INCOSE SFBAC Monthly Meeting
12 September 2006

Using SysML to Develop a Spacecraft Specification and Design Model, Part 1

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Agenda - Outline

Part 1:

- Project Introduction
- Space System Specification and Design Model Discussion
  - Discuss views and contents
- Systems Modeling Language (SysML) Discussion
  - Discuss diagrams
- Applicability of SysML Diagrams to Space System Views

Part 2:

- Project Results

Project Summary

- Information concerning numerous unmanned satellites will be extracted from an extensive collection of references and used to develop specification and design models for a satellite, a spacecraft bus, and spacecraft subsystems.

- The specification and design models will be developed using the Object Management Group (OMG) set of SysML diagrams.

- The project will provide a set of SysML diagrams that can be adopted by a program, then tailored for their use.

- In addition, the project results will include a determination of how adequate the set of SysML diagrams is to develop space-system specification and design models or vice versa.

- The project will culminate with the submission of a report and a presentation to Cal Poly.

- Additional presentations will be provided to the local INCOSE chapter, and a paper may be submitted to an upcoming INCOSE symposium.

Project Objectives

Project Requirements/Goals:

* Project should be work focused/practical (i.e., of benefit to Lockheed Martin [LM])
* Need to identify a LM mentor as a primary advisor
* Need to identify a faculty advisor from the Cal Poly AERO department
* Need to submit Project paper anywhere from 30 – 50 pages
• Need to have enough material for a one-hour presentation

Class Objectives:

• Individual project fulfilling the culminating experience of the Space Systems Engineering Specialization.
• Completion of the project includes a written report and final presentation.
• The report must include the project's significance, objectives, methodology, and a conclusion or recommendation.
• Course provides the students with the opportunity to study a topic of their choice.
• The students will develop independent study and analysis skills.
• Students also will develop the ability to present their results and methodology including the significance of their work.

Project Objectives (2)

* Satisfy curriculum requirement
* Extract data using model view structure
* Learn more about space systems
* Validate model views and contents
* Learn more about SysML
* Gain experience modeling using the SysML diagrams
* Develop SysML diagrams for satellite, spacecraft bus, and spacecraft subsystems
• Determine how to update model view structure to be compatible with the set of SysML diagrams

Project Support

- LM Mentor – Sanford (Sandy) Friedenthal
  - Principal systems engineer at Lockheed Martin
  - Lead developer for advanced systems engineering processes and methods
  - Liaison between INCOSE and OMG
  - Chair of the OMG Systems Engineering Domain Special Interest Group
  - Chair of the SysML Submission Team
- Faculty Advisor – Dr. David Marshall, Cal Poly
  - Co-Instructor for AERO 512
    - Taught use cases, sequence diagrams, configuration management, and software integration and testing
  - Research interests: aerodynamics, computational fluid dynamics

Space System Hierarchy for Project Scope

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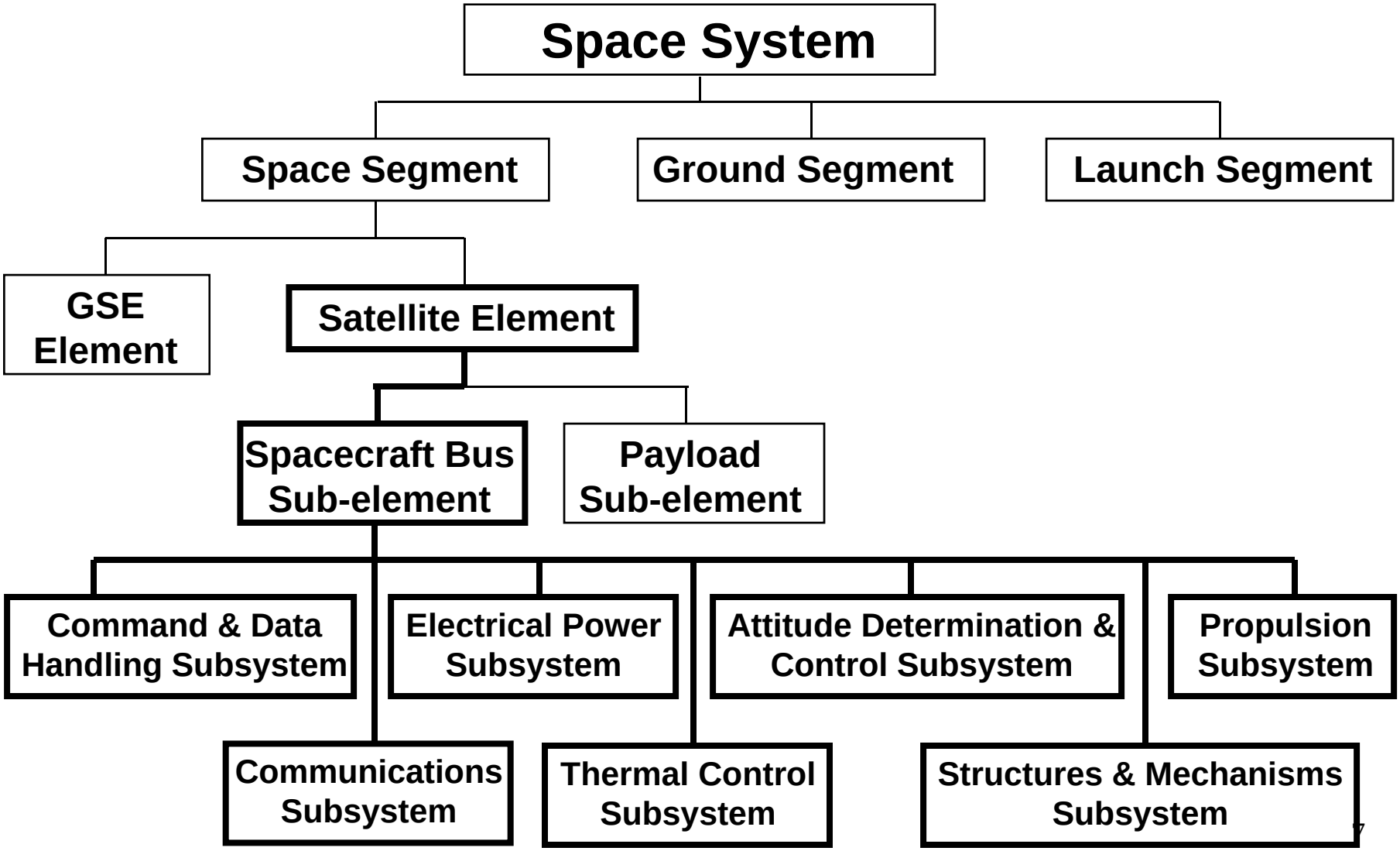

Project Process/Activities

- Study SysML documents to become more familiar with the SysML concepts and diagrams.
- In parallel with the study of SysML documents, perform data extraction from a wide variety of sources
- When a sufficient amount of data has been extracted and recorded, compare the data collected for each like-object (i.e., Satellite Element, the Spacecraft Bus Sub-element, and each of the Spacecraft Subsystems.)
- Using the extracted data for each like-object, build a specification and design model for each like-object (i.e., Satellite Element, the Spacecraft Bus Sub-element, and each of the Spacecraft Subsystems.)
- Using these models, convert them into a set of SysML diagrams for each of the Satellite Element, the Spacecraft Bus Sub-element, and the Spacecraft Subsystems.
- Prepare project report and presentation.
  - This briefing will provide the foundation by which to prepare the project presentation.
- Present INCOSE Briefing Part 2 in the spring or summer 07 timeframe
- Prepare a paper for the next available INCOSE symposium.

Data Extraction Format

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Object Name	Role View	View	Parameter	Source
	(Satellite Element or	(Context or		
	Spacecraft Bus Sub-element or	Structure or		
	Spacecraft Subsystem)	Attributes or		
		Identification or		
		Behavior or		
		Development or Requirements or		
		Verification or		
		Operations or		
		Performance or Trivia)		

Project Schedule

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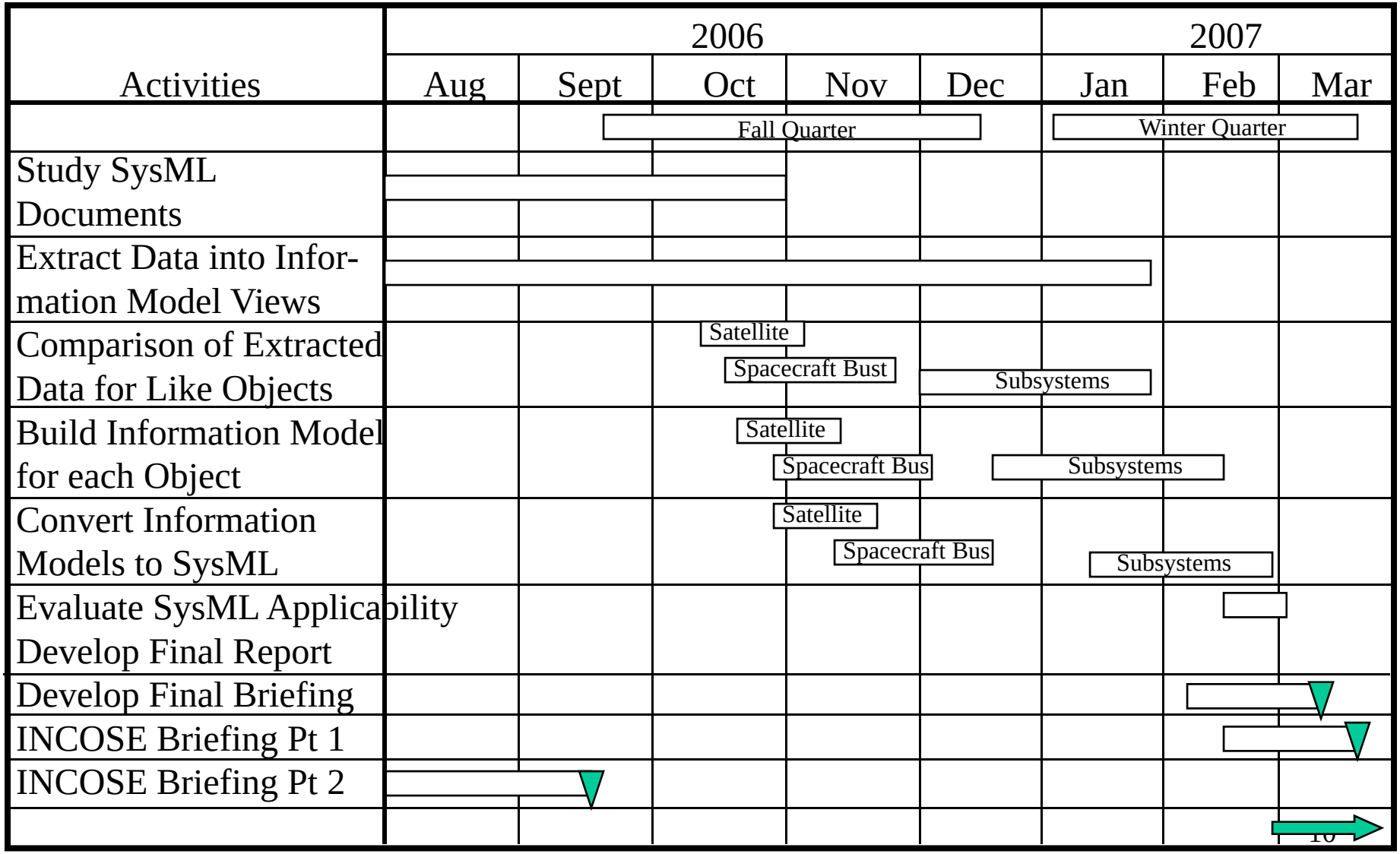
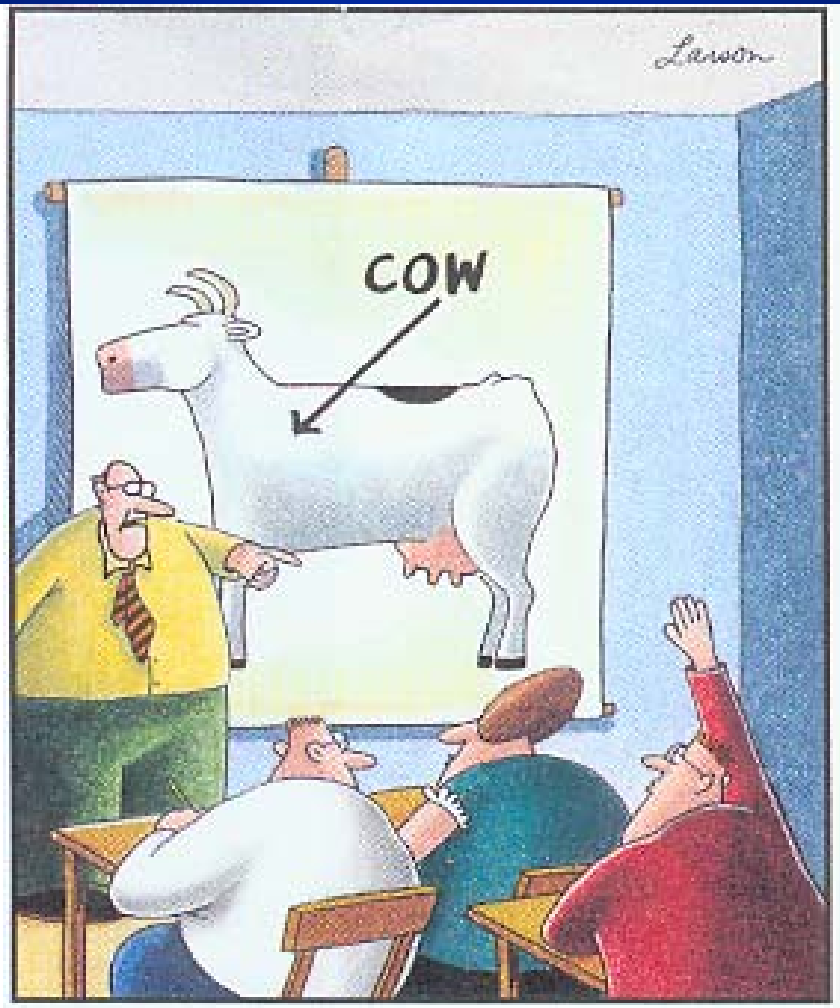


Space System Specification and Design Model

Far Side – This is a cow.

