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RobMoSys

Composable Models and Software for Robotics Systems

Deliverable D2.2: Initial preparation of (meta-)models, prototypical DSLs, tools and implementation

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Executive Summary

This is an accumulative Deliverable for Tasks T2.2 to T2.7. The individual contributions of the respective Tasks are highlighted in the individual sections in this Deliverable document. This Deliverable provides the *initial* preparation of (meta-)models, prototypical DSLs, tools and implementations. Improved versions will follow in the successive Deliverable D2.3 in M27 and the final Deliverable D2.4 in M48.

This Deliverable D2.2 is about robotics (software) component (meta-)models for composition-oriented (software) engineering and their prototypical implementations (exploiting existing background of the partners as much as possible). It serves as a software baseline for the other WPs and for preparing the first wave of open calls.

The RobMoSys consortium uses a Wiki for the content of this document. This allows for a living document with a continuous publishing process following the principles of composition for its content. While the basic principles expressed in this initial version will remain stable, refinements and extensions as well as improvements will be added continuously.

Thus, this document serves as a guide through that material of the Wiki visible on the RobMoSys website which is relevant to this Deliverable. A snapshot of the content of the Wiki at the time of delivery of this document is attached in the appendix.

Content

1 Introduction

RobMoSys is about managing the interfaces between different roles (robotics expert, domain expert, component supplier, system builder, installation, deployment and operation) and separate concerns in an efficient and systematic way by making the step change to a set of fully model-driven methods and tools for composition-oriented engineering of robotics systems.

This Deliverable D2.2 has the focus on the RobMoSys composition structures considering the different roles and adhering to the generic meta-structures defined in the Deliverable D2.1.

An initial version of a **Glossary** provides definitions for the most relevant terms in the context of RobMoSys. See

- Wiki Page on "**Glossary**"

This document refers to the RobMoSys wiki. A snapshot is attached in the appendix of this document for simple printing. Additionally, it can be accessed online at

- http://www.robmosys.eu/wiki-sn-01/

We refer to specific wiki pages like this: *Wiki Page on "<Title of wiki page>"*. These wiki pages can be accessed via its title in the appendix and in the RobMoSys Wiki Jump-Page at

- http://www.robmosys.eu/wiki-sn-01/jumppage

The live version of the wiki at http://www.robmosys.eu/wiki also reflects updates and ongoing additions after the submission of this document. An up-to-date jump-page can be found at

- http://www.robmosys.eu/wiki/jumppage

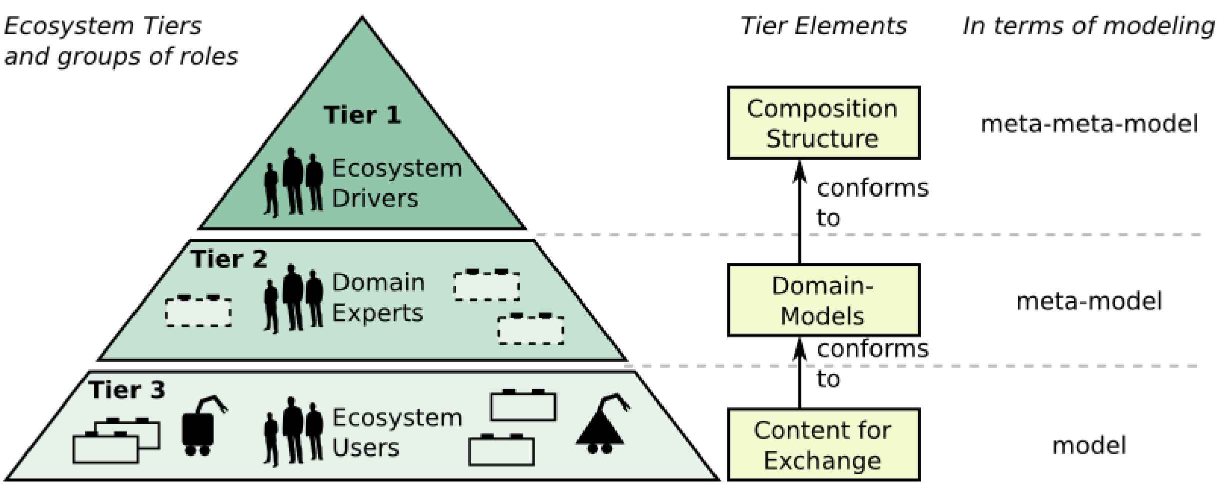


Figure 1: Tiers of an Ecosystem, their elements and the elements in terms of modeling.

Tier 1 distinguishes generic composition structures (Modeling Foundation Guidelines and Meta-Meta-Model Structures such as scientific grounding and block port connector concepts) and the **RobMoSys composition structures** (concepts for robotics building blocks). These structures are refined for the robotics sub-domains (e.g. manipulation, object recognition) to provide guidance and structure for users of the ecosystem on tier 3 (for example, building blocks suppliers and users).

While Deliverable D2.1 focusses on *generic* composition structures, this Deliverable D2.2 focusses on the **RobMoSys composition structures** (which are both at Tier 1) and its meta-models to be used by Tier 2 and Tier 3.

2 Approach

2.1 Introduction

The term "meta" in relation to a model refers to the abstraction between a model and its meta-model where the model conforms to its more abstract representation in a meta-model. Thereby, the meta-model by itself might be a model that conforms to yet another meta-model. Therefore, the meta-relation is not absolute but relative. In some cases, it makes sense to add further meta levels (such as in the term meta-meta-model in figure 1) in order to represent a hierarchy that is visible at once. However, the relative relation remains. Moreover, each individual meta-level by itself might be subdivided into further "sub" meta-levels such as e.g. the three meta-levels on tier 1 (see figure 2). Again, because the meta relation is relative there is no need to distinguish between a top-level (meta-)model and its "sub" (meta-)models as this distinction would be purely artificial. In this document the **RobMoSys composition structures** on the lowest level of composition Tier 1 will be referred to as **RobMoSys meta-models**.

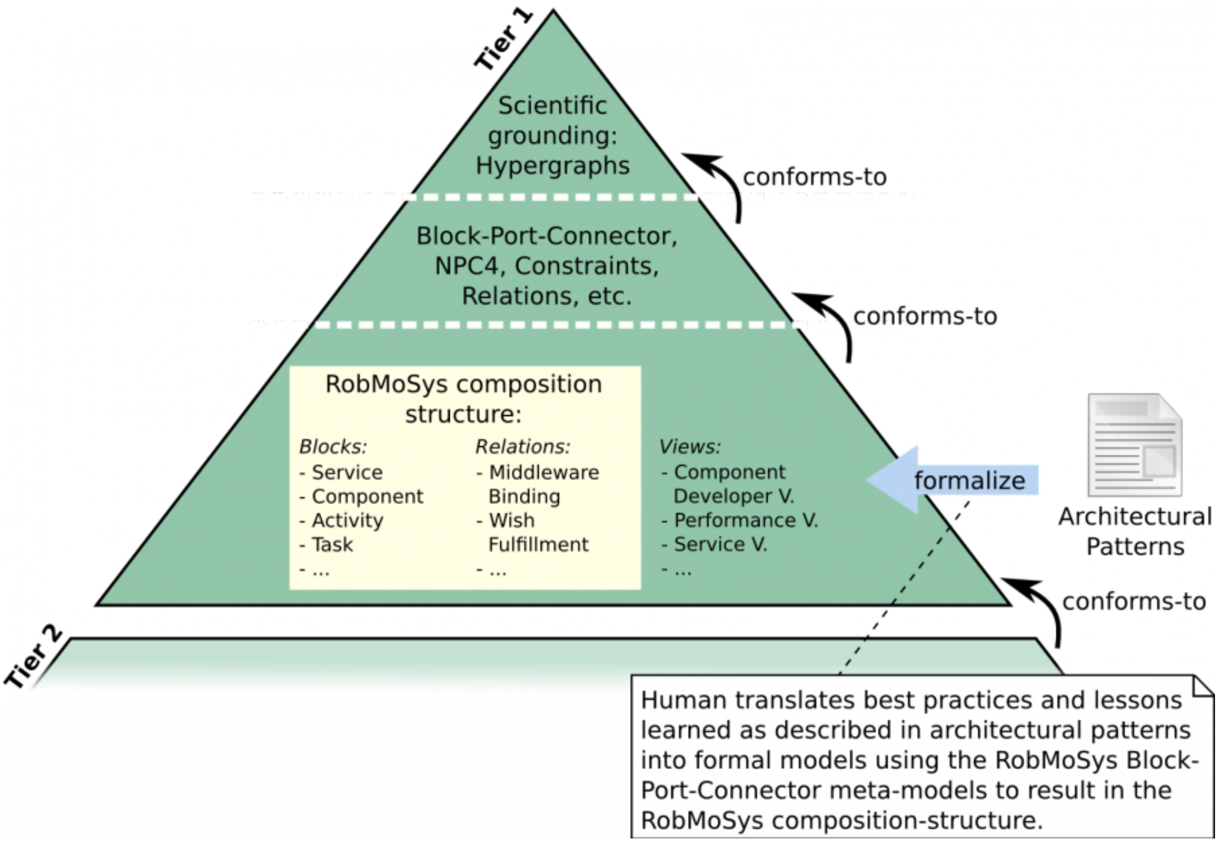


Figure 2: Details of the structure of Tier-1.

One of the benefits of the RobMoSys composition structures is to support role-specific views for both other tiers 2 and 3. It is important to notice that while the individual views focus on isolated aspects of an overall system, the views by themselves are not isolated but are interlinked over the RobMoSys composition structures. This is important for ensuring the overall system consistency, composition, composability and compositionality even if the individual roles independently contribute to the overall system.

The following list of Wiki pages provide further technical details with respect to the RobMoSys composition structures and views:

- Wiki page on "**RobMoSys Composition Structures**"
- Wiki page on "**Views**"

Another aspect of the RobMoSys composition structures is that they serve as an intermediate abstraction level between the *generic* composition structures (i.e. the blocks-ports-connectors, the entity-relation model and the hypergraph meta-level) and the models on tiers 2 and 3. This lowest abstraction level on tier 1 is where the structural, behavioral and workflow knowledge is formalized. Model-driven tools are realized on composition Tier 1, but they cross all tiers to support creating and working on models of the respective tiers.

The following sections 2.2, 2.3, 2.4 and 2.5 accordingly address the Tasks T2.2, T2.3, T2.4 and T2.5 and individually refer to the according Wiki pages that describe the role-based composition structures in RobMoSys.

2.2 Behavioral Modeling (Task T2.2)

The Task T2.2 refers to robotics behavior models that allow modeling situation-specific and dynamic behavior of the robot which can be realized through Task coordination, different forms of process networks or finite state automatons. As an initial baseline in the Deliverable D2.2, this Task T2.2 contributes with the SmartTCL language that can be used for defining robotic behaviors in open calls and for realizing the pilots in RobMoSys. The following Wiki pages provide further technical details:

- Wiki page on "**Robotic Behavior Metamodel**"
- Wiki page on "**Gazebo/Tiago/SmartSoft Scenario**" (this page provides examples of working behavior models)

2.3 Composition, Composability, Compositionality (Task T2.3)

The Task T2.3 deals with challenges of - and around - software component (meta-)models. This includes the relationship between functional blocks and behavior models, their configurations and interplay within a component and the interaction between components on system level.

This Task T2.3 contributes to the initial baseline of the Deliverable D2.2 with the RobMoSys component meta-model that also addresses the definition of services that again rely on a clear definition of communication patterns and communication objects. The following Wiki pages provide additional technical details with respect to the Task 2.3:

- Wiki page on "**Component Metamodel**"
- Wiki page on "**Service Metamodel**"
- Wiki page on "**Communication-Pattern Metamodel**"
- Wiki page on "**Communication-Object Metamodel**"
- Wiki page on "**System Component Architecture Metamodel**"

It is important to notice, that a component meta-model in isolation is virtually useless as long as it ignores all the other (meta-)models around it. For instance, the component (meta-)models are used (i.e. referenced) in system (meta-)models for composing the systems out of flexibly configurable building blocks. Therefore, the RobMoSys component meta-model allows the definition of structures with purposefully left open variation points that are used in later development phases (such as e.g. during system composition) to adjust the components to the application-specific system needs. This enables a systematic match-making (also referred to as management of constraints) between required application-specific system constraints and offered variability in components. This match-making ranges from syntactic matches, over matching intervals, up to matching constraints in the most generic form. As an initial baseline in D2.2 it is considered already a great step forward to support the involved developer roles in manually managing the constraints. Some of these match-makings can also be automated using constraint solvers in later refinements in e.g. the Deliverable D2.3 or D2.4.

The match-makings as described above appear on different levels such as:

- refining task-net and considering their resource constraints
- matching task-nets with services over skills
- selection of components with their services according to an architectural service design
- matching activity constraints of individual components with application-specific end-to-end requirements of system-level cause-effect-chains
- matching offered and required quality (e.g. accuracy) to minimize resources

Using these composition structures enables traceability of individual design choices and improves exchangeability and composability of individual building blocks because their properties (i.e. variability and constraints) are known and thus can be brought together between the original and exchanged parts.

2.4 Separation of Roles and Separation of Concerns (Task T2.4)

This Task T2.4 is about finding meaningful combinations of related concerns considering the needs of the involved developer roles. These needs and role-specific use-cases are collected in so called "architectural patterns" which serve as input for the definition of the RobMoSys composition structures (see also section 2.3).

The following Wiki pages provide additional technical details with respect to Task T2.4:

- Wiki page on "**Architectural Patterns**"
- Wiki page on "**Roles in the Ecosystem**"
- Wiki page on "**Separation of Levels and Separation of Concerns**"

These definitions already provide an initial baseline within the Deliverable D2.2. However, as in the other Tasks above, these definitions will be iteratively refined in the successive Deliverables D2.3 and D2.4.

2.5 Non-functional Properties and QoS Management (Task T2.5)

In contrast to many other approaches in robotics, RobMoSys considers the management of non-functional (i.e. QoS) aspects as a first class citizen from the very beginning in the overall robotics software development. This is reflected by the Task T2.5.

As an initial baseline for the Deliverable D2.2, this Task contributes a novel performance view that can be used to design and manage performance-related system aspects without violating with the component-internal implementation constraints. Further technical details for the performance view can be found in the Wiki page:

- Wiki page on "**Cause-Effect-Chain and its Analysis Metamodels**"
- Wiki page on "**Architectural Pattern for Stepwise Management of Extra-Functional Properties**"

Task T2.5 will be further refined in the successive Deliverables D2.3 and D2.4 by e.g. a reservation-based approach for resource management.

3 Tooling

3.1 Introduction

While the RobMoSys composition structures by themselves are independent of any realization technology, there are different realization options that can be used. The RobMoSys consortium provides a reference implementation of model-driven tooling using Eclipse Ecore as the underlying technology (see figure 3).

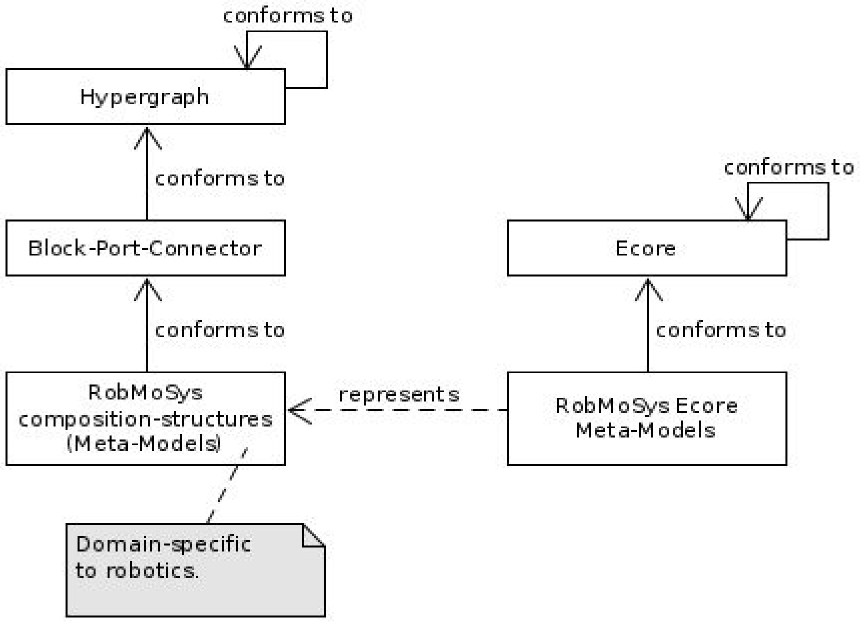


Figure 3: Realization alternative using Ecore

Moreover, various (graphical and textual) model editors as well as code generators can be implemented that all conform to the RobMoSys Ecore meta-models (see figure 4). For implementing the model editors the Sirius, Papyrus and Xtext Eclipse plugins can be used. As an initial software baseline for other WPs and for the open-calls, the initial modeling tools in RobMoSys (as part of this Deliverable D2.2) provide SmartSoft-based code generators that conform to the so far specified RobMoSys composition structures. Some existing Papyrus -based modeling tools provide a rich baseline that will be made conformant with the RobMoSys structure over that run-time of the project. The following Wiki page provides technical details for the current software baseline for development-environments and tools including statements on conformance to the RobMoSys composition structures:

- Wiki page on "**The SmartSoft World**"
- Wiki page on "**Papyrus for Robotics**"

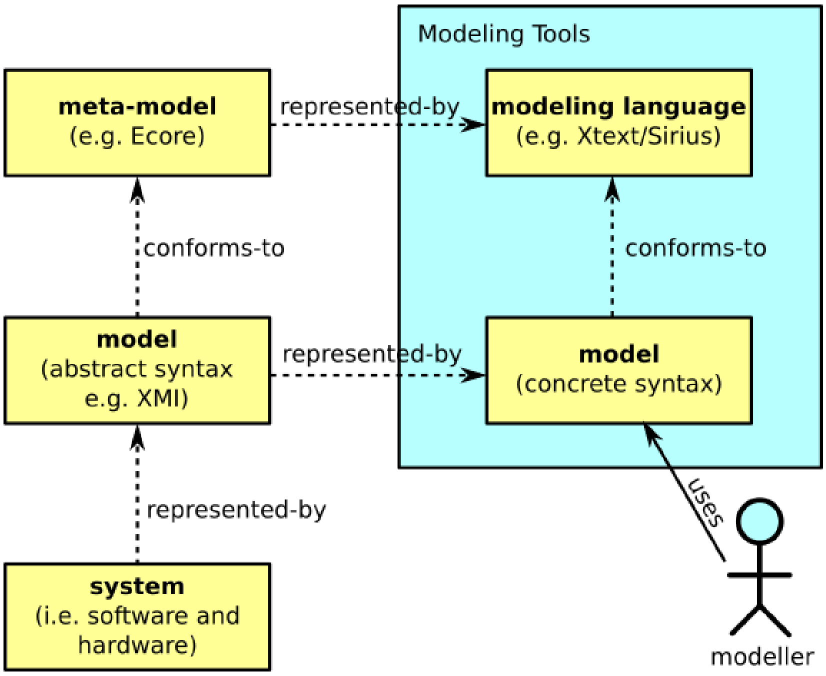


Figure 4: Modeling Tool Implementation Options

The successive Deliverables D2.3 and 2.4 will iteratively refine the RobMoSys composition structures as well as their realization in the conformant modeling tools. In this way, an initial software baseline is provided for both the open call applicants and the RobMoSys core consortium partners. At the same time, these initial software baseline is meant to be refined and extended throughout the open calls and by the RobMoSys consortium itself in the upcoming Deliverables D2.3 and D2.4.

