RobMoSys

Modeling Principles and Modeling Foundations in RobMoSys

- *Composable Models and Software for Robotics Systems*
- *Towards an EU Digital Industrial Platform for Robotics*

Tutorial at ACM / IEEE 21st Int. Conf. On Model Driven Engineering Languages and Systems (MODELS)

https://robmosys.eu
https://discourse.robmosys.eu
https://robmosys.eu/wiki

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cea
Hochschule Ulm University of Applied Sciences
KU LEUVEN
TECHNISCHE UNIVERSITÄT MÜNCHEN
COMAU
PAL ROBOTICS
SIEMENS
EUnited Robotics European Robotics Association
eclipse

The Big Picture…

We need to provide technical solutions in robotics that

- *provide great performance*
- *are safe, secure, robust, resilient, predictable, conforming to legal and ethical norms etc.*
- *are affordable, economically justifiable, manageable etc.*

- Can we think of complex robotic systems *before* we build them?
- How to manage all the heterogeneous sciences for different parts and aspects of a robotic system?
- How to answer “what if” questions?
- How to find *adequate* solutions?

You can not go through all combinations of all parameters with real systems in order to know about all the possible outcomes for the properties of your system and then select the one best fitting your requirements.

You need to be able to answer “what if” questions with tools which give the answers quickly and which are user-friendly and allow you to end up with an ***adequate solution*** (trade-off analysis, multi-criteria-optimization, constrained-based reasoning, …).

The Concept of a Data Sheet
Abstraction, Variation Points, Composition, Separation of Roles, …

RobMoSys

Certified Organic • Whole
CHOCOLATE

Nutrition Facts
Serving Size 1 cup (240mL/8fl. oz.)
Servings Per Container 16

Amount Per Serving	
Calories 210	Calories From Fat 70
	% Daily Value *
Total Fat 8g	**12%**
Saturated Fat 5g	**25%**
Cholesterol 30mg	**10%**
Sodium 190mg	**8%**
Total Carbohydrates 26g	**9%**
Dietary Fiber 1g	**4%**
Sugars 24g	
Protein 8g	

Vitamin A	6%	Vitamin C	6%
Calcium	25%	Iron	4%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

Ingredients: Organic Pasteurized Whole Milk, Organic Evaporated Cane Sugar, Organic Cocoa (processed with alkali) Organic Cocoa, Organic Tapioca Starch, Sea Salt, Carrageenan, Organic Vanilla

PICTURE QUALITY
- Full HD 1080p
- Motion Rate 60
- Wide Color Enhancer

SMART
- Smart TV
- Full Web Browser

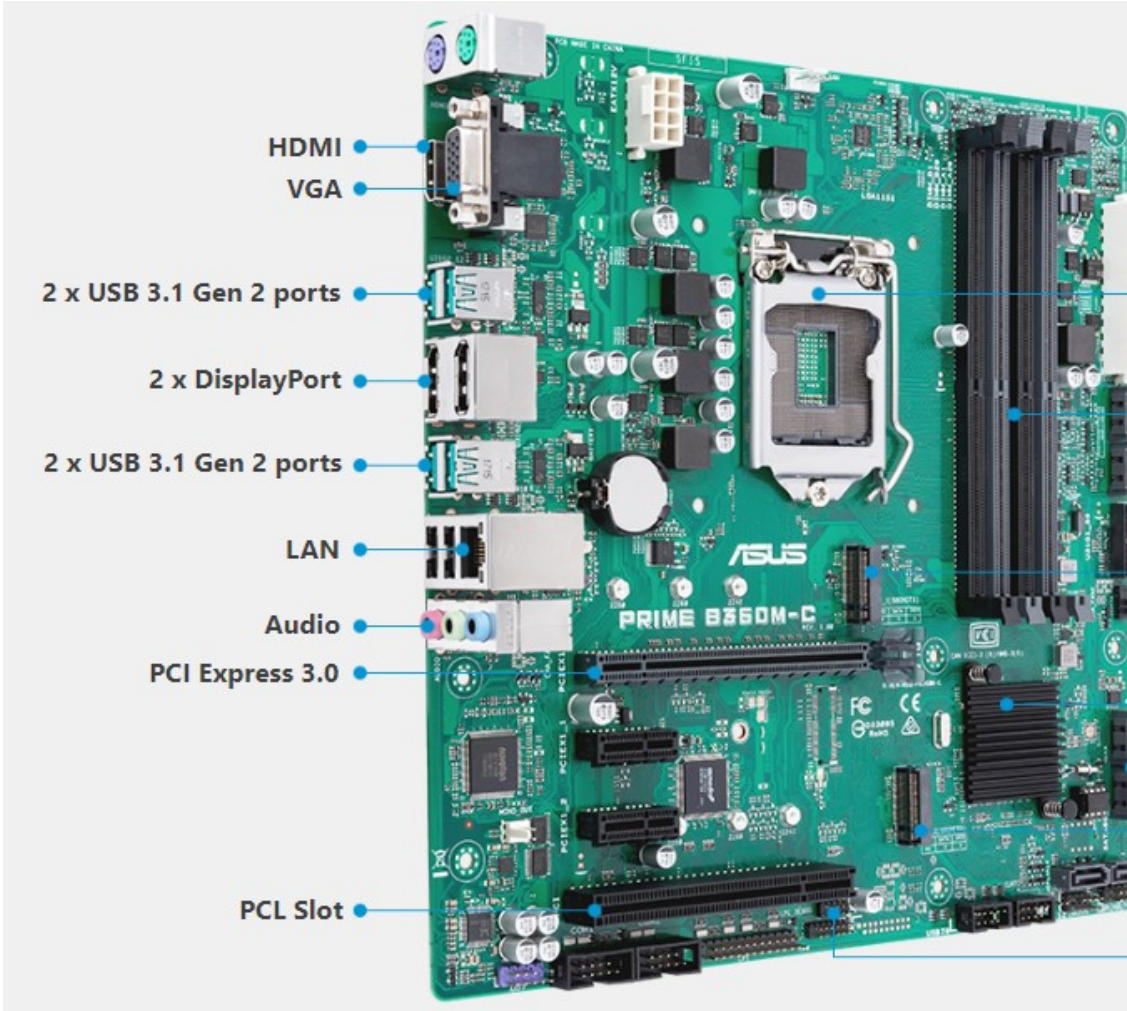
CONNECTIONS
- 2 HDMI® Connections
- 2 USB Connections
- 802.11n Wi-Fi Built In
- 1 Component in
- 1 Composite In (Shared with AV Component input)

SMART CONNECTIVITY
- Mobile Screen Mirroring
- ConnectShare™ Movie
- Wi-Fi Direct

AUDIO
- Dolby® Digital Plus
- DTS® Studio Sound
- DTS® Premium Sound 5.1™

ECO SENSOR

INCLUDES
- Standard Remote Control



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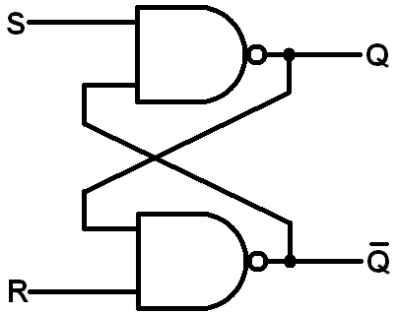
RobMoSys



$\bar{S}$	$\bar{R}$	Q	State
1	1	Previous State	No change
1	0	0	Reset
0	1	1	Set
0	0	?	Forbidden

FAIRCHILD SEMICONDUCTOR™

DM7400
Quad 2-Input NAND Gates

General Description

This device contains four independent gates each of which performs the logic NAND function.

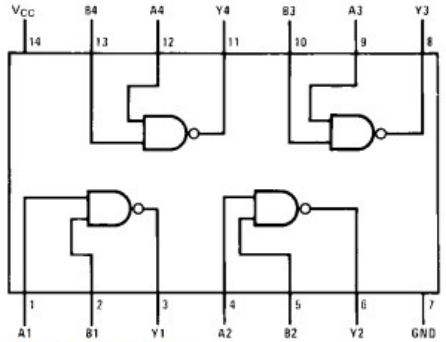
Elements of the data sheet
- general description
- ordering code
- absolute maximum ratings
- recommended operating conditions
- electrical characteristics
- switching characteristics
- physical dimensions
- life support policy

Ordering Code:

Order Number	Package Number	Package Description
DM7400M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-012, 0.150" Narrow
DM7400N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300" Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter "X" to the ordering code.

Connection Diagram



Function Table

$Y = \overline{AB}$

Inputs		Output
A	B	Y
L	L	H
L	H	H
H	L	H
H	H	L

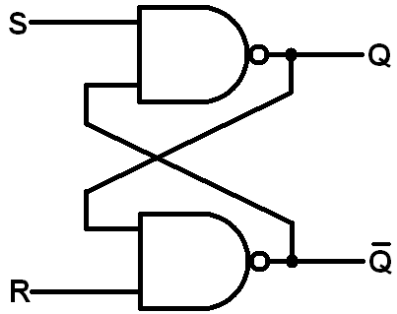
H = HIGH Logic Level
L = LOW Logic Level

Switching Characteristics

at V_{CC} = 5V and T_A = 25°C

Symbol	Parameter	Conditions	Min	Max	Units
t_{PLH}	Propagation Delay Time LOW-to-HIGH Level Output	C_L = 15 pF, R_L = 400Ω		22	ns
t_{PHL}	Propagation Delay Time				

The Concept of a Data Sheet
Abstraction, Variation Points, Composition, Separation of Roles, …



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DM7400N	N14A

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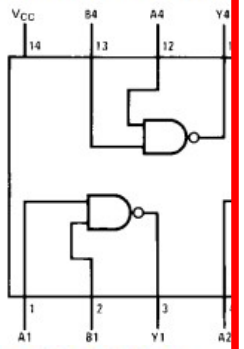
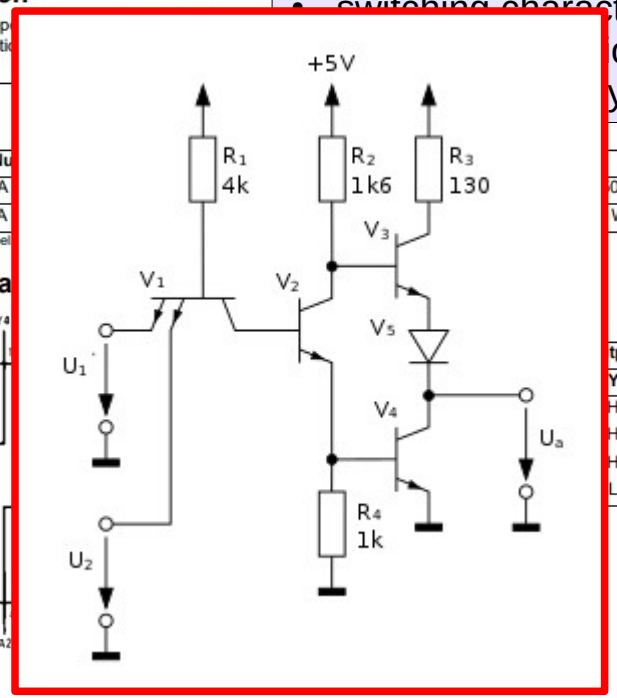
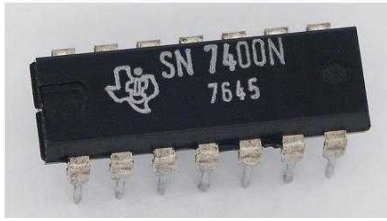


