Systems Engineering Advancement Research Initiative

Architecture Frameworks in System Design: Motivation, Theory, and Implementation

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SEARI
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Agenda

- Role of Artifacts in System Design
- Overview of Architecture Frameworks
- Metrics of Architecture Framework Effectiveness

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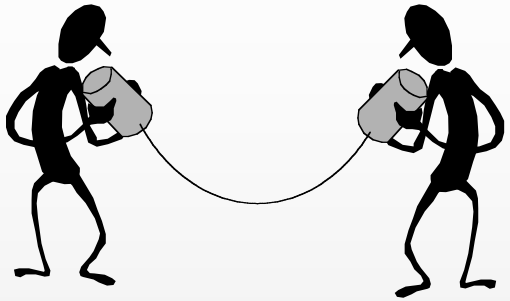
Three key roles of artifacts in system design

Communication



Knowledge Retention

Managing Complexity

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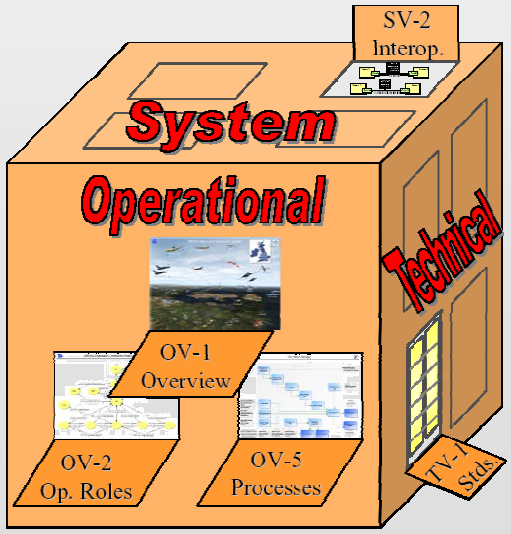
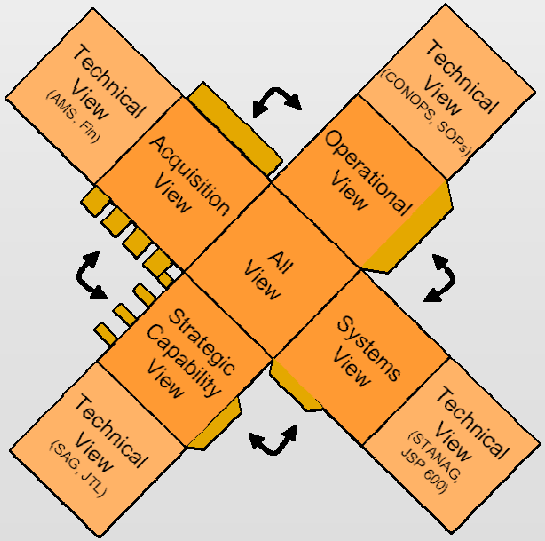
What are Architecture Frameworks?

- Tool for managing complexity by structuring data in a common language and common format
  - Establishes standards for the description of architectures
  - Defines the product and how the product must be constructed and operated
  - Presents information with a set of views, each of which is understandable to a different stakeholder community



MoDAF
"Unwrapped"



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Desired attributes of Modern Artifacts produced by Architecture Frameworks

- Mechanism to leverage expert knowledge regarding the ***complete and comprehensive description*** of the system from multiple stakeholder perspectives
- Means to provide technical information ownership and ***configuration control*** to give teams access to best and current information
- Construct for ***encapsulating information*** in a manner that can enable effective use of model-based systems engineering approaches and toolsets
- Approach that reconciles the systems engineer's drive to provide a complete system description with the ***pragmatic reality*** that any one engineer can effectively specify only partial information

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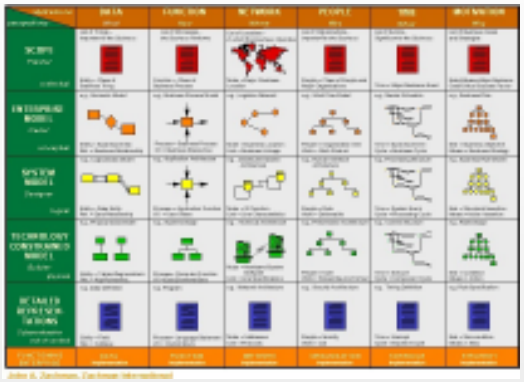
Overview of Architecture Frameworks