3.2 Integration of Modeling Principles in a Meta-model (Task T2.6)

The Task 2.6 is about enabling composition not only for the software aspects but in particular for the modeling tools and the meta-model realizations themselves. Therefore, as introduced above, RobMoSys separates the definition of the RobMoSys composition structures from their realizations using e.g. Eclipse Ecore. Moreover, even the Ecore-based realizations are independent of their actual implementations using e.g. Xtext/Sirius Eclipse plugins. This clear separation of technologies enables dedicated contributions from open calls and independent refinement of the MDSE tooling on different levels.

- Wiki page on "**Realization Alternatives**"
- Wiki page on "**Modeling Principles**"
- Wiki page on "**Modeling Twin**"

These technology-separation-structures provide an initial baseline as part of the Deliverable D2.2. Successive Deliverables D2.3 and D2.4 will refine and extend these structures.

3.3 Tooling and Run-time Execution (Task T2.7)

The Task T2.7 is about the realization of prototypical tooling that underpins the feasibility of modeling approaches from the preceding Tasks T2.2 to T2.6. The following Wiki page provides technical details for the roadmap and current status of the RobMoSys tooling:

- Wiki page on "**Roadmap of Tools and Software**"
- Wiki page on "**The SmartSoft World**"
- Wiki page on "**Papyrus for Robotics**"

The conformance of these tools and software baseline to the RobMoSys composition structures is described in the above wiki pages. In order to ensure that the tools themselve are usable considering the different roles on tier 2 and tier 3, some early system examples are developed using these tools. The following Wiki page provides details for the TIAGO navigation scenario:

- Wiki page on "**Gazebo/Tiago/SmartSoft Scenario**"

Further system examples using the recent tooling evolutions will be developed throughout the lifetime of the RobMoSys project as part of the deliverables D2.3 and D2.4. A collection of components is readily available under Open Source Licenses for immediate use. Moreover, the recent version of existing baseline can be used within the open calls and within the other WPs. This ensures conformance to the overall RobMoSys composition structures as detailed above.

4 Appendix

A snapshot as of June 23rd, 2017 of the RobMoSys Wiki is attached in the appendix for simple printing. The snapshot can be accessed online via http://robmosys.eu/wiki-sn-01. The live version of the wiki can be found at http://www.robmosys.eu/wiki.

RobMoSys Wiki

This is the RobMoSys Wiki for technical content and structures. For general information of the project or its open calls, please refer to the project website [http://www.robmosys.eu].

Please note: The RobMoSys consortium is continuously updating this wiki to provide early insights. See the changelog. If you came here through a RobMoSys document, please see the jumppage to find referred pages.

RobMoSys will enable the composition of robotics applications with managed, assured, and maintained system-level properties via model-driven techniques. It will establish structures that enable the management of the interfaces between different robotics-related domains, different roles in the ecosystem, and different levels of abstractions. Two documents provide an overview and introduction:

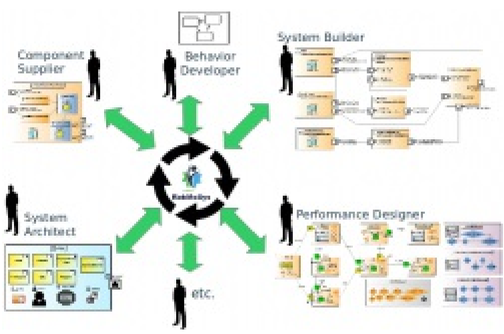
- “Section 1 / Excellence”: excerpt of RobMoSys Grant Agreement, Annex 1 (part B) .
- Presentation of the RobMosys project at European Robotics Forum 2017, Edinburgh .

Glossary

The glossary contains descriptions of used terms.

Your Role in the RobMoSys Ecosystem

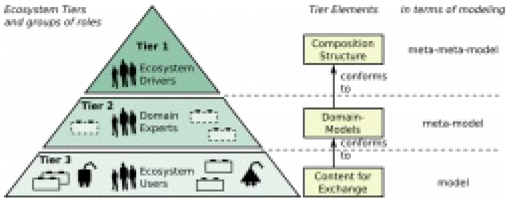
Start reading here to see what your role is in the RobMoSys ecosystem or learn more about Roles in the Ecosystem. Main ecosystem users are:



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

In addition to the regular RobMoSys ecosystem participants, there are also other roles in the RobMoSys ecosystem like the Model-Driven Engineering tool developers (see RobMoSys Composition Structures) and framework builders (see Software Baseline).

General Principles



RobMoSys manages the interfaces between different roles (robotics expert, domain expert, component supplier, system integrator, installation and deployment, operation) and separates concerns in an efficient and systematic way by making the step change to a set of fully model-driven methods and tools for composition-oriented engineering of robotics systems. The following list of pages provide some fundamental principles in RobMoSys.

- Separation of Levels and Separation of Concerns
- Architectural Patterns
- Ecosystem Organization and Tiers
- User-Stories
- PC Analogy: Explaining RobMoSys by the example of the PC domain

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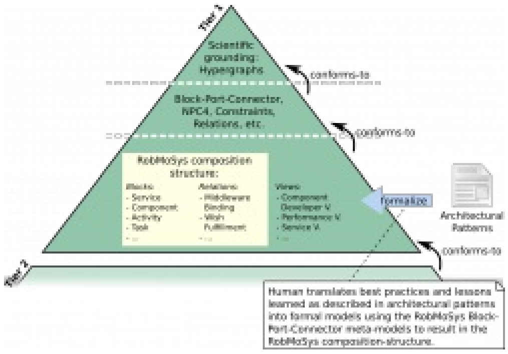
Tier 1: Modeling Foundations



RobMoSys considers Model-Driven Engineering (MDE) as the main technology to realize the so far independent RobMoSys structures and to implement model-driven tooling. The Wiki pages below collect some basic modeling principles related to realizing the RobMoSys structures.

- Roadmap of MetaModeling
- Modeling Principles
  - Modeling Twin
  - Realization Alternatives
- Tier 1 Structure
  - Scientific Grounding: Hypergraph and Entity-Relation model
  - Block-Port-Connector
  - RobMoSys Composition Structures
  - Views which are used by roles

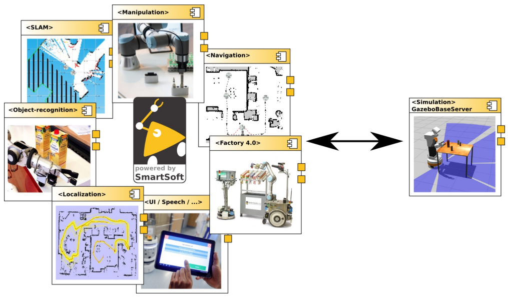
Tier 2: Examples of Domain Models

RobMoSys allows the definition of domain-specific models and structures at composition Tier 2. To illustrate this concept, RobMoSys defines the following extendable content for Tier 2.

- Flexible Navigation Stack
- Active Object Recognition
- Motion Stack
- Perception Stack
- etc.

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

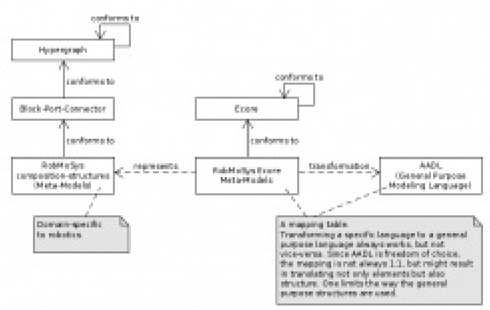
- Roadmap of Tools and Software
- Development Environments and Tools
    - SmartSoft World
    - Papyrus for Robotics
    - to be extended

Tier 3: Existing Building Blocks and Scenarios

- Components
    - SmartSoft Components
- Scenarios and Systems
    - Gazebo/Tiago/SmartSoft Scenario

Other Approaches in the RobMoSys Context

RobMoSys follows a reuse-oriented approach. This means that reinvention should be kept to a minimum and existing approaches should be used wherever possible. The following list provides some common approaches that are considered relevant within the RobMoSys context.



- General Purpose Modeling Languages (SysML/UML) and Dynamic-Realtime-Embedded (DRE) domains (AADL, MARTE, etc.)
- Robotics Approaches (ROS, YARP, RTC, etc.)
- Middlewares (DDS)

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http://www.robmosys.eu/wiki-sn-01/start

Changelog

The RobMoSys consortium is continuously updating this wiki to provide early insights. This changelog will help you to track major changes.

June 23rd, 2017

- Major improvements of the RobMoSys composition structures
- Severall corrections and refinements of multiple pages in the Wiki
- Wiki snapshot freeze [http://robmosys.eu/wiki-sn-01/]

June 13st, 2017

- Improvement of the main page/front page

June 6st, 2017

- Several small improvements of pages in the Modeling section
- Refined description of architectural pattern for Bundling Components

June 1st, 2017

- Added Service Metamodel
- Added Communication-Pattern Metamodel
- Added Communication-Object Metamodel
- Updated Component Metamodel

May 29th/31st, 2017

- Updated Glossary
- Added Roles and Views in the Ecosystem
- Added General Principles
- Added Modeling details
- Added other approaches in context of RobMoSys
- Added Tools Tools and Software Baseline

May 3rd, 2017

- Initial public release of
  - RobMoSys Glossary
  - Architectural Patterns
  - Separation of Levels and Separation of Concerns
  - Service-Based Composition Approach/Ecosystem Organization

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http://www.robmosys.eu/wiki-sn-01/changelog

RobMoSys Glossary

The glossary contains descriptions of used terms.

General Terms

Ecosystem

A collaboration model (cf. Bosch2010[1], Iansiti2004[2]), which describes the many ways and advantages in which stakeholders (e.g. experts in various fields or companies) network, collaborate, share efforts and costs around a domain or product.

Robotics is a diverse and interdisciplinary field, and contributors have dedicated experience and can contribute software building blocks using their expertise for use by others and system composition.

Participants in an ecosystem do not necessarily know each other, thus the challenge is to organize the contributions without negotiating technical agreements and without adhering to a synchronized development process to organize the contributions.

See Ecosystem Organization

Digital Platform

There are two different definitions of digital platforms:

- Economical Definition: Multi-sided market gateways creating value by enabling interaction between two or more complementary customer groups.
- Innovation Definition: Reference architecture/implementation with an innovation ecosystem triggering broad value creation.

Platform is not to be confused with the MDA's [http://www.omg.org/mda/] definition. This definition relates to a concrete technology (in most cases referring to a communication middleware technology such as e.g. CORBA).

System Composition (Activity)

The action or activity of putting together a service robotics application from existing building blocks (here: software components) in a meaningful way, flexibly combining and re-combining them depending on the application's needs.

System composition puts a focus on the new whole that is created from existing parts rather than on making parts work together only by glueing them together: the whole still consists of its parts, they do still exist as entities and are thus still exchangeable. This is in contrast to integration.

Software components that are subject to composition shall be taken as-is (and only configured on model level within predefined configuration boundaries). Software components thus have to be built with this intention right from the beginning. The context in which they will later be composed is unknown, which puts special requirements on their composability and the overall workflow.

Composition is about guiding the roles via superordinate composition-structures. It is about about adhering to a composition structure, thus gaining immediate access to all other parts that also adhere to this (same) structure. In contrast, integration is about building adapters between (all) parts or even modifying the parts themselves.

Composition is about the management of the interfaces between different roles (participants in an ecosystem) in an efficient and systematic way.

Composition is about explicating and managing properties.

Composition is about access restrictions and views for roles.

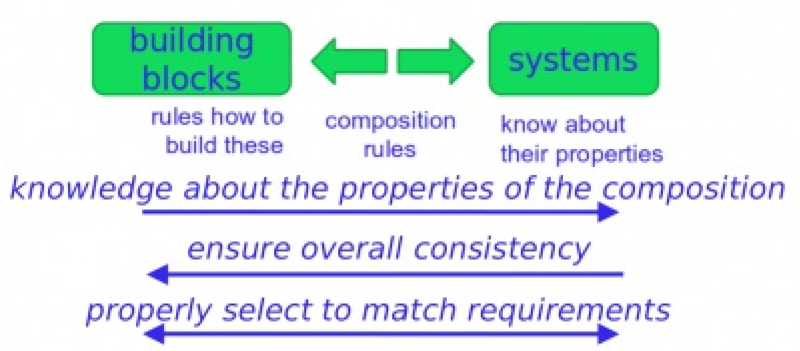
System Integration (Activity)

The activity that requires effort to combine components, requiring modification or additional action to make them work with others (see Petty2013[3]).

A distinction between integration and composition can be drawn by the effort (see [4]): the ability to readily combine and recombine composable components distinguishes them from integrated components, which are modified with high effort to make them work with others, essentially by writing adapters. The integrated part amalgamates with the whole (i.e. the whole becomes one part, individual parts blend together, as red and green water will mix), thus making it hard to remove or exchange individual parts from the whole. If they are removed, it requires new adapters/adjustments.

We distinguish integration as an activity and integration as in "integration-centric".

Composability



- The ability to combine and recombine building blocks *as-is* into different systems for different purposes in a meaningful way.
- It is the basic prerequisite for system composition since it is the property that makes *parts* become *building blocks*. Composability has aspects both between components (parts) and the application (whole). Composability comprises syntactic and semantic aspects.
- Composability requires that properties of sub-system are invariant ("remain satisfied") under composition
- Splittability is "inverse" relationship of composability

Compositionality

- The ability to compose different modules in a methodological way in order to meet predictable functional and extra-functional requirements.
- Compositionality is a system-level design concern, that reflects the extent to which system designers are able to predict the behaviour of their system on the basis of the formally known behaviour of each of the system's components.

Component

A component is the unit of composition that provides functionality to the system through formally defined services at a certain level of abstraction (cf. Szyperski2002[5]).

A component holds the implementation to bridge between services and functions. A component is defined through a component model and can realize one or more services and interacts with others through services only. When speaking of components, we refer to explicit software components as in the SmartSoft World, in contrast to *component* as a synonym for an arbitrary piece or element of something (as e.g. in AADL [http://www.aadl.info/]).

A component comprises several levels. It is the unit of composition that is being exchanged in the ecosystem.

See also:

- Architectural Pattern for Bundling Components
- Component Metamodel
- Component Supplier role
- Component Development View

Service

A service can be defined in two different ways:

- a service in the sense of service-oriented architectures (SOA) that provides a self-contained business functionality to a consumer independent of its realization
- one concrete form of a service that is targeted at composition of software components for robotics (see Service Level)

System

A combination of interacting elements organized to achieve one or more stated purposes. [6]

System-of-systems

Any system should, in itself, be usable as a building block in a larger system-of-systems. In other words, being a component or a system is not an inherent property of any set of software pieces that are composed together in one way or another.

Architecture

An organizational structure of a system that describes the relationships and interactions between the system's elements. Architectural aspects can be found at different levels of abstraction.

Extra-Functional Properties

Extra-functional properties (see Sentilles2012[7]) are system-level requirements that rule the way in which the system must execute a function, considering physical constraints as time and space. Typical extra-functional properties specify constraints on progress, frequency of execution, maximum time for the execution, mean time between failures, etc.

Synonyms

- non-functional properties

Modeling Twin

A modeling twin describes the packaging of a software/hardware artefact with its model-based representation in order to ship it as a whole (i.e. bundle) to other participants in an ecosystem. The model part of the modling twin is mandatory while the software/hardware part is optional (depending on the current artefact at hand).

See: Modeling Twin

View

RobMoSys foresees the definition of modeling views that cluster related modeling concerns in one view, while at the same time connecting several views in order to be able to define model-driven tooling that supports in the design of consistent overall models and in communicating the design intents to successive developer roles and successive development phases.

In this sense, a view establishes the link between primitives in the RobMoSys composition structures and the RobMoSys roles. Views enable roles to focus on their responsibility and expertise only. The RobMoSys composition structures ensure composability of building blocks contributed and used by the role.