Elements of the data sheet

- general description
- ordering code
- absolute maximum ratings
- recommended operating conditions
- electrical characteristics
- switching characteristics
- …ons
- …y





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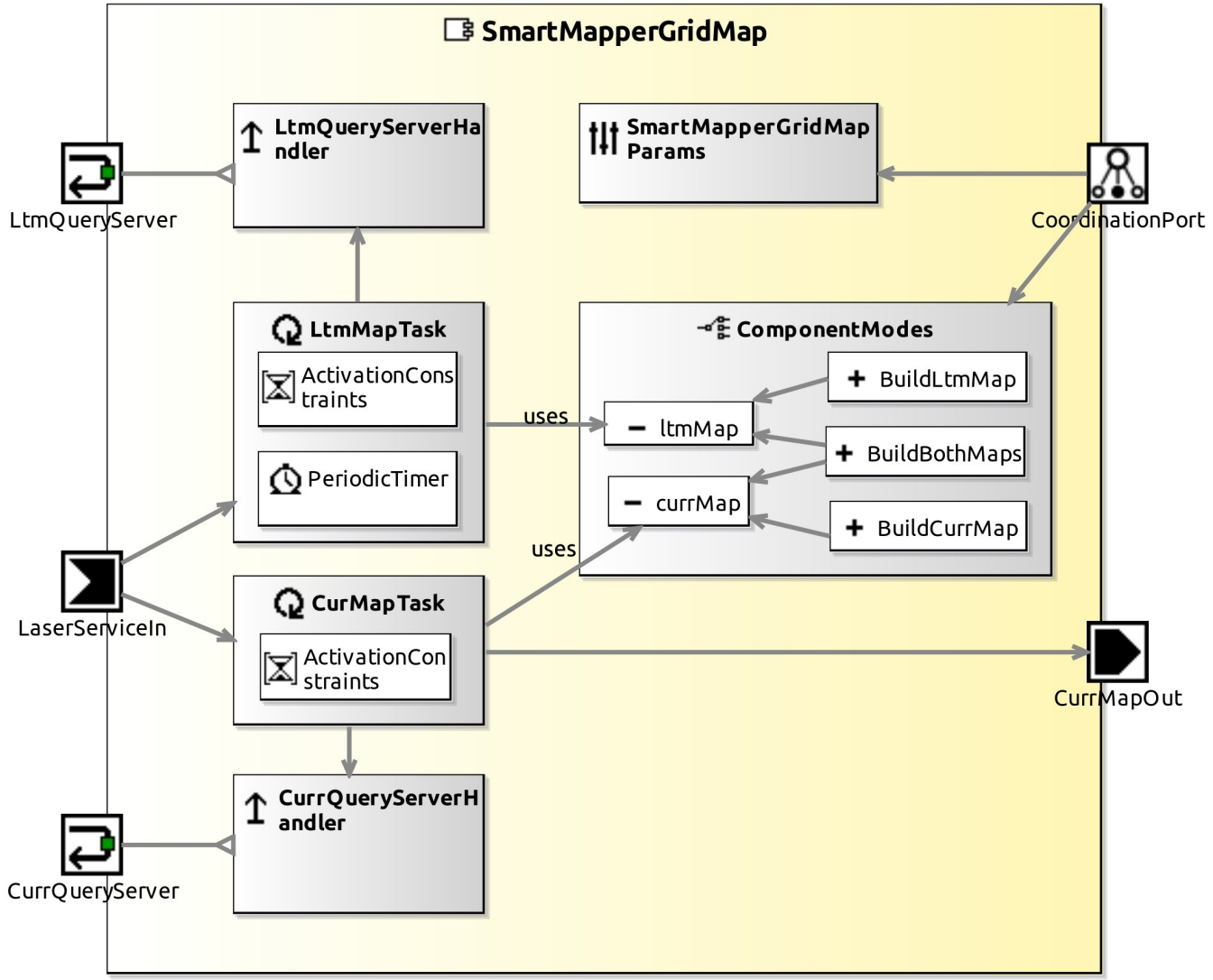
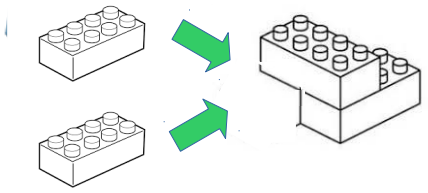
RobMoSys

```
ComponentDocumentation SmartMapperGridMap{
    Description : "The SmartMapperGridMap provides mapping services bas

                  The current map represents the late

                  The longterm map holds cell values

                  Both grid maps can be saved to XPM

                  Note: This component is used in Tut
    License : "LGPL"
    HardwareRequirements : "-"
    Purpose : "Navigation"


    NeutralMode : "No maps are being built."
    ComponentMode BuildBothMaps : "Both the current and the longterm ma
    ComponentMode BuildCurrMap : "The current map is being built."
    ComponentMode BuildLtmMap : "The longterm map is being built."

    ComponentPort LaserServiceIn {
        Description : "Port has to be connected to the laser compor
        NeutralMode : "Port is neutral, does not consume new input
        ComponentMode BuildBothMaps : "Uses laser scans to build lo
```



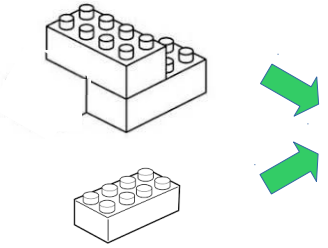
The Challenge and the Role of Models, Tools, Software in RobMoSys

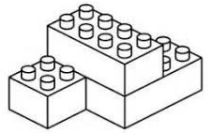
from devices to robots that act



...

from devices to robots that act





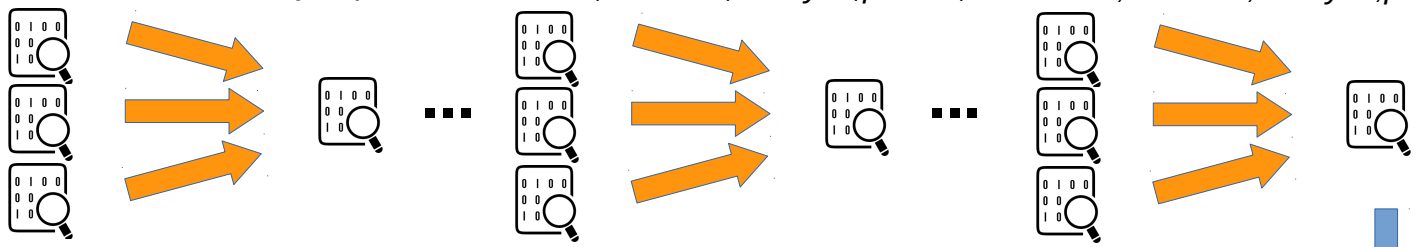
- *how to know that these blocks fit together?*
- *how to know what the properties of the combination of these blocks are?*
- *...*

The Challenge and the Role of Models, Tools, Software in RobMoSys

from models to models
enrich,combine, analyze,predict,

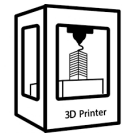
from models to models
enrich,combine, analyze,predict, ..

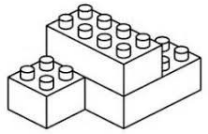
from models to models
enrich,combine, analyze,predict, ...



- *how to make these models “act”?*
- *how to link these models to devices and robots?*
- *specifying, analyzing, predicting, synthesizing, …*
  => how do these properties end up in the real system?
  => are these properties in the real system?
- *descriptive, declarative, executable, …*
  => you need solvers, interpreters, ...
- *just models everywhere…*
  - *code can be analyzed as well, …*
  - *levels of indirection vs. levels of abstraction*
- *...*

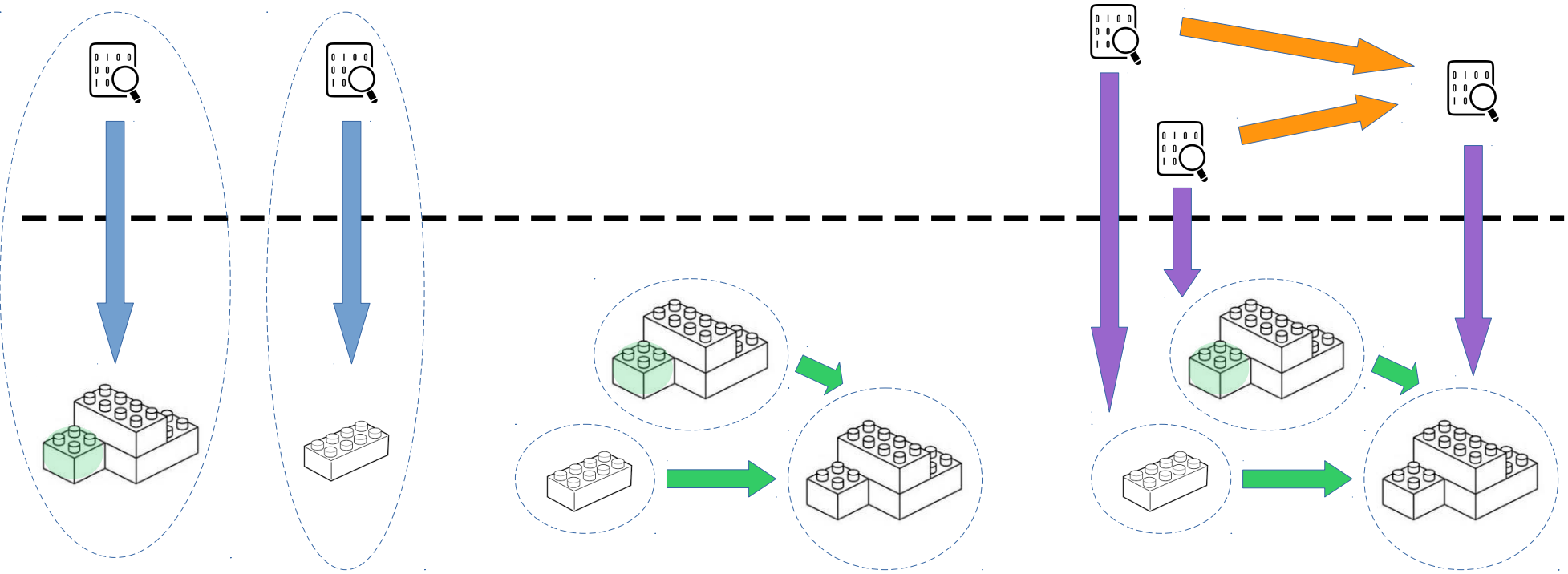
from models to robots that act
generate, execute, ...



