Quantifying Resilience in Component-Based Software Architecture Models

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Overview

- Focus: how can component-based, software-intensive systems be made more resilient?
  - *Through model-based techniques for design-time architecture specification and analysis accompanied by corresponding run-time support.*

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What is Resilience?

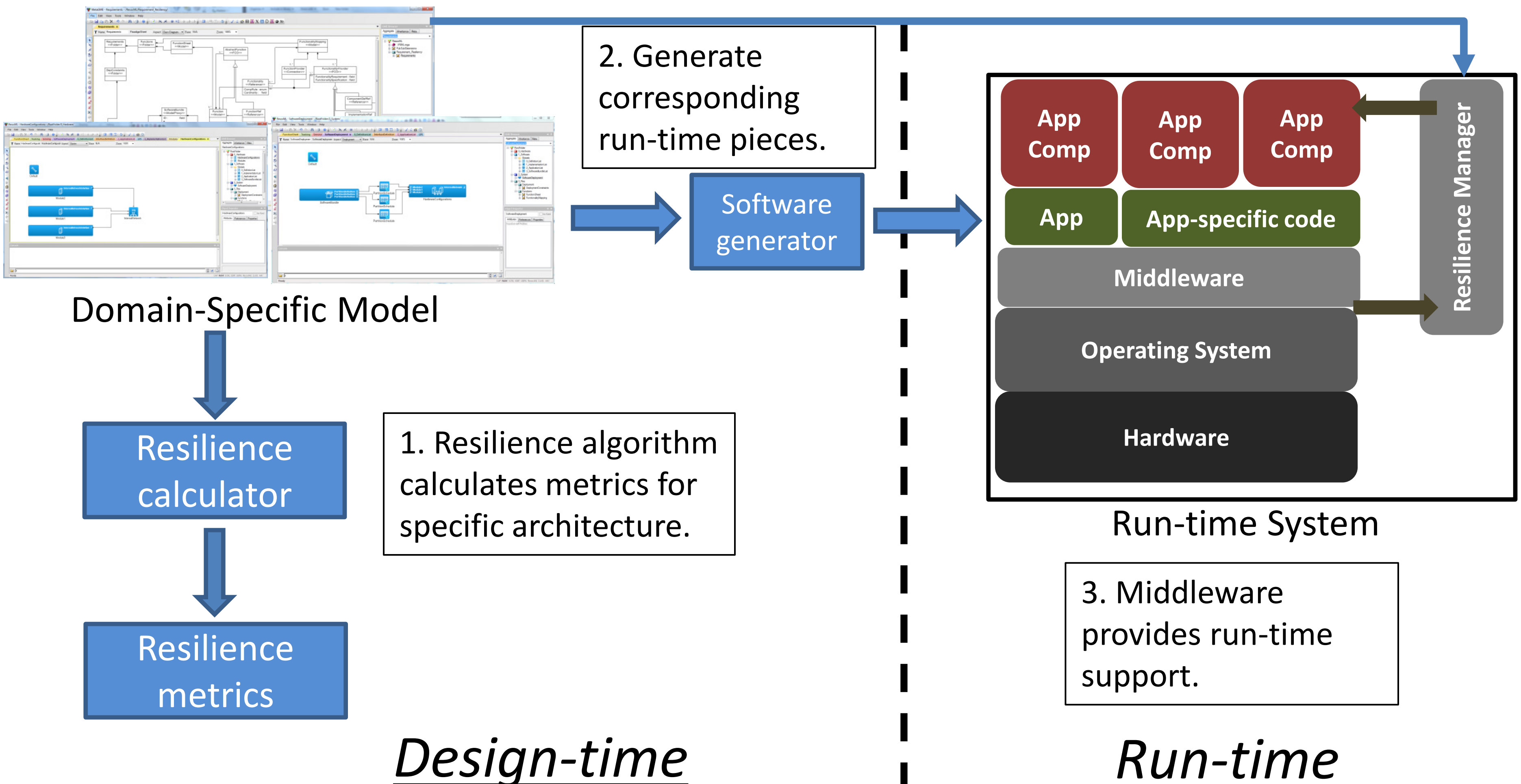
- Webster:
  - *Capable of withstanding shock without permanent deformation or rupture*
  - *Tending to recover from or adjust easily to misfortune or change*
- Technical:
  - *The persistence of the avoidance of failures that are unacceptably frequent or severe, when facing changes. [Laprie, '04]*
  - *A resilient system is trusted and effective out of the box in a wide range of contexts, and easily adapted to many others through reconfiguration or replacement. [R. Neches, OSD]*
- Intuitive:
  - The ability to "bounce-back" after something changes
- We focus on model-based development for Resilient Software Systems
  - Design-time techniques + run-time support = resilience

