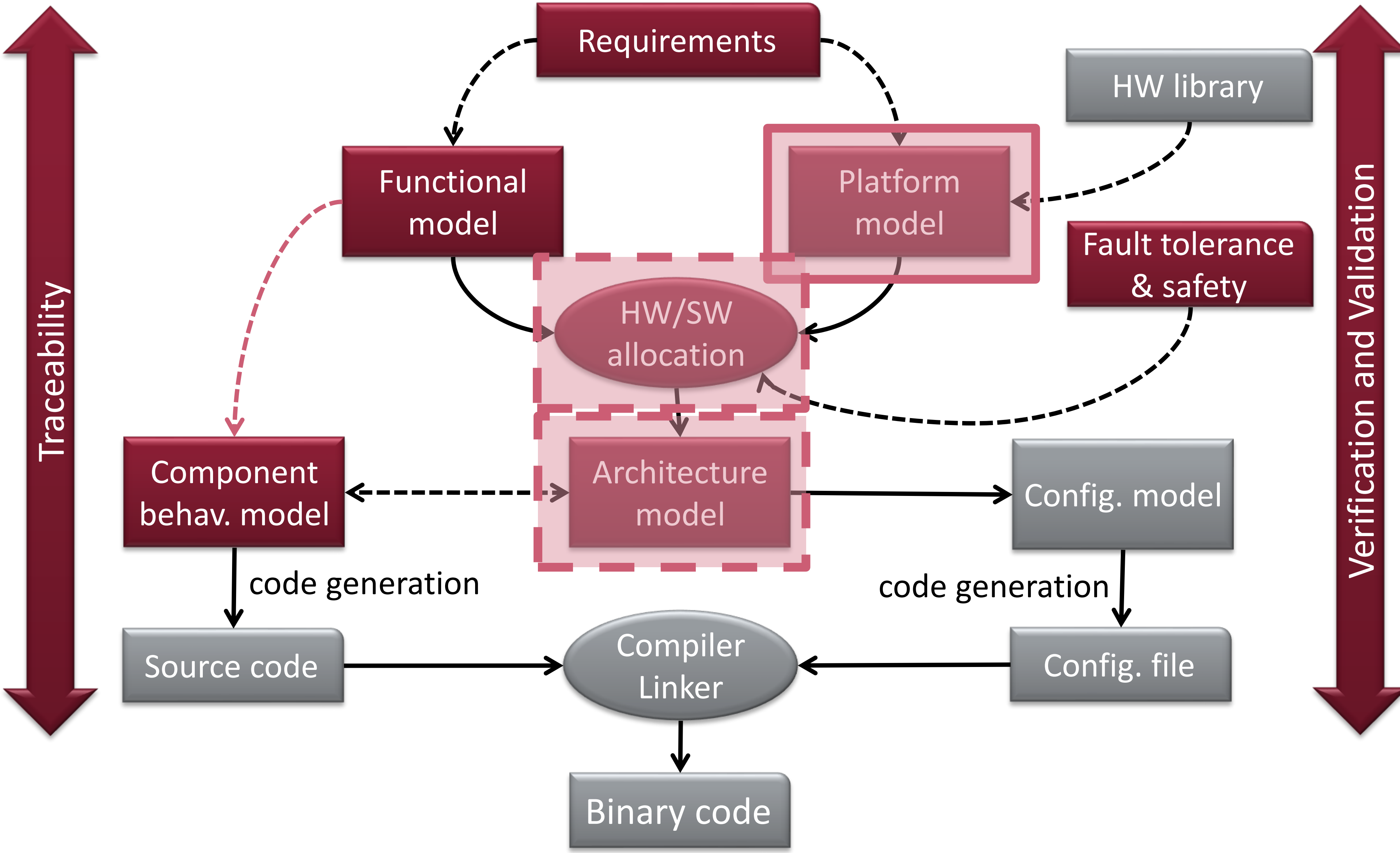
Platform modeling and allocation

Systems Engineering BSc Course

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

- Systems provide functions

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

- 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

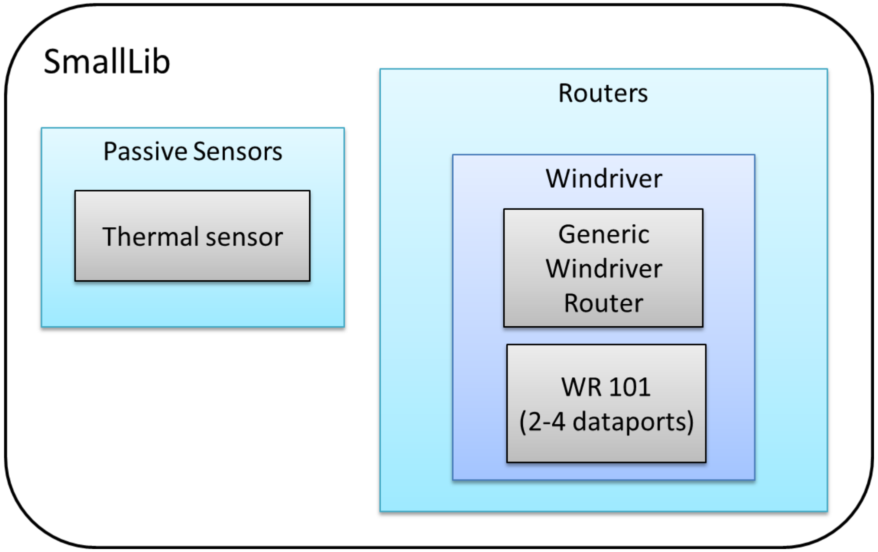
Platform model

- 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

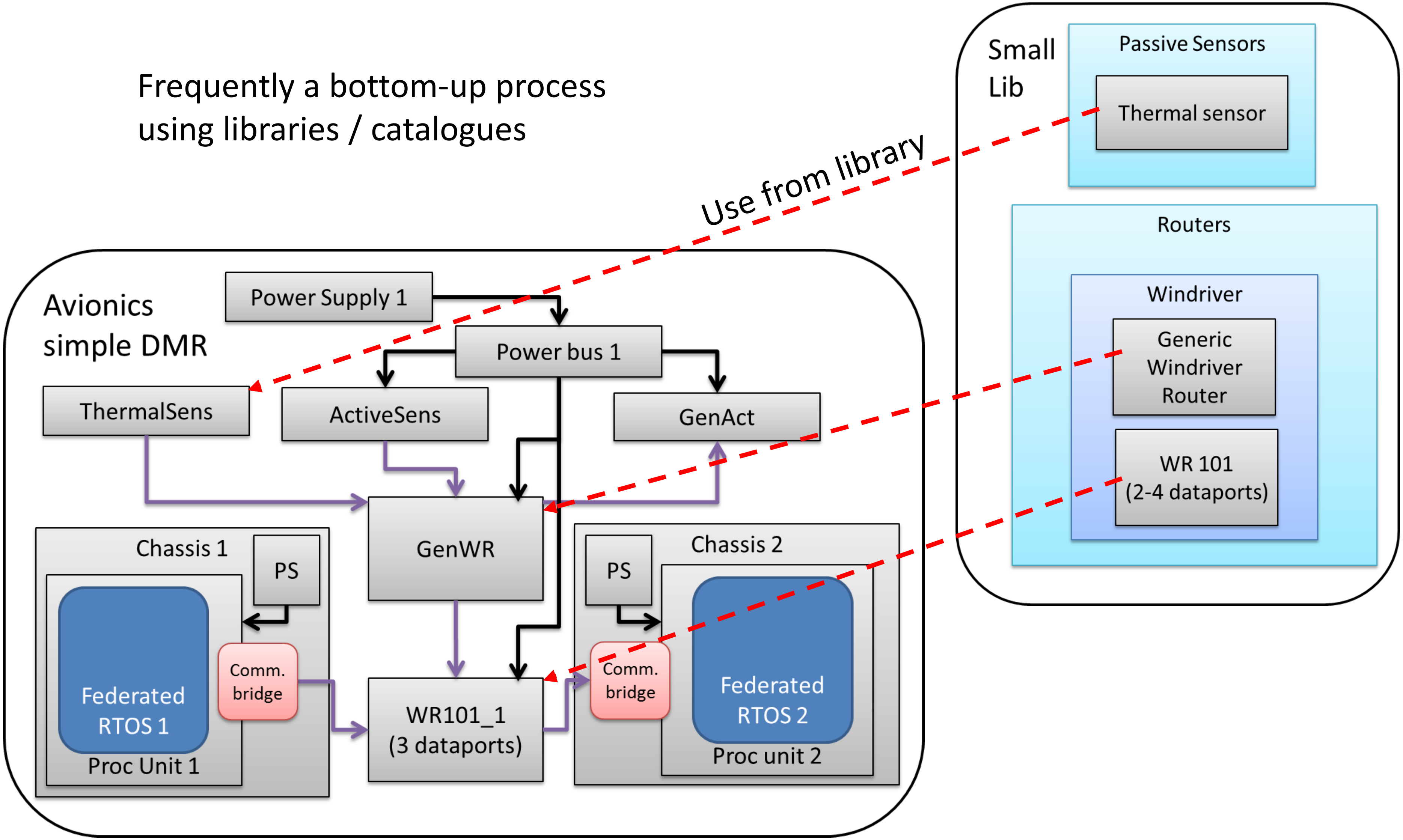


Defining the platform model II.

