Carnegie Mellon
Software Engineering Institute

Agenda

SAE AADL: An Industry Standard for Embedded Systems Engineering

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SAE AADL Standard
An Enabler of Predictable Model-Based System Engineering

- Notation for specification of task and communication architectures of Real-time, Embedded, Fault-tolerant, Secure, Safety-critical, Software-intensive systems
- Fields of application: Avionics, Automotive, Aerospace, Autonomous systems, …
- Based on 15 Years of DARPA funded technologies
- Standard approved by SAE in Sept 2004
- www.aadl.info

SAE AS-2C AADL Subcommittee

- Bruce Lewis (US Army AMRDEC): Chair
- Peter Feiler (SEI): technical lead, author & editor
- Steve Vestal (Honeywell): co-author
- Ed Colbert (USC): UML Profile of AADL
- Joyce Tokar (Pyrrhus Software): Ada & C Annex

Other Voting Members

- Boeing, Rockwell, Honeywell, Lockheed Martin, Raytheon, Smith Industries, General Dynamics, Airbus, Axlog, European Space Agency, TNI, Dassault, EADS, High Integrity Solutions

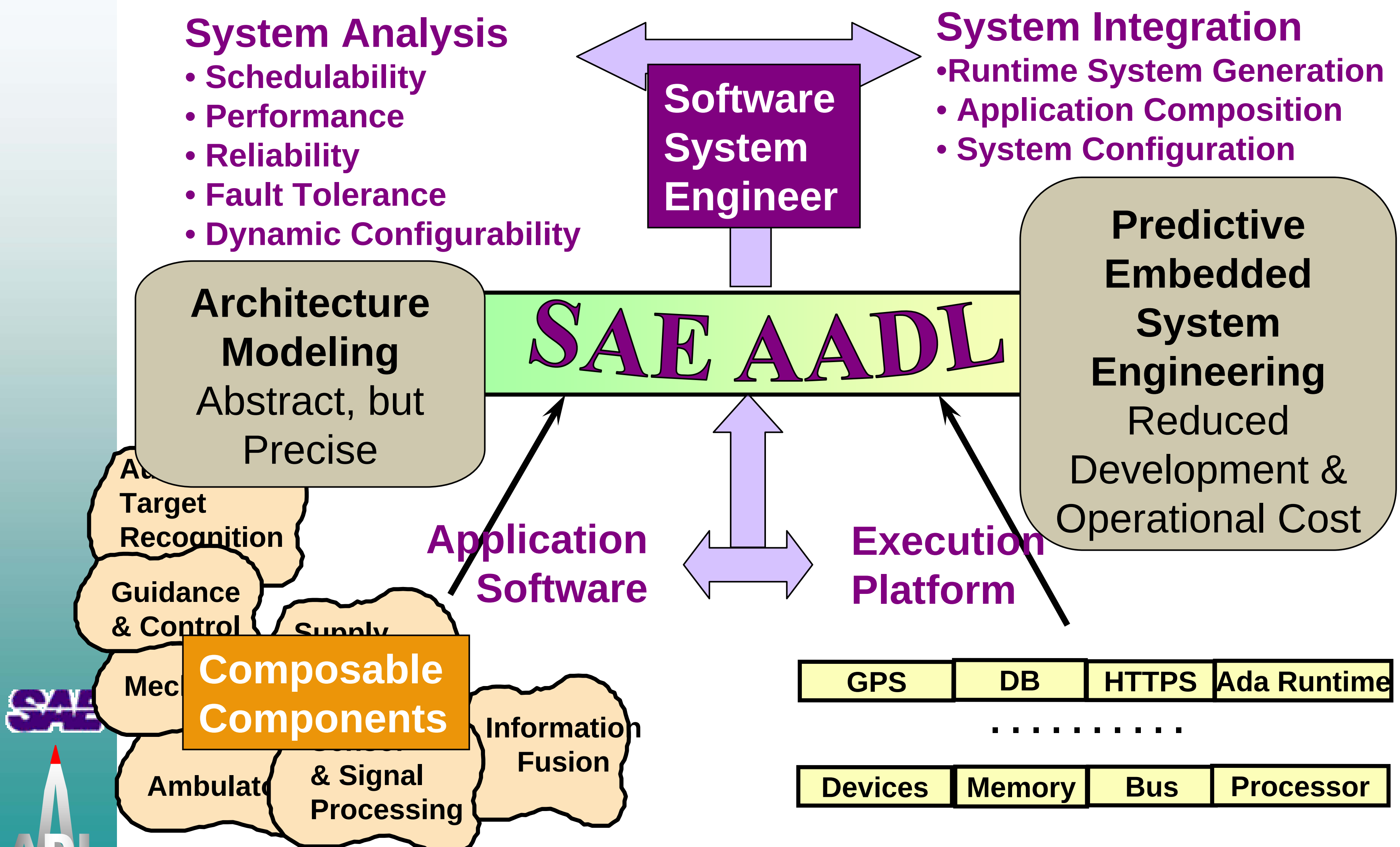
Coordination with

- NATO Aviation, NATO Plug and Play, French Government COTRE, SAE AS-1 Weapons Plug and Play, OMG UML & SysML