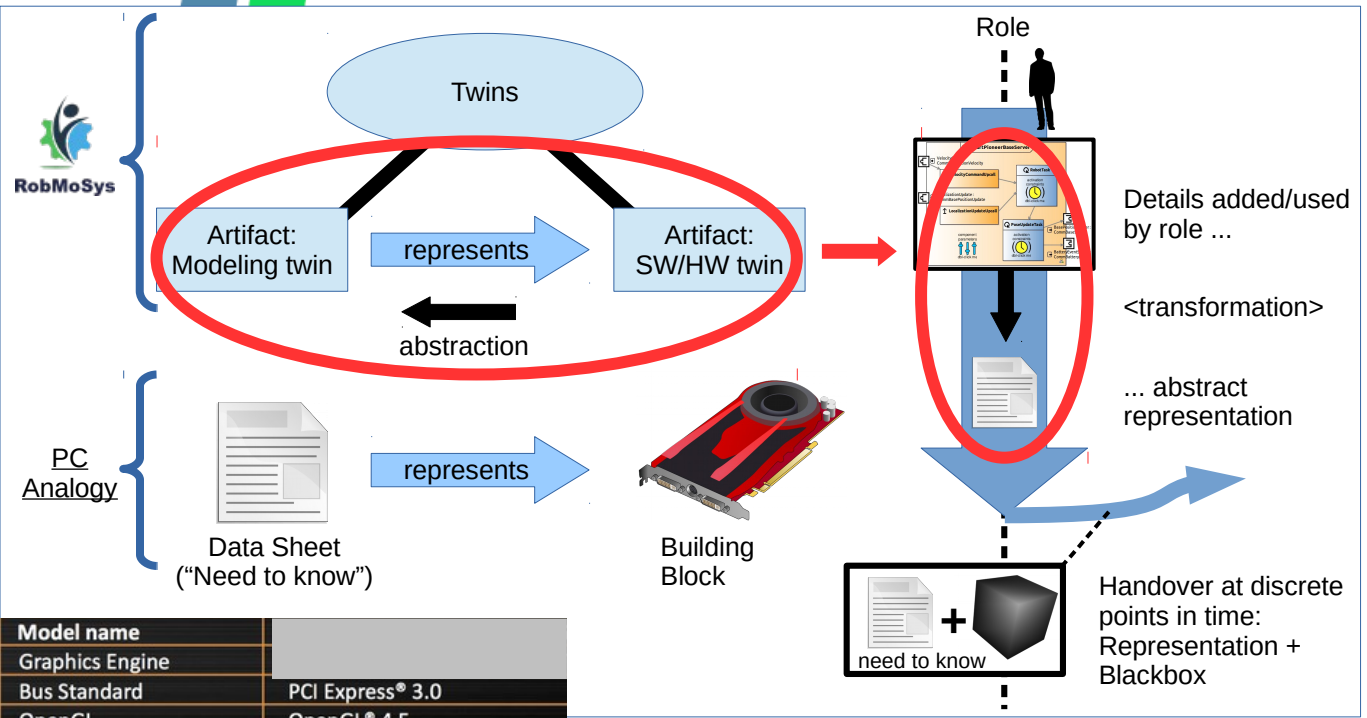


The Challenge and the Role of Models, Tools, Software in RobMoSys

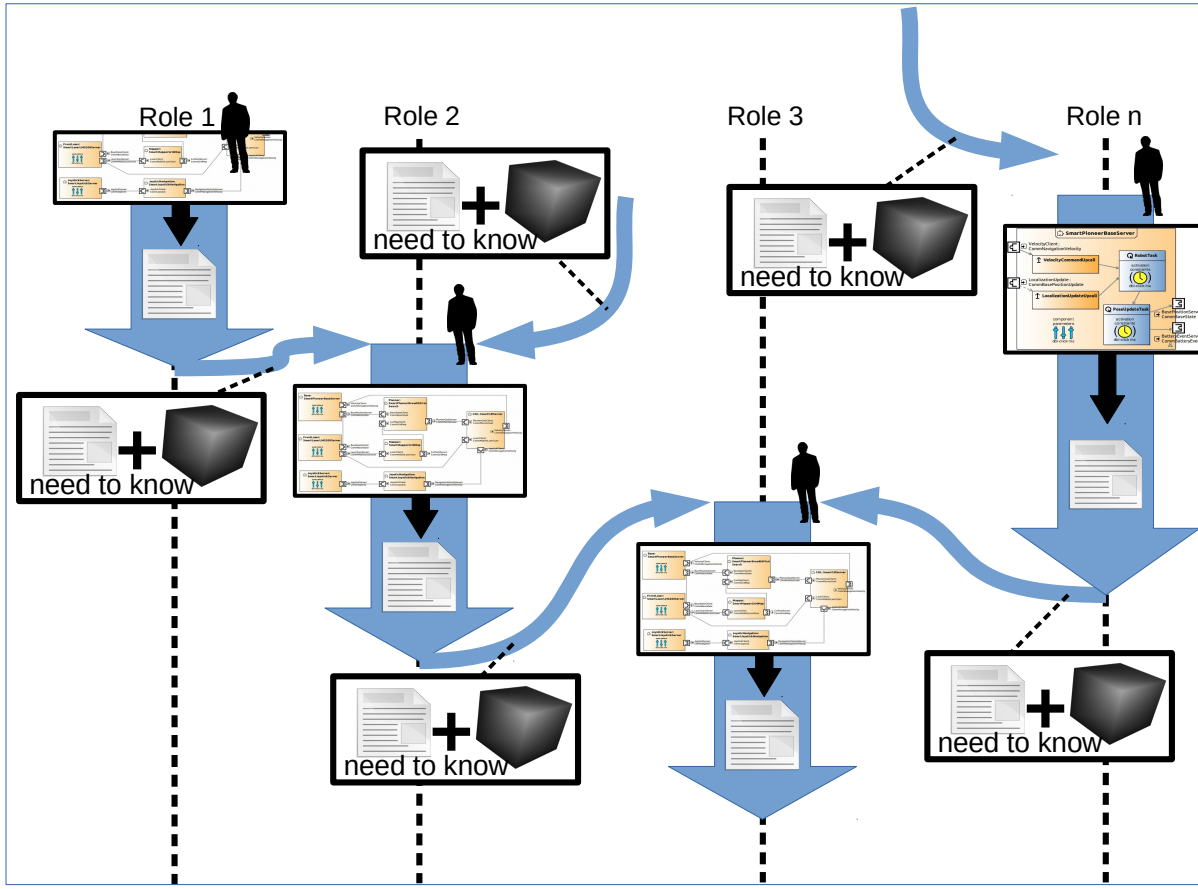
- *closed building blocks which come with ports and variation points described in a digital data sheet with “need to know” information to allow proper use of the building block via its ports*



Digital Data Sheet, Concurrent Activities, Variation Points and Composition

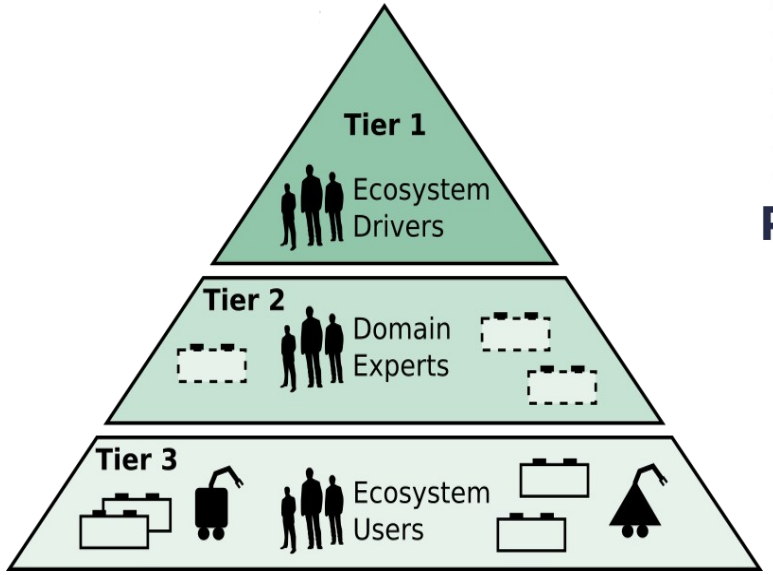


Model name	
Graphics Engine	
Bus Standard	PCI Express® 3.0
OpenGL	OpenGL® 4.5
Video Memory	11GB GDDR5X
GPU boost Clock	OC mode : 1708 MHz Gaming mode : 1683 MHz
GPU base Clock	OC mode : 1594MHz Gaming mode : 1569 MHz
	3584
Memory Clock	OC mode : 11100 MHz Gaming mode : 11010 MHz
Memory Interface	354-bit
DVI Output	1x Native Dual-link DVI-D
HDMI Output	2x Native HDMI 2.0
HDCP compliant	YES
DisplayPort	2x Native DisplayPort 1.4
Power Connectors	2x 8 pin
Software Bundled	& Driver
Max. Digital Resolution	7680 x 4320
Dimension	11.73 x 5.28 x 2.07 inches



*Support as much freedom as possible while still ensuring **composability** despite **separation of roles***

Which patterns and structures form the *Sweet Spot* between *Freedom of Choice* and *Freedom from Choice*?



RobMoSys

Separation of Concerns
- computation
- communication
- coordination
- configuration

splitting apart…

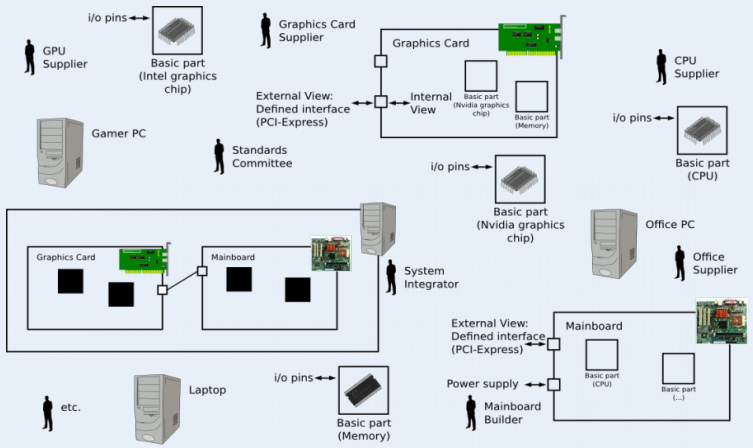
Composition, Composability, Compositionality
- computation
- communication
- coordination
- configuration

…putting together

Separation of Roles!