- 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

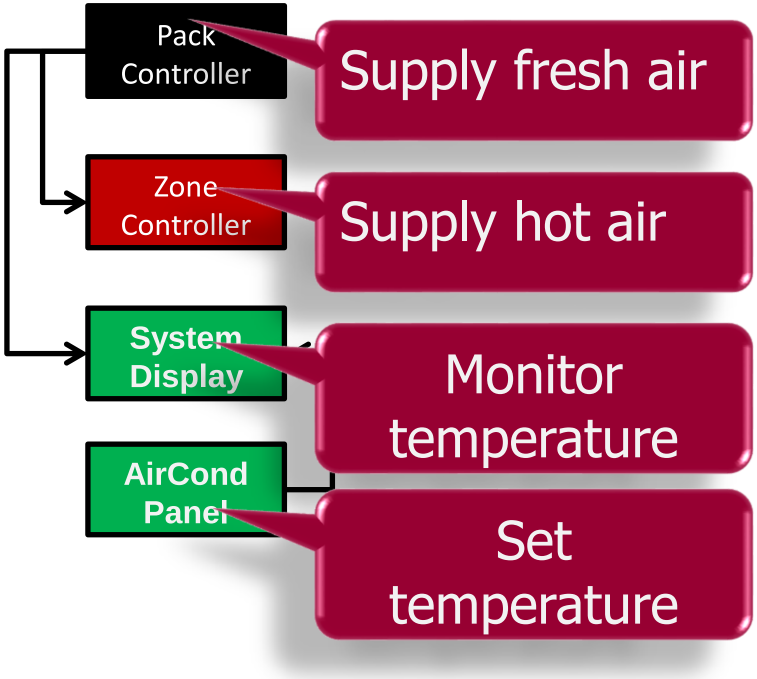


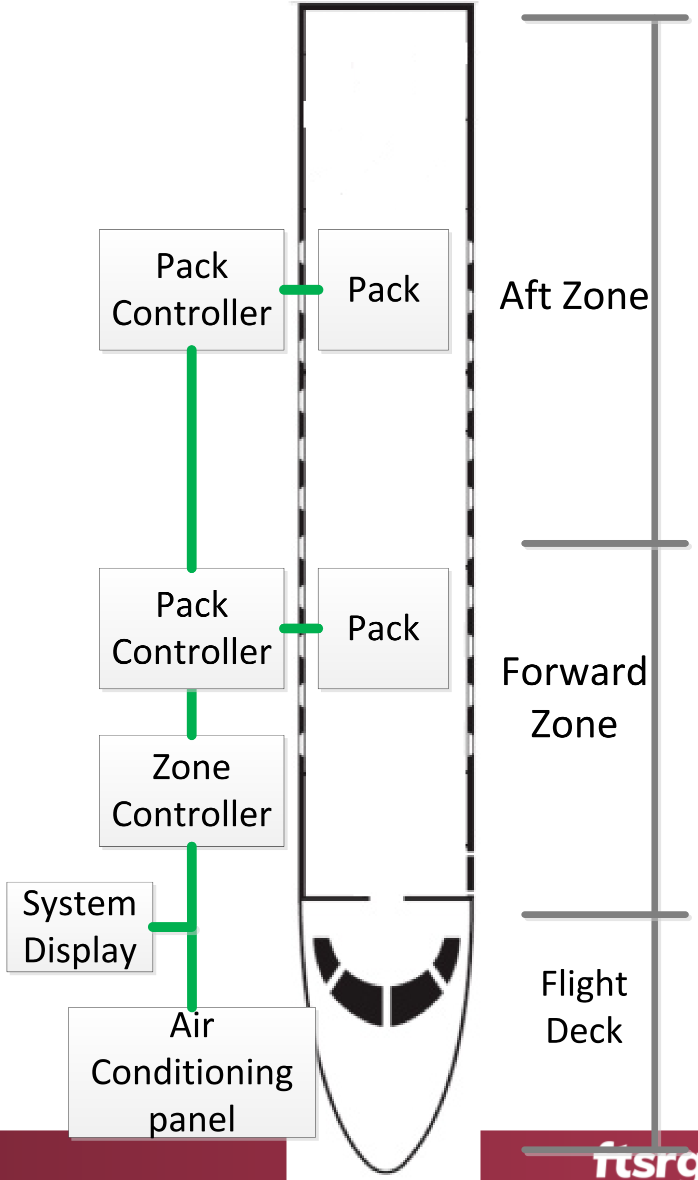
Functions to Platform allocation

Usually HW-SW allocation

Allocation example

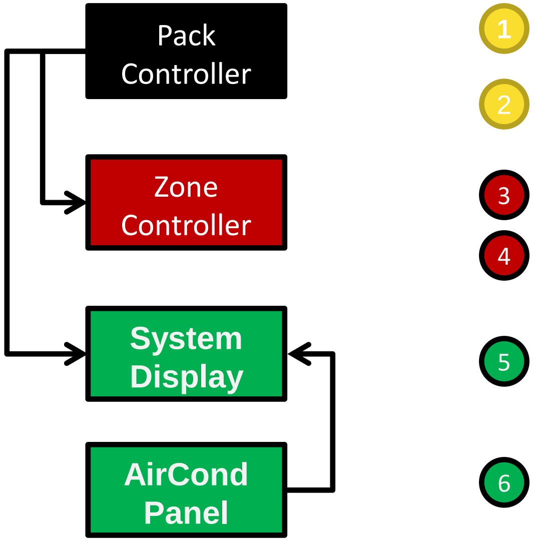
Functions



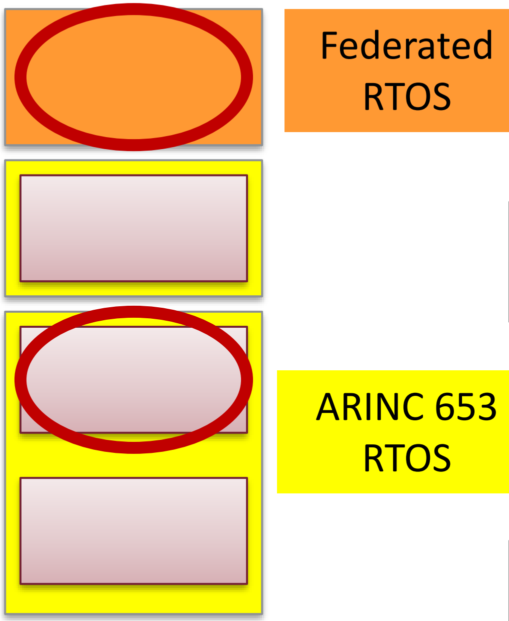


Allocation example – functions to partitions

Functions

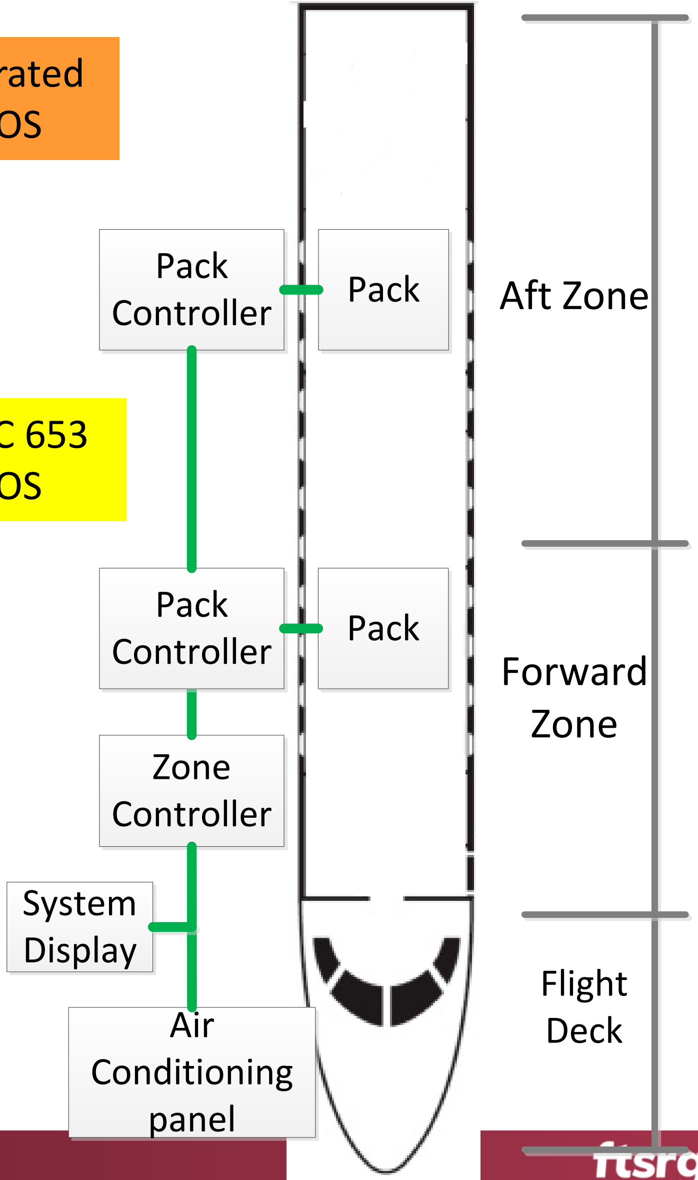


Partitions

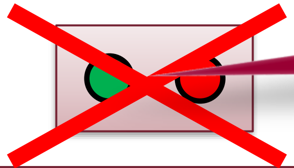


Federated RTOS

ARINC 653 RTOS

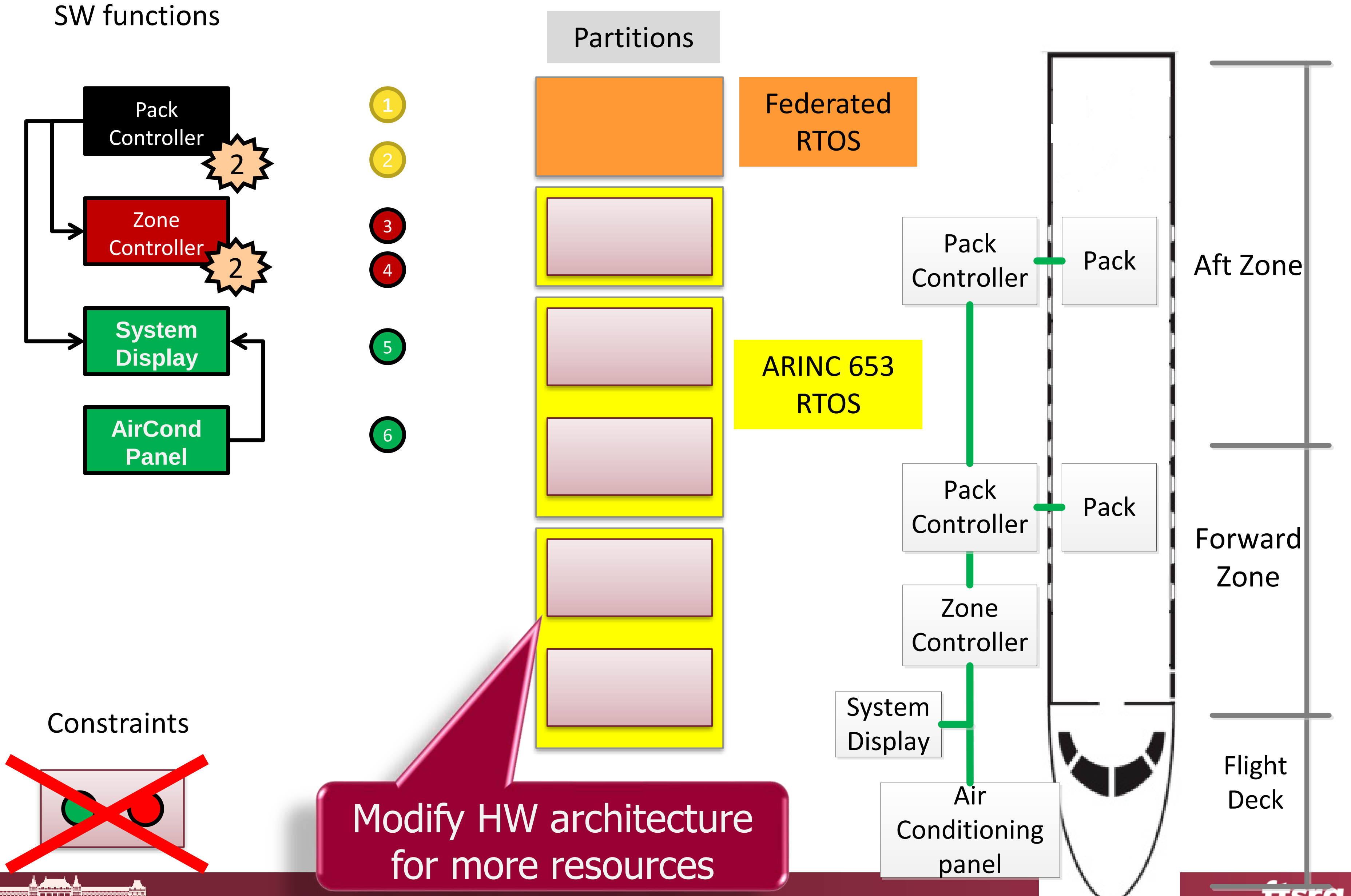


Constraints



Only one function per partition

Allocation example – functions to partitions

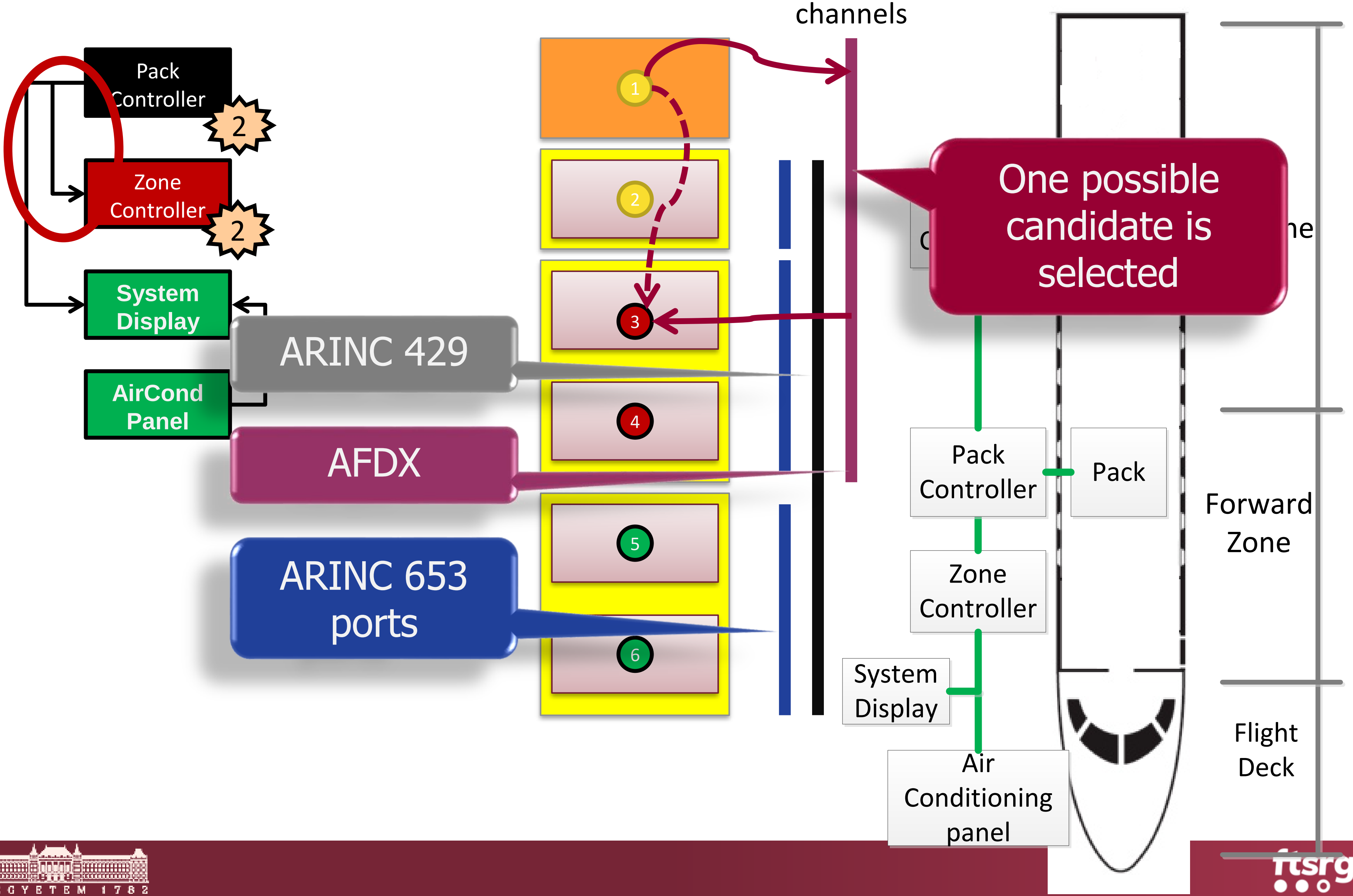


Modify HW architecture for more resources

Allocation example – communication channels

SW functionality

HW Communication channels



One possible candidate is selected

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

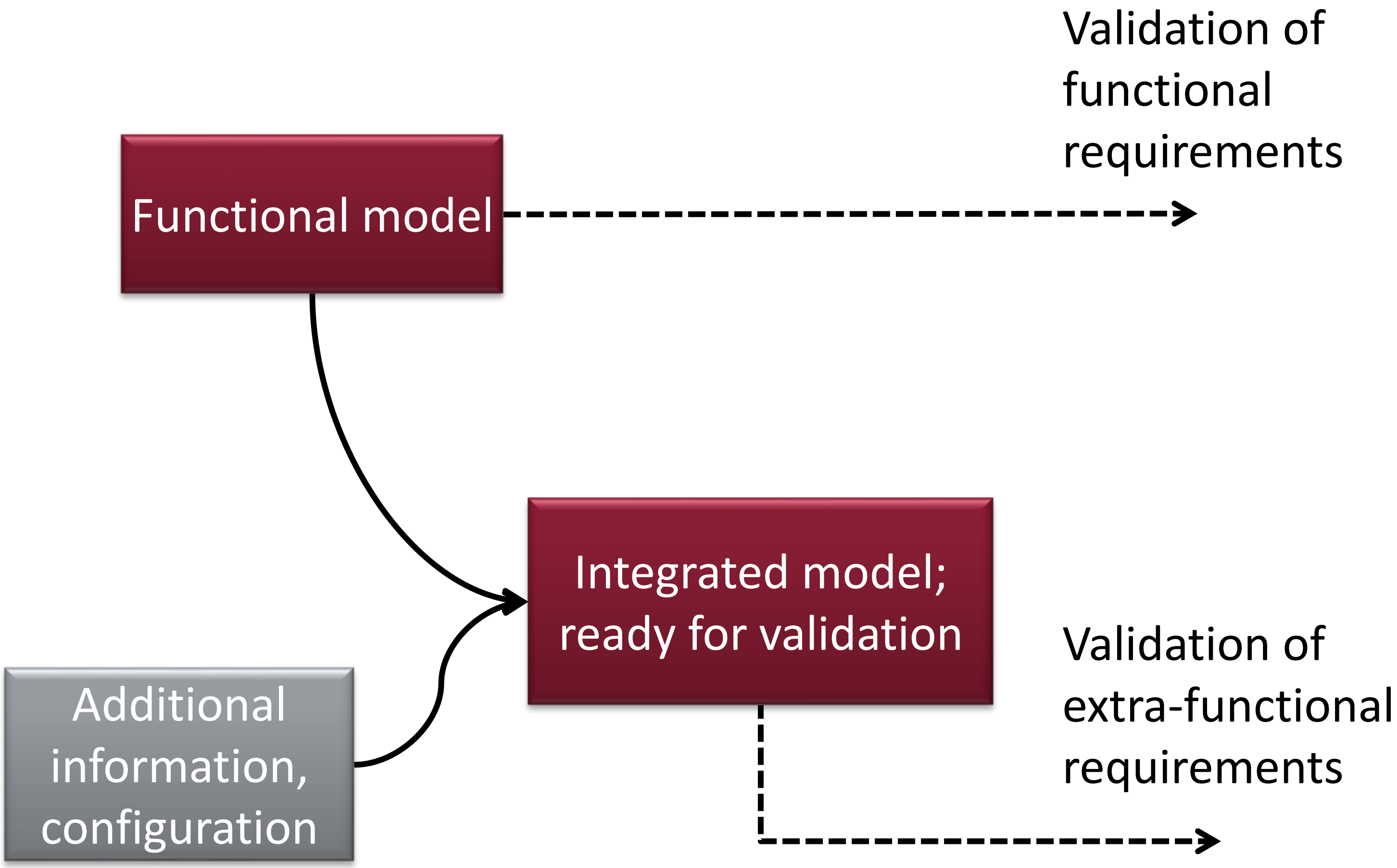
- Multi-level allocation
  - Complexity is handled on multiple abstraction-levels → allocation is handled between all hierarchies
