Architecture Analysis with AADL
The Speed Regulation Case-Study

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What this talk is about?

1. Actual issues for Safety-Critical systems design

2. Why Model-Based Engineering techniques are helpful

3. How AADL can detect issues early and avoid potential rework

Agenda

Introduction on Model-Based Engineering

Presentation of the Case Study

System Overview

AADL model description

Architecture Analysis

Conclusion

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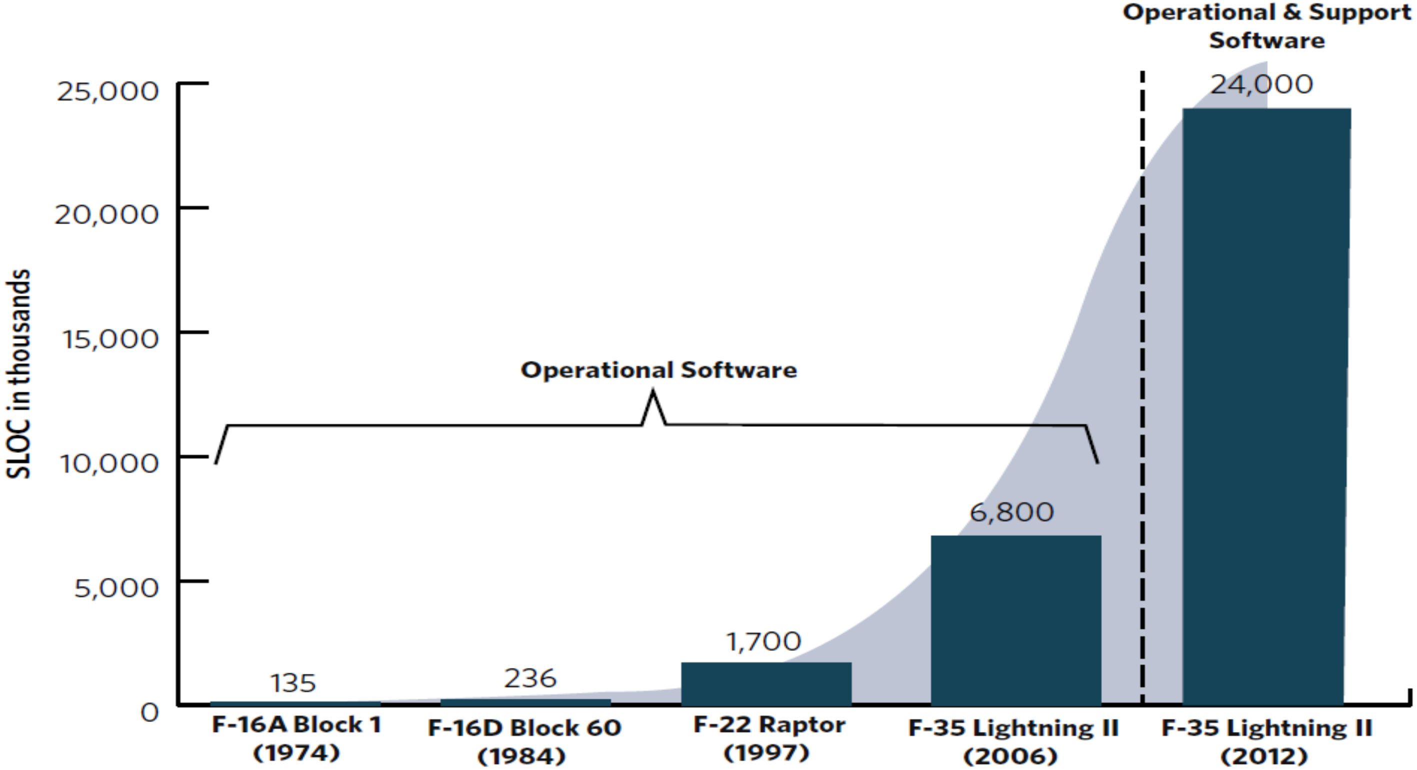
Polling Question 1

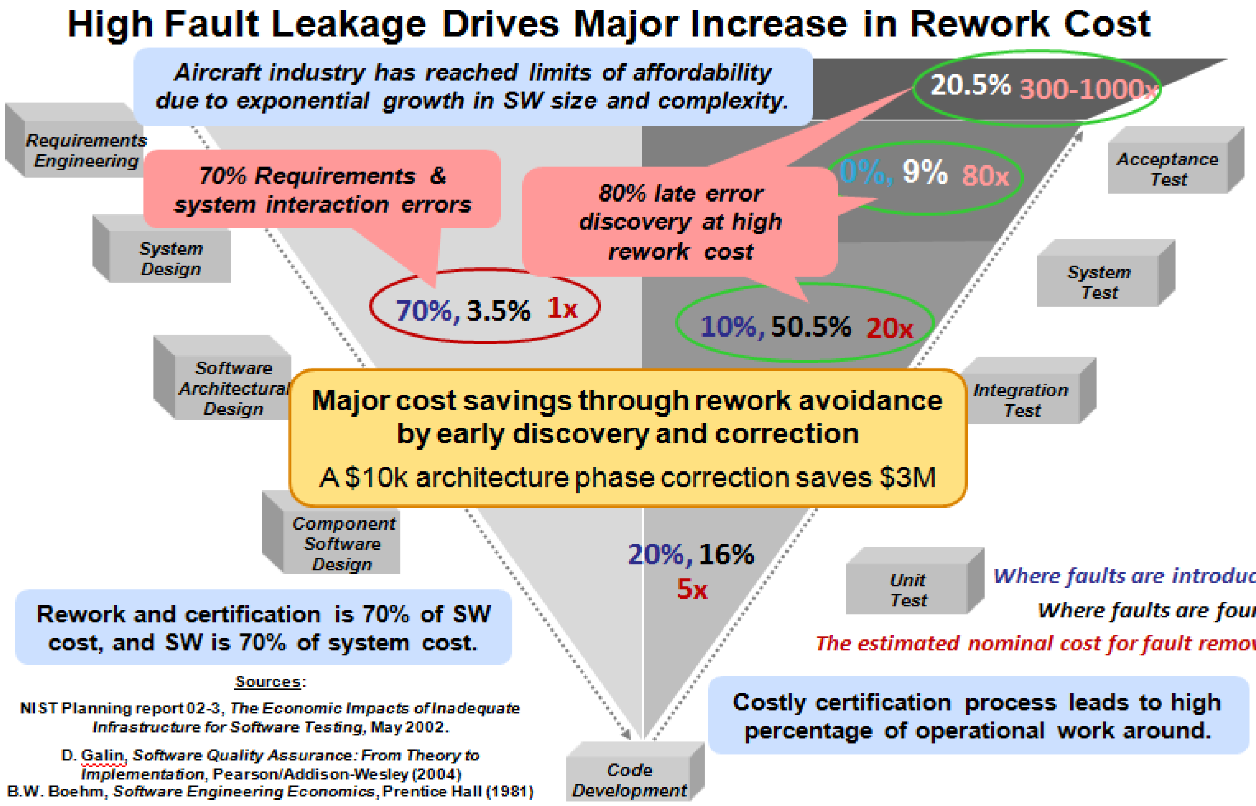
Do you know what Model-Based Engineering is?

Safety-Critical Systems are Intensively Software-Reliant



Source: *"Delivering Military Software Affordably"* in Defense AT&L

Errors are introduced early but detected (too) lately



Many Errors stems from Architecture or Integrati… ues

Global Variable used among different functions

- **Potential issues**: inconsistent values, …
- **Root Cause**: Architecture Desi…

Use of COTS components wit…

- **Potential impac…** …
- **Root Ca…** …gration

Timing is…

- … enforced, bad values
- … ation policy, lack of analysis

…hould I continue this list?

Fact1: All these errors could be detected at Design-Time

Fact2: They are actually detected during integration tests

Fact3: They incur rework costs and postpone product delivery

Why Model-Based Engineering Matters?

Capture system architecture with designers requirements

- Focus on system structure/organization (e.g. shared components)
- Tailor architecture to specific engineering domain (e.g. safety)

Validate the architecture

- Check requirements enforcement (e.g. no global variable)
- Detect Potential issues (e.g. interfaces consistency)

Early Analysis

- Avoid late re-engineering efforts (e.g. less rework after integration)
- Support decisions between different architecture variations

Polling Question 2

Do you already know AADL?