Context for Resilience

- Resilient Software Systems are needed in many domains: desktop applications, web-based systems, collaborative systems, service-oriented systems, etc.
- Focus area: DREMS
  - **D**istributed: applications are executed on a distributed platform with dynamically changing topology
  - **R**eal-time: applications have to satisfy real-time requirements
  - **E**mbedded: applications may interact with the physical world
  - **M**anaged: applications are managed external by an authority
  - **S**ystems
- Examples:
  - On-board software for vehicles with networked processors
  - Swarm of UAVs executing wide-area surveillance missions
  - Distributed C2 systems with real-time requirements
  - Fractionated spacecraft (with wireless links) that provides a ‘platform as a service’

Modeling Overview

- Development is centered around *models*

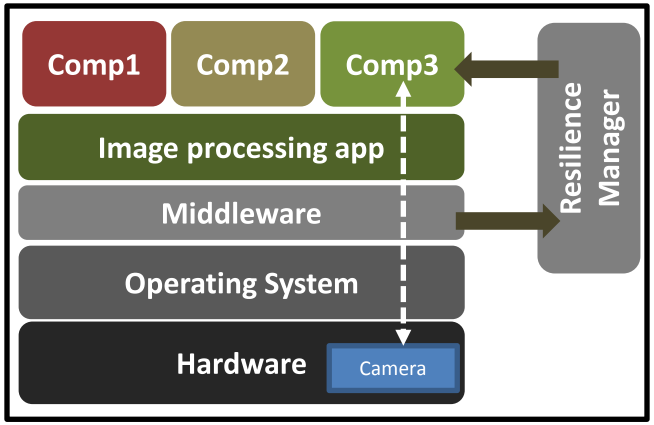


Domain-Specific Modeling Language

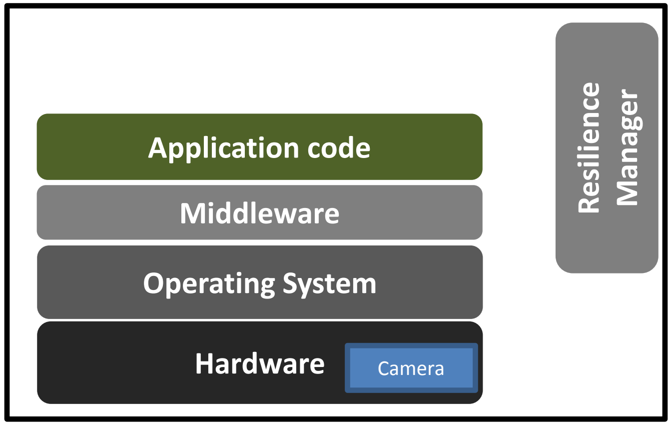
- A DSML is used to define the resilient software architecture
- Why a DSML?
  - Existing modeling languages do not cover the entire development process and are not integrated with comprehensive generators
  - Lack of support for resilience in existing modeling languages (SysML, AADL)
- What does a model enable?
  - Specification of software architecture
  - Code generation (app code, glue code, deployment scripts)
  - System integration (integrating multiple applications, deployments)
  - Analysis (resilience, scheduling)
- What does a model contain?
  - Software (communicating components)
  - Hardware (the physical nodes, resources)
  - Deployment of software onto hardware
  - Resilience description

2 Resilience Scenarios

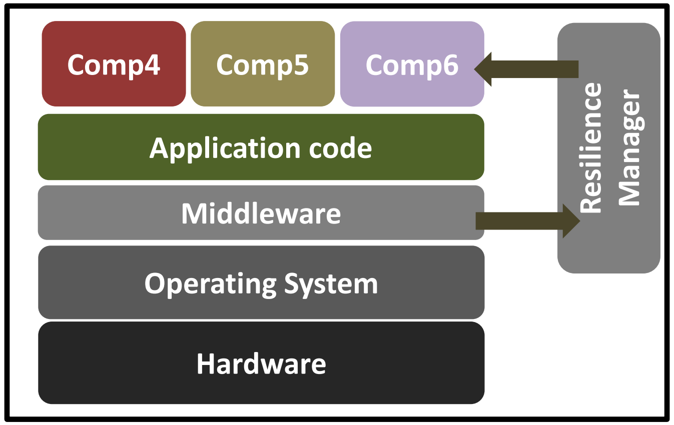
Consider a system with three nodes running an image processing application.
The application has 3 components.
Comp3 requires a specialized camera piece of hardware.



