A Component Model and Software Architecture for CPS

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NASA Cooperative Agreement NNX08AY49A

Outline

- Software components for real-time systems
- ARINC-653 features
- CCM features
- The ARINC Component Model
  - Components and interactions
  - Modeling and generation
  - Application: Software Health Management
  - Implementation
  - An Example
- Lessons Learned / Summary

Notional Design Flow for High-Confidence Software Systems

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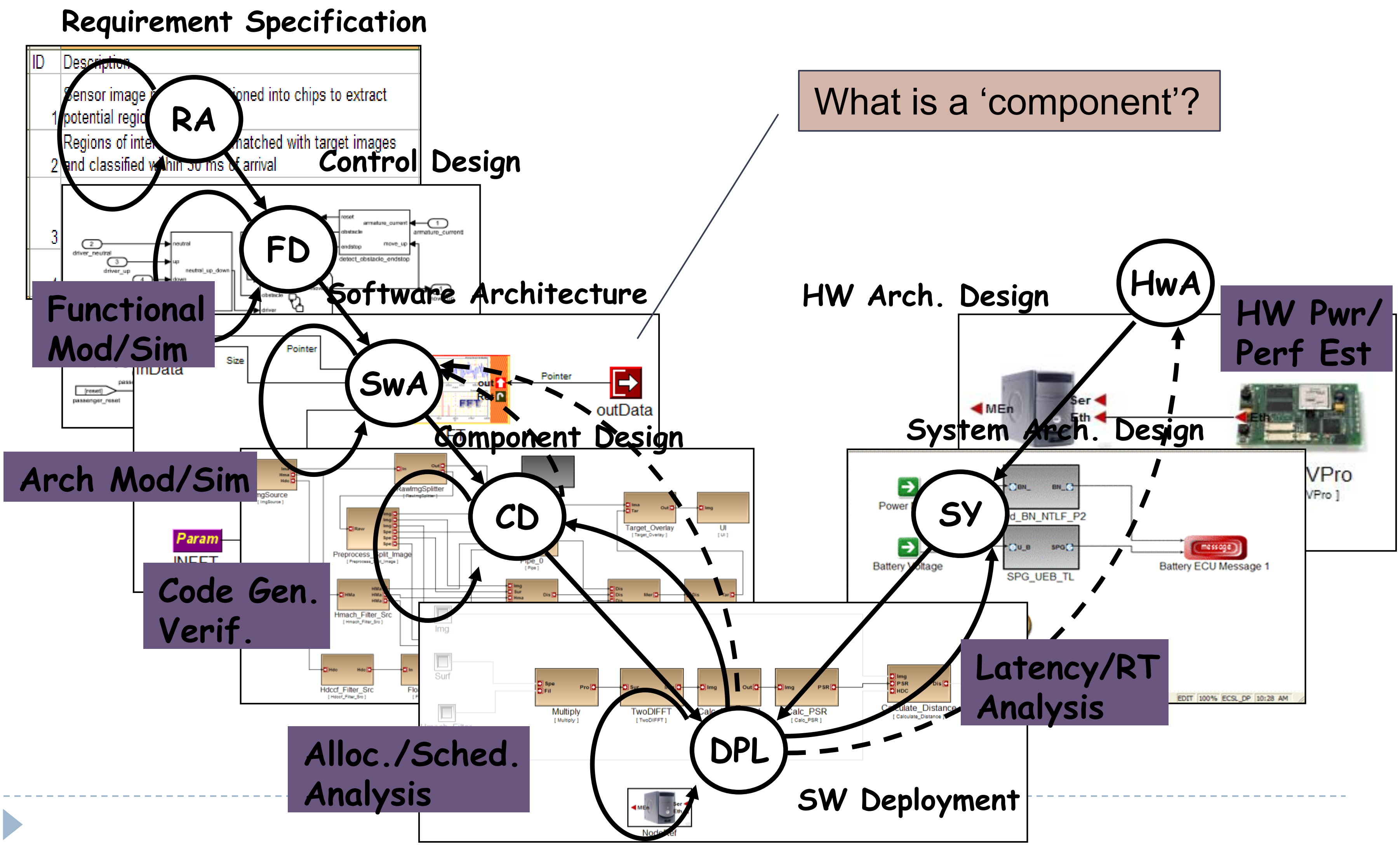


Hard Real-time Components?