- Resulting System Architectures are used for validating system level functional/non-functional aspects
  - Timing requirements, safety requirements, etc.
  - Used methods: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

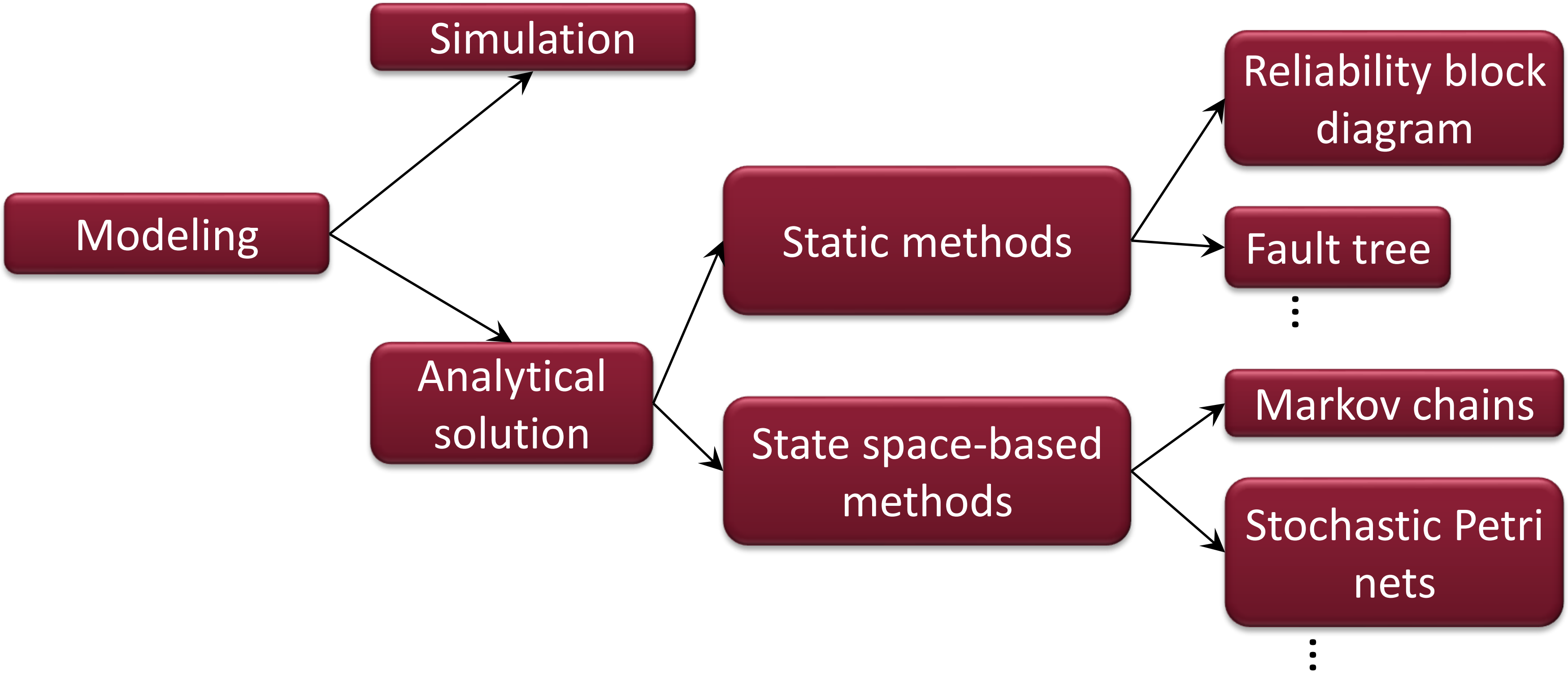
Additional information, configuration

Validation of extra-functional requirements

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**: performance regardless of the presence of faults.

Example: dependability analysis taxonomy



Modeling

Simulation

Analytical solution

Static methods

State space-based methods

Reliability block diagram

Fault tree

⋮

Markov chains

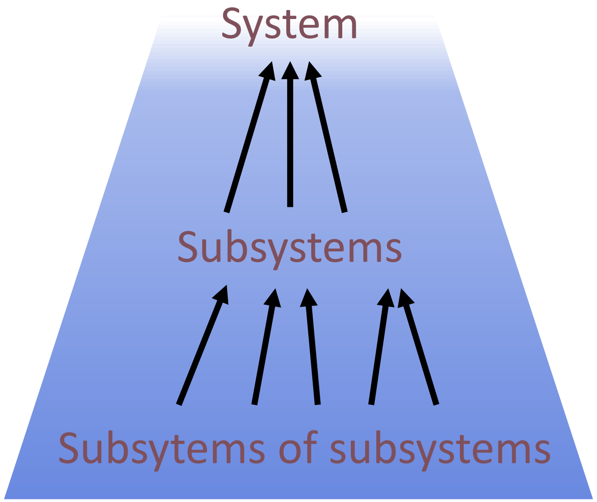
Stochastic Petri nets

⋮

Modeling platform in SysML

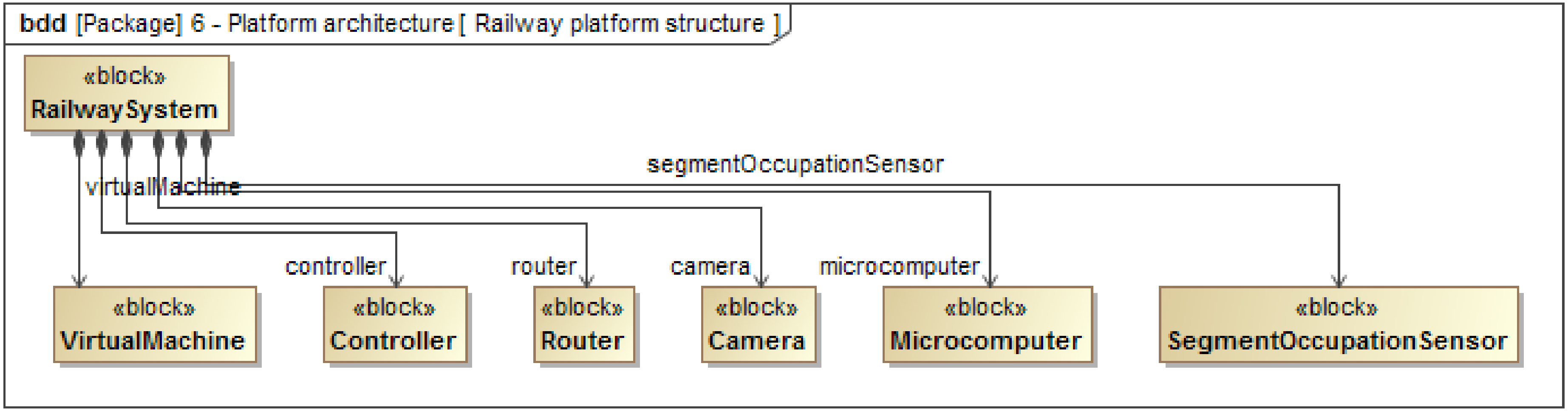
Platform modeling techniques

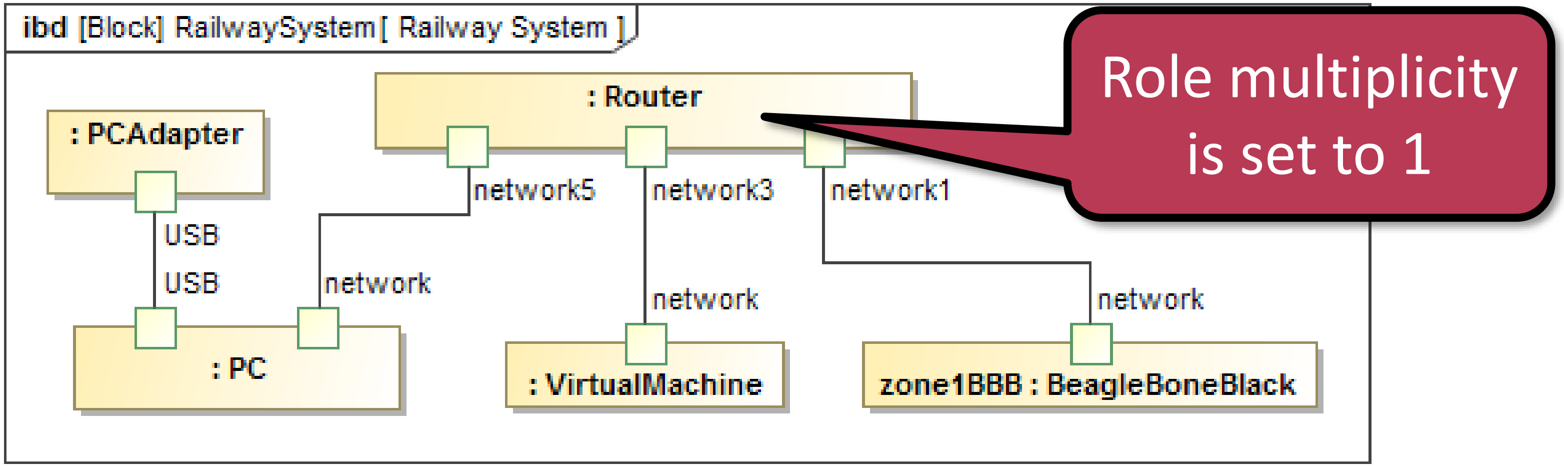
- Running platform is composed of existing (hardware) elements
- Approach: bottom-up using composition
  - ☺ Subsystems can be tested one-by-one
  - ☺ There are always some working parts during development
  - ☹ Exact roles of the subsystems are revealed late