11

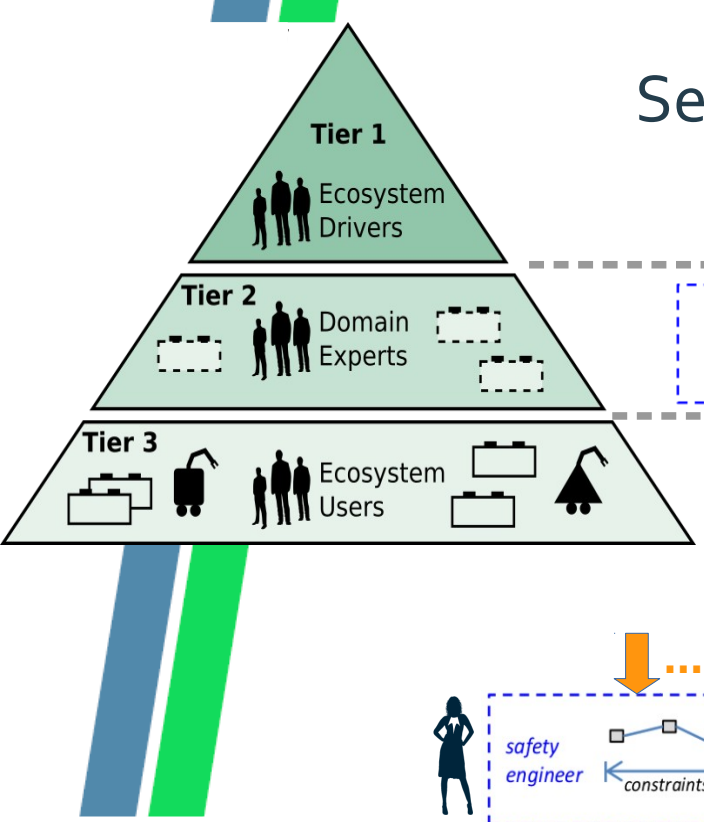
- All can be ***blocks*** with hierarchy (containment, collection).
- Blocks define structure where ***ports*** link inner parts of a block with the outer view on the block.
- Ports are linked via ***connectors***.
- Blocks come with ***data sheets***



- building blocks with data sheets (outer view on block)
- different stakeholders in different roles
- composition instead of integration

- Composition is about the **management** of the **interfaces** between different **roles** (participants in an ecosystem) in an efficient and systematic way.
- Composition is about guiding the roles via **superordinate composition-structures**.
- Composition is about explicating and managing **properties**.
- Composition is about the right **levels of abstraction and views** for roles.

Separation of Roles, Digital Data Sheets, Composition, ...

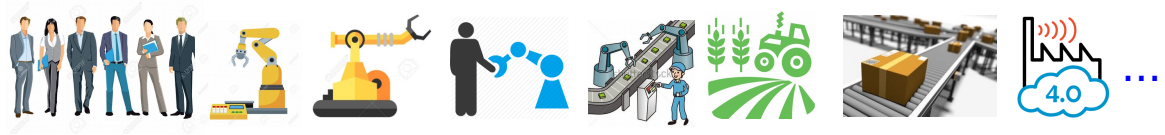


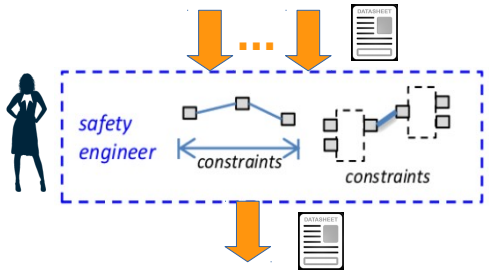
conform to

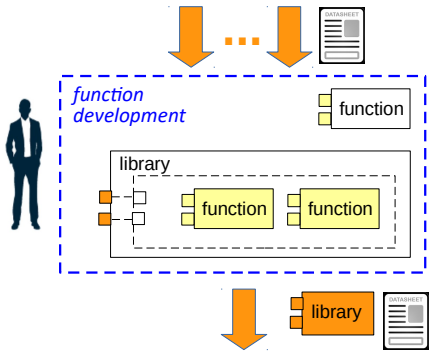
digital data structures by domain experts

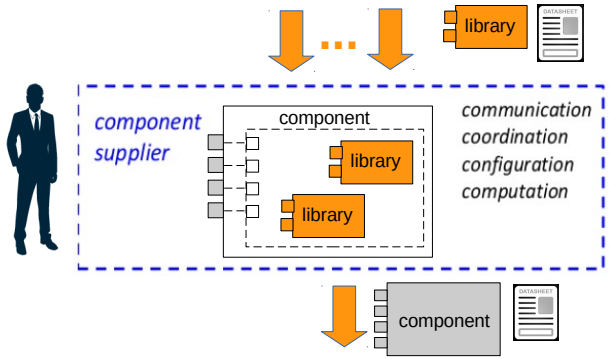
service definitions by domain experts

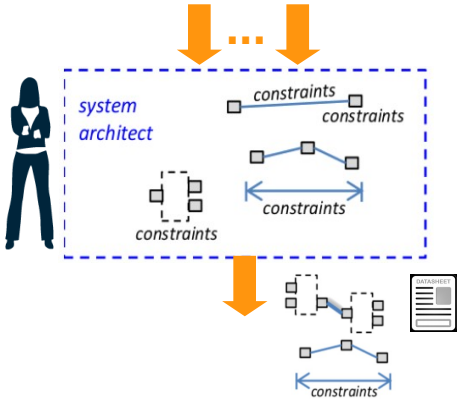
conform to

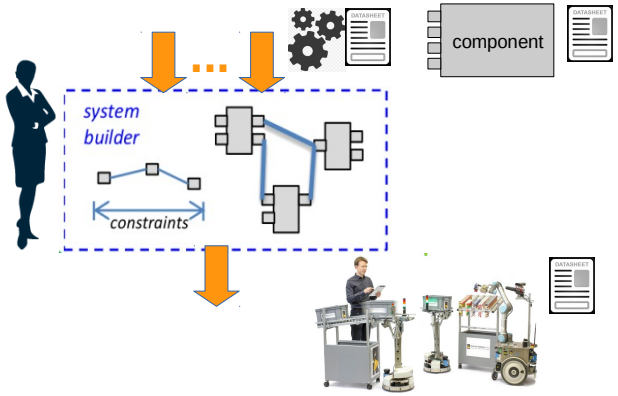


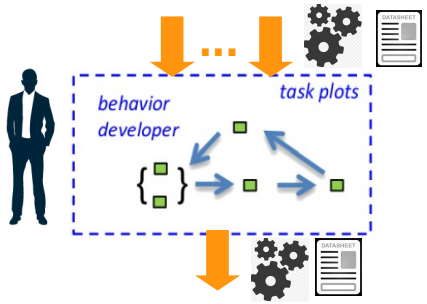


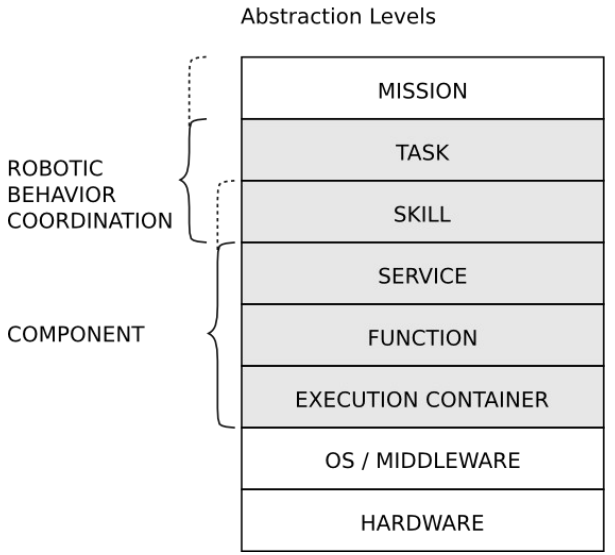








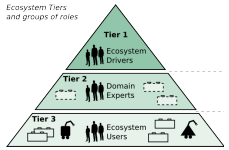




Methodology and (Meta)Models

RobMoSys: Roles and Views

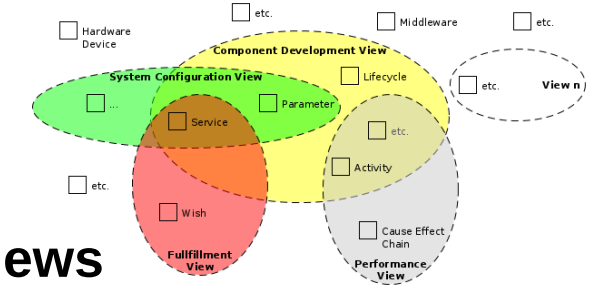
Structures



RobMoSys Composition Structures expressed in **meta-models:**

- Robotic Behavior Metamodel
- Communication-Object Metamodel
- Communication-Pattern M.-M.
- Component-Definition Metamodel
- Deployment Metamodel
- Functional Architecture Metamodel
- Cause-Effect-Chain …
- … and its Analysis Metamodels
- Service-Definition Metamodel
- System Component Architecture MM
- ...

Views



Each role uses dedicated ***views*** to work on models, the modeling twin and the building block, e.g.

- Communication Pattern View
- Component Development View
- Service Design View
- System Configuration View
- Performance View
- Service Architecture View
- ...

Participants

The participants in the ecosystem take one or several ***roles*** to use and supply building blocks:

- Behavior Developer
- Component Supplier
- Function Developer
- Performance Designer
- Safety Engineer
- Service Designer
- System Architect
- System Builder
- ...