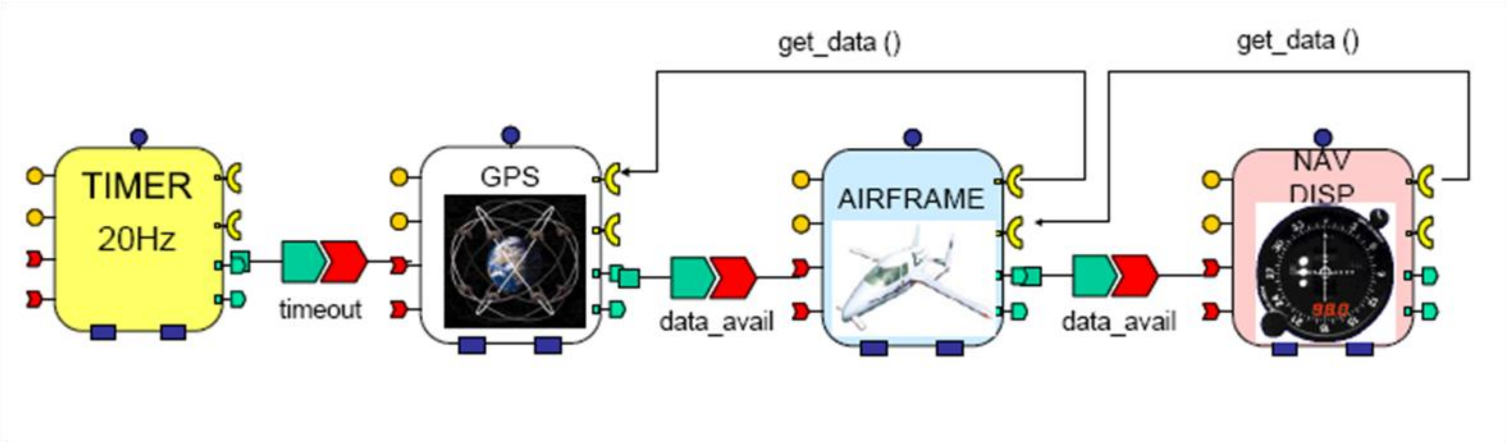
- Need:
  - A Component Model suitable for hard real-time systems that codifies all component interactions and allows specification of timing requirements
- Real-time CORBA?
  - QoS and scheduling attributes on CCM
- MARTE UML Profile?
  - Specifications for timing properties in UML models
- AUTOSAR?
  - Component execution model? (Only recently added).

ARINC-653/APEX: Partitioning Kernel API

- Partitions:
  - Spatial and Temporal separation of activities – Fault isolation!
  - Partition memory size and temporal duration are fixed
- Within a partition (shared address space)
  - Multiple processes (static); periodic/aperiodic, with opt deadline
  - Primitives for process interactions: buffers and blackboards, semaphores and events
  - Health monitor (to restart processes)
- Across partitions (isolated address spaces)
  - Fixed allotment of CPU time
  - Message-based interactions via channels connecting sampling and queuing ports
- Multiple processors ('modules') – few details standardized

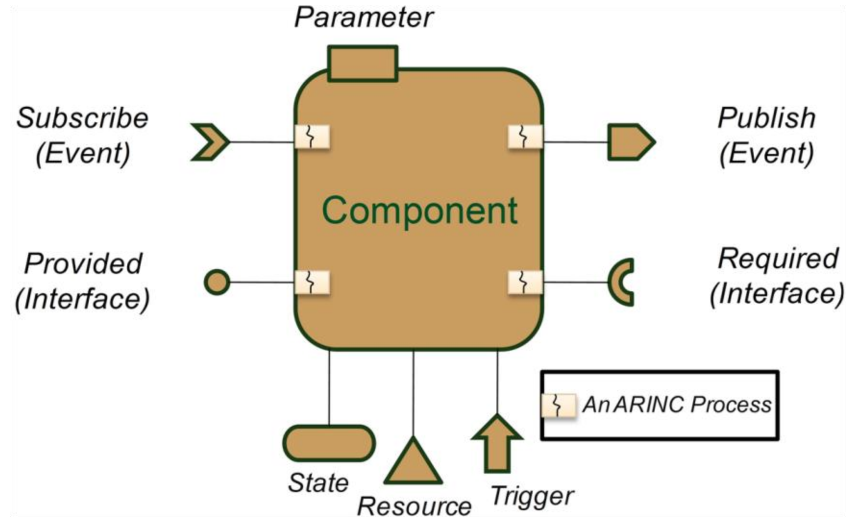
CORBA Component Model

- Components
  - Generalized 'objects' with state
  - Synchronous (call/return) interactions via provided/required interfaces
  - Asynchronous (publish/subscribe) interactions via publish/subscribe interfaces
- Component homes
  - Lifecycle and resource management for components