Architecture Analysis Design Language

SAE Standard for Model-Based Engineering

- First version in 2003, actual version 2.1

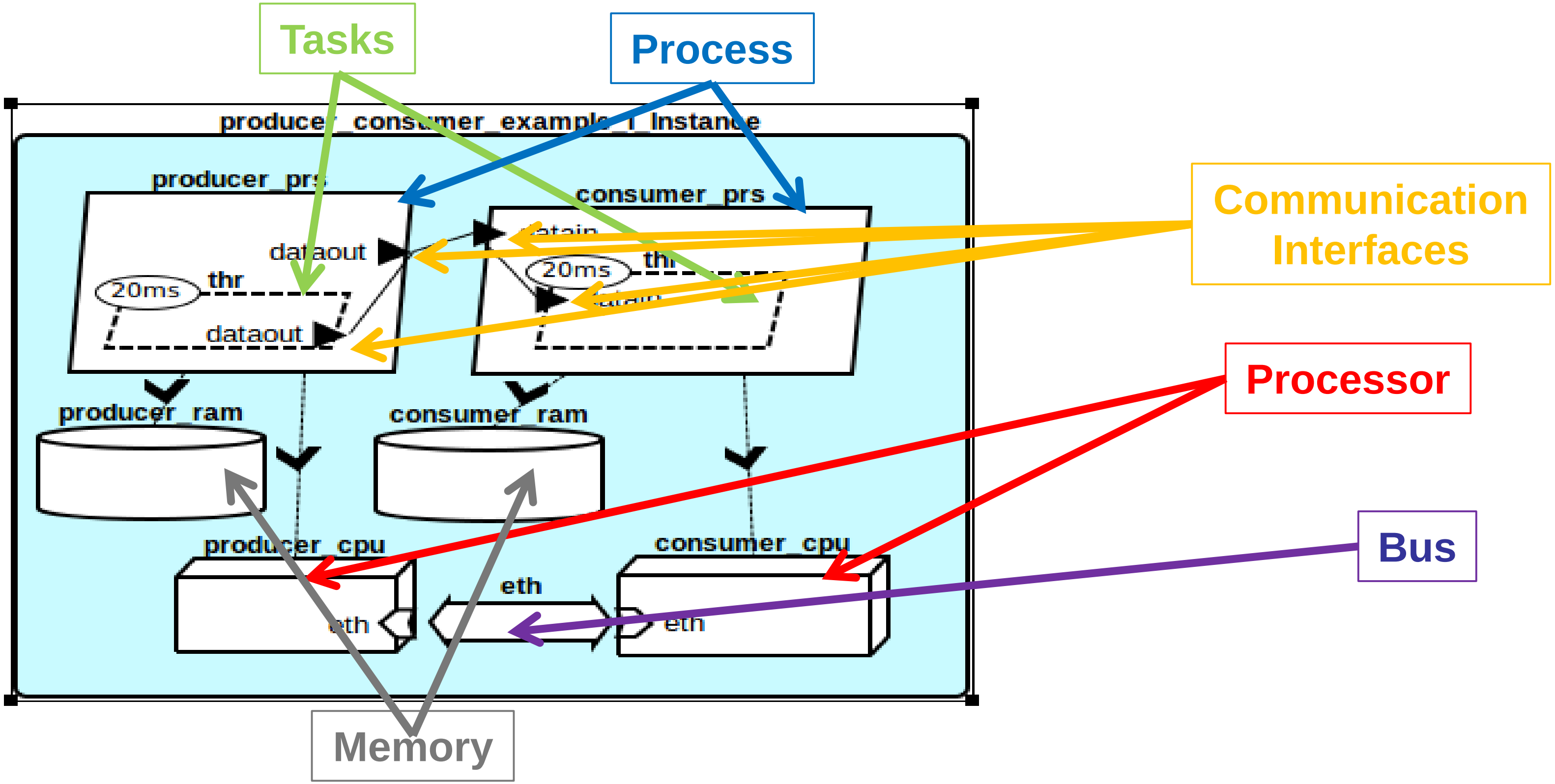
Definition of System and Software Architecture

- Specialized components with interfaces (not just “blocks”)
- Interaction with the Execution Environment (processor, buses)

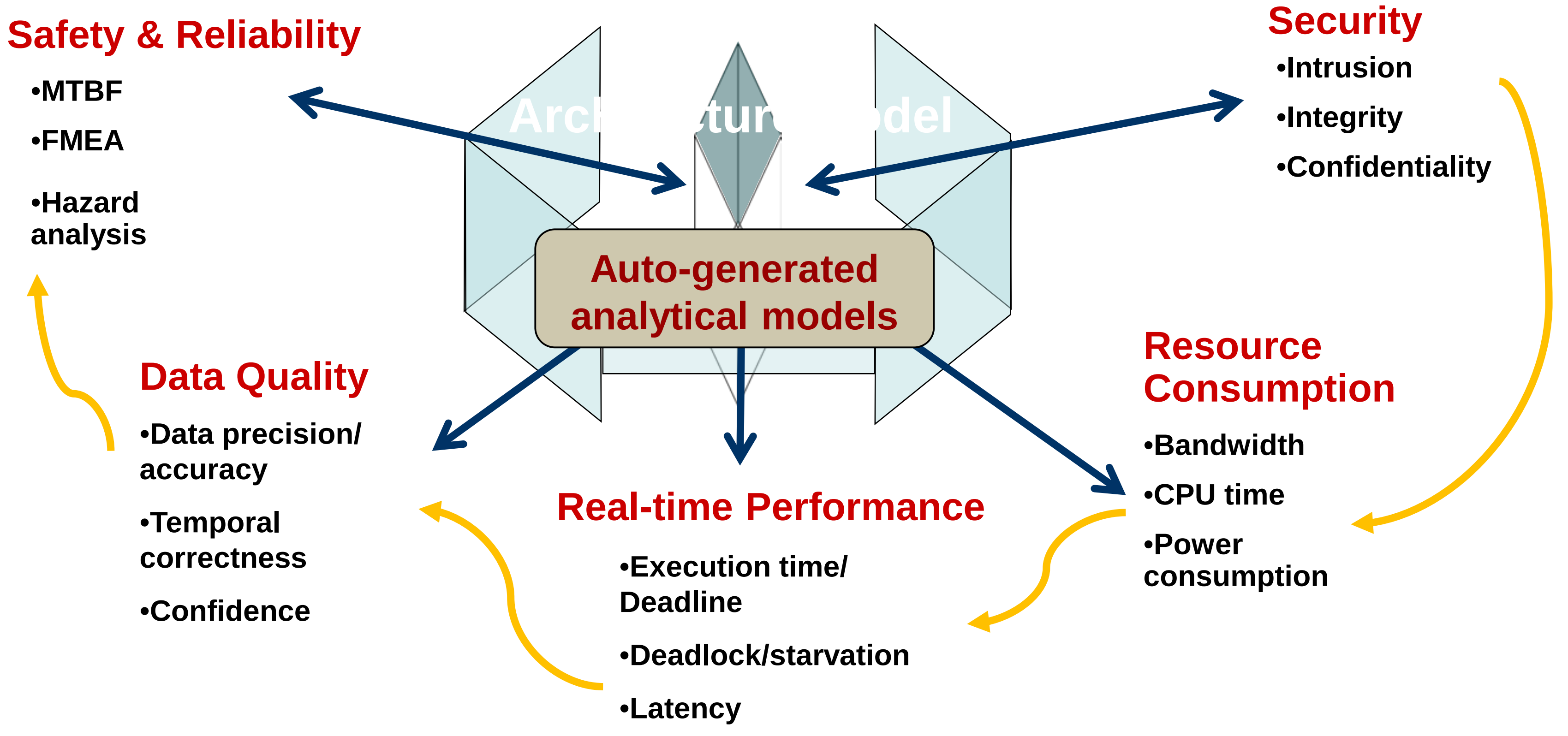
Extension mechanisms

- User-Defined Properties (integrate your own constraints)
- Annexes (existing for safety, behavior, etc.)

AADL Model Example



Architecture Analysis Design Language



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Objectives of this Study

Learn Architecture Modelling with AADL and the OSATE workbench

Model a family of systems with their variability factors

Analyze the Architecture from a performance perspective

Discover Safety Issues using Architecture Models

Support Architecture Alternatives Selection

Illustrate the Process with a relevant case study

Case-Study Description

Self-Driving car speed regulation

Obstacle detection with user warning

- Camera detection
- Infra-red sensor

Automatic Speed and Brake

- Two speed (wheel, laser) sensors
- Redundant GPS

Polling Question 3

On what aspect would you like to focus?

Case-Study Objectives

Help designers to choose the *best* Architecture

- Best reliability, avoid potential failure/error
- Meet timing and performance requirements