Node 1



Node 2



Node 3

2 Resilience Scenarios

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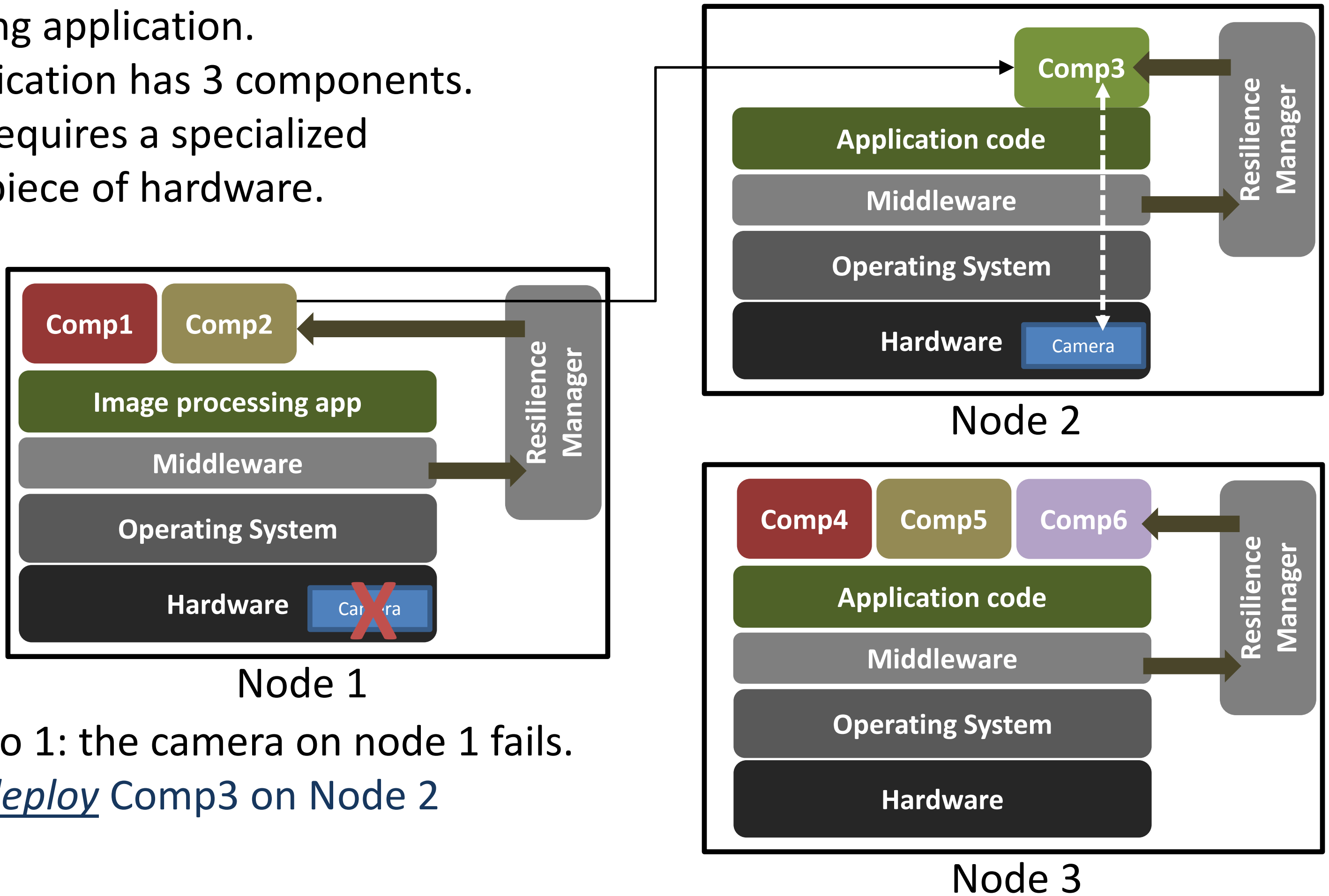