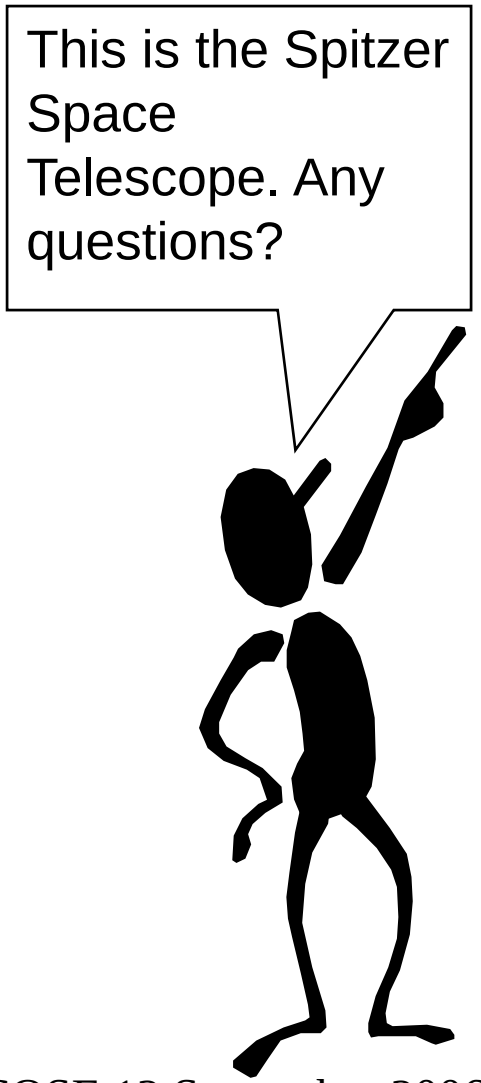


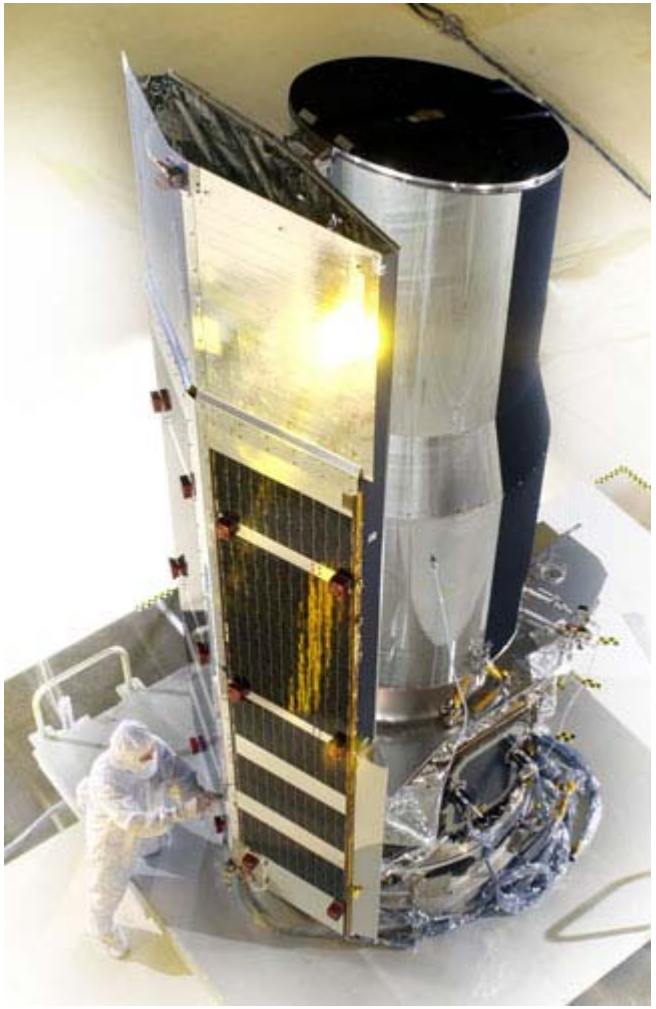
"Yes ... I believe there's a question in the back."

Courtesy FarWorks, Inc.

Near Side - This is the Spitzer Space Telescope.

SFBAC



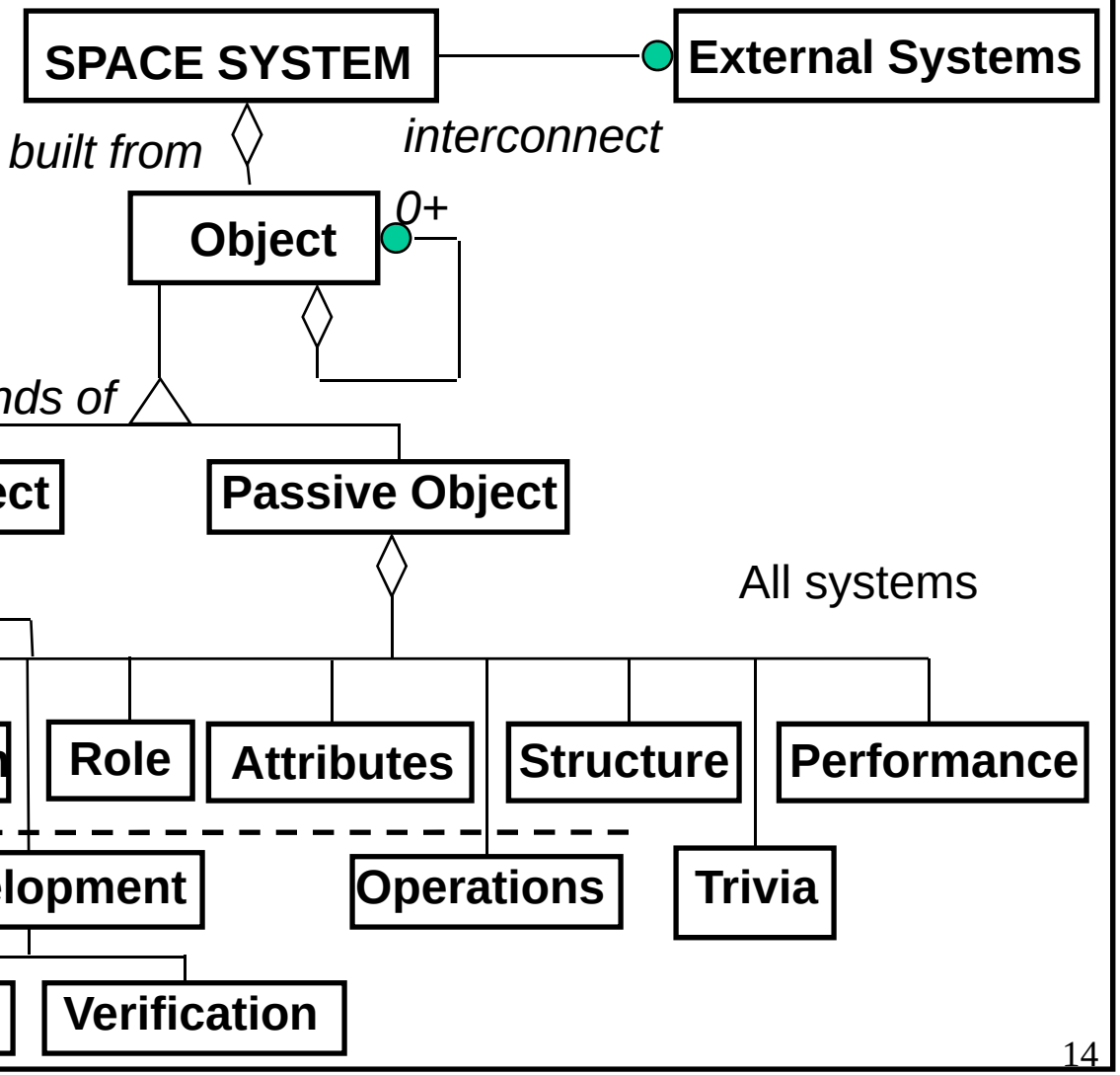


Courtesy NASA/JPL-Caltech

Spacecraft System Specification and Design Model

Context

- Mission objectives
- Mission profile
- External Interfaces
- Environments
- Customer expectations/ benefits
- Other constraints



Space System Specification and Design Views

Specification and Design Model For Context View

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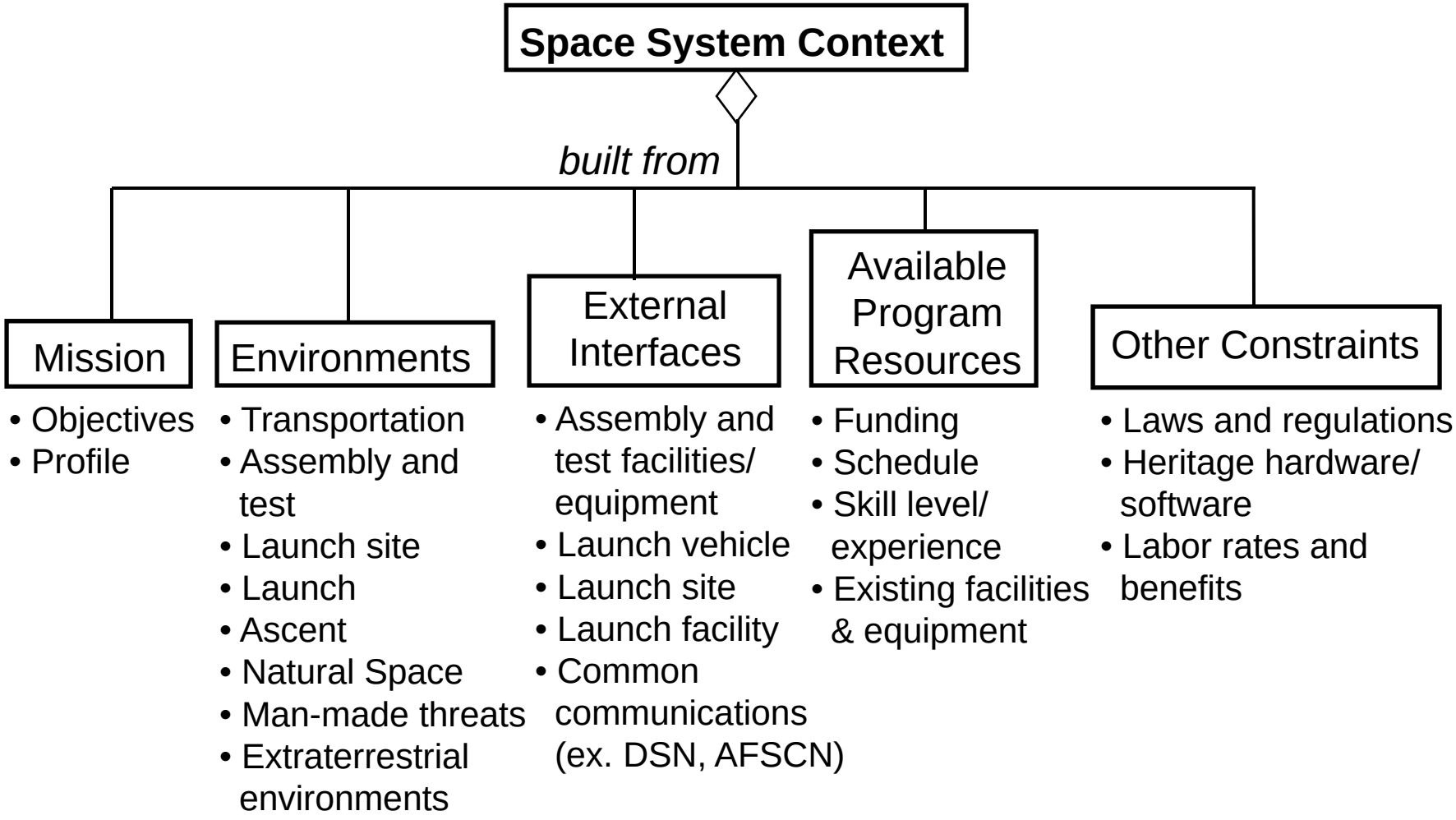