Analyze Architecture according to stakeholders criteria

- Try to analyze what really matters

Quantify architecture quality from different perspectives

- **Latency**
- **Resources and Budgets**
- **Safety/Reliability**

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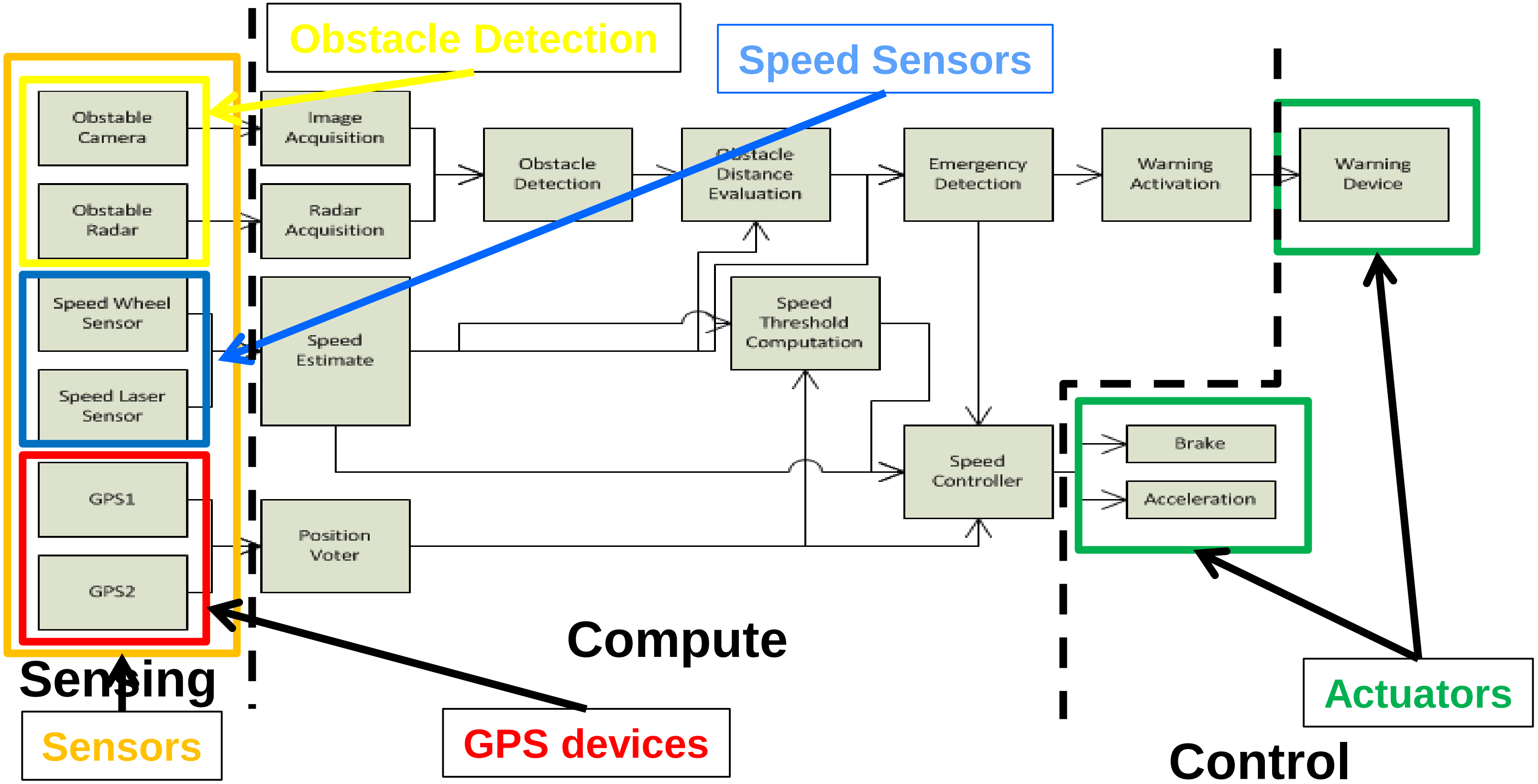
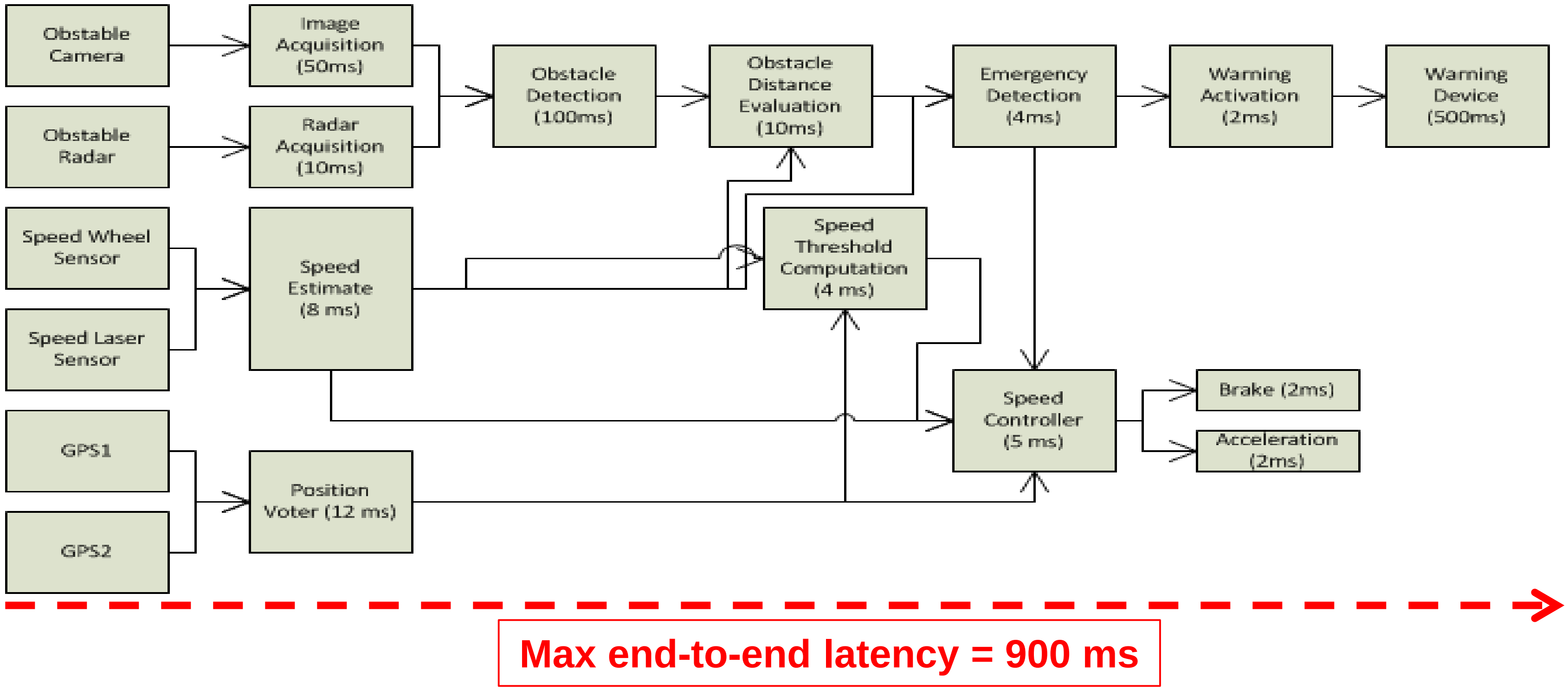
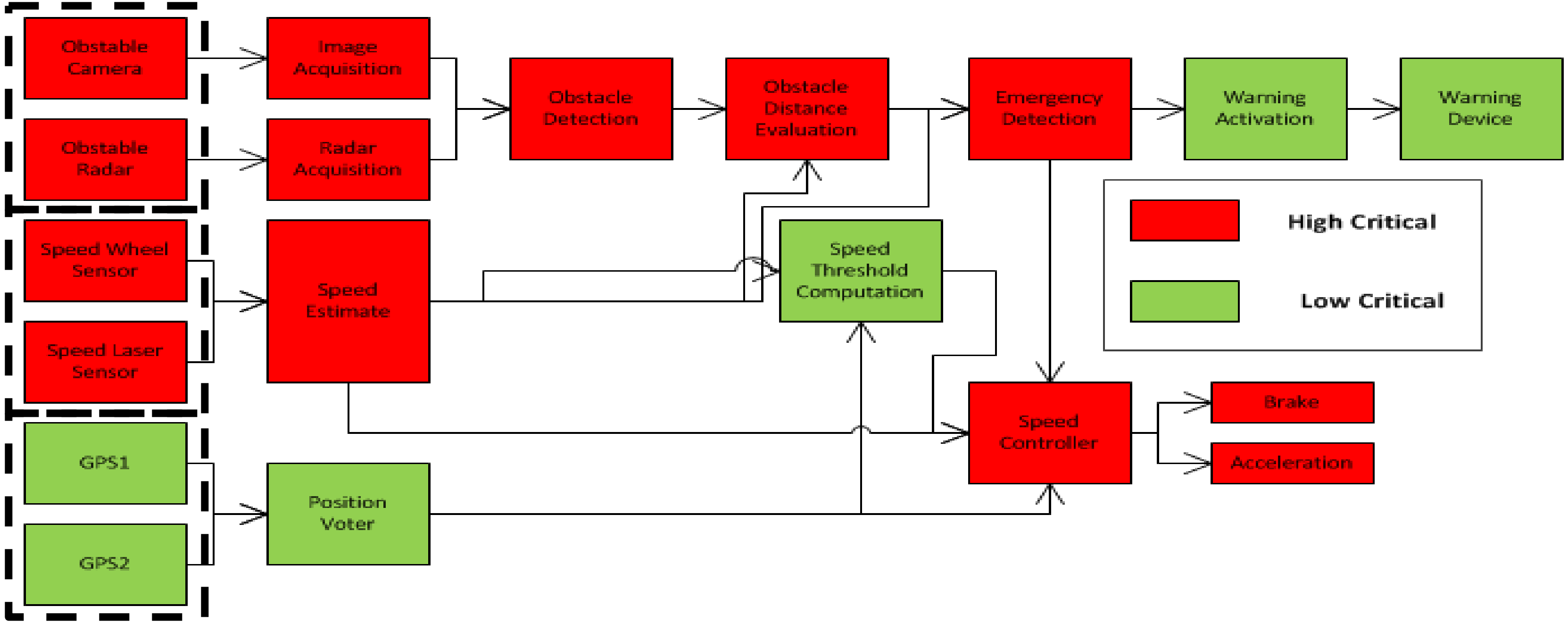
Functional Architecture



Functional Architecture, timing perspective



Functional Architecture, criticality perspective



Redundancy Groups (performs the same function)