Scenario 1: the camera on node 1 fails.
-> *Redeploy* Comp3 on Node 2

2 Resilience Scenarios

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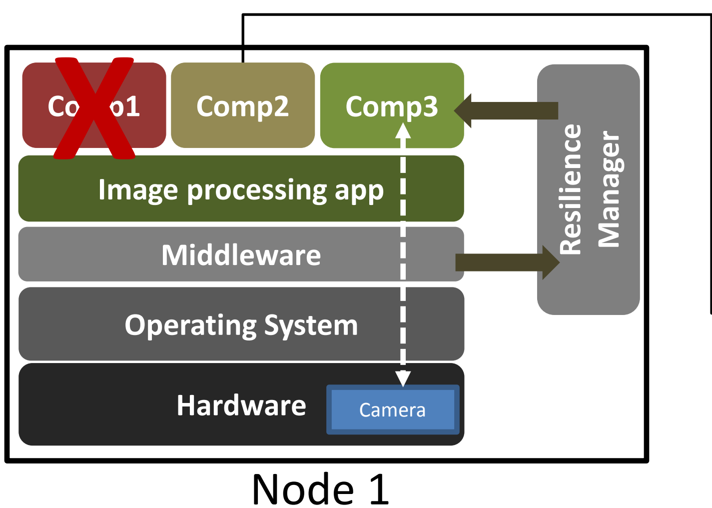
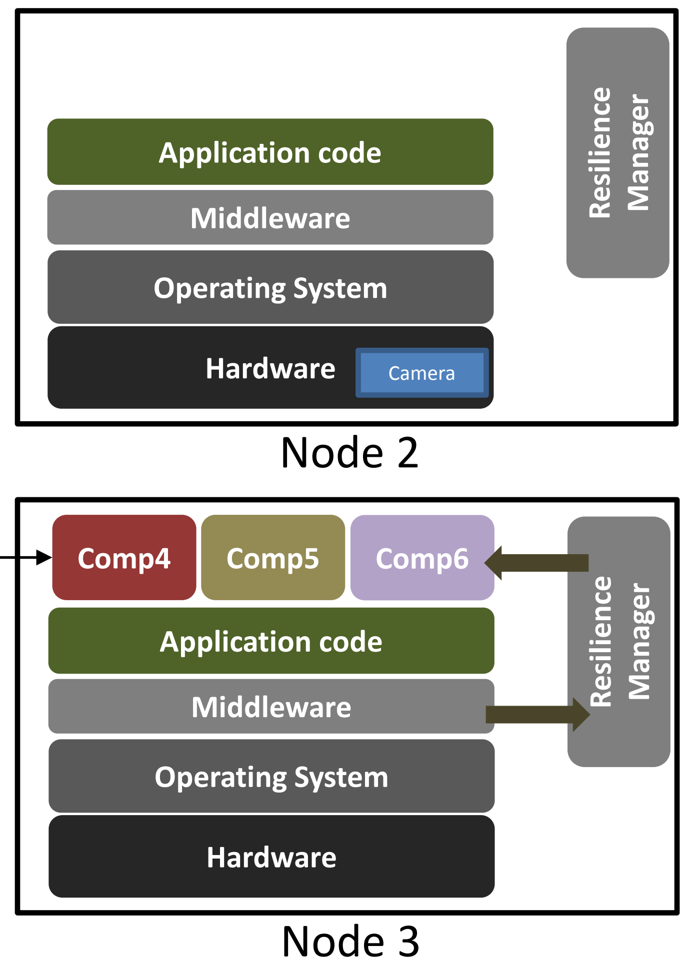




Scenario 2: Comp1 on Node 1 fails.
-> _Use_ Comp4 on Node 3 (it provides the same functionality)

Capturing Resilience

- The examples above provide resilience in two ways:
  1. Redeploy a component onto another node
  2. Use an alternate implementation of the same functionality provided by another component
- Method 1 requires a way to specify *resource requirements*
- Method 2 requires a way to specify *functionality*

Models Specify…

- Hardware
  - Nodes (with security labels)
  - Physical resources (e.g, camera)
  - Computation resource limits (e.g., memory)
  - Network links
- Software
  - Components and their interfaces
  - Required resources and % amounts
  - Security labels
- Applications
  - How components are connected
  - The “critical” components
  - Deployment (including constraints)

Modeling resilience

- Model three things:
  - *Functionality* the system provides
  - *How* the system can provide that functionality
  - Deployment *constraints*
- Functionality:
  - Hierarchically decompose functionality into basic functions
- How functionality is provided:
  - Map functionality hierarchically to applications, component assemblies or components
- Deployment constraints:
  - Restrict how software is deployed onto computing nodes and networks (e.g., application requires a camera)