Source Material – Context

- Mission Profile - Mission Phases, Mission Critical Events, Orbit Parameters, Eclipse Periods, Solar Conjunction Periods, Ground Station Contacts
- External Interfaces - AIT Facility, Ground Support Equipment (GSE), Transporter, Launch Site, Launch Facilities, Launch Vehicle, Ground Station
- Environments - Weather, AIT Facility, Transportation, Launch Site, Launch, Ascent, On-orbit (Natural, Man-made)
- Other constraints - Budget, Schedule, Use of Heritage Hardware/ Software, Labor Rates, Laws and Regulations, Existing Facilities & Equipment, Political Environment

Specification and Design Model For Identification View

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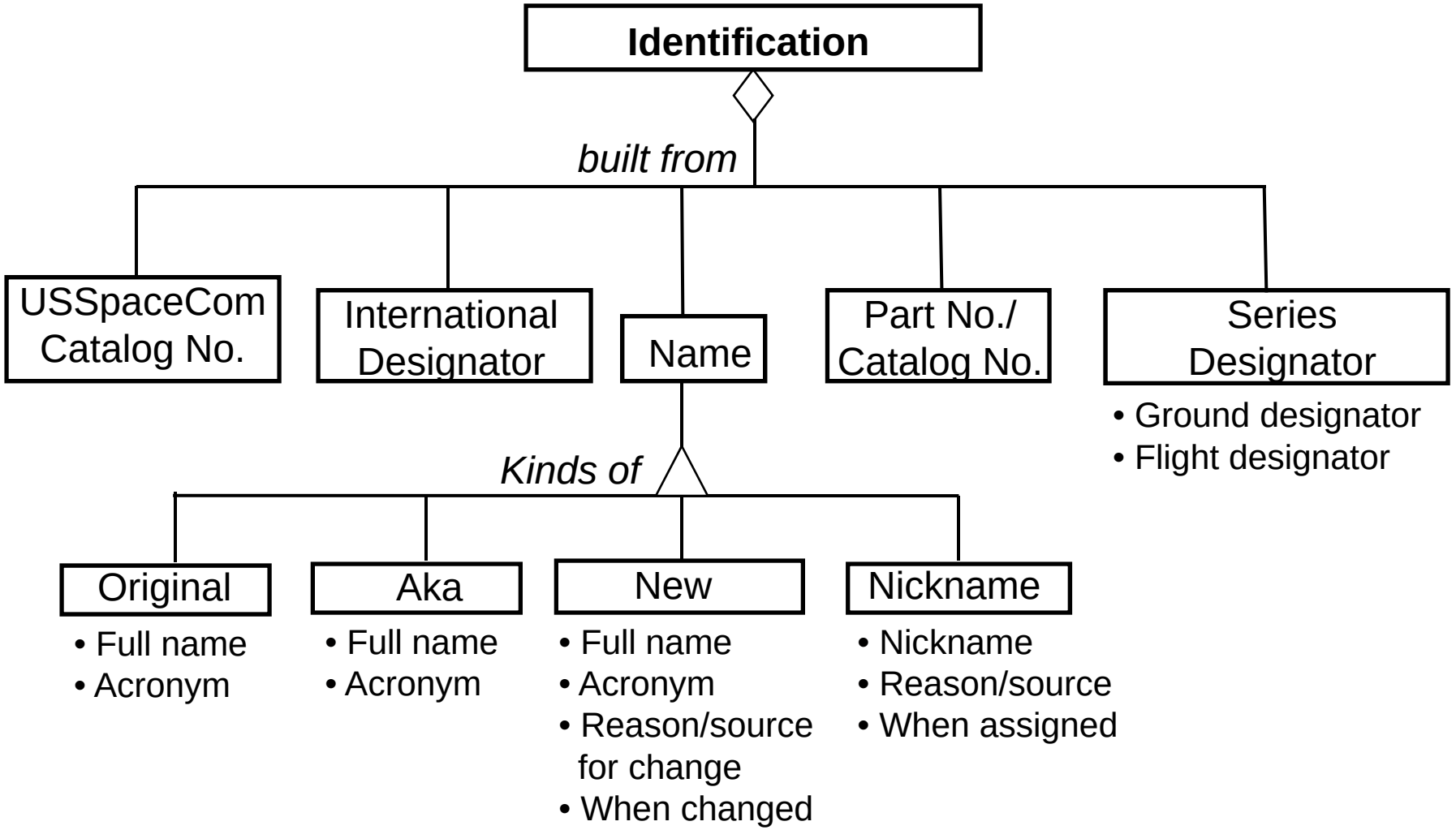

Specification and Design Model For Role View

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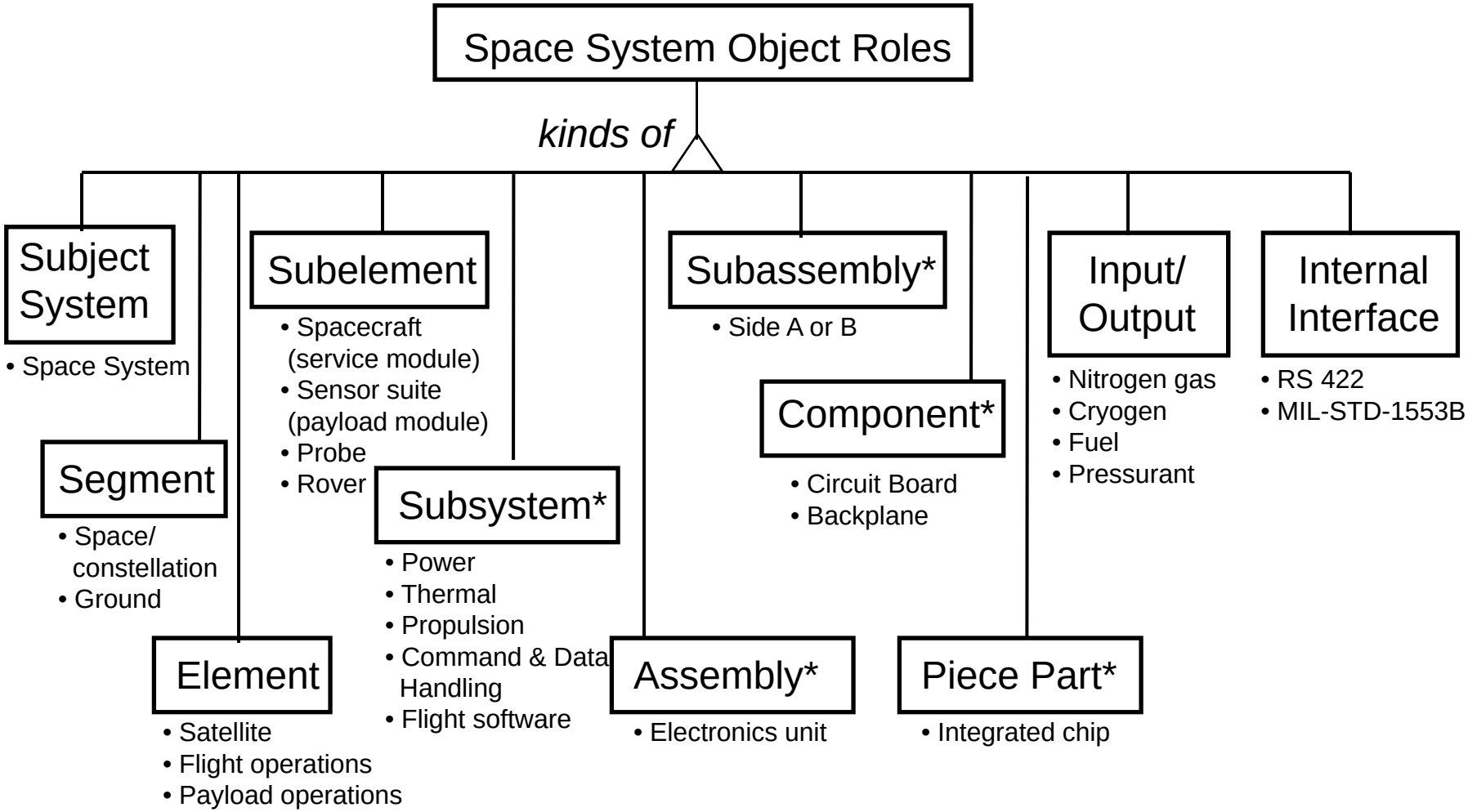

* Or software equivalent

Specification and Design Model For Attributes View

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- Attributes (or Characteristics) - all properties needed for the engineering problem at hand (those parameters typically found on a specification sheet)

Hardware Attributes		Software Attributes
• Mass properties	• Thermal conductivity	• Programming language
• Ballistic coefficient	• Reflectivity	• Number of lines of code
• Dimensions-stowed & deployed	• Maintainability	• Software heritage
• Shape	• Safety level	• Reusability
• Pointing accuracy	• Program heritage	• Modularity
• Coordinate system	• Field of view	• Price
• Name of Supplier	• Resolution	• Name of supplier
• Reliability/Mission Life	• Materials	
• Non-recurring cost	• Magnetic field levels	
• Orbital parameters	• Pressure level	
• Natural frequency	• Purity level	
• Color	• EMI level	
• Volume	• Radiation hardness	
• Power input/output	• Antenna gain	
• Heat dissipation	• RF frequencies	
• Operating temperature limits	• Clock speed	
	• Memory size	

Specification and Design Model For Structure View

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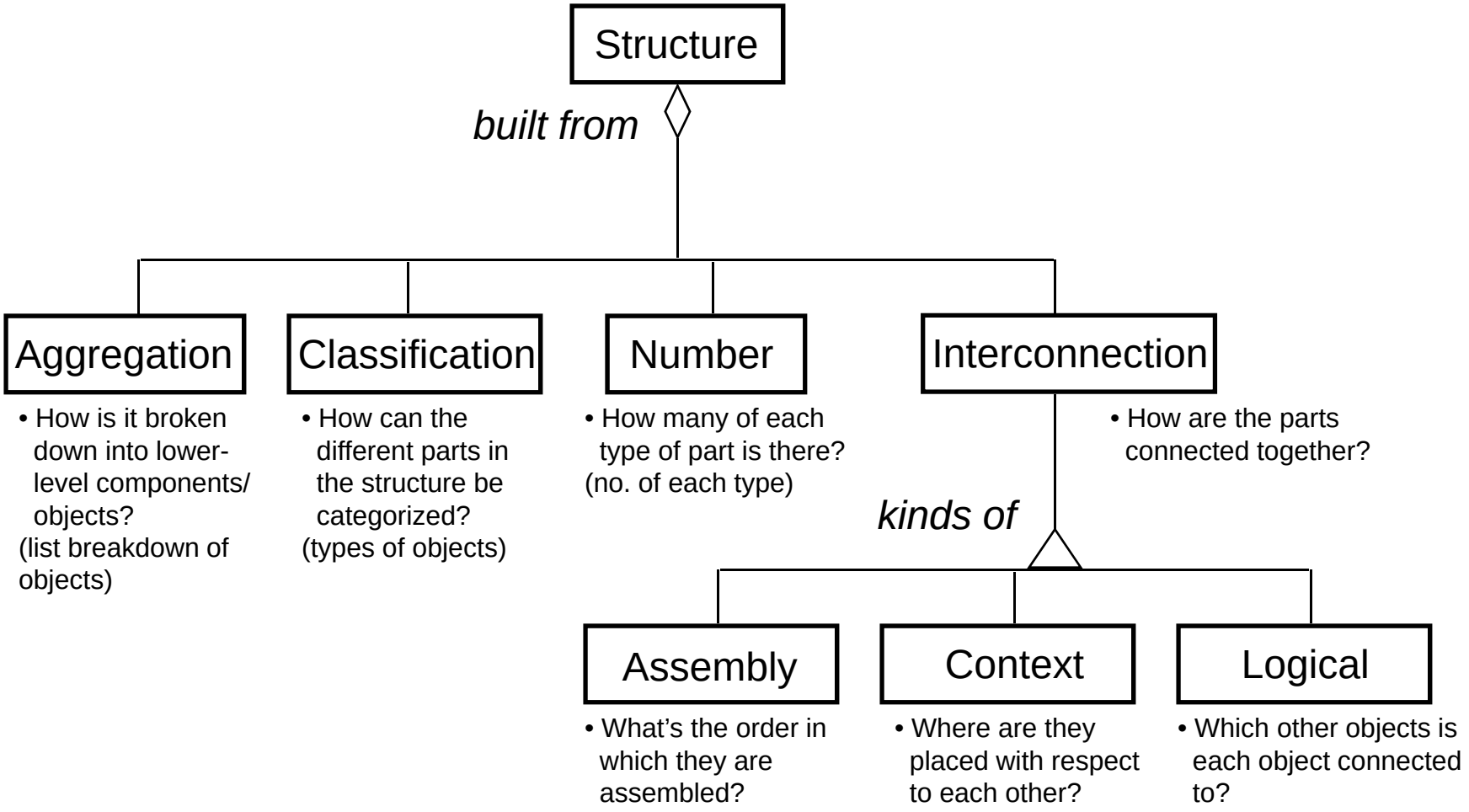