Tooling

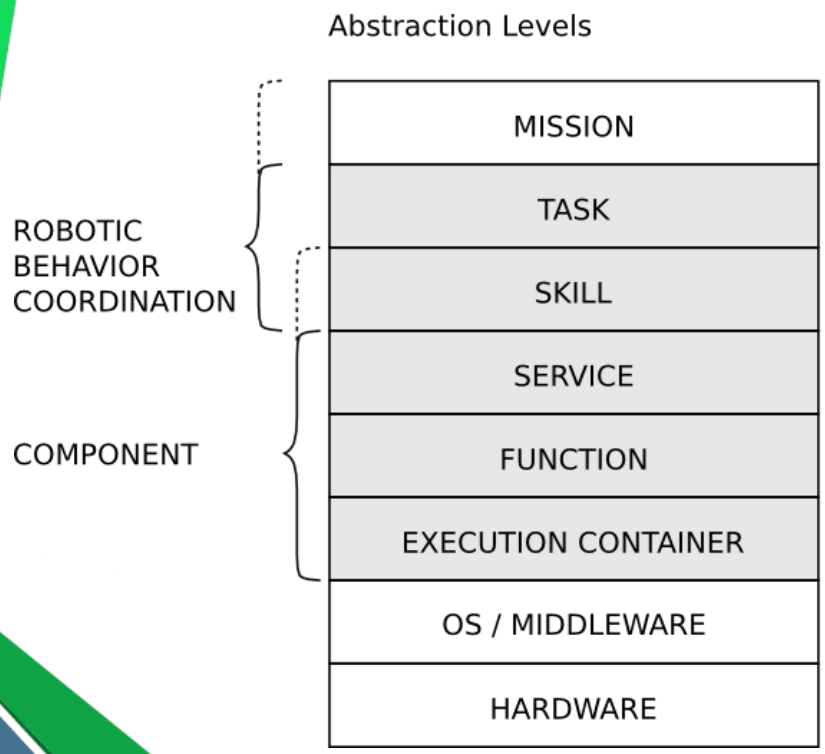
… …

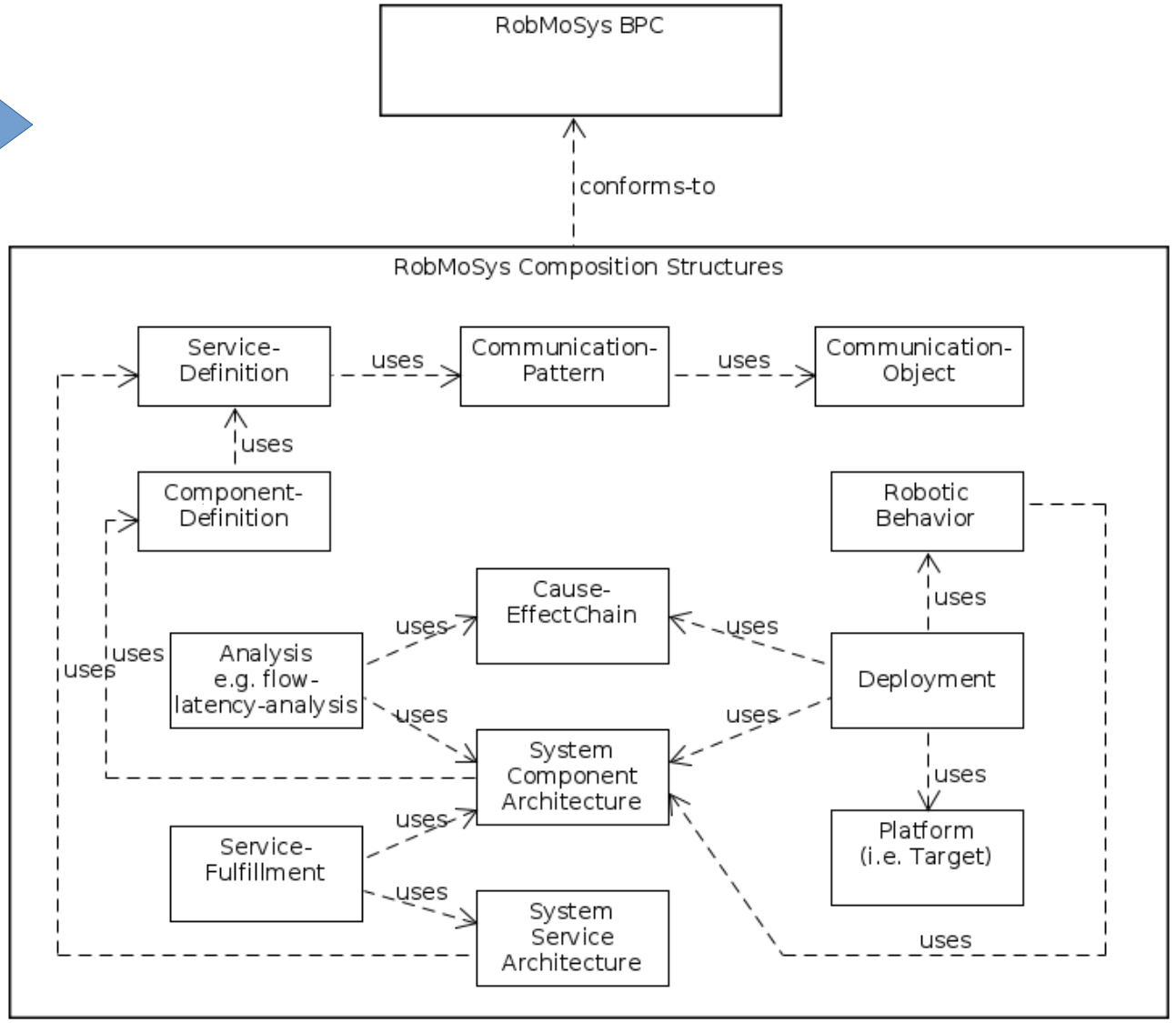
Which patterns and structures form the *Sweet Spot* between *Freedom of Choice* and *Freedom from Choice*?

*Support as much freedom as possible while still ensuring **composability** despite **separation of roles***

RobMoSys Composition Structures

Via Architectural Patterns

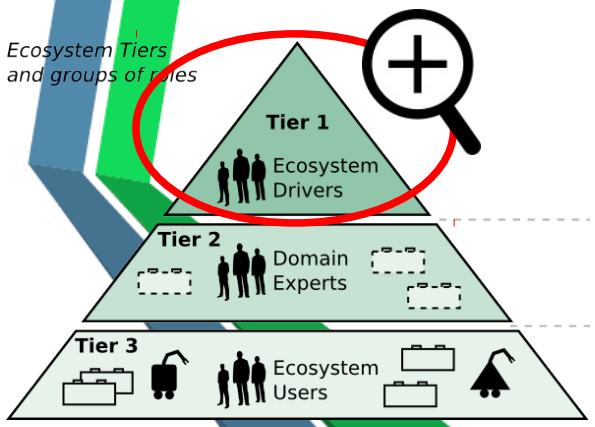


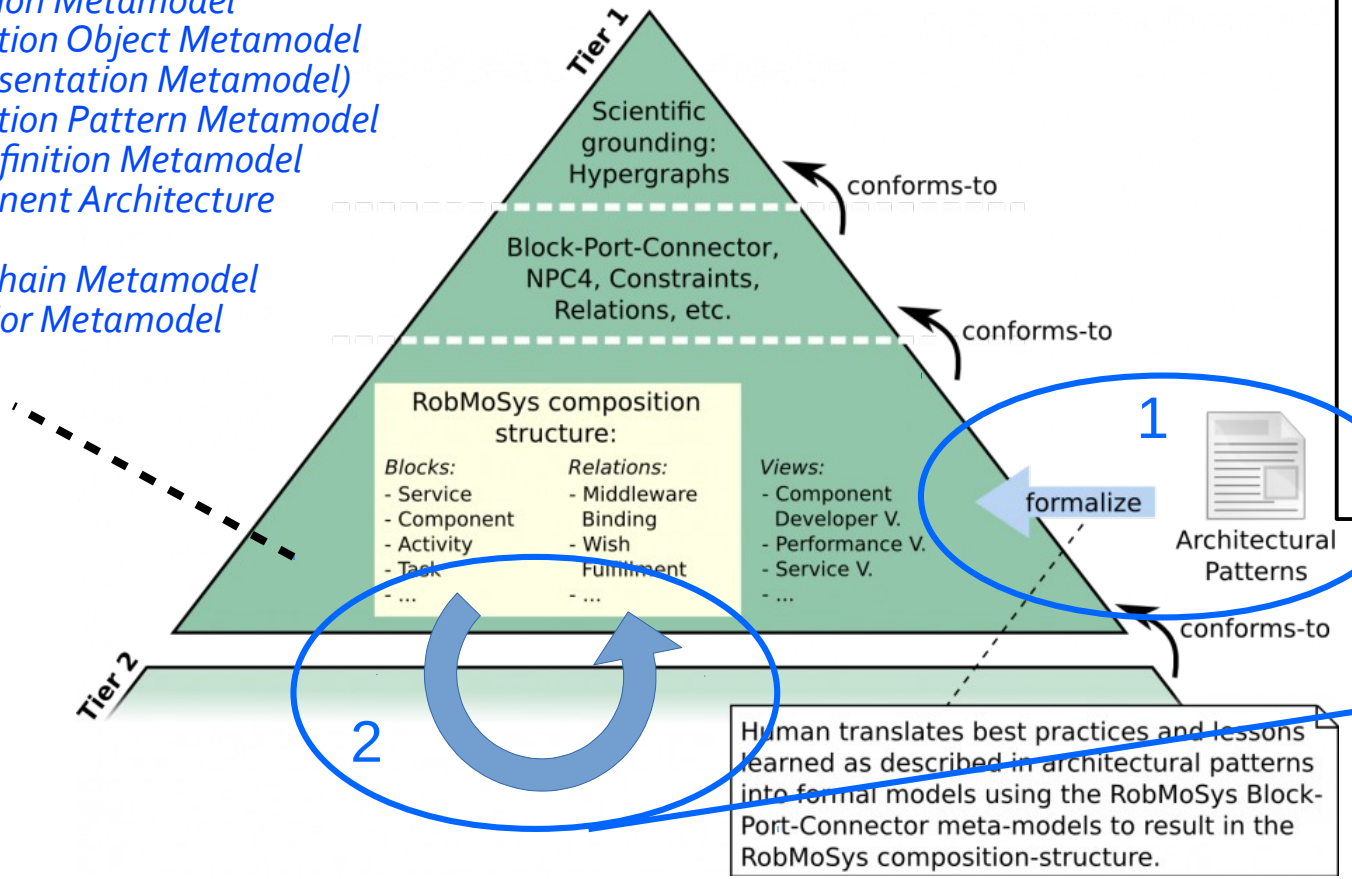


Tier 1: Modeling Foundations

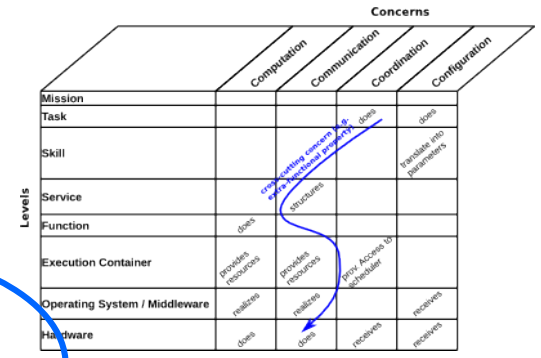
Tier 1 provides the **general structures for composition.** Three levels can be distinguished:

- *Service-Definition Metamodel*
  - *Communication Object Metamodel (Data Representation Metamodel)*
  - *Communication Pattern Metamodel*
- *Component Definition Metamodel*
- *System Component Architecture Metamodel*
- *Cause-Effect-Chain Metamodel*
- *Robotic Behavior Metamodel*
- *…*



