
  - Too focused on software systems
  - Includes elements that are not needed for RASDS
  - Some commercial tool support now
- System Modeling Language (SysML)
  - Has most of the required features (and more)
  - Needs some extensions for RASDS viewpoints and details
  - Commercial tools support expected late 2004 / early 2005
- xADL
  - Extensible approach that can accommodate RASDS
  - xADL needs to be customized, not interoperable w/ XMI
  - Tool support from UCI and USC, academic quality

SysML Background

- Informal partnership of modeling tool users, vendors, etc.
  - Organized in May 2003 to respond to UML for Systems Engineering RFP
  - Includes many aerospace companies and major UML tool vendors
- Charter
  - The SysML Partners are collaborating to define a modeling language for systems engineering applications, called Systems Modeling Language™ (SysML™). SysML will customize UML 2 to support the specification, analysis, design, verification and validation of complex systems that may include hardware, software, data, personnel, procedures, and facilities.
- References:
  - SysML Partners Web Site http://www.sysml.org
  - See also SysML Specification Draft v0.3 on this web site

Source: SysML Partners

SysML Language Architecture



Source: SysML Partners

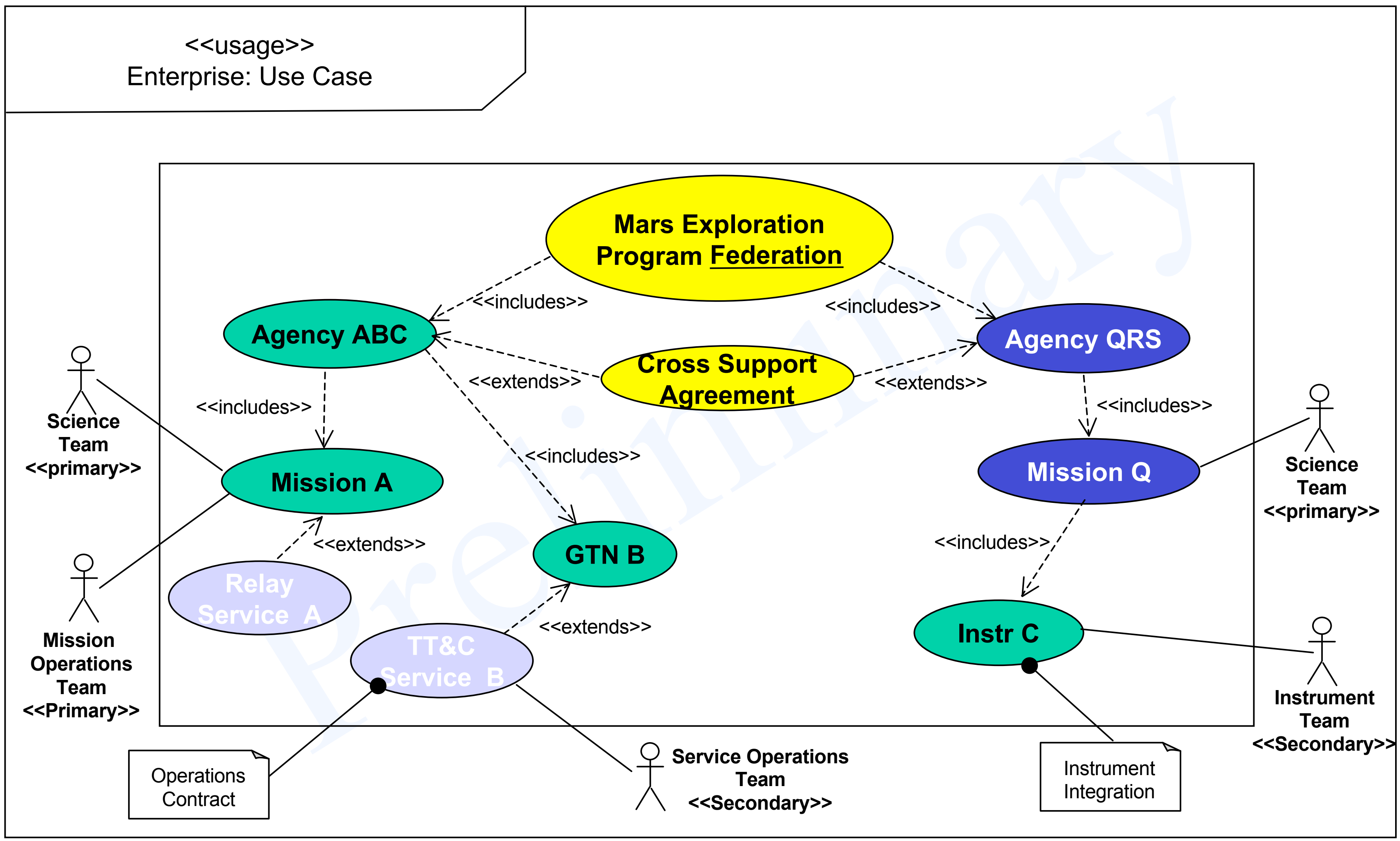
Mapping RASDS into SysML

- No simple one for one mapping
- RASDS uses Viewpoints to expose different concerns of a single system
- SysML uses specific diagrams to capture system structure, behavior, parameters and requirements
- Several SysML diagrams, focused on different object classes, may be usefully applied to any given RASDS Viewpoint
- Extended SysML Views may be used to define the relationships between Viewpoints and Diagrams
- SysML will support more accurate fine grained modeling of structure, relationships and behavior than was expected of RASDS