ACM:
The ARINC Component Model

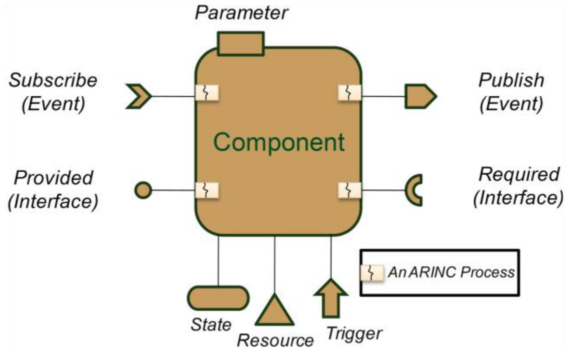
- Provide a CCM-like layer on top of ARINC-653 abstractions
- Notional model:



- Terminology:
  - Synchronous: call/return
  - Asynchronous: publish-return/trigger-process
  - Periodic: time-triggered
  - Aperiodic: event-triggered

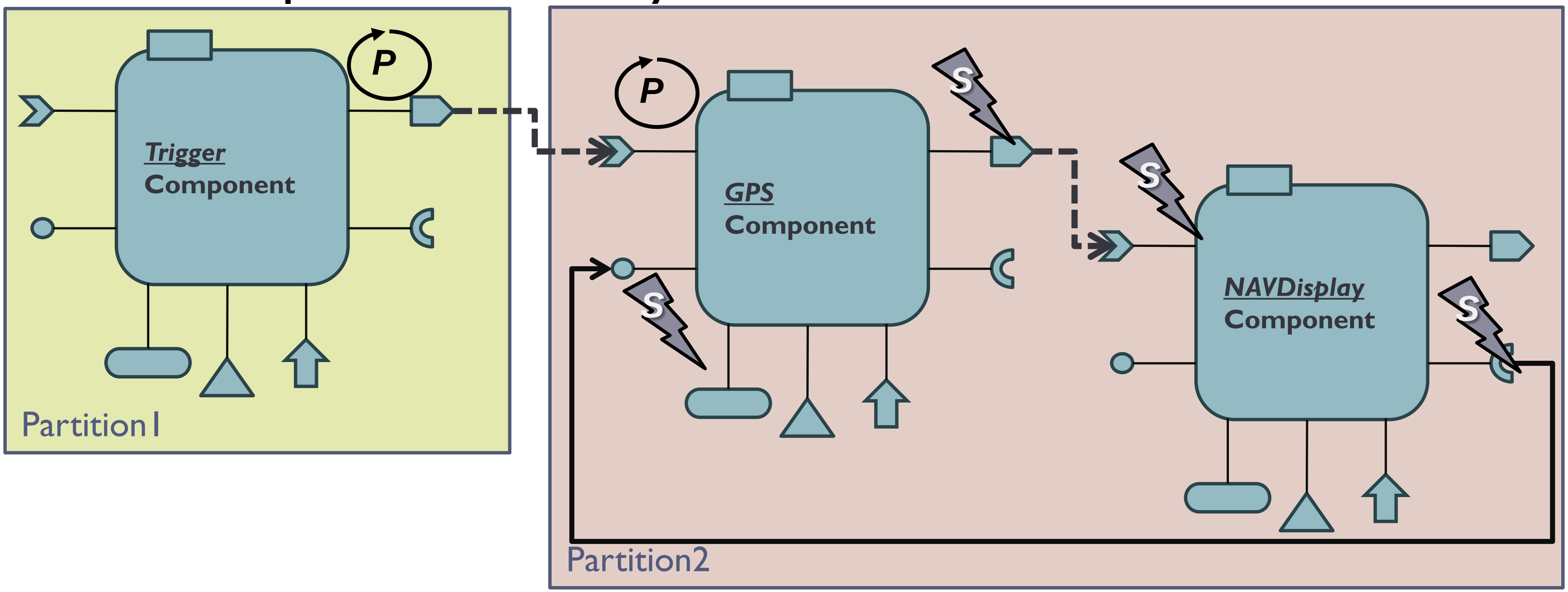
ACM:
The ARINC Component Model

- Each ‘input interface’ has its own process
  - Process must obtain read-write/lock on component
- Asynchronous publisher (subscriber) interface:
  - Listener (publisher) process
  - Pushes (receives) one event (a struct), with a validity flag
  - Can be event-triggered or time-triggered (i.e. 4 variations)
- Synchronous provided (required) interface:
  - Handles incoming synchronous RMI calls
  - Forwards outgoing synchronous RMI calls
- Other interfaces:
  - State: to observe component state variables
  - Resource: to monitor resource usage
  - Trigger: to monitor execution timing



ACM:
The ARINC Component Model

- A component assembly



Components interact via asynchronous/event-triggered and synchronous/call-driven connections.

Example: The *Trigger* component is released periodically and it publishes an event upon each activation. The *GPS* component subscribes to this event and is triggered sporadically to obtain GPS data from the receiver, and when ready it publishes its own output event. The *Display* component is triggered sporadically via this event and it uses a required interface to retrieve the position data from the *GPS* component.