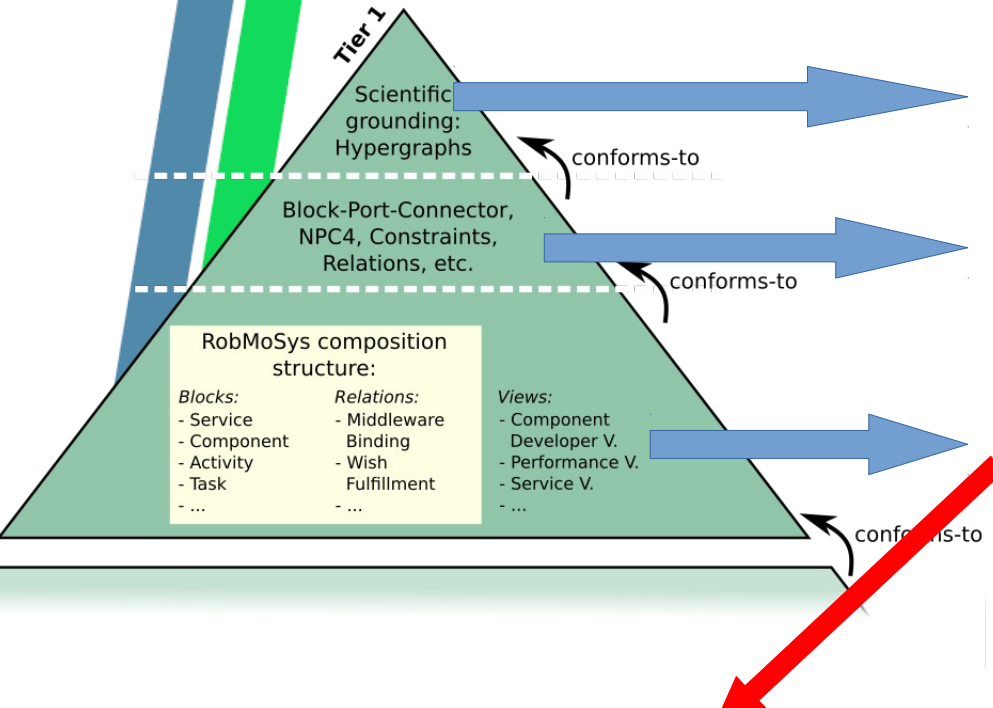


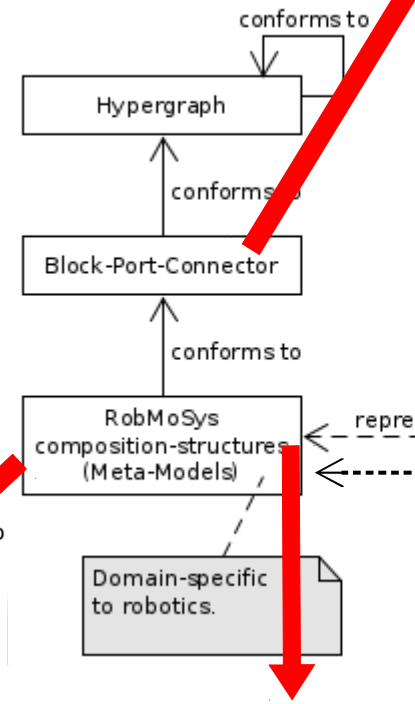
Architectural Patterns:
- levels / concerns
- composability
- separation of roles



But how to come up with structures?
→ 1: Existing Knowledge
→ 2: Iterate by applying internally and via ITP

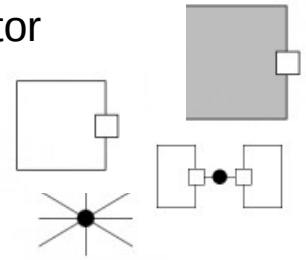
RobMoSys Tier 1 in Detail

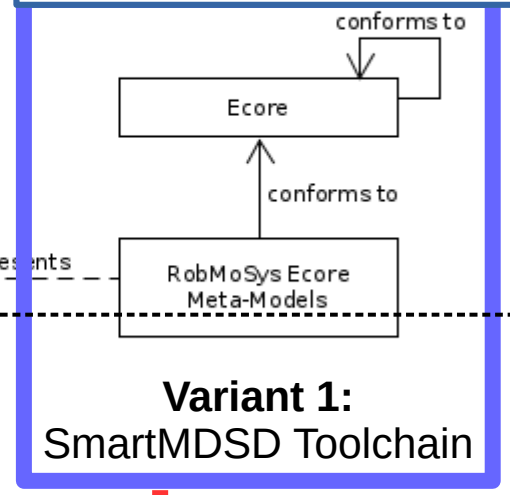




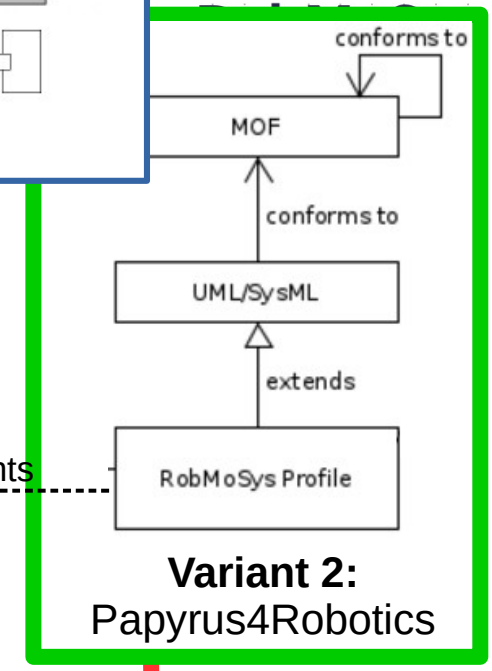
Block-Port-Connector (BPC) Model

- Block, port, connector
- Has-a
- Contains
- Connection
- Collection
- ...



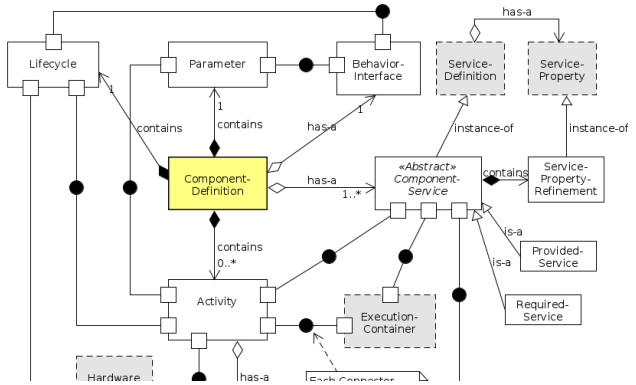


Variant 1:
SmartMDSD Toolchain

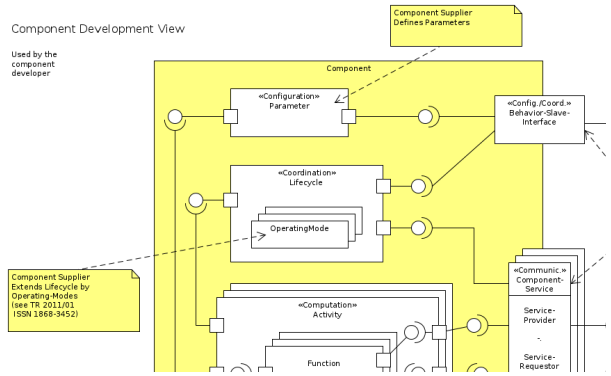


Variant 2:
Papyrus4Robotics

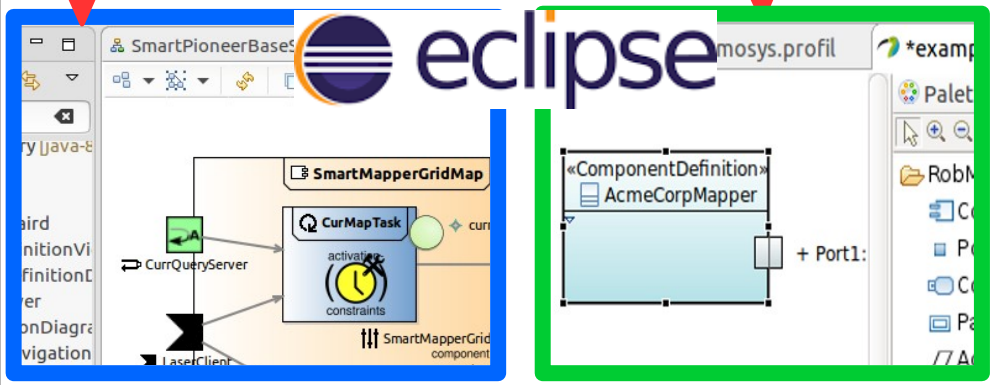
Composition Structures



Role-Specific Views



Realization in RobMoSys Tooling



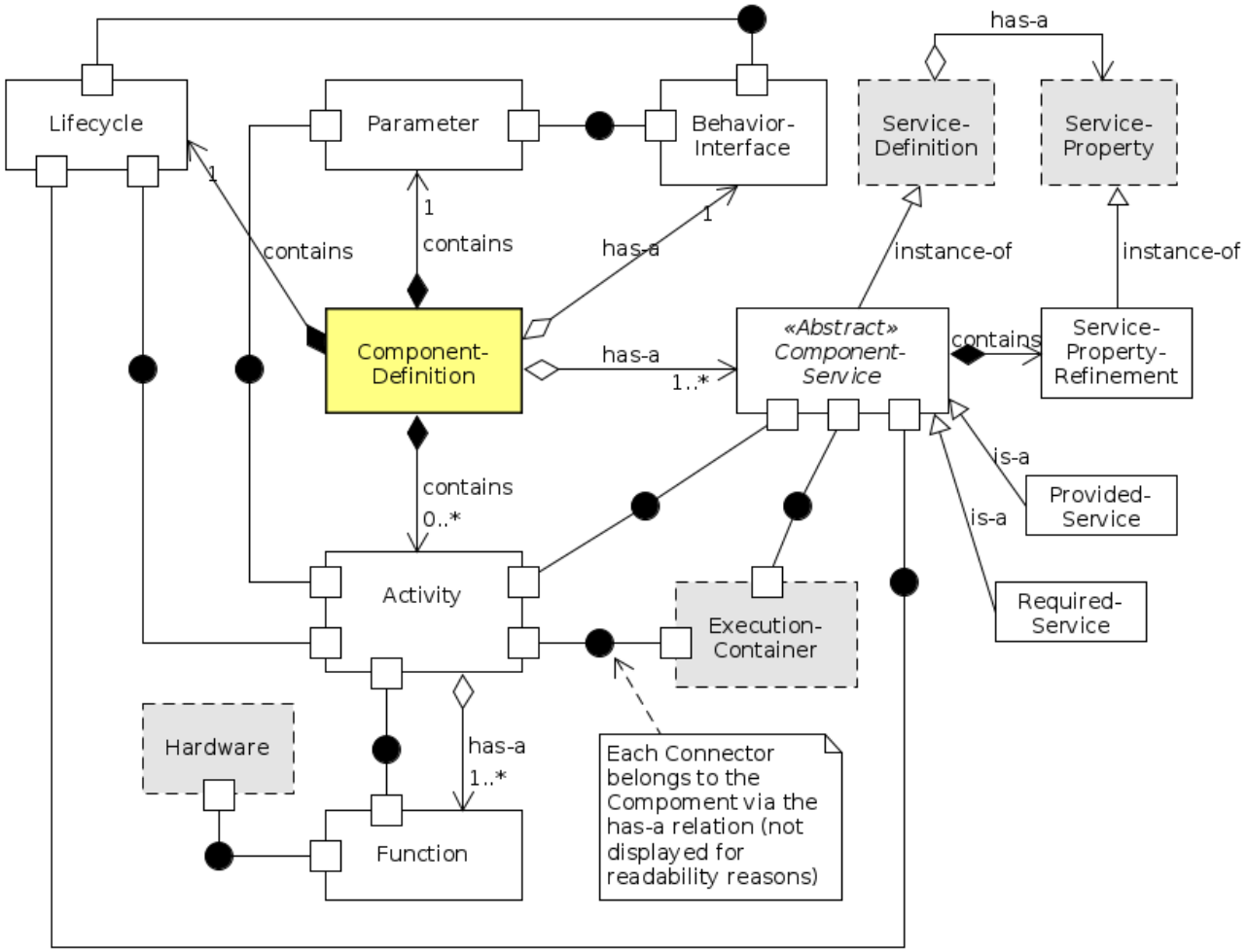
RobMoSys Tier 1 in Detail

Block-Port-Connector (BPC) Model

- Block, port, connector
- Has-a
- Contains

Block-Port-Connector to Define Meta-Models (Composition Structures)

- Robotic Behavior Metamodel
- Communication-Object Metamodel
- Communication-Pattern Metamodel
- Component-Definition Metamodel
- Deployment Metamodel
- Functional Architecture Metamodel
- Cause-Effect-Chain and its Analysis Metamodels
- Platform Metamodel
- System Service Architecture and Service Fulfillment Metamodels
- Service-Definition Metamodel
- System Component Architecture Metamodel
- ...