Resilience Example

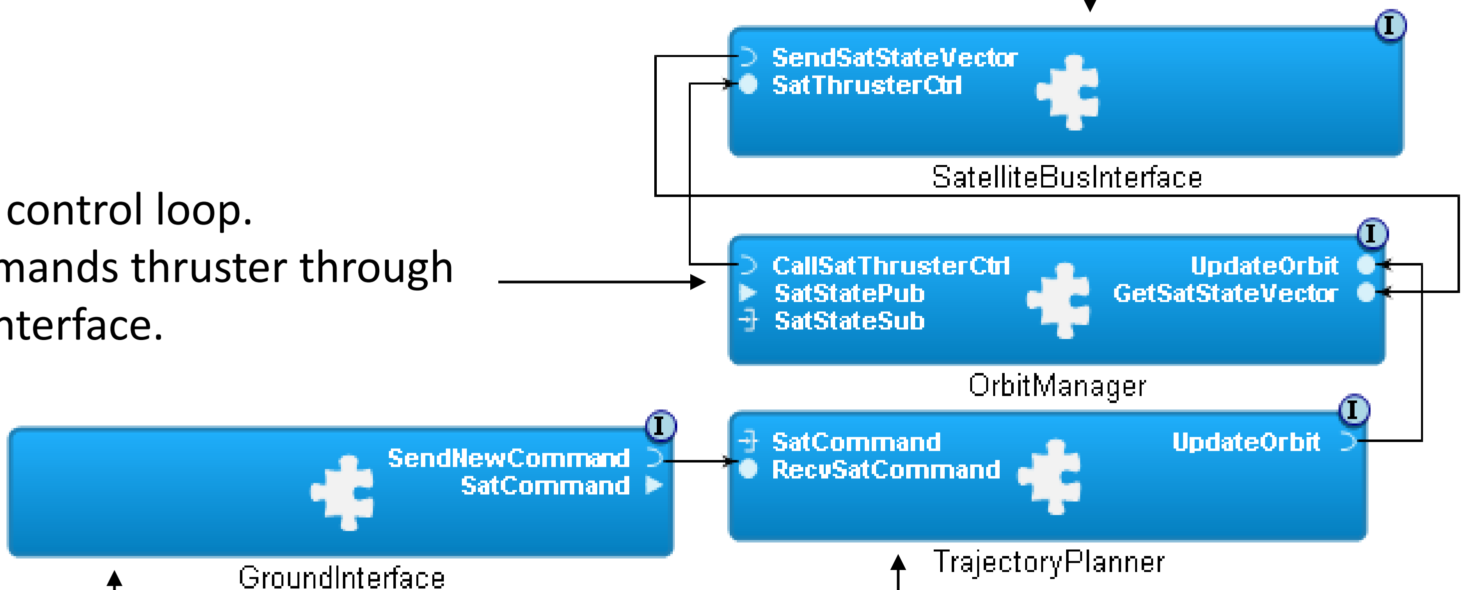
- Consider an example with three satellite nodes
- **Satellite 1 contains**:
  - High-resolution (HR) camera
  - Low-res (LR) camera
  - GPU
  - Ground link
- **Satellite 2 contains:**
  - HR camera
  - GPU
  - Ground link
- **Satellite 3 contains**
  - LR camera
  - Ground link
- Each satellite has an instance of two different applications…

2 Applications

- Cluster Flight Application
  - 4 components

Provides access to sat bus hardware.

Runs control loop.
Commands thruster through
bus interface.



Provides access to/from ground.

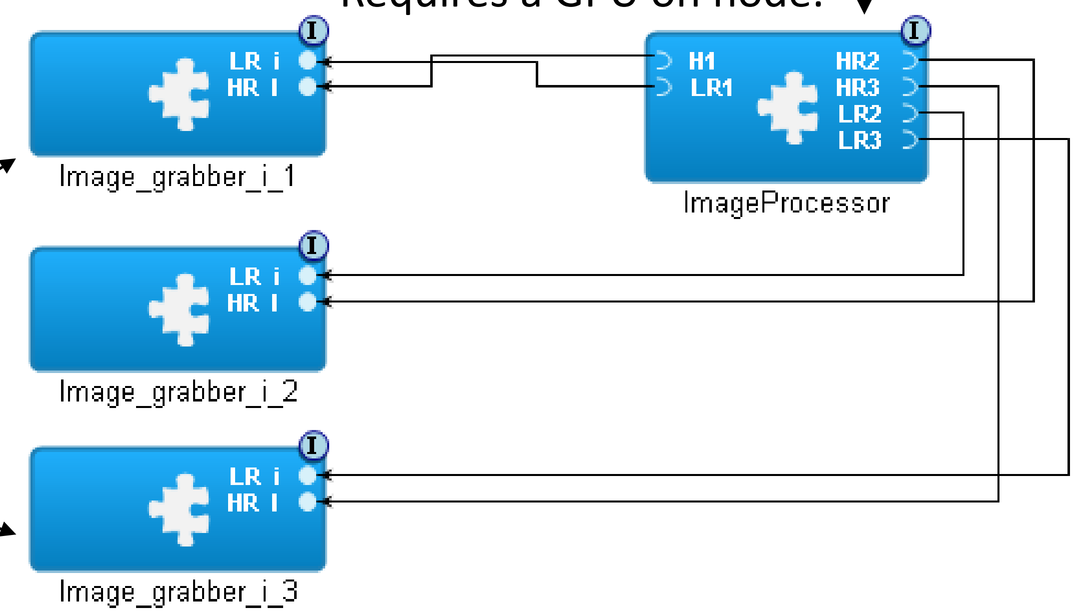
Updates orbit based on ground commands.

