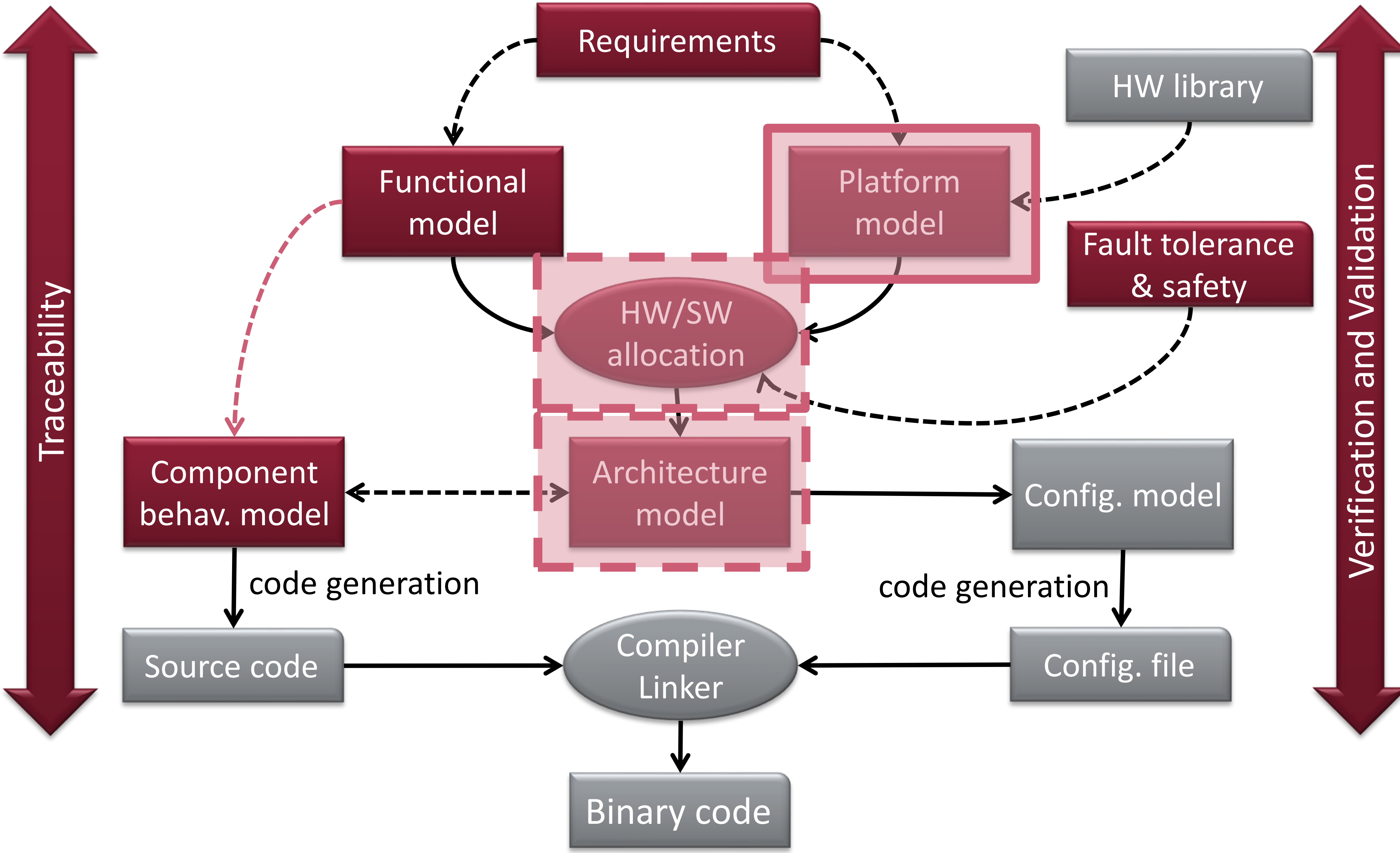
Platform modeling and allocation

Systems Engineering BSc Course

Budapest University of Technology and Economics
Department of Measurement and Information Systems

Platform-based systems design



Learning Objectives

Platform models

Addressing non-functional requirements in the platform model
Addressing constraints coming from the runtime platform like computation and communication resources

Allocation

Understanding the concept of allocation
Identify the basic design decisions made during allocation (resource allocation., scheduling, communication allocation)

Case studies

- See examples of allocation information from different domains
- Analyze extra-functional properties of the integrated allocation model

Why platform models are needed

Runtime platform

- Systems provide functions
- Functions are defined using
  - Functional models
  - Component behavior models
- How to realize these functions?

Runtime platform

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- How to realize these functions? → in Software!

Runtime platform

- Systems provide functions

- Functions are defined using
  - Functional models
  - Component behavior models

- How to realize these functions? → in Software!
  - Maybe in hardware? (e.g., sensors, GPU, FPGA, etc.)
  - What will execute our software functions?
  - How will they be able to communicate

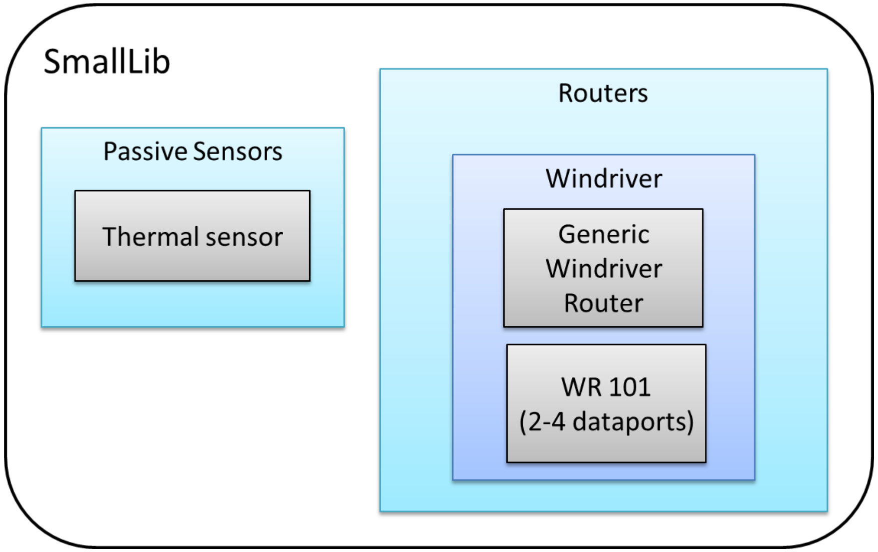
Platform model

- The platform model specifies the physical building blocks of the execution platform
  - the execution resources
    - memory, CPU, etc.
  - the available communication resources
    - Network interfaces, routers, etc.
  - the properties of the used HW elements
    - Weight
    - Availability
    - Size
    - etc.

Defining the platform model I.

- Resource capturing phase
  - Specification of reusable hardware entities
    - Coming from HW libraries/technical dictionaries
    - Defined by HW designers within the project

    → atomic hardware units of the execution platform
      - Embedded systems: Processor, Communication controller
      - Define hardware properties

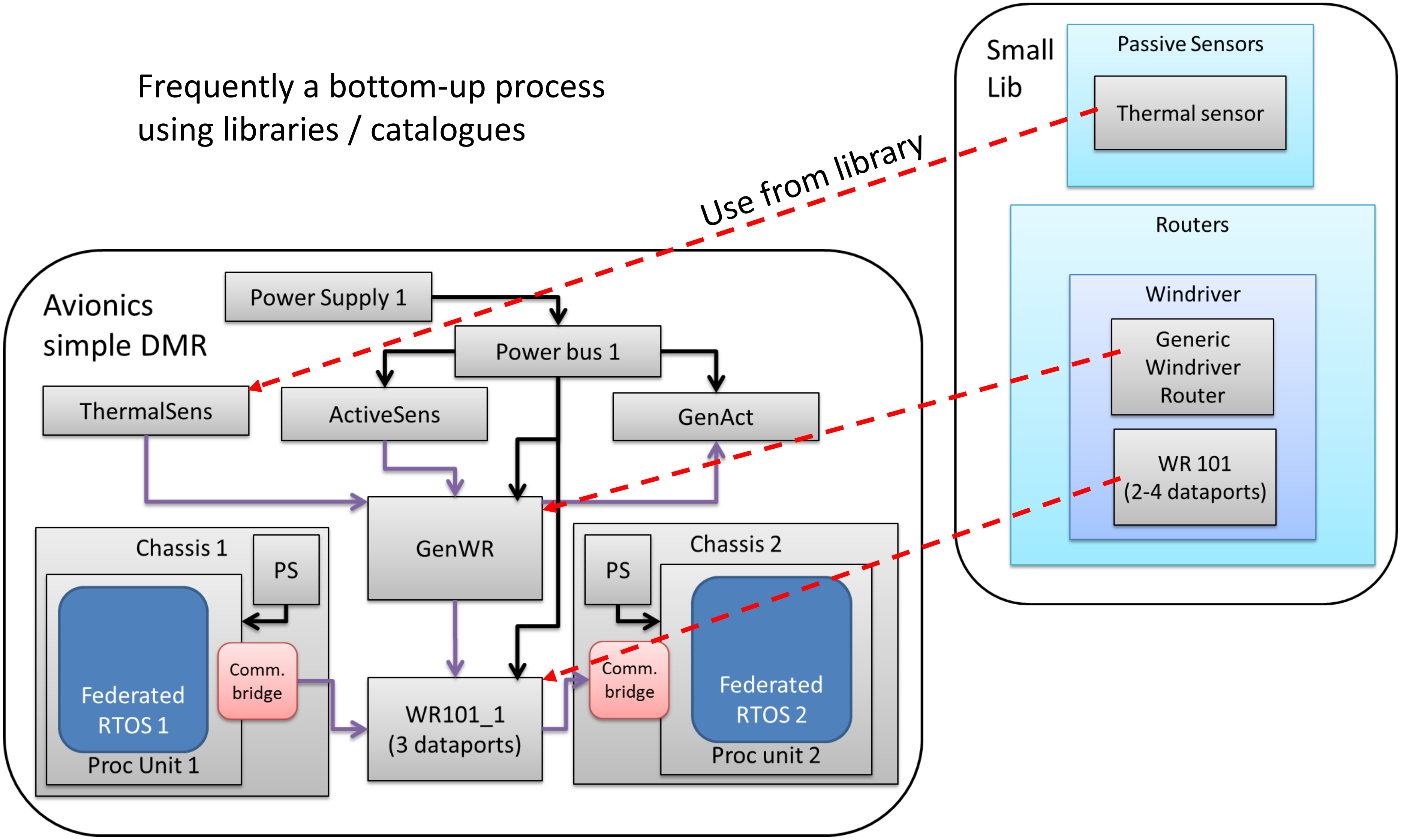


Defining the platform model II.

- Platform composition phase
  - (Already available HW design → only modifications)
  - Definition from bottom-up based on the atomic building blocks
- Similar modeling task as the functional component definition BUT
  - Connecting blocks == physical linkage
  - Part-whole relationship == physical containment
  - Physical HW properties are needed to be taken into consideration
    - Size, weight, number of ports, etc.

Defining the platform model II.