See: RobMoSys Views

Engineering Model

In contrast to Scientific Modelling [https://en.wikipedia.org/wiki/Scientific_modelling], engineering models additionally need to be machine-processable in order to enable composition and usage of this model in other models. This is a fundamental feature that improves scalability and modularity of models and model-driven engineering methods. In other words, engineering models always need to provide a benefit and serve a clear purpose with respect to all the other surrounding models of the overall system where this model is part of.

General Principles

Separation of Roles

A principle that enables and supports different groups of stakeholders in playing their role in an overall development workflow without being required to become an expert in every field (in what other roles cover).

A role has a specific view on the system at an adequate abstraction level using relevant elements only.

It is closely related to separation of concerns and a necessary prerequisite for system composition towards an robotics ecosystem.

Separation of Concerns

A principle in computer science and software engineering that identifies and decouples different problem areas to view and solve them independent from each other (see Dijkstra1982[8]).

It is the basis for separation of roles and a necessary prerequisite for system composition towards an robotics ecosystem.

Freedom OF choice vs. freedom FROM choice

System development tools generally follow one of the two following approaches:

- One approach is called freedom **of** choice. One tries to support as many different schemes as possible

and then leaves it to the user to decide which one best fits his needs. However, that requires huge expertise and discipline at the user side in order to avoid mixing noninteroperable schemes. Typically, academia tends towards preferring this approach since it seems to be as open and flexible as possible. However, the price to pay is high since there is no guidance with respect to ensuring composability and system level conformance.
- Freedom **from** choice (see Lee2010[9]) gives clear guidance with respect to selected structures and can ensure composability and system level conformance. However, there is a high responsibility in coming up with the appropriate structures such that they do not block progress and future designs.

Architectural Pattern

- A selection of a (sub)set of concerns and levels to fulfill an objective
- An architectural pattern addresses a single level, may connect two related levels or may involve several levels
- See Architectural Patterns
- e.g. extra-functional property

Objectives for Architectural Patterns

- Facilitate building systems by composition
- Support Separation of Roles

Block, Port and Connector

A recurring principle for structuring meta-models at different levels of abstraction. It can be applied on the same level and between different levels.

See Block-Port-Connector

Concerns

Computation (Concern)

Computation is related to active system parts that consume CPU time

Communication (Concern)

Communication concerns the exchange of information between related entities on the same level and also between the levels themselves

Coordination (Concern)

- Design and modeling of robot behaviors
  - i.e. what happens when and who is involved
- it includes:
  - execution order, (system) states
  - error-handling, resp. error propagation
  - run-time adaptation and (online) reconfiguraiton
  - contingency handling and adaptation rules and strategies

Configuration (Concern)

- Configuration involves several entities (in contrast to parametrization which typically involves one entity)

    - for example: a set of components (path planning, localization, motion execution) that is configured to work together (move to a destination)
- includes static/dynamic parameter-settings of individual components
- includes static/dynamic wiring between interacting components

Cross-Cutting Concern

A concern that cannot be separated from others or decomposed and influences or affects multiple properties and areas in a system possibly at different levels of abstraction. For example, security cannot be considered in isolation and cannot be added to a given application by introducing a security-module; it rather has to be considered in all areas of the system.

Example

- Non-Functional Properties involve several concerns

Roles

A certain task or activity with associated concerns that someone (individual, group or organization) takes in the composition-workflow using a view. For example, the Component Supplier role uses the Component Development View view to come up with a component model that conforms to the Component Metamodel.

Someone that takes a particular role typically is an expert in a particular field (e.g. object recognition). A role takes a particular perspective or view on the overall workflow or application. It is associated with certain tasks, duties, rights, and permissions which do not overlap with other roles.

A role has a specific view on the system at an adequate abstraction level using relevant elements only. A role is responsible for supplying a part of the system. "Role" in the sense of a participant of the ecosystem.

See also:

- Roles in the Ecosystem
- RobMoSys Views

Acknowledgement

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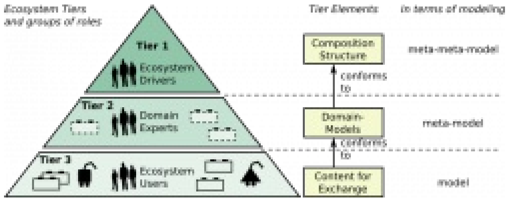
General Principles



RobMoSys manages the interfaces between different roles (robotics expert, domain expert, component supplier, system integrator, installation and deployment, operation) and separates concerns in an efficient and systematic way by making the step change to a set of fully model-driven methods and tools for composition-oriented engineering of robotics systems. The following list of pages provide some fundamental principles in RobMoSys.

- Separation of Levels and Separation of Concerns
- Architectural Patterns
- Ecosystem Organization and Tiers
- User-Stories
- PC Analogy: Explaining RobMoSys by the example of the PC domain

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Separation of Levels and Separation of Concerns

The figure below illustrates the separation of levels and the separation of concerns. Please also refer to the glossary for descriptions of used terms. The levels indicate abstractions in a robotics system.

The levels can be seen as an analogy to "ISO/OSI model" for robotics that addresses additional concerns beyond communication. The analogy is interesting, because ISO/OSI partitions the communication aspect in different levels of abstraction that then help to discuss and locate contributions. The ISO/OSI separations in levels allows to develop efficient solutions for each level. Establishing such levels for robotics would clearly help to communicate between robotics experts–as ISO/OSI does in computer science.

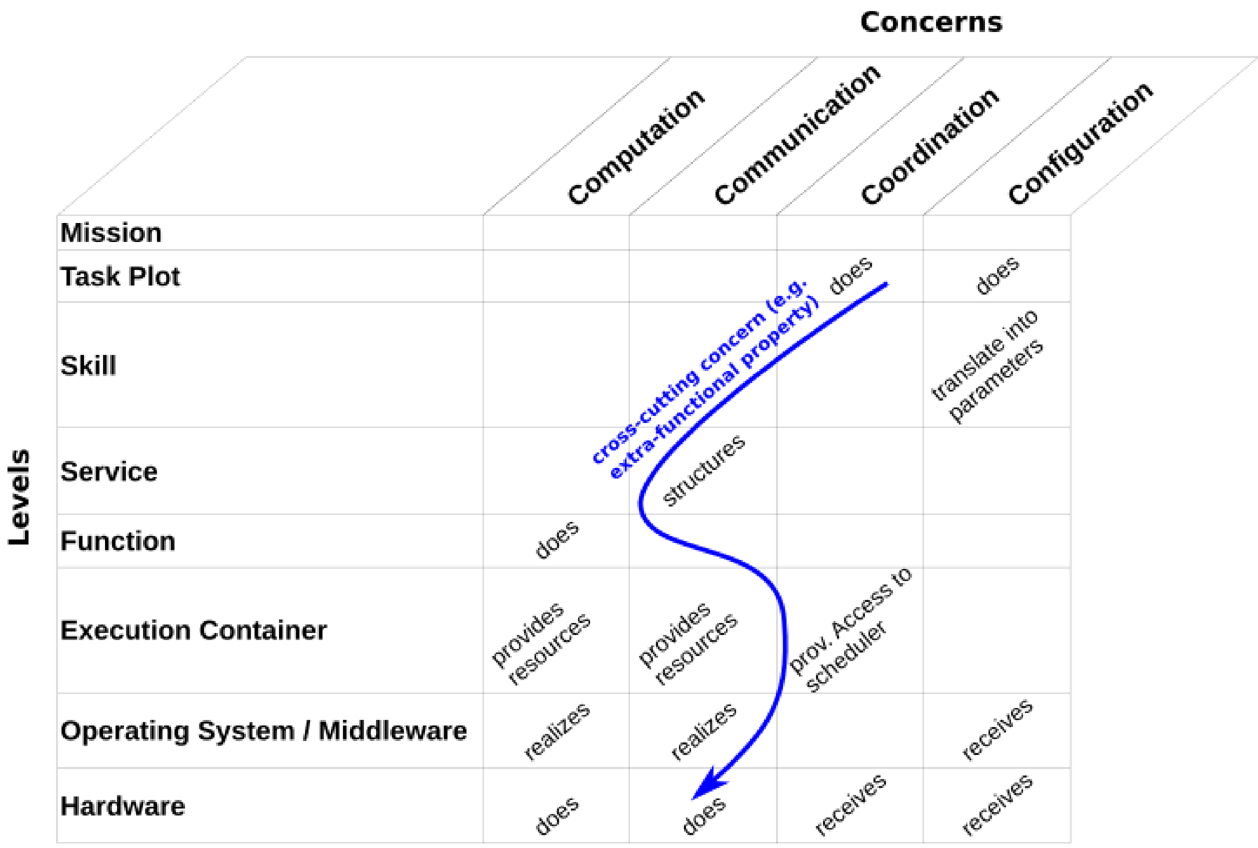
The levels and concerns can be used to identify and illustrate architectural patterns. An architectural pattern combines several levels and several concerns. The blue line is an abstract example.

About the Levels

- The lower levels address more concerns and are more cross-cutting in their nature
- The higher levels are more abstract and address less concerns / individual concerns. They thus allow a better separation of concerns and separation of roles.
- By definition, a level can not be defined on its own, since its semantics is the relationships between the items at this "level" and those at the other levels. This exercise to get these relationships well-defined is a tough one, this is of high priority though, since "level"/"layer" is one of the most often used term in (software) architecture.
- A layer is on top of another, because it depends on it. Every layer can exist without the layers above it, and requires the layers below it to function. A layer encapsulates and addresses a different part of the needs of much robotic systems, thereby reducing the complexity of the associated engineering solutions.
- A good layering goes for abstraction layers. Otherwise, different layers just go for another level of indirection. An abstraction layer is a way of hiding that allows the separation of concerns and facilitates interoperability and platform independence.

On the number and separation of levels

- Individual levels always exist but are not always explicitly visible.
- Transition between layers can be fluent
- There are single layer approaches (clear separation between layers offering full flexibility in composition) but also hybrid ones (combining several adjacent layers into one loosing flexibility). For example, ROS1 implemented both the middleware and execution container while in ROS2, the middleware level is planned to be separated.
- Different levels might require different technologies
- Individual levels may also be separated horizontally (e.g. fleet of robots vs. an individual robot, or group of components vs. an individual component)



The individual Levels

Mission (Level)

- A higher level objective/goal for the robot to achieve.
- At run-time, a robot might need to prioritize one mission over another in order to rise the probability of success and/or to increase the overall quality of service

Examples

- In logistics: do order picking for order 45
- serve customer
- serve as butler

Synonyms

- goal
- objective

Task (Level)

- A task (on the Task level) is a symbolic representation of what and how a robot is able to do something, independent of the realization.
- A job that is described independent of the functional realization.
- Includes explicit or implicit constraints.
- tasks might be executed in sequence or in parallel
- task-sets might be predefined statically (at design-time) or dynamically generated (e.g. using a symbolic planner)
- tasks might need to be refined hierarchically (i.e. from a high-level task down to a set of low-level

tasks)
- not to be confused with tasks in the sense of processes/threads (see Execution Container)

Examples

- Move to room nr. 26
- Grasp blue cup
- Get a cup from the kitchen
- deliver coffee

Synonyms

- job

Skill (Level)

Defines basic capabilities of a robot. The area of transition between high-level tasks and concrete configurations and parameterizations of components on the service-level.

Skills enable tasks to become independent of the actual realization in components.

A collection of skills is required for the robot to do a certain task. For example, a butler robot requires skills for navigation, object recognition, mobile manipulation, speaking, etc. A component often implements a certain skill, but skills might also be realized by multiple components.

Skill-level often interfaces between symbolic and subsymbolic representations.

Examples

- An abstract high level task (e.g. move-to kitchen) is mapped to concrete configurations and services that components offer (e.g. parameterize path planning, localization and motion execution components with destination set to kitchen).
- grasp object with constraint

Synonyms

- capability
- system-function

Service (Level)

A service is a system-level entity that serves as the only access point between components to exchange information at a proper level of abstraction.

Services follow a service contract and separate the internal and external view of a component. They describe the functional boundaries between components. Services consist of communication semantics, data structure and additional properties.

Components realize services and might depend on existence of a certain type of service(s) in a later system.

Function (Level)

- a coherent set of algorithms, for example implemented in libraries, that serve a unique functional purpose
- a piece of software that performs a specific action when invoked using a certain set of inputs to achieve

a desired outcome.[1]

Example

- A function implemented in an library, e.g. OpenCV Blob Finder
- An implemented algorithm, e.g. PID-controller
- Functions developed or modeled in Matlab, Simulink, etc.
- Inverse kinematics (IK) solver

Synonyms

- functional block

Execution Container (Level)

- provides the infrastructure and resources for the functional level
- provides mappings towards the underlying infrastructure (e.g. operating system, communication middleware).

Example

- Access to scheduler
- Threads, eventually processes

Operating System and Middleware (Level)

e.g. phread, socket, FIFO scheduler

Operating System

An Operating System is, for example, responsible for:

- Memory management
- Inter-Process-Communication
- Networking-Stack, e.g. TCP
- Hardware Abstraction Layer

Examples

- Linux, Windows
- FreeRTOS, QNX, vxWorks

Middleware (Communication Middleware)

A communication middleware is a software layer between the application and network stack of the operating system. Communication middlewares are very common in distributed systems, but also for local communication between applications. They provide an abstract interface for communication independent of the operating system and network stack.

There are many distributed middleware systems available. However, they are designed to support as many different styles of programming and as many use-cases as possible. They focus on freedom of choice and, as result, there is an overwhelming number of ways on how to implement even a simple two-way communication using one of these general purpose middleware solutions. These various options might result in non-interoperable behaviors at the system architecture level.

For a component model as a common basis, it is therefore necessary to be independent of a certain middleware.

Examples

- OMG CORBA
- OMG DDS
- ACE

Hardware (Level)

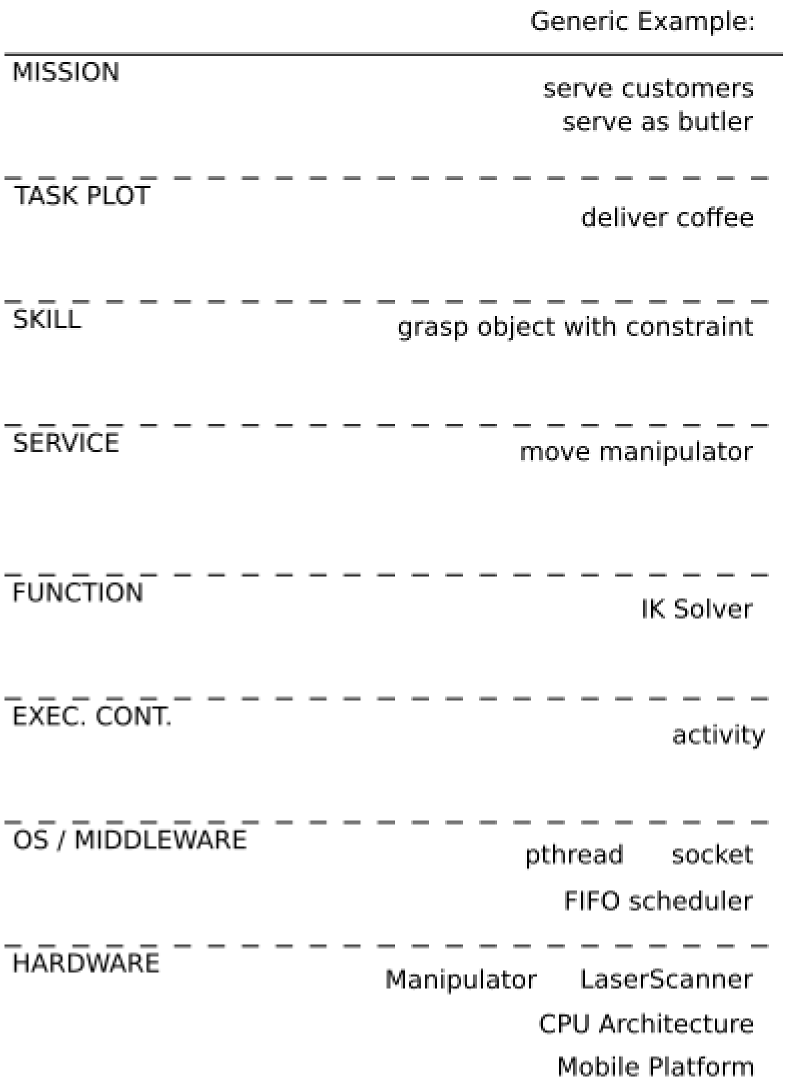
Solid pieces of bare metal that the robot is built of and uses to interact with the physical environment. It includes actors/sensors and processing unit.