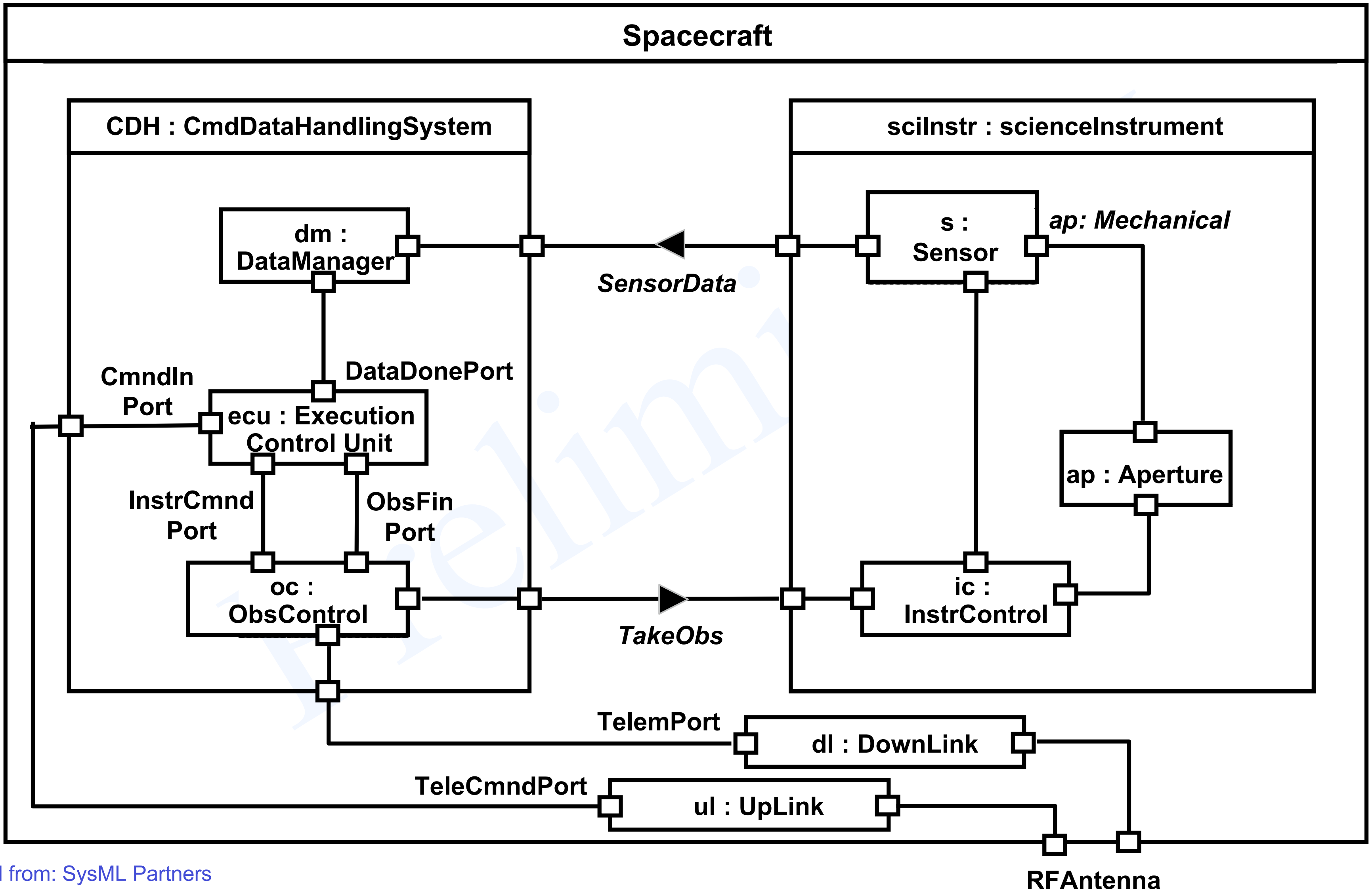
Mapping RASDS into SysML

- Enterprise
  - Organizational component & collaboration diagrams
  - Use case, interaction overview diagrams
  - Requirements & constraints for rules, policies & agreements
- Connectivity
  - Physical component, composition, collaboration & class diagrams
  - Parametric diagram for physical link characterization
- Functional
  - Logical component, collaboration & class diagrams
  - Activity, state chart, parametric, & timing diagrams
- Informational
  - Information class & parametric diagrams
- Communication
  - Protocol component & collaboration diagrams
  - State machine, sequence, activity & timing diagrams

Enterprise View Using SysML Use Case Diagram

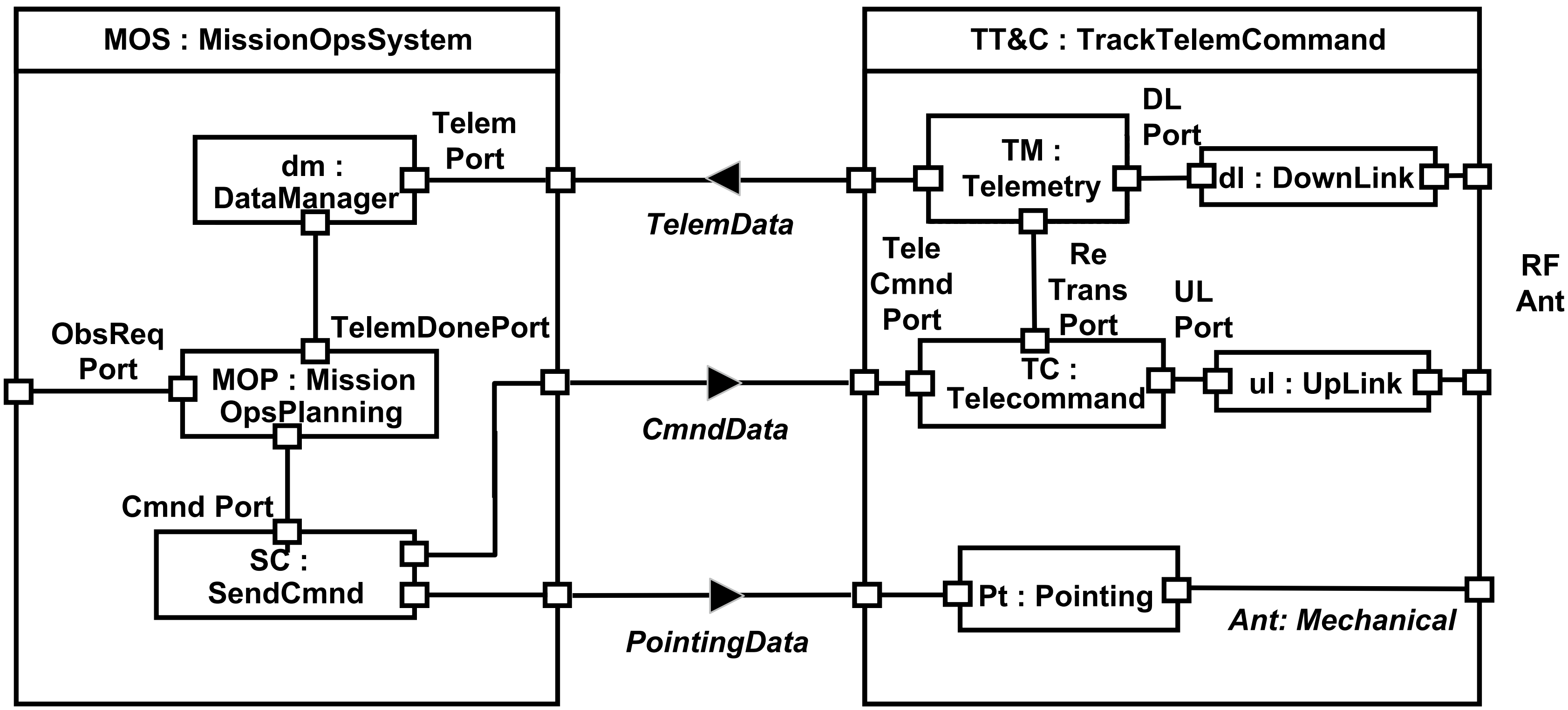


Connectivity View (Nodes & Links) Using SysML Components (Spacecraft)