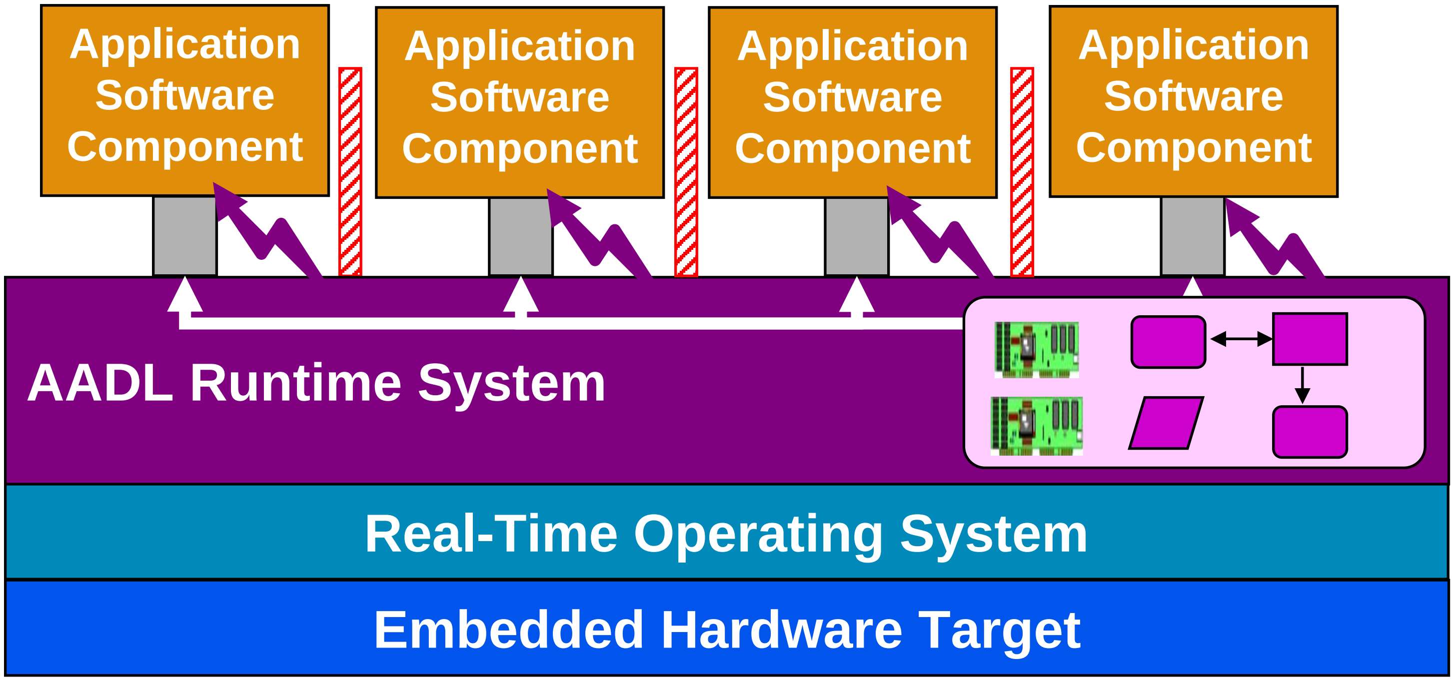
Potential Users

- Airbus — New System Engineering Approach incorporates AADL
- European Space Agency — Modeling of Satellite Systems, Architecture Verification - ASSERT
- Rockwell Collins — Modeling of Avionics Computer System
- Lockheed Martin
- Smith Industries — Embedded System Engineering & AADL
- Raytheon
- Boeing FCS
- Common Missile — Apply AADL for systems integration modeling & analysis
- System Plug and Play — NATO/SAE AS1 Weapon System Integration

AADL-Based Engineering



A Partitioned Portable Architecture



Strong Partitioning

- Timing Protection
- OS Call Restrictions
- Memory Protection

Interoperability/Portability

- Tailored Runtime Executive
- Standard RTOS API
- Application Components

MetaH: Proof of Concepts for AADL

1991 DARPA DSSA program begins
1992 Partitioned PFP target (Tartan MAR/i960MC)
1994 Multi-processor target (VME i960MC)
1995 Slack stealing scheduler
1998 Portable Ada 95 and POSIX middleware configurations
1998 Extensibility through MetaH-ACME Mapping
1998 Reliability modeling extension
1999 Hybrid automata verification of core middleware modules

Numerous evaluation and demonstration projects, e.g.

- Missile G&C reference architecture, demos, others (AMCOM SED)
- Hybrid automata formal verification (AFOSR, Honeywell)
- Missile defense (Boeing)
- Fighter guidance SW fault tolerance (DARPA, CMU, Lockheed-Martin)
- Incremental Upgrade of Legacy Systems (AFRL, Boeing, Honeywell)
- Comanche study (AMCOM, Comanche PO, Boeing, Honeywell)
- Tactical Mobile Robotics (DARPA, Honeywell, Georgia Tech)
- Advanced Intercept Technology CWE (BMDO, MaxTech)
- Adaptive Computer Systems (DARPA, Honeywell)
- Avionics System Performance Management (AFRL, Honeywell)
- Ada Software Integrated Development/Verification (AFRL, Honeywell)
- FMS reference architecture (Honeywell)
- JSF vehicle control (Honeywell)
- IFMU reengineering (Honeywell)

AADL in Context

Research ADLs

- MetaH
  - Real-time, modal, system family
  - Analysis & generation
  - RMA based scheduling
- Rapide, Wright, ..
  - Behavioral validation
- ADL Interchange
  - ACME

Industrial Strength

- UML 2.0, UML-RT
- HOOD/STOOD
- SDL

DARPA Funded Research since 1990

UML Profile

Airbus & ESA

Basis

Extension

Influence

Alignment

Enhancement

AADL
Extensible
Real-time
Dependable

AADL: The Language

Components with precise semantics

- Thread, thread group, process, system, processor, device, memory, bus, data, subprogram

Completely defined interfaces & interactions

- Data & event flow, synchronous call/return, shared access
- End-to-End flow specifications

Real-time Task Scheduling

- Supports different scheduling protocols incl. GRMA, EDF
- Defines scheduling properties and execution semantics