2 Applications

- Wide-area imaging application
  - Uses cameras on different nodes to create a combined image
  - Each satellite runs an image grabber component (HR or LR)
  - Only one instance of ImageProcessor runs at any time, but it can be redeployed

Combines and processes individual images.
Requires a GPU on node.

Captures images.
Requires either a
HR or LR camera on node.



Functional Requirements

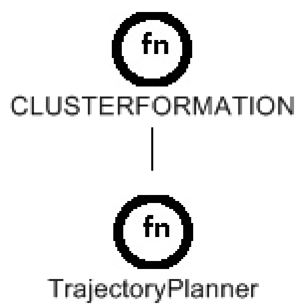
- Capture the functional breakdown required for the mission
  - Cluster flight
  - Wide area imaging
- All functions map to application/component instances
- Failure of one component/hardware resource/network link is used to compute whether the mission function is unavailable.
- Thereafter an alternative configuration (if available) can be chosen to recover the functionality.

Specifying Functionality I

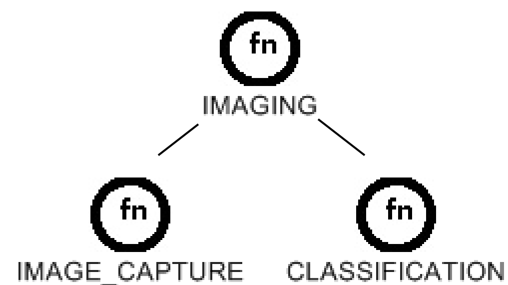
- Define functionality (hierarchically)
  – Specifies what must be present on system

Communication to ground

Cluster flight



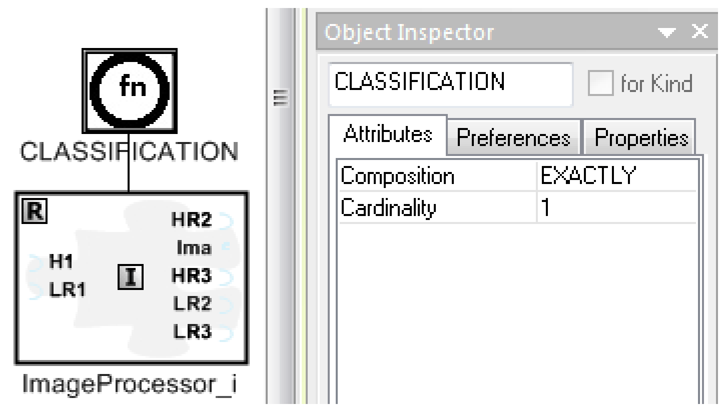
Imaging service



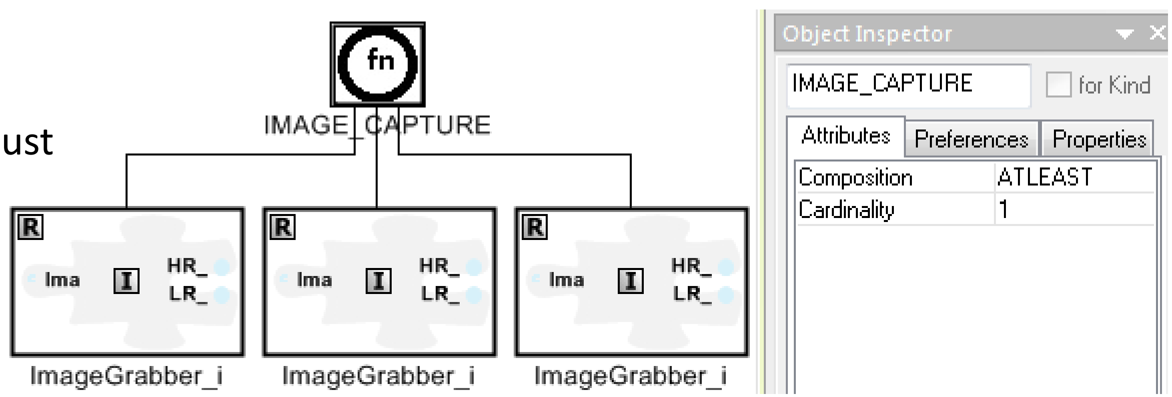
Specifying Functionality - II

- For each functionality, specify how it is provided

The classification functionality is provided by the ImageProcessor Component.
Exactly 1 instance should be running.