Deployment Alternatives

Alternative 1: reduce cost and complexity

Two processors and one shared bus

Potential interactions for functions collocated on the same processor

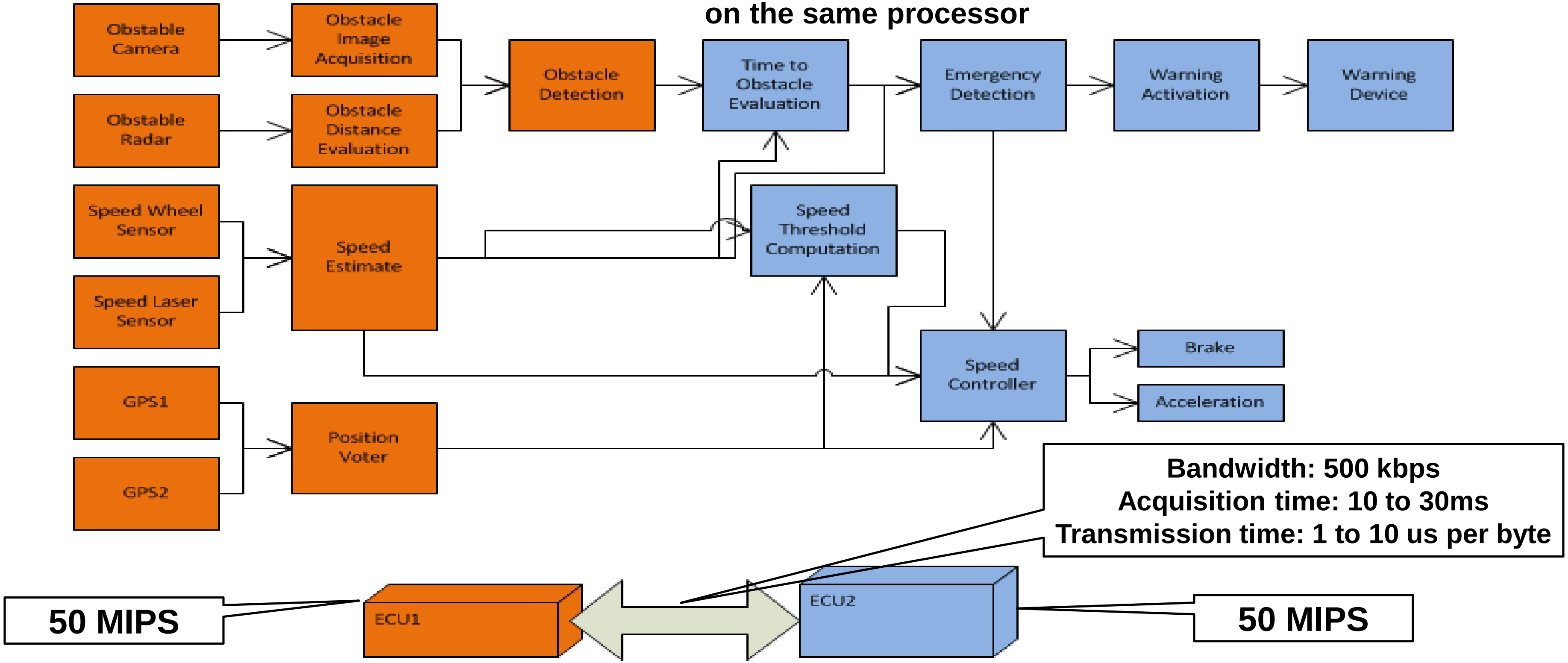
Alternative 2: reduce potential fault impact

Increase potential production cost (more hardware)

Three processors inter-connected with two buses

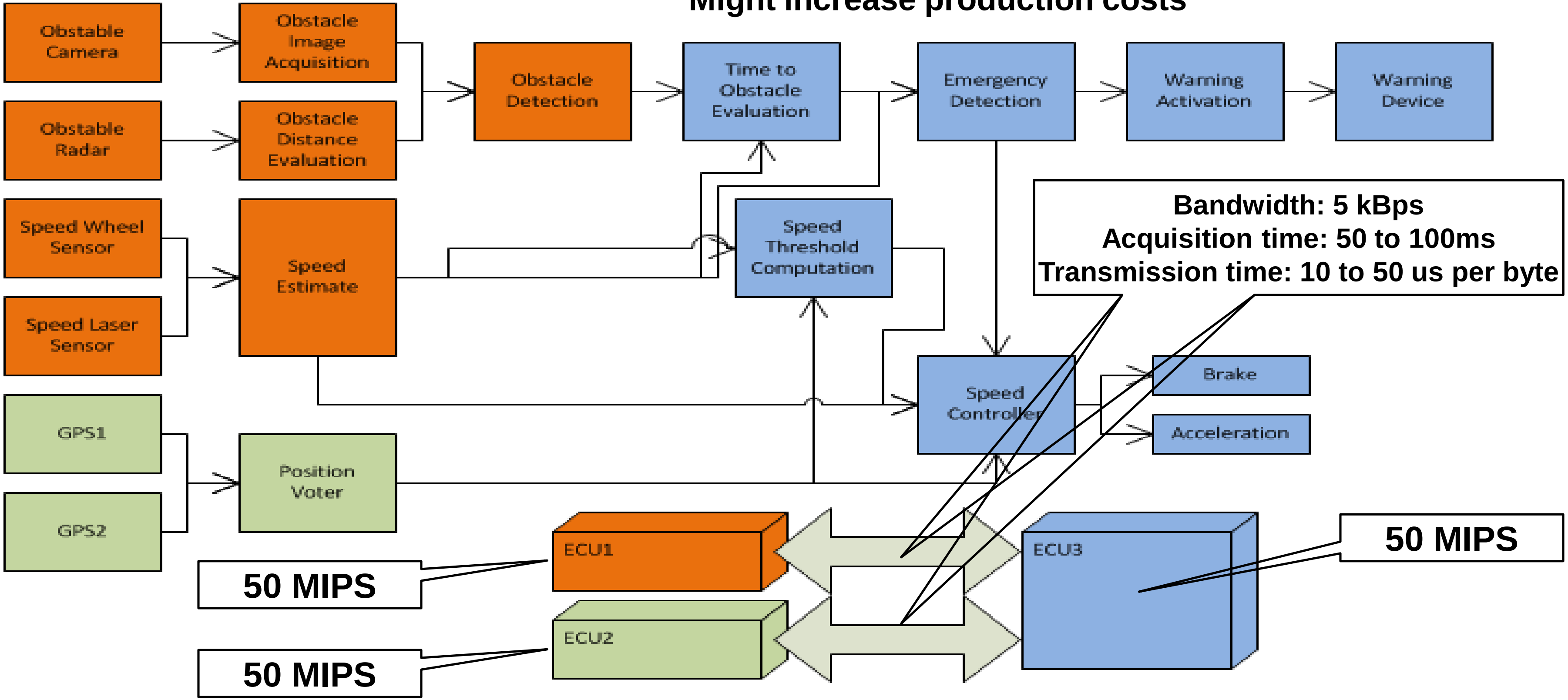
Architecture Alternative 1

Reduce Cost and Complexity
Potential interactions for functions collocated on the same processor



Architecture Alternative 2

Reduce Fault Impact
Might increase production costs



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Modeling Guidelines

Separate architecture aspects in different files

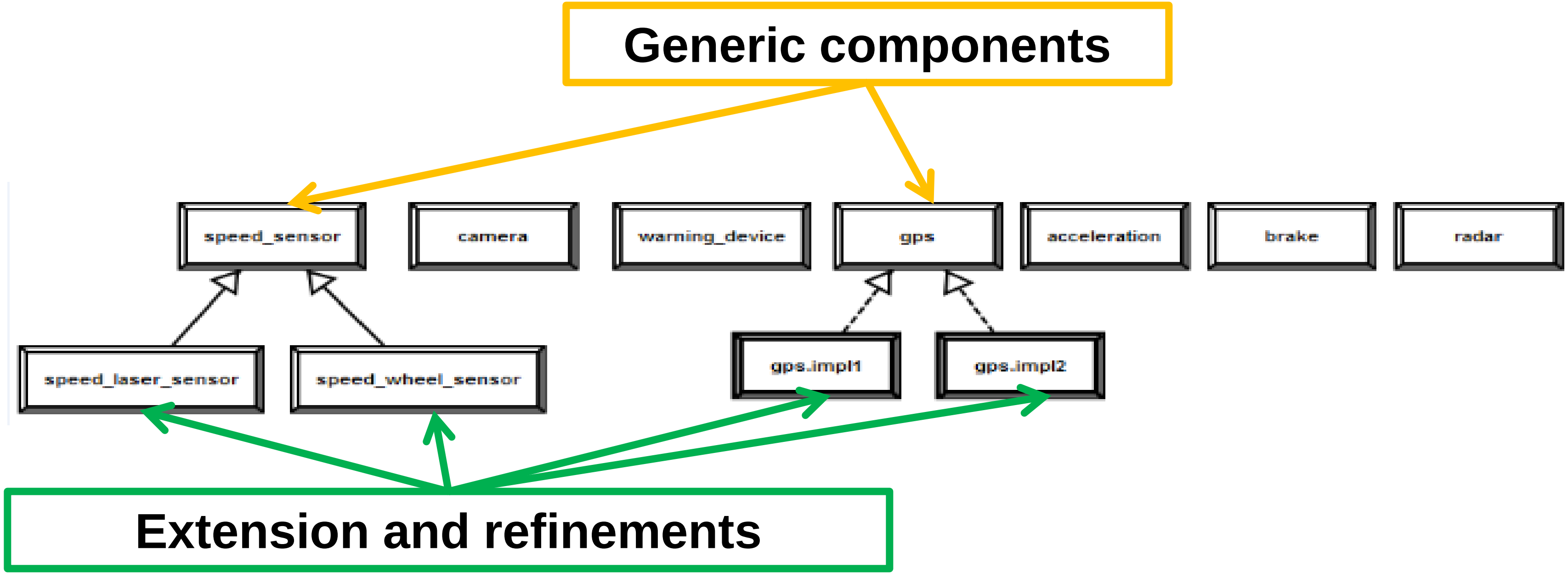
Leverage AADL extension and refinement mechanisms

- Capture common characteristics, avoid copy/paste
- Extend generic components

Use properties to quantify quality attributes

- Processed by tools to evaluate architecture quality
- **Specify once**, use by several analysis tools
- **Ensure Analyses Consistency**

Model Organization – devices



Model Organization – devices – textual model

```
device radar
features
    distance_estimate : out data port speed_regulation::icd::distance;
flows
    f0 : flow source di
properties
    Period => 10ms;
annex EMV2 {**
    use types speed_reg

    error propagations
        distance_estimate : out propagation {NoValue,InvalidValue};
    flows
        ef0 : error source distance_estimate{NoValue,InvalidValue};
    end propagations;

    properties
        emv2::severity => ARP4761::Major applies to distance_estimate.novalue;
        emv2::likelihood => ARP4761::Probable applies to distance_estimate.novalue;
        emv2::hazards =>
            ([   crossreference => "N/A";
                 failure => "NoValue";
                 phases => ("all");
                 description => "No information from the Radar";
                 comment => "Error if both the camera and the radar does not send any value";
            ])
            applies to distance_estimate.novalue;

        emv2::severity => ARP4761::Minor applies to distance_estimate.invalidvalue;
        emv2::likelihood => ARP4761::Probable applies to distance_estimate.invalidvalue;
        emv2::hazards =>
            ([   crossreference => "N/A";
                 failure => "InvalidValue";
                 phases => ("all");
                 description => "Invalid distance sent by the radar";
                 comment => "First occurrences of invalid data Should be handled by the distance estimator.";
            ])
            applies to distance_estimate.invalidvalue;
**};
end radar;
```