Modal, configurable systems

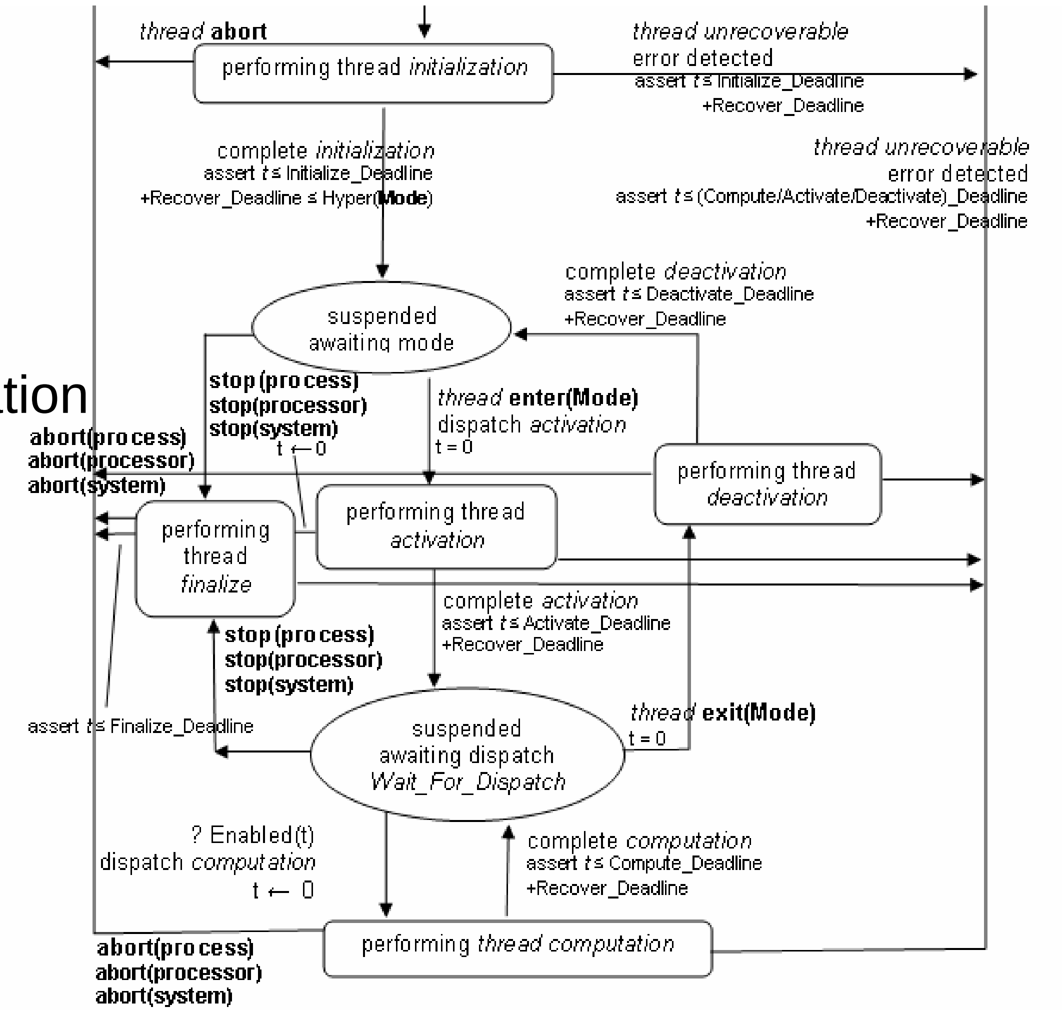
- Modes to model transition between statically known states & configurations

Component evolution & large scale development support

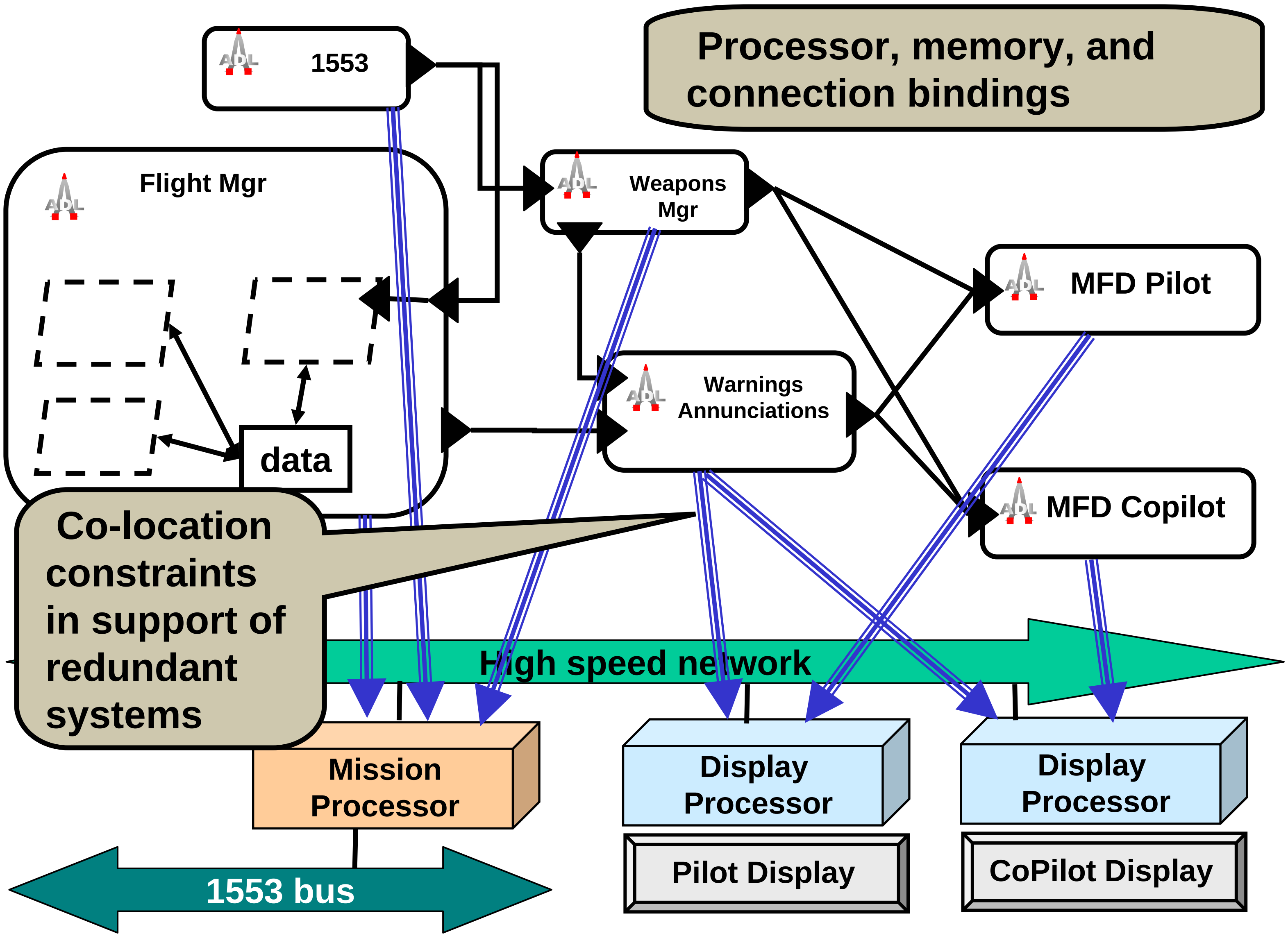
AADL language extensibility

Thread Execution Semantics

- Dispatch protocols
- Nominal & recovery
- Fault handling
- Resource locking
- Mode switching
- Initialization & finalization