ACM:
The ARINC Component Model

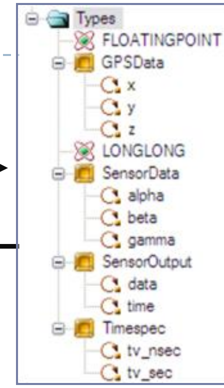
- Mapping the CCM concepts to APEX in ACM

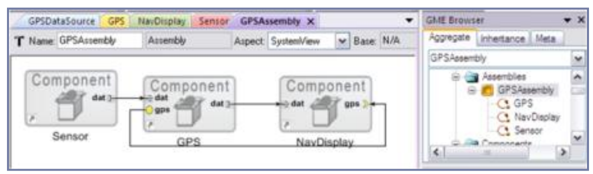
ACM: APEX Component Model				APEX	APEX Concept Used
Component method		Periodic		Periodic process	Process start, stop Semaphores
		Sporadic		Aperiodic process	
Invocation	Synchronous Call-Return	Periodic Target	Co-located	N/A	
			Non-co-located	N/A	
		Sporadic Target	Co-located	Caller method signals callee to release then waits for callee until completion.	Event, Blackboard
			Non-co-located	Caller method sends RMI (via CM) to release callee then waits for RMI to complete.	TCP/IP, Semaphore, Event
	Asynchronous Publish-Subscribe	Periodic Target	Co-located	Callee is periodically triggered and polls 'event buffer' – validity flag indicates whether data is stale or fresh	Blackboard
			Non-co-located		Sampling port, Channel
		Sporadic Target	Co-located	Callee is released when event is available	Blackboard, Semaphore, Event
			Non-co-located	Caller notifies via TCP/IP, callee is released upon receipt	Queuing port, Semaphore, Event

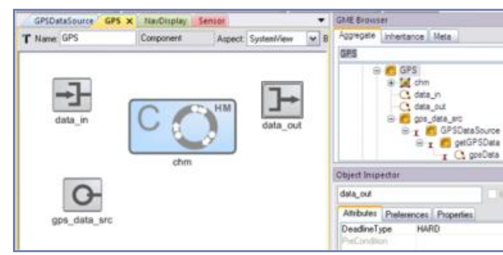
- Observe:
  - All component interactions are realized via the framework
  - Process (method) execution time has deadline, which is monitored

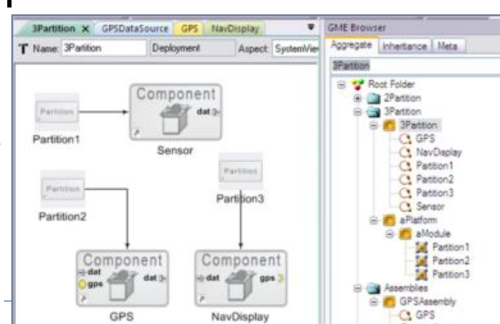
Modeling Language

- Modeling elements:
  - Data types: primitive, structs, vectors
  - Interfaces: methods with arguments
  - Components:
    - Publish/Subscribe ports (with data type)
    - Provided/Required interfaces (with i/f type)
    - Health Manager
  - Assemblies
  - Deployment
    - Modules, Partitions
    - Component → Partition