Component Name

Timing constraints
(latency analysis)

Error propagations and flows

Types of faults
(all safety analysis tools)

Documenting the faults
(safety analysis)

Model Organization – Interfaces Specifications

Data types being used to communicate across functions

Data size properties
(resource allocation and latency analysis)

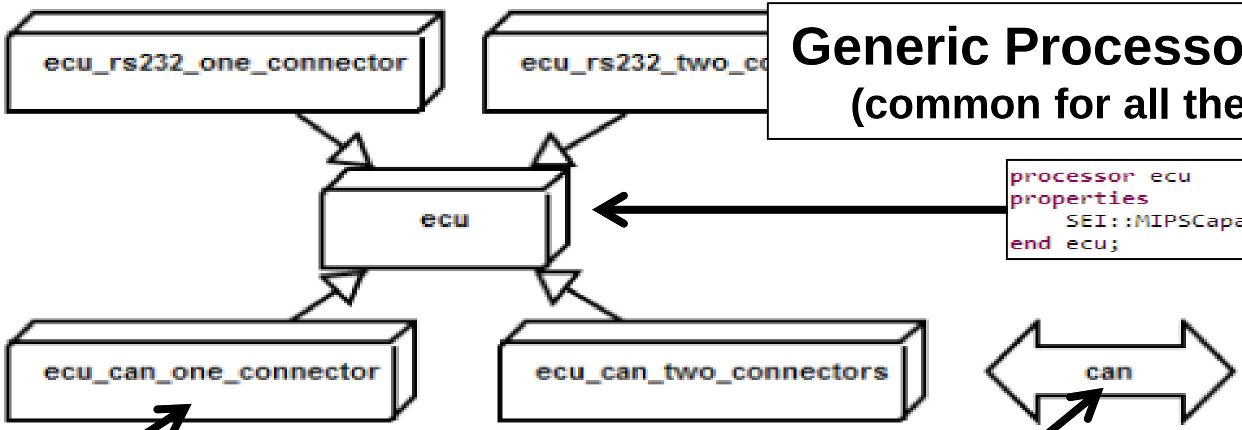
```
data gps_position
properties
    data_size => 50 Bytes;
    data_model::data_representation => Array;
end gps_position;

data sp
end

d
pr
    da
    data_mo
end picture;

data boolean
properties
    data_size => 1 bits;
end boolean;
```

One property, several analyses

⇨Ensure Analyses Consistency

```
  ta speed_command_type
properties
    ta_model::data_representation => enum;
      model::enumerators => ("brake", "accel");
    ize => 2 bits;
    command_type;

   peed_command
  d speed_command;

data implementation speed_command.i
subcomponents
    kind : data speed_command_type;
    value : data base_types::unsigned_16;
end speed_command.i;

data distance extends base_types::unsigned_32
end distance;
```

Model Organization – platform



Generic Processor Component
(common for all the architecture)

```
processor ecu
properties
    SEI::MIPSCapacity => 50.0 MIPS;
end ecu;
```

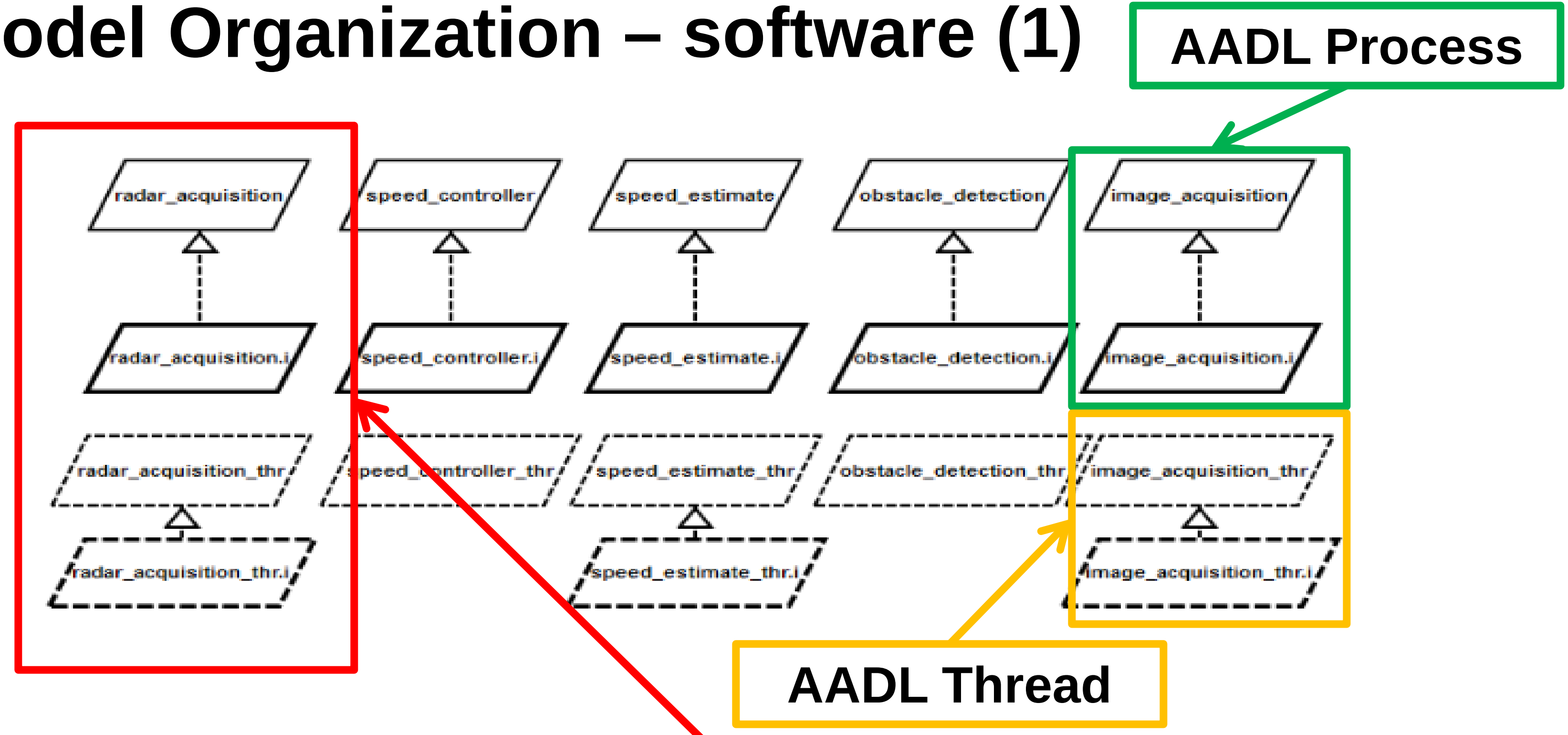
```
processor ecu_can_one_connector extends ecu
features
    socket : requires bus access can;
end ecu_can_one_connector;
```

```
bus can
properties
    Latency => 1 Ms .. 1 Ms;
    SEI::BandWidthCapacity => 500000.0 bitsps;
    Transmission_Time => [ Fixed => 10 ms .. 30ms;
                           PerByte => 1 us .. 10 us; ];
end can;
```

Processor extension, specify bus connections
Share properties of inherited component

Timing information
(latency analysis)

Model Organization – software (1)



One software function = 1 AADL process + 1 AADL thread

Model Organization – software – textual notation (1)

```
process radar_acquisition
features
    obstacle_distance : in data port speed_regulation::icd::distance;
    obstacle_detected : out data port speed_regulation::icd::boolean;
flows
    f0 : flow path obstacle_distance -> obstacle_detected;
annex EMV2 {**
    use types       speed_regulation::error_library;
    use behavior    speed_regulation::error_library::simple;

    error propagations
        obstacle_distance : in propagation {NoValue,InvalidValue};
        obstacle_detected : out propagation {NoValue,InvalidValue};
        processor : in propagation {SoftwareFailure, HardwareFailure};
    flows
        ef0 : error path obstacle_distance{NoValue} -> obstacle_detected{NoValue};
        ef1 : error path obstacle_distance{NoValue} -> obstacle_detected{InvalidValue};
        ef3 : error path obstacle_distance{InvalidValue} -> obstacle_detected{InvalidValue};
        ef2 : error path processor{HardwareFailure,SoftwareFailure} -> obstacle_detected{NoValue};
    end propagations;

    component error behavior
    transitions
        t0 : Operational -[processor{SoftwareFailure}]-> Failed;
        t1 : Operational -[processor{HardwareFailure}]-> Failed;
        t2 : Failed -[processor{NoError}]-> Operational;
    propagations
        p1 : Failed -[]-> obstacle_detected{NoValue};
    end component;
**};
end radar_acquisition;
```

Component type

Communication interfaces

Data flow specification (latency analysis)

Error specification (safety analyses)

Subcomponents and connections

```
process implementation radar_acquisition.i
subcomponents
    thr : thread radar_acquisition_thr.i;
connections
    c0 : port obstacle_distance -> thr.obstacle_distance;
    c1 : port thr.obstacle_detected -> obstacle_detected;
flows
    f0 : flow path obstacle_distance -> c0 -> thr.f0 -> c1 -> obstacle_detected;
end radar_acquisition.i;
```

Component implementation

Model Organization – software – textual notation (2)

```
thread radar_acquisition_thr
features
    obstacle_distance : in data port speed_regulation::icd::distance;
    obstacle_detected : out data port speed_regulation::icd::boolean;
flows
    f0 : flow path obstacle_distance -> obstacle_detected;
properties
    Dispatch_Protocol => Periodic;
    Period            => 10ms;
    sei::mipsbudget   => 4.0 mips;
end radar_acquisition_thr;
```

Data flow
(latency analysis)