Examples

- Sensors: laser scanner, camera
- Actuators: manipulator, robot base/mobile platform
- Processing units: embedded computer, cpu architecture

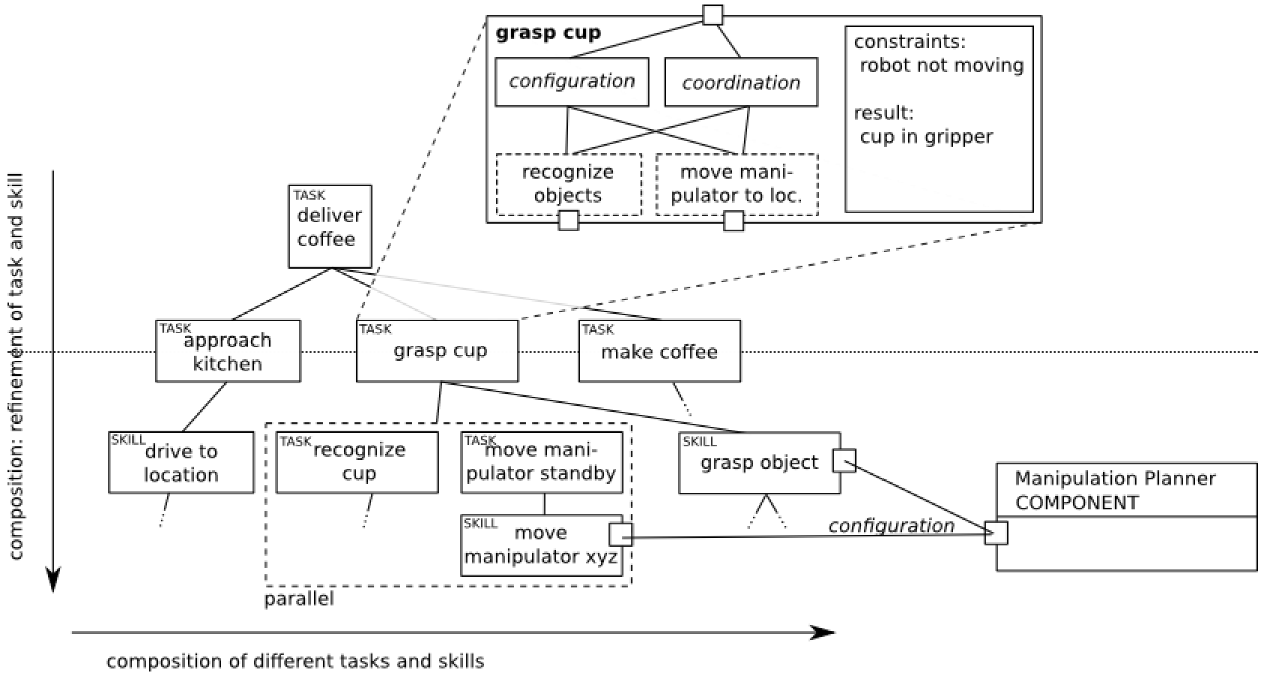
Example: Levels

- Below are examples for each of the levels.
- They demonstrate the level of abstraction that can be found in each layer.



Example: Composition of Tasks

- Below is an example of how tasks can be composed.
- It shows how tasks and skills can be composed flexibly
- Several tasks can be composed to be executed in sequence or in parallel (horizontal composition)
- A task can be refined with other tasks (vertical composition): Abstract tasks are refined to more concrete tasks.
- Refinement of tasks may be static or dynamic
  - Static: The tasks and eventually the order is known. E.g. making coffee always involves approaching the machine, putting a cup into the machine, pressing the button, etc.
  - Dynamic: The tasks and the order are not known in advance (i.e. to be solved by symbolic planning): E.g. it is not known what is the best way to clean up the table after customers left (what order, what to stack into each other, what to carry at once/first/next/last, etc.)
- Skills will finally translate to configurations of one or more components (lower right). E.g. moving the manipulator requires to configure the component for collision-free manipulation-planning in a certain environment and the manipulator component to move along these collission-free trajectories.
- Grasp cup relies on the existence of a task “recognize-object” which is later bound to “recognize-cup”.
- There are constraints that have to be maintained during the execution of a task, for example: the robot is not moving while manipulating.
- There are results of a task that effect execution of other tasks, even after the current task was finished. For example, grasping a cup means that the cup still is in the gripper after the execution is done.



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Architectural Patterns

Introduction

Buschmann et. al.[1] provides the following descriptive definition of a pattern in general:

> "A pattern describes a particular recurring design problem that arises in specific design contexts, and presents a solution to it. The solution scheme is specified by describing its constituent components, their responsibilities and relationships, and the ways in which they collaborate." [2]

Moreover, Buschmann et. al.[3] lists some common properties of a pattern:

- "Patterns document existing, well-proven design experience."
- "Patterns provide a common vocabulary and understanding for design principles."
- "Patterns support the construction of software with defined properties."
- "Patterns help you build complex and heterogeneous software. Patterns help you manage software complexity."

The proposed scheme by Buschmann for describing a software pattern consists of a **Context**, **Problem** and the **Solution**. This triple is used below to also describe individual architectural patterns which analogously address recurring design problems in robotics software development, each occurring in a specific design context, and present a well-proven solution to the design problem. There are two fundamental objectives that drive the design of all presented architectural patterns, namely:

- Facilitate building systems by composition
- Support Separation of Roles

Each architectural pattern needs to contribute towards these two objectives.

Template for an Architectural Pattern

This is a template for describing an architectural pattern including the required sections that the description must comprise.

Context

A context describes a situation in which the design problem occurs. Also relate the context to:

- the Levels and Concerns
- involved Roles

Problem

This part describes a **recurring problem** that repeatedly arises in a given context. This can start with a general, open ended problem and get more concrete with **driving forces** and concrete **requirements** that the solution must fulfill. Also, **constraints to consider** and **desired properties** of the sokution can be expressed here.

Solution

The solution describes how the problem is solved, thereby balancing the driving forces. In some cases, available technologies can be listed here that solve the given problem.

Optional: Discussion

Any discussion of shortcomings, differences or references to other patterns can be described here.

Optional: Example(s)

Specific scenarios or technologies that help to understand the problem and/or solution can be listed here.

List of Architectural Patterns

(alphabetical order)

- Architectural Pattern for Bundling Components
- Architectural Pattern for Communication
- Architectural Pattern for Component Parametrization
- Architectural Pattern for Managing Transitions of System States
- Architectural Pattern for Task-Plot Coordination (Robotic Behaviors)
- Architectural Pattern for Service Definitions
- Architectural Pattern for Stepwise Management of Extra-Functional Properties

Further Candidates for Architectural Patterns

- Architectural Pattern for Coordination-Frame Transformation
  - Transformation tree (e.g. TF in ROS, Time-Stamps, Pose-Stamps, etc.)
- Subsidiarity Principle
  - at any time a clear control hierarchy
  - delegate decision spaces top-down in the hierarchy
- Knowledge Representation
  - central Knowledge Base
  - synchronize and conflate distributed system-models over global IDs
- Reservation based Resource Management
  - in KB through Tasks and Skills for coordination of Components

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1) , 2) , 3)
Frank Buschmann, Regine Meunier, Hans Rohnert, Peter Sommerlad, Michael Stal. “Pattern-Oriented Software Architecture, Volume 1, A System of Patterns”. Wiley Press, 1996, ISBN: 978-0-471-95869-7 [http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0471958697.html]

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Architectural Pattern for Stepwise Management of Extra-Functional Properties

Context

Besides of “pure” functions, realistic systems also need to specify and to manage extra-functional properties that might involve different system parts at different levels of abstraction. Extra-functional system properties specify how well a system performs given a certain system configuration.

There are two main developer roles that are involved in the specification of extra-functional properties:

- Component Supplier specifies functional constraints of individual building blocks (i.e. components)
- System Builder defines extra-functional properties within the predefined boundaries by the involved components

Extra-functional properties are cross-cutting in nature (i.e. combining communication, computation and coordination) and relate to several levels of abstraction:

- Task Plot (level) provides the run-time context for the extra-functional properties
- Service (level) link components and is mainly related to the communication concern of extra-functional properties
- Function (level) is related to the computation concern of extra-functional properties
- Execution Container (level) relates to the coordination concern of extra-functional properties
- Hardware (level) finally does both, computation and communication of extra-functional properties

Problem

- Extra-functional system properties such as e.g. end-to-end response times are cross-cutting in nature and typically involve knowledge and contributions from different developer roles (e.g. component developers and system builders) who are often working independently in different places and at different points in time. This easily leads to inconsistencies in the system. Resolving inconsistencies typically requires expert knowledge and deep insights into all the distributed system parts
- Extra-functional properties bridge between functional constraints in individual building blocks and application-specific system requirements
- Extra-functional properties might be grounded in several system parts that are distributed over several components
- Tracing and assuring extra-functional properties might involve additional (dedicated) analysis tools

Solution

- The specification of functional aspects of individual building blocks must be linked with the definition of application-specific, extra-functional system aspects on model level
- Individual building blocks specify functional constraints that restrict the remaining design space to be exploited for a later system design
- System-specification allows only those design options that do not conflict with the individual building-block constraints

- Dedicated analysis tools simulate run-time conditions and predict extra-functional system behavior (i.e. the run-time performance quality of a system)
- Optionally: a run-time monitoring mechanism can assure compliance with specified extra-functional properties

Example

End-to-end response time from sensing until acting in a service robot can be considered as one particular extra-functional property

- this end-to-end response time typically involves several interconnected components forming a data-flow chain of components
- each component in a chain contributes with a certain delay to the overall end-to-end time
- the component's internal delay might be the result of the internally used device driver with certain execution characteristics or otherwise result from the internally configured activities (i.e. tasks/threads)
- individual components should leave as much configuration freedom as possible and only specify really needed functional constraints (such as an unchangeable device driver behavior)
- a specified system-level end-to-end response time needs to be checked with respect to predefined functional constraints in individual components and the overall end-to-end run-time behavior of the entire chain of components
    - for analysing the run-time behavior of the entire chain of components at design-time, dedicated, matured and powerful analysis tools such as SymTA/S can be used
    - run-time behavior can also be directly monitored in an executed robotic system using a dedicated monitoring infrastructure

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Architectural Pattern for Bundling Components

Context

- A common way to handle system complexity is Component-Based Software Engineering
- Individual components are composable building-blocks that can be (re-)used in different applications (i.e. systems)
- Components in a system are not independent of each other but need to exchange data
- Interconnected components realize (and collaboratively execute) overall system functions (e.g. the navigation stack)

Component bundling is the main responsibility of Component Suppliers.

This architectural pattern relates to the following abstraction levels:

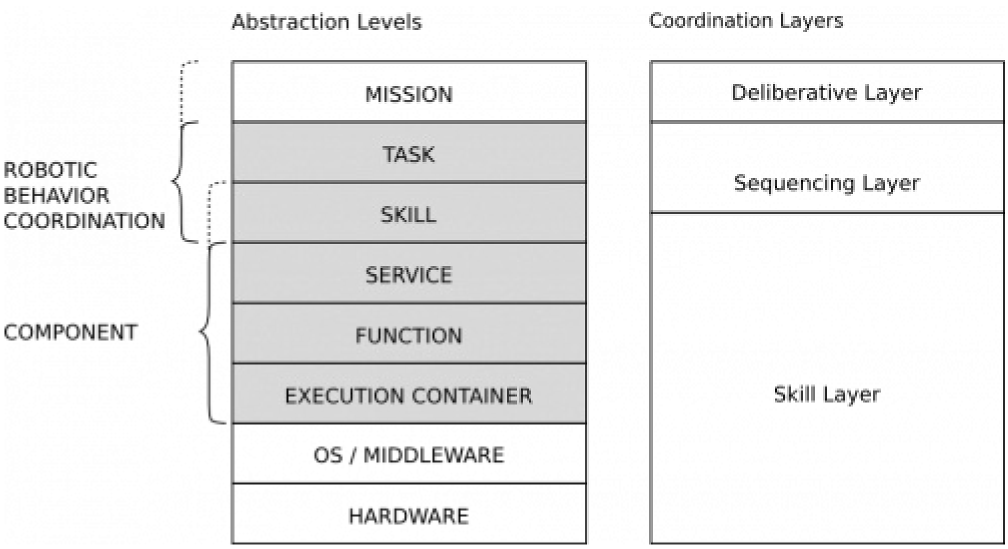
- Skill (level) requires a coordination interface for each component
- Service (level) specifies interaction points to other components (i.e. the communication concern)
- Function (level) realizes the component's internal functionality
- Execution Container (level) links functionality with the execution platform (i.e. the computation concern)
- Hardware (level) allows to directly interact with sensors and/or actuators within a component

Problem

- The overall system behavior at run-time is the result of sets of interconnected components that need to be executed in a systematic and deterministic way.
- Real-world environments are open-ended and unpredictable in nature which requires a certain adaptability and flexibility of the robot system behavior.
    - System flexibility in turn requires run-time reconfigurability of individual components. Configuration options of individual components might involve design-time and run-time configurability and depend on the internal (i.e. functional) realization of a component.
- There are cases where several provided services might need to be realized in a single component (e.g. because the used library cannot be separated into several components)
- The overall role of a component is manifold:
    - to realize a coherent set of provided services
    - to specify dependencies to other services (provided by other components)
    - to encapsulate (i.e. decouple) the functional (internal) realization of services from their general representation on system level
    - to specify allowed configuration options and possible run-time modes (i.e. to be used from the skill level)
    - to hide platform-related details such as communication middleware, operating system and internally used device drivers (i.e. mapping to the execution container and interacting with sensors/actuators)

Solution

The concept of a component spans across several abstraction levels:



From a functional point of view, a component spans over “Execution Container”, “Function”, “Service” and optionally also the “Skill” levels. From the robotic behavior coordination point of view, a component is on the level of robotic skills[1].

A flexible component model that allows different bundlings of several provided services and that decouples the service definition from its realization within a component:

- a component can realize more than one provided service but a certain provided service is realized by exactly one distinct component
- a component should implement or use a service but not define it (service definition is a separated step)

In addition to the “regular” services a component also implements a generic configuration and coordination interface that provides access to:

- the component's life-cycle state automaton
- admissible run-time modes (i.e. activity states)
- the component's configuration parameters (i.e. allowed parameter sets)
- the coordinated dynamic wiring of component’s services (i.e. without conflicting with the component's internal functionality)

See also:

- Component metamodel

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[http://dx.doi.org/10.1080/095281397147103].

Architectural Pattern for Managing Transitions of System States

(To be extended)

- (i.e. System-Mode Transitions)
- synchronize system-modes over shared IDs
- recognize (i.e. awareness about) transitive system-states

Context

…

Problem

…

Solution

…

Discussion

…

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Architectural Pattern for Component Parametrization

(To be extended)

- Run-time parameters
- Unified/generic parameter service for components
- Transaction model for consistent parameter sets

Context

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Problem

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Solution

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Discussion

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Architectural Pattern for Communication

Context

Communication between entities (i.e. exchange of information). Communication is a concern and relates to the following levels:

- Service (level) structures communication
- Execution container (level) provides resources for communication
- Operating System / Middleware (level) realizes communication
- Hardware (level) does communication

This architectural pattern relates to the following roles:

- Service Designer: selects communication pattern (see below)
- System Builder: selects communication middleware

Problem

- A huge number of communication middlewares
- A huge number of overlapping and conflicting communication schemes
- Requirements that the solution must fulfill:
  - Realize vertical (i.e. layers) and horizontal (e.g. components) exchange of information (with the goal to enable communication, coordination and configuration)
  - Support different schemes for data-flow oriented communication and coordination/configuration concerns
  - At the minimum provide:
    - Publish/Subscribe (i.e. data-flow) communication semantics
    - Request/Response (i.e. on demand) communication semantics
  - Support independence of the underlying middleware solution (i.e. middleware abstraction layer)
  - Reduce the huge variety of overlapping communication semantics in order to improve composability between components
  - Decouple the access to communication within a component (functional-level) from the communication between two interacting components (service-level)

Solution

An essential set of communication patterns that is rich enough to cover common communication use-cases, yet at the same time reduced enough to support composability.

- CommunicationPatterns (for continuous data transfer)
  - Request/Response
    - e.g. SmartSoft-Query
  - Publish/Subscribe
    - e.g. SmartSoft-Push (sub-variants: PushNewest and PushTimed)
- ConfigurationPattern (for component configuration)
  - Component Parametrization

        - e.g. SmartSoft-Parameter
    - Dynamic Wiring
        - e.g. SmartSoft-Wiring
- CoordinationPattern (for skill realization)
    - Component Lifecycle Automaton
        - e.g. SmartSoft-State (generic lifecycle state automaton)
    - Component (activity) Modes
        - e.g. SmartSoft-State (user-defined states) and SmartSoft-Parameter (trigger)
    - Component Feedback
        - e.g. SmartSoft-Event

See also:

- Communication Patterns

Discussion

Different middlewares allow for different middleware abstraction levels. For instance, message-based middlewares require a protocol-based abstraction, while e.g. DDS allows for a higher level of abstraction (i.e. directly using the publish/subscribe communication with accordingly preselected QoS attributes). In any case, middleware details should be hidden from both, the component's internal communication access and the communication semantics between components.

The separation of patterns into groups for Communication (i.e. continuous data exchange), Configuration (i.e. parametrization of individual components) and Coordination (i.e. skill-component interaction) provides solutions for recurring communication problems and clarifies the purpose of a particular pattern.

The communication access from within a component (i.e. communication interface access) needs to be as flexible as possible as long as it does not violate with the clearly specified communication semantics outside of the component (resp. between interacting components).

Not every semantic detail needs to be made explicit on model level (some may come from "de-facto standard" implementations). The focus in models need to be on a consistent representation and systematic management of different communication schemes.

Acknowledgement

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- Lotz2017 Alex Lotz, "Managing Non-Functional Communication Aspects in the Entire Life-Cycle of a Component-Based Robotic Software System," 2017. (unpublished work)
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Architectural Pattern for Service Definitions

(To be extended)

- Granularity of components and services
- Abstraction-level of services

Context

…

Problem

…

Solution

…

Discussion

…

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Architectural Pattern for Task-Plot Coordination (Robotic Behaviors)

A description of this architectural pattern can be found here [http://www.servicerobotik-ulm.de/drupal/?q=node/86]. The architecture is a generic architecture for robotics behavior. Its implementation in the SmartSoft World is SmartTCL [http://www.servicerobotik-ulm.de/drupal/?q=node/84] and Dynamic State Charts [http://www.servicerobotik-ulm.de/drupal/?q=node/87]. In terms of the abstraction levels, this pattern addresses task and skill levels; in terms of concerns, it addresses coordination and configuration.