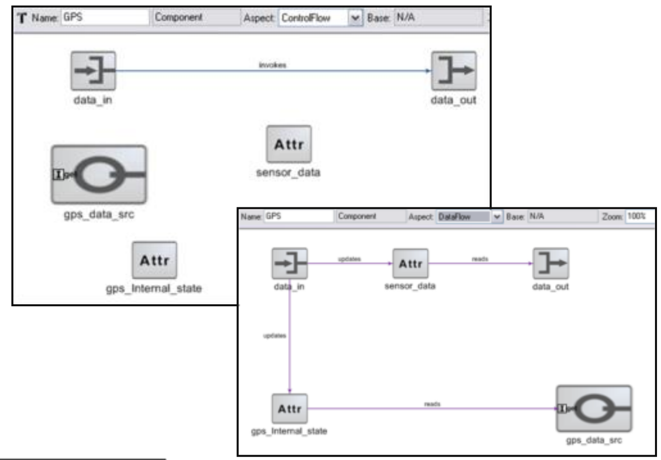




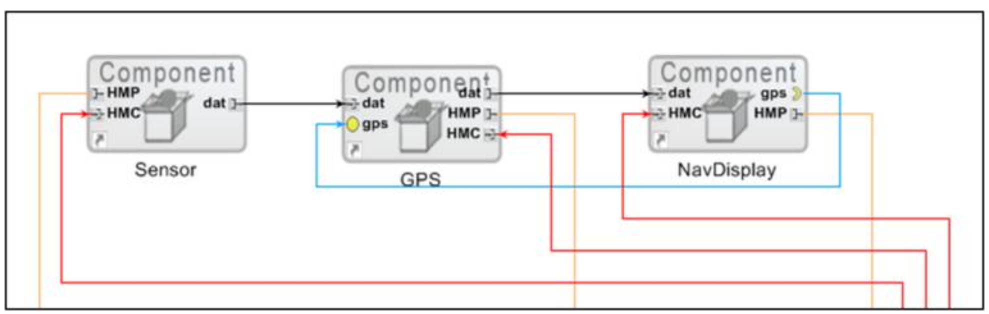


Modeling

- Needs for analysis: component internals + assembly
  - Component internal data- and control flows



  - Component Assembly Model

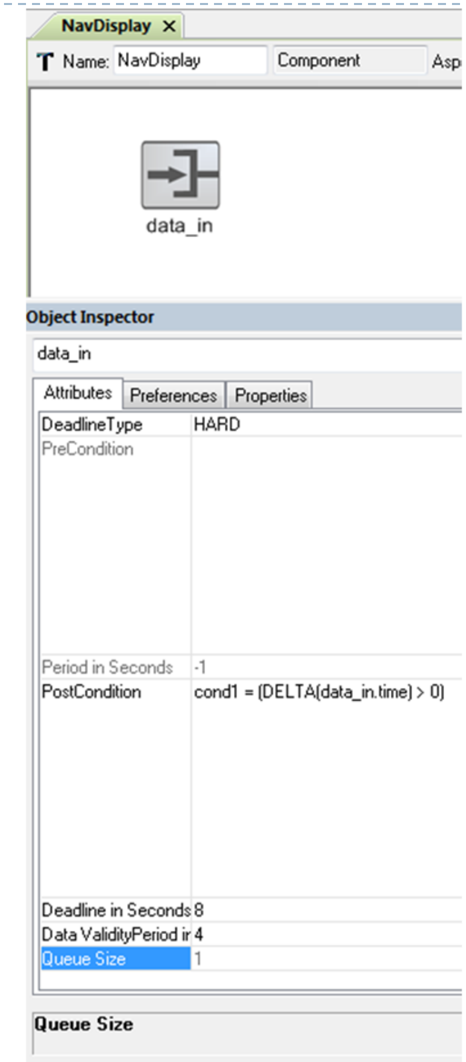


Background

- Project on Model-based Software Health Management
  - How to build 'software health management functions' into systems that monitor, diagnose, and mitigate software defects at run-time?
  - Concept
    - Use model-based fault diagnostics techniques for monitoring and diagnosis
    - Use model-based software development techniques to design, analyze, and generate the code for the software health management function