Source: Engineering Complex Systems With Models and Objects, Oliver

Specification and Design Model For Behavior View

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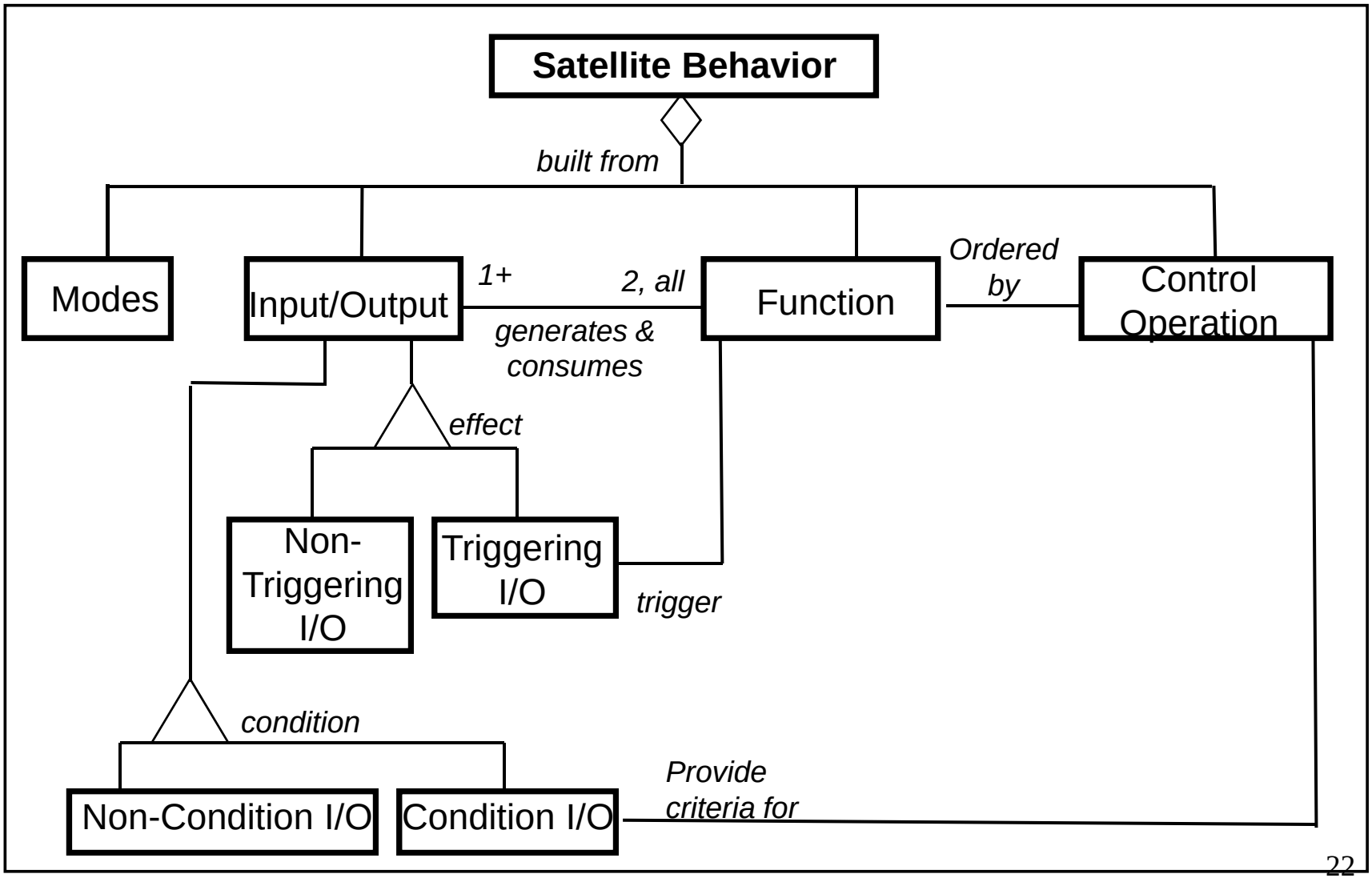

Specification and Design Model For Development View

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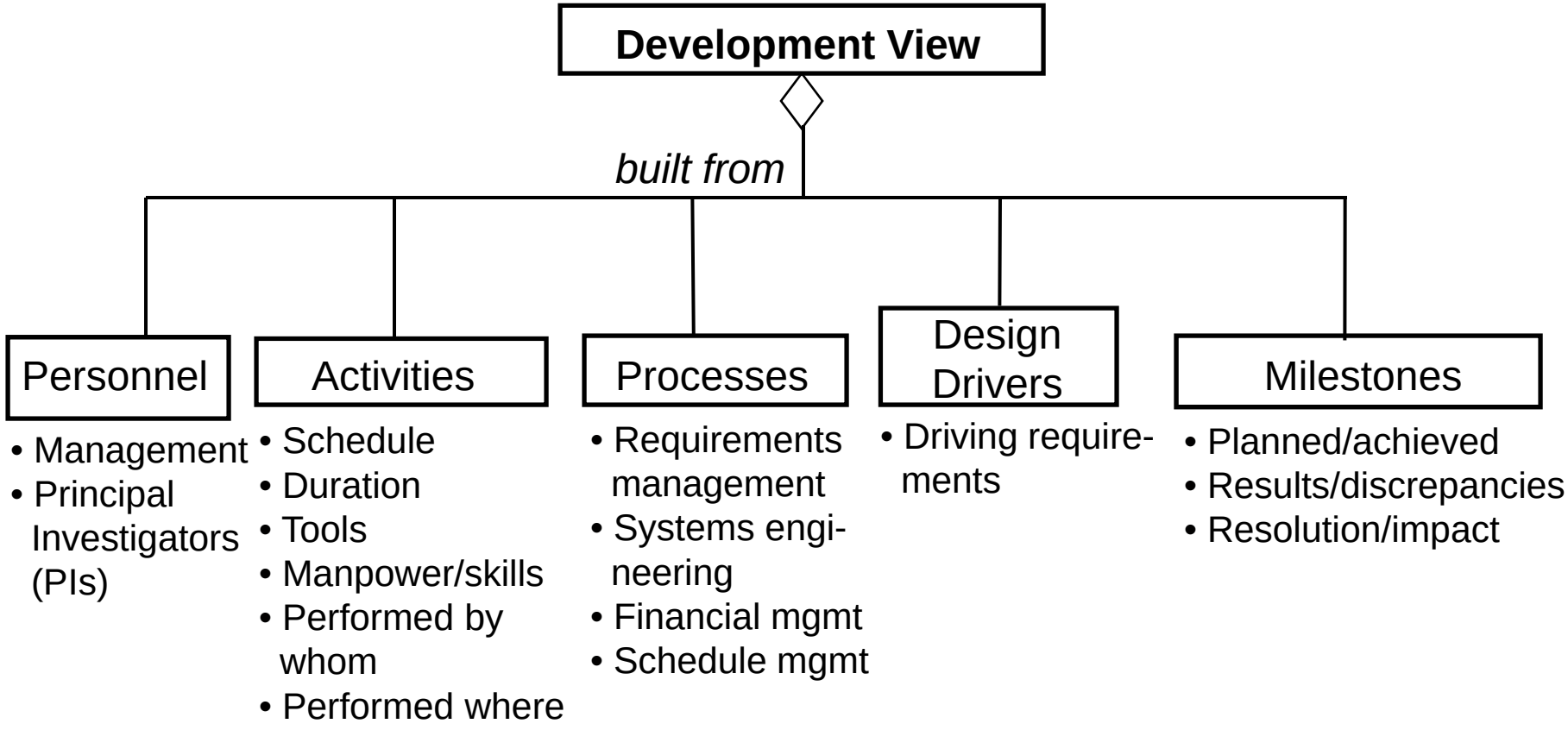
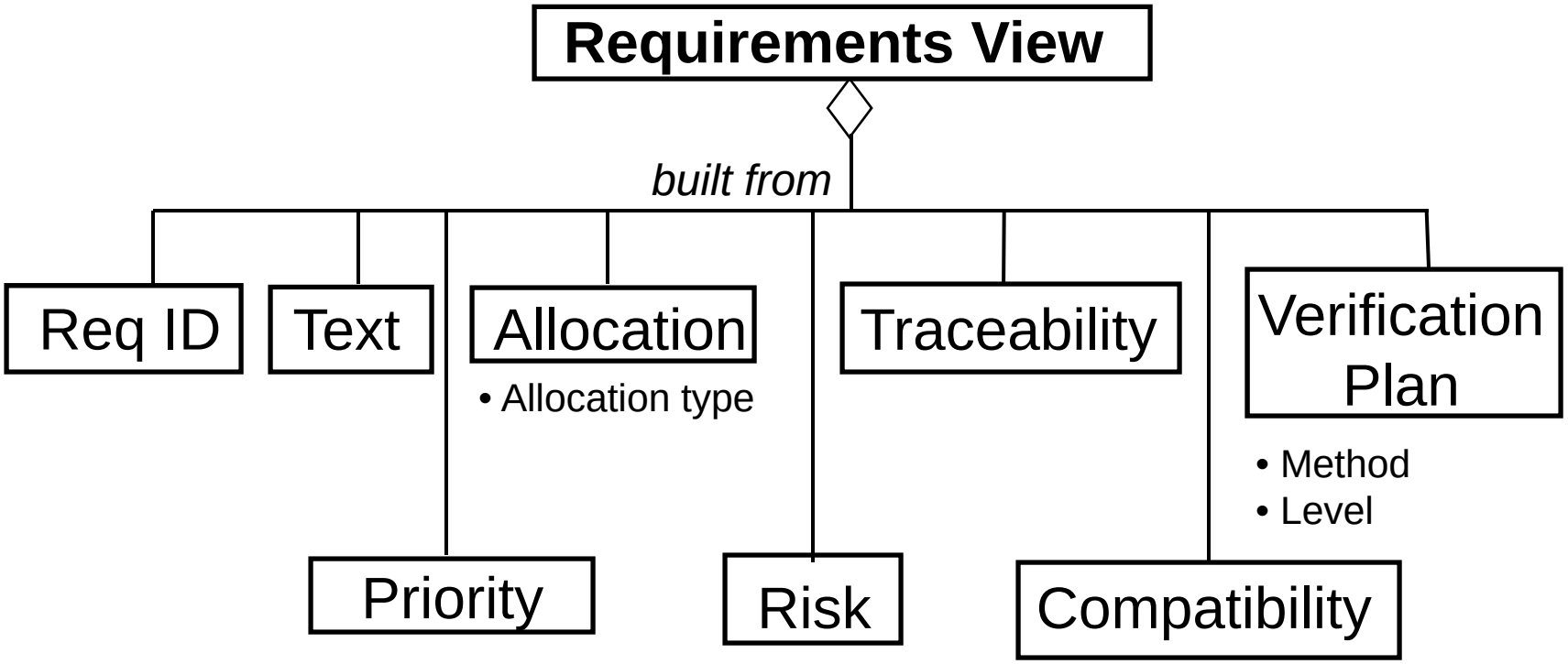