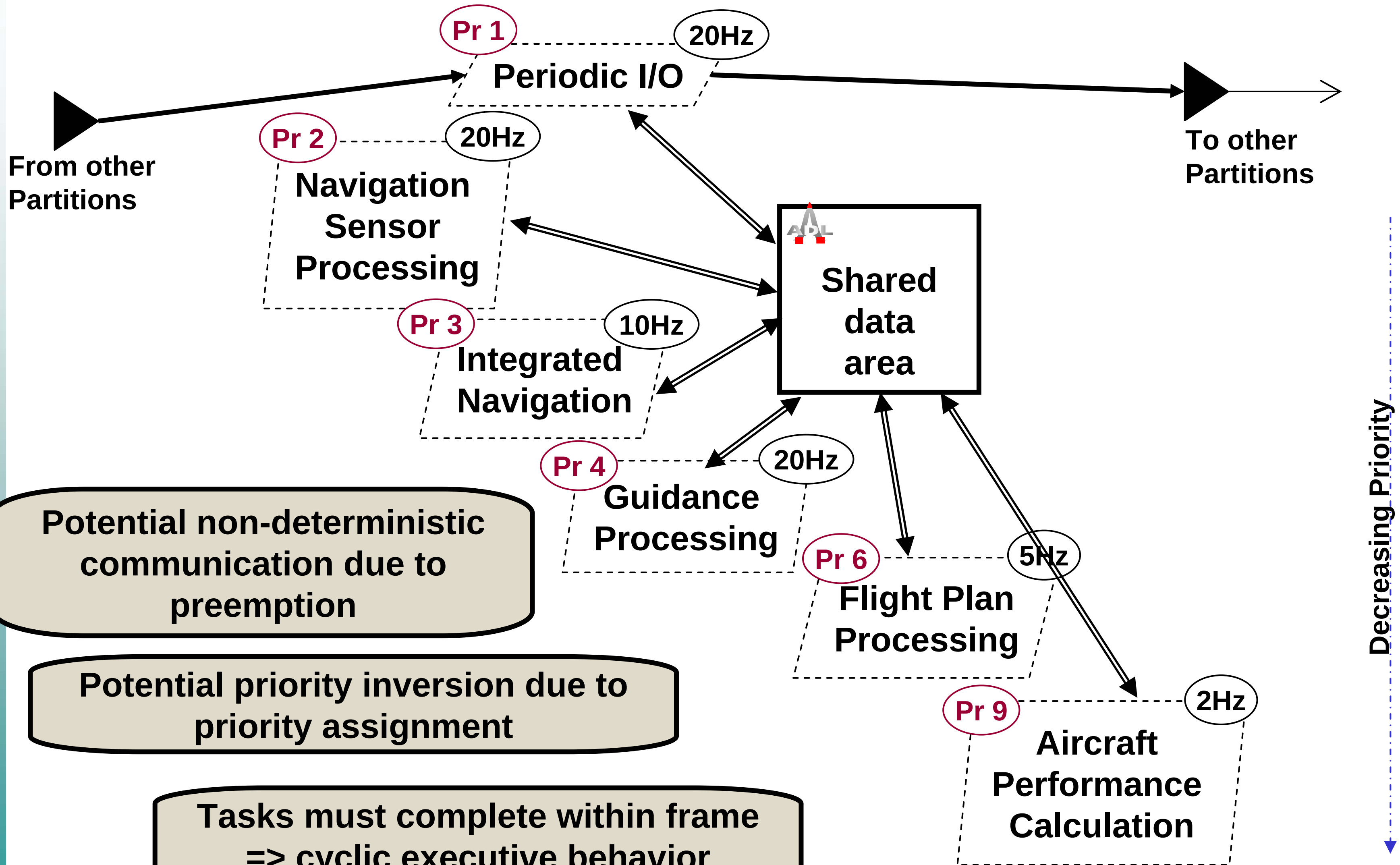
Execution Platform Bindings



An Avionics System Case Study

- Migration from static timeline to preemptive scheduling
  - Identified issues with shared variable communication
  - Migration potential from polling tasks to event-driven tasks
- Flexibility, predictability & efficiency of port-based communication
  - Defined communication timing semantics
  - Support for deterministic transfer & optimized buffers
- Effectiveness of connection & flow semantics
  - Support end-to-end latency analysis
- Analyzable fault-tolerant redundancy patterns
  - Orthogonal architecture view without model clutter