Platform models in SysML

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



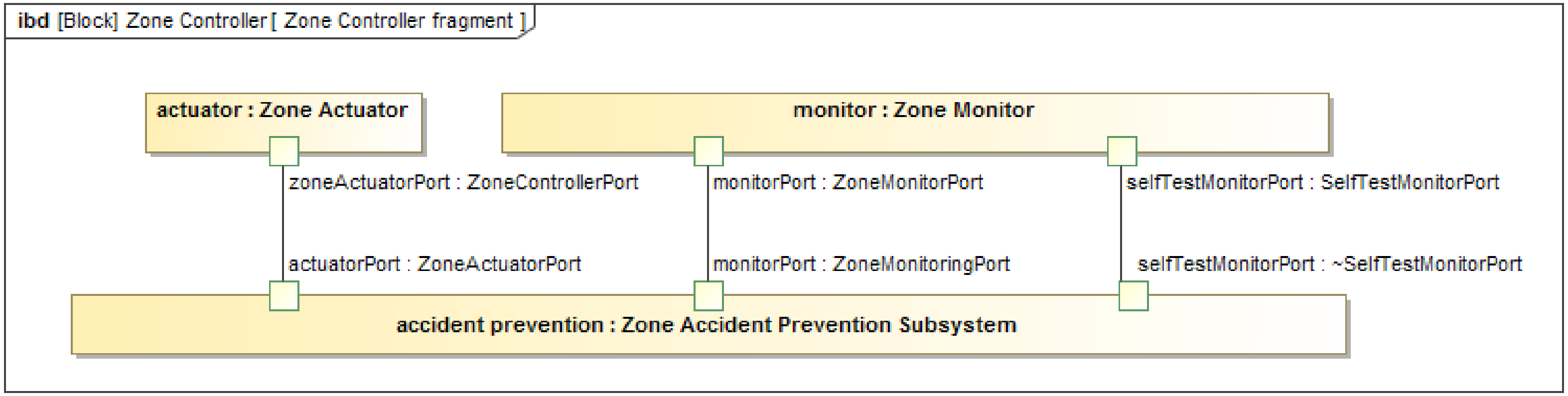


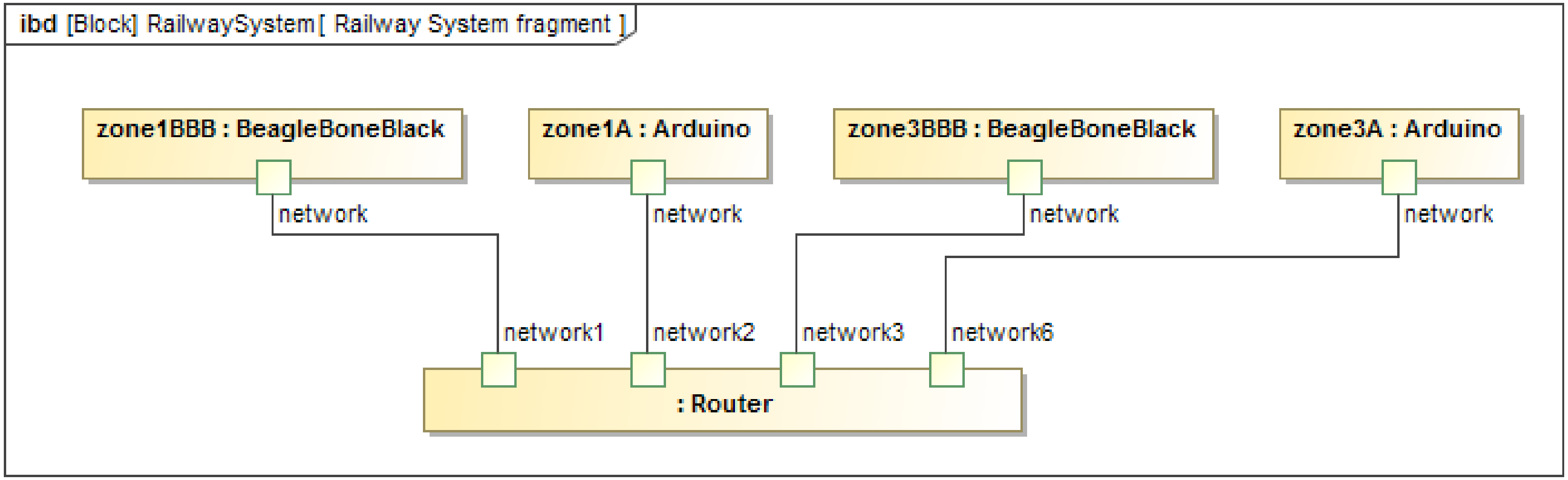
Role multiplicity is set to 1

Modeling allocation in SysML

Allocation example: railway system

- Functional structure

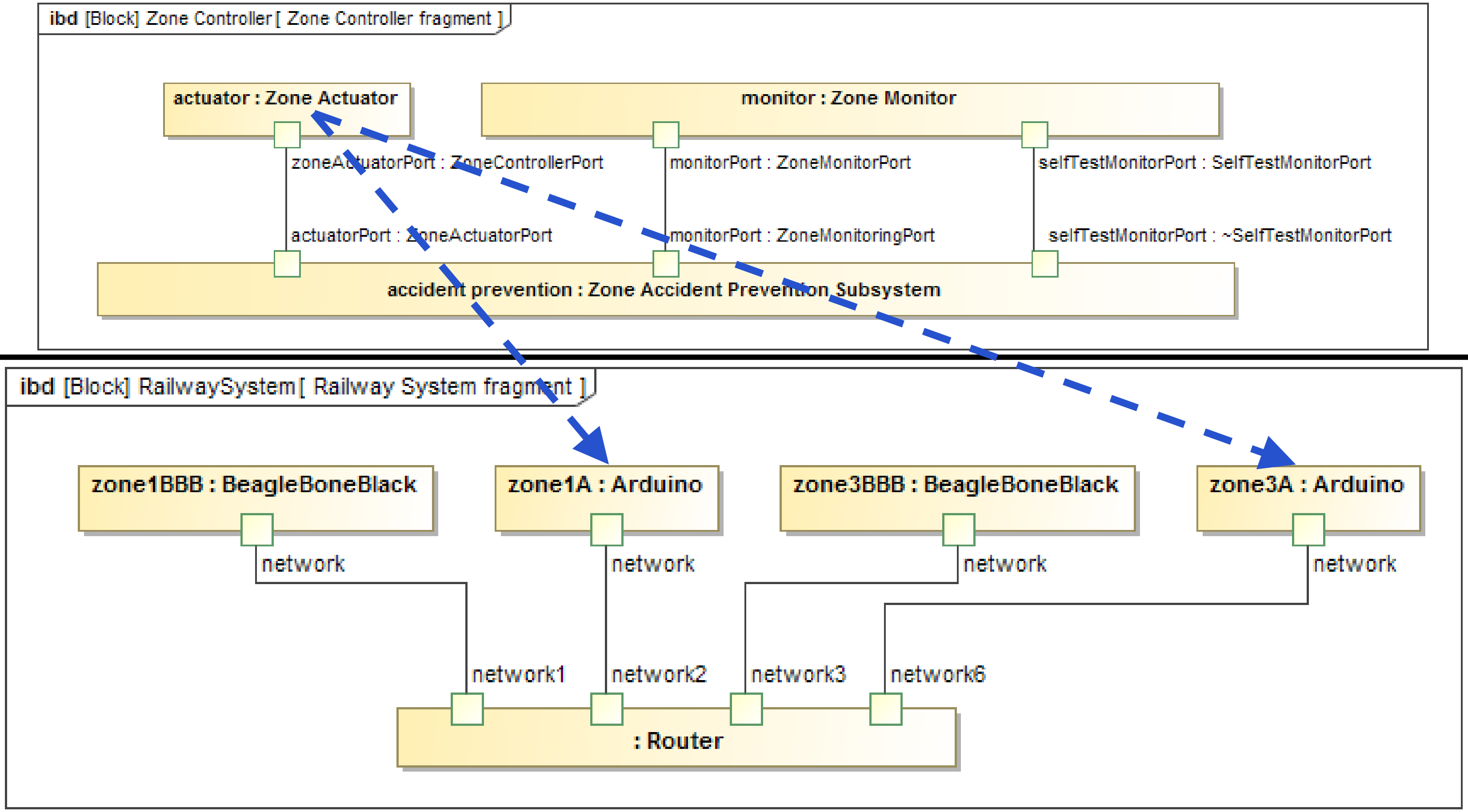

ibd [Block] Zone Controller [Zone Controller fragment]
actuator : Zone Actuator
monitor : Zone Monitor
zoneActuatorPort : ZoneControllerPort
monitorPort : ZoneMonitorPort
selfTestMonitorPort : SelfTestMonitorPort
actuatorPort : ZoneActuatorPort
monitorPort : ZoneMonitoringPort
selfTestMonitorPort : ~SelfTestMonitorPort
accident prevention : Zone Accident Prevention Subsystem


ibd [Block] RailwaySystem [Railway System fragment]
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

- Platform structure

Allocation example: railway system

- Functional structure



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monitor : Zone Monitor

zoneActuatorPort : ZoneControllerPort

monitorPort : ZoneMonitorPort

selfTestMonitorPort : SelfTestMonitorPort

actuatorPort : ZoneActuatorPort

monitorPort : ZoneMonitoringPort

selfTestMonitorPort : ~SelfTestMonitorPort

accident prevention : Zone Accident Prevention Subsystem

ibd [Block] RailwaySystem [Railway System fragment]

zone1BBB : BeagleBoneBlack

zone1A : Arduino

zone3BBB : BeagleBoneBlack

zone3A : Arduino

network

network

network

network

network1

network2

network3

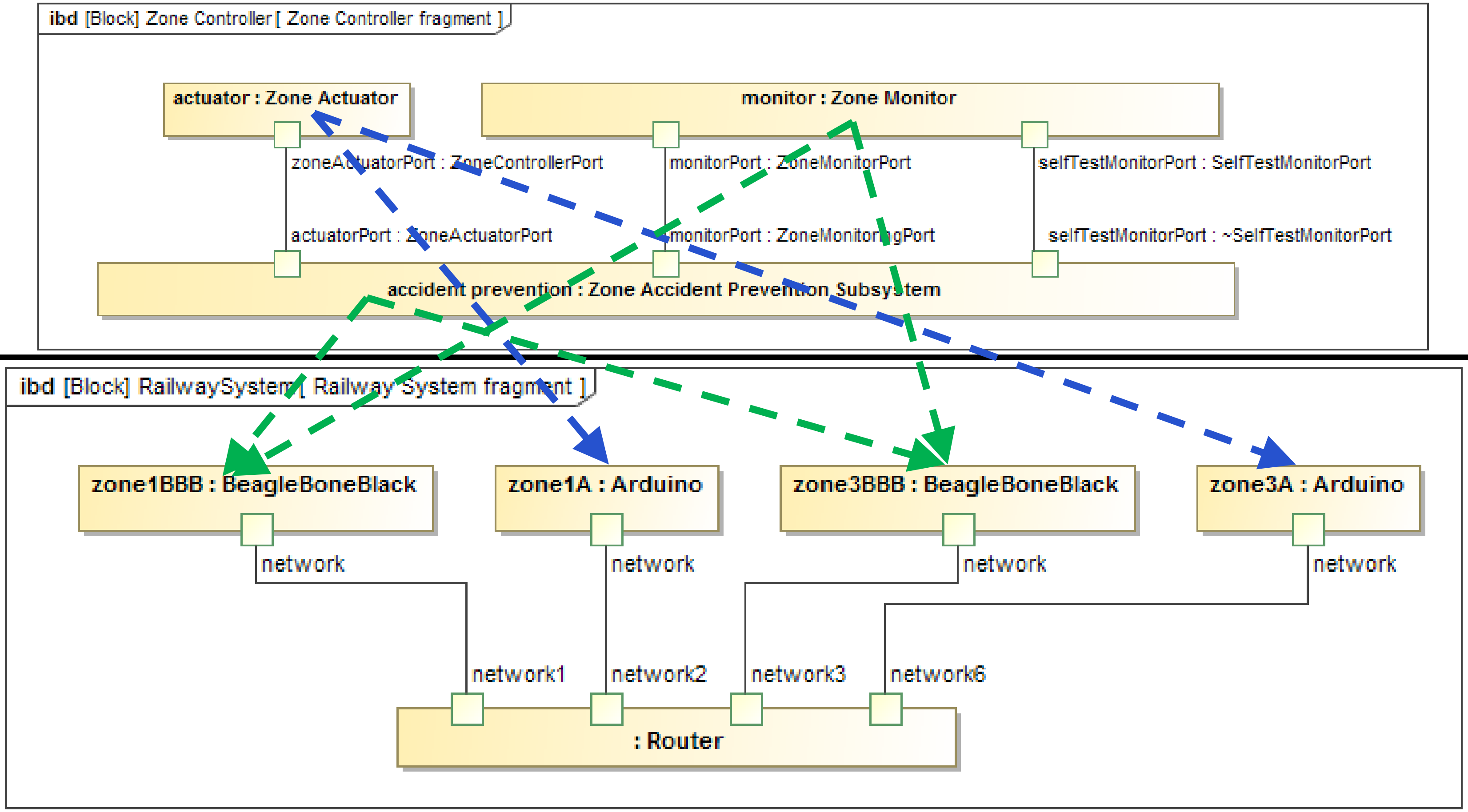
network6

: Router

- Platform structure

Allocation example: railway system

- Functional structure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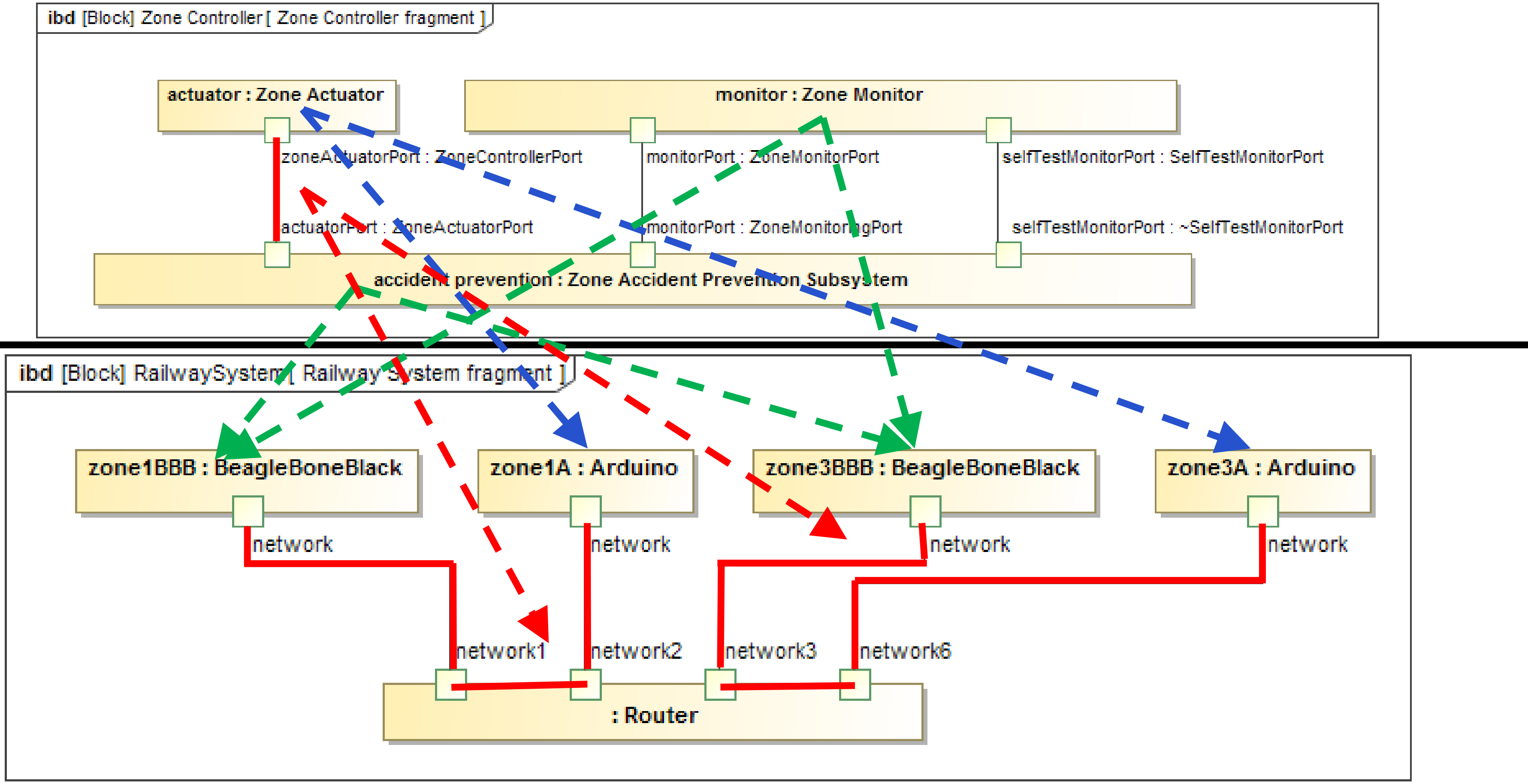
monitor : Zone Monitor
zoneActuatorPort : ZoneControllerPort
monitorPort : ZoneMonitorPort
selfTestMonitorPort : SelfTestMonitorPort
actuatorPort : ZoneActuatorPort
monitorPort : ZoneMonitoringPort
selfTestMonitorPort : ~SelfTestMonitorPort
accident prevention : Zone Accident Prevention Subsystem
ibd [Block] RailwaySystem [Railway System fragment]
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