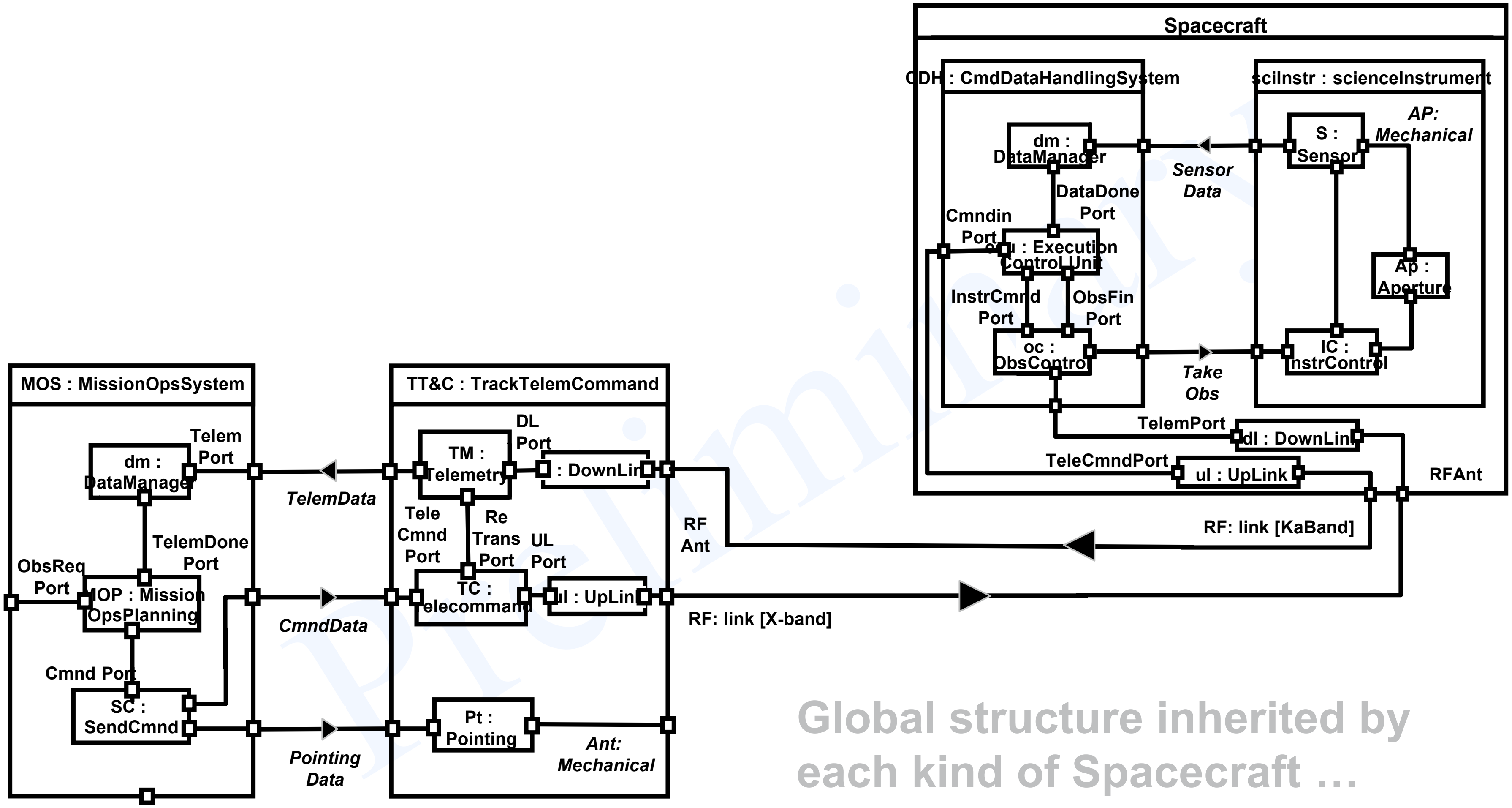


Derived from: SysML Partners

Connectivity View (Nodes & Links) Using SysML Components (MOS & TT&C Systems)