Shown: Component-Definition Metamodel

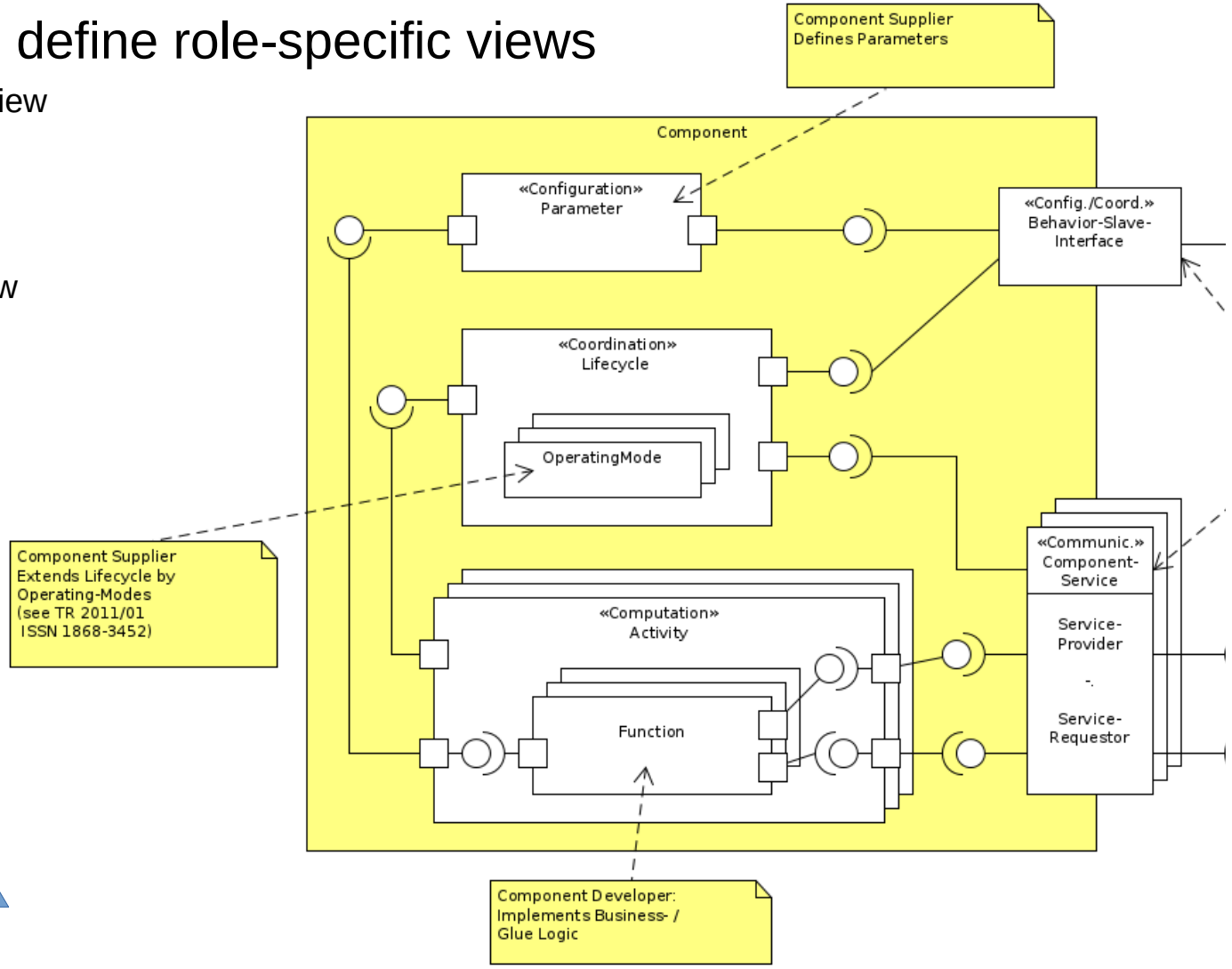
RobMoSys Tier 1 in Detail

Block-Port-Connector (BPC) Model

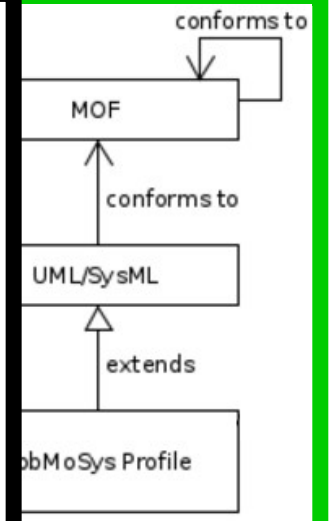
- Block, port, connector
- Has-a
- Contains

BPC::Collection to define role-specific views

- Communication Pattern View
- Component Development View
- Execution Container View
- Service Design View
- System Configuration View
- Performance View
- Deployment View
- Service Architecture View
- Service Fulfillment View
- …

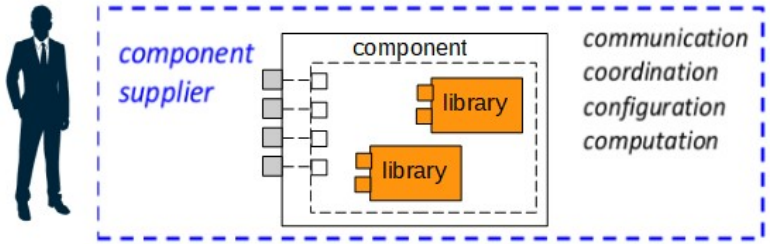


Shown: Component Development View



Variant 2:
yrus4Robotics

Example: Software Component



RobMoSys

Communication:
- Send
- Query
- Push
- Event

Coordination / Configuration:
- Parameter
- State (Lifecycle)
- Dynamic Wiring
- Monitoring

coordination service

state

monitoring

parameter

dynamic wiring

Component Lifecycle

Init

Alive

<<further user defined modes can be added in here>>

FatalError

Shutdown

Monitoring

User Space Component Builder

managed tasks

functional library

functional library

send

query

query

...

System Builder

execution container (tasks, ...)