Frequently a bottom-up process using libraries / catalogues

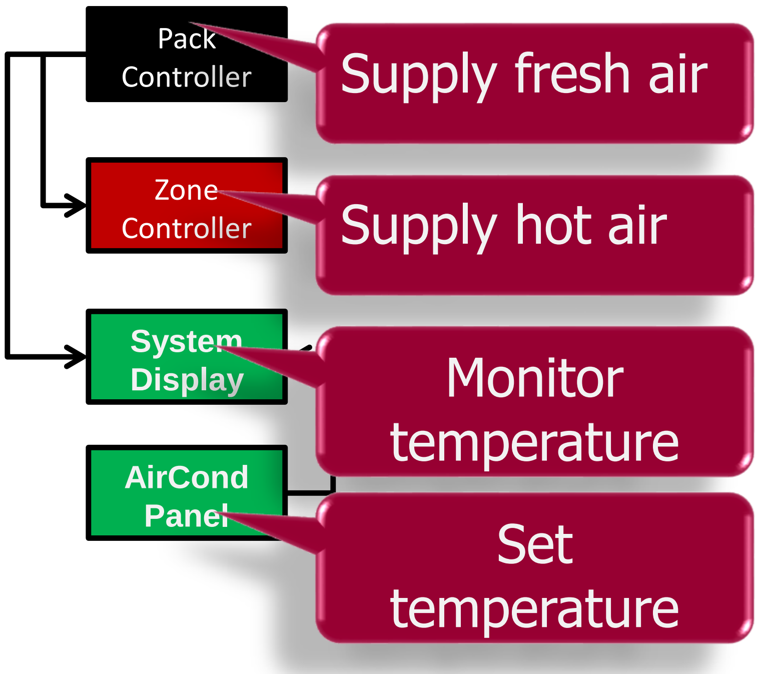


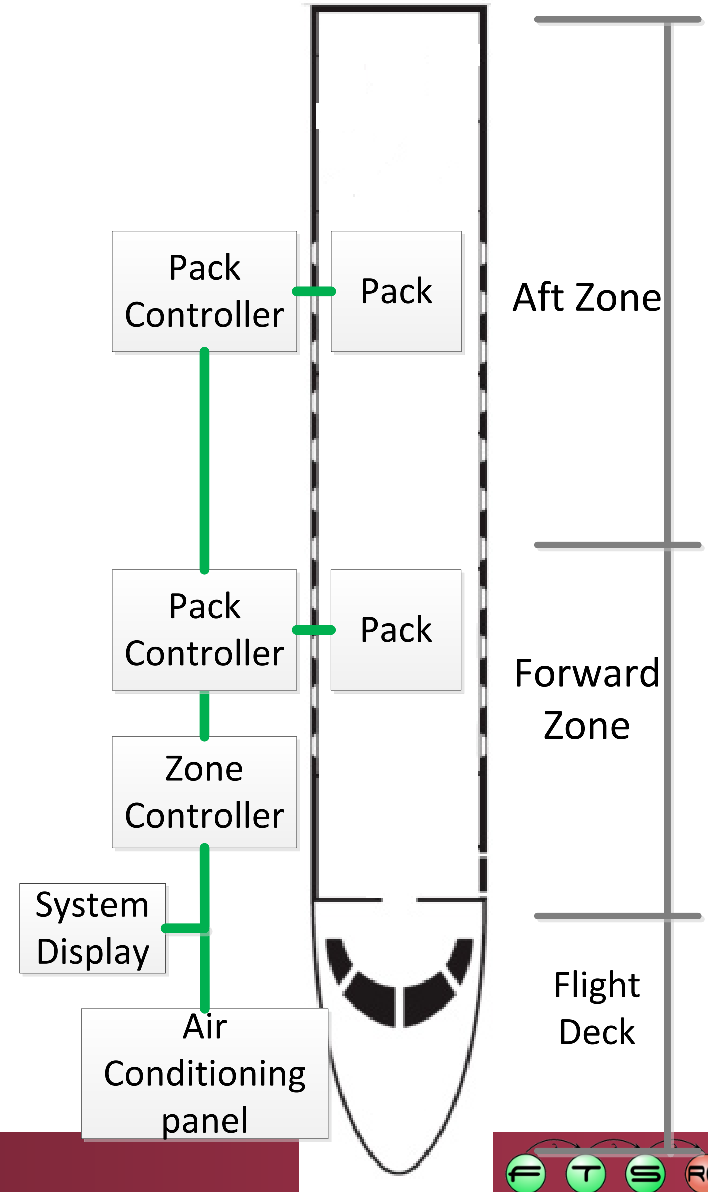
Functions to Platform allocation

Usually HW-SW allocation

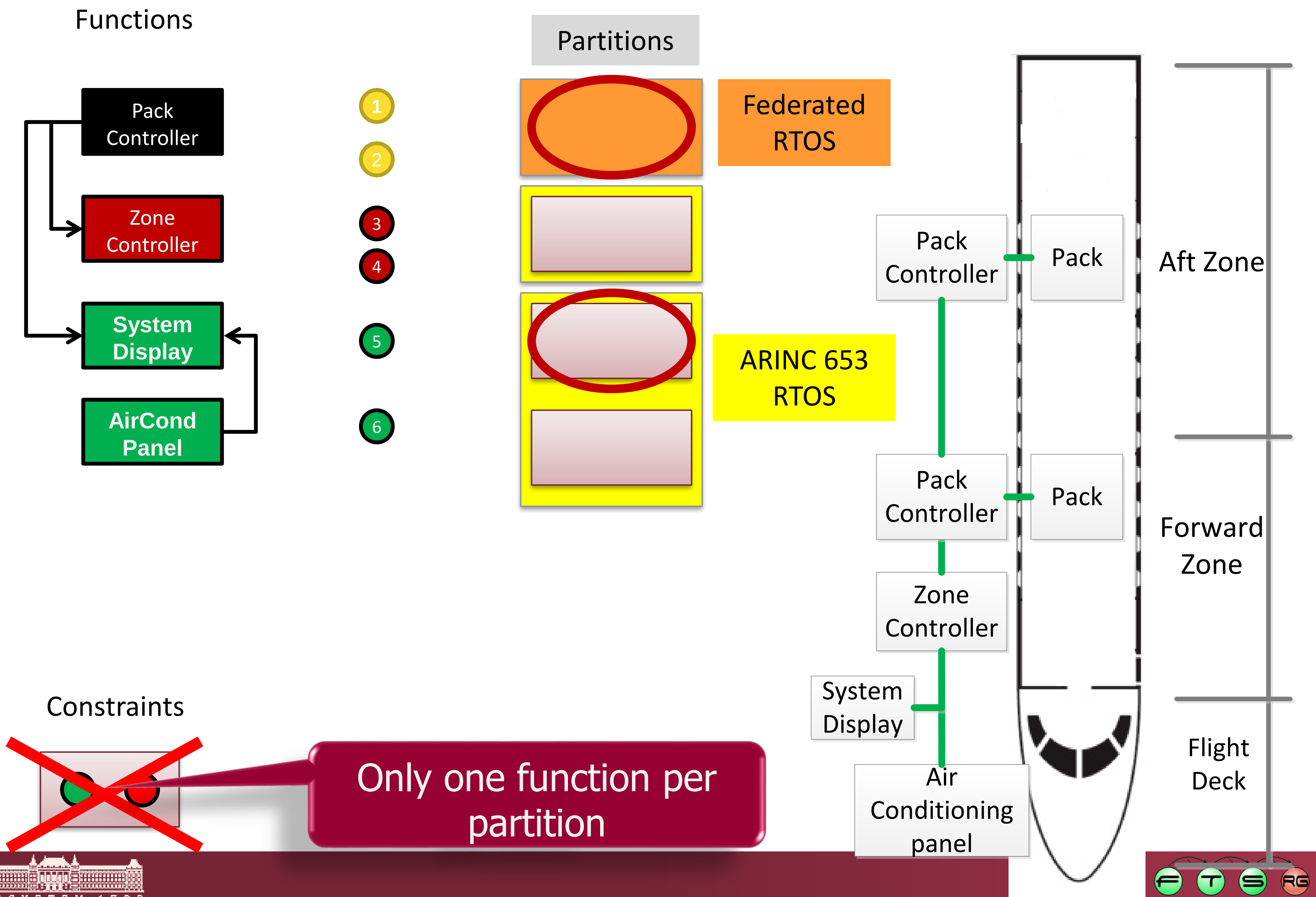
Allocation example

Functions

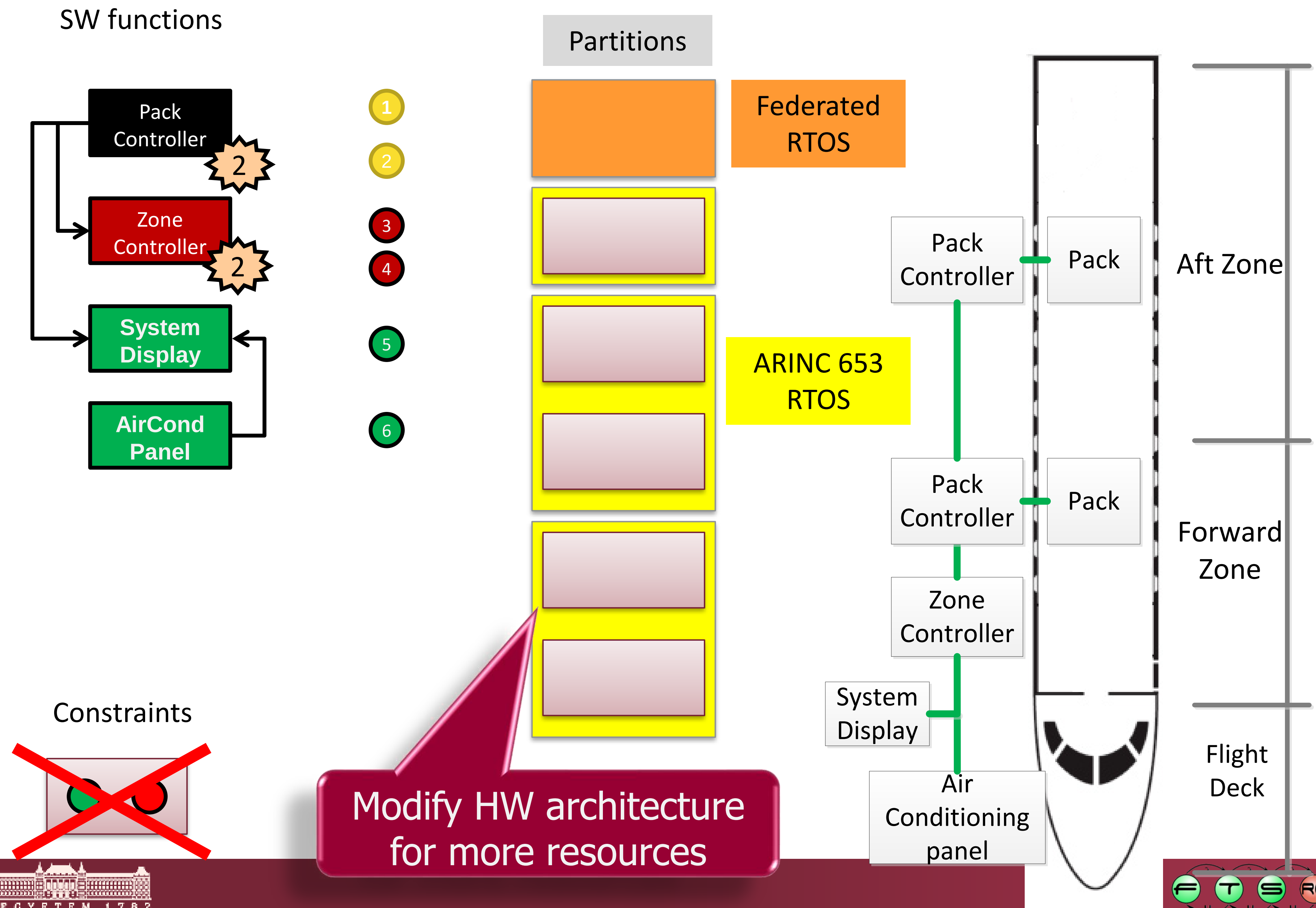




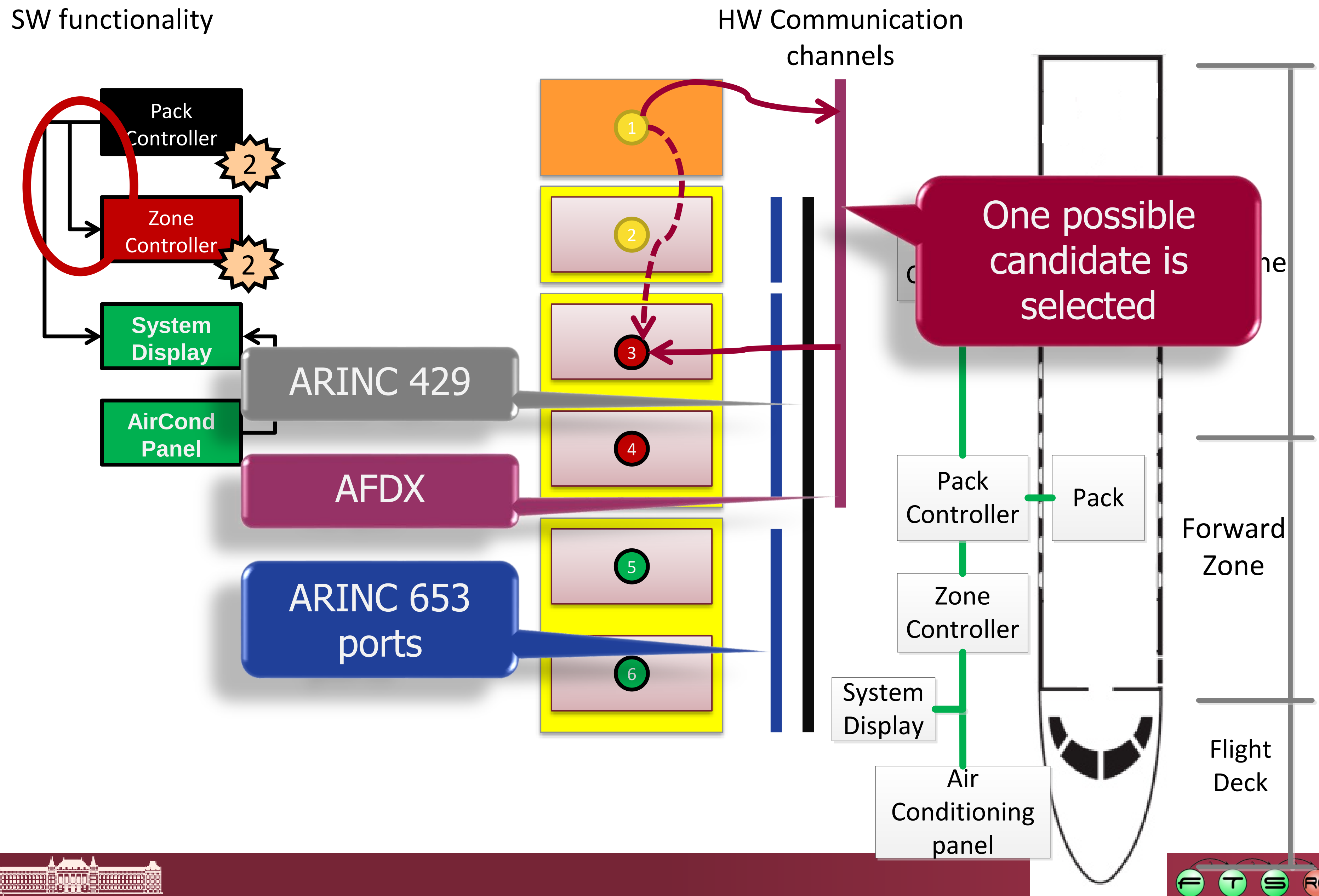
Allocation example – functions to partitions



Allocation example – functions to partitions



Allocation example – communication channels



Allocation

- **Input:**
  - Functional model + platform model
  - Additional non-functional constraints
- **Output:**
  - System Architecture

- The *System Architecture* defines for each instance of a Function
  - *where and when to execute*
  - *when to communicate*
  - *and on which bus*

Where and when to execute

- Allocate the functions to their designated execution resource
  - Processor, GPU, server, node, etc.
- Schedule the execution of functions
  - Based on their required execution window
    - **Major driver of the allocation process**
- Constraints (usually) taken into consideration

- Platform (HW)
  - Available memory
  - CPU performance
  - Redundancy

- Functional (SW)
  - Memory required
  - Execution window required
  - Safety aspects
    - E.g., criticality levels

When to communicate and on which bus

- Allocate Function model level communication means to platform communication resources
  - Information flow to bus mapping
  - Data/message mapping to platform representation
  - Scheduling
    - Messages, buses, routers
    - **Major driver of the allocation process**
  - Constraints (usually) taken into consideration

- Platform (HW)
  - Connectivity
    - comm. architecture
    - Routing
    - Supported modes
  - Bandwidth & Speed
  - Precision
    - Data mapping
  - Redundancy
    - Independent paths

- Functional (SW)
  - Message properties
    - size
    - priority
  - Communication mode
    - 1-1, 1-n, n-n
  - Safety aspects
    - WCET

Additional aspects of the allocation

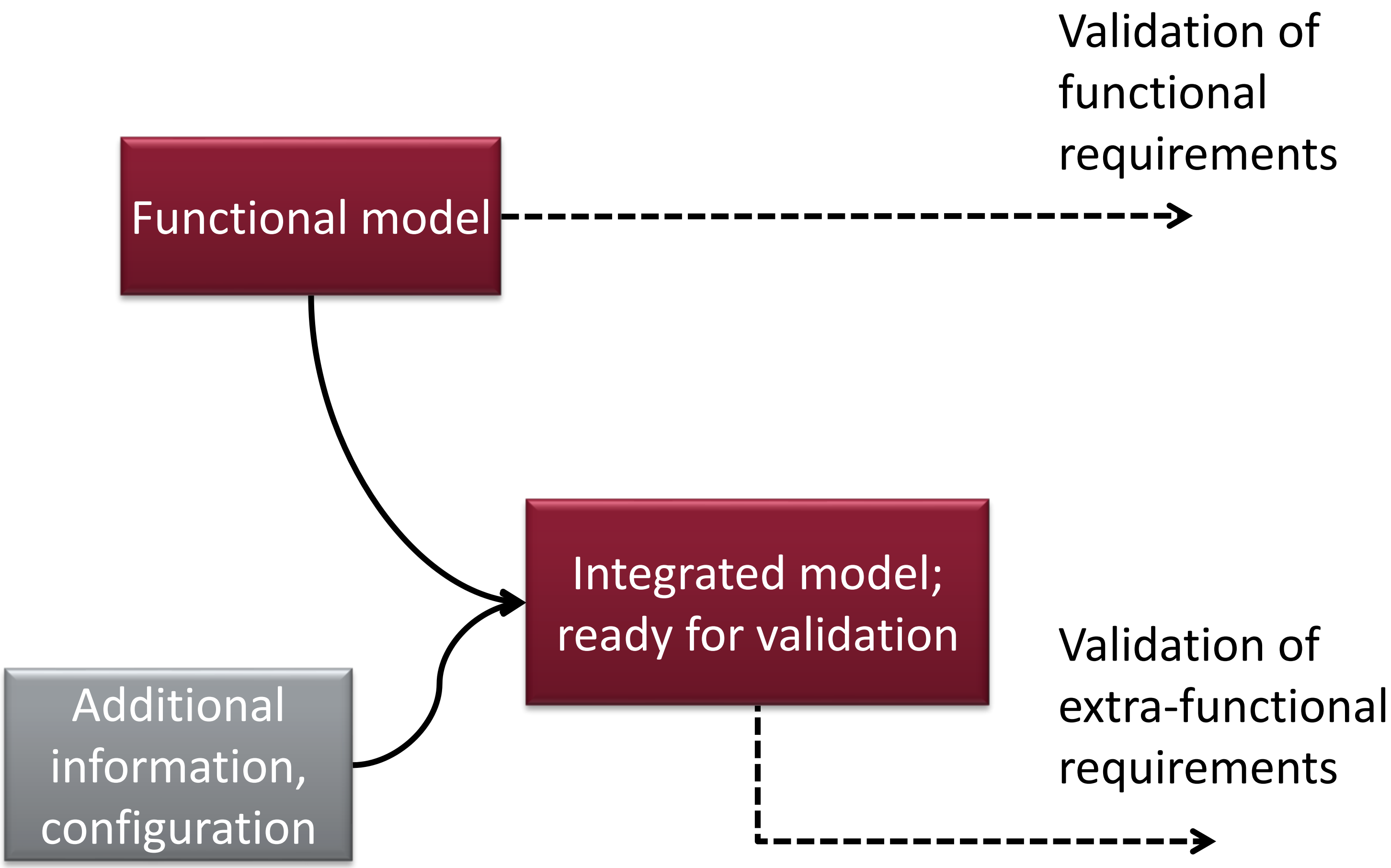
- Multi-level allocation
  - Complexity is handled on multiple abstraction-level → allocation is handled between all hierarchies
- Resulting System Architectures are used for validating system level functional/non-functional aspects
  - Timing requirements, safety requirements, etc.
  - Used methods: Static checks, simulations, HiL, etc.
- No perfect allocation → Multi-dimension optimization problem
  - Design Space Exploration

Extra-functional properties

System properties

- **Functional requirements →**
  Functional properties:
  functions that the system is able to perform
  - including how the system behaves while operating – also called operational properties.
- **Extra-functional requirements →**
  Extra-functional properties:
  - no bearing on the functionality of the system
  - describing instead attributes, constraints, metrics…
  - …regarding performance, design, quality of service, environmental impact, failure and recovery, etc.