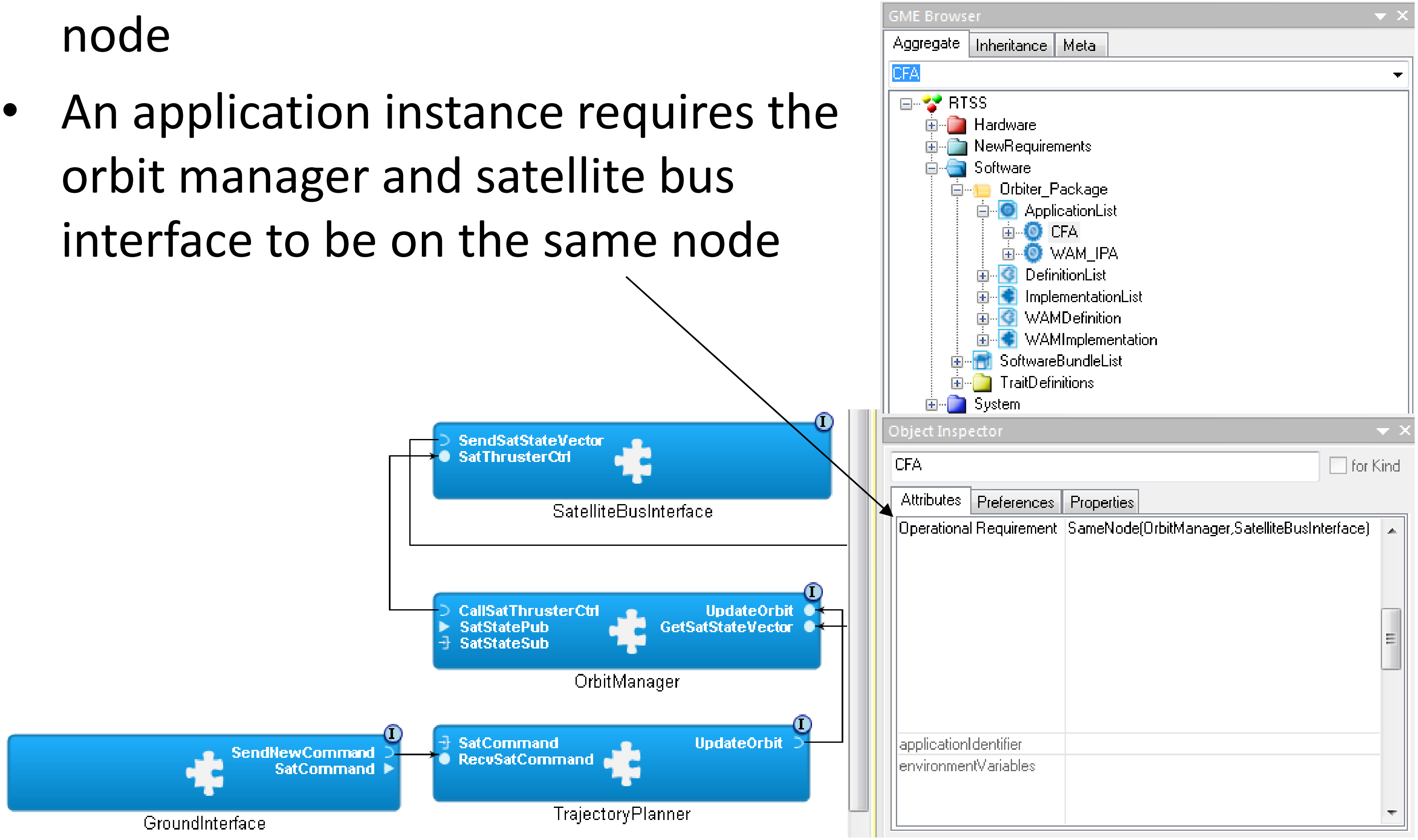


The image capture functionality is provided by the ImageGrabber component.
At least 1 of these components must be running.