Enterprise

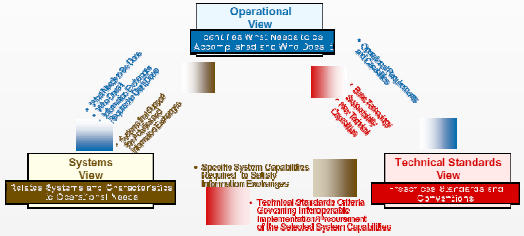


Zachman Framework

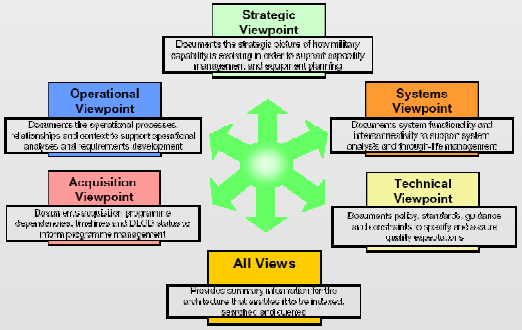
The Open Group Architecture Framework (TOGAF)

Federal Enterprise Architecture Framework (FEAF)

System



Dept. of Defense Architecture Framework (DoDAF)



Ministry of Defence Architecture Framework (MoDAF)

Other

Computer Integrated Manufacturing Open Systems Architecture (CIMOSA)

Integrated Architecture Framework (IAF)

Architectural Descriptions of Software Intensive Systems (IEEE 1471)

Reference Model for Open Distributed Processing (RM-ODP)

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Metrics of Architecture Frameworks Effectiveness

1. Purposefulness
2. Applicability
3. Internal Consistency
4. External Consistency
5. Clarity
6. Scalability
7. Execute-ability
8. Analytic Extensibility

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Purposefulness and Applicability

- Architecture construction had a clear purpose:
  - *To understand the key interaction within the spacecraft that effect science operation and how they can be maintained/improved through service**
- *Chose to construct views that best met that need:*
  - ***AV-1** and **OV-1** to capture overall mission*
  - ***SV-1** to identify key spacecraft components*
  - ***OV-5** to understand how operation occur and identify points of failure*
  - ***SV-8** to represent past and planned servicing missions*

* Richards, M., Shah, N., Hastings, D. and Rhodes, D., "Managing Complexity with the Department of Defense Architecture Framework: Development of Dynamic System Architecture Model," Conference on Systems Engineering Research, Los Angeles, CA, April 2006.

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Overview and Summary Information (AV-1) – Hubble Space Telescope

- **Description**
  - The Hubble Space Telescope is a joint venture of the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA). Launched into Low Earth Orbit on April 24, 1990 by the Space Shuttle Discovery (STS-31), Hubble's location above the Earth's atmosphere enables high resolution imaging of astronomical objects.
  - Hubble features a 2.4 meter primary mirror, is composed of more than 400,000 parts and contains 26,000 miles of electrical wiring. Total dimensions of the telescope are 13.3 meters in length and 4.3 meters in diameter. Hubble weighs 11,110 kg.

- **Purpose**
  - Hubble Space Telescope is a scientific instrument and its main scientific objectives are to determine:
    - The constitution, physical characteristics, and dynamics of celestial bodies.
    - The nature of processes which occur in the extreme physical conditions existing in and between astronomical objects.
    - The history and evolution of the universe.
    - Whether the laws of nature are universal in the space-time continuum.

- **Scope**
  - The Hubble Space Telescope program includes the orbiting observatory, the Space Telescope Science Institute, and the Space Telescope Operations Control Center. The system is supported by the Space Shuttle, the Tracking and Data Relay Satellite System, and the NASA Communications Network.