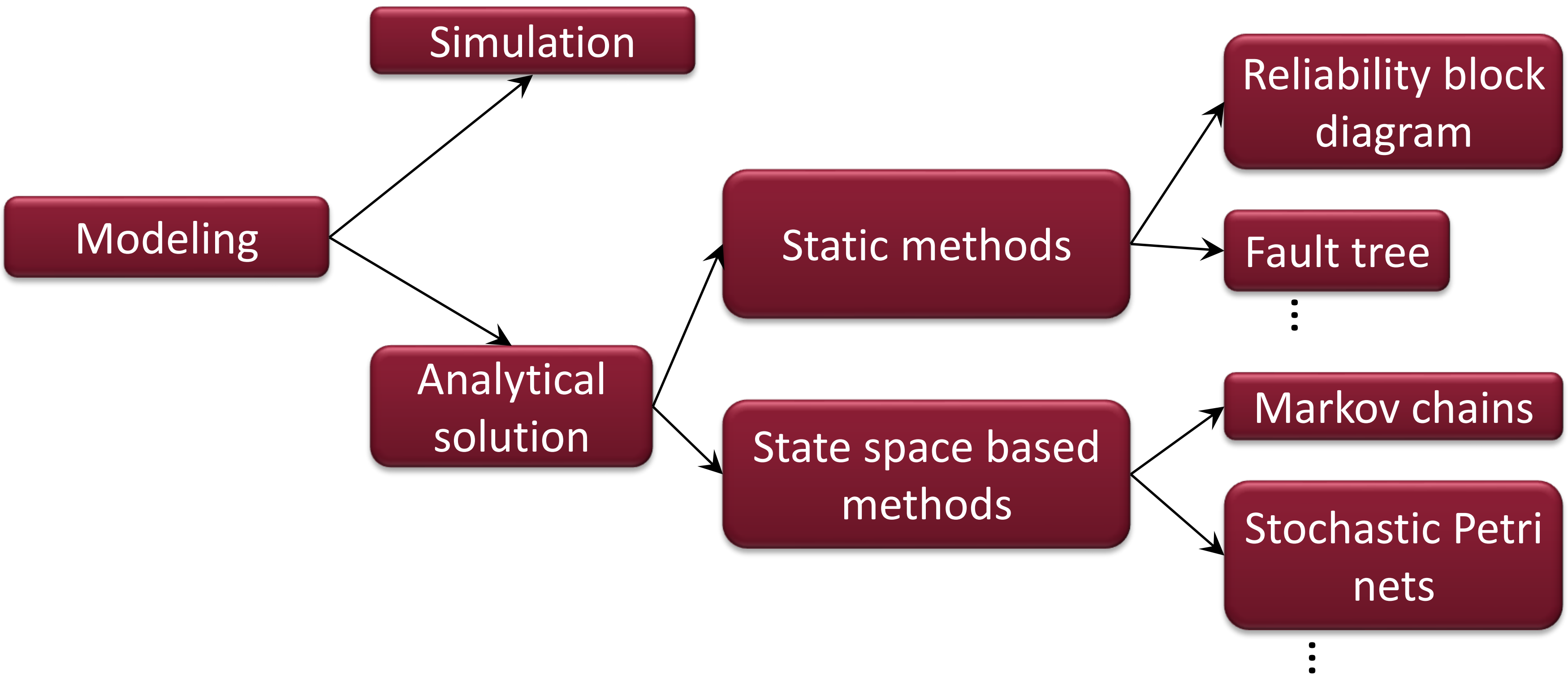
Approach


Validation of
functional
requirements
Functional model
Integrated model;
ready for validation
Validation of
extra-functional
requirements
Additional
information,
configuration

Example extra-functional properties

- **Dependability**: the ability to deliver service that can justifiably be *trusted*.
- Attributes of dependability:
  - **availability**: readiness for correct service.
  - **reliability**: continuity of correct service.
  - **safety**: absence of catastrophic consequences on the user(s) and the environment.
  - **integrity**: absence of improper system alterations.
  - **maintainability**: ability to undergo modifications and repairs
- **Performability**: If the performance of a computing system is "degradable" performance and reliability issues must be dealt with simultaneously in the process of evaluating system effectiveness. For this purpose, a unified measure, called "performability" is introduced and the foundations of performability modeling and evaluation are established.

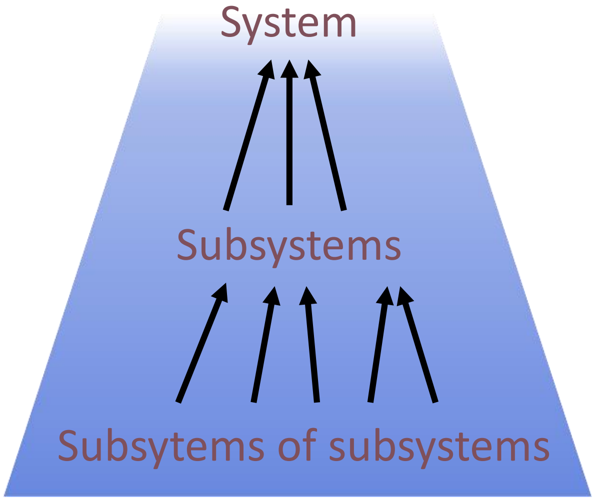
Example: dependability analysis taxonomy



Modeling platform in SysML

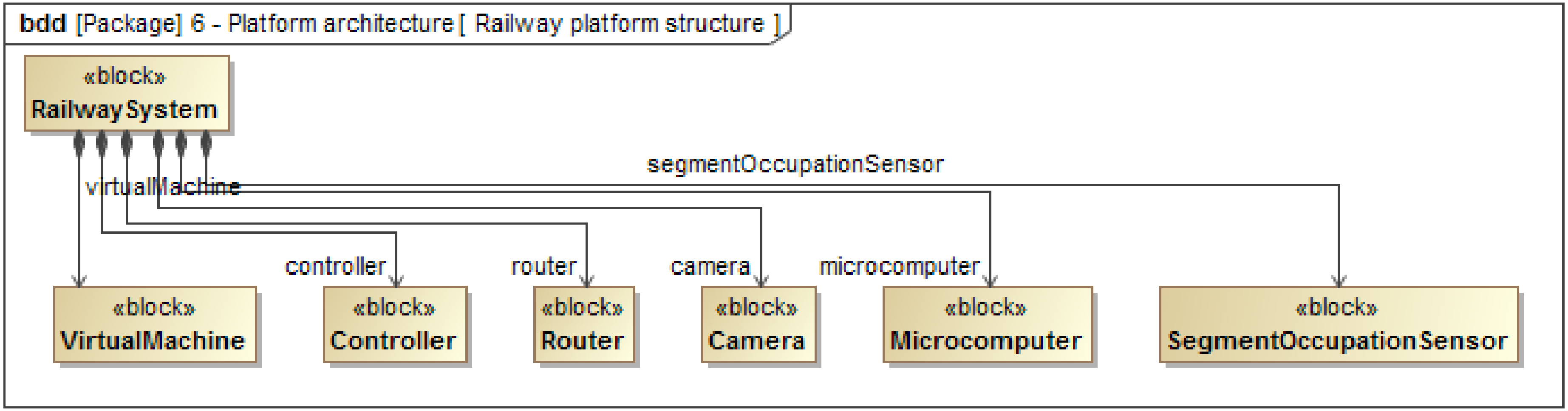
Platform modeling techniques

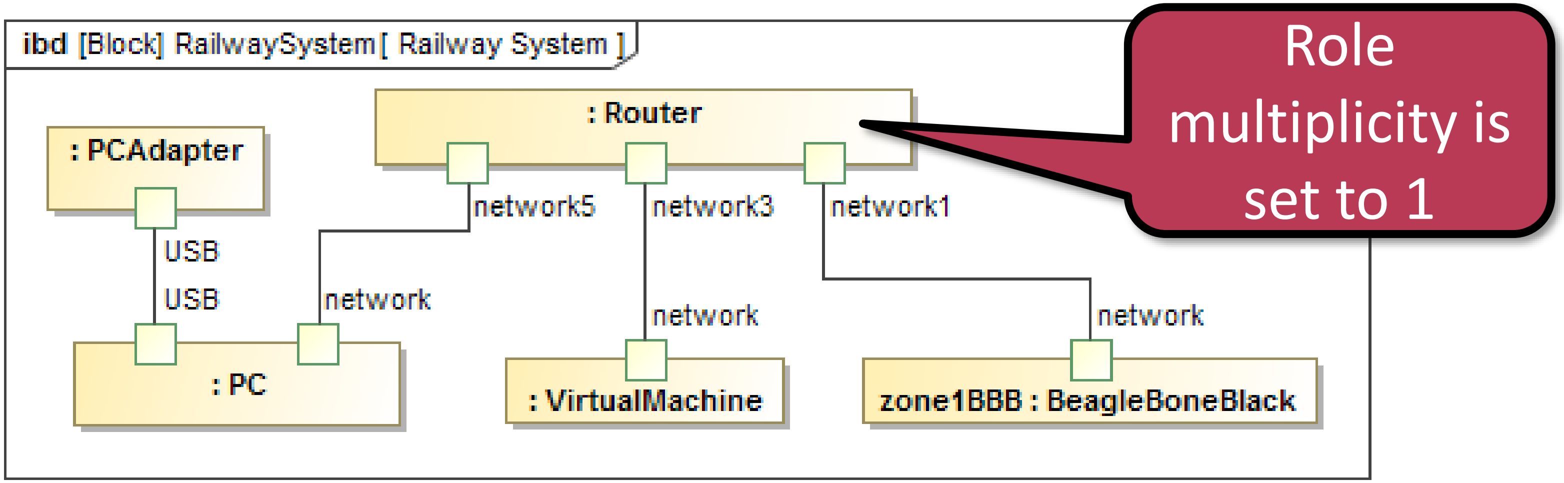
- Running platform is composed of existing (hardware) elements
- Approach: bottom-up using composition
  - ☺ Subsystems can be tested one-by-one
  - ☺ There are always some working parts during development
  - ☹ Exact roles of the subsystems are revealed late



Platform models in SysML

- Models composed of blocks → BDD, IBD are used.