Time information
(latency analysis)

Resource Budgets
(resource allocation analysis)

Model Organization – safety specification

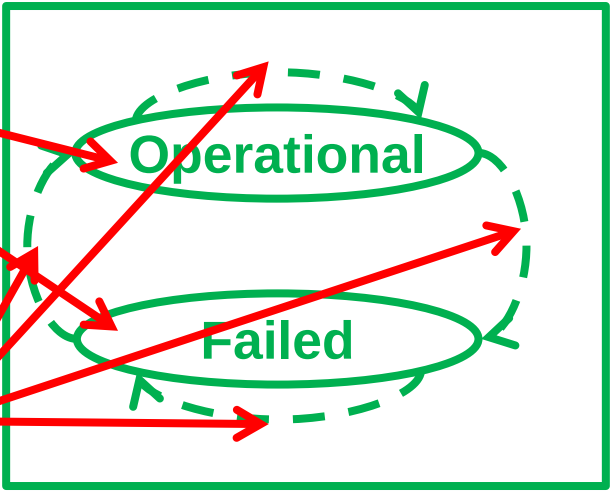
```
package speed_regulation::error_library
public
annex EMV2 {**
    error types
        NoPower                   : type;
        ValueEr
        NoValue                           alueError;
        Invalid                           ueError;
        Hardwar
        SoftwareFailure           : type;
    end types;
    error behavior simple
    states
        Operational : initial state;
        Failed      : state;
    end
**};
end spee
```

Error types that could be raised

Error states

Component-specific error transitions (to be added on a component-basis)

Reusable error state machines to be attached to components



Model Organization – define error flows – error source

```
device camera
features
    picture : out data port speed_regulation::icd::picture;
flows
    f0 : flow source picture;
properties
    Period => 200ms;
annex EMV2 {**
    use types speed_regulation::error_library;

    error propagations
        picture : out propagation {NoValue};
    flows
        ef0 : error source picture{NoValue};
    end propagations;
**};
end camera;
```

Reuse predefined types

Define error types propagated on component interfaces

Define the error sources, what interfaces initiates an error flow

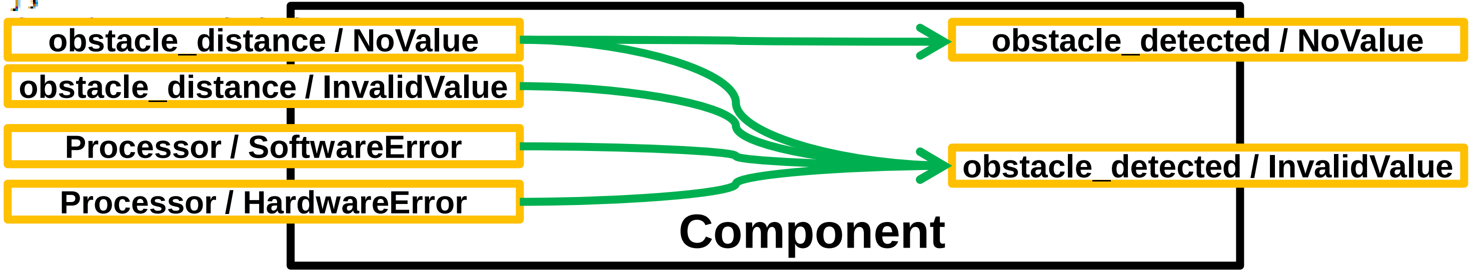
Model Organization – define error flows – error path

```
annex EMV2 {**
    use types        speed_regulation::error_library;
    use behavior     speed_regulation::error_library::simple;

    error propagations
        obstacle_distance : in propagation {NoValue,InvalidValue};
        obstacle_detected : out propagation {NoValue,InvalidValue};
        processor : in propagation {SoftwareFailure, HardwareFailure};
    flows
        ef0 : error path obstacle_distance{NoValue} -> obstacle_detected{NoValue};
        ef1 : error path obstacle_distance{NoValue} -> obstacle_detected{InvalidValue};
        ef3 : error path obstacle_distance{InvalidValue} -> obstacle_detected{InvalidValue};
        ef2 : error path processor{HardwareFailure,                                   e};
    end propagations;
**};
```

Reuse predefined types and behavior

Define error types propagated on component interfaces

Define the propagations flows



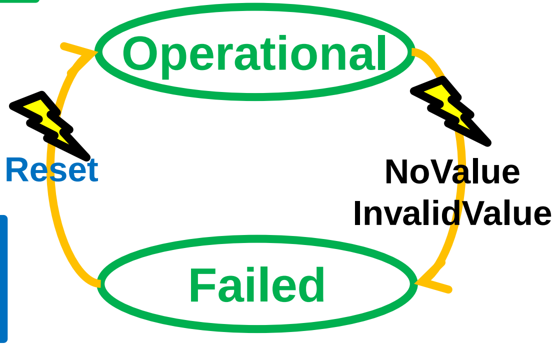
Model Organization – error sink & define component error behavior

```
device warning_device
features
    warning : in data port speed_regulation::icd::boolean;
flows
    f0 : flow sink warning;
properties
    Period => 500ms;
annex EMV2 {**
    use types        speed_regulation::error_library;
    use behavior     speed_regulation::error_library::simple;

    error propagations
        warning : in propagation {NoValue,InvalidValue};
    flows
        ef0 : error sink warning{NoValue,InvalidValue};
    end propagations;

    component error behavior
    events
        Reset : recover event;
    transitions
        t0 : Operational -[warning{NoValue}]-> Failed;
        t1 : Operational -[warning{InvalidValue}]-> Failed;
        t2 : Failed -[Reset]-> Operational;
    end component;
**};
end warning_device;
```

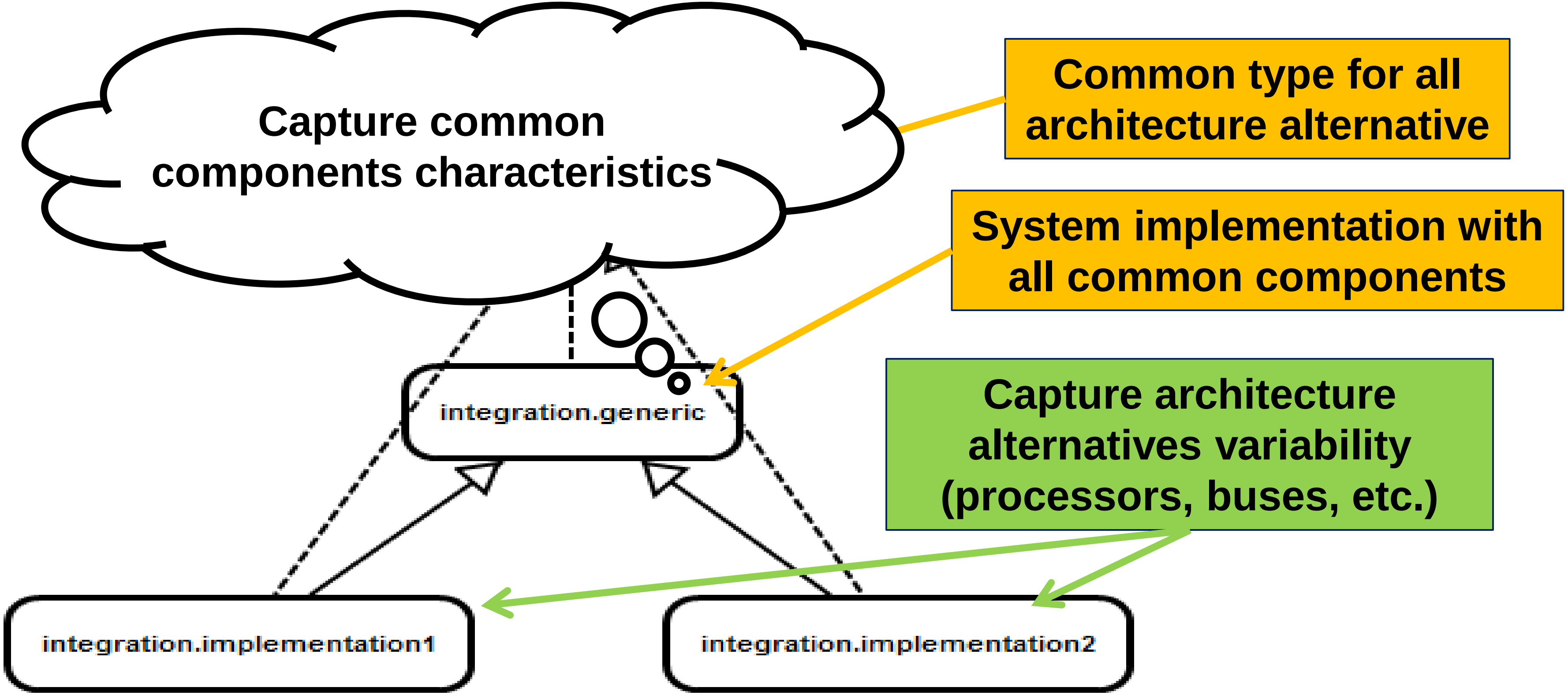
Use predefined error types and component behavior