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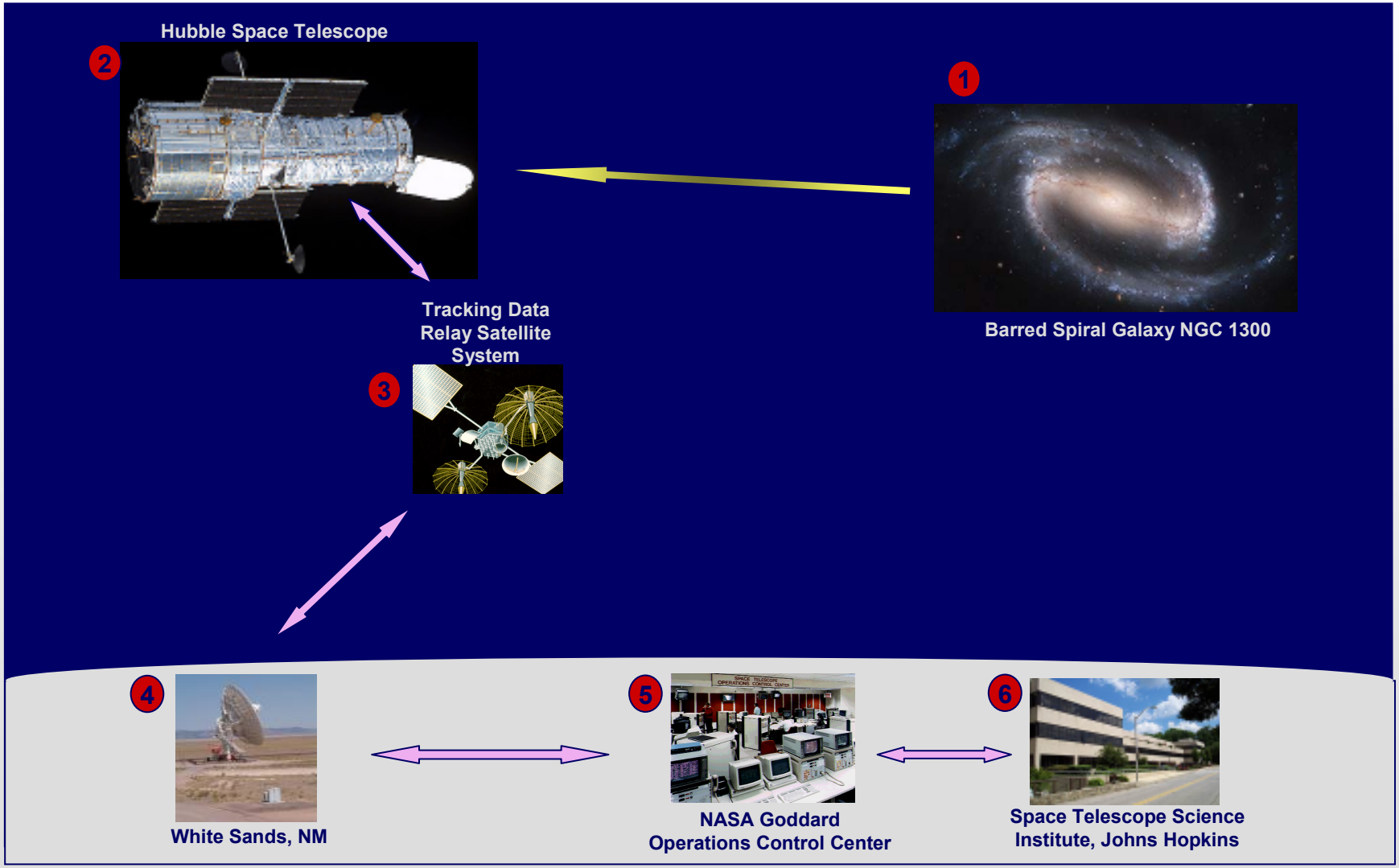
High Level Operational Concept Graphic (OV-1)



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Consistency

- **Internal:** Terminology and representation semantics must be consistent from view to view
  - *Tools such as Vitech's CORE helped maintain naming conventions when decomposing the system and building the views*
  - *Easy in our case since only two architects, however we were still careful to be precise with terminology -- e.g. defining a mission vs. a campaign, etc.*
- **External:** Consistency must also exist with respect to external documents and other related architectures
  - *Reviewed literature (e.g. NAS report of servicing options) on the spacecraft and, where practical, used widely accepted representations and terminology*