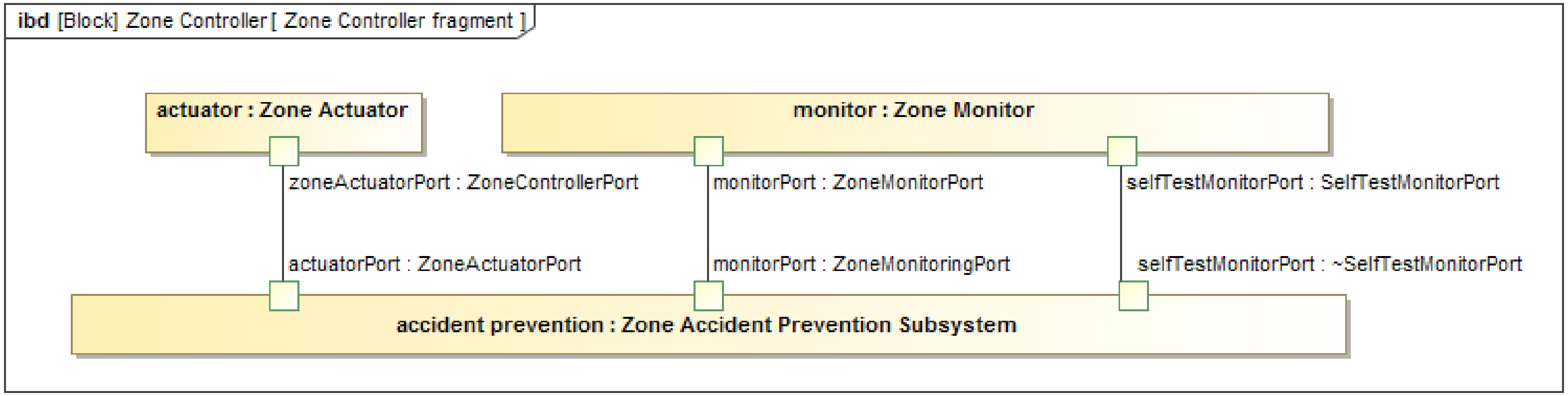


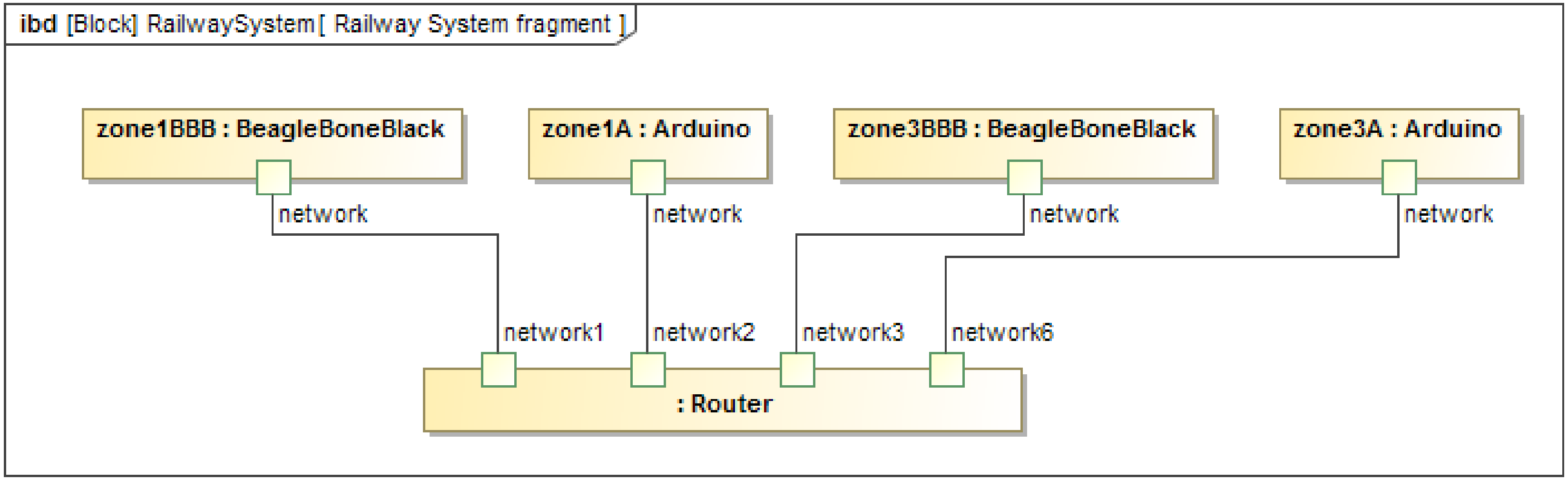


Modeling allocation in SysML

Allocation example: railway system

- Functional structure

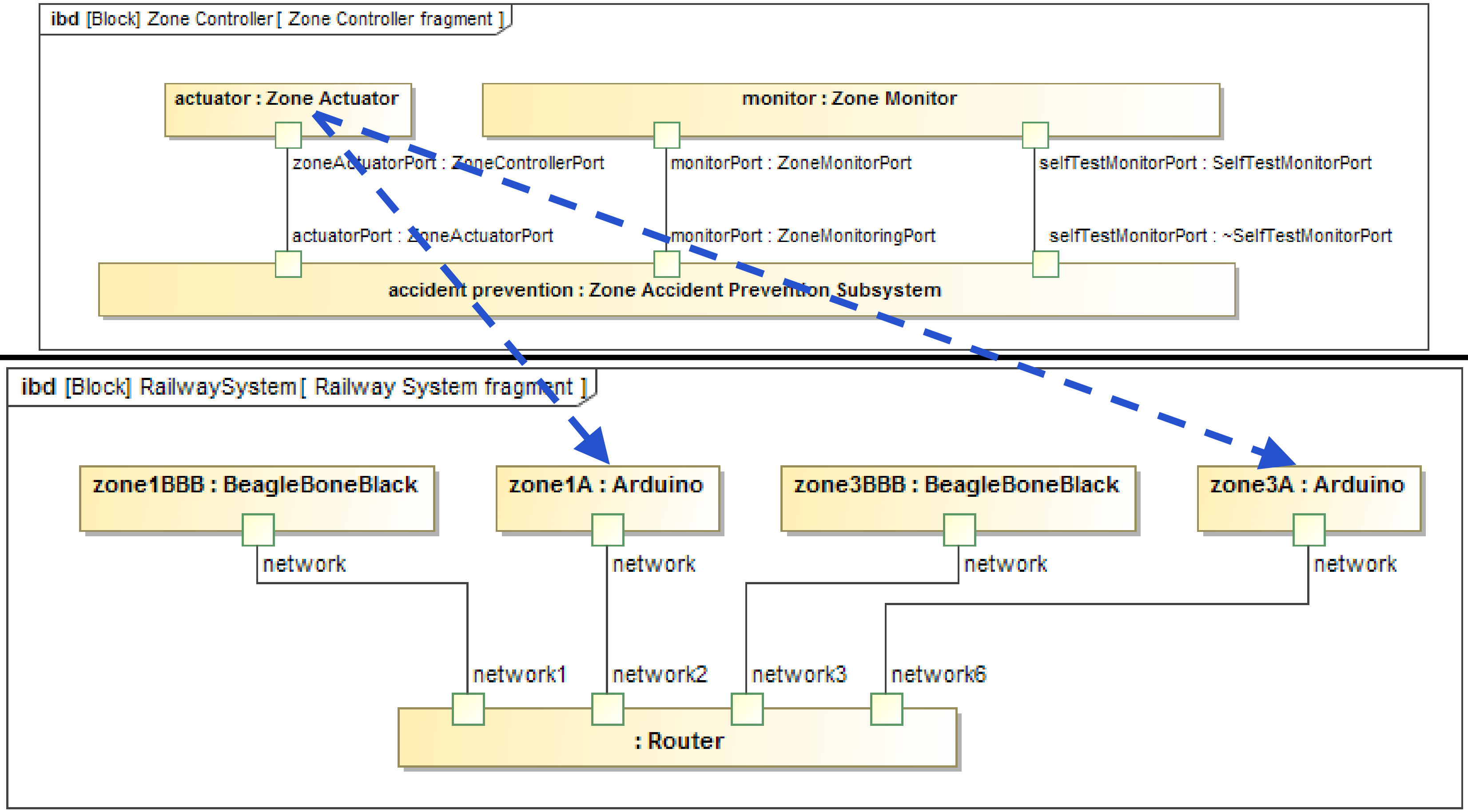




- Platform structure

Allocation example: railway system

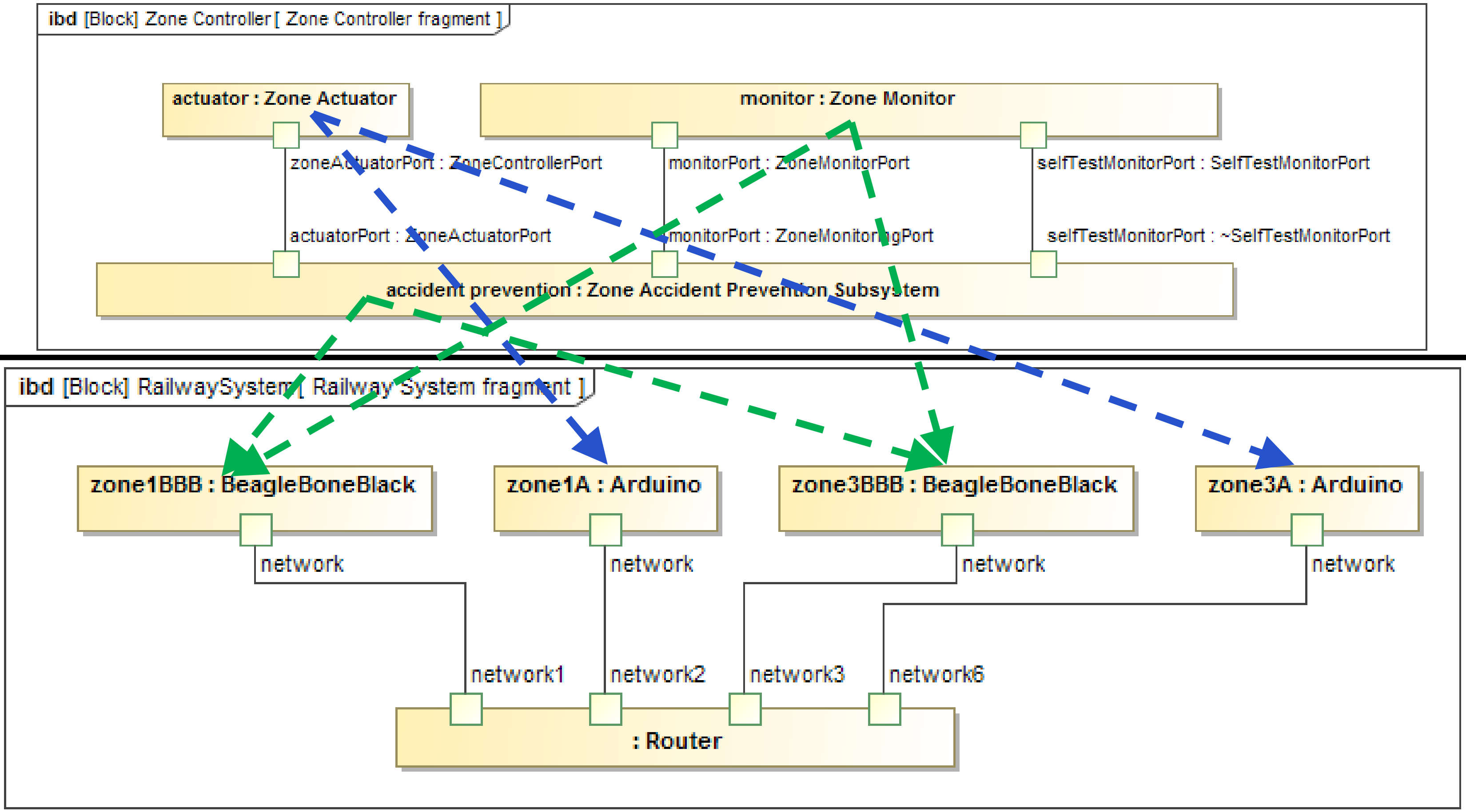
- Functional structure



- Platform structure

Allocation example: railway system

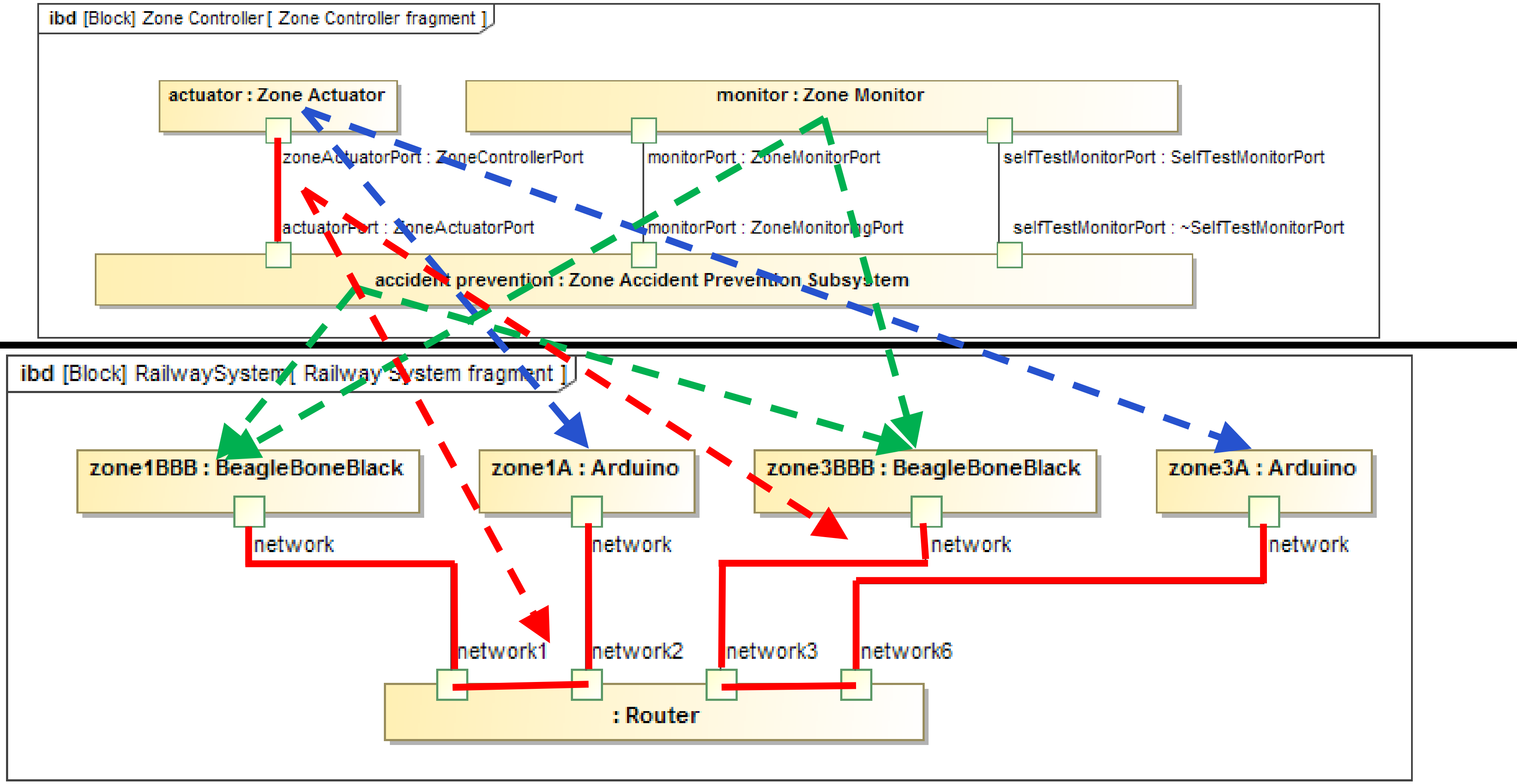
- Functional structure



- Platform structure

Allocation example: railway system

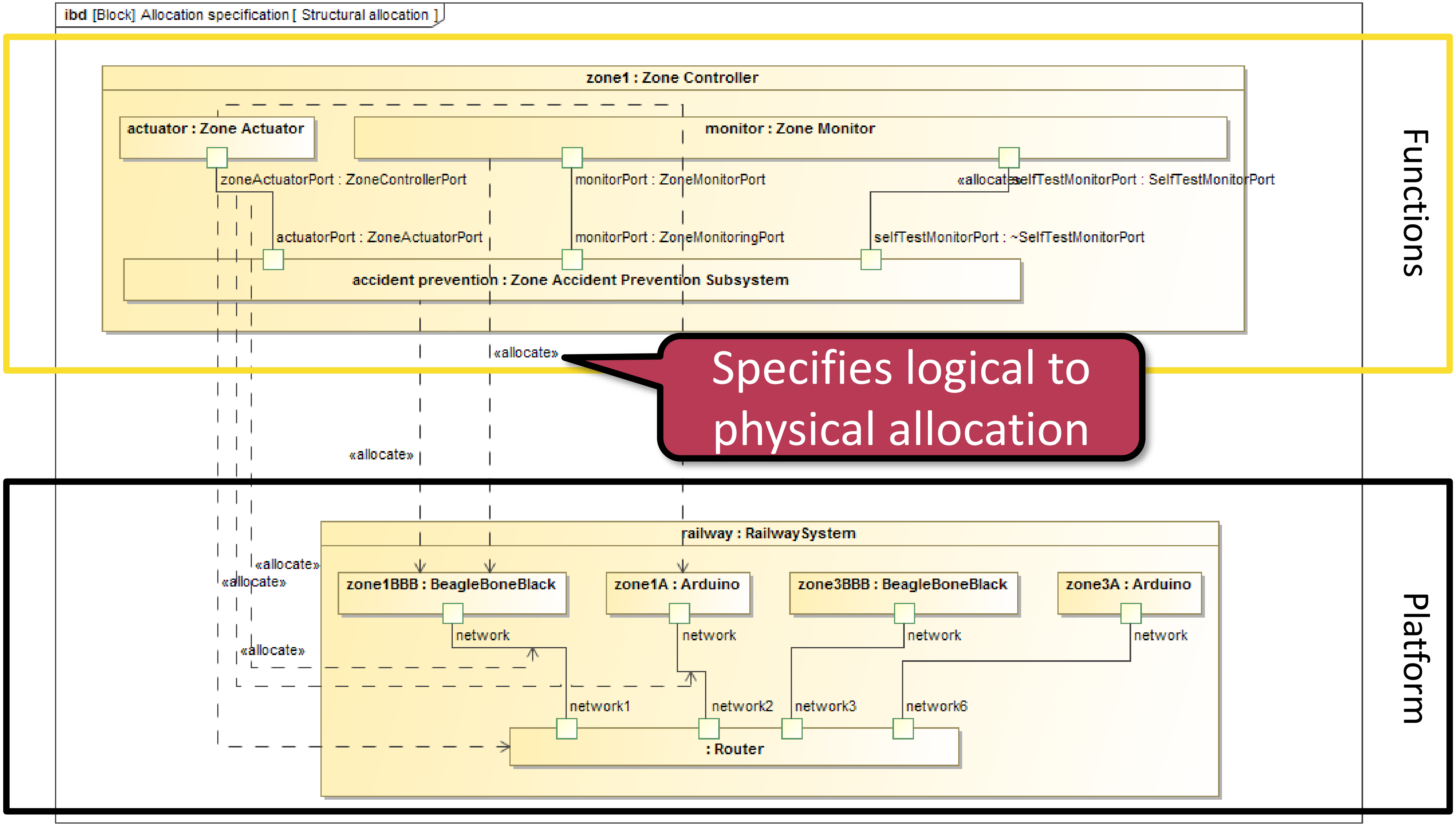
- Functional structure



- Platform structure

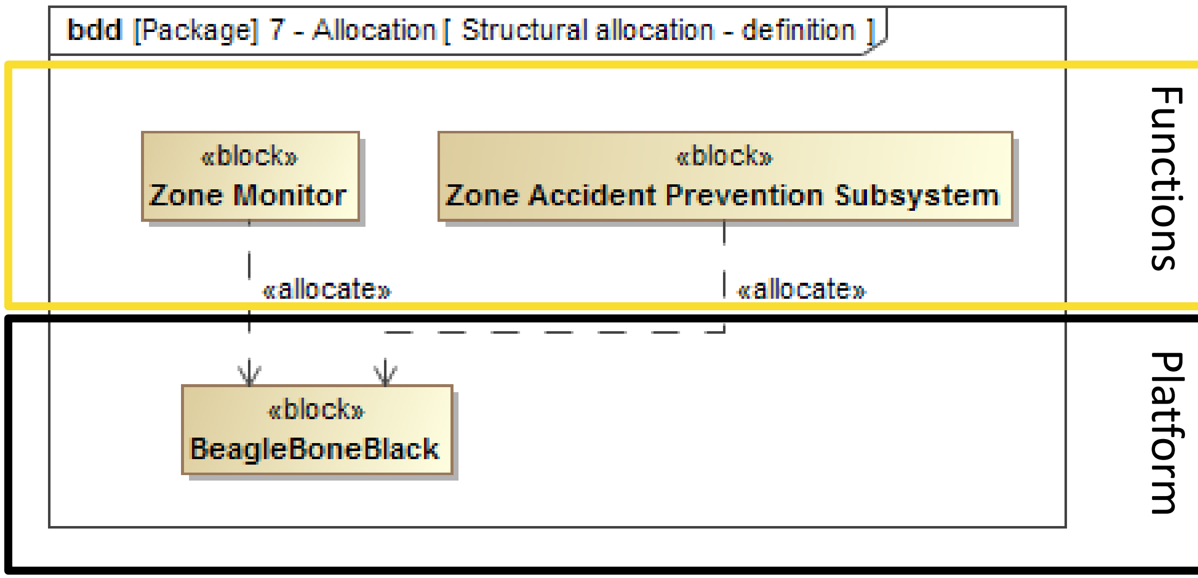
The allocation relation in SysML

- Structural allocation: usage



The allocation relation in SysML

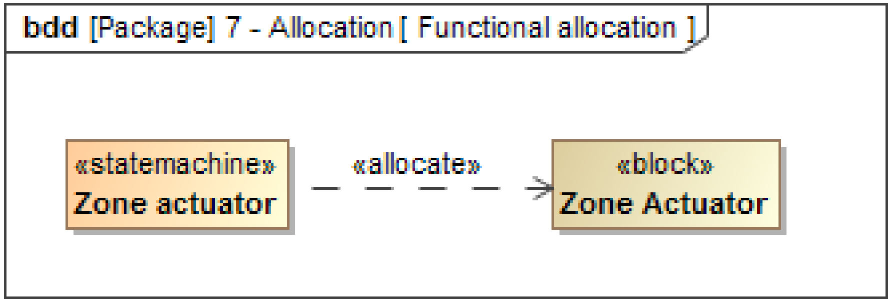
- Structural allocation: definition



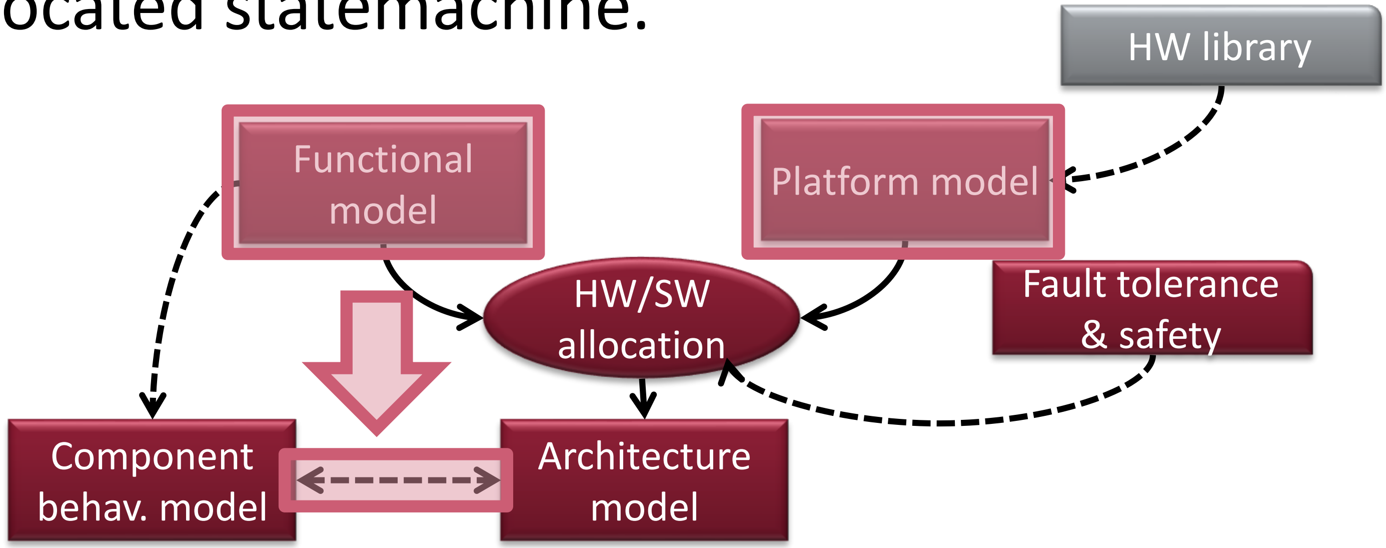
  - Wherever a BBB is used in the system, a zone monitor and an accident prevention subsystem is assumed to be allocated to it

The allocation relation in SysML

- Functional allocation: definition



  - A zone actuator behaves as it is described in the allocated statemachine.