Specification and Design Model For Requirements View



Specification and Design Model For Verification View

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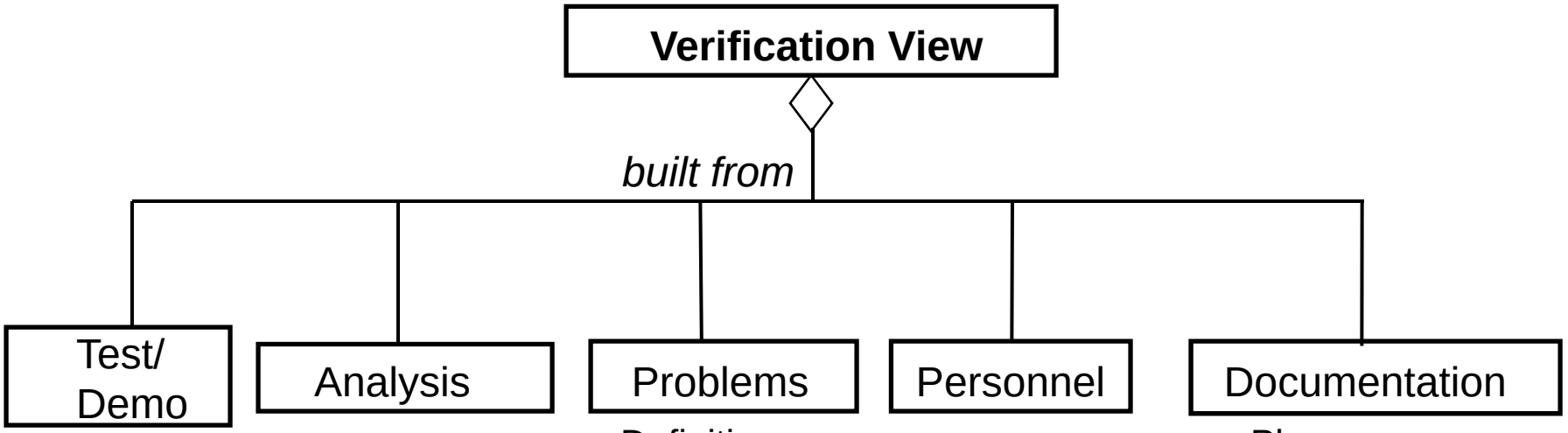

- Name/type
- Location
- Test conductor
- Duration
- Environment
- Test profile
- Reviews

- Definition
- Resolution
- Impact
- Design changes

- Plans
- Reports

Specification and Design Model For Operations View

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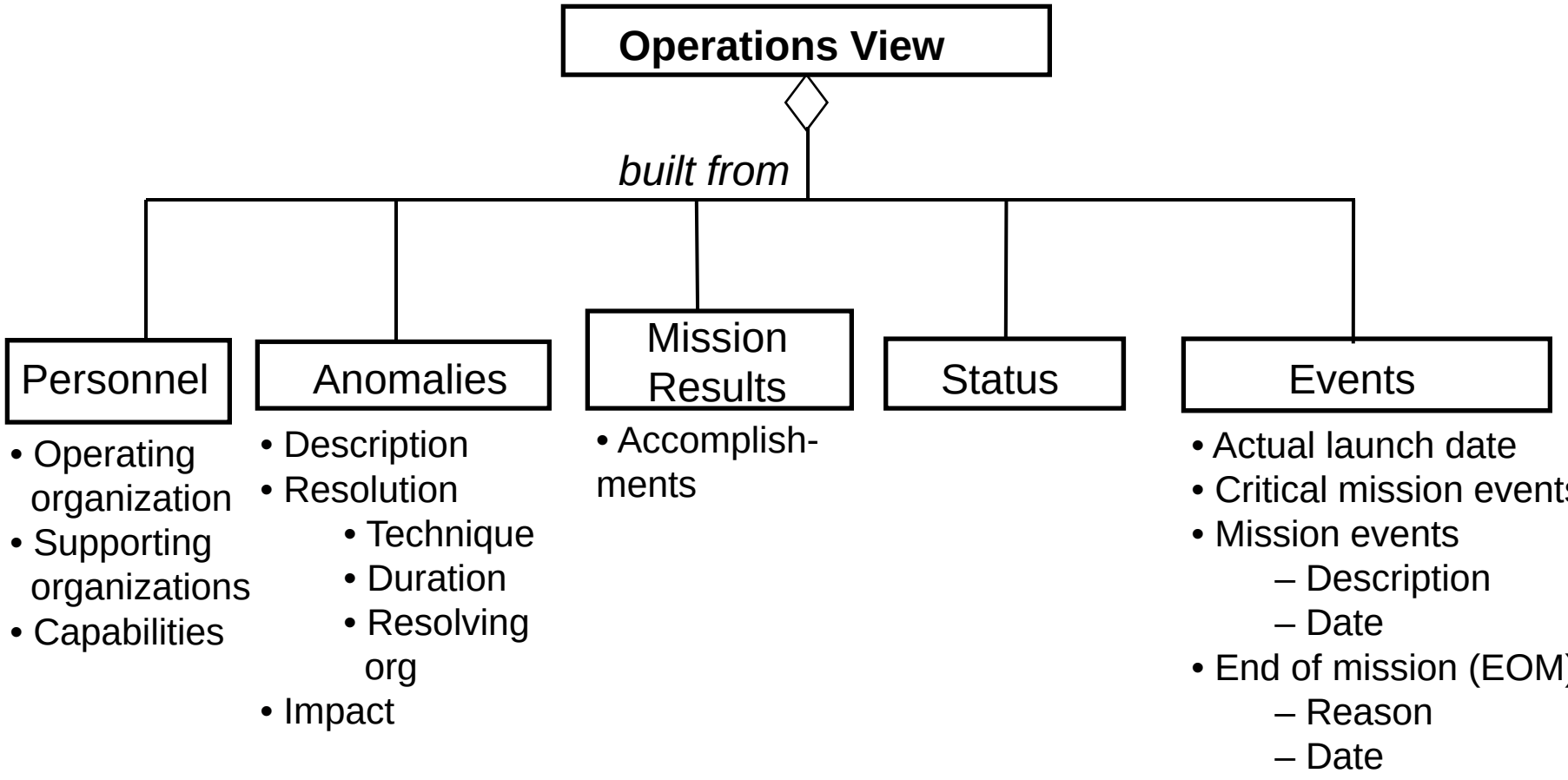

Specification and Design Model For Trivia View

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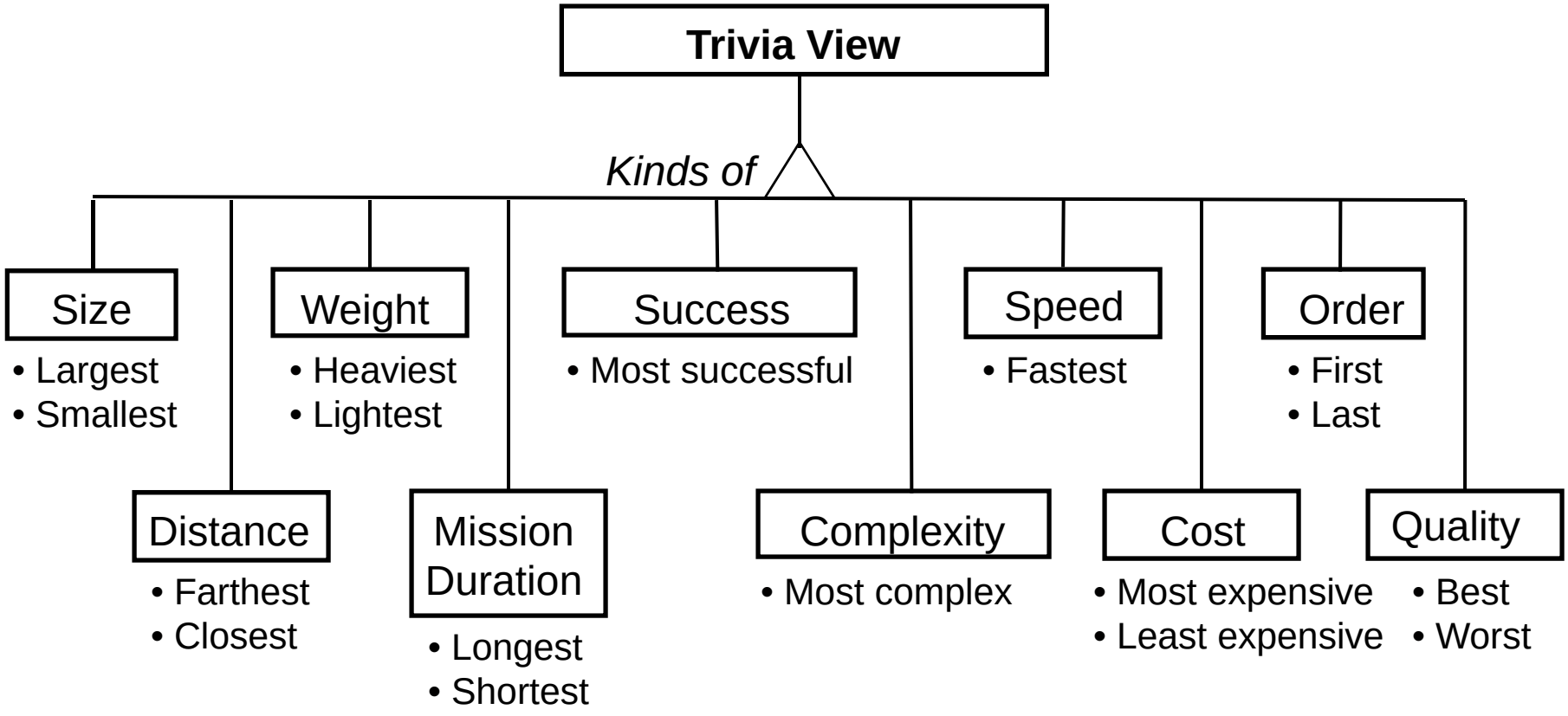
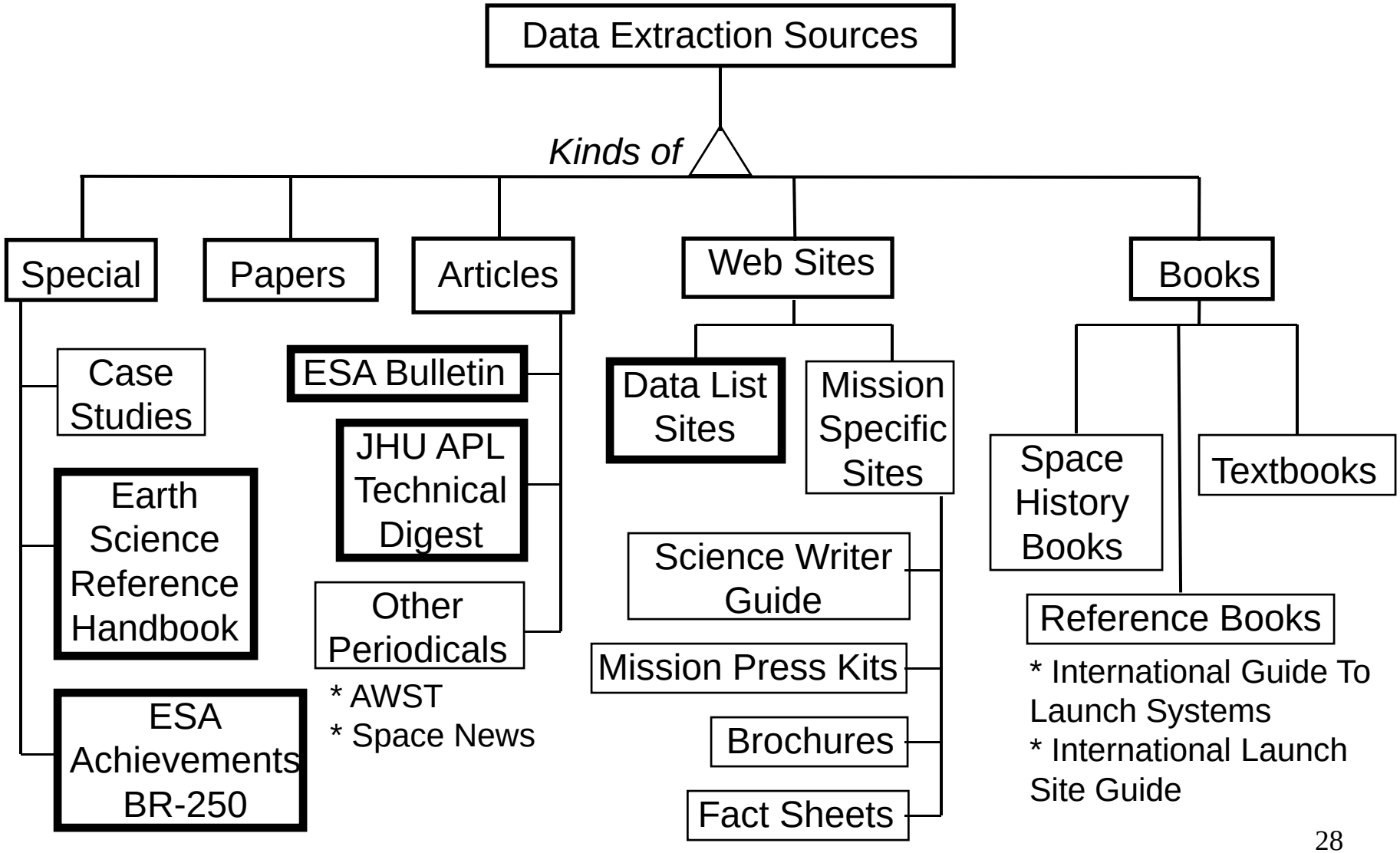