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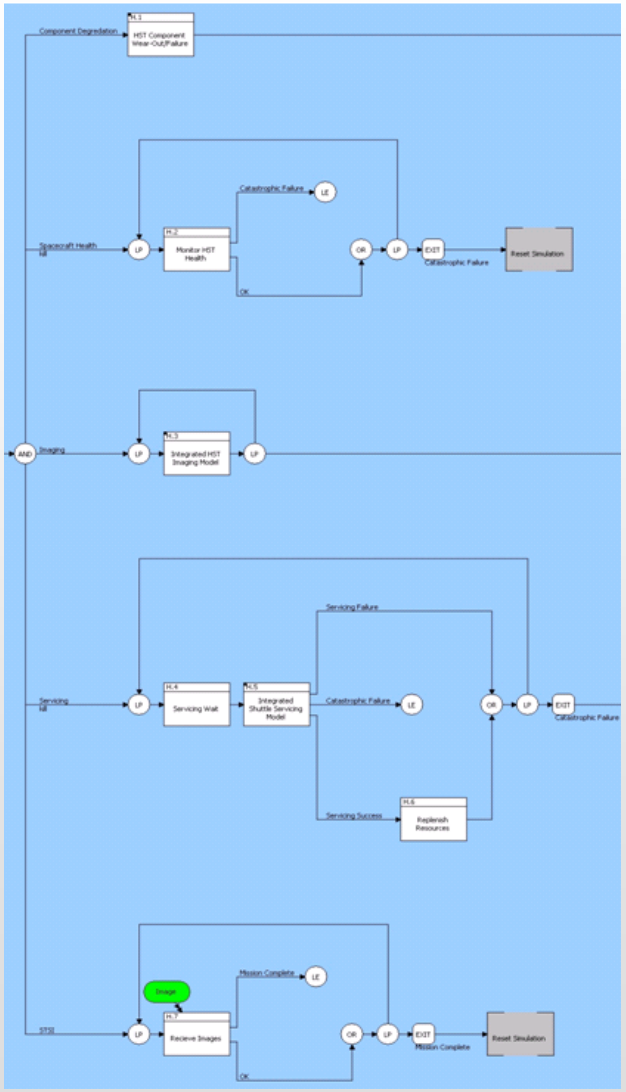
Clarity

- The work products must be understandable to the client
  - *Used standard or easy learn representation such functional flow block diagrams*



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Scalability

- Views should allow representation of the system at multiple levels of abstraction so that appropriate details is visible to different clients
  - *Represented both functional and physical hierarchy with the CORE representation*
  - *Being able to first represent abstract structure of Hubble operations and then add detail aided in organizing simulation development*

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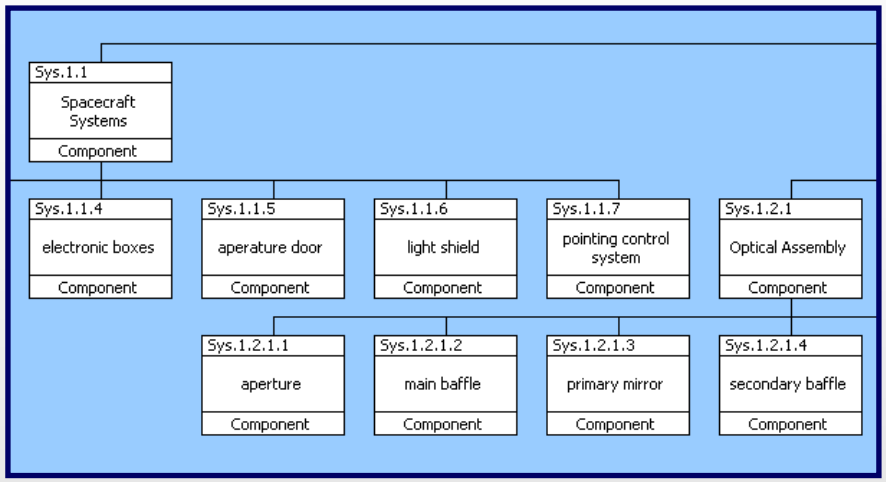
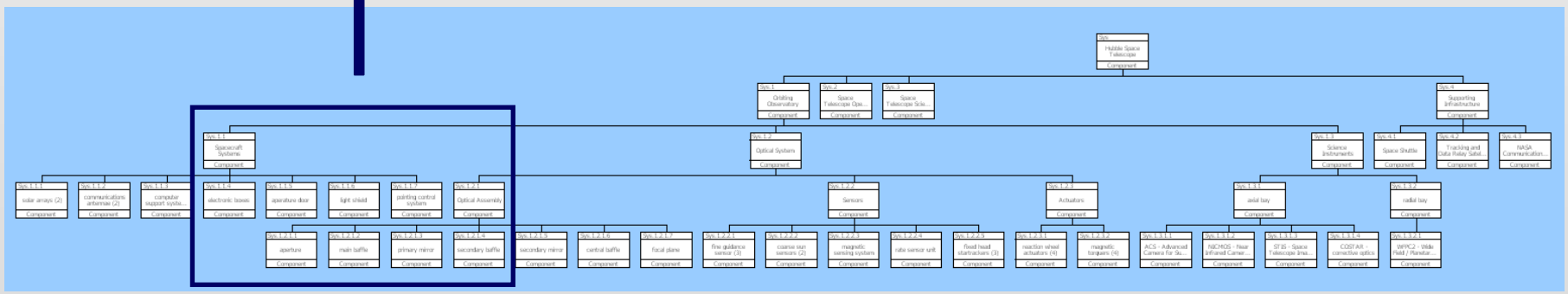
Systems Interface Description (SV-1)