SysML allocation matrix

Columns: functional elements

Rows: platform elements

	Zone Controller	+accident prevention : Zone Accident Prev...	+actuator : Zone Actuator	+monitor : Zone Monitor	+segmentActuatorPort : SegmentActuator...	+turnoutActuatorPort : TurnoutActuatorPort	+zoneMonitorPort : ZoneMonitorPort	Connector[actuatorPort - zoneActuatorPort]
RailwaySystem	↙							
: Router								↙
+zone1A : Arduino			↙		↙	↙		
+zone1BBB : BeagleBoneBlack		↙		↙			↙	
+zone3A : Arduino			↙		↙	↙		
+zone3BBB : BeagleBoneBlack		↙		↙			↙	
Connector[network - network3]								↙
Connector[network - network2]								↙
Connector[network - network1]								↙
Connector[network - network6]								↙

SysML allocation matrix

	Zone Controller	+accident prevention : Zone Accident Prev...	+actuator : Zone Actuator	+monitor : Zone Monitor	+segmentActuatorPort : SegmentActuator...	+turnoutActuatorPort : TurnoutActuatorPort	+zoneMonitorPort : ZoneMonitorPort	Connector[actuatorPort - zoneActuatorPort]
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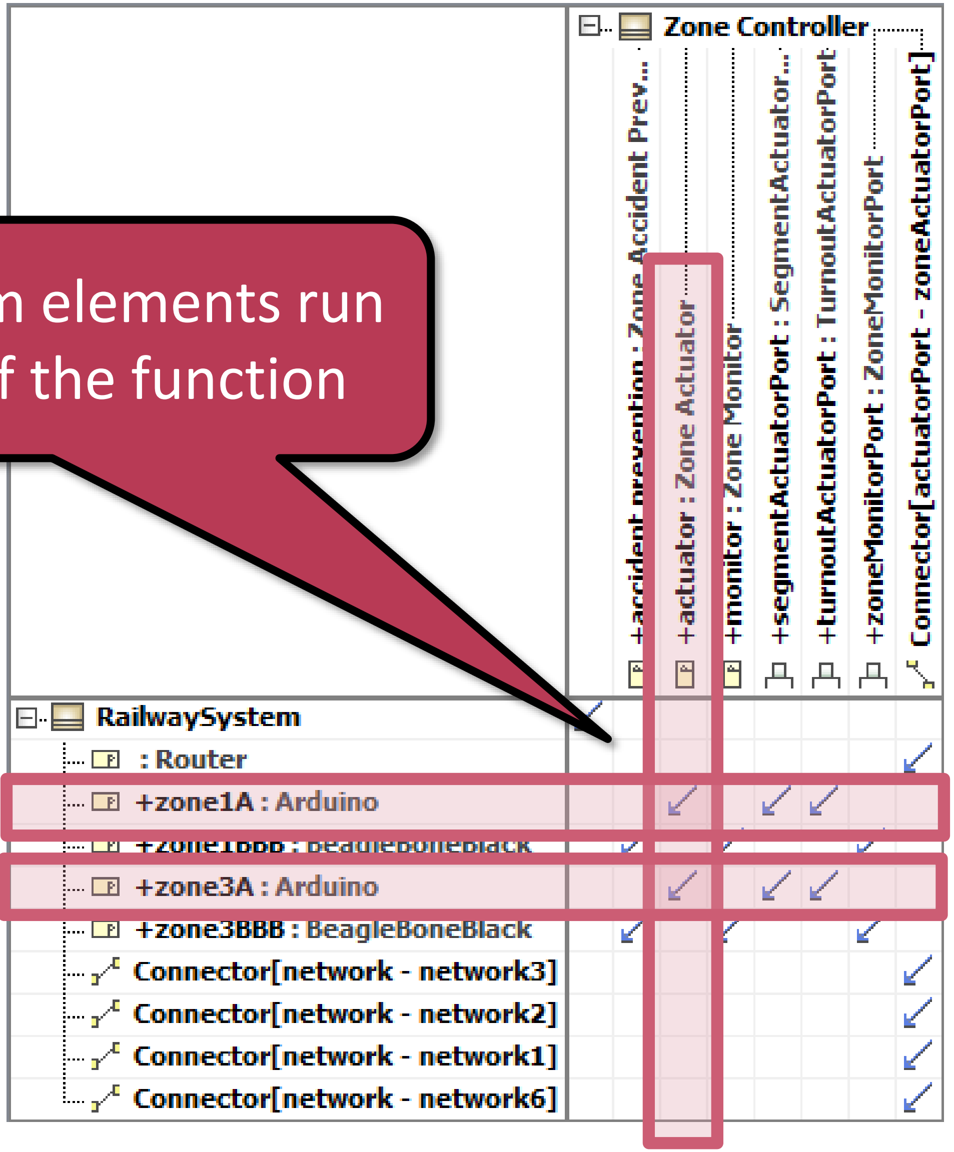
+zone3A : Arduino			↙		↙	↙		
+zone3BBB : BeagleBoneBlack		↙		↙			↙	
Connector[network - network3]								↙
Connector[network - network2]								↙
Connector[network - network1]								↙
Connector[network - network6]								↙

Arrow pointing downward:
function to platform allocation
(colum to row)

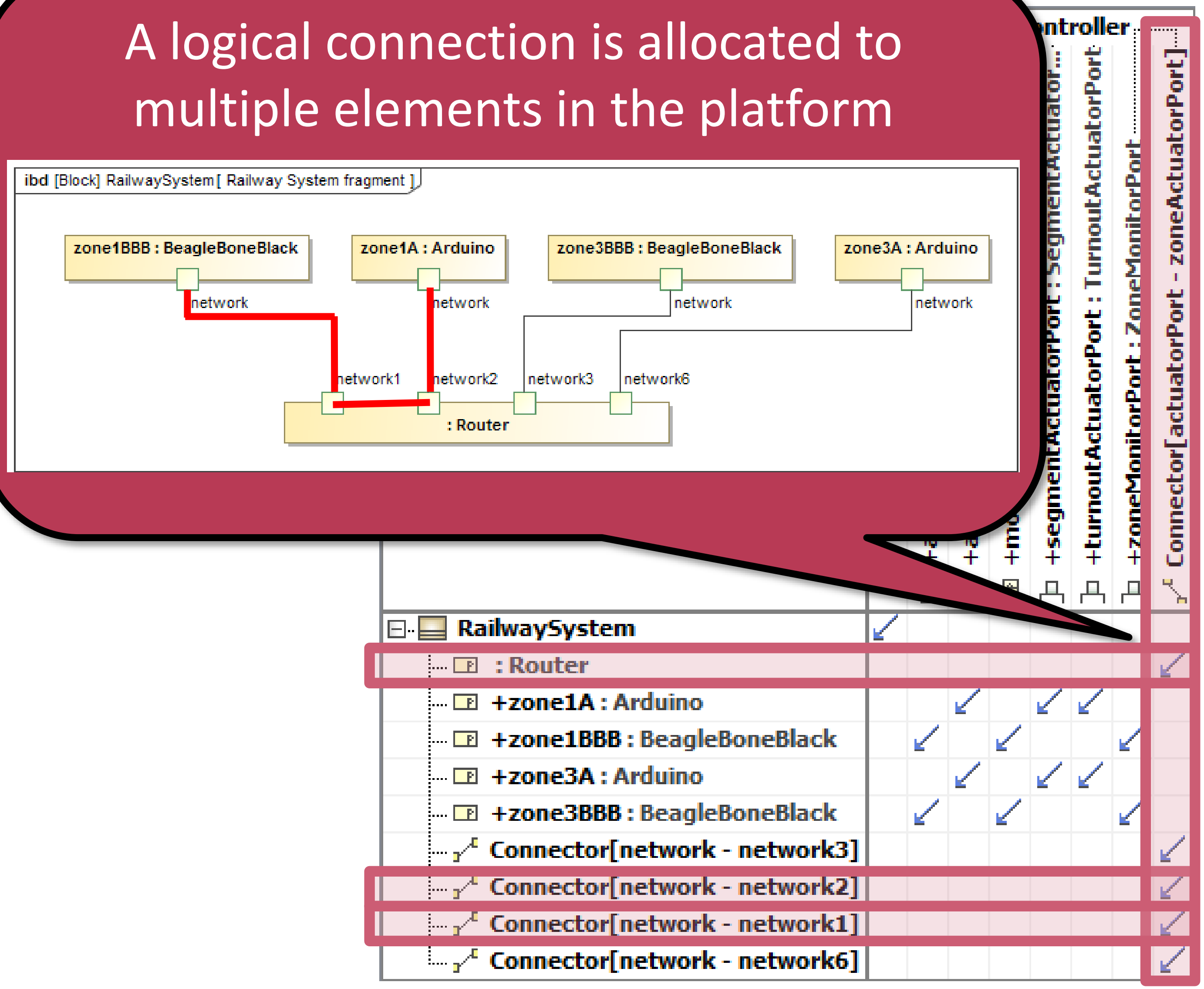
SysML allocation matrix

Multiple platform elements run the instances of the function



SysML allocation matrix

A logical connection is allocated to multiple elements in the platform



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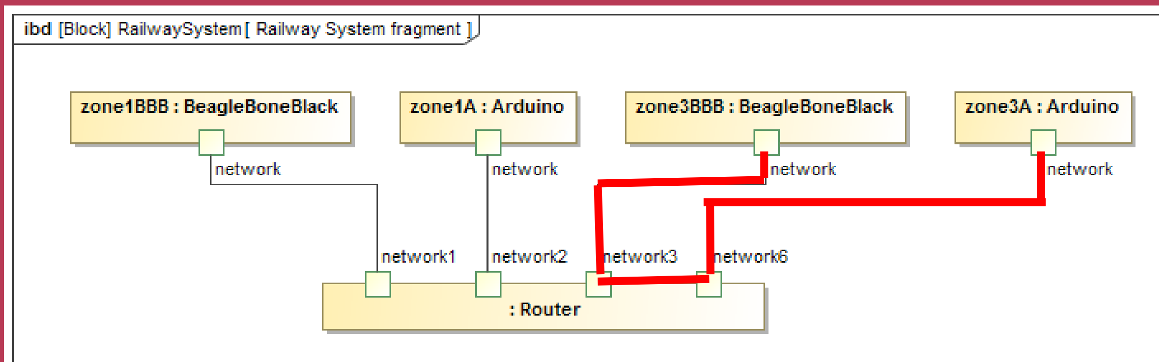
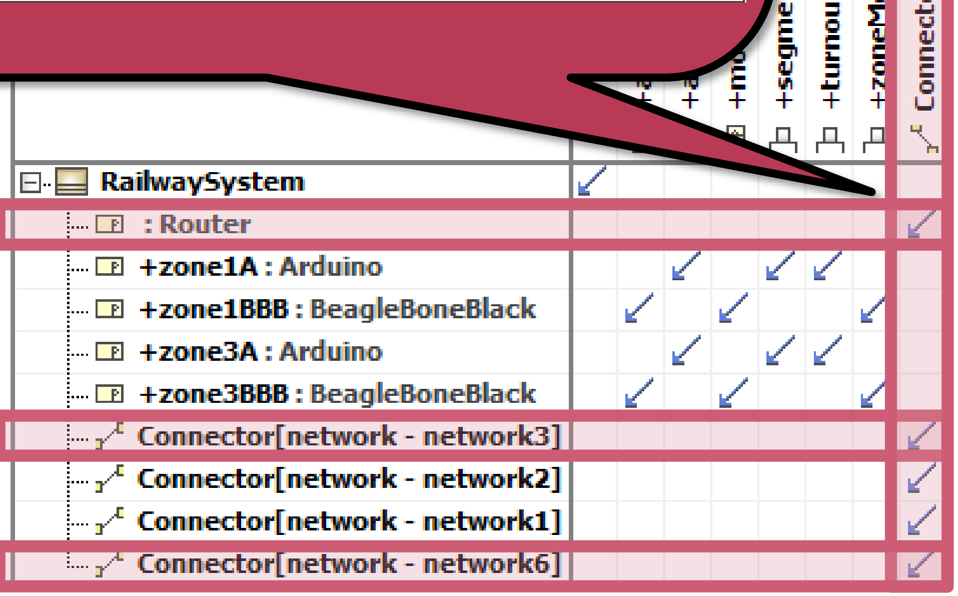




Allocation constraints

- Platform element capabilities
  - What kind of resources does the platform element have?
- Realization of connections
  - Are the connections between the functions supported by the platform?
- Standards and additional well-formedness rules
  - Such as „critical and non-critical functions shall not run on the same platform element".

Advantages of allocation matrices

- A function cannot be deployed to the same device twice.
- Allocation of the logical connections can be validated by examining endpoints and continuity of the corresponding platform connection.
- By examining the safety levels of the allocated functions row by row, critical and non-critical functions cannot be allocated to the same device.

Best practices / Goals

- Avoid single point of failures
- Fault tolerant design patterns
  - See lecture on *Safety-critical systems: Architecture*
- Cost efficiency
  - Weight
  - Price

Case Study

AUTOSAR

History

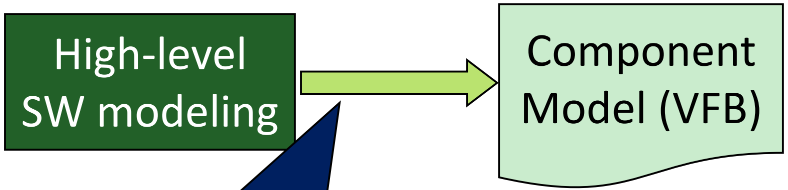
- AUTomotive Open System ARchitecture
- Started in 2002
- BMW, Bosch, Daimler, Conti, VW, + Siemens
- Industrial standardization group
  - Current standard version: 10-18 (end 2018)
- Members: OEMs, Tool vendors, Semiconductor manufacturers Europe-dominated
- Scope
  - Modeling and implementation of automotive systems
  - Distributed
  - Real-time operating system
  - String based interaction with HW and environment
- Out of scope
  - GUI, Java, internet connectivity, File systems, Entertainment systems, USB connectivity etc.