Connectivity View (Composition) Using SysML Components

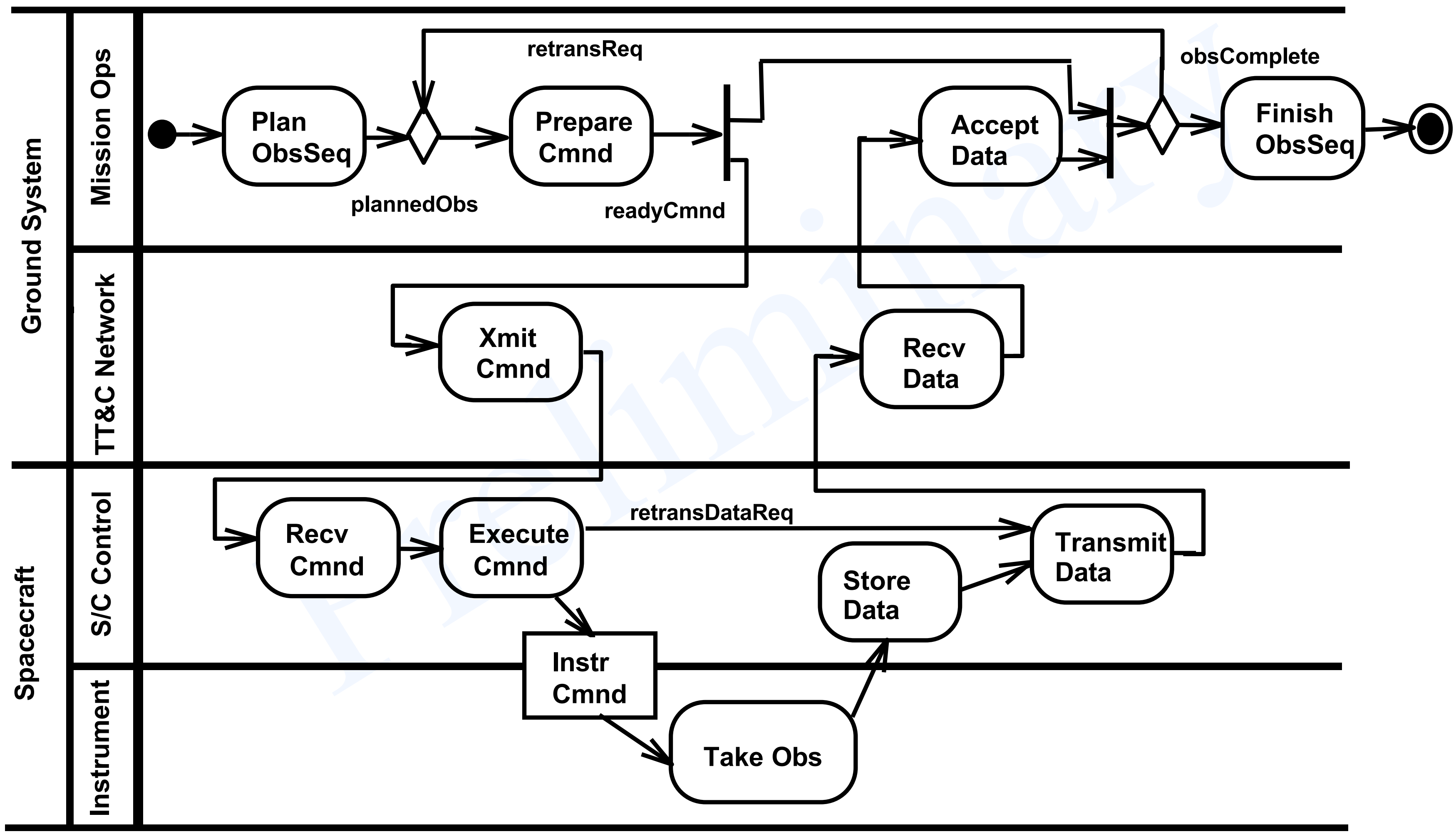


Global structure inherited by each kind of Spacecraft …

… and constrained for each kind

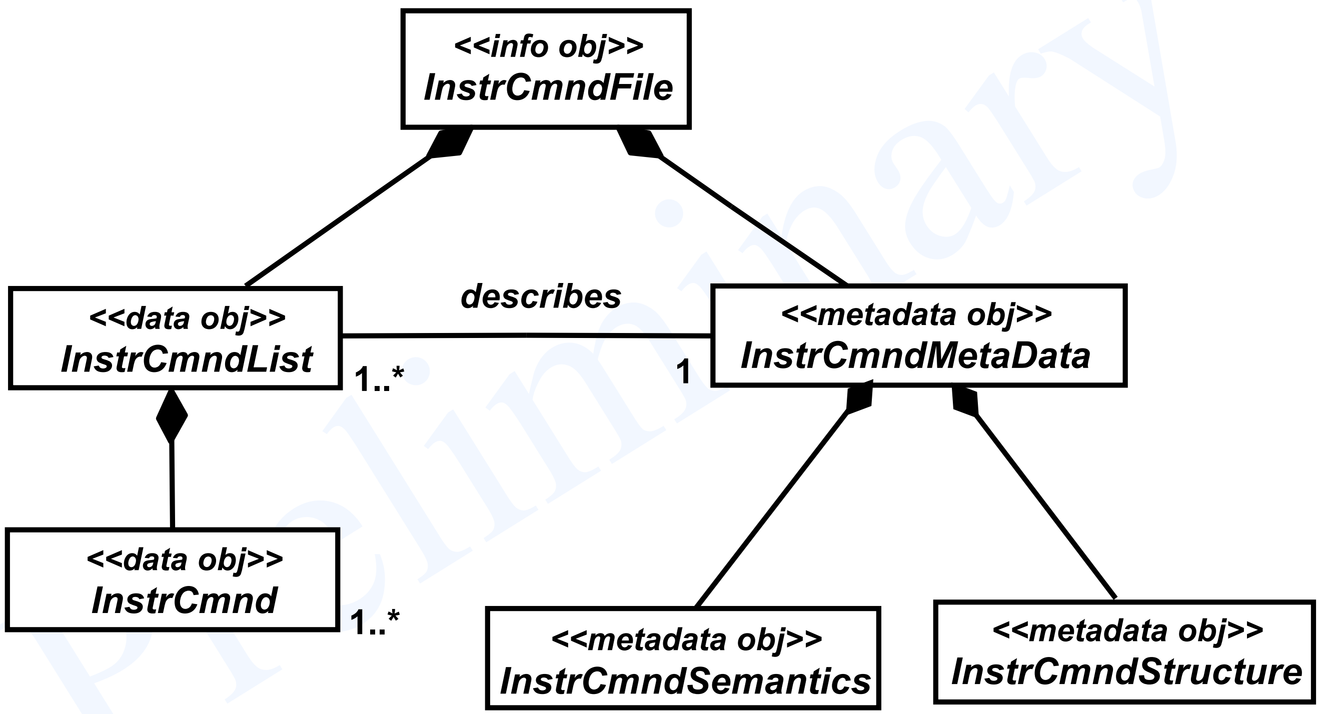
Functional View Using SysML Activity Diagram

- Showing component allocations (optional)



Informational View Using SysML Class Diagram

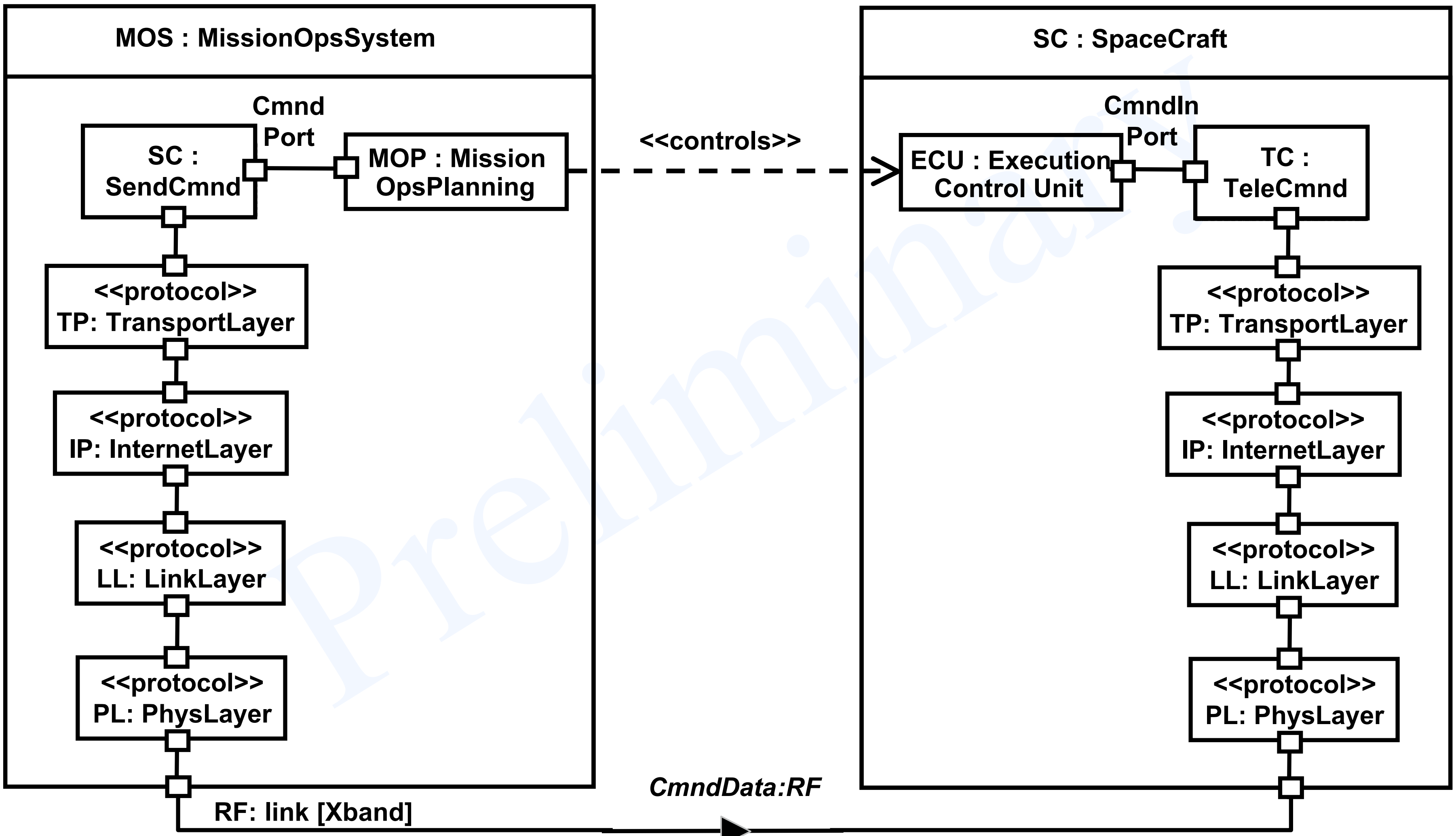
- Reusable, refinable information structure:



Global representation inherited by each kind of Information Object

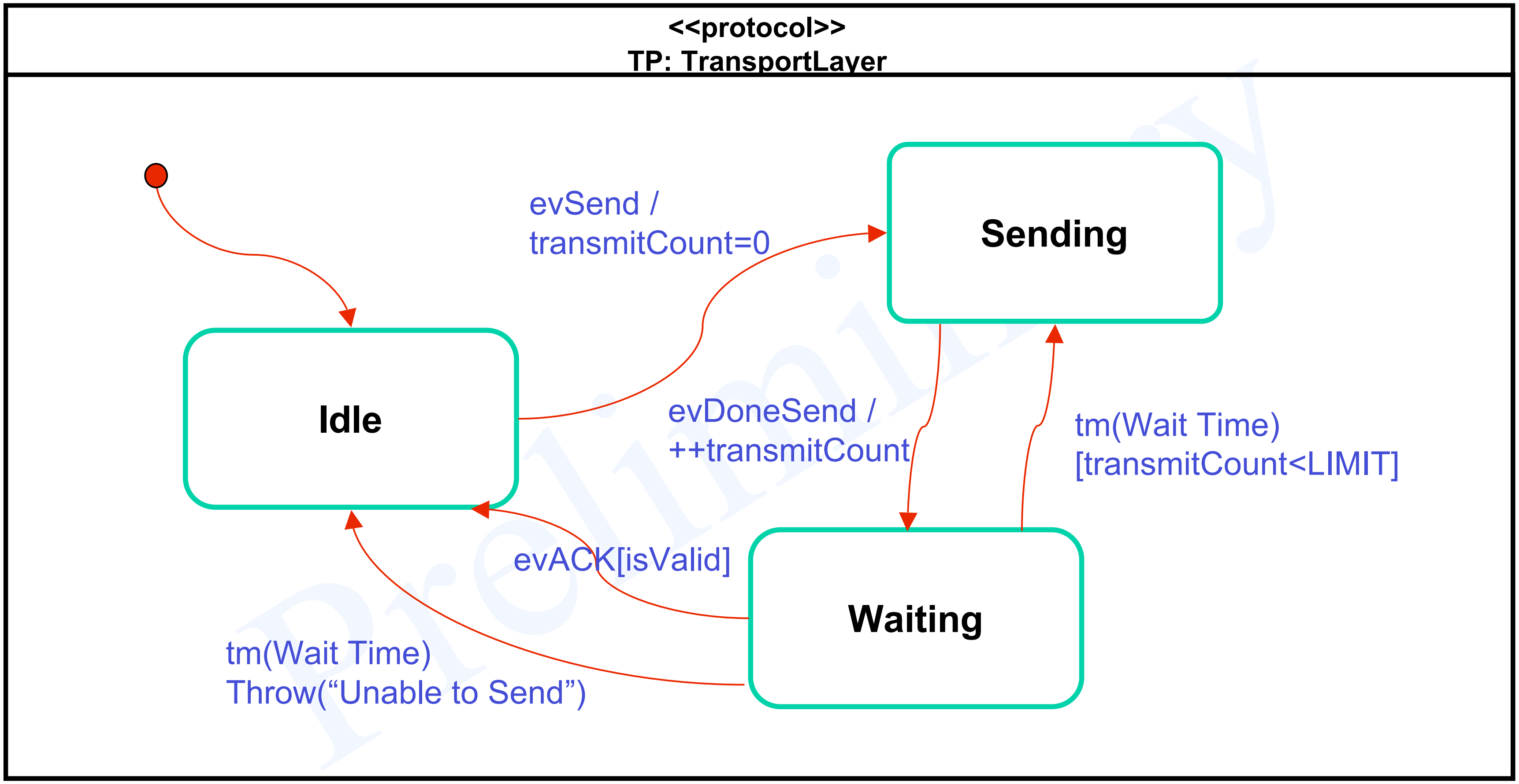
Derived from: SysML Partners

Communication View (Protocol Objects) Using SysML Component Diagram



Derived from: SysML Partners

Communication View Using SysML State Machine Diagram



Protocol specifications inherited by each instance of Protocol Objects

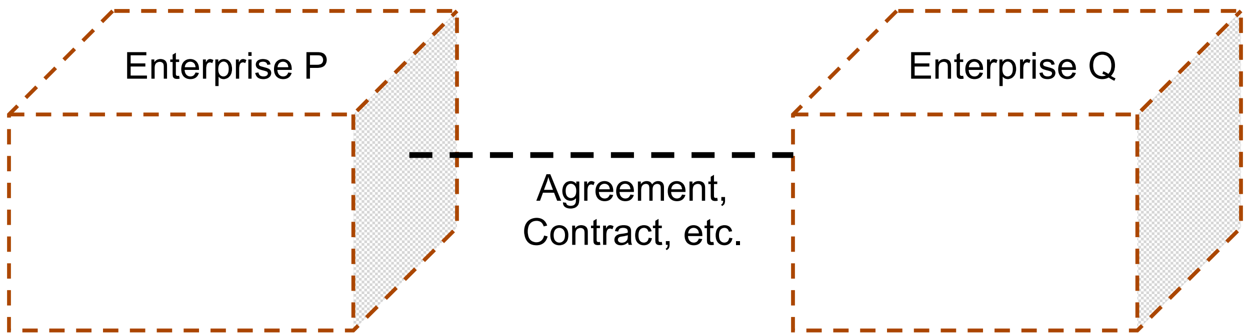
Derived from: SysML Partners

Acknowledgements

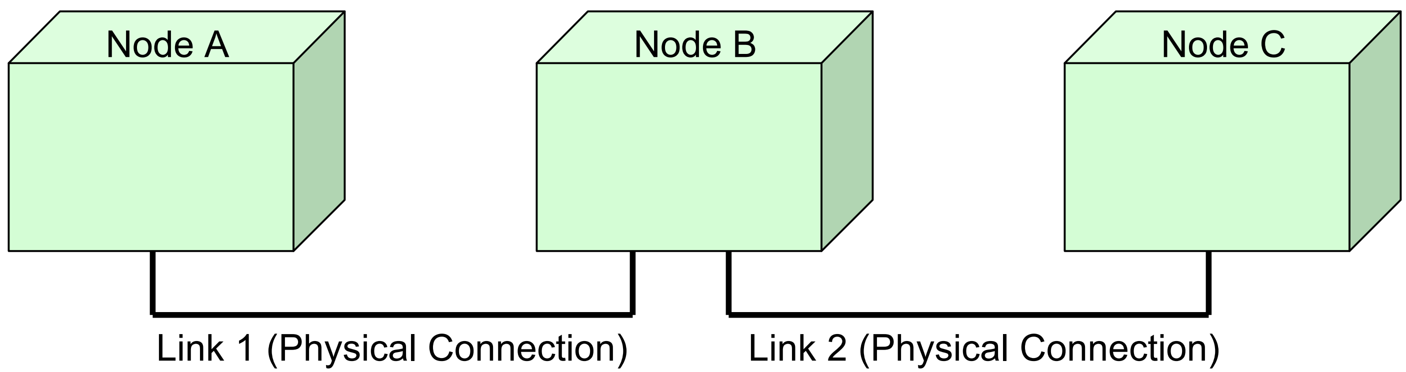
- This task was carried out as part of the program of work of Consultative Committee for Space Data Systems (CCSDS).
- It was performed by the Architecture Working group (AWG), chaired by Takahiro Yamada, ISAS
- Other AWG members who actively participated are listed below:
  - Fred Brosi, NASA/GST
  - Dan Crichton, NASA/JPL
  - Adrian Hooke, NASA/JPL
  - Steve Hughes, NASA/JPL
  - Niklas Lindman, ESA/ESOC
  - Nestor Peccia, ESA/ESOC
  - Lou Reich, NASA/CSC
  - Don Sawyer, NASA/GSFC
  - Peter Shames, NASA/JPL
  - Anthony Walsh, ESA/Vega

BACKUP SLIDES

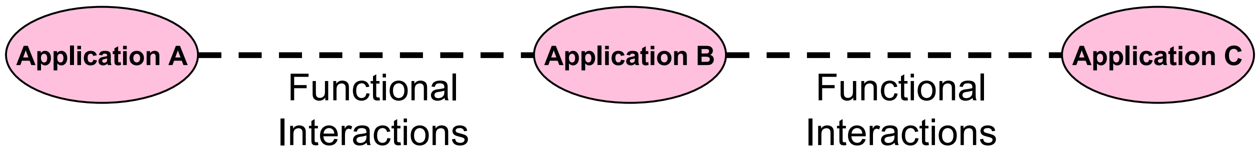
Enterprise View (Enterprise Objects)