Define component-specific error events

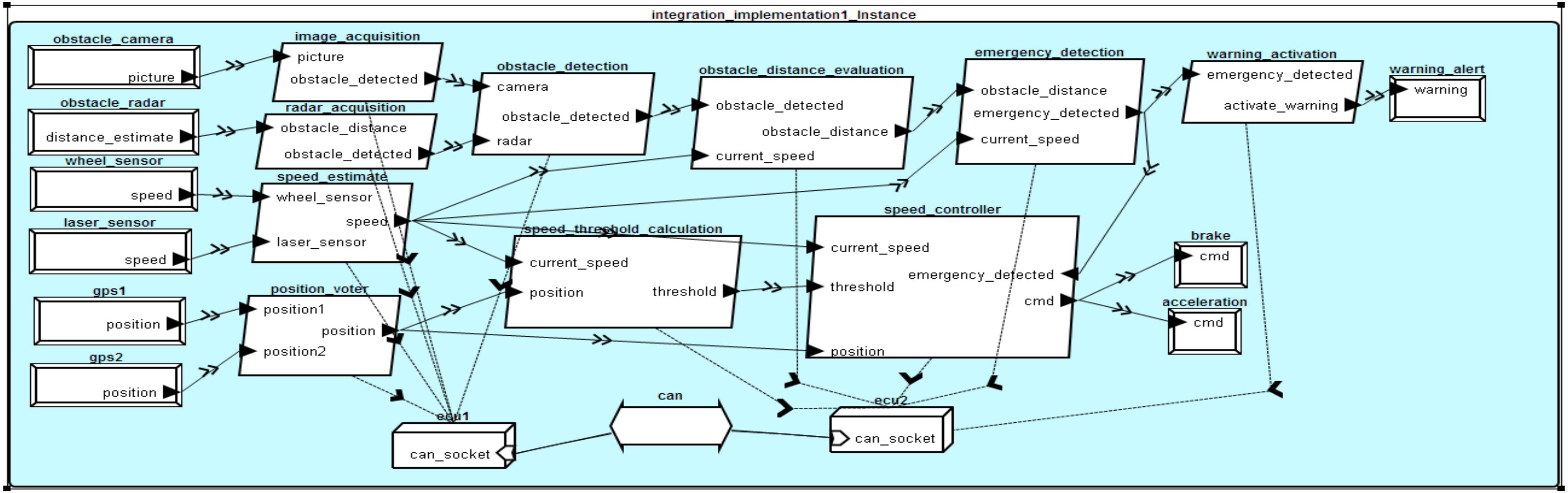
Component-specific error transitions



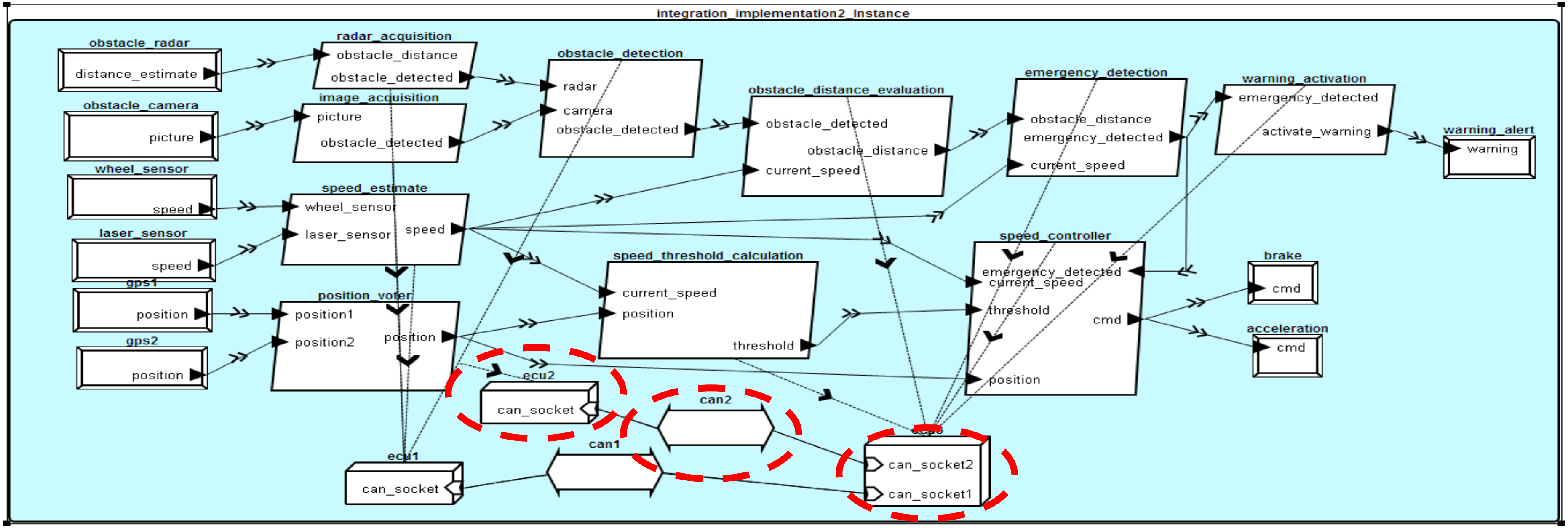
Model Organization – architecture alternatives



Architecture Alternative 1: model instance



Architecture Alternative 2: model instance



Variability Factors with Alternative 1

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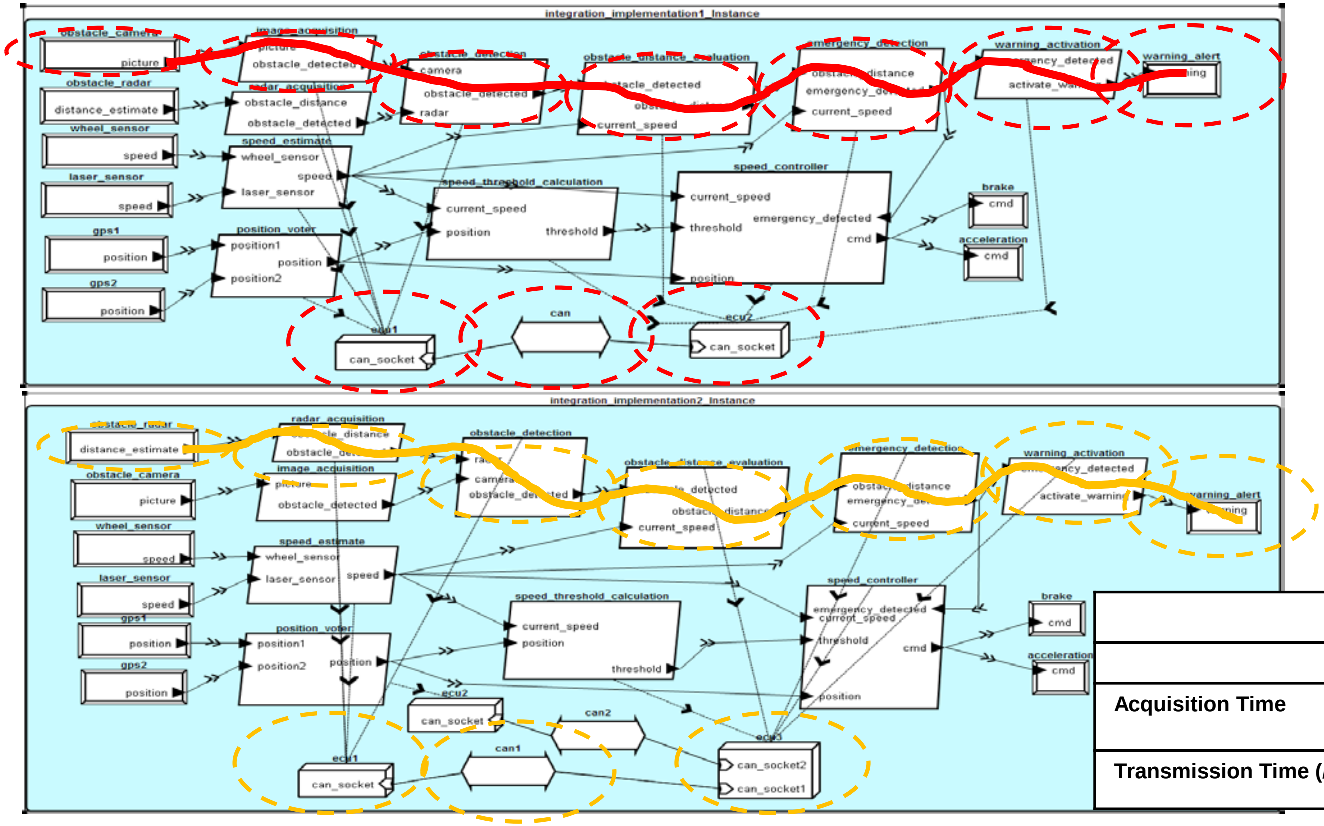
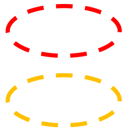
Latency Analysis, principles





Potential impact on latency

Bus characteristics		
	Alternative1	Alternative2
Acquisition Time	10 to 30 ms	200 to 500 ms
Transmission Time (/B)	1 to 10us	2 to 5 ms