A Naïve Thread-based Design

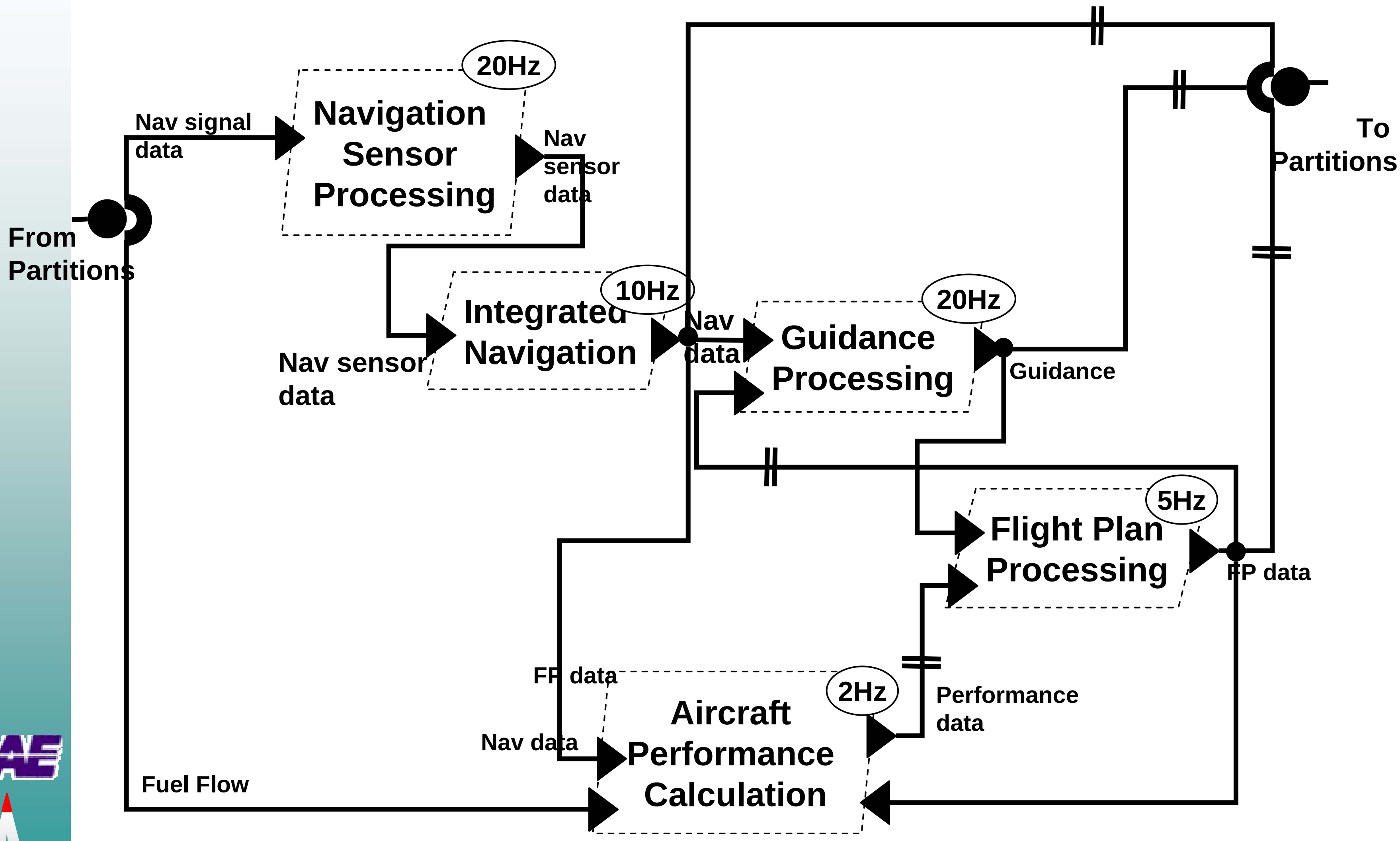


Potential non-deterministic communication due to preemption

Potential priority inversion due to priority assignment

Tasks must complete within frame => cyclic executive behavior

Flight Manager in AADL



Data Stream Latency Analysis

- Flow specifications in AADL
  - Properties on flows: expected & actual end-to-end latency
  - Properties on ports: expected incoming & estimated output latency
- End-to-end latency contributors
  - Delayed connections result in sampling latency
  - Immediate periodic & aperiodic sequences result in cumulative execution time latency
- Phase delay shift & oscillation
  - Noticeable at flow merge points
  - Variation interpreted as noisy signal to controller

Potential hazard

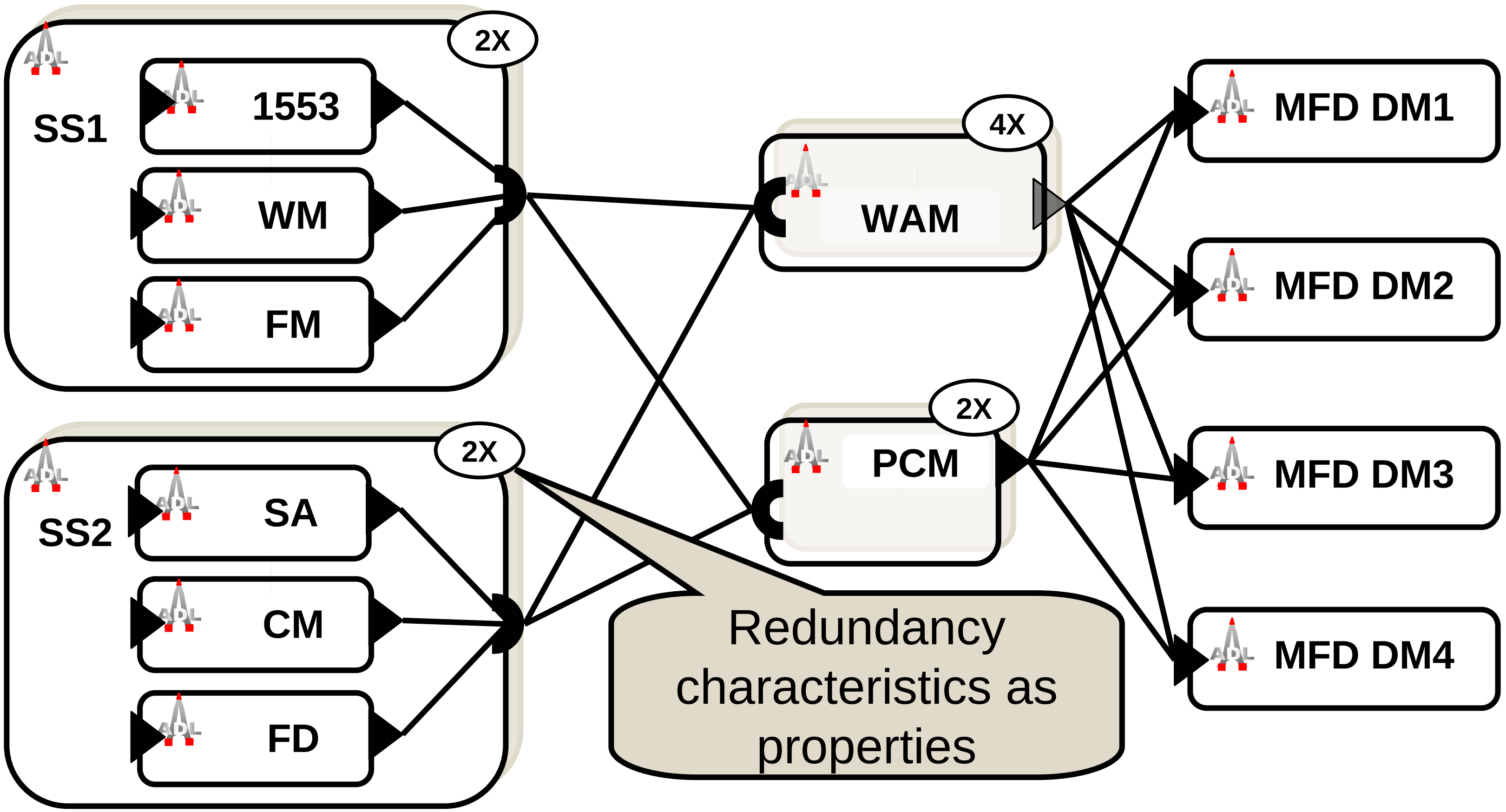
Latency calculation & jitter accumulation