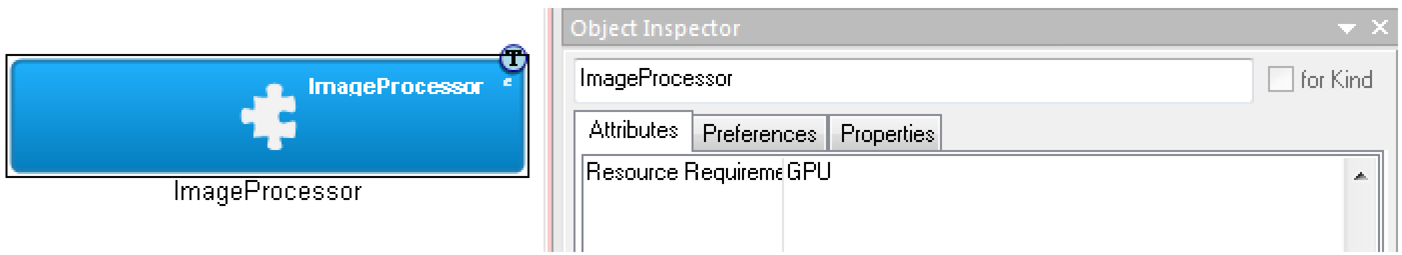
Deployment Constraints

- One instance of CFA runs on each node
- An application instance requires the orbit manager and satellite bus interface to be on the same node

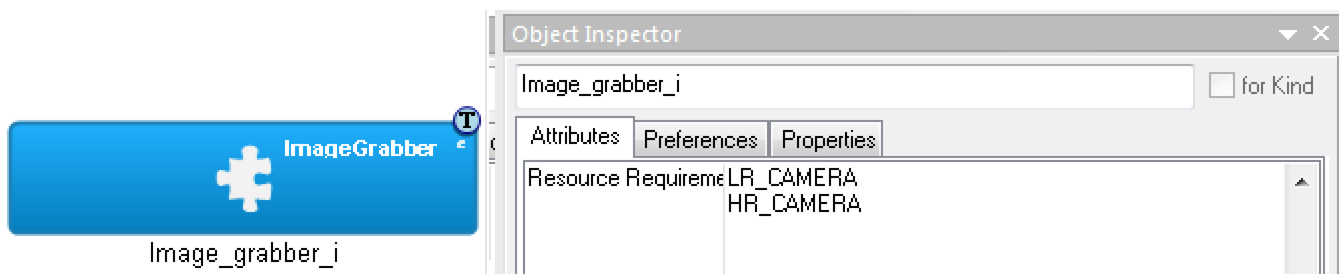


Specifying Resource Requirements

- The ImageGrabber components need an LR or HR camera



- The ImageProcessor components need a GPU



Operational requirements

- All components/Application have operational requirements
  - CFA Application
    - SameNode(OrbitManager,SatelliteBus)
  - OrbitManager
    - SameNode(CallSatThrusterCtrl)
    - SameNode(GetStateVector)
  - TrajectoryPlanner
    - Atleast(1, (SatCommand_Subscriber,ReceiveSatCommand))
  - ImageGrabber
    - ImageGrabber _1: Atleast(1,(HR_1,LR_1))
    - ImageGrabber _2: Atleast(1,(HR_2))
    - ImageGrabber _3: Atleast(1,(LR_3))
  - ImageProcessor
    - ImageProcessor_1: Atleast(1,GPU_1)
    - ImageProcessor_2: Atleast(1,GPU_2)
    - Atmost(1,(ImageProcessor_1, ImageProcessor_2, ImageProcessor_3))

Calculating resiliency metric

- Question: how to measure the resiliency?
- Two ways to quantify:
  - *Worst case: Minimum number of failures that make the mission infeasible*
  - *Best case: Maximum number of failures that the system can sustain while the mission remains feasible*
- We translate the requirements and specifications into an SMT problem which calculates the metrics

Resilience Metric

- Metric = [2,23]
  - Assumption: all 6 functions are required
- Complete failure of Sat2
  - ImageProcessor on Sat2 is out, another ImageProcessor on Sat1 or Sat3 should be activated.
- Failure of GPU on Sat1
  - GPU is required by the Image Processor
  - Therefore, a reconfiguration is required which activates image processor on Sat3
- Failure of Ground Link on Sat 1
  - No reconfiguration is required. The ground command is disseminated by either Sat2 or Sat3 via pub sub ports

Future Work

- Given a configuration and a failure, what is the “optimal” reconfiguration?
  - Consider increasing horizon
  - Integrate empirical reliability measures

Questions?