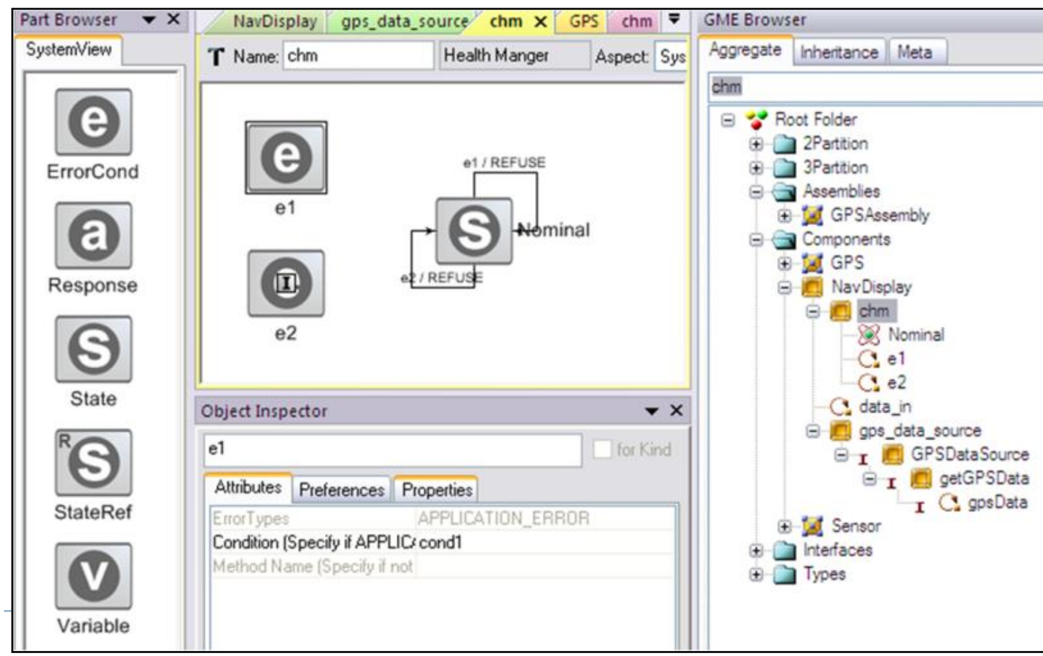
Modeling Language: Monitoring

- Monitoring on component interfaces
  - Subscriber port → 'Subscriber process' and Publisher port → 'Publisher process'
    - Monitor: pre-conditions and post-conditions
    - On subscriber: Data validity ('age' of data)
    - Deadline (hard / soft)
  - Provided interface → 'Provider methods' and Required interface → 'Required methods'
    - Monitor: pre-conditions and post-conditions
    - Deadline (hard / soft)
  - Can be specified on a per-component basis
- Monitoring language:
  - Simple, named expressions over input (output) parameters, component state, **delta**(var), and **rate**(var,dt). The expression yields a Boolean condition.



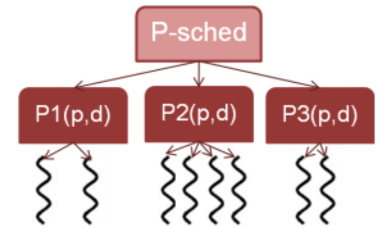
Modeling Language: Component Health Manager

- Reactive State Machine
  - *Event* trigger:
    - Predefined condition (e.g. deadline violation, data validity validation)
    - User-defined condition (e.g. pre-condition violation)
  - Reaction: mitigation *action* (start, reset, refuse, ignore, etc.)
  - *State*: current state of the machine
  - (Event X State) → Action

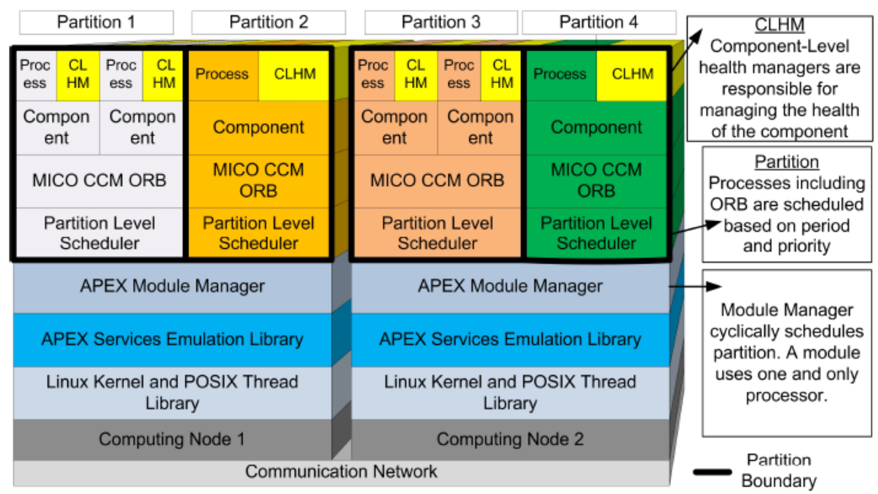


ACM:
A Prototype Implementation

- ARINC-653 Emulator
  - Emulates APEX services using Linux API-s
  - Partition → Process, Process → Thread
  - Module manager: schedules partition set
  - Partition level scheduler: schedules threads within partition



- CORBA foundation
  - MICO CCM ORB
  - No modifications
- CLHM: Component-level Health Manager