To be extended. This architectural pattern is about:

- continuous vs. discrete
- task-plot description (i.e. hierarchical task-tree)
- using external solvers as experts on demand (i.e. symbolic planer)

Context

…

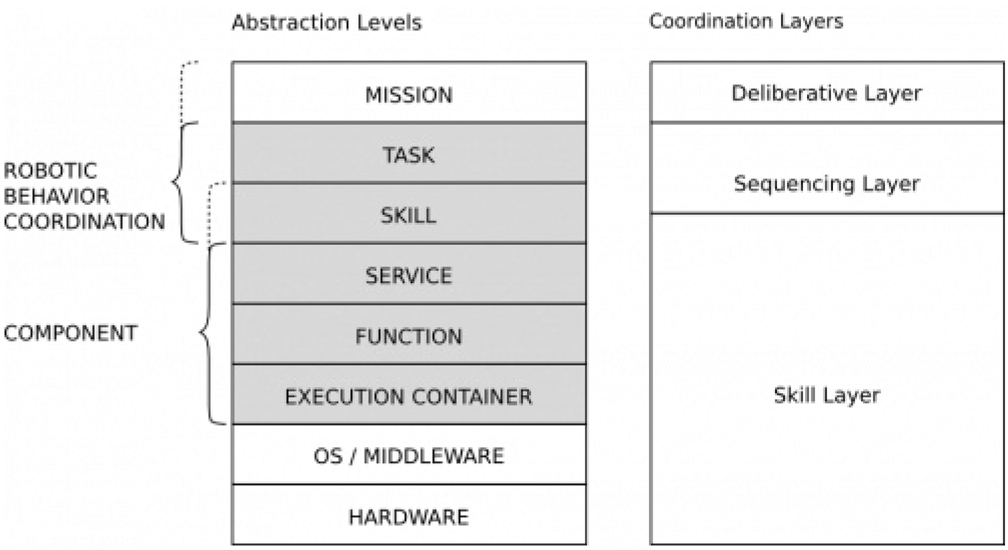
Problem

…

Solution

…

Robotic Behavior spans across several levels:



Discussion

…

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Ecosystem Organization

Fix Me! add Max and Sally descriptions here; as presented at ERF

Composition Tiers

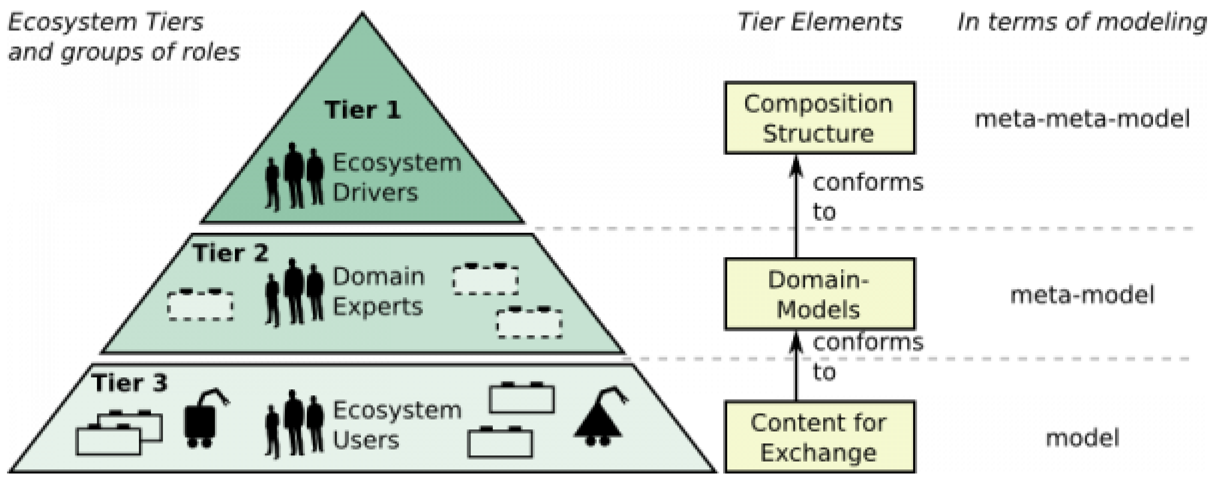
The general composition structure distinguishes three tiers.

RobMoSys envisions a robotics business ecosystem in which a large number of loosely interconnected participants depend on each other for their mutual effectiveness and individual success. The modeling foundation guidelines and the meta-meta-model structures are driven by the needs of the typical tiers of an ecosystem and the needs of their stakeholders (see figure 1). The different tiers are arranged along levels of abstractions. Figure 1 also illustrates the amount of experts or people contributing or using the particular tiers.

Tier 1 structures the ecosystem in general for robotics. It is shaped by the drivers of the ecosystem that define an overall composition structure which enables composition and which the lower tiers conform to (similar to, for example, the ecosystem of the Debian GNU/Linux OS and its structures). Tier 1 is shaped by few representative experts for ecosystems and composition. This is kick-started by the RobMoSys project. Structures defined on Tier 1 can be compared to structures that are defined for the PC industry. The personal computer market is based on stable interfaces that change only slowly but allow for parts changing rapidly since the way parts interact can last longer than the parts themselves and there is a huge amount of cooperating and competing players involved. This resulted in a tremendous offer of composable systems and components.

Tier 2 conforms to these foundations, structuring the particular domains within robotics and is shaped by the experts of these domains, for example, object recognition, manipulation, or SLAM. Tier 2 is shaped by representatives of the individual sub-domains in robotics.

Tier 3 conforms to the domain-structures of Tier 2 to supply and to use content. Here are the main “users” of the ecosystem, for example component suppliers and system builders. The number of users and contributors is significantly larger than on the above tiers as everyone contributing or using a building block is located at this tier.



Tier 1: Composition-Structure – Meta-Structure

Tier 1 structures the ecosystem in general for robotics, independent of the sub-domains. It is shaped by the drivers of the ecosystem that define an overall structure which enables composition and which is to be filled by the lower tiers. Tier 1 defines general concepts and models for system composition such as the concept of service definitions, concept of components, and the composition-workflow that is tailored to service robotics. See Tier 1 Details for more information.

In terms of meta-modeling, elements of this tier correspond to/are meta-meta-models

Elements on this tier

RobMoSys Composition Structures, e.g.

- concept of service definitions
- concept of components, i.e. the Component Metamodel
- a set of communication semantics to choose from

Examples of roles on this tier

Content on this tier is defined by the ecosystem drivers, e.g. the RobMoSys consortium.

See also

- Tier 1 Details

Tier 2: Robotics-Domain-Specific Structures – Robotics Domain Models

Tier 2 structures the particular domains within service robotics. It is shaped by the experts of these domains, for example experts from object recognition, from manipulation, or from SLAM. This is a community effort which structures each robotics domain by creating domain-models. Experts working at this level define concrete service definition models, for example a service definition for robot localization.

Domain-models, for example, are "Service Definitions" that cover data structure, communication semantics and additional properties for specific services such as "robot localization". To find such a service definition, domain experts of each particular domain discuss how to represent the location/position of a robot and what additional attributes are required and how they are represented (e.g. how the accuracy is represented).

In terms of meta-modeling, elements of this tier correspond to/are meta-models

Examples of elements on this tier

- service definitions for localization
- definition of how a robot pose with uncertainty is represented

Examples of roles on this tier

- These are experts in the particular domain (SLAM, object recognition, manipulation), for example the manipulation domain to come up with domain-models for a composable motion stack based on the RobMoSys composition structures on Tier 1.
- Service Designer role

Tier 3: Ecosystem Content

Tier 3 uses the domain-structures from Tier 2 to fill them with content: to supply or to use content. It is shaped by the users of the ecosystem, for example component suppliers and system builders. They use the domain-models to create models as actual "content" of the ecosystem to be supplied and used. On this tier, for example, concrete Gmapping component for SLAM that provides a localization service is supplied to a system builder to compose a delivery robot.

In terms of meta-modeling, elements of this tier correspond to/are models (of components/systems)

Examples of elements on this tier

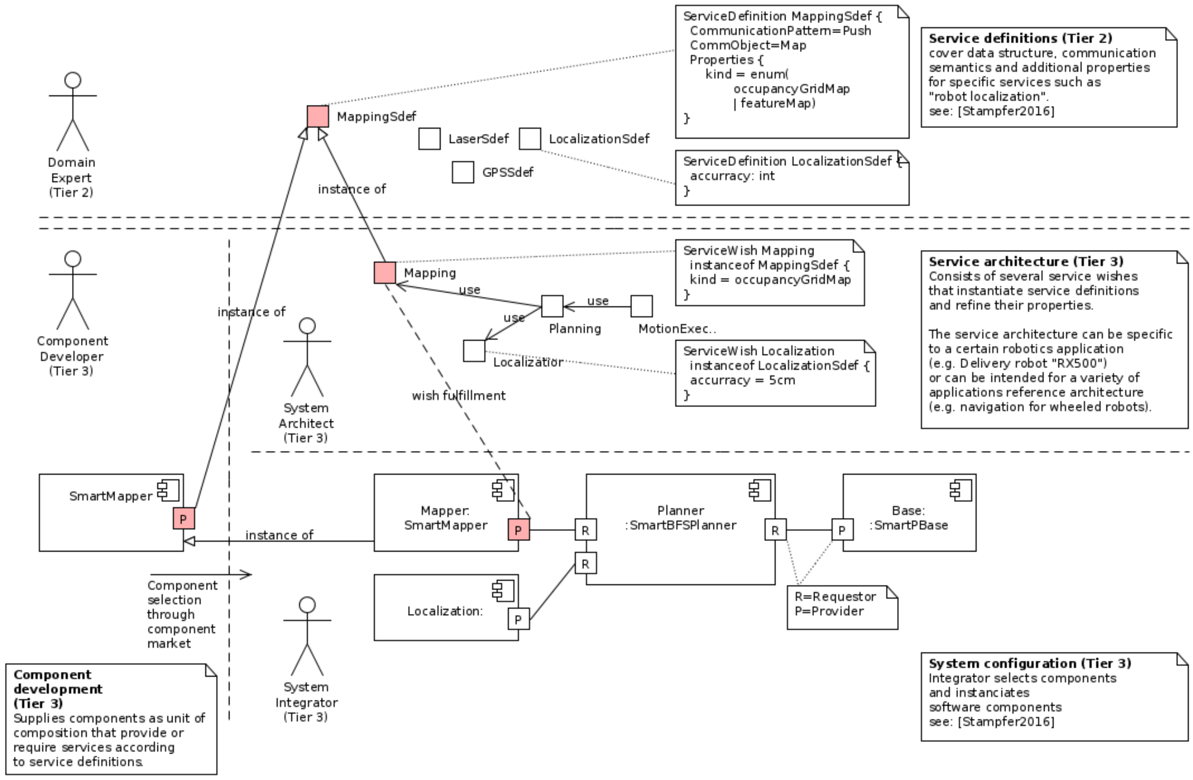
- Components for AMCL localization, Gmapping, etc. providing a localization service
- Task plot: how to make coffee
- Composed applications: A restaurant butler robot
- Component model based on the Component Metamodel

Examples of roles on this tier

- Component Supplier
- System Architect
- System Builder

Example: Service-based Composition Approach

The service-based composition approach is an example to illustrate the use of the composition tiers. Below is the illustration that corresponds to the role descriptions. The service-based composition approach uses service-definitions as central architectural element for composition of software components. We call the links between service definition, service wish, and service with fulfillment the “service triangle”.



[Stampfer2016] Dennis Stampfer, Alex Lotz, Matthias Lutz and Christian Schlegel. "The SmartMDSD Toolchain: An Integrated MDSD Workflow and Integrated Development Environment (IDE) for Robotics Software". Special Issue on Domain-Specific Languages and Models in Robotics, Journal of Software Engineering for Robotics (JOSER), 7(1), 3-19 ISSN: 2035-3928, July 2016.

See also

- Analogy: The PC Domain
- Roles in the Ecosystem
- Tier 1 Details

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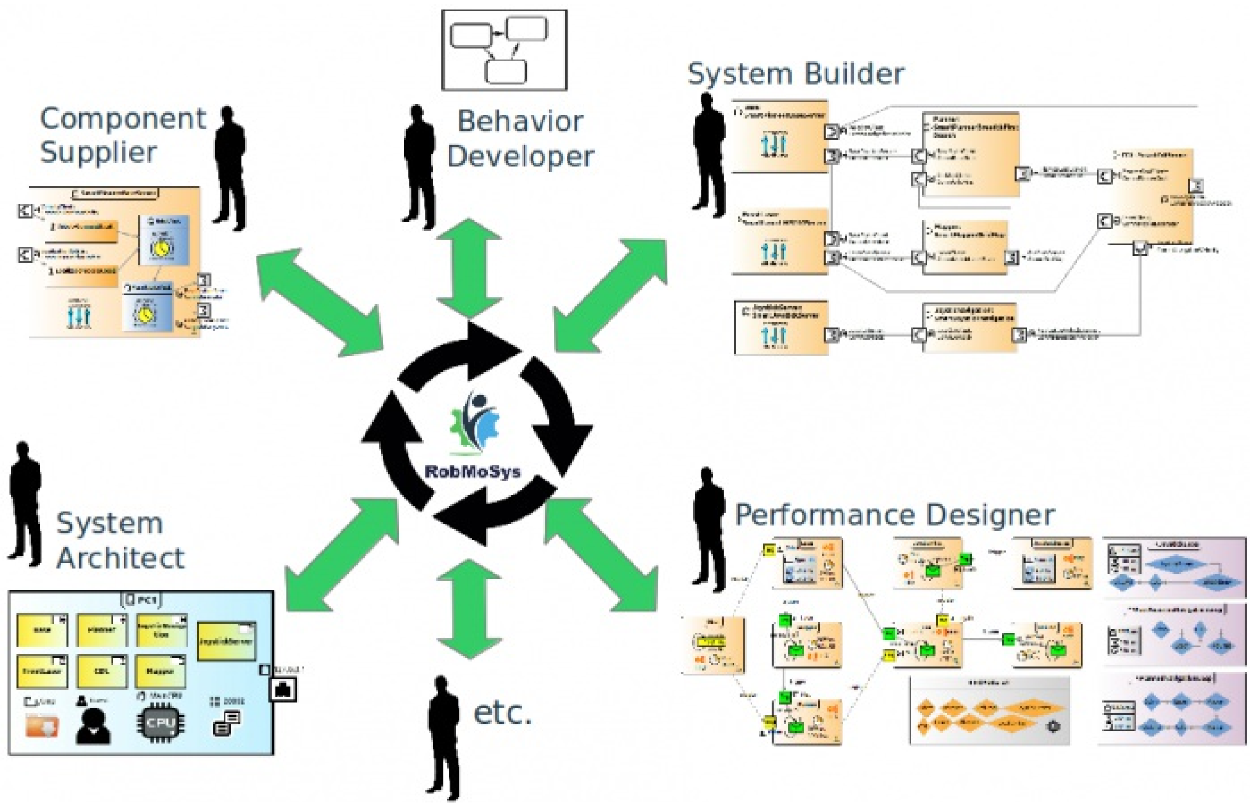
Roles in the Ecosystem

The participants in the ecosystem (see Ecosystem Organization) take one or several “roles” to use and supply building blocks. The RobMoSys composition structures define which parts are variable and which parts are fixed, i.e. guided by the structures to ensure composability. Each role uses dedicated views to work on models and Modeling Twin



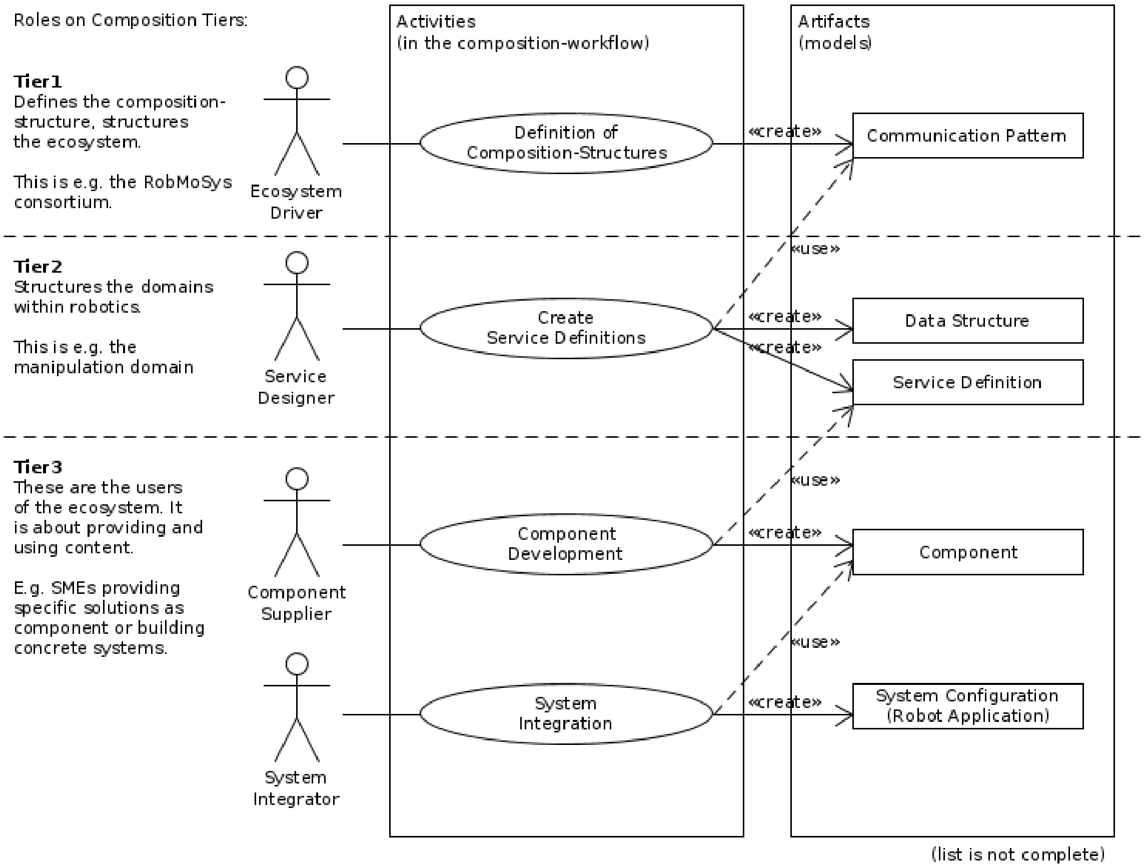
List of Roles

(alphabetical order)

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

Roles in Context of Composition Tiers

The figure below illustrates the roles and their corresponding activities that use or create models on each composition tier.