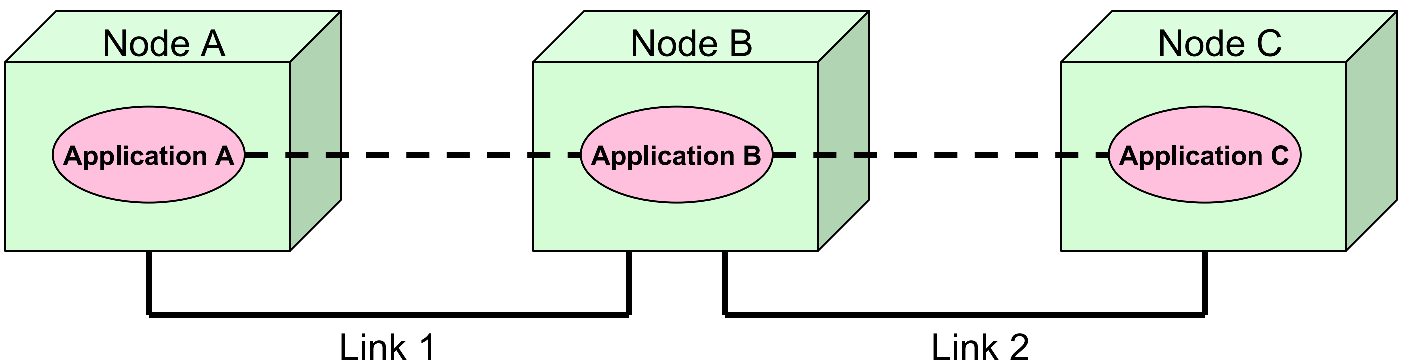
Connectivity View (Nodes and Links)



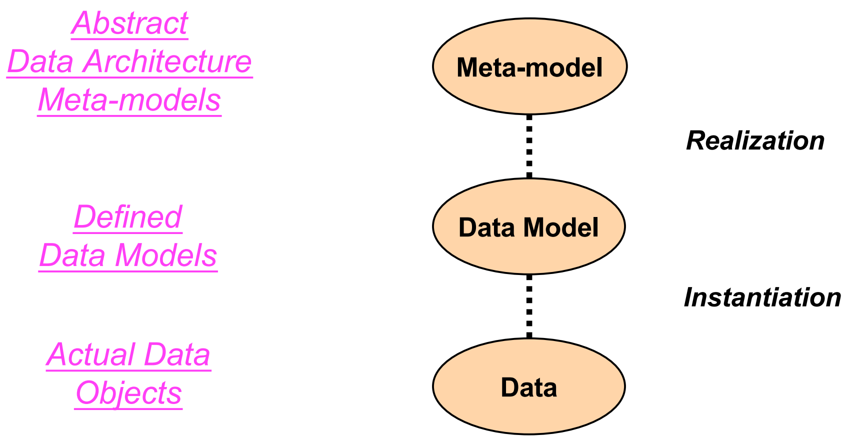
Functional View (Functional Objects)



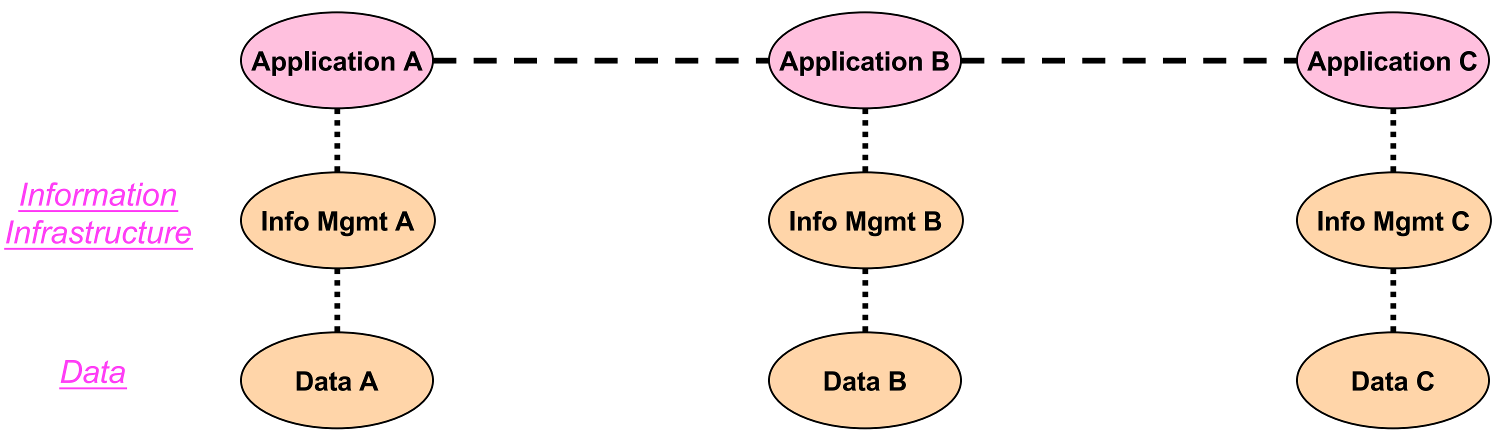
Connectivity+Functional View (Nodes, Links and Functional Objects)



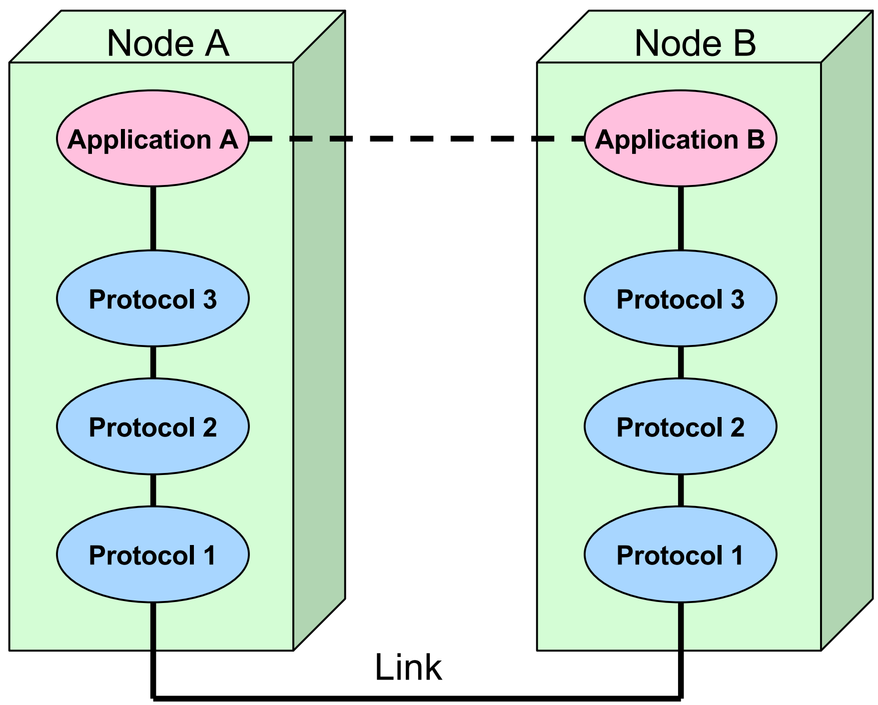
Information View (Information Objects)



Functional+Information View (Functional Objects and Information Objects)



Connectivity+Functional+Communication View (Nodes, Links, Functional Objects and Communications Objects)