Other Flow Characteristics

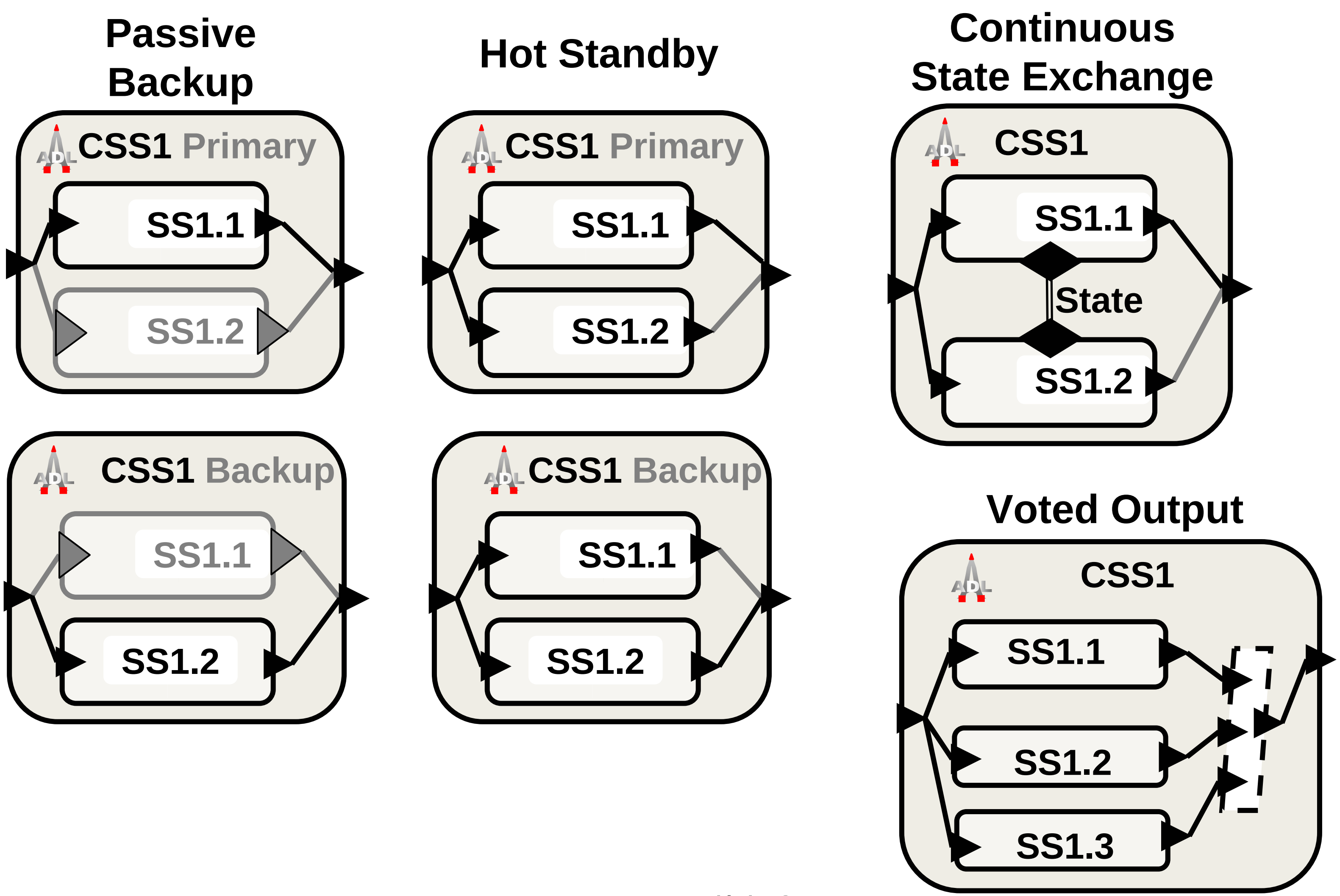
- Miss rate of data stream
  - Accommodates incomplete sensor readings
  - Allows for controlled deadline misses
- State vs. state delta communication
  - Data reduction technique
  - Implies requirement for guaranteed delivery
- Data accuracy
  - Reading accuracy
  - Computational error accumulation
- Message acknowledgment semantics
  - In terms of flow steps