- Platform structure

Allocation example: railway system

- Functional structure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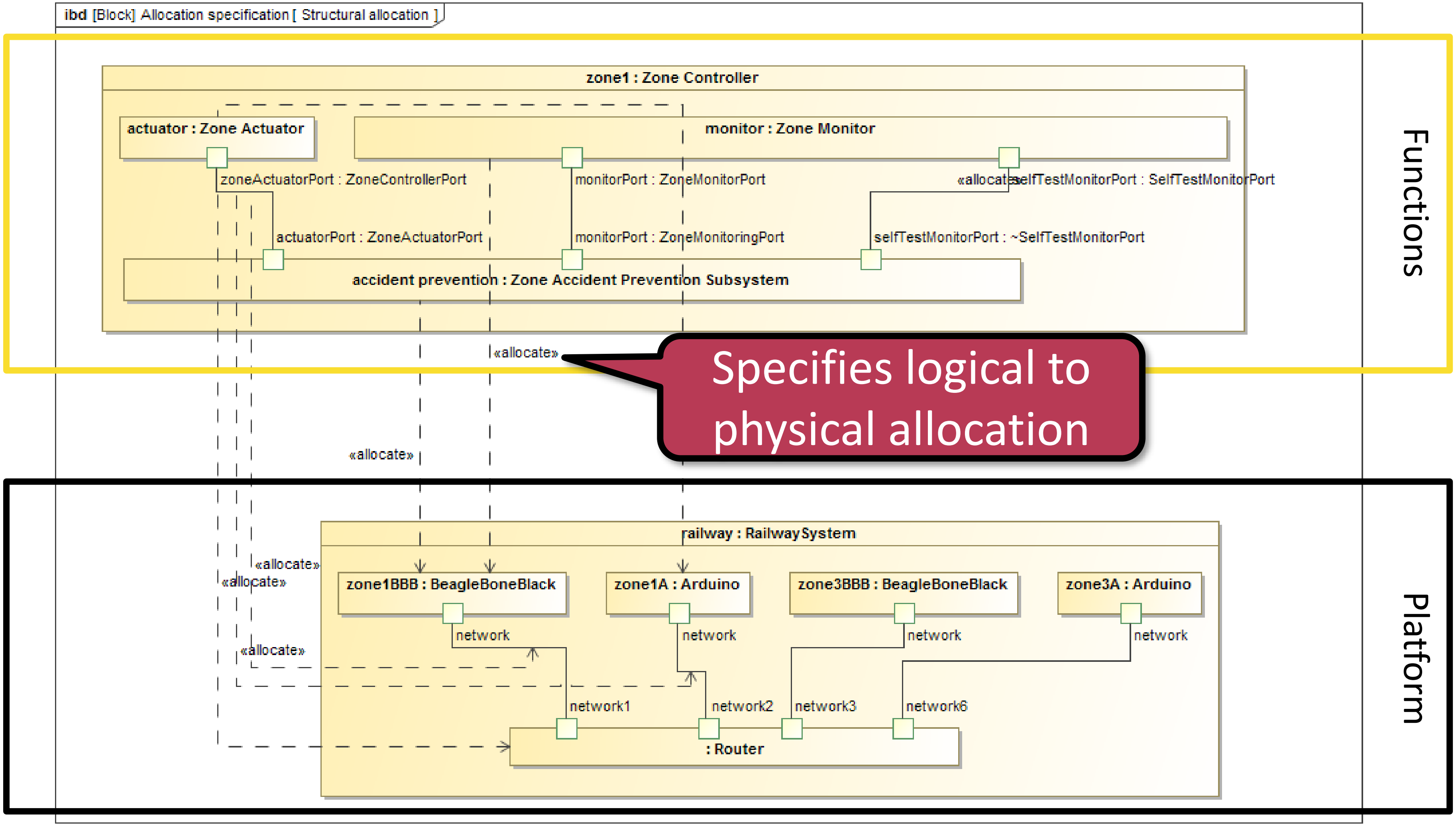
monitor : Zone Monitor
zoneActuatorPort : ZoneControllerPort
monitorPort : ZoneMonitorPort
selfTestMonitorPort : SelfTestMonitorPort
actuatorPort : ZoneActuatorPort
monitorPort : ZoneMonitoringPort
selfTestMonitorPort : ~SelfTestMonitorPort
accident prevention : Zone Accident Prevention Subsystem
ibd [Block] RailwaySystem [Railway System fragment]
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

- Platform structure

The allocation relation in SysML

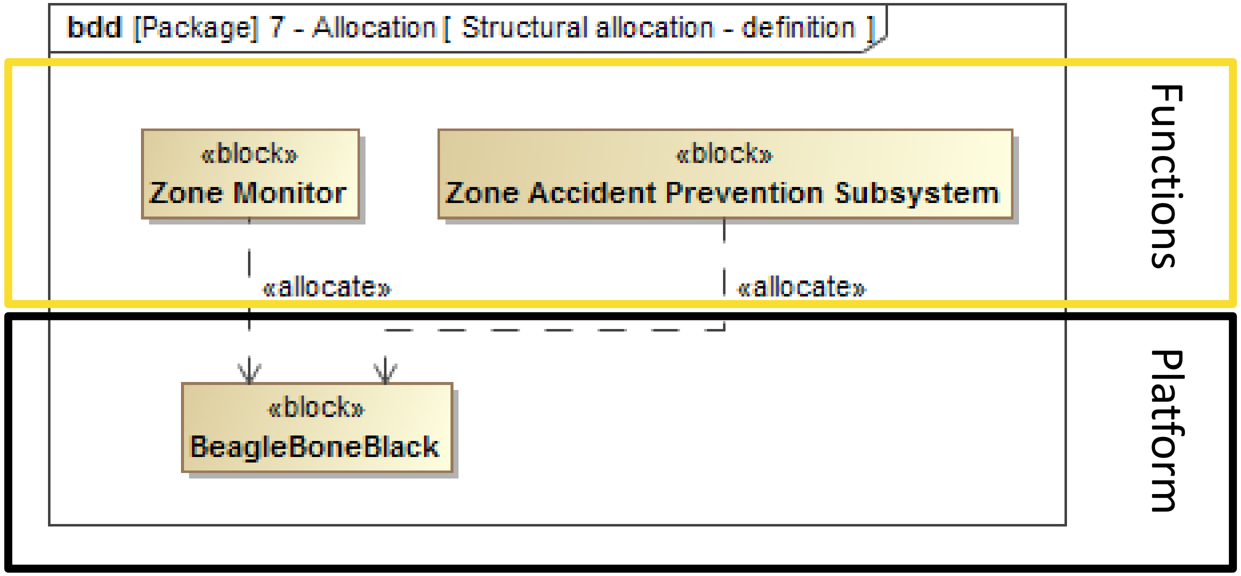
- Structural allocation: usage


ibd [Block] Allocation specification [Structural allocation]
zone1 : Zone Controller
actuator : Zone Actuator
monitor : Zone Monitor
zoneActuatorPort : ZoneControllerPort
monitorPort : ZoneMonitorPort
«allocate»
selfTestMonitorPort : SelfTestMonitorPort
actuatorPort : ZoneActuatorPort
monitorPort : ZoneMonitoringPort
selfTestMonitorPort : ~SelfTestMonitorPort
accident prevention : Zone Accident Prevention Subsystem
«allocate»
«allocate»
railway : RailwaySystem
«allocate»
«allocate»
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
«allocate»
network1
network2
network3
network6
: Router
Functions
Platform

Specifies logical to physical allocation

The allocation relation in SysML

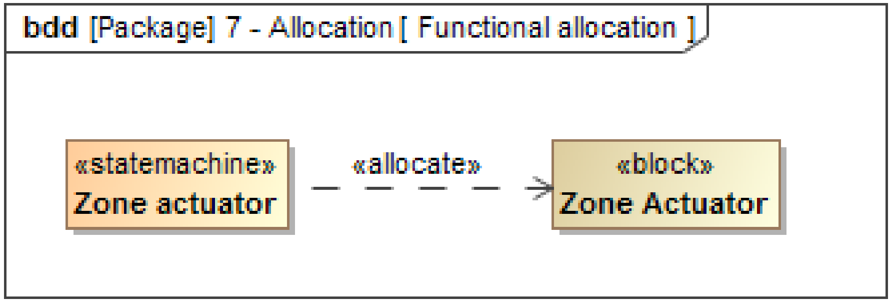
- Structural allocation: definition


bdd [Package] 7 - Allocation [Structural allocation - definition]
«block»
Zone Monitor
«block»
Zone Accident Prevention Subsystem
«allocate»
«allocate»
«block»
BeagleBoneBlack
Functions
Platform

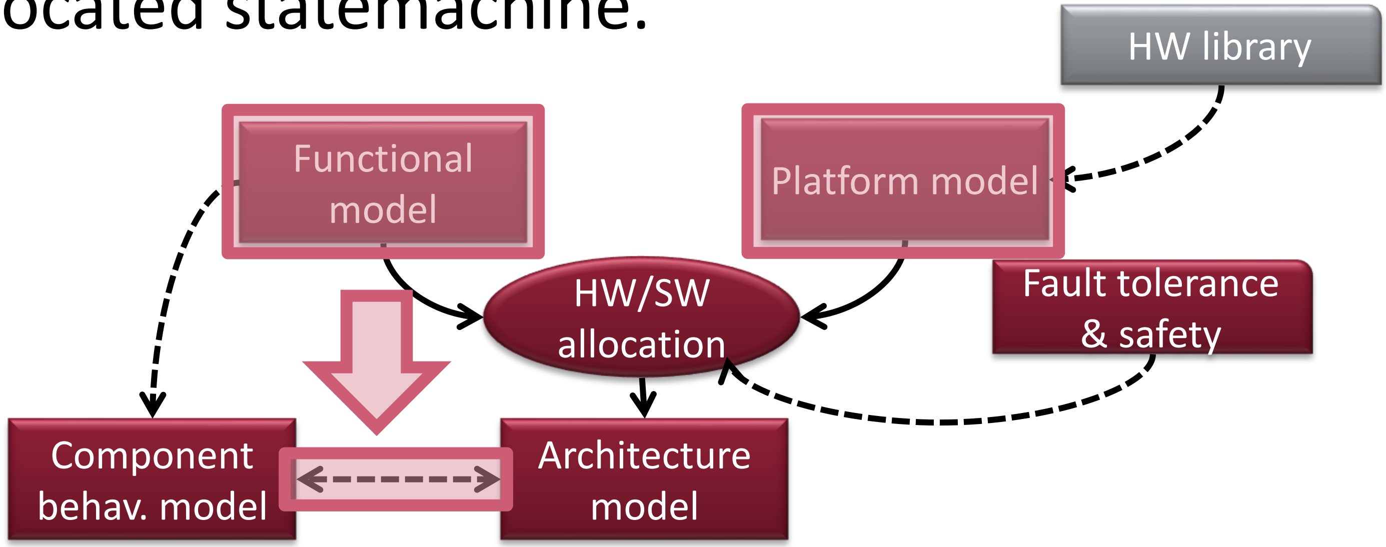
  - Wherever a BBB is used in the system, a zone monitor and an accident prevention subsystem is assumed to be allocated to it