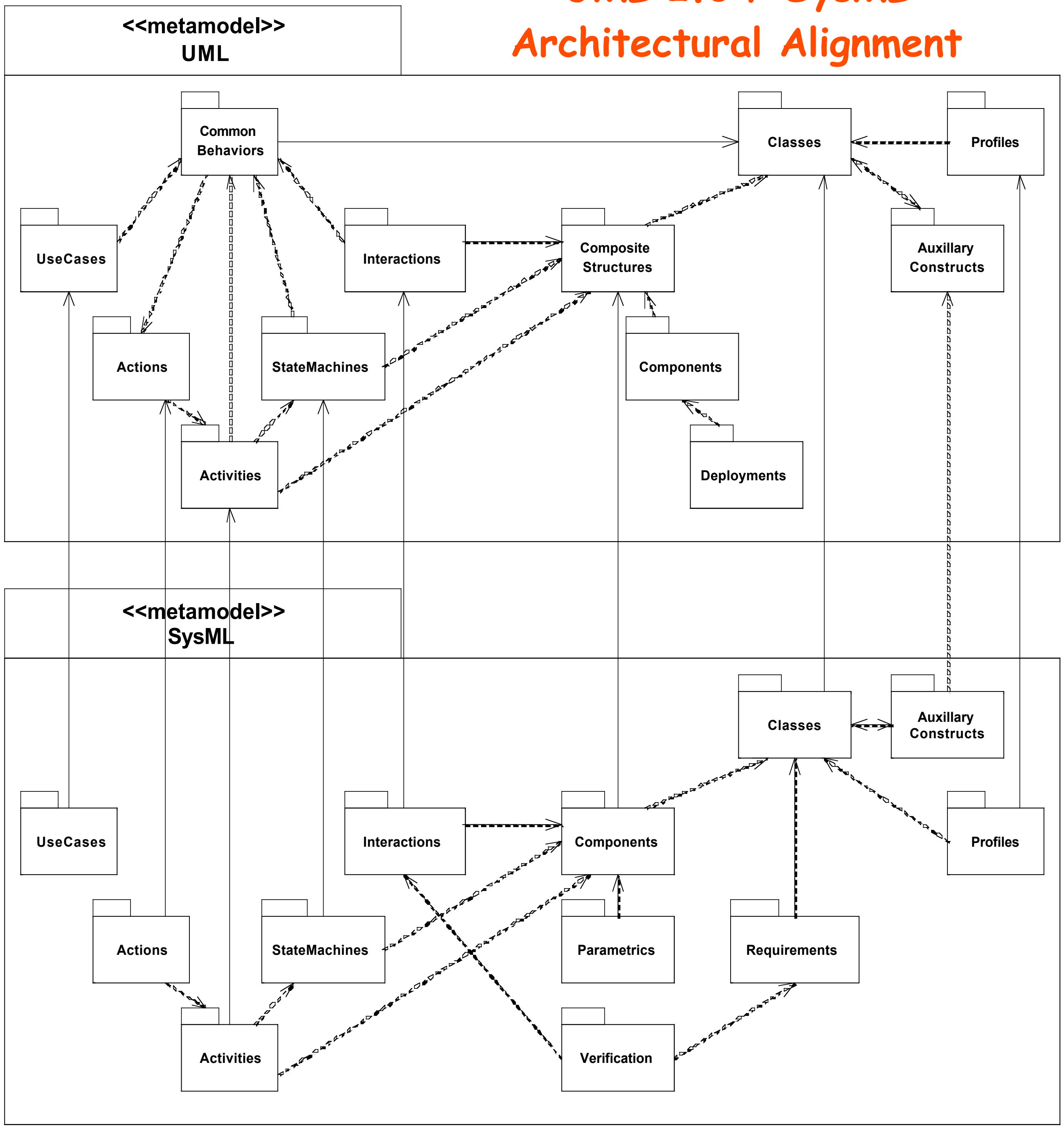


SysML Motivation

- Systems Engineers need a standard language for analyzing, specifying, designing, verifying and validating systems
- Many different modeling techniques
  - Behavior diagrams, IDEF0, N2 charts, …
- Lack broad based standard that supports general purpose systems modeling needs
  - satisfies broad set of modeling requirements (behavior, structure, performance, …)
  - integrates with other disciplines (SW, HW, ..)
  - scalable
  - adaptable to different SE domains
  - supported by multiple tools