Redundancy Specification

- Redundancy abstraction
- Co-location constraints on execution platform binding

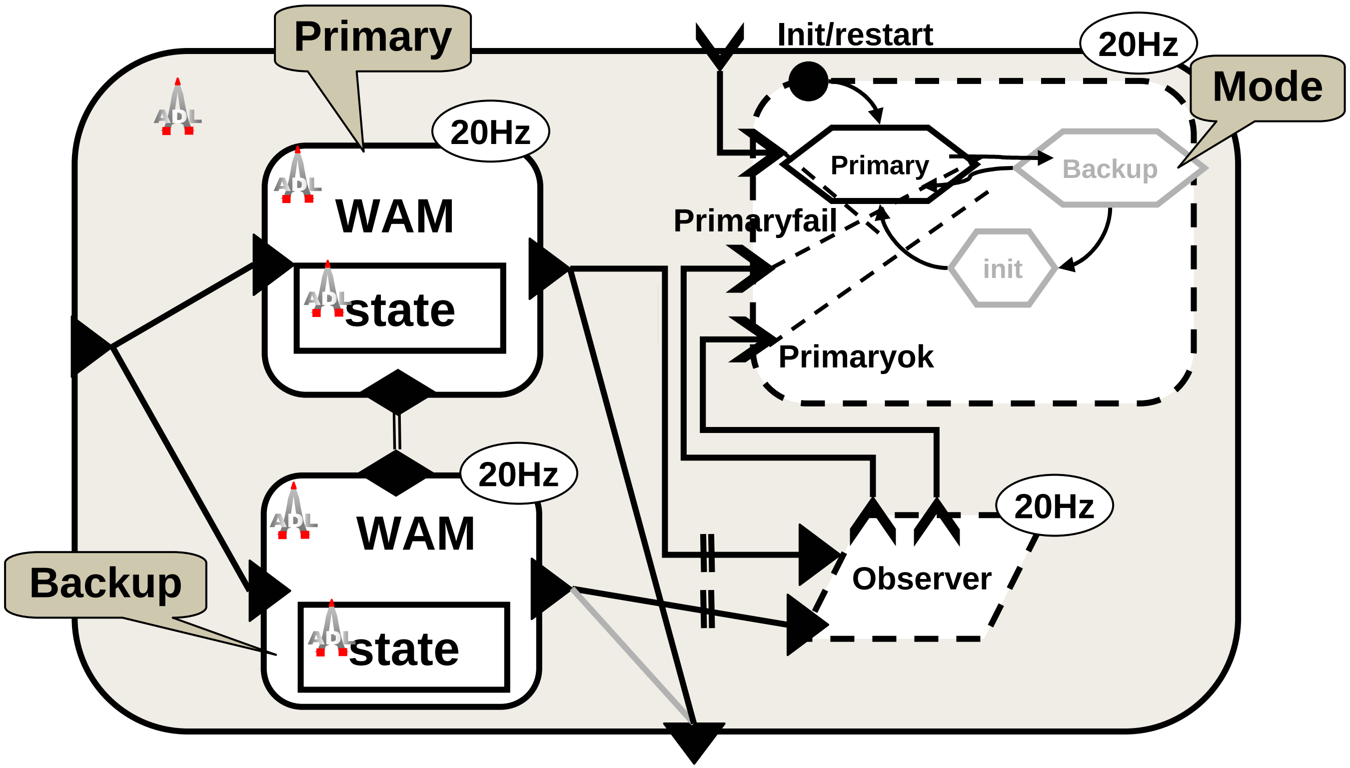


Primary/Backup Patterns



Primary Backup Synchronization

- External and internal mode control
- Errors reported as events
- Supports reasoning about Primary/Backup logic



AADL Language Extensions

- New properties through property sets
- Sublanguage extension
  - Annex subclauses expressed in an annex-specific sublanguage
- Project-specific language extensions
- Language extensions as approved SAE AADL standard annexes
- Examples
  - Reliability modeling
  - ARINC 653
  - Behavior
  - Constraint sublanguage

Example Annex Extension

```
THREAD t
  FEATURES
    sem1 : DATA ACCESS semaphore;
    sem2 : DATA ACCESS semaphore;
END t;

THREAD IMPLEMENTATION t.t1
  PROPERTIES
    Period => 13.96ms;
    cotre::Priority => 1;
    cotre::Phase => 0.0ms;
    Dispatch_Protocol => Periodic;
```

```
ANNEX cotre.behavior {**
   STATES
     s0, s1, s2, s3, s4, s5, s6, s7, s8 : STATE;
     s0 : INITIAL STATE;
   TRANSITIONS
     s0 -[ ]-> s1 { PERIODIC_WAIT };
     s1 -[ ]-> s2 { COMPUTATION(1.9ms, 1.9ms) };
     s2 -[ sem1.wait ! (-1.0ms) ]-> s3;
     s3 -[ ]-> s4 { COMPUTATION(0.1ms, 0.1ms) };
     s4 -[ sem2.wait ! (-1.0ms) ]-> s5;
     s5 -[ ]-> s6 { COMPUTATION(2.5ms, 2.5ms) };
     s6 -[ sem2.release ! ]-> s7;
     s7 -[ ]-> s8 { COMPUTATION(1.5ms, 1.5ms) };
     s8 -[ sem1.release !]-> s0;
  **);
END t.t1;
```