The allocation relation in SysML

- Functional allocation: definition



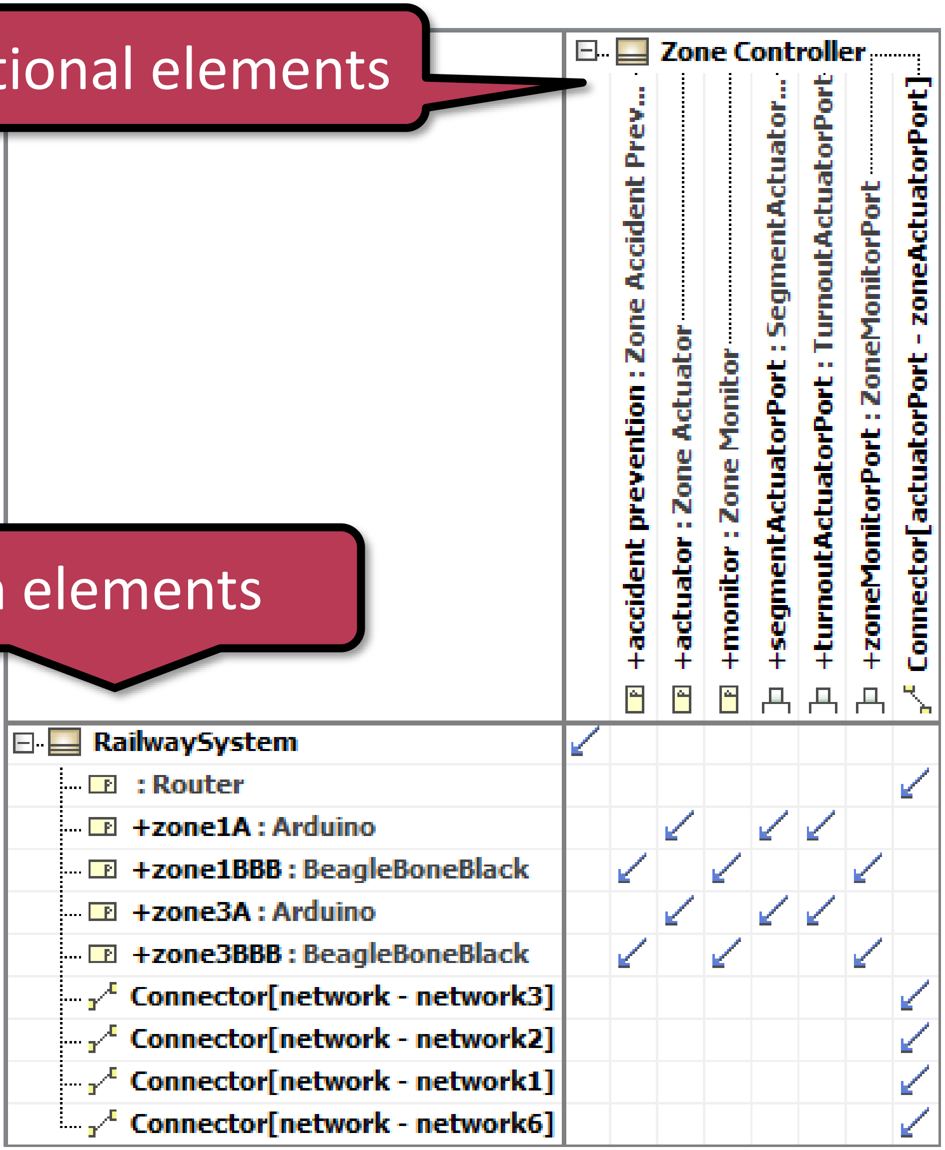
  - A zone actuator behaves as it is described in the allocated statemachine.



SysML allocation matrix

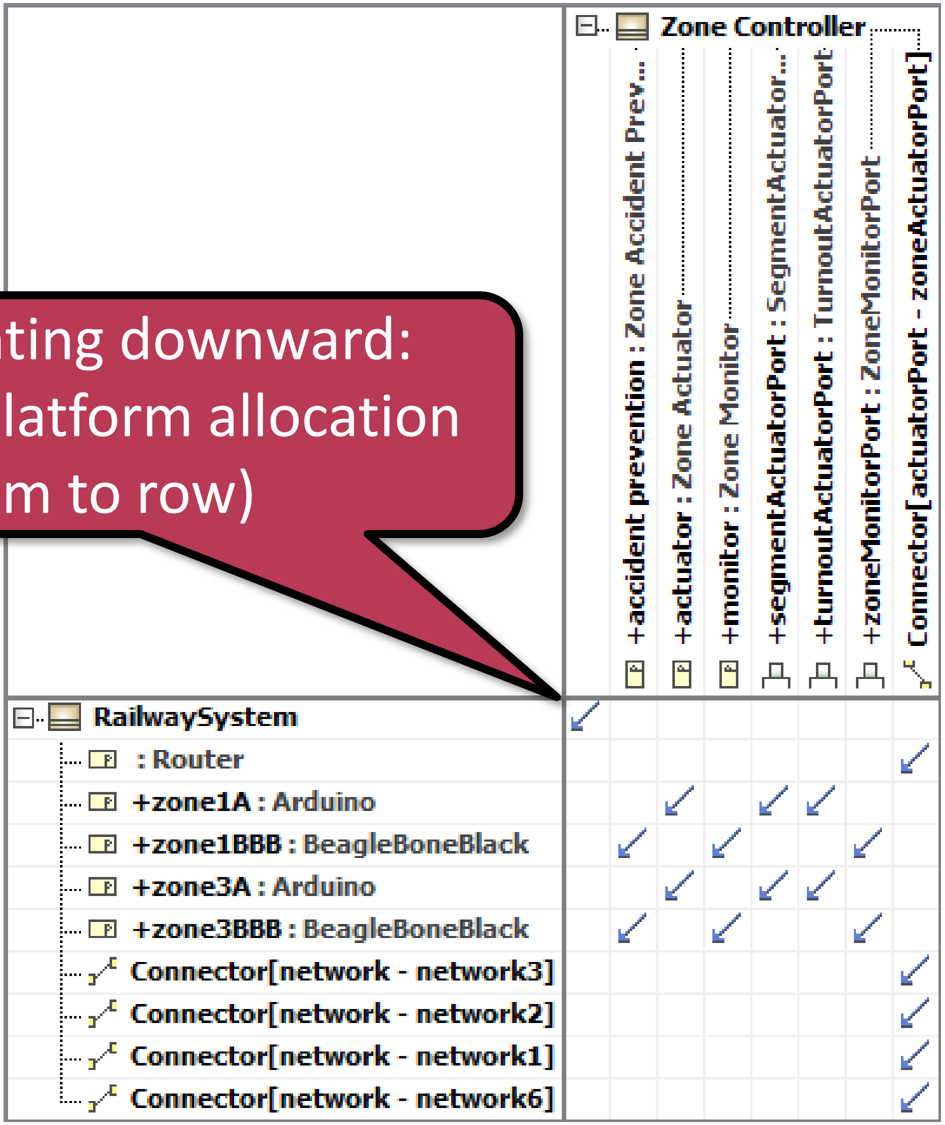
Columns: functional elements

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]								↙

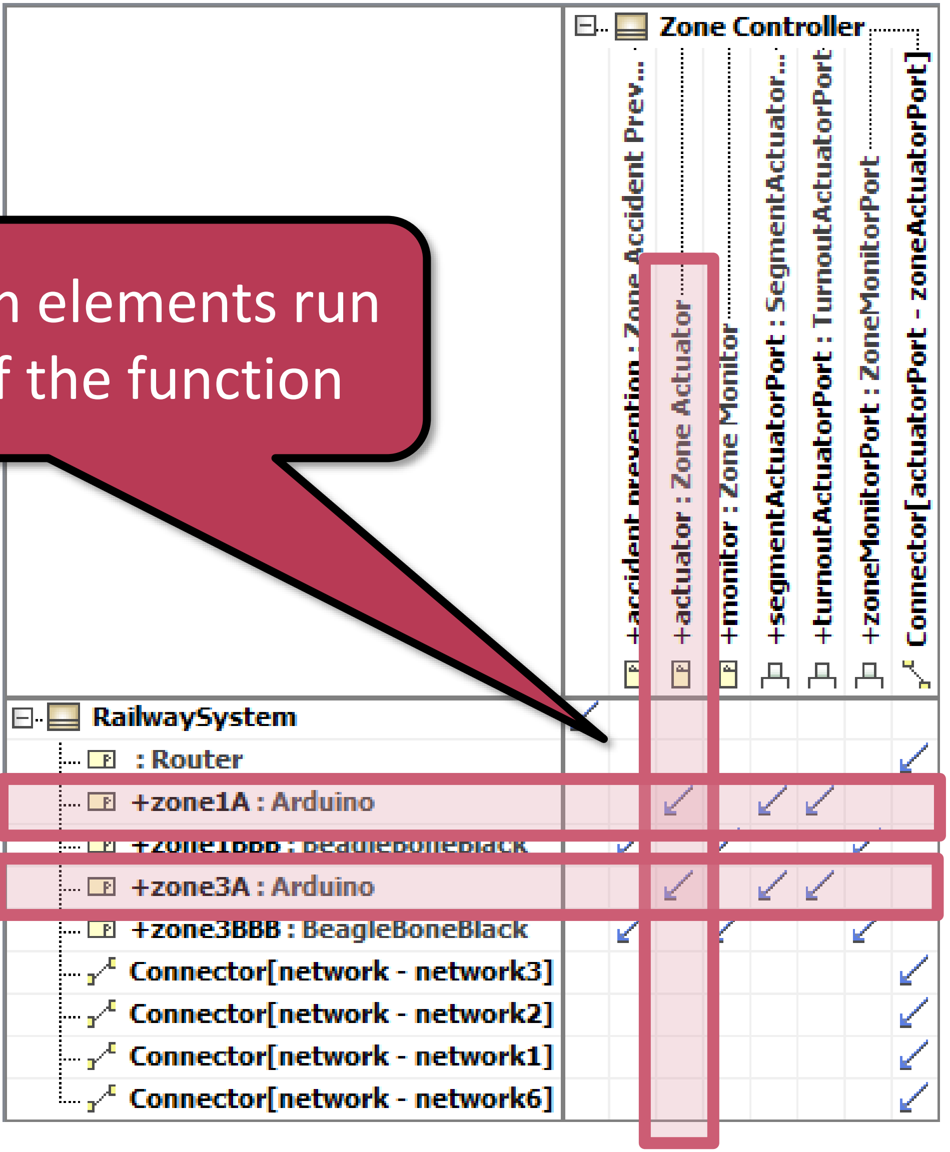
SysML allocation matrix



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



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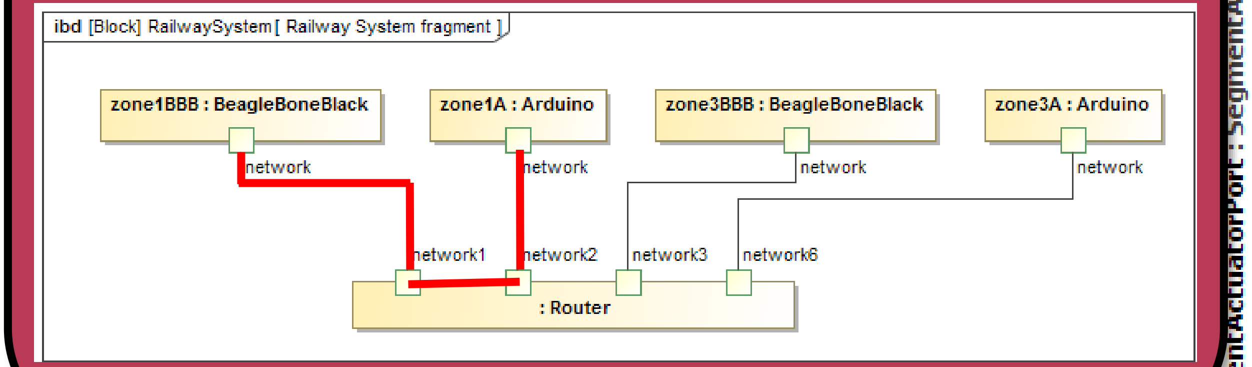
+zone1BBB : BeagleBoneBlack		↙		↙			↙	
+zone3A : Arduino			↙		↙	↙		
+zone3BBB : BeagleBoneBlack		↙		↙			↙	
Connector[network - network3]								↙
Connector[network - network2]								↙
Connector[network - network1]								↙
Connector[network - network6]								↙

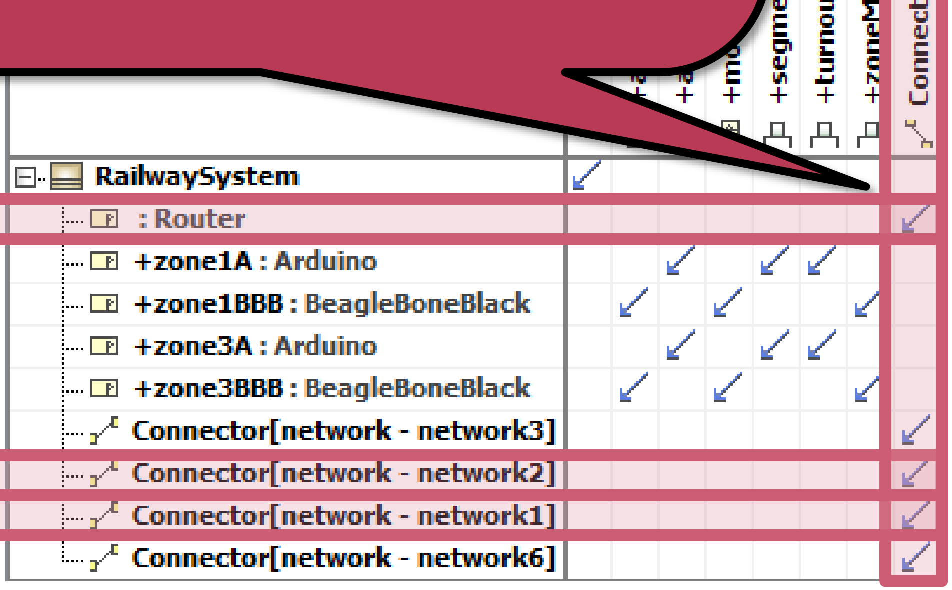
Multiple platform elements run the instances of the function

SysML allocation matrix

A logical connection is allocated to multiple elements in the platform



ibd [Block] RailwaySystem[Railway System fragment]
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