Key Concepts of AutoSAR

- A standard runtime architecture
  - component-oriented
  - layered
  - extensible
    - New functionalities
    - New components (component implementations)
  - all major interfaces standardized
  - Standardized Run Time Environment (RTE)
- A standard modeling and model interchange approach
  - follows the principles of model-driven design
  - supports the interchange of designs
  - supports the collaborative development
    - Between different developers,
    - Teams,
    - And even companies
- Conformance test framework
  - assuring the conformance to the standard
  - Still evolving – new in version 4.0

High-level design flow

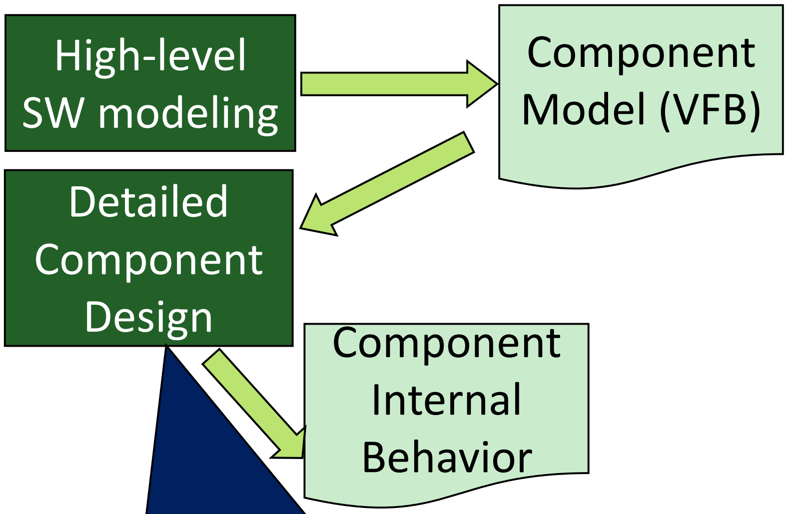
High-level design process



High-level software modeling

- Definition of
  - components
  - component ports
  - port interfaces
  - data types – logical
- Result
  - Virtual Functional Bus (VFB)-level software model

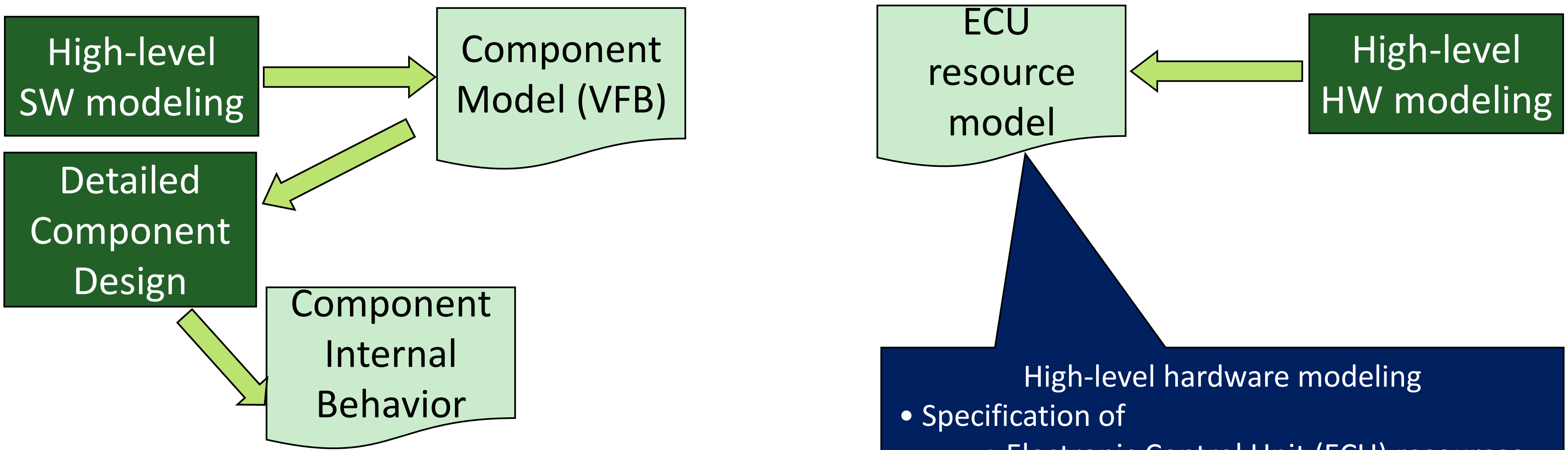
High-level design process



Detailed component design

- Specification of
  - component internal behavior
  - functional breakdown
  - implementation/use of ports
- Non-AutoSAR
  - specification of detailed behavior
  - any tool can be used
    - UML
    - Simulink
    - etc.
- Result
  - AutoSAR component internal behavior model
  - Non-AR: behavioral models/design

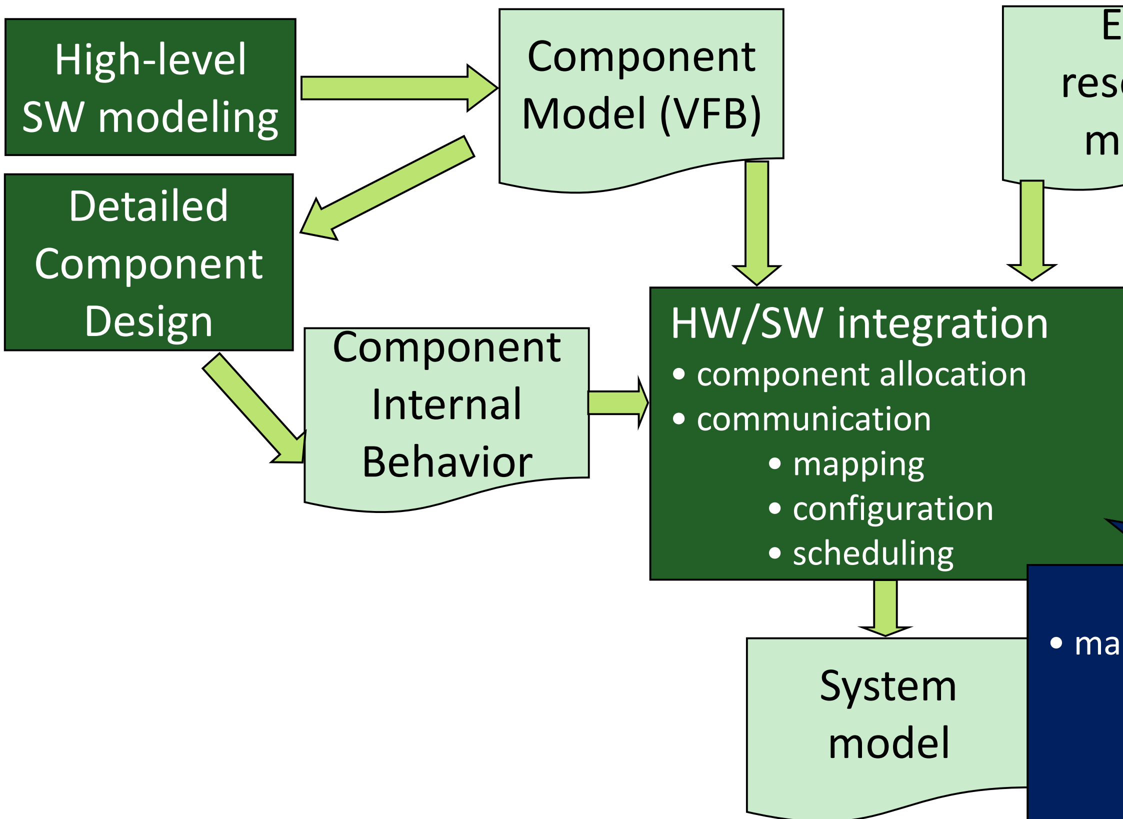
High-level design process



High-level hardware modeling

- Specification of
  - Electronic Control Unit (ECU) resources
    - CPU
    - memories
    - peripherals
    - communication hw
  - system topology
    - ECU instances
    - clusters
    - connections
- Result
  - ECU resource model – for all ECUs
  - System topology model

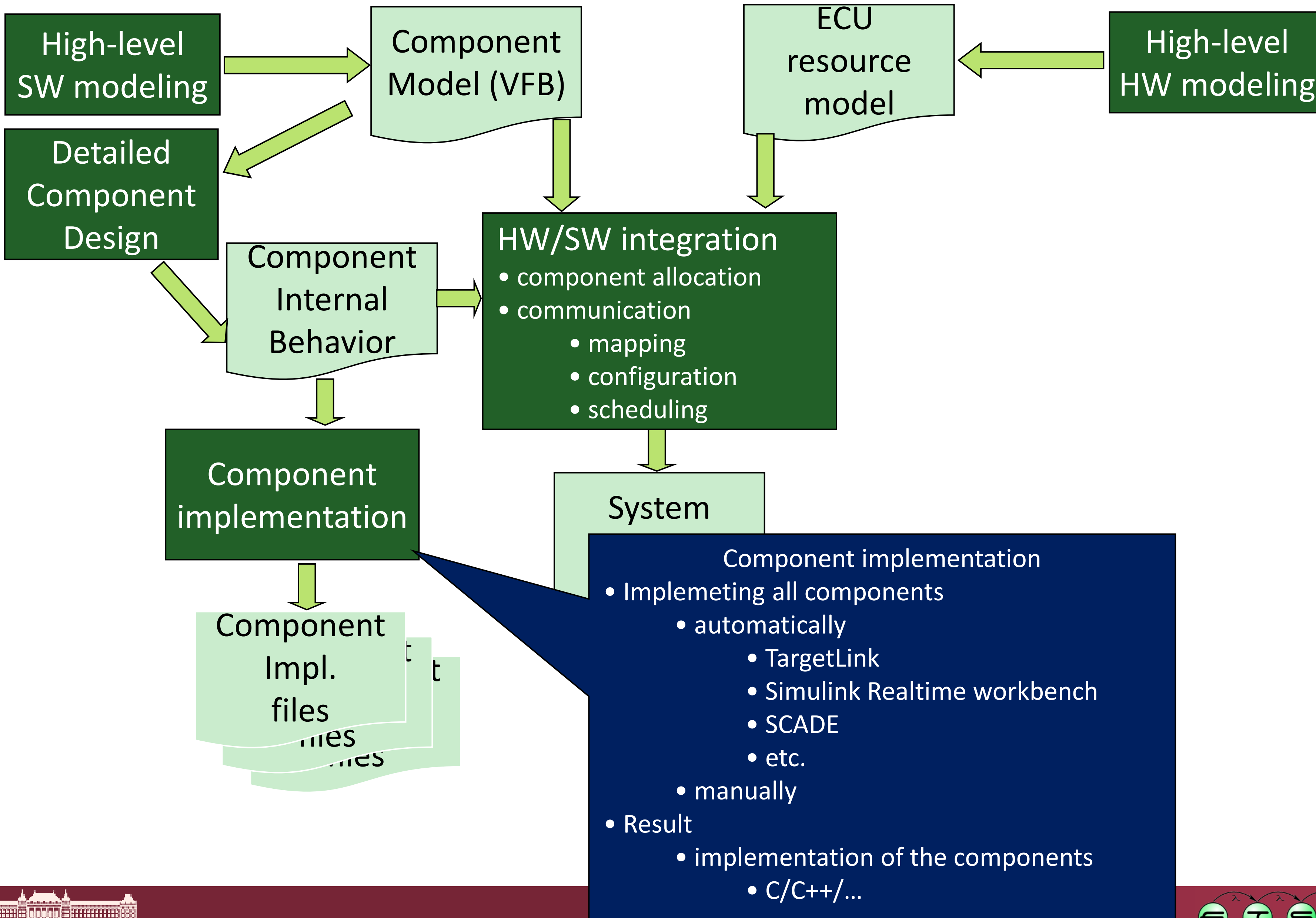
High-level design process



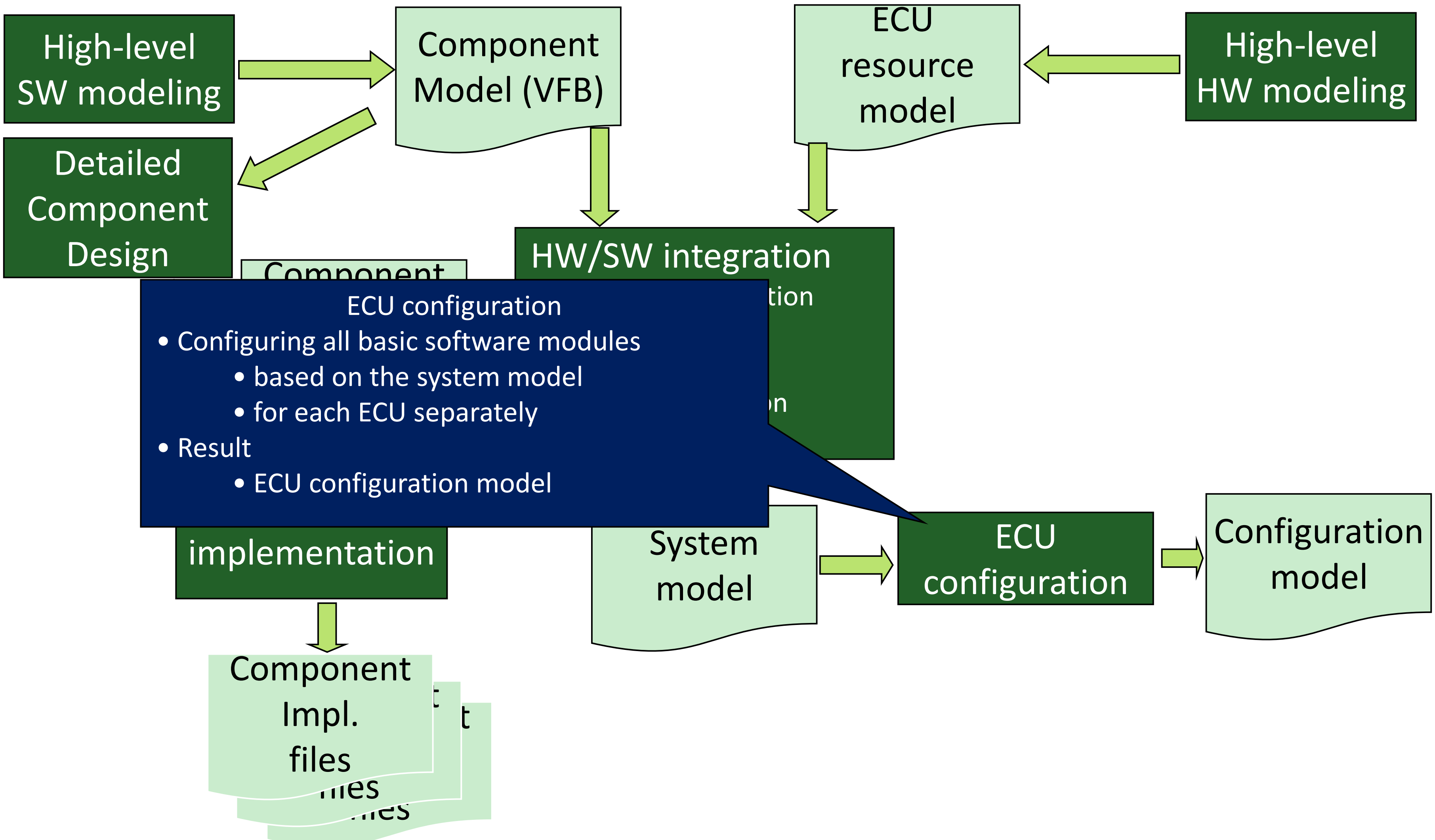
Hardware-software integration

- mapping
  - software component allocation
  - component implementation selection
  - data-element to signal mapping
    - inter-ECU communication
- communication configuration
  - signal to Protocol Data Unit (PDU) mapping
  - PDU to frame mapping
  - Signal, PDU, Frame triggering
  - Cluster and controller configuration
  - Frame scheduling (LIN, FlexRay)
- Result
  - System model describing the integrated HW/SW system