ACM:
A Prototype Implementation

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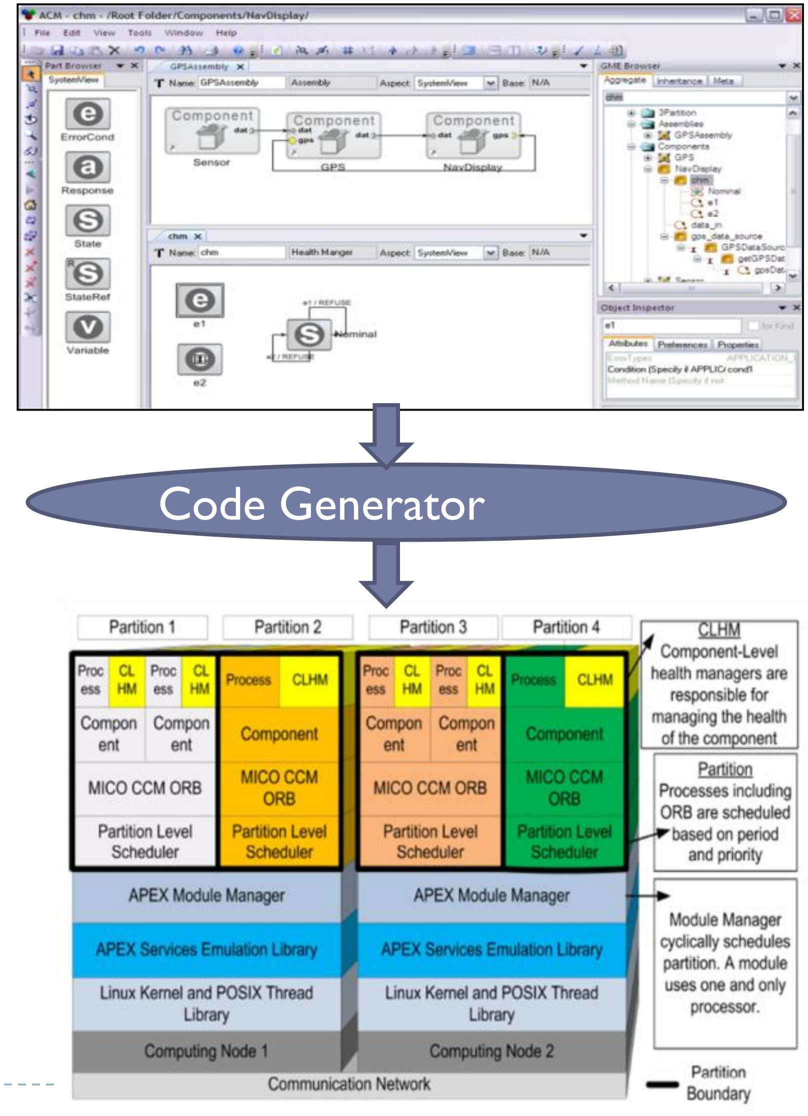
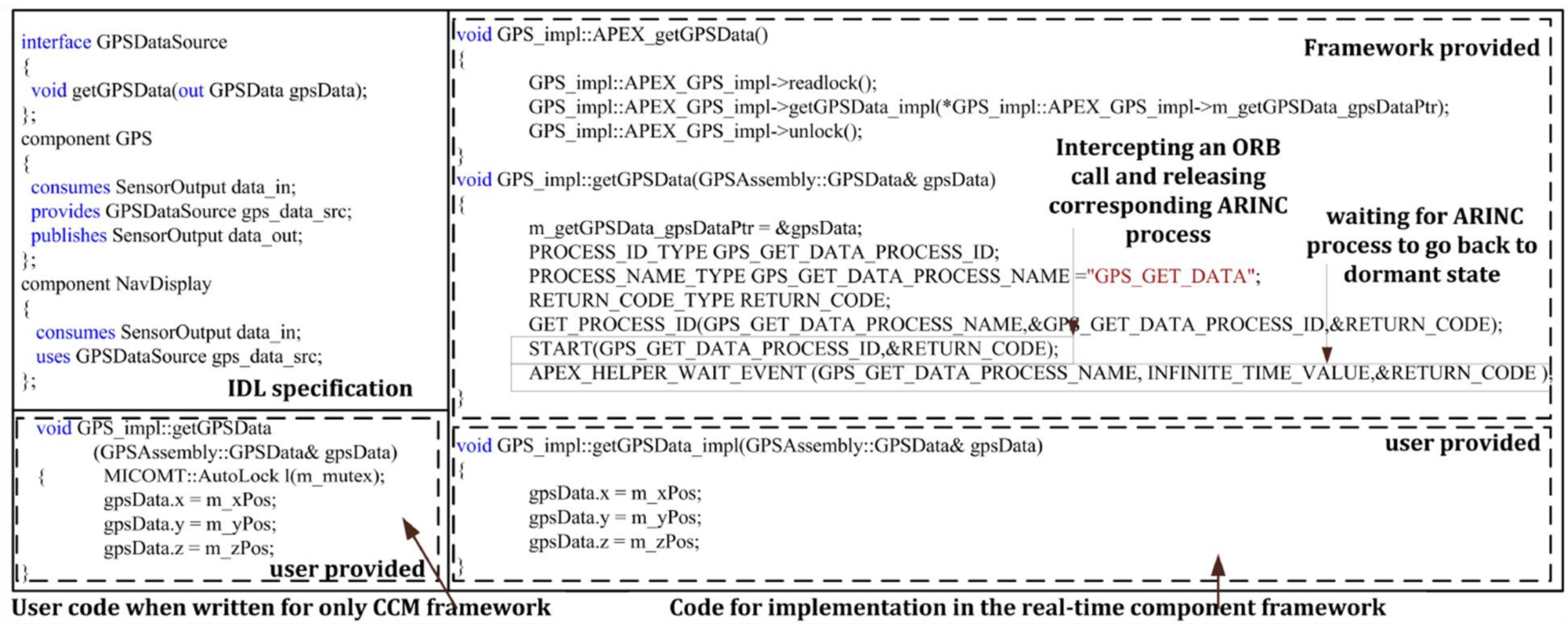
- Platform:
  - ARINC-653 Emulator on Linux
  - MICO (open source CORBA)
  - Module manager, infrastructure
- Code generator
  - Produces 'glue code' for the component framework
  - Compiles monitoring expressions
  - Builds code for CHM