See also

- Ecosystem Organization to learn about Ecosystem and its Composition Tiers
- RobMoSys Views to learn about the concept of views that roles use
- Modeling Twin

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System Builder

This role on Tier 3 puts together systems from building blocks (i.e. software components). Based on a system architecture from a system architect, the system builder selects components (provided by component suppliers) from the ecosystem that realize the needed services. Matchmaking must be made on the basis of offered services and on other properties, e.g. the required accuracy. Another concern of system builders is to package everything together such as e.g. also the robotic behavior models from behavior developers and making the system ready for deployment.

Synonym:

- Within the literature, this role is sometimes called “system integrator” which is considered inappropriate within the RobMoSys context, because of its close relation to “system integration” which contrasts to system composition (see glossary).

Related views and models:

- System Component Architecture Metamodel

See also:

- System Architect
- Component Supplier
- User Stories including this role
- Roles in the Ecosystem

Function Developer

Provides content on function-level to be used by component suppliers.

Synonym:

- none

Related views and models:

- Fix Me! to be defined

See also:

- Component Supplier
- User Stories including this role
- Roles in the Ecosystem

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Service Designer

These are the domain experts on Tier 2 that design individual service definitions for use by Tier 3 roles component supplier and system architect. This enables the definition of “de-facto” standard service definitions within a specific robotics sub-domain such as “object recognition”, “mobile manipulation”, “SLAM”, etc. For example, they can define what is a common (good) representation for a “localization” service that should be used (and shared) within the “SLAM” domain.

Synonym:

- none

Related views and models:

- Service Design View
- Service-Definition Metamodel

See also:

- Component Supplier
- System Architect
- User Stories including this role
- Roles in the Ecosystem

Performance Designer

Designs the overall system performance by considering several activities in combination and modeling causal dependency chains. Further details can be found in:

- Alex Lotz, Arne Hamann, Ralph Lange, Christian Heinzemann, Jan Staschulat, Vincent Kesel, Dennis Stampfer, Matthias Lutz, and Christian Schlegel. "Combining Robotics Component-Based Model-Driven Development with a Model-Based Performance Analysis." In: IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR). San Francisco, CA, USA, Dec. 2016, pp. 170–176. LINK [http://dx.doi.org/10.1109/SIMPAR.2016.7862392]

Synonym:

- none

Related views and models:

- Performance Metamodel

See also:

- User Stories including this role
- Roles in the Ecosystem

Component Supplier

A component supplier is a role on Tier 3 that offer software components as units of composition that provide or require services (service-level) and contain functions. He/she models the component by using existing service definitions and functions. He/she therefore uses models from the roles service designer and function developer.

Synonym:

- component developer

Related views and models:

- Component Development View
- Component-Definition Metamodel

See also:

- Service Designer
- Function Developer
- User Stories including this role
- Roles in the Ecosystem

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Behavior Developer

Develops task-plots to be used by system builders describing which sequences of tasks (i.e. actions) the robot needs to perform for achieving certain goals at run-time. He/she acts on the level of task-plots.

Synonym:

- none

Related views and models:

- Robotic Behavior Metamodel

See also:

- User Stories including this role
- Roles in the Ecosystem
- Architectural Pattern for Task-Plot Coordination (Robotic Behaviors)

Safety Engineer

The Safety Engineer is responsible to define safety-related system aspects and closely interacts with system builders.

Synonym:

- none

Related views and models:

- … link view (to be defined)
- … link model (to be defined)

See also:

- User Stories including this role
- Roles in the Ecosystem

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System Architect

This role on Tier 3 designs a system architecture based on existing service definitions from service designers. The resulting system architecture is independent of specific components and can be used by system builders to select according components for realizing this system architecture. In other words, a system architect provides a kind of “system blueprint” for system builders who can realize this system by selecting appropriate components. For example, a system architect might design a robot navigation stack based on mapping, localization, and motion-execution services.

Synonym:

- none

Related views and models:

- System Service Architecture Metamodel

See also:

- Service Designer
- System Builder
- User Stories including this role
- Roles in the Ecosystem

User Stories

The following user-stories provide more detailed examples of the primary user-stories [http://robmosys.eu/user-stories/] and the user-stories presented at the ERF 2017 [http://robmosys.eu/download/sara-tucci-cea-christian-schlegel-hs-ulm-presentation-of-the-robmosys-project/]. The user-stories are supposed to guide RobMoSys consortium to provide the structures and the open call third party partners to apply.

User-stories are described in the *As user, I want*-style:

- As a (role), I want (goal, objective, wish), so that (benefit)
- As a (role), I can (perform some action), so that (some goal is achieved)

Some user-stories are described in context of a specific ecosystem participant or role. Some are not described in a specific context and can apply to multiple roles. For example what is of interest to an integrator can be of interest to a supplier since the integrator might also supply a system (see system-of-system).

See also:

- Roles in the Ecosystem

Composable commodities for robot navigation with traceable and assured properties

A very generic but extremely important user story illustrating the full scope of RobMoSys by a single example: Based on model-driven tools, develop and provide composable navigation components with all their explicated properties, variation points, resource requirements etc. (the modeling twin / data sheet). Become able to compose your navigation system out of these readily available commodity building blocks according to your needs and be sure that your needs are being matched, that the properties become traceable etc.

- I, as system builder, just want to become able to compose robotics navigation out of commodity building blocks according to my needs with predictable properties, assured matching with my requirements, free from interference. It is just astonishing that this is not yet possible in robotics. (with MoveBase being exactly an example of 1how it should not be)

Description of building blocks via model-based data sheets

RobMoSys achieves a specific level of quality and traceability in building blocks, their composition and the applications.

as a **component supplier**

- I want my component to become part of as many systems as possible to ensure return-of-investment for development costs and to make profit.
- I need to offer my software component (building block) such that others can easily decide whether it fits their needs and how they can use it.
- I want to offer my software component with a data sheet in form of a digital model (see xxx). A data sheet contains everything you need to know to become able to use that software component in a proper

way (interface between the component and its environment) while protecting intellectual property. It contains information about the internals of the software component only as long as this is needed for a proper use.

as a **system builder**

- I want to select from available components the one which best fits my requirements and expectations (provided quality, required resources, offered configurability, price and licensing, etc.)
- I want to check via the data sheet (in form of a digital model) whether that building block with all its strings attached fits into my system given the constraints of my system and given the variation points of the building block. Thereto, I want to be able to import it into my system design to perform e.g. a what-if analysis etc.
- I want to extract from my system design the specification of a missing building block such that someone else can apply for providing a tailored software component according to my needs
- I want to use components as grey-box, use them “as-is” and only adjust them within the variation points expressed in the data-sheet without the need to examine or modify source code.

Replacement of component(s)

A hardware device is broken and the identical device is not available anymore (deprecated, discontinued, only next version available). As a system builder,

- I want to check whether all my relevant system level properties and constraints are matched when I use the new device.
- I also want to know how I need to configure it for that.

The very same holds true for software components where a software library used is not available anymore with updates of other libraries etc.:

- As a system builder, when I remove a software component from a system, I want to know which constraints define the now white spot in my design in order to fill in another one with the proper configuration to again match the system level properties.

Example:

- From laser-based localization to visual localization
- Replacing a 6 DOF manipulator with a 5 DOF manipulator

Composition of components

I want to be able to predict selected properties of the composition of various software components given their individual properties, their configurations, their composition. For example, I want to know about the required resources, whether there are bottlenecks somewhere, whether there are no unnecessarily high update rates without consumers requiring them etc.

I want to know about the consistency of the overall settings in order to increase the trust into the system. I want to know that critical paths are transformed from design-time into run-time monitors and sanity checks, e.g.

Quality of Service

I would like to know whether the amount of resources and the achieved performance (in general, quality of task achievement) is adequate. I want to know what kind of impact a decrease in resource assignment has on the performance of the functionalities of the robot.

I want to make sure that properties are traceable through the system and are managed through the development and composition steps. For example

- qualities at service ports of components are linked with component configurations which are linked with configurations of the execution container and the underlying OS and middleware
- at deployment time (system builder), reservation based resource management should be tool supported

Determinism, e.g. for robot navigation

As system builder, I want my system (e.g. navigation system on a mobile robot) to work exactly the same way again when I change the platform (e.g. change the mobile base or the laser ranger or the computing platform in a mobile robot).

- I want to know that the intended functional dependencies and intended processing chains are finally realized within my system composition
- I want to know that relevant functional dependencies are still valid even after replacing one of my onboard computers by a different one

Free from hidden interference

- When extending a system, I want to know that I do not interfere with the already setup components, already used resource shares etc.
- I want to be sure that deploying further components onto my system is free from hidden interference or hidden side-effects.

Management of Non-Functional Properties

As system builder,

- I want to be able to adhere to functional and, in particular, to non-functional properties when composing software components.
- I want to re-use software components as black (gray) boxes with explicated variation points such that application-specific system-level attributes can be matched without going into the internals of the building blocks.
- I want to be able to work on explicated system level properties: allow to design system properties such as end-to-end latencies and explicit data-propagation semantics during system composition without breaking component encapsulation.
- I want to be able to match / check / validate / guarantee required properties via proper configurations of variation points, via sound deployments etc.

Separation of roles (in particular, between component providers (driven by technology) and system builders (driven by the application domain) is considered a basic prerequisite towards the next level of market maturity for software in robotics, and thus towards a software business ecosystem. Support for the system builder is needed in order to know about the properties of resulting systems instead of wondering whether they match the requirements or whether they are resource-adequate etc.

Gap between design-time assumptions and run-time situation

When a system is deployed, design-time assumptions might not hold. For many systems it is difficult to know when the system fails during operation.

- As a system builder, I want to generate sanity checks, monitors and watchdogs from my design-time models to be able to detect unwanted behavior and to detect operation outside of specified ranges.

System analysis tools

There are analysis tools in related domains not yet accessible to robotics as they are complex to use. I would like to have support from these tools during the design of components, their selection and composition etc. I want to better address what-if questions, to perform trade-off analysis etc. These tools should be attached to robotics via dedicated model transformations without requiring me to get into them.

Task modeling for task-oriented robot programming

- Reusable and composable task blocks which express knowledge about how to execute tasks (action plot) and what are good ways to execute tasks (qualities).
- Management of the constraints such that composition for parallel and nested execution is free of conflicts and that open variation points can be bound at run-time according to the given situation ways to link generic task descriptions (with all their constraints and resource requirements) with software components (with all their configurations etc.)

Safety

- As safety engineer, I want to model limits for critical properties like the maximum speed when carrying around a hot coffee, when maneuvering in a crowded environment, the maximum speed dependent on visibility ranges etc.
- As safety engineer, I model constraints for particular applications and environments.
- As system builder, I want to be able to import these constraints such that tools help me to ensure design-time consistency and run-time conformance with them (via generated hard-coded limits, via monitors, via sanity checks etc.)

It is important to highlight what we are trying to say about system safety (not necessarily to prove), because systems are safe in a particular context under a particular set of assumptions (e.g. by run-time monitors etc.). The focus is possibly shifted from fail-safe to safe-operational, which may include some liveness in it. It is about efficient falsification (the following things cannot happen) rather than costly verification (it always behaves only like that).

Analogy: The PC Domain

We use the analogy of hardware in the PC Domain to illustrate concepts of RobMoSys. Using an analogy, we can describe particular concepts in a given context (the pc domain), which is easier to understand since the context of the PC domain is widely known. One can then transfer information given to the robotics domain. The PC domain is only an analogy that helps to illustrate concepts; the PC domain is different than robotics, so do not read too much into the examples given here.

Configuration, Composition, and Integration

Using the PC Domain, we illustrate the terms Configuration, Composition, and Integration.

Configuration

Configuration is lik going to a retail store that is specialized in a certain range of products, e.g. Dell or Apple, and as for a computer. What you get is a list of possible configurations of a computer where you can select its components from a list of predefined components. This means going through a product configurator, selecting the base product and selecting some extra options, e.g. hard drive capacity.

This essentially is a product line approach where parts of the product line and its variants is even visible to the customer.

Composition

Composition is like going to a computer retail store and buying and assembling the parts in an assisted way: for example, based on the items in the shopping cart, let the customer know:

- that the five PCIe cards will not fit the mainboard with only 4 slots
- that the power supply is not sufficient to power the system
- that the graphics card has an additional power socket which is not provided by the power supply

There are some online computer retailers that provide this kind of features. All this information is available in data sheets, but not all customers have the knowledge and experience to understand it. They need the support described above. Even experts are lost in case there is no data sheet.

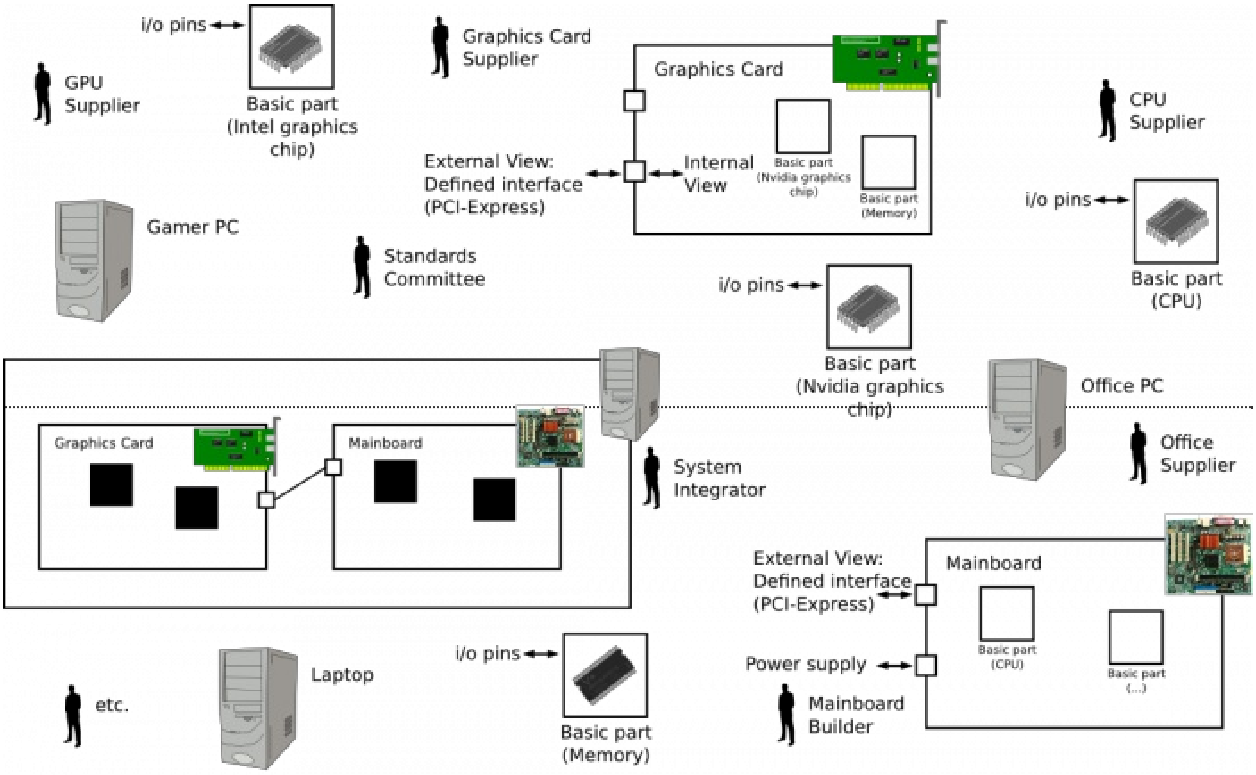
In robotics, there is neither a superordinate structure such as PCIe, no data-sheets for components, and no support for selecting components.

Integration (in contrast to composition)

Integration is like assembling parts with non-standard interfaces that do not allow to separate and exchange parts afterwards, for example, a battery that is soldered inside a laptop. Even after ripping out the battery, it cannot be used as there is no knowledge about the battery, no data sheet: How much power? How about electrical polarity/pin assignments? One starts to reverse-engineer to discover the properties using a voltmeter and other tools.

Ecosystem Example: Graphics Cards

In the PC industry, different ecosystem participants can supply and use building blocks to flexibly compose systems based on their needs. There are graphics card suppliers that do not know where their product is being used or for what purpose. They supply their graphics card and adhere to an specified interface (e.g. PCI express) to make sure it can be used with any mainboard. They can build their graphics card using off-the-shelf building blocks (e.g. Nvidia graphics chip and standard memory). They provide data sheets for the graphics card that specifies the properties of the product which are necessary to use it. The data sheet does not need to expose internal details or layouts (protected IP) of the graphics card.



Suppliers and Users collaborate and exchange building blocks in an ecosystem to flexibly compose systems based on their need.