Data Extraction Sources

SFBAC



Data Extraction Sample

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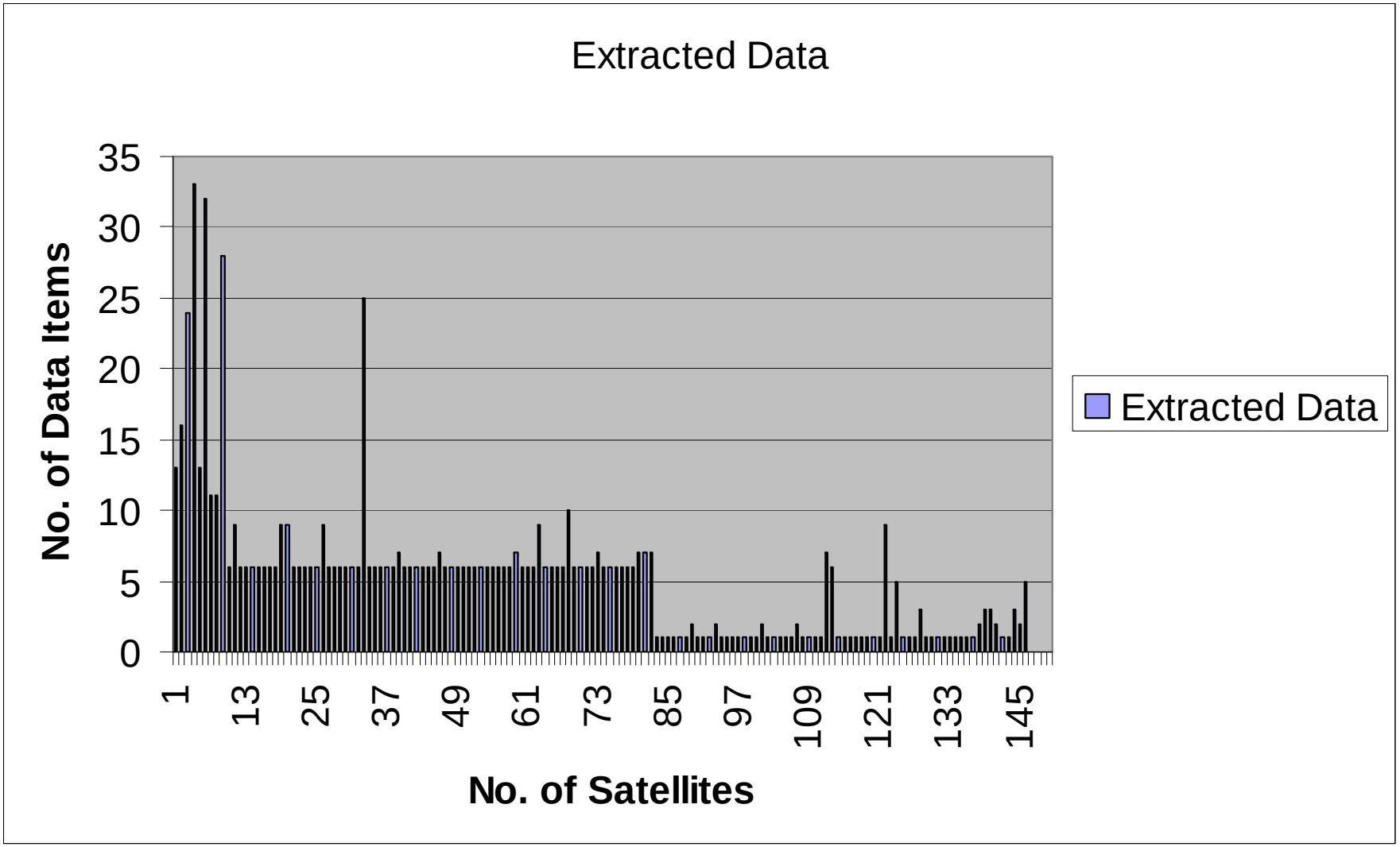
Name	Role	View	Parameter	Source
ESRO-2B	Satellite Element	Identification	Acronym: ESRO – European Space Research Organization	ESA Achievements, BR-250, June 2005
		Identification	International Designator: 1968-041A	http://msl.jpl.nasa.gov/home.html
		Identification	AKA: Iris	http://msl.jpl.nasa.gov/home.html
		Context	Mission Type: Science	ESA Achievements, BR-250, June 2005
		Context	Mission Objective: Cosmic rays, solar X-rays	ESA Achievements, BR-250, June 2005
		Context	Launch Site: WSMC	http://msl.jpl.nasa.gov/home.html
		Context	Launch Vehicle: Scout B	http://msl.jpl.nasa.gov/home.html
		Context	Program Type: Government (European)	ESA Achievements, BR-250, June 2005
		Context	Orbit Type: LEO	http://msl.jpl.nasa.gov/home.html
		Attributes	Mass: 75 kg	http://msl.jpl.nasa.gov/home.html
		Development	Procuring Agency: ESRO	ESA Achievements, BR-250, June 2005
		Development	Principal Contractor: Laboratoire Central de Telecommunications (Paris)	ESA Achievements, BR-250, June 2005
		Operations	Actual Launch Date: 1968 May 17	ESA Achievements, BR-250, June 2005
		Operations	Mission Results: Continued transmitting data until reentry	ESA Achievements, BR-250, June 2005
		Operations	Status: Destroyed during reentry	ESA Achievements, BR-250, June 2005
		Operations	Reentry Date: 1970 June 26	ESA Achievements, BR-250, June 2005

Data Extraction Results (as of 9/3/06) *SFBAC*



SysML Background and Introduction

- SysML is a modeling standard created by the Object Management Group as an extension of their Unified Modeling Language™ (UML®)
  - OMG has been an international, open membership, not-for-profit computer industry consortium since 1989.
  - OMG membership includes hundreds of organizations, with half being software end-users in over two dozen vertical markets, and the other half representing virtually every large organization in the computer industry and many smaller ones.
  - Most of the organizations that shape enterprise and Internet computing today are represented on the OMG Board of Directors.
  - OMG Task Forces develop enterprise integration standards for a wide range of technologies, including: Real-time, Embedded and Specialized Systems, Analysis & Design, Architecture-Driven Modernization and Middleware and an even wider range of industries, including: Business Modeling and Integration, C4I, Finance, Government, Healthcare, Legal Compliance, Life Sciences Research, Manufacturing Technology, Robotics, Software-Based Communications and Space.
- SysML reuses a subset of UML 2.1 and provides additional extensions needed to address the requirements in the UML for SE RFP.

Source: http://www.omg.org/

OMG SysML References

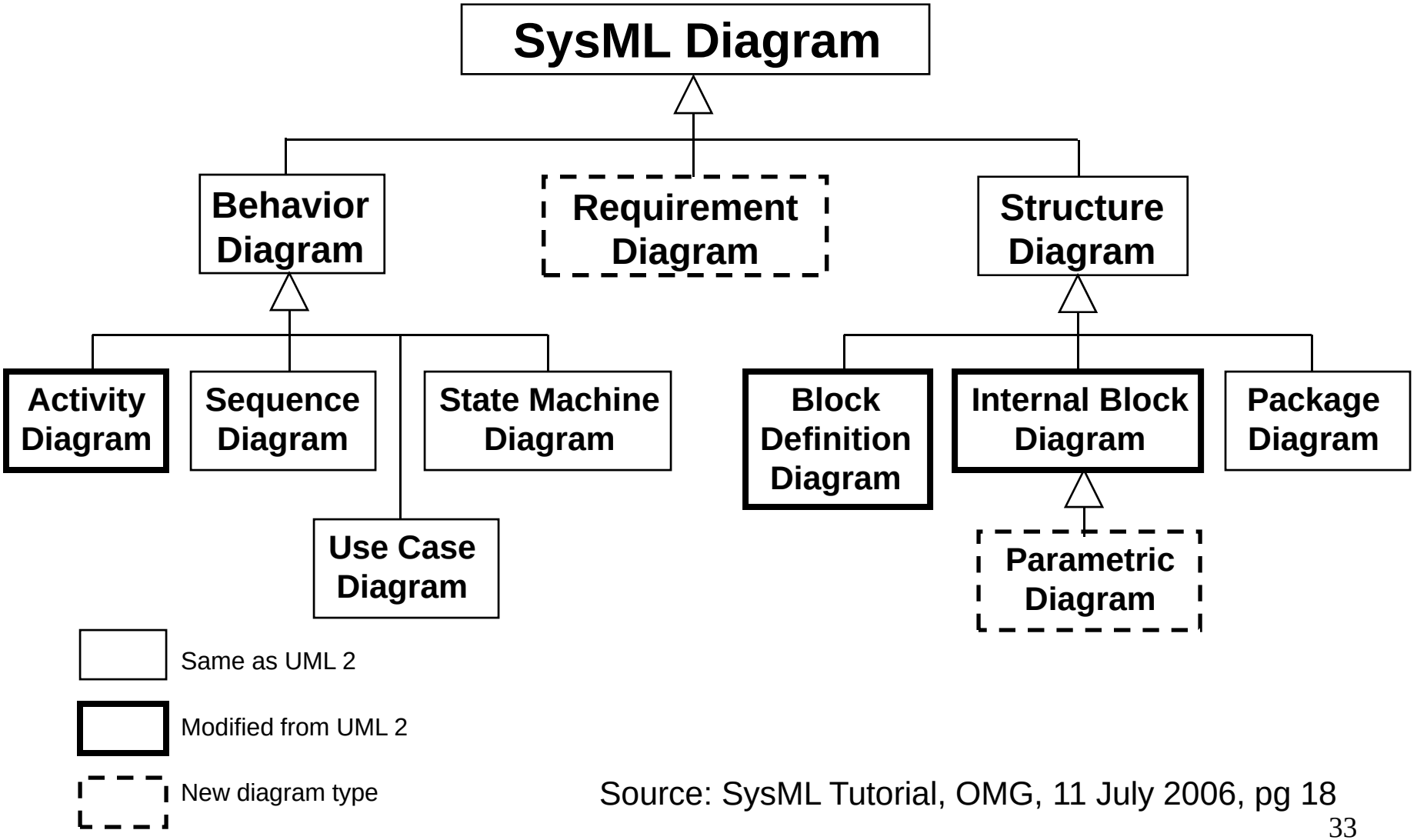
- The official OMG SysML web site (http://www.omgsysml.org/)
  - SysML specifications
    - * OMG SysML Specification, dated May 2006
  - Publications
    - * Paper
    - * Articles
    - * Tutorials
      - o OMG SysML Tutorial 11 July 2006 (INCOSE 2006)

- Other SysML-related papers can be found by web search

- Number of SysML related papers in the INCOSE Symposium proceedings

- SysML-related papers are also available in the INCOSE INSIGHT and Systems Engineering Journal

SysML Diagram Taxonomy



Source: SysML Tutorial, OMG, 11 July 2006, pg 18

SysML Diagram Descriptions

- The system structure is represented by block definition diagrams and internal block diagrams.
  - A block definition diagram describes the system hierarchy and system/ component classifications.
  - The internal block diagram describes the internal structure of a system in terms of its parts, ports, and connectors.

- The package diagram is used to organize the model.

- The behavior diagrams include the use case diagram, activity diagram, sequence diagram, and state machine diagram.
  - A use-case diagram provides a high-level description of functionality that is achieved through interaction among systems or system parts.
  - The activity diagram represents the flow of data and control between activities.
  - A sequence diagram represents the interaction between collaborating parts of a system.
  - The state machine diagram describes the state transitions and actions that a system or its parts perform in response to events.

Source: http://www.omgsysml.org/

SysML Diagram Descriptions (2)

• SysML includes a graphical construct to represent text based requirements and relate them to other model elements.

• The requirements diagram captures requirements hierarchies and requirements derivation, and the satisfy and verify relationships allow a modeler to relate a requirement to a model element that satisfies or verifies the requirements.

– The requirement diagram provides a bridge between the typical requirements management tools and the system models.

• The parametric diagram represents constraints on system property values such as performance, reliability, and mass properties, and serves as a means to integrate the specification and design models with engineering analysis models.

• SysML also includes an allocation relationship to represent various types of allocation, including allocation of functions to components, logical to physical components, and software to hardware.