- Identified 42 system components, with decomposition ranging from level three for supporting infrastructure to level five for Orbiting Observatory



Partial list of components from CORE explorer window

Sys.1.2.1.4 secondary baffle
Sys.1.2.1.5 secondary mirror
Sys.1.2.1.6 central baffle
Sys.1.2.1.7 focal plane
Sys.1.2.2 Sensors
Sys.1.2.2.1 fine guidance sensor (3)
Sys.1.2.2.2 coarse sun sensors (2)
Sys.1.2.2.3 magnetic sensing system
Sys.1.2.2.4 rate sensor unit
Sys.1.2.2.5 fixed head startrackers (3)
Sys.1.2.3 Actuators
Sys.1.2.3.1 reaction wheel actuators (4)
Sys.1.2.3.2 magnetic torquers (4)
Sys.1.3 Science Instruments
Sys.1.3.1 axial bay
Sys.1.3.1.1 ACS - Advanced Camera for Surveys
Sys.1.3.1.2 NICMOS - Near Infrared Camera and Multi-Object Spectrometer
Sys.1.3.1.3 STIS - Space Telescope Imaging Spectrograph
Sys.1.3.1.4 COSTAR - corrective optics
Sys.1.3.2 radial bay
Sys.1.3.2.1 WFPC2 - Wide Field / Planetary Camera 2
Sys.2 Space Telescope Operations Control Center
Sys.3 Space Telescope Science Institute
Sys.4 Supporting Infrastructure
Sys.4.1 Space Shuttle
Sys.4.2 Tracking and Data Relay Satellite System
Sys.4.3 NASA Communications Network