Source: SysML Partners

UML 2.0 / SysML Architectural Alignment



Source: SysML Partners

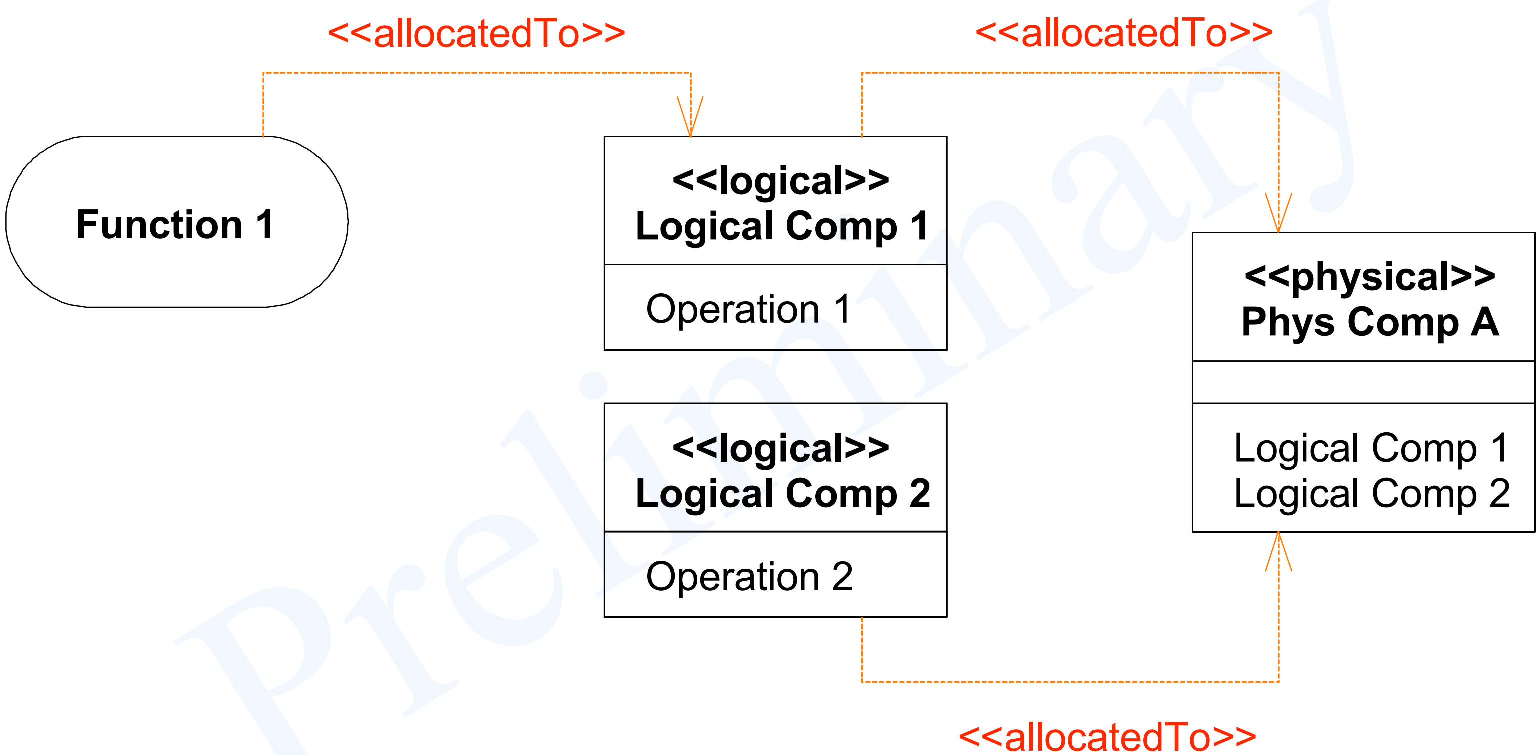
Analysis of Using SysML for RASDS

- **Analyzed requirements in UML for Systems Engineering RFP and SysML Draft Response (January 25, 2004)**
- Initial analysis indicates that SysML meets or exceeds the requirements for RASDS, with some specific exceptions:
  - The ability to explicitly relate model elements in multiple model viewpoints is partially addressed by SysML
  - Must be augmented by RASDS methodology specific views, relationships and constraints.
- ***SysML specification is still being finalized***, elements are expected to further evolve before completion. SysML is expected to be adopted by the OMG & INCOSE in late 2004, tool support will follow shortly.
- SysML Partners view RASDS exercise as a useful set of test cases to validate their approach, has driven evolution of some elements (views)

Further Considerations on Use of SysML

- Viewpoint in SysML is a constrained set of elements from ***meta-model*** selected for a particular purpose.
- View in SysML is a constrained set of elements selected from a ***user model*** for a particular purpose.
- These align with RASDS usage, but details of specifying RASDS views are yet to be finalized
- The behavior and executability aspects of SysML are outside current RASDS scope, but are expected to prove useful.
- Requirements and parametric diagrams are not currently required for RASDS, but are likely to be useful in the long run.
- SysML provides behavioral specifications in state charts and activity diagrams, but some model behavior specifications may require use of some TBD script language.
- SysML is expected to support evolution of mission designs via elaboration of successive levels of detail in a model.

Functional – Logical – Physical Allocation: Viewpoint Relationships



Preliminary

Derived from: SysML Partners

Next Steps

- Validate SysML modeling approach
  - Complete analysis of RASDS to SysML mapping
  - Validate with SysML Partners
  - Seek concurrence with CCSDS SAWG community

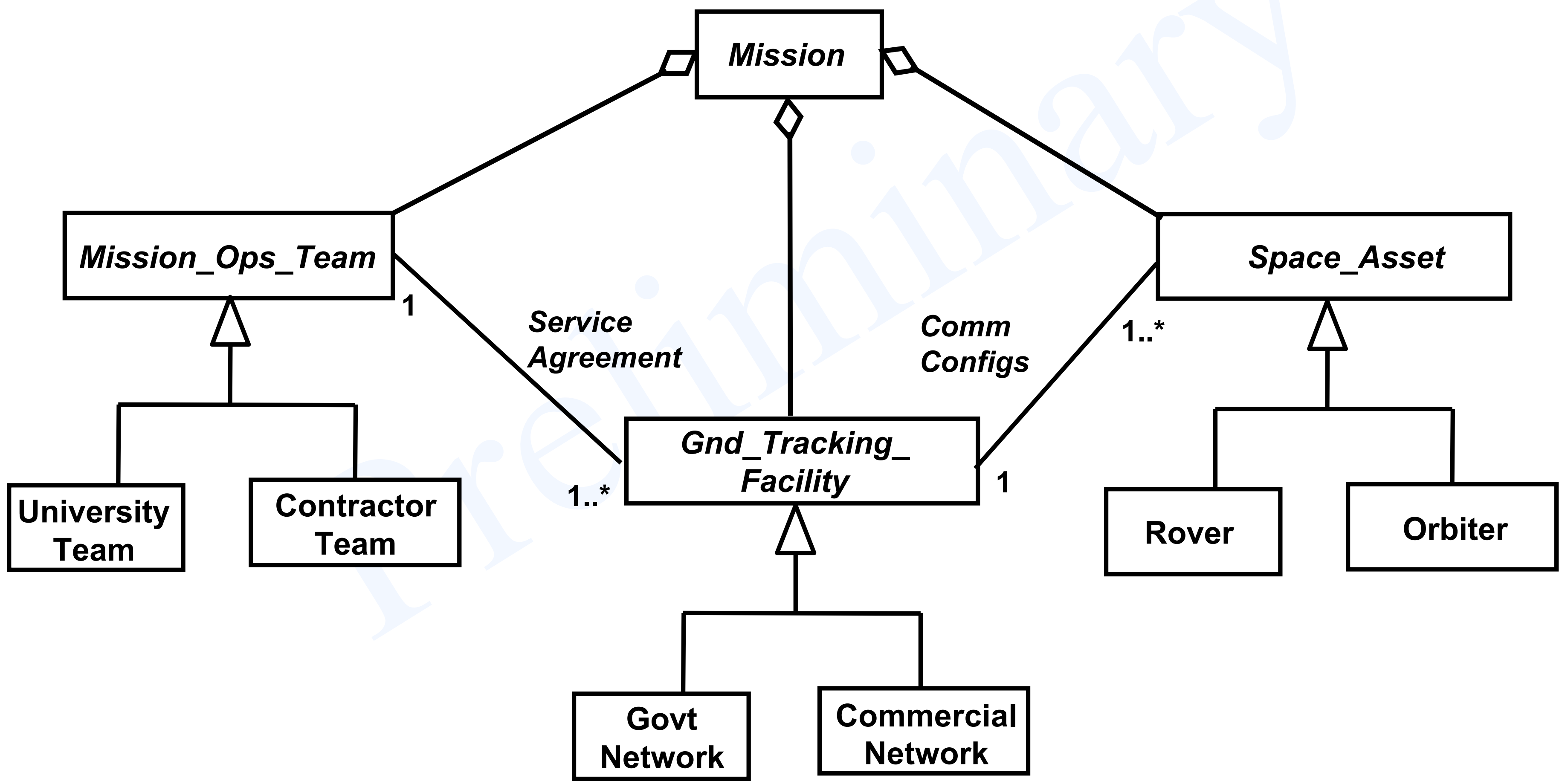
IFF agreed, then:

- Adopt an agreed RASDS formalism
  - Select specific formal methods from SysML for describing RASDS architectures and systems
  - Agree to final common representation and methods

- Generate baseline RASDS approach
  - Develop agreed SysML meta-models for Viewpoints
  - Define extensible library of component instances

Enterprise View Using SysML Class Diagram

- Mission Organization Options:



Derived from: SysML Partners

RASDS Requirements on Tools / Environment

1. **Support Architectural Modeling** – provide means for developing, validating, extending, and sharing RASDS compliant models

2. **Flexibility** – allow multiple approaches to be explored at the same time

3. **Model Integrity** – provide means for ensuring model integrity by checking relationships across views and updating them automatically (or flagging problems)

4. **Model Validation** – provide means for validating model completeness and well formedness

5. **Relative Ease of Use** – exhibit good ergonomics, be easy to learn and use, and provide other ease of use features like contextual help

6. **Repository / Model Sharing** – provide means for storing complete models, model elements, fragments, and templates, and for sharing these across a working group. Facilitate re-use and sharing

RASDS Requirements, contd

- **Other Considerations:**
  - Selected set of mission / space systems deployments must be developed and agreed
  - Mission lifecycle views, concept, design, development, launch, operation
  - Architectural model lifecycle, abstract to concrete, relationship to design
  - Extracting "suitable for framing" viewpoints for different audiences from models
  - Development of prototypes of various architecture elements and approaches
  - Explore means to do trade space evaluation driven by architecture models