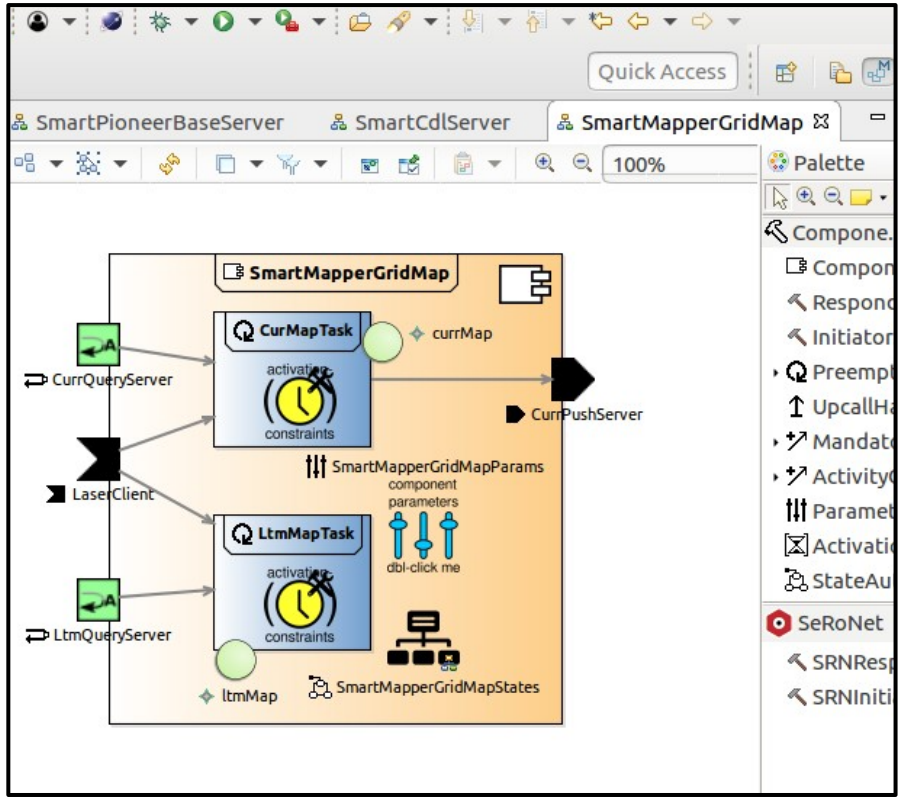
middleware / OS

RobMoSys Tier 1 in Detail

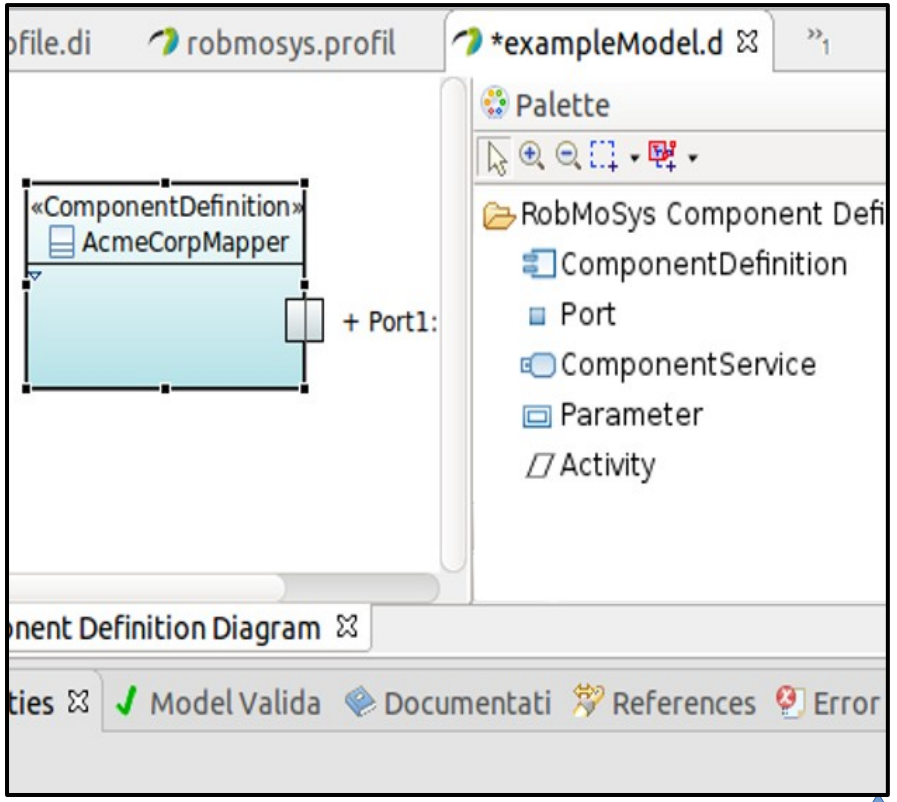
Block-Port-Connector (BPC) Model

- Block, port, connector
- Has-a
- Contains

RobMoSys Tooling to make use of Composition Structures

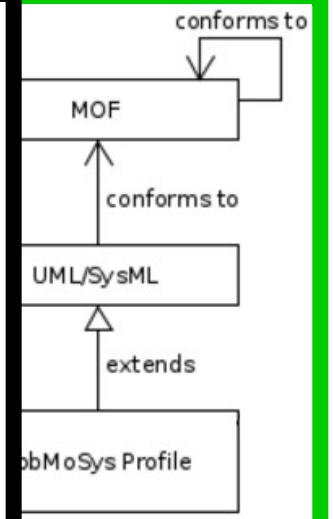


SmartMDSD Toolchain

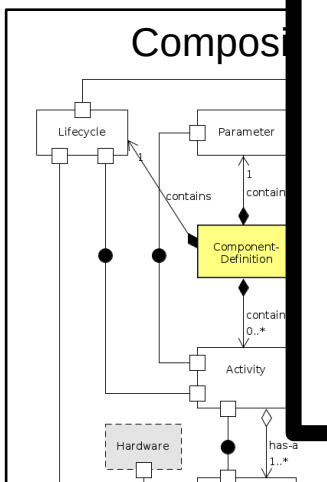


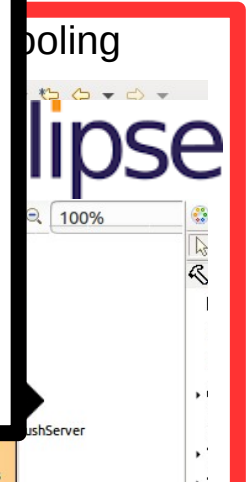
Papyrus4Robotics

eclipse

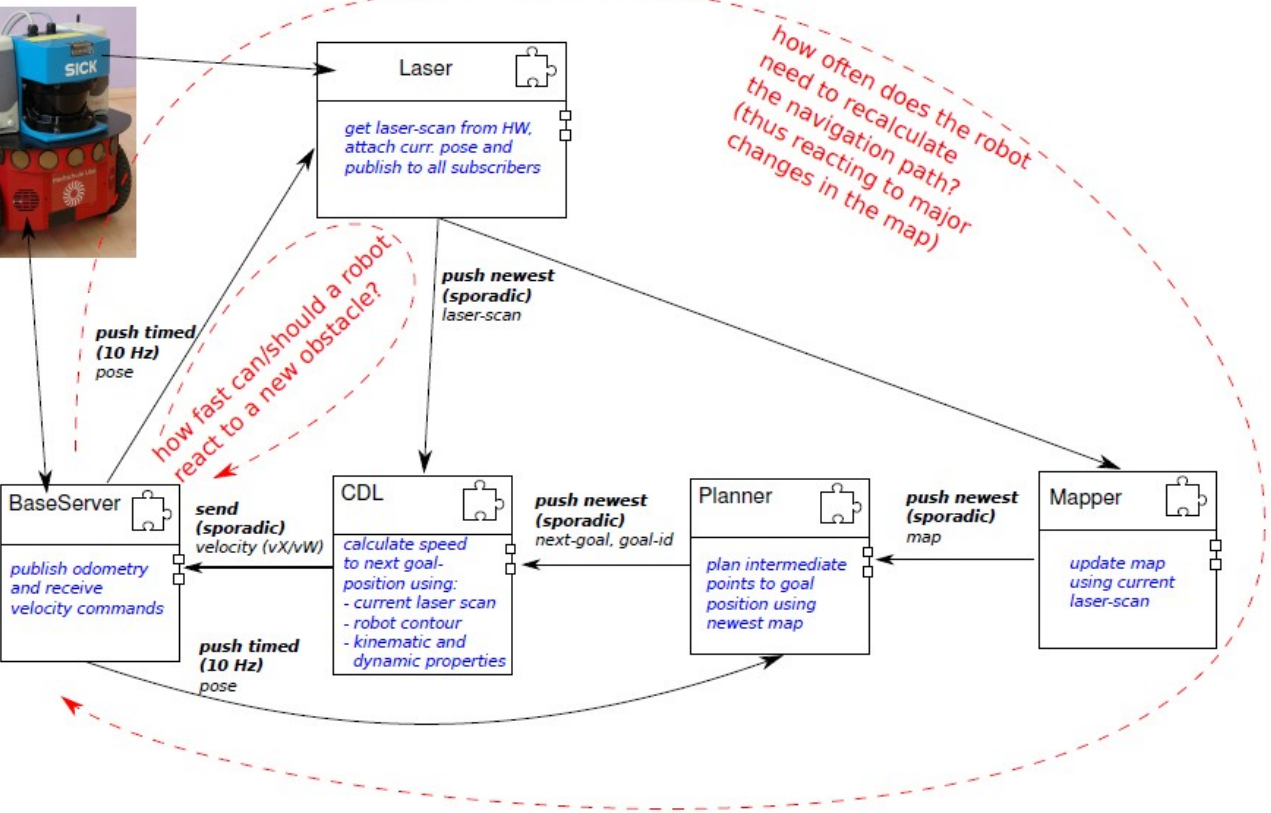


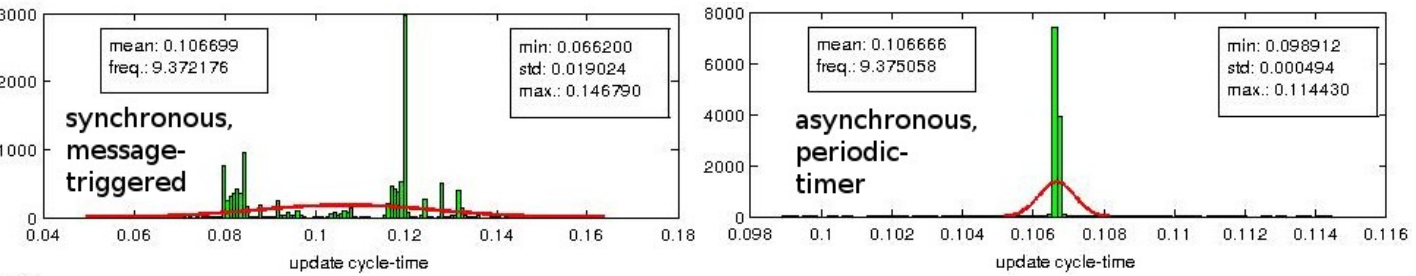
Variant 2:
Papyrus4Robotics





Horizontal / Vertical Composition: Dependency Graphs => Example Performance View

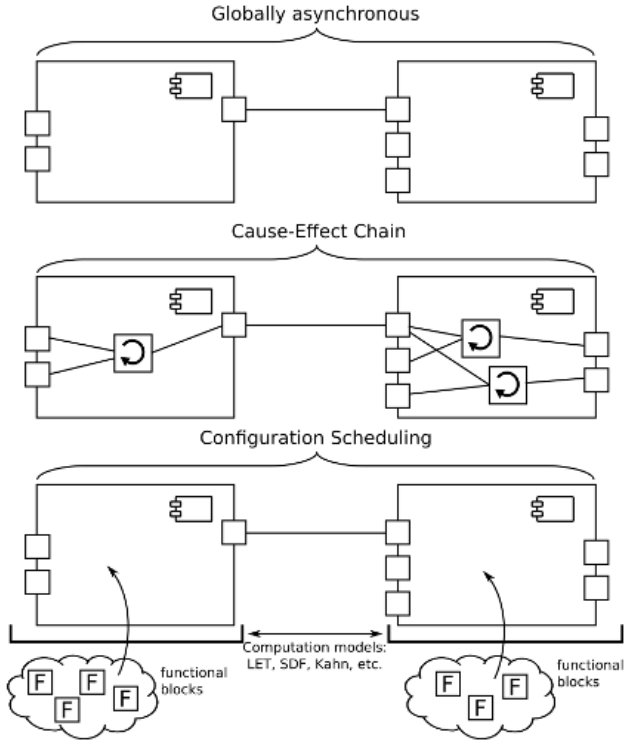


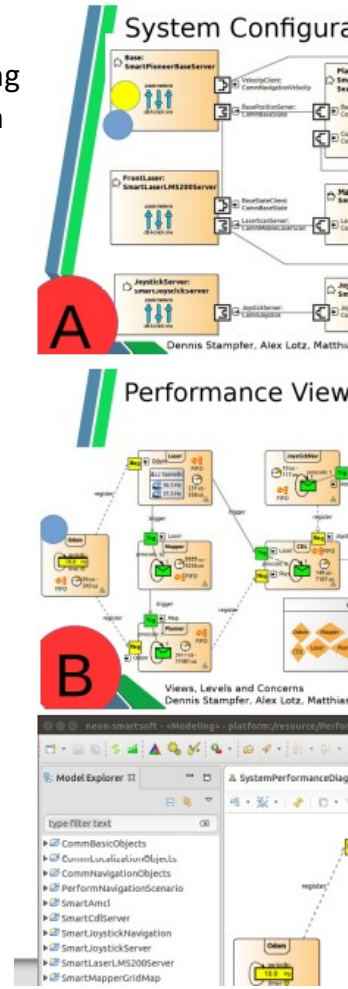


Activation-jitter (measured on the robot) of the CDL task before (top) and after (bottom) the model change

computation model configuration

- data consistency / data sync / data quality / data aging
  - inject register / trigger semantic for communication
  - inject port trigger / timed trigger for computation
  - inject scheduling constraints





- https://robmosys.eu/wiki/
- https://discourse.robmosys.eu/

RobMoSys

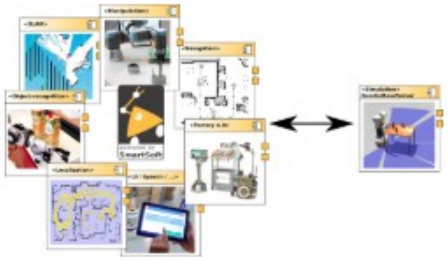
Community Corner

In this section, we feature early adoptors of RobMoSys methodology, composition structures, or tooling.

- Get in touch: Discourse Forum and Events
- Integrated Technical Projects (ITPs) of Open Call I
- Demonstrations and intermediate results:
  - Robotic Behavior in RobMoSys using Behavior Trees and SmartSoft (MOOD2BE ITP)

Tools and Software Baseline

RobMoSys provides a set of tools and a software baseline that already conform to the RobMoSys approach. This set can serve as a starting-point for implementations or demonstrations.



Tooling Baseline

- Roadmap of Tools and Software
- Development Environments and Tools
  - SmartSoft World
  - Papyrus for Robotics
  - to be extended

Tier 3: Existing Building Blocks and Scenarios

- Components
  - SmartSoft Components
- Scenarios and Systems
  - Gazebo/Tiago/SmartSoft Scenario
  - Cause-Effect-Chain Example Scenario