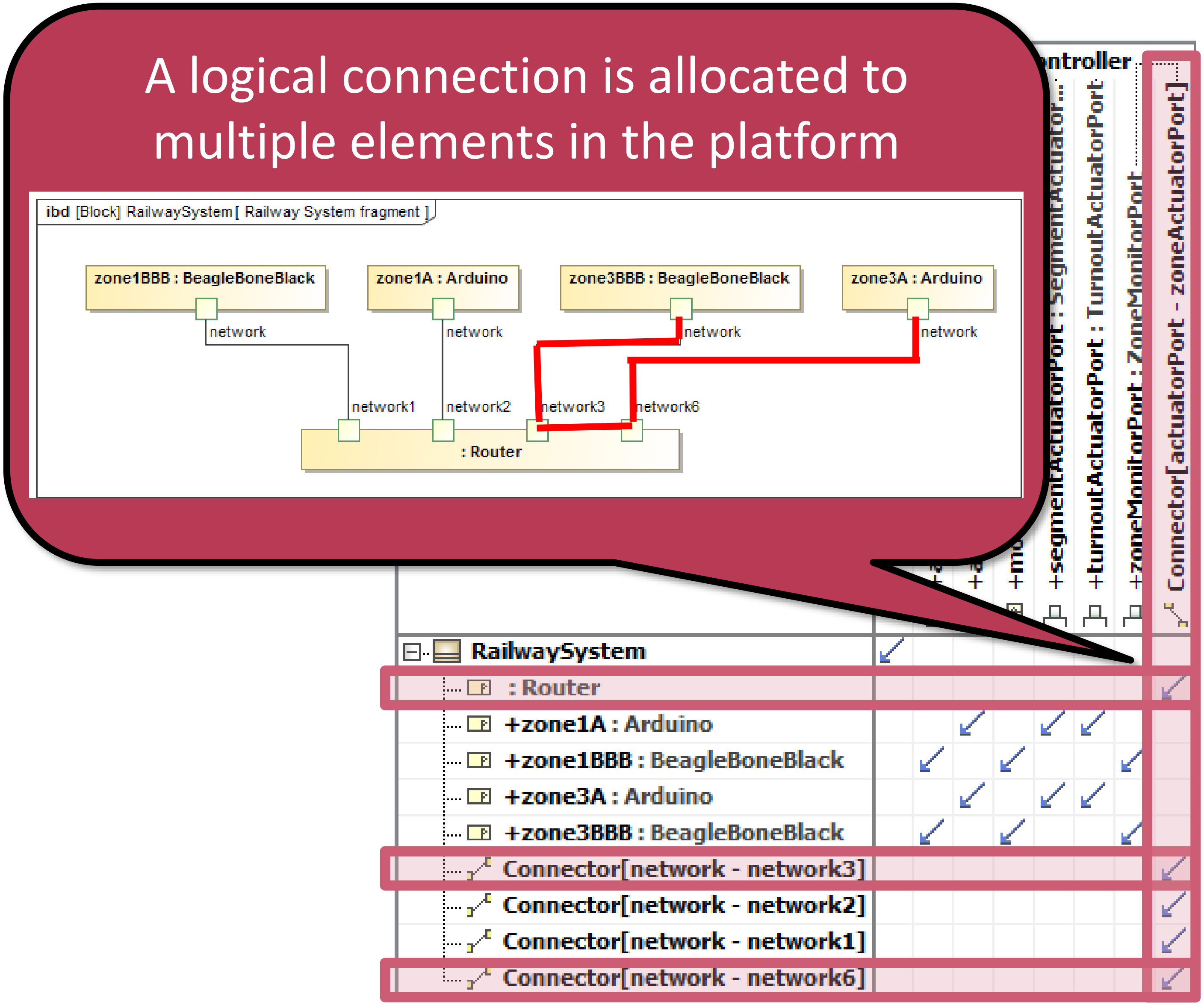


		+...	+...	+mo...	+segmentActuatorPort : SegmentActuator...	+turnoutActuatorPort : TurnoutActuatorPort	+zoneMonitorPort : ZoneMonitorPort	Connector[actuatorPort - zoneActuatorPort]
RailwaySystem	↙							
: Router								↙
+zone1A : Arduino			↙		↙	↙		
+zone1BBB : BeagleBoneBlack		↙		↙			↙	
+zone3A : Arduino			↙		↙	↙		
+zone3BBB : BeagleBoneBlack		↙		↙			↙	
Connector[network - network3]								↙
Connector[network - network2]								↙
Connector[network - network1]								↙
Connector[network - network6]								↙

...ntroller

SysML allocation matrix

A logical connection is allocated to multiple elements in the platform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zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

		+	+	+mo	+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]								↙

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

Analysis of extra-functional properties of a service

Validation of service configurations

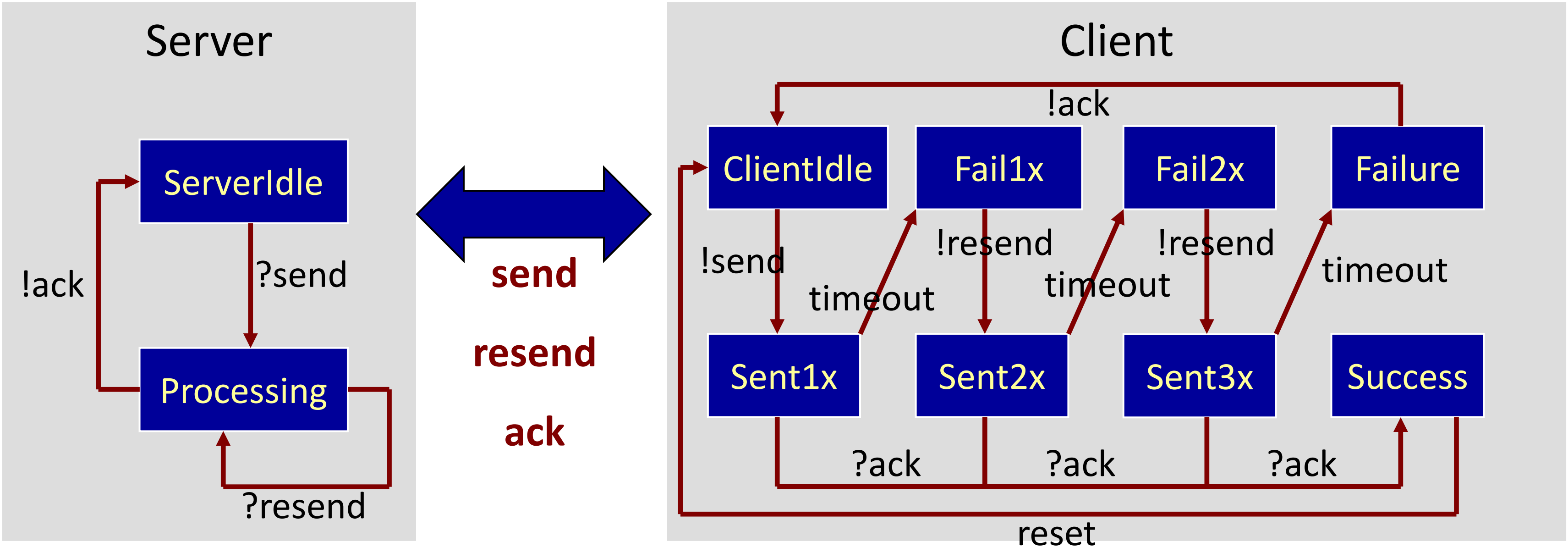
- Performability analysis
  - „Performability = Performance + Reliability”
- What happens in case of a failure?
  - E.g. the middleware responsible for reliable messaging resends the lost message → the guaranteed response time may increase (e.g. too low timeout → several false resends).
- What is the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

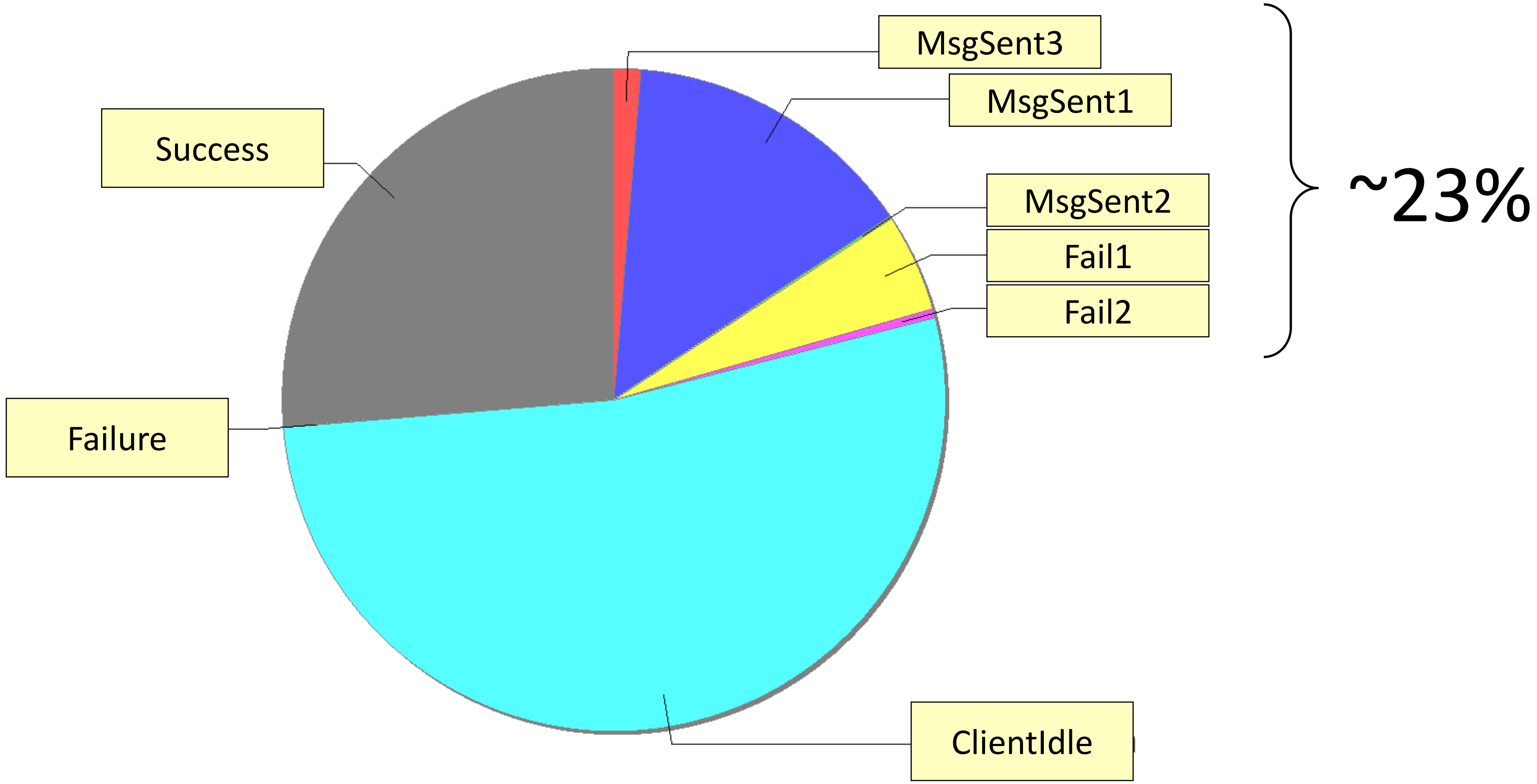
- Describes the platform
- Its parameters are included in the configuration model



Analysis results: utilization

Analysis in steady-state

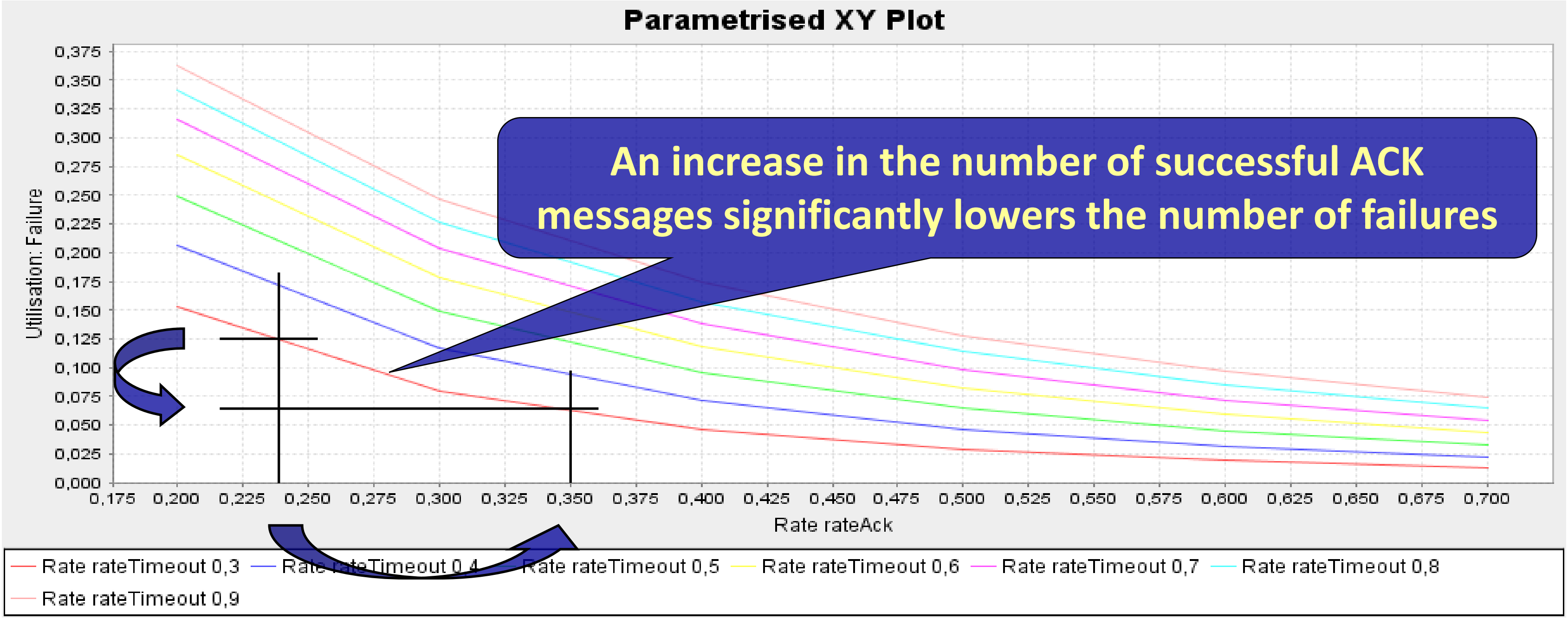
How much time does error handling take?



Sensitivity analysis results

Sensitivity analysis: what to change?