COTRE thread properties

COTRE behavioral annex

Courtesy of cotre

Reliability Modeling Approach

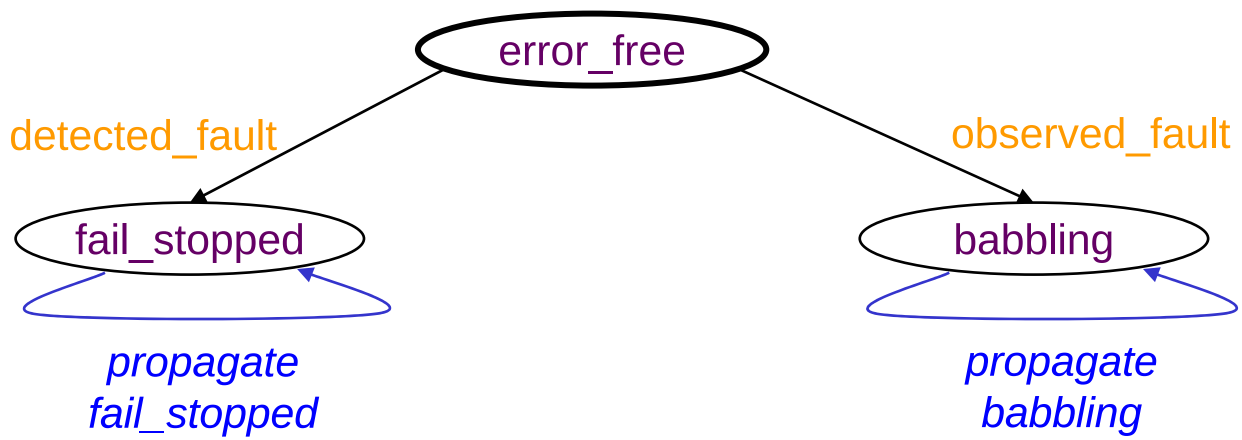
Error state & occurrence model as AADL extension

- Error states and transitions
- Fault events & occurrence rates
- Error propagation rates
- Masking of subcomponent and propagation errors

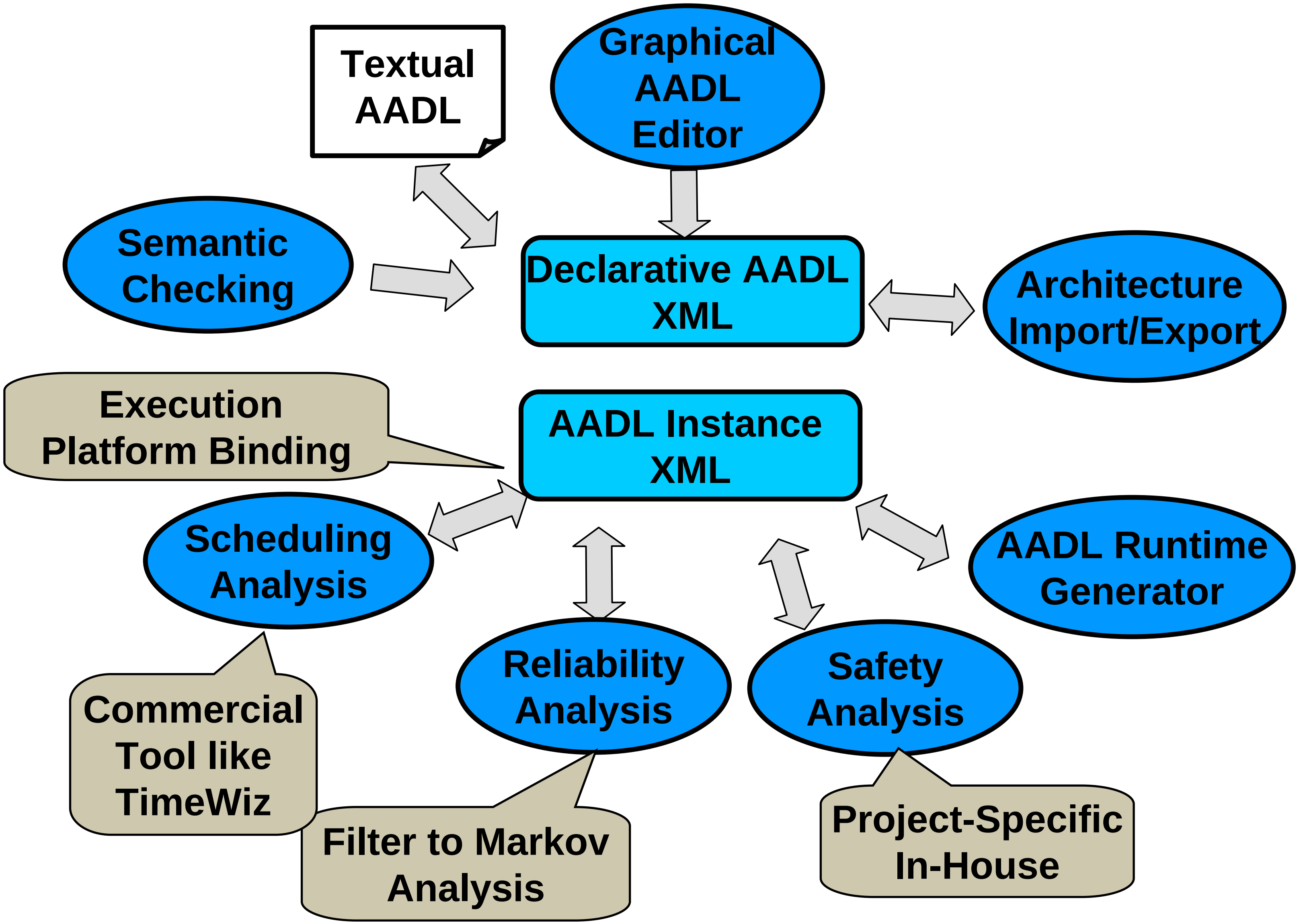
Reflects hazard analysis, component failure modes & effects analysis

Architecture model provides

- Dependency information
- Isolation analysis
- Basis for stochastic process model generation



An XML-Based AADL Tool Strategy



Open Source AADL Tool Environment

- OSATE is
  - Developed by the Software Engineering Institute
  - Available at under a no cost Common Public License (CPL)
  - Implemented on top of Eclipse Release 3 (www.eclipse.org)
  - Generated from an AADL meta model using the Eclipse Modeling Framework (EMF)
  - A textual & graphical AADL front-end with semantic & XML/XMI support
  - Extensible through architecture analysis & generation plug-ins
- OSATE offers
  - Low cost entrypoint to the use of SAE AADL

SAE AADL and OSATE: Enablers of Embedded Systems Research

- Industry standard architecture modeling notation & model interchange format facilitates
  - Interchange of architecture models between contractors & subcontractors
  - Common architecture model for non-functional system property analysis from different perspectives
  - In-house prototyping of project specific architecture analysis & generation
  - Architecture research with access to industrial models & industry exposure to research results