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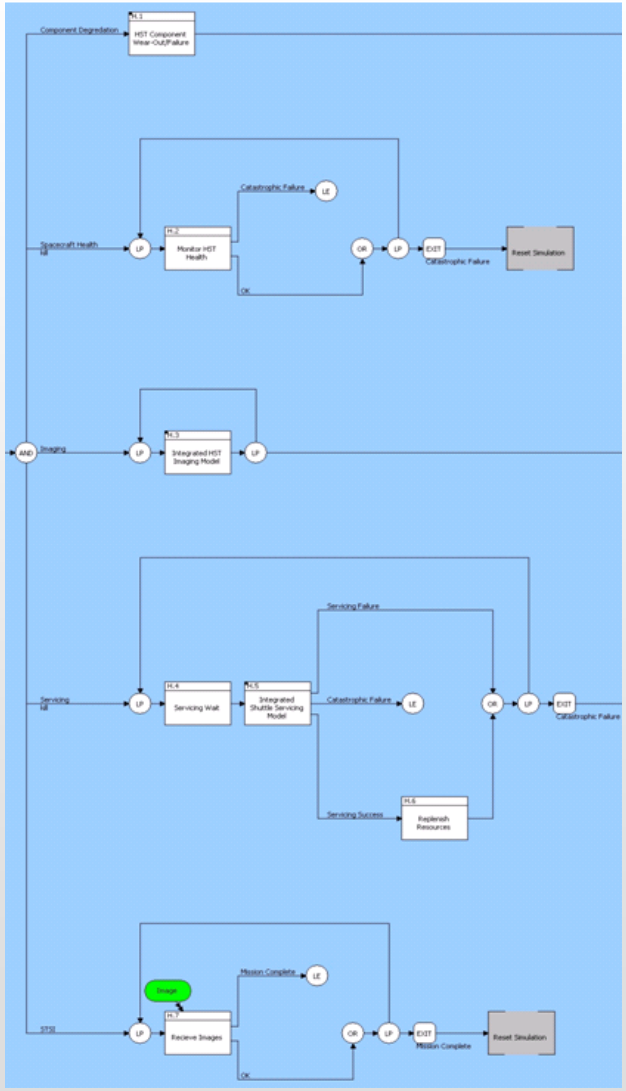
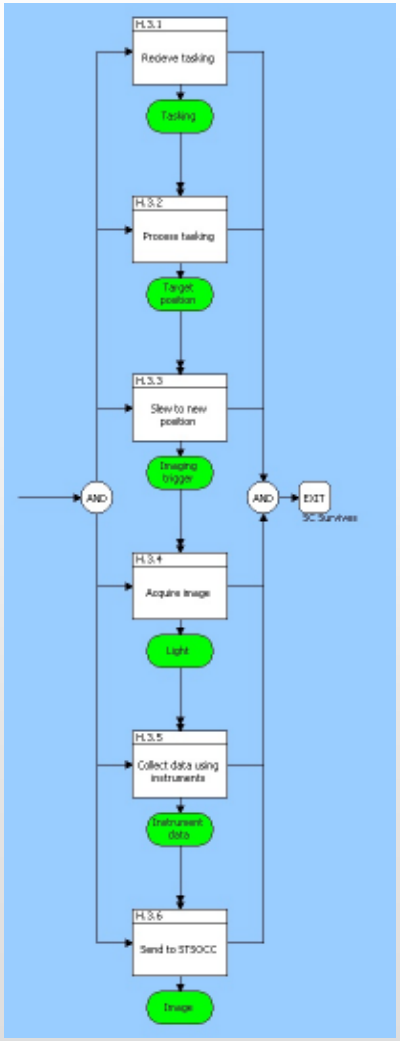
Servicing Simulation Threads



- Component failure and degradation thread
  - Deterministic: batteries
  - Probabilistic: avionics, gyroscopes, reactions wheels, and fine-guidance sensors
- Health thread
  - fully functional
  - survival mode
  - dead
- Imaging thread
- Servicing thread x2 (Shuttle and robotic)
  - Launch and Rendezvous
  - Dock
  - Access
  - Service
- Science dissemination thread
  - Terminates simulation once 120 nominal months complete



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Execute-ability

- Systems are dynamic entities
- Architectures should represent key dynamics through executable model
  - *Used CORE discrete event simulation to evaluate candidate servicing architectures for Hubble*