What Enables Composition in the PC Domain?

Enablers of composability in the PC domain are:

- Building blocks **adhere to superordinate structures** (e.g. PCIe)
- Building blocks **explicate properties in data sheets** (e.g. power supply, form factor, thermal information)

Thanks to this enablers, the following is possible in the PC domain and RobMoSys aims at the same for robotics:

Views

Thanks to explicated properties in data sheets, specific views on a system can be taken. They are independent and each address concerns of the system. For example:

- A form factor view: will everything fit into the case? Are there enough slots in the casing for assembling the hard discs?
- A thermal view: how is heat flowing through the system and is the ventilation sufficient?
- A power supply view:

- General layout view: are there enough slots in the casing to access the PCI cards from the outside? Are there enough slots PCIe slots on the mainboard?

RobMoSys uses Views to group elements of the composition structure which are addressed by one role.

Decoupling supply and use

Thanks to data sheets, one can plan a system and come up with a blueprint for later assembly since data sheets contain all necessary information. The physical devices do not need to be present at that stage and can be assembled by someone else based on the blueprint. The blueprint can be used to verify the system: for example the performance might not be sufficient for the intended application.

IP is still flexible

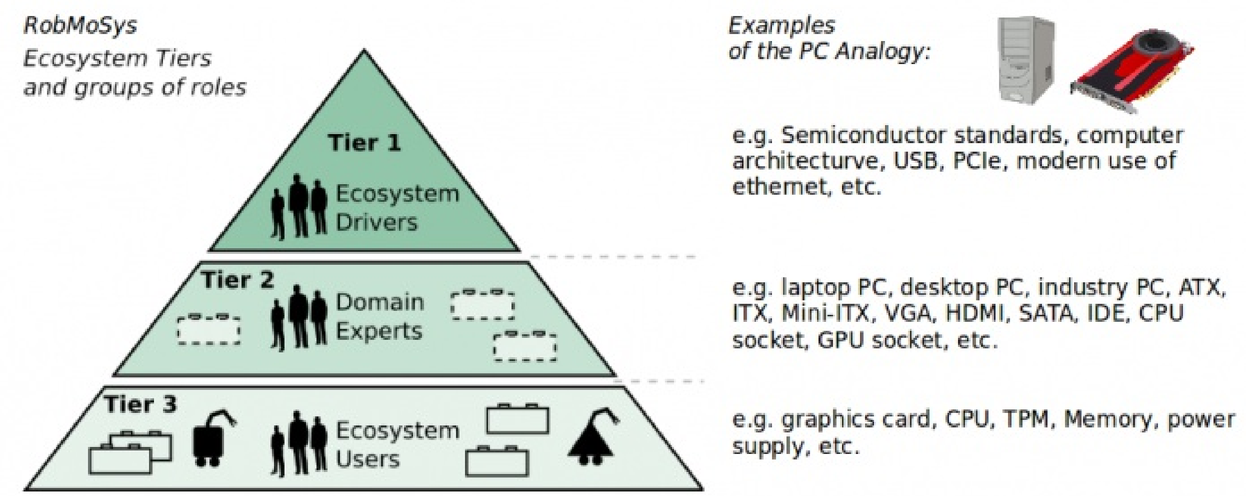
Exposing properties in a data sheet does not mean to expose intellectual property (IP). It is only about exposing the information that is relevant to use it (e.g. external view / interface), size of the device, power supply, etc. Information about the internals of the building block (circuit layout, chipset used, capacitors used, etc.)

Flexible composition Combinations and alternatives

Adhering to superordinate structures means gaining access to all other building blocks that adhere to the same structure. This gives high flexibility in composing parts.

RobMoSys Composition Tiers in the PC Domain

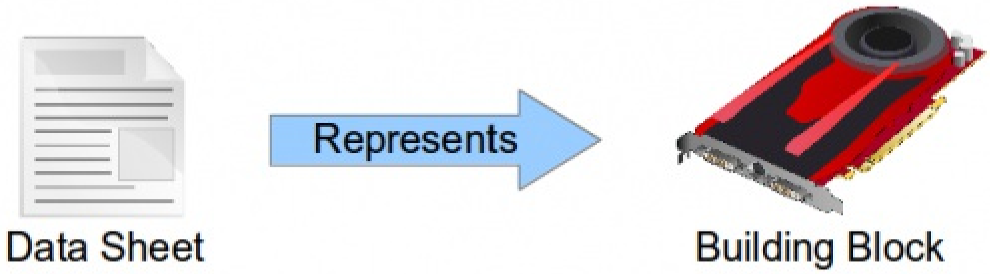
The below picture illustrated the Ecosystem Organization in composition Tiers using examples of the PC domain.



The RobMoSys composition Tiers illustrated with examples of the PC domain.

Data Sheets and The Modeling Twin

Data sheets in the PC domain are comparable to the Modeling Twin in RobMoSys. Data sheets represent a physical building block. See What Enables Composition in the PC Domain to learn about the benefits.



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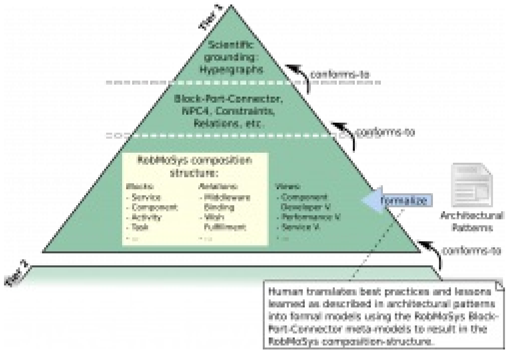
Tier 1: Modeling Foundations



RobMoSys considers Model-Driven Engineering (MDE) as the main technology to realize the so far independent RobMoSys structures and to implement model-driven tooling. The Wiki pages below collect some basic modeling principles related to realizing the RobMoSys structures.

- Roadmap of MetaModeling
- Modeling Principles
    - Modeling Twin
    - Realization Alternatives
- Tier 1 Structure
    - Scientific Grounding: Hypergraph and Entity-Relation model
    - Block-Port-Connector
    - RobMoSys Composition Structures
    - Views which are used by roles

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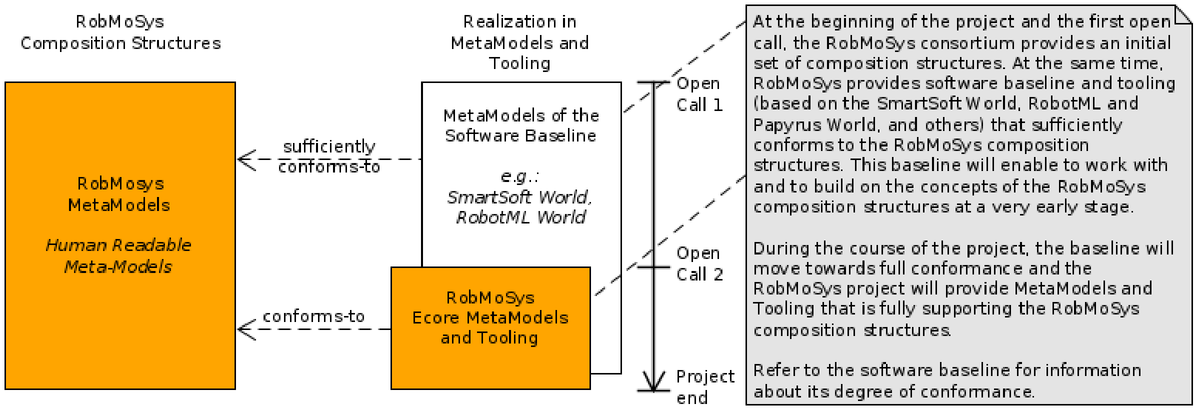
Roadmap of MetaModeling

The RobMoSys project makes available a baseline of already existing metamodels. They sufficiently conform to the RobMoSys composition structures. For example, the SmartMARS metamodel form the The SmartSoft World and also metamodels in the Papyrus4Robotics World.

In the course of the project, RobMoSys is going to provide an Ecore implementation of the RobMoSys structures. RobMoSys Structures: Realization Alternatives describes this in more detail and also lists alternatives.



See also

- The given description also holds true for the Roadmap of Tools and Software
- Conformance of SmartMARS Metamodel to RobMoSys composition structures

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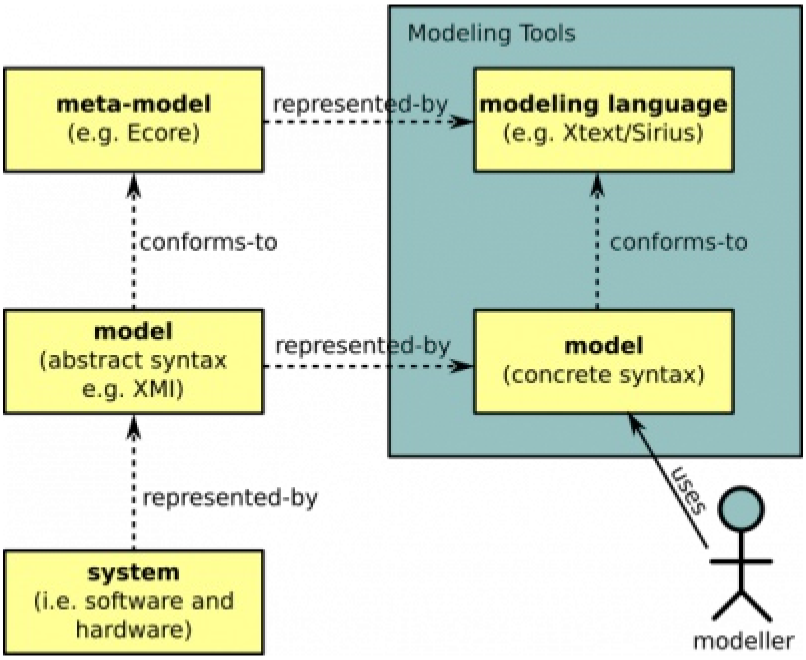
Basic Modeling Principles

There is a subtle relationship between the (meta-)models, the actual modeling languages and the concrete models. This relationship is depicted in the figure below.

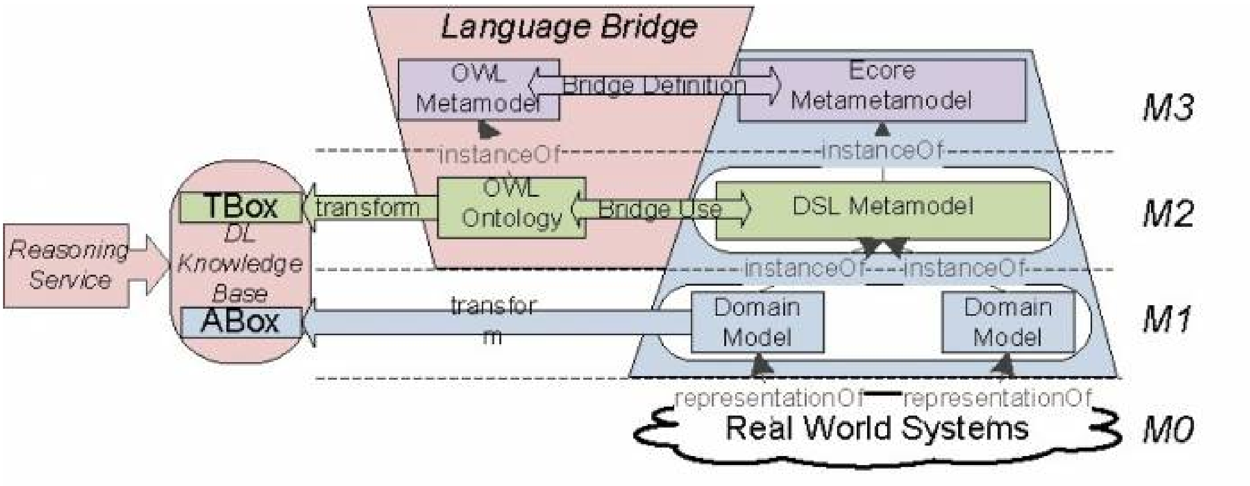


A modeller (i.e. a modeling-tool user who creates models) always works with a concrete syntax. This syntax can be textual, graphical, tabular or any combination thereof. The concrete syntax (sometimes also called notation) is defined by (i.e. it conforms to) the **modeling language**. The concrete syntax of a modeling language is independent of the abstract syntax of an actual **meta-model**. However, the structure of the **modeling language** must adhere to the structures defined in a **meta-model**. In most cases, it makes sense to first specify the meta-model, then to generate a modeling language out of the meta-model and then to adjust only the syntax of the modeling language (without affecting the structure). A model created by the modeller is typically only a representation for the in-memory model that uses the abstract syntax. The abstract syntax is also used to serialize the models in order to make them persistent.

Finally, the model itself is an abstract representation of the actual system (which can be either software, hardware or any combination thereof). Often, it makes sense to package the model with the related software/hardware parts and to ship them together as a so called modeling twin.

Ecore-OWL language-bridge

There is a relation between meta-models and ontologies that can be bridged as described here [http://twouse.blogspot.de/2010/08/owl-ecore-language-bridges.html].



This image is borrowed from twouse.blogspot.de [http://twouse.blogspot.de/2010/08/owl-ecore-language-bridges.html]

The strength of ontologies is the representation of knowledge with extensible structures. Moreover, ontologies allow reasoning on knowledge and the inference of further knowledge. The strength of meta-models is the definition of clear and unambiguous structures. This is particularly useful to represent physical entities and physical properties of the real-world. There are robotics use-cases where in some cases ontologies and in other cases meta-models can be preferred. Therefore it is reasonable to allow using both of them in combination, rather than restricting the usage of only one of them in isolation.

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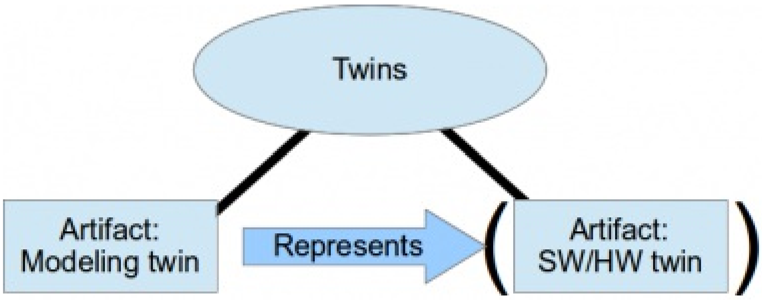
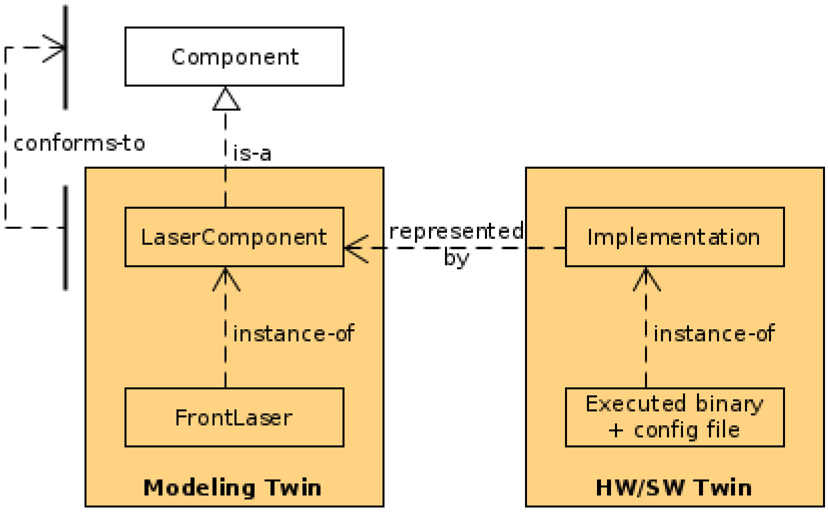
Modeling Twin

All entities in the market and all entities that are shared in the ecosystem come as twins. Twins consist of a model (modeling twin) that represents the Software or Hardware artifact (SW/HW twin). Think of the modeling twin as a bridge between traditional software artifacts and the modeling world. The modeling twin is similar to data sheets in the PC Analogy.



The modeling twin is always supplied and handed over between roles in the ecosystem. The SW/HW twin might be supplied later or might not exist at all. It might not exist, for example, when the artifact is purely intended for modeling. Entities in the market will never be just HW/SW artifacts without a modeling twin as then the artifact cannot be used. One can continue building a system independently with only the modeling twin, then supplying the HW/SW twin later.



The modeling twin is a representative and abstraction of the artifact it represents. It explicates necessary properties to work with it. Supplying a modeling twin does not equal to exposing all details: IP can still be protected as the modeling twin only have to expose the information that is relevant to use it: internal structures can remain hidden.

The modeling twin is is similar to the “digital twin”[1] in IoT and industry 4.0. It, however, is beyond bridging the physical world to the digital world: it focuses on having a representative of physical entities or software entities for modeling purposes.