Source: http://www.omgsysml.org/

Applicability of SysML Diagrams to Satellite Views

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SysML Diagrams	Views											
	Context	Identification	Role	Attributes	Structure	Performance	Behavior	Development	Requirements	Verification	Operations	Trivia
Activity Diagram*												
Sequence Diagram												
Use Case Diagram												
State Machine Diagram												
Requirement Diagram**								X				
Block Definition Diagram*												
Internal Block Diagram*												
Parametric Diagram**						X						
Package Diagram												

*** Modified from UML 2.0 **New diagram type**

Utility of SysML Diagrams to Model Satellites

- Helps prevent starting from scratch - no more reinventing the wheel when starting a new project
- Guidelines for design development to help ensure completeness
- Description document outline and content completeness
- Help to ensure specification development completeness
- Red Team review guide for both developers and reviewers – completeness of proposal/proposed design
- Program knowledge base not entirely dependent on just the knowledge of personnel working on the program

What if a Single Systems Engineer …? *SFBAC*

Backup Charts

Project Guidelines

Project Steps (from Prof Eric Mehiel, 2/16/06)

1. Identify a project you would like to work on. This project can be part of your regular work duties, or an extension of your work duties.

Your project can also be self-defined and have no relationship to your current duties. The possibilities are quite open. There are a couple of practical things you should keep in mind:

a. A copy of your project must be deposited in the Cal Poly library. NO PROPRIETARY TOPICS!

b. You should be able to complete all project work within 5 units

c. Your LM mentor should be someone you have relatively easy access to. Your LM mentor should help guide you through your project by identifying resources and previous work in the area of your project.

d. Your Cal Poly advisor will help you navigate through the bureaucracy here on campus. Your Cal Poly advisor will act as your official academic advisor and should also be capable of guiding you through your project.

2. Once you have identified a project and an advisor, write a one page (at least) summary of your project. You should address the following area:

a. A brief review of previous work, (literature review)

b. Proposed schedule

c. Outline the work you intend to complete

d. Any issues that could hinder your project completion

3. Finally, after you, your LM mentor, and your Cal Poly advisor have agreed to a project proposal, you can sign up for 2 or 3 units of Aero 599 per quarter. Therefore, your project should be completed within two quarters. You and your Cal Poly advisor will agree upon a grading philosophy prior to enrolling. For example, if I was your advisor, I would have you take 2 and then 3 units. Your grade for your first 2 units would be based on a first draft of your literature review and your adherence to your proposed schedule. Your grade for your final 3 units would be based on the overall quality of your work.

Dr. David W. Oliver Tutorials & Textbook *SFBAC*

- Attended two Dr. David Oliver tutorials presented by INCOSE SFBAC
  - Engineering Complex Systems with Models and Objects (1997)
  - Concept Analysis with Objects and Models (1999)
- Read Dr. Oliver's book
  - "Engineering Complex Systems with Models and Objects"
  - Softcopy was provided free to INCOSE members
- First put into practice developing SIRTF Spacecraft System Design Description (SSDD)
- Wrote a paper from my SIRTF SSDD experience and presented paper at INCOSE Symposium 2000 (Minneapolis)
  - "The Use of an Information Model to Describe the SIRTF Spacecraft"
- Continuing to use information modeling wherever possible

State and Mode Assumptions

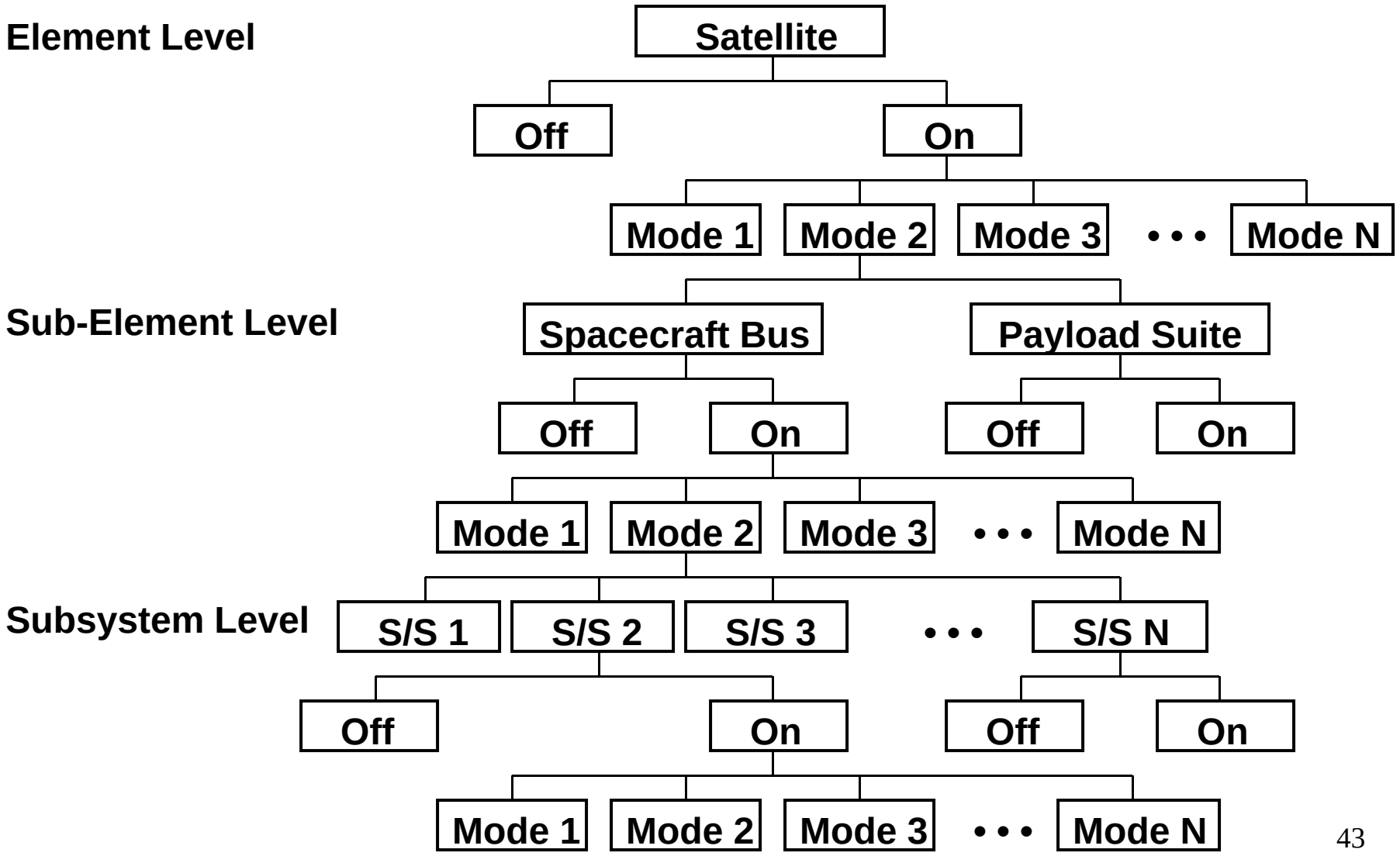
Definitions

- State - unique condition of existence (ex., either On or Off)

- Mode -
  1) Once On, a unique combination of functions derived from the available/allowable states of the lower level items
  2) a variation of the On state if more than one state (or configuration) is available in the On/powered condition (ex., partially On, fully On)

A mode can be a state but a state is not necessarily a mode. (A state can be Off; a mode can only exist if the state is On.)

Satellite States & Modes Hierarchy *SFBAC*



Generic Satellite Functions

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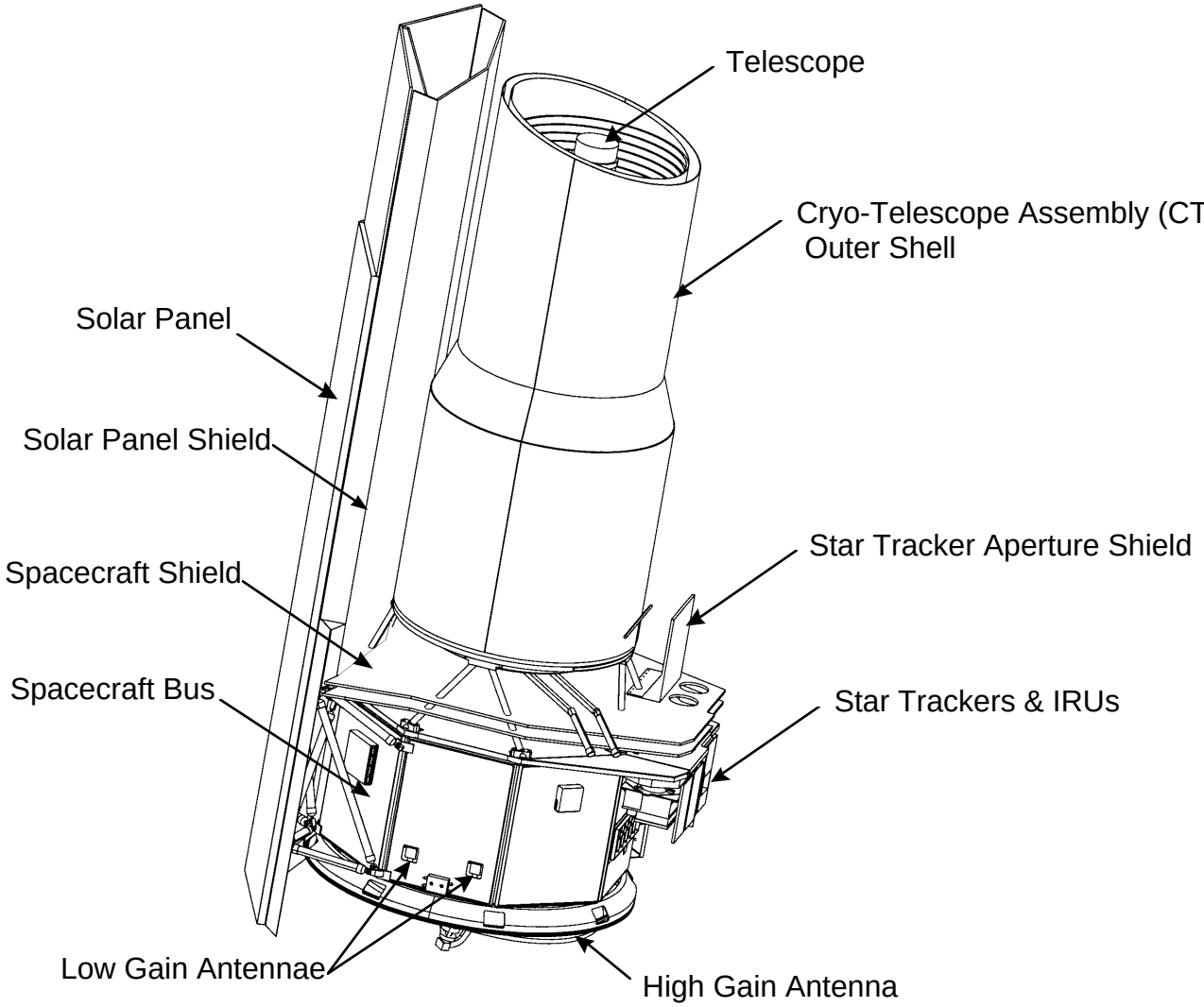
- Mission payload functions
- Mode control
- Command handling
- Data handling
- Power generation
- Power distribution
- Thermal control
- Attitude determination
- Attitude control
- Momentum management
- Thrust control
- Uplink reception
- Downlink transmission
- Time management
- Mechanism control
- Fault protection