High-level design process



High-level design process



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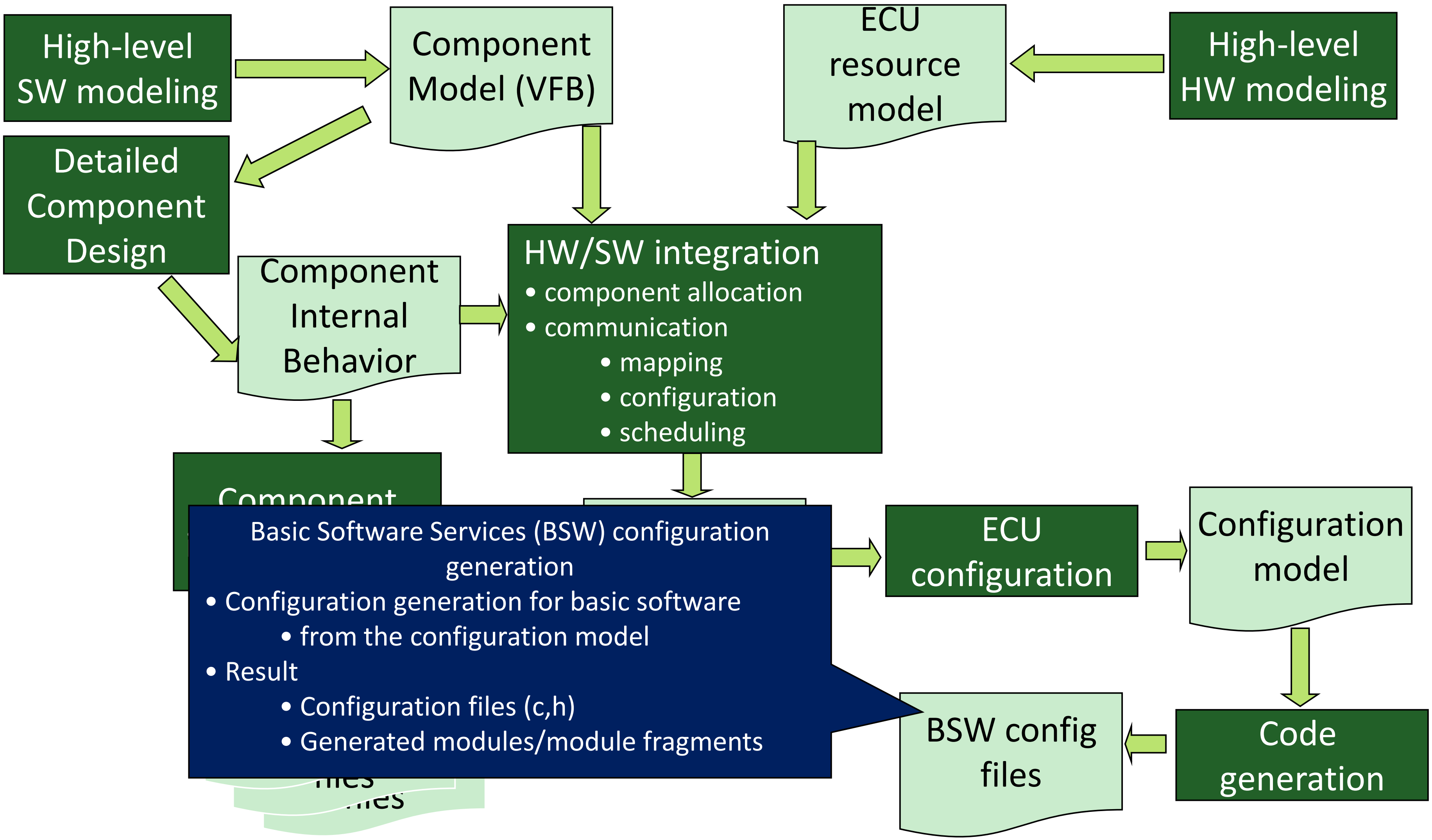

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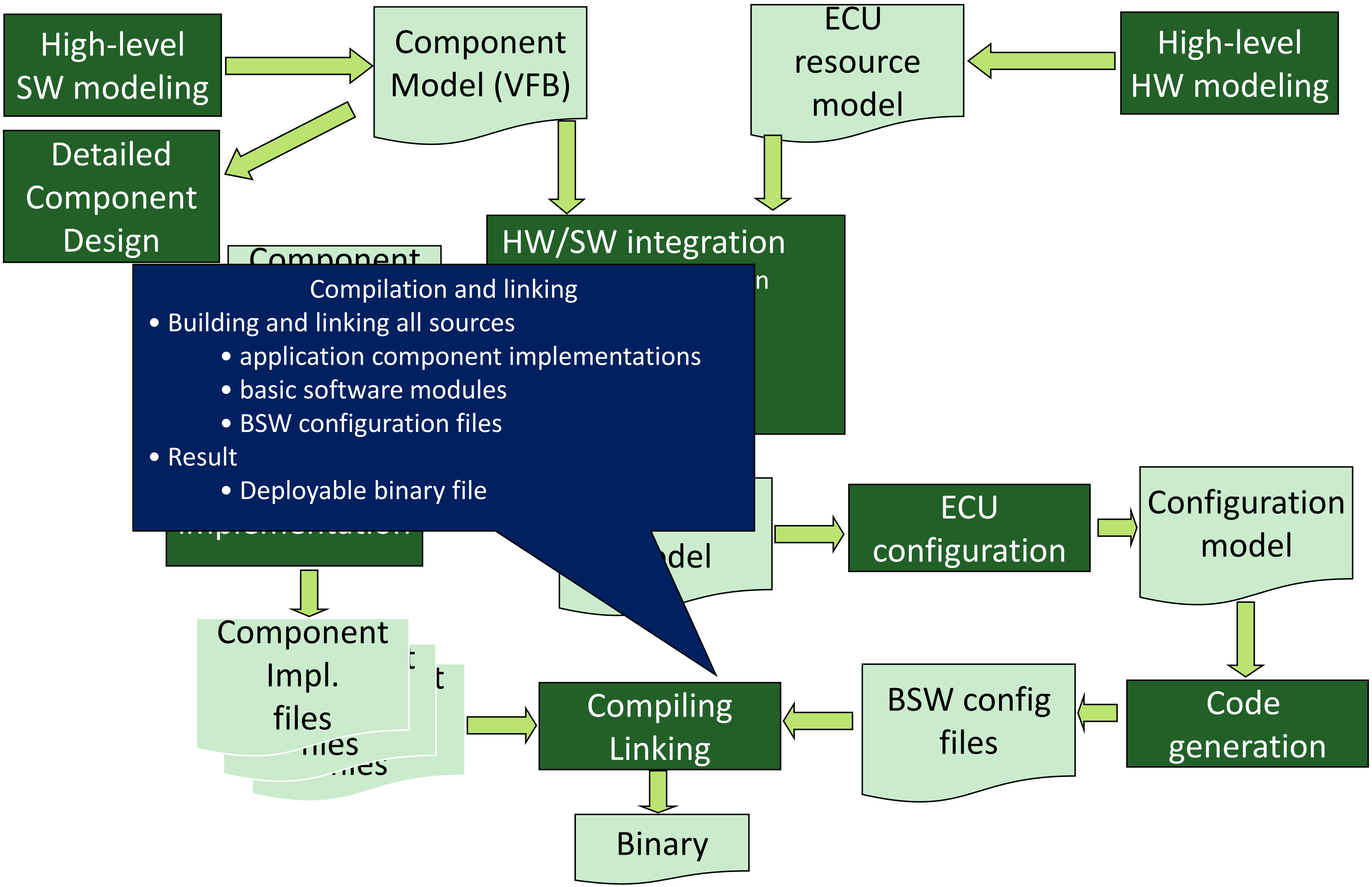
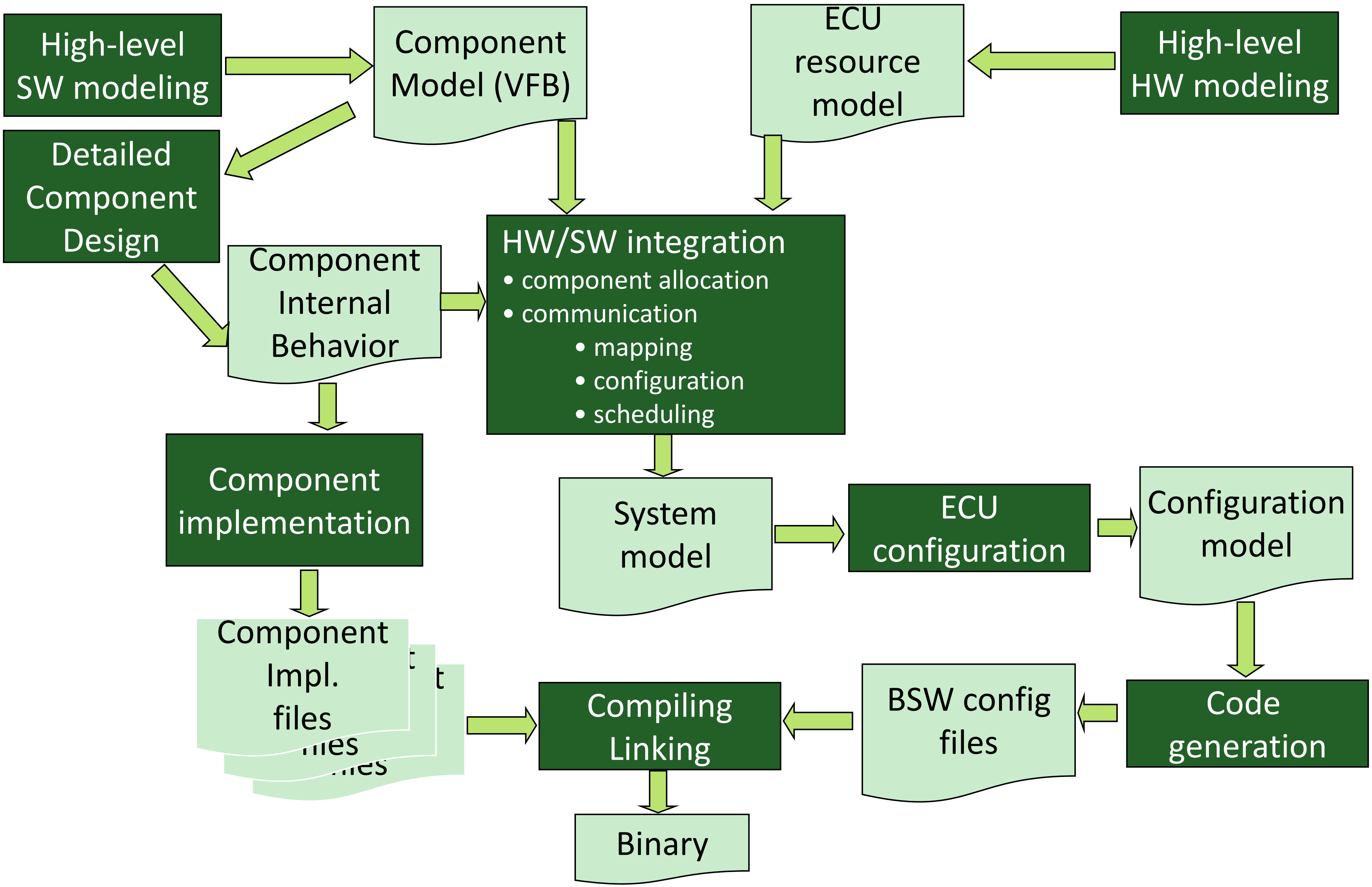


High-level design process



Models in the design flow

- Software Component Template
  - Components, ports, interfaces
  - Internal behavior
  - Implementation (files, resource consumption, run time, etc.)
- ECU Resource Template
  - Hardware components, interconnections
- System Template
  - System topology, HW/SW mapping
  - Comm. matrix

Models in the design flow 2

- Basic Software Module Template
  - BSW modules
    - Services
    - Schedulable entities
    - Resource consumption
- ECU Configuration Parameter Definition Template
  - Configurable parameters of BSW modules
- ECU Configuration Description Template
  - Actual configurations of BSW modules
  - Based on the ECU Parameter Definition

AUTOSAR vs. UML/SysML/... modeling

- AUTOSAR defines models with
  - Domain Specific Constructs
  - *Precise* syntax
  - Synthesizable constructs
    - Direct model -> transformations
    - Direct model -> detailed model mappings
  - Different abstraction levels
    - From Virtual Function Bus to configuration
- Result
  - Models *are* primary design *and* implementation artifacts
    - More precise, consistent modeling should be done

Case study

Analysis of extra-functional properties of a service

Validation of service configurations

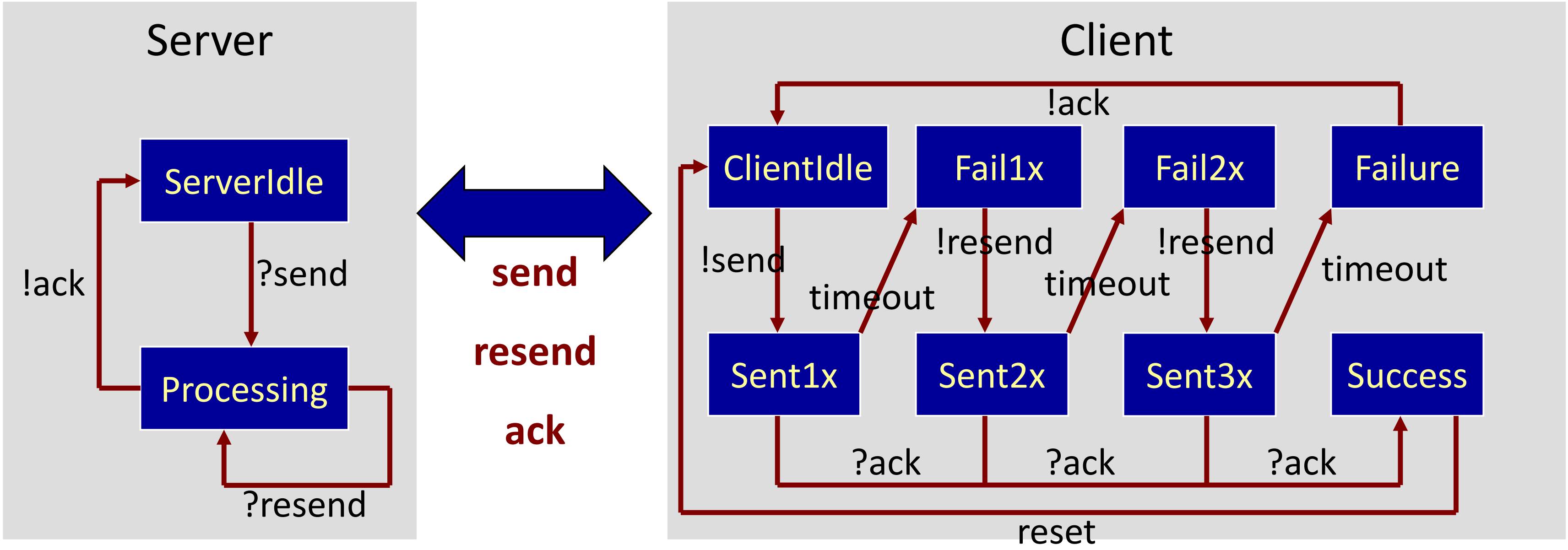
- Performability analysis
  - „Performability = Performance + Reliability”
- What happens in case of a failure?
  - E.g. the middleware responsible for reliable messaging resends the lost message → the guaranteed response time may increase (e.g. too low timeout → several false resends).
- What is the price of reliability? (performance-reliability *tradeoff*)
- How to set SLA parameters?

What do we model from all of this?