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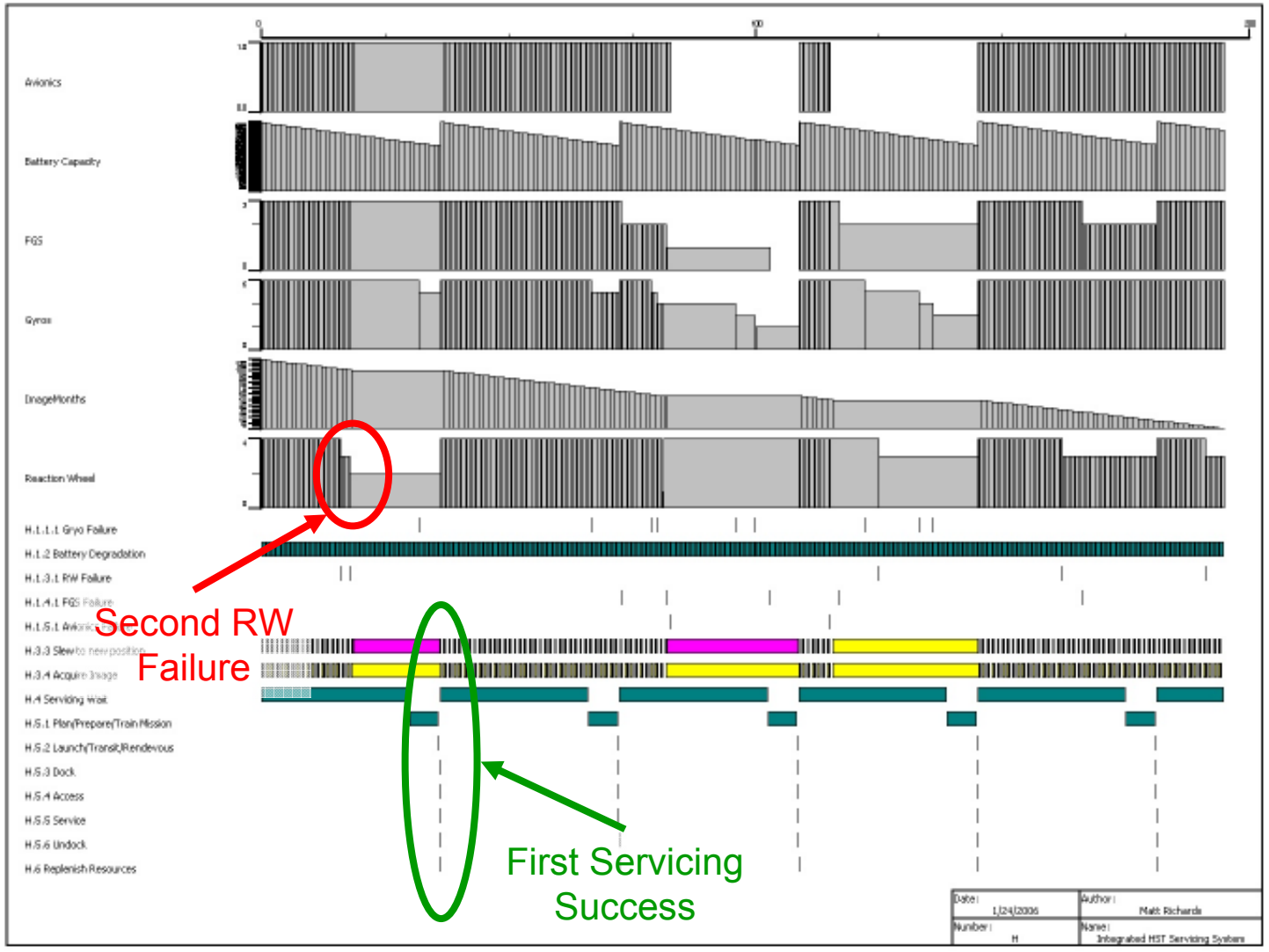
Sample Space Shuttle Servicing



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Analytic Extensibility

- Architecture should be able to interface with more specialized models and representational tools
  - *Could not easily connect model to other tools*
  - *Additional/more detailed analysis will require new models*
  - *Can still leverage terminology and qualitative relations represented in the framework as the basis for model design*

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Conclusions

- Artifacts are created during design to communicate, codify knowledge and manage complexity
- Architecture frameworks provide a mechanism for creating a consistent set of artifact that support collaborative development, ensure configuration control, organize information in a useful form and manage complexity
- Successful architectures exhibit purposefulness, applicability, internal consistency, external consistency, clarity, scalability, execute-ability, and analytic extensibility

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Backup

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Communication Role

- Design rarely occurs in a vacuum
  - Even when it does, communication of the design is often required for implementation
- Developing common syntax and semantics is key to successful collaborative design

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Knowledge Retention

- Design builds on prior experience
- Artifacts externalize knowledge and allow it to distributed
- Abstraction in artifact creation results in loss of some tacit knowledge (Nonaka CHECK this?)
- *Nonaka graphic of* seci-bà

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Managing Complexity

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Operational Activity Model (OV-5)