See also

- PC Analogy

1)

Dr. Michael Grieves and John Vickers. “Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems (Excerpt)”, Excerpted based on: Trans-Disciplinary Perspectives on System Complexity. Online [http://research.fit.edu/camid/documents/doc_mgr/1221/Origin%20and%20Types%20of%20the%20Digital%20Twi

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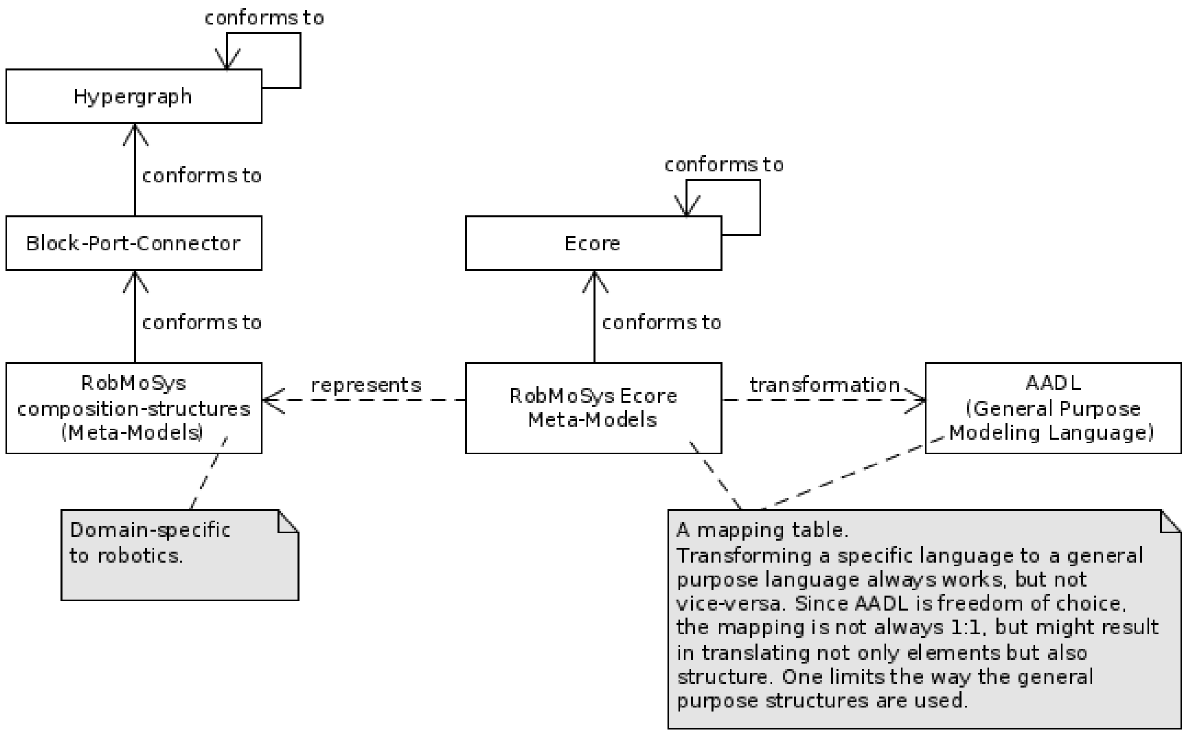
RobMoSys Structures: Realization Alternatives

This page describes alternatives for realizing the RobMoSys Composition Structures. This list of alternatives shows examples and is not meant to be complete.

Example 1: Using Ecore

A meta-model is an abstract representation of a model. A meta-model in itself can be considered as a model that may or may not have an even more abstract representation (i.e. a meta-meta-model). There are no theoretical limits for going up the abstraction hierarchy. However, from a practical point of view, at a certain abstraction level it simply does not make much sense to go further up the hierarchy. Instead, there often is a meta-level that is abstract enough to define its own language. Example languages for such a level are: Eclipse Ecore and Essential MOF (EMOF). Nevertheless, it might make sense to go higher up the abstraction hierarchy above Ecore in order to define meta-levels that ease interfacing between the different realization technologies. Such a higher meta-level is for instance the Hypergraph notation. The relation between e.g. the Ecore based meta-models and the more abstract meta-levels is depicted in the figure below.

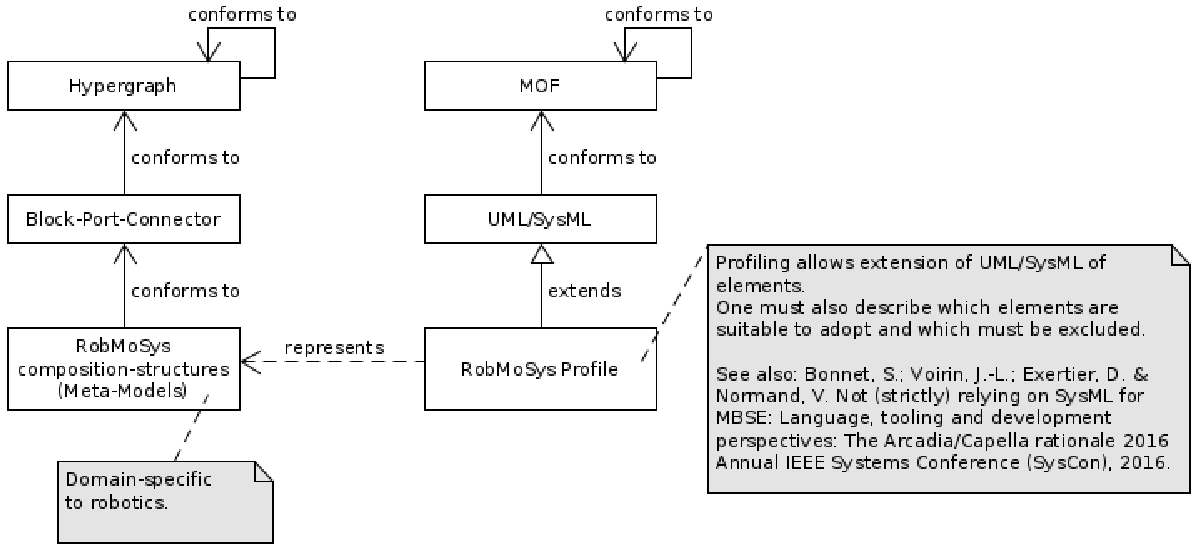


The left side of the figure shows a meta-level hierarchy starting with a Hypergraph on top, over Blocks-Ports-Connectors and down to RobMoSys composition structures. This hierarchy allows formal definition of meta-levels for the required structures independent of a particular realization technology. In the middle of the figure, a specific realization technology (in this case Ecore) is used to implement the RobMoSys meta-models. This is only an example and many other technologies can be used instead in a similar fashion. Moreover, other existing modeling languages (such as AADL) can be easily interlinked with the RobMoSys structures by defining model-to-model transformations. This is a powerful extension mechanism that allows usage of matured and powerful tools in robotics.

In the course of the project, RobMoSys is going to provide an Ecore implementation of the RobMoSys structures.

A preliminary implementation of Ecore meta-models for the two topmost abstraction levels within Tier 1 (on the left in the figure above), namely the Entity-Relation and Block-Port-Connector meta-models, is available at Preliminary Ecore implementation of ER and BPC meta-models.

Example 2: Using UML/SysML Profiling

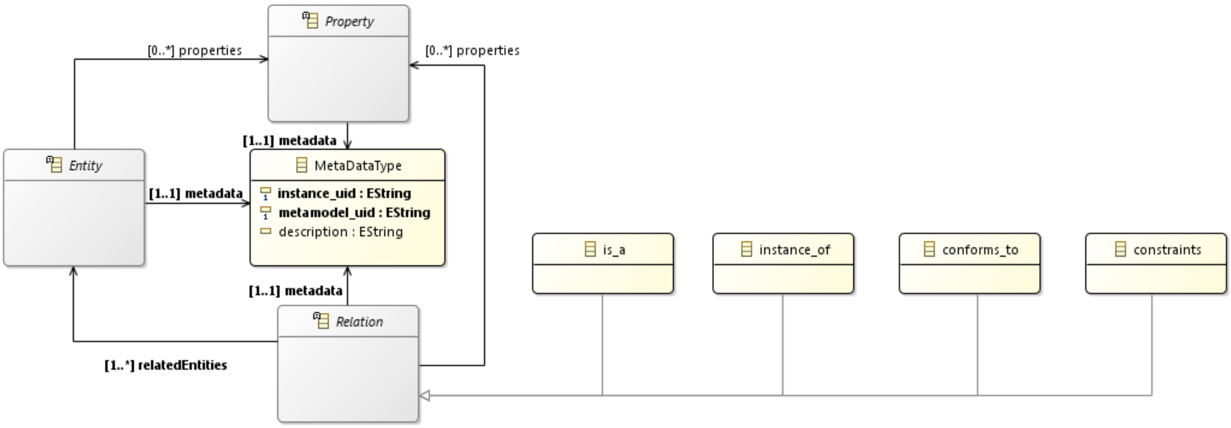


The figure above shows another example of using a different realization technology, in this case the UML/SysML and MOF as base structures. The RobMoSys structures on the left are unaffected by this different technology choice. It is worth mentioning that while the UML standard also specifies the graphical notation, the extension mechanism through profiling might be a bit more challenging when it comes to restricting the already defined modeling structures. These pros and cons need to be traded off when choosing a modeling technology.

Preliminary Ecore implementation of ER and BPC meta-models

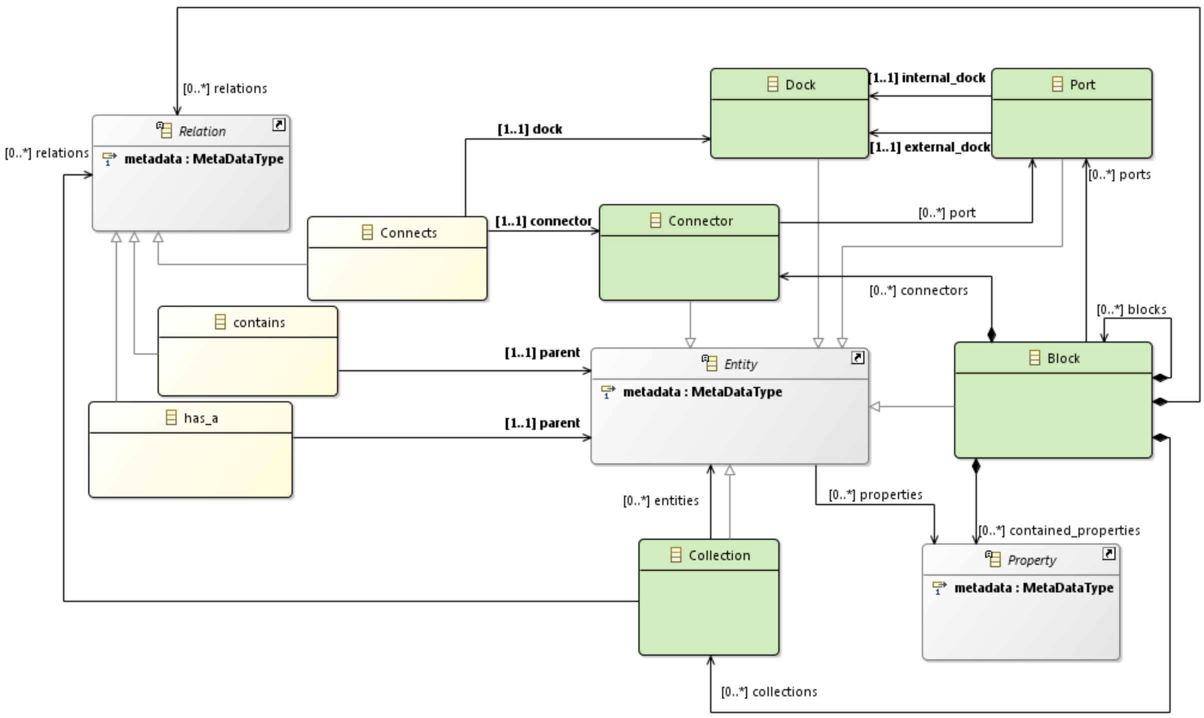
Entity-Relation (ER) meta-model

The concepts provided by the ER meta-model comply with the definitions in Scientific Grounding



Block-Port-Connector (BPC) meta-model

The following meta-model includes concepts that are defined in Block-Port-Connector



Eclipse/Ecore implementation of ER and BPC meta-models

Eclipse/Ecore implementation of the above meta-models can be downloaded here

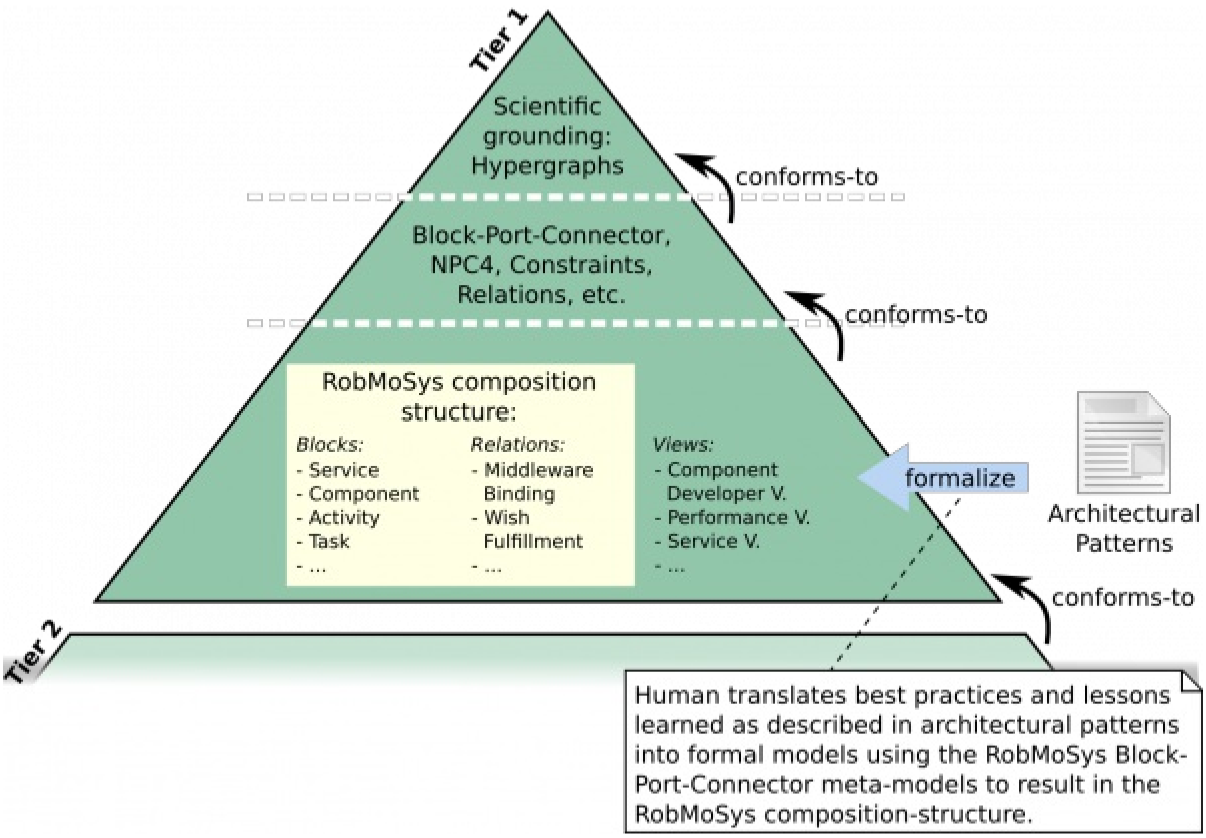
To access these meta-models you will need to:

1. Install Eclipse Neon Modeling [http://www.eclipse.org/downloads/packages/eclipse-modeling-tools/neon3].

2. Import the plugins in your workspace.

Tier 1 in Detail

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



Hierarchical Hypergraphs and Entity-Relation Model

Hierarchical Hypergraphs can be considered as the topmost abstraction level within Tier 1. It allows definition of a sound scientific grounding and a formalization in a most flexible model. Any modeling structure can be represented by a Hypergraph. The specific structures on the levels below are always specializations (i.e. refinements) of a Hypergraph.

The Hypergraph and Entity-Relation Model page provides additional details.

Block-Port-Connector

The next level on Tier 1 is the definition of blocks, ports and connectors as a general meta-level that allows definition of any domain-specific meta-model such as e.g. the RobMoSys composition structure (see below).

The Block-Port-Connector page provides a more detailed description.

RobMoSys composition structure

RobMoSys composition structures provide domain-specific meta-structures that are used on the lower Tier 2 and Tier 3 to design robotics models in specific robotics subdomains.

The RobMoSys Composition Structures page provides further details.

RobMoSys Views

The RobMoSys views are a complementary technique to the RobMoSys composition structures. This technique supports definition of role-specific modeling views that allow modification and refinement of specific primitives without breaking the overall structures. This is a useful technique that directly supports separation of roles and at the same time allows realization of model-driven tooling that ensures overall system consistency.

The RobMoSys Views page provides further details.

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http://www.robmosys.eu/wiki-sn-01/modeling:tier1

Scientific Grounding

The highest abstraction level that is considered in RobMoSys is related to Hierarchical Hypergraphs and Entity-Relation models. The Entity-Relationship[1] model was one of the first approaches for formal "data base" models of knowledge.[2] It has gained renewed interest because of the rising popularity of the "Semantic Web"[3].

One of the main challenges is to represent context, more in particular, to deal with the combinatorial explosion in the number of relationships needed to represent – and interconnect – all relevant pieces of information and knowledge in multi-domain ICT and engineering systems. Such interconnected knowledge forms graph networks of links and properties. This fact poses difficulties to Lisp, Prolog, or other "programming languages" for Artificial Intelligence (AI), since they only have representations for relationship trees as first-class citizens. The same holds for the frame languages [https://en.wikipedia.org/wiki/Frame_language] [4] in AI, which considered "multiple inheritance" as a key feature. This last feature, together with "data encapsulation", are two major aspects of strict object oriented languages and models, that make "open world" [5][6] knowledge representations difficult; the SOLID [https://en.wikipedia.org/wiki/SOLID_(object-oriented_design)] principles of object orientation better support knowledge representation, especially via its "D" feature, that is, the *Dependency inversion principle*, which states that one should "depend upon abstractions, not on concretions". However, none of these approaches offers infinitely composable knowledge representations, because they only partially support the essential features outlined in the sections below.

Hierarchical Hypergraph

The modern, higher