Spitzer Space Telescope Element

SFBAC



Courtesy NASA/JPL-Caltech

Spitzer Space Telescope Sub-Elements

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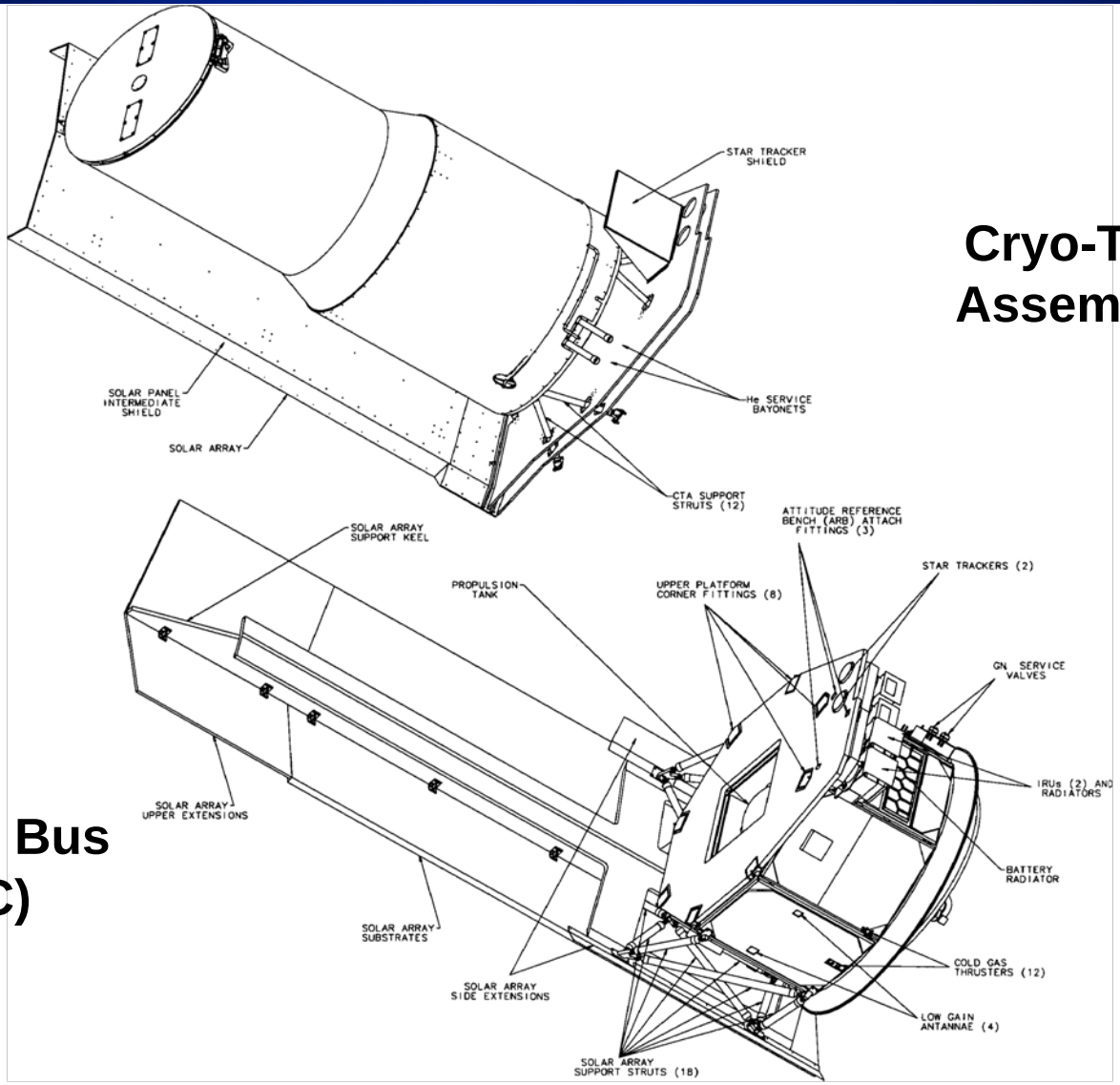

Cryo-Telescope Assembly (Ball)

Spacecraft Bus (LMSSC)

Courtesy NASA/JPL-Caltech

SIMPLE Use Case Example

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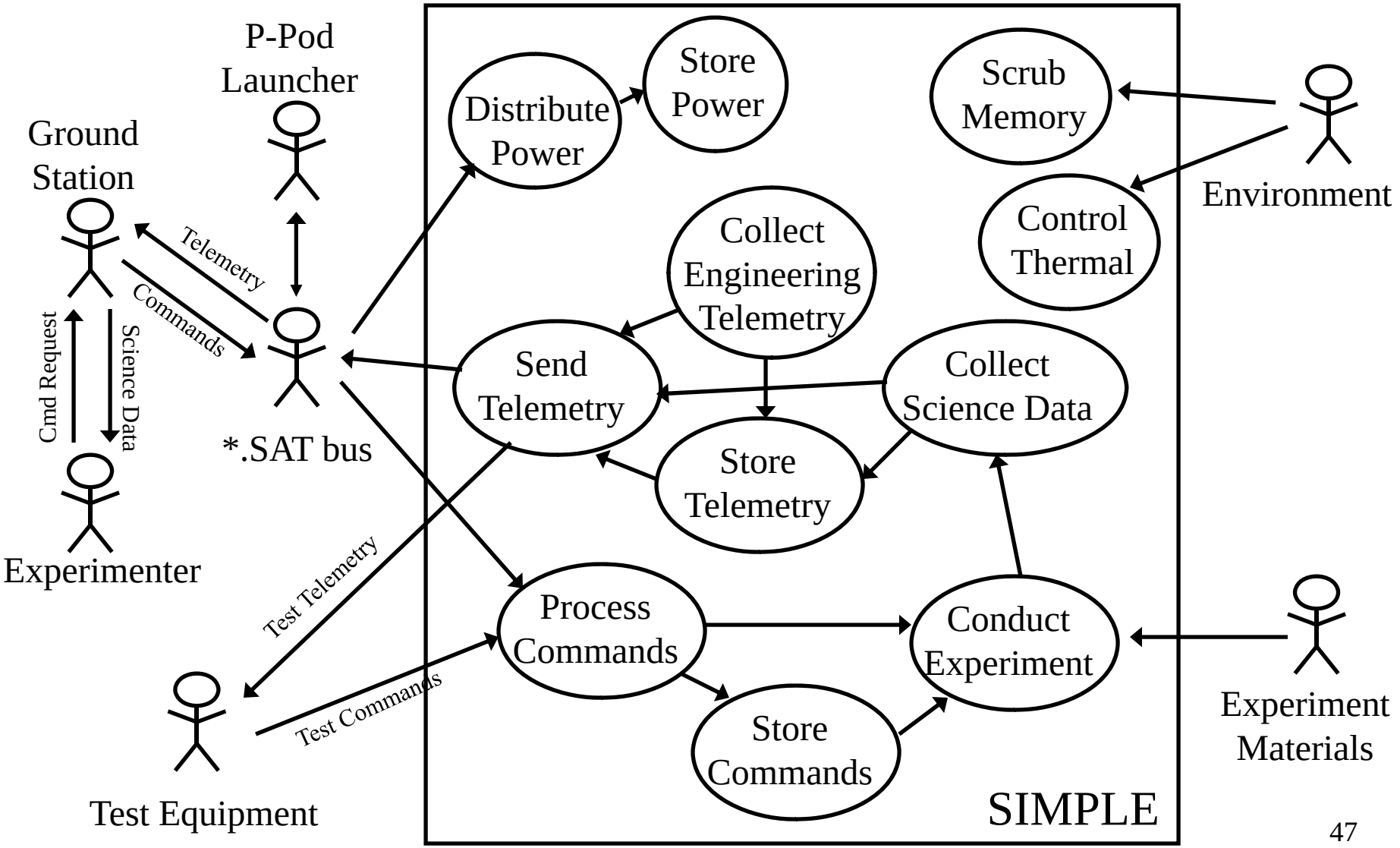

KISSat Orbital Operations Sequence Diagram

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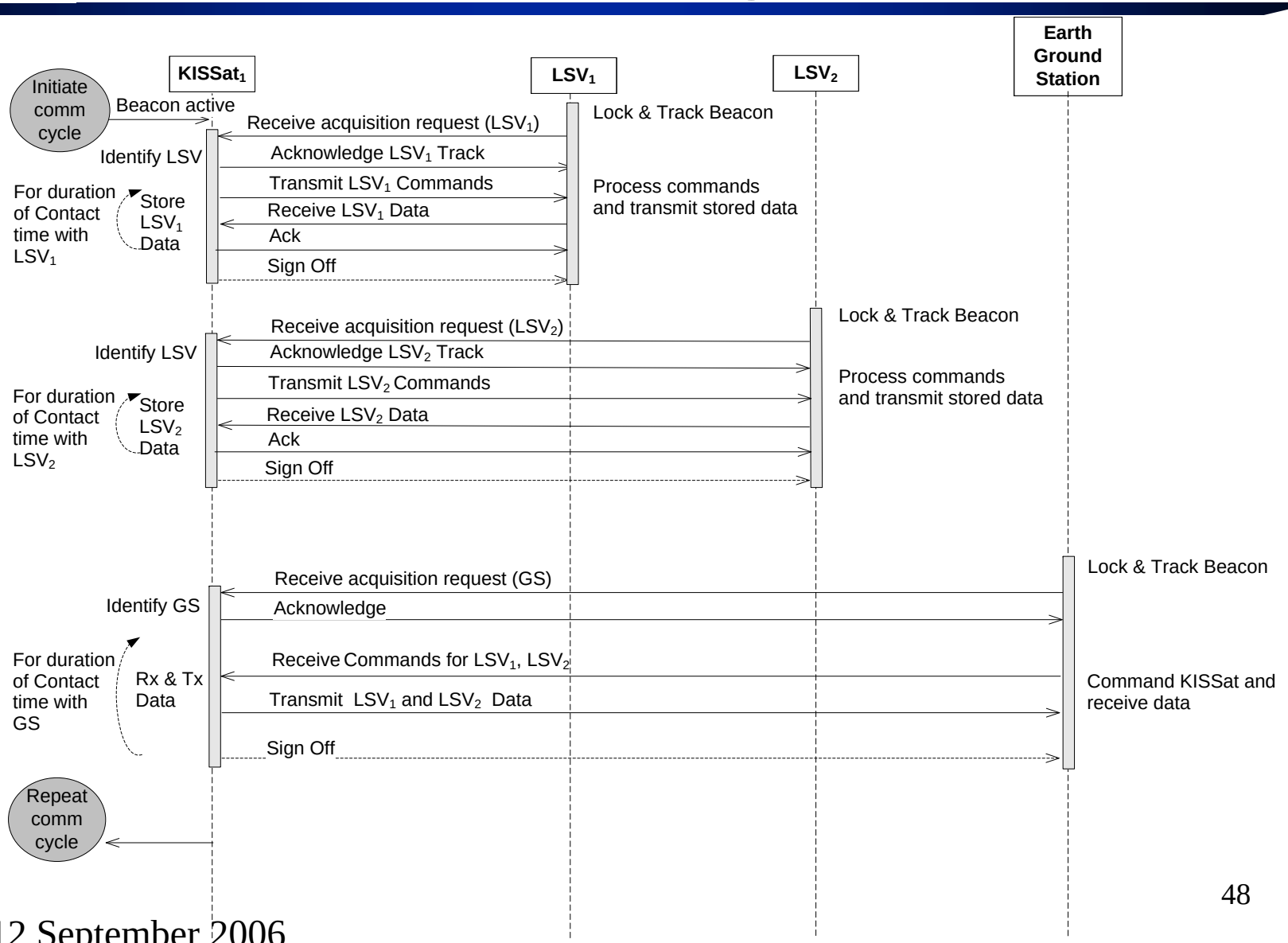
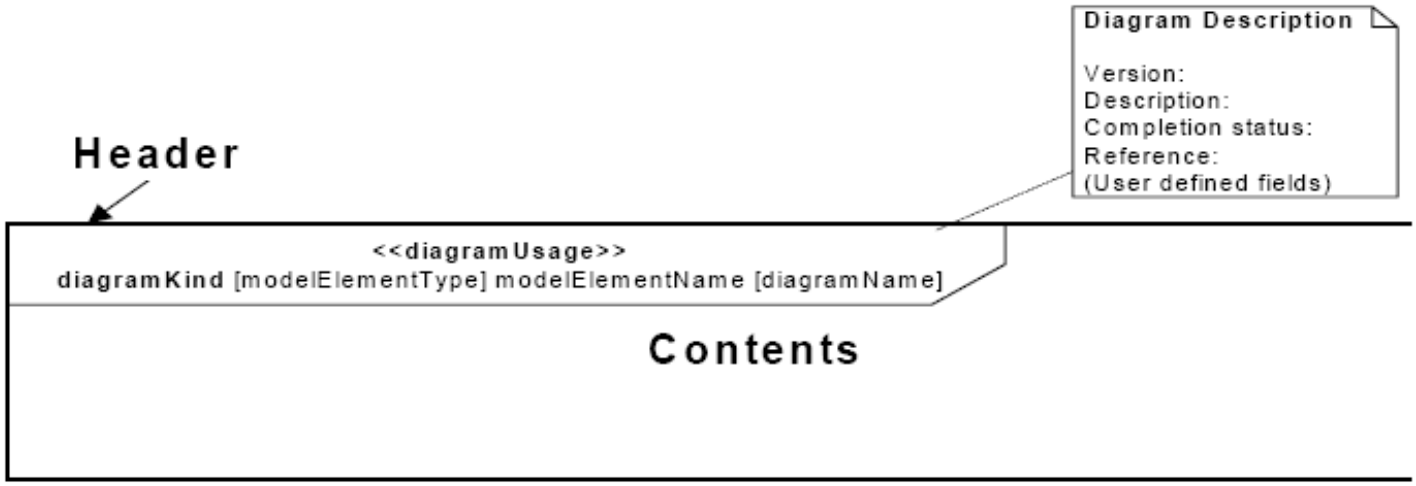


SysML Background and Introduction (2)

•The **«block»** is the basic unit of structure in SysML and can be used to represent hardware, software, facilities, personnel, or any other system element.

• Each SysML diagram has a *frame*, with a *contents area*, a *heading, and a Diagram Description*



Source: http://www.omgsysml.org/

Great Wall of China Utility Curve

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