Latency Analysis, results

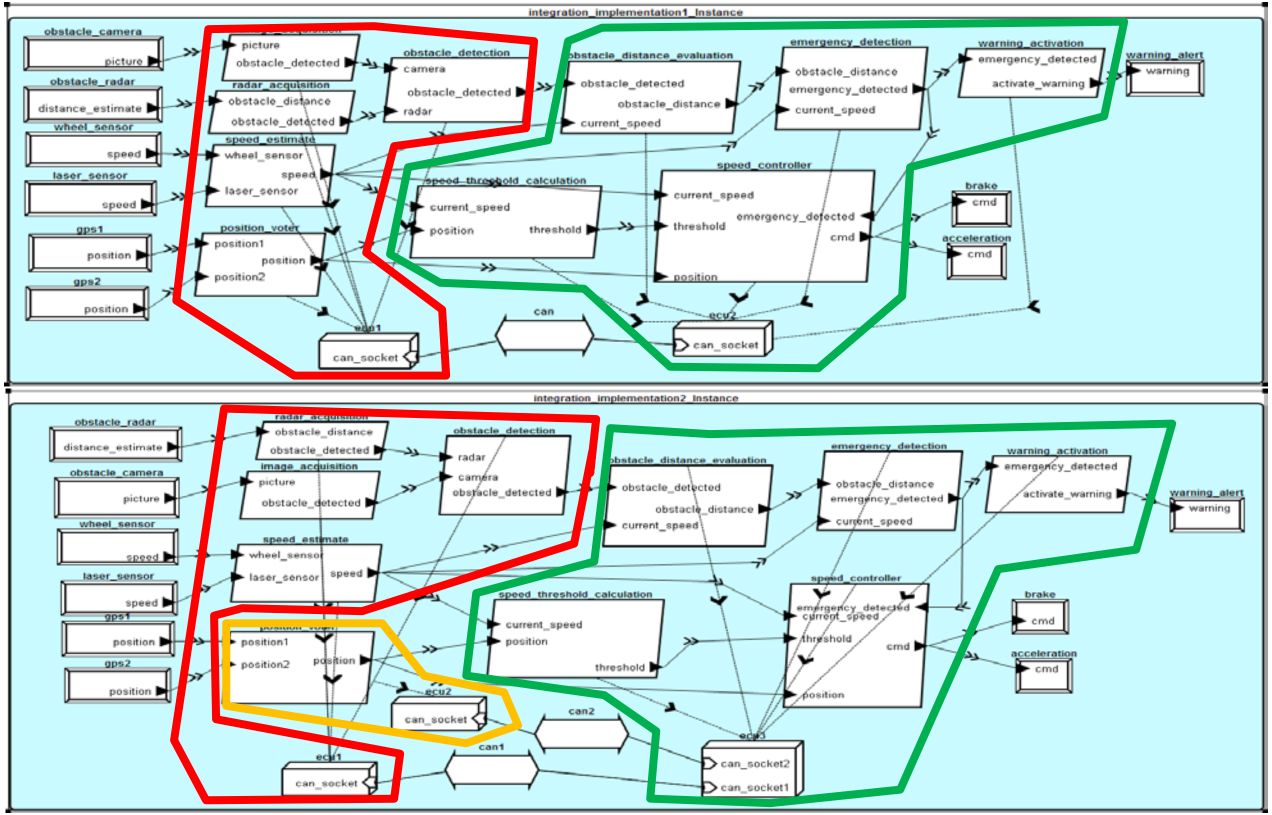
Architecture Alternative 1

flow	model element	name	deadline or conn delay	total	expected
f0: End to End Latency report					
f0 (Synchronous)	device	obstacle_camera:f0	200.0 ms	200.0 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_camera.pictur	0.0 us	200.0 ms	900.0 ms
f0 (Synchronous)	thread	image_acquisition.thr:f	50.0 ms	250.0 ms	900.0 ms
f0 (Synchronous)	Connection	image_acquisition.thr.c	0.0 us	250.0 ms	900.0 ms
f0 (Synchronous)	thread	obstacle_detection.thr:	100.0 ms	350.0 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_detection.thr.	30.00125 ms	380.00125 ms	900.0 ms
f0 (Synchronous)	thread	obstacle_distance_eval	10.0 ms	390.00125 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_distance_eval	0.0 us	390.00125 ms	900.0 ms
f0 (Synchronous)	thread	emergency_detection.t	4.0 ms	394.00125 ms	900.0 ms
f0 (Synchronous)	Connection	emergency_detection.t	0.0 us	394.00125 ms	900.0 ms
f0 (Synchronous)	thread	warning_activation.thr:	2.0 ms	396.00125 ms	900.0 ms
f0 (Synchronous)	Connection	warning_activation.thr.	0.0 us	396.00125 ms	900.0 ms
f0 (Synchronous)	device	warning_alert:f0	500.0 ms	896.00125 ms	900.0 ms
f0 (Synchronous)	Total		0.0 us	896.00125 ms	900.0 ms
f0: End-to-end flow f0 calculated latency (Synchronous) 896.00125 ms is less than expected latency 900.0 ms					

Architecture Alternative 2

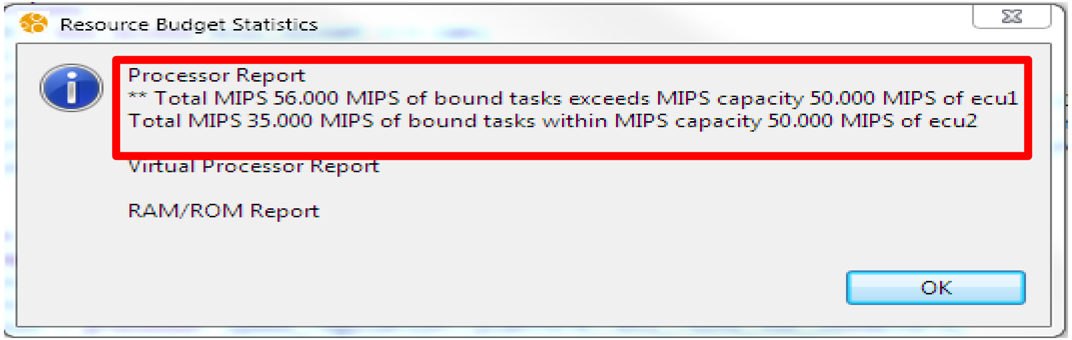
flow	model elemer	name	deadline or conr	total	expected
f0: End to End Latency report					
f0 (Synchronous)	device	obstacle_camera:f0	200.0 ms	200.0 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_camera.picture -	0.0 us	200.0 ms	900.0 ms
f0 (Synchronous)	thread	image_acquisition.thr:f0	50.0 ms	250.0 ms	900.0 ms
f0 (Synchronous)	Connection	image_acquisition.thr.obs	0.0 us	250.0 ms	900.0 ms
f0 (Synchronous)	thread	obstacle_detection.thr:f0	100.0 ms	350.0 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_detection.thr.ob	100.00625 ms	450.00625 ms	900.0 ms
f0 (Synchronous)	thread	obstacle_distance_evalua	10.0 ms	460.00625 ms	900.0 ms
f0 (Synchronous)	Connection	obstacle_distance_evalua	0.0 us	460.00625 ms	900.0 ms
f0 (Synchronous)	thread	emergency_detection.thr	4.0 ms	464.00625 ms	900.0 ms
f0 (Synchronous)	Connection	emergency_detection.thr	0.0 us	464.00625 ms	900.0 ms
f0 (Synchronous)	thread	warning_activation.thr:f0	2.0 ms	466.00625 ms	900.0 ms
f0 (Synchronous)	Connection	warning_activation.thr.ac	0.0 us	466.00625 ms	900.0 ms
f0 (Synchronous)	device	warning_alert:f0	500.0 ms	966.00625 ms	900.0 ms
f0 (Synchronous)	Total		0.0 us	966.00625 ms	900.0 ms
ERROR: f0: End-to-end flow f0 calculated latency (Synchronous) 966.00625 ms exceeds expected latency 900.0 ms					

Resources Allocation Analysis, principles

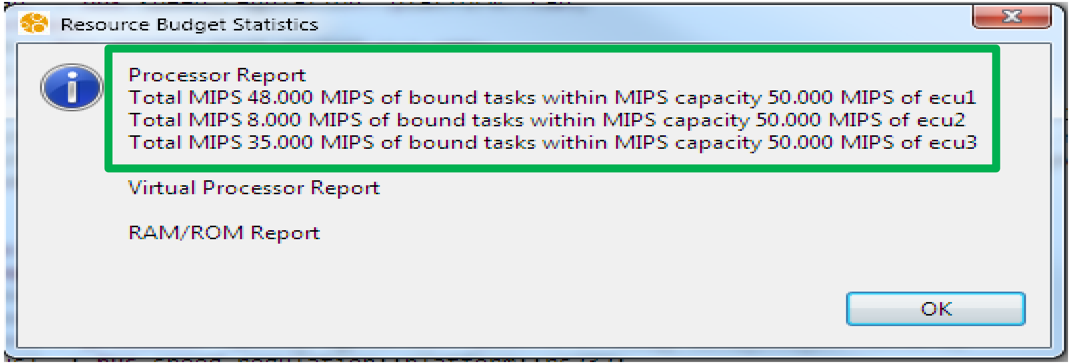


Resources Allocation Analysis, results

Architecture Alternative 1



Architecture Alternative 2



Safety Analyses Overview

Functional Hazard Analysis (FHA)

Failures inventory with description, classification, etc.

Fault-Tree Analysis (FTA)

Dependencies between errors event and failure modes

Fault-Impact Analysis

Error propagations from an error source to impacted component

Need to combine analyses

Connect results to see impact on critical components

Safety Analysis, FHA, results

Architecture Alternative 1: 15 errors contributors

Architecture Alternative 2: 17 errors contributors

Difference stems from additional platform components (ecu)

Have to consider criticality of fault impacts

Safety Analysis, FTA results

Architecture Alternative 1: 15 errors contributors

Architecture Alternative 2: 17 errors contributors

Difference stems from additional platform components (ecu)

Have to consider criticality of fault impacts

Safety Analysis, Fault Impact, results

Architecture Alternative 1 & 2: 443 error paths

Use the same paths

The additional ECU in alternative 2 covers path from ecu2 in Alternative 1

Impact on components criticality

Defect on the additional bus in Architecture 2 impact low-critical functions

Isolate defect from low-critical functions to affect high-critical

Analysis Summary

	Architecture 1	Architecture 2
Latency	✓	✗
Resources Budgets	✗	✓
Safety	✗	✓
Cost	✓	✗

What is the *“best”* architecture?

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Conclusions

Safety-Critical Systems Development issues is not a fatality

- Late detection of errors is no longer possible
- Need for new methods and tools

AADL supports Architecture Study and Reasoning

- Evaluate quality among several architectures
- Ease decision making between different architecture variations
- Analysis of Architectural change on the whole system

User-friendly and open-source workbench

- Graphical Notation
- Interface with other Open-Source Tools

Useful Resources

AADL wiki – http://www.aadl.info/wiki

Model-Based Engineering with AADL book

SEI blog post series http://blog.sei.cmu.edu

Mailing-List
see. https://wiki.sei.cmu.edu/aadl/index.php/Mailing_List

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