- Abstract behavior
  - Server
  - Client
- Message handling parameters (derived)
  - Method for handling messages
  - Number of resends
  - Parameters of **send**, **resend**, **ack**
    - (exponential distribution)

Middleware model

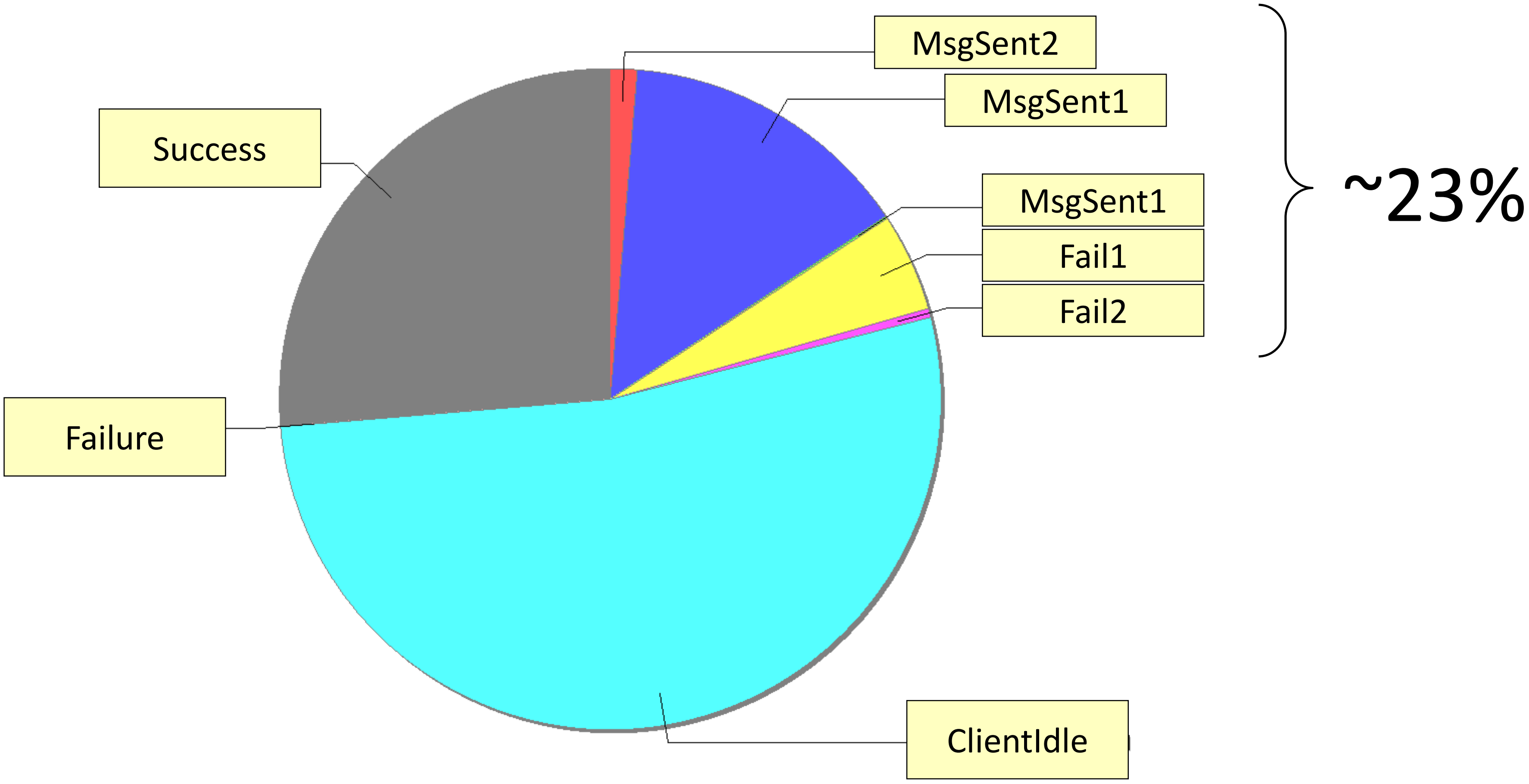
- Describes the platform
- Its parameters are included in the configuration model



Analysis results: utilization

Analysis in steady-state

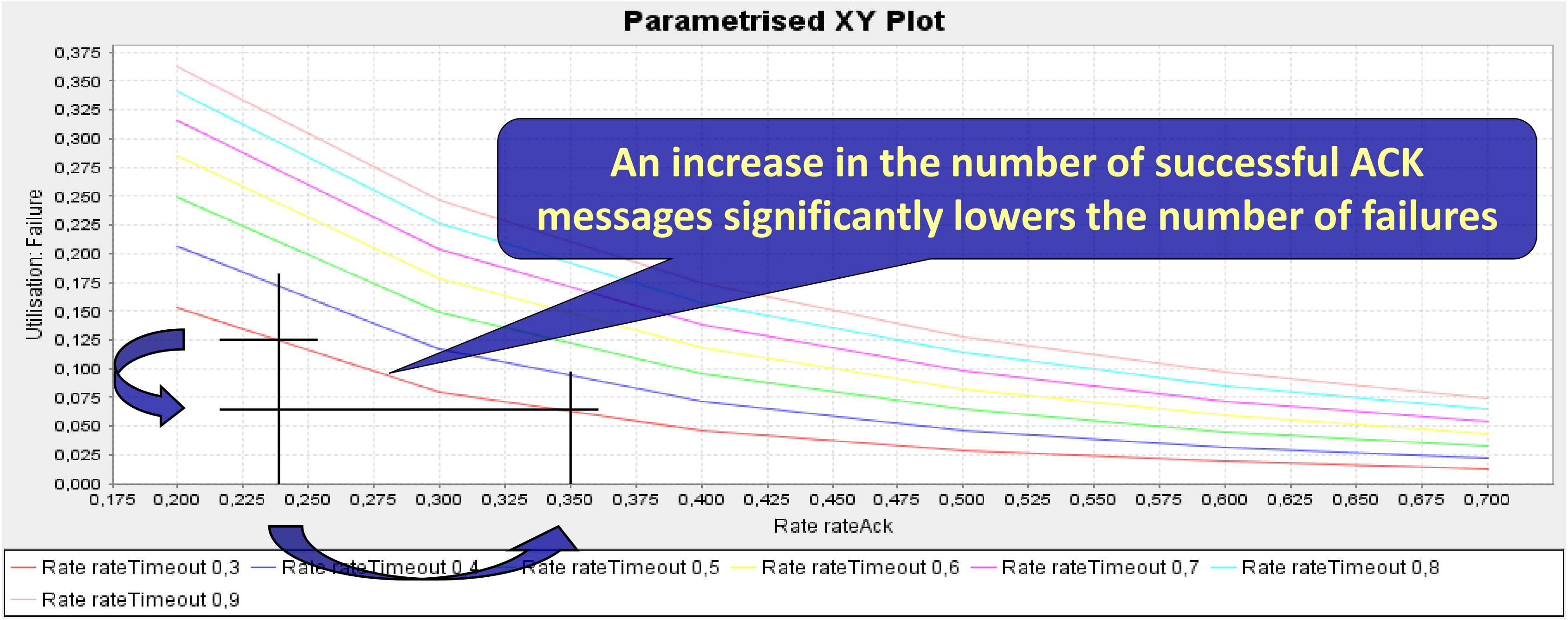
How much time does error handling take?



Sensitivity analysis results

Sensitivity analysis: what to change?

Probability of system level failures with respect to timing parameters of „resend”?



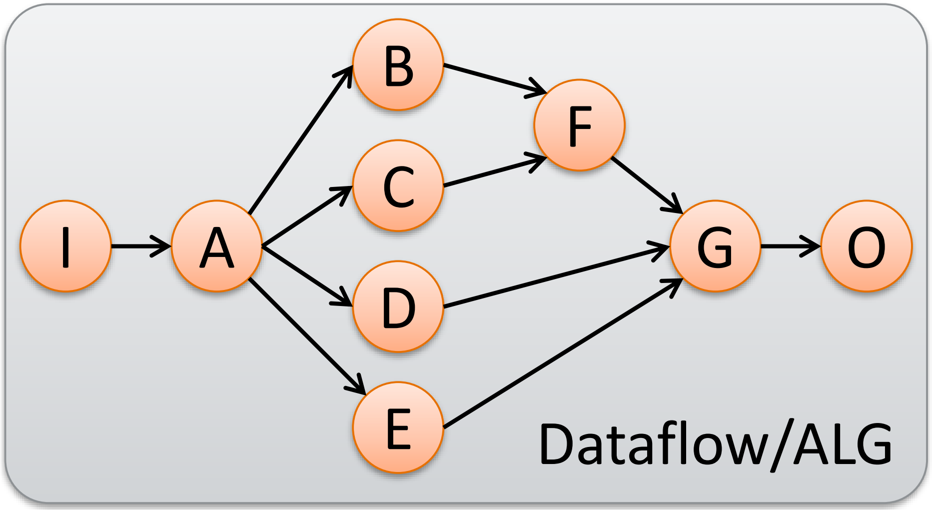
Case study

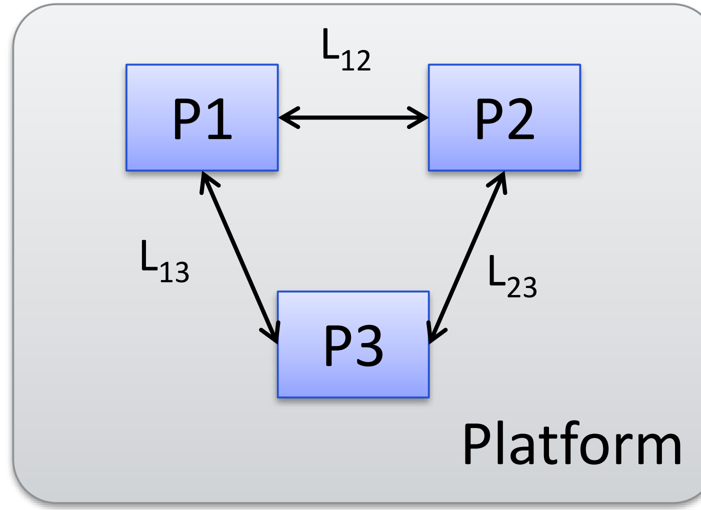
Schedule execution on a distributed platform

Scheduling

- **Platform model**: computation nodes and communication channels between them.
- **Algorithm model**: data-flow graph with operations as vertices and data-dependencies as edges.
- **Challenge**: schedule operations on the computation nodes for execution
  - Network communication takes time
  - Local results can be accessed instantly

Example [A. Girault]





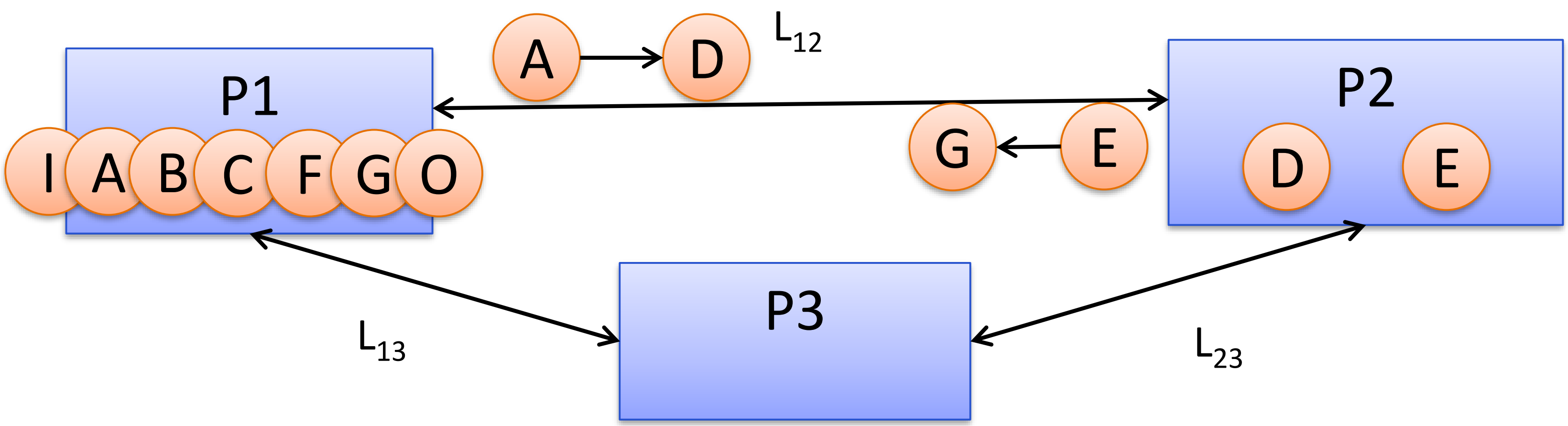
WCET	I	A	B	C	D	E	F	G	O
P1	10	20	30	20	30	10	20	14	14
P2	13	15	10	30	17	12	25	10	X
P3	X	10	15	10	30	20	10	15	18

Src/Trg	P1	P2	P3
P1	0	15	10
P2	15	0	20
P3	10	20	0

1) Create schedule (when and where to run what?)
2) Create fault-tolerant (FT) schedule if at most 1 proc may fail

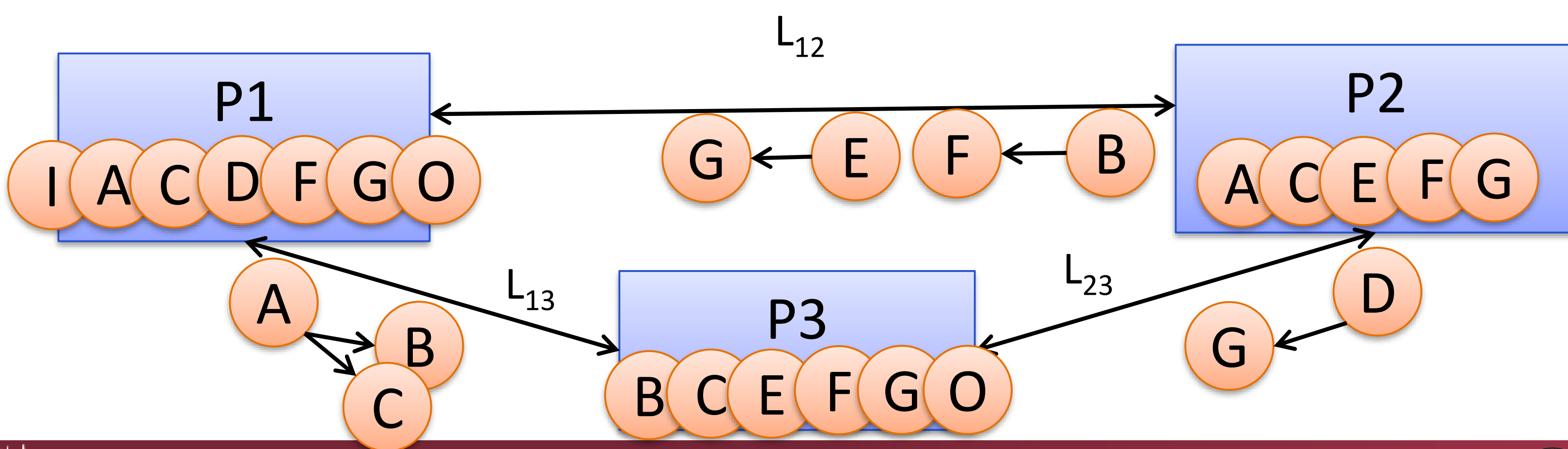
Naive solution (no FT)

	P1		L12		P2		L23		P3		L13	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
I	0	10										
A	10	30	30	45								
B	30	60										
C	60	80										
D					45	62						
E			74	89	62	74						
F	80	100										
G	100	114										
O	114	128										



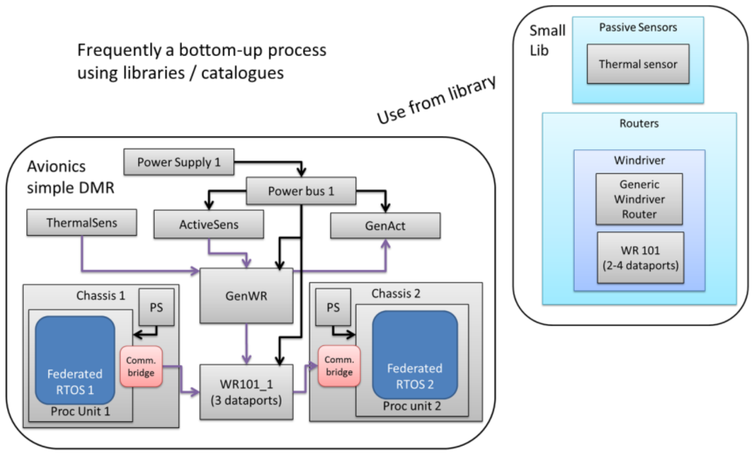
FT Allocation and Schedule

	P1		L12		P2		L23		P3		L13	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
I	0	10			0	13						
A	10	30			13	28					30	40
B			38	53	28	38			40	55		
C	30	50							55	65		
D	50	80			38	55	55	75				
E			67	82	55	67			65	85		
F	80	100							85	95		
G	100	114							95	110		
O	114	128							110	128		



Summary

Defining the platform model II.

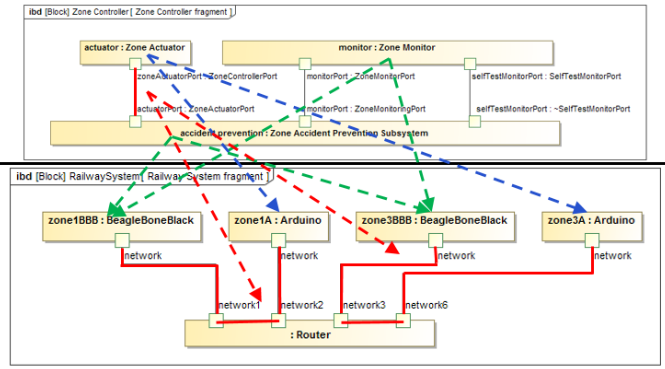


Allocation

- **Input:**
  - Functional models + platform model
- **Output:**
  - System Architecture
- The *System Architecture* defines for each instance of a Function
  - *where and when to execute*
  - *when to communicate and on which bus*
  - *who can be addressed in communication*

Allocation example: railway system

- Functional structure



- Platform structure

System properties

- **Functional requirements →**
  Functional properties:
  functions that the system is able to perform
  - including how the system behaves while operating – also called operational properties.
- **Extra-functional requirements →**
  Extra-functional properties:
  - no bearing on the functionality of the system
  - describing instead attributes, constraints, metrics…
  - …regarding performance, design, quality of service, environmental impact, failure and recovery, etc.