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



An increase in the number of successful ACK messages significantly lowers the number of failures

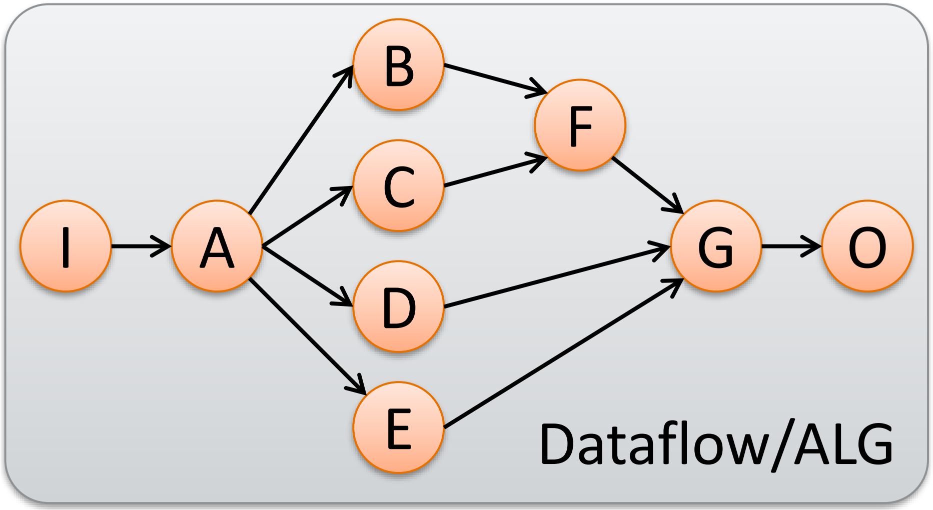
Case study

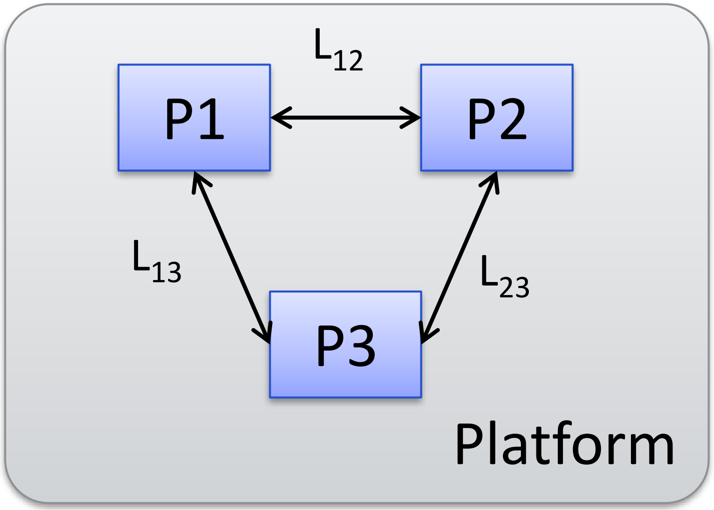
Schedule execution on a distributed platform

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]





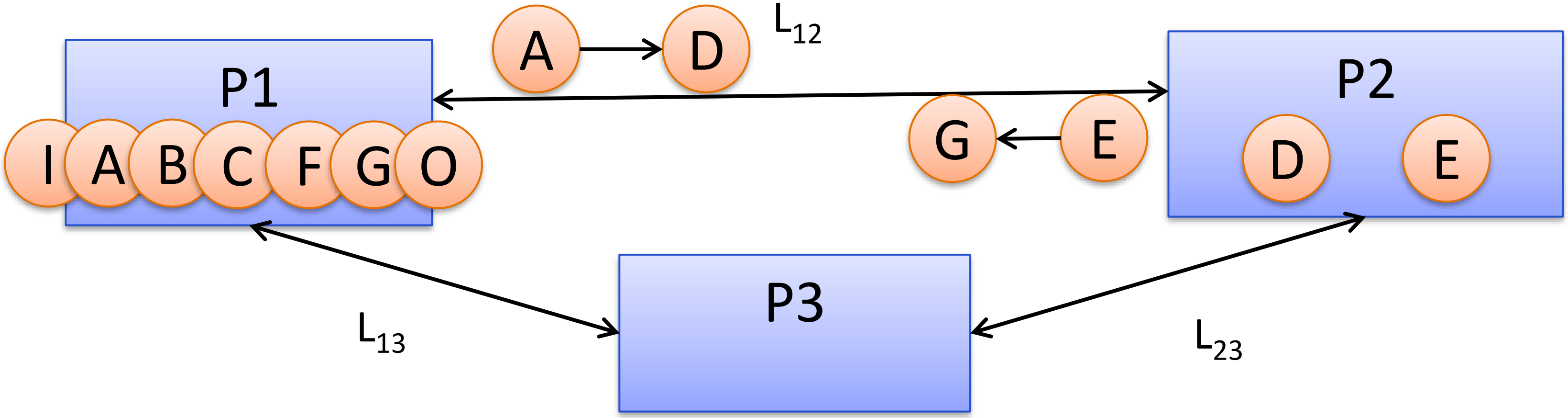
WCET	I	A	B	C	D	E	F	G	O
P1	10	20	30	20	30	10	20	14	14
P2	13	15	10	30	17	12	25	10	X
P3	X	10	15	10	30	20	10	15	18

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

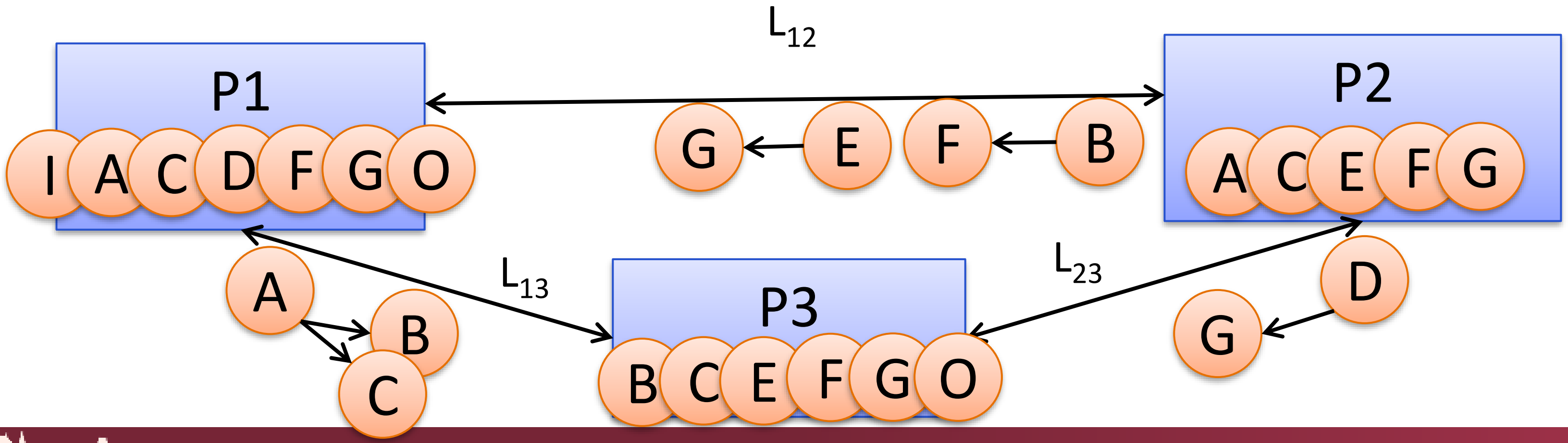
Naive solution (no FT)

	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										

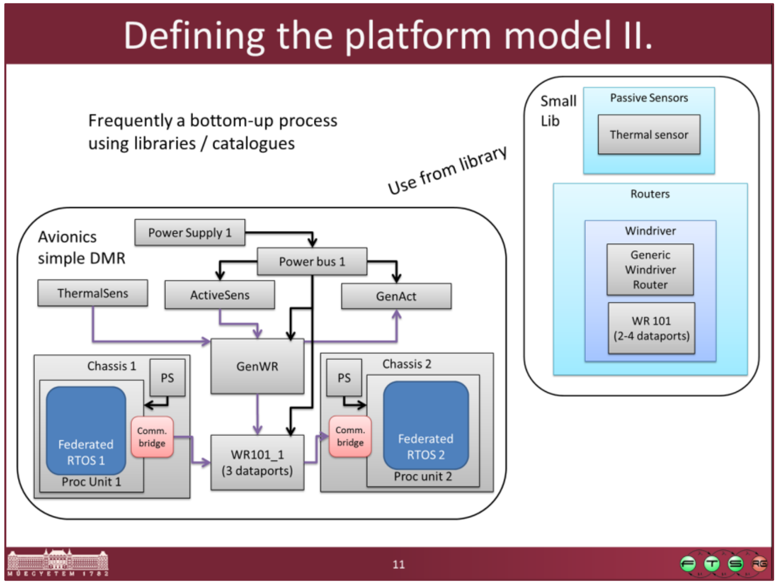


FT Allocation and Schedule

	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		

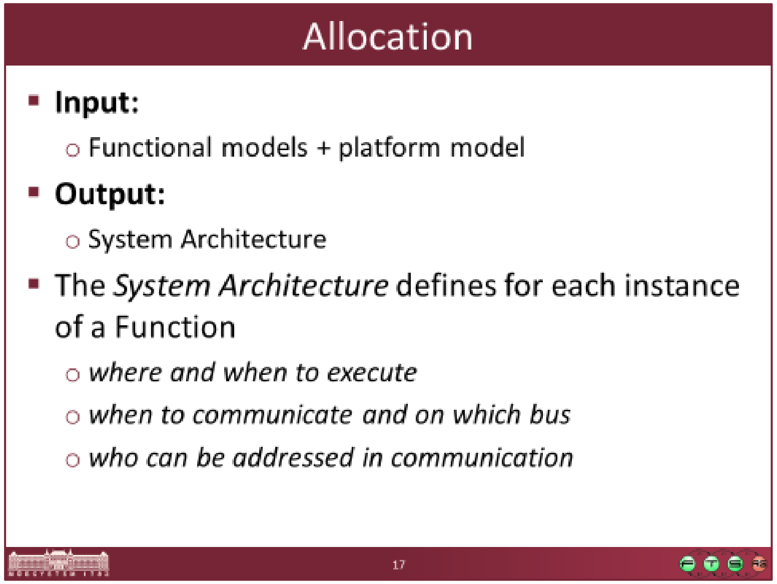


Summary



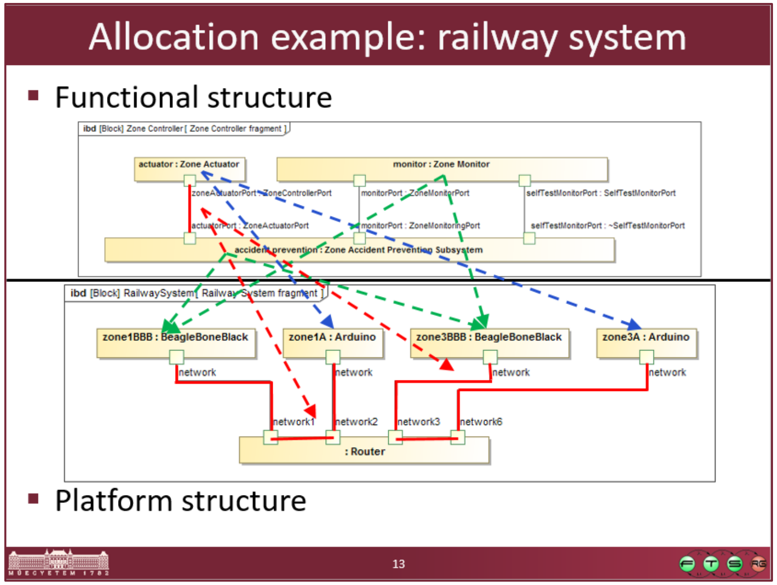
Defining the platform model II.

Frequently a bottom-up process using libraries / catalogues



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*

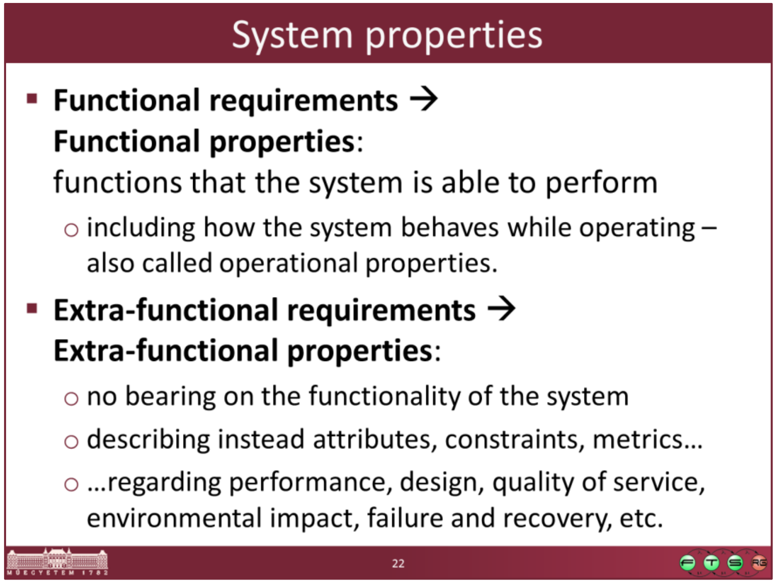


Allocation example: railway system

- Functional structure

ibd [Block] Zone Controller [Zone Controller fragment]
actuator : Zone Actuator
monitor : Zone Monitor
zoneActuatorPort : ZoneControllerPort
monitorPort : ZoneMonitorPort
selfTestMonitorPort : SelfTestMonitorPort
actuatorPort : ZoneActuatorPort
monitorPort : ZoneMonitoringPort
selfTestMonitorPort : ~SelfTestMonitorPort
accident prevention : Zone Accident Prevention Subsystem
ibd [Block] RailwaySystem [Railway System fragment]
zone1BBB : BeagleBoneBlack
zone1A : Arduino
zone3BBB : BeagleBoneBlack
zone3A : Arduino
network
network
network
network
network1
network2
network3
network6
: Router

- 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.