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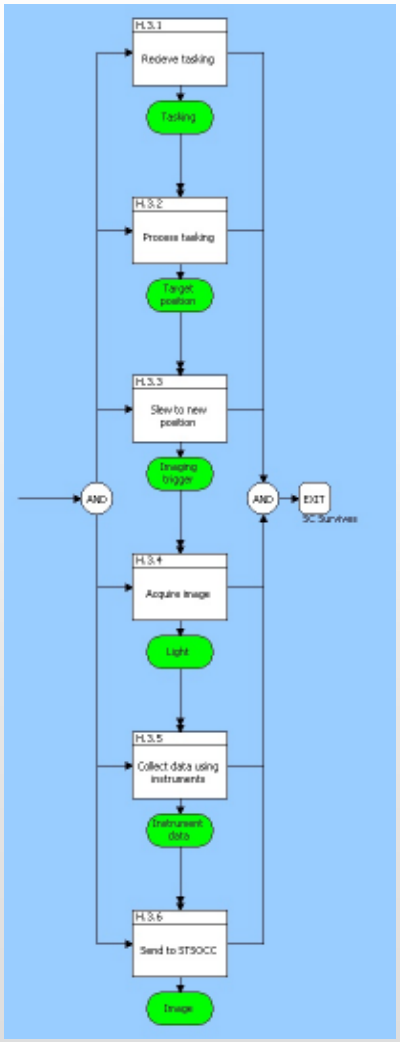
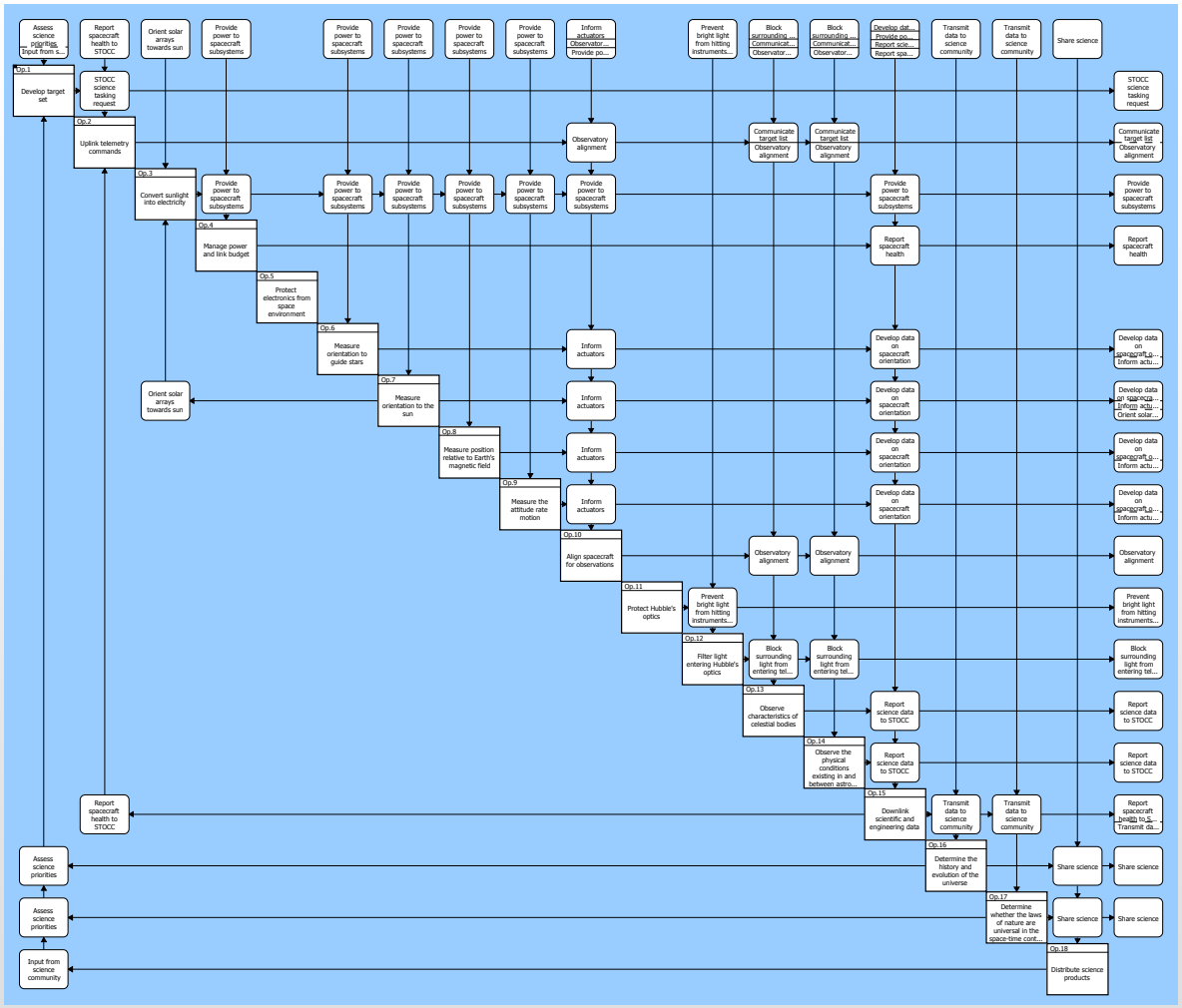
Imaging Thread





Operational Activities N2 Diagram

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