Designer supplies functional code

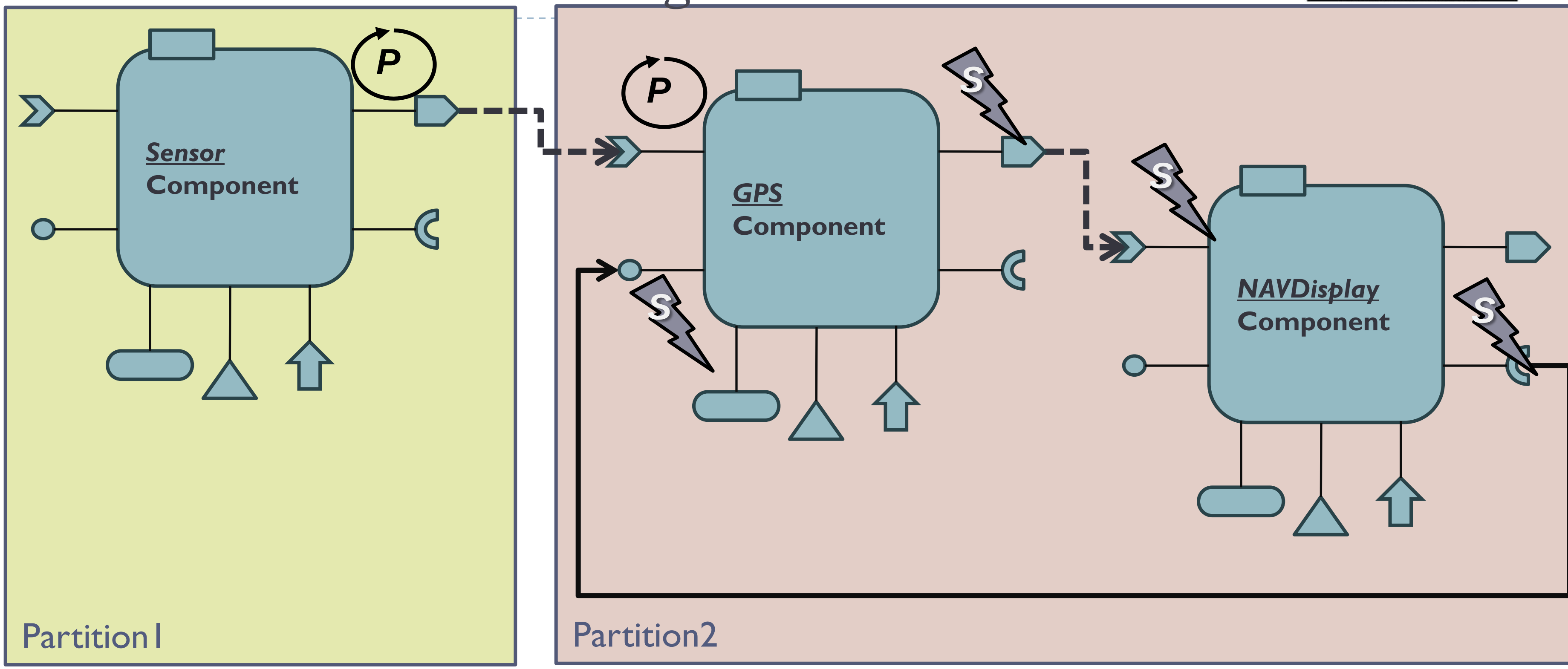


ACM: Model-based Development

- Graphical models are used the generate 'infrastructure' code



Example:
Fault Detection and Mitigation scenarios



Fault	Detected at	Fault source	Mitigation
Hard deadline violation	GPS Trigger interface	GPS Component	Stop and restart
Stale data (missing update)	NAVDisplay Subscribe port	GPS Component	Use previous value
Missing sensor event	GPS Subscribe port	Sensor Component	Use previous value
Rate of change is too high	NAVDisplay required interface	GPS Component	Use previous value

Lessons Learned / Summary

- Two worlds: The highly dynamic CCM and the strictly static ARINC do not mesh well
- Allocating a thread to every method is possibly a waste of resources
- For analyzability a deeper modeling of component structure and behavior is needed

- ACM: Steps towards a hard real-time component model
  - CCM: provides the essential component abstraction
  - ARINC: provides the API / platform
- Model-based configuration and code generation helps
- ACM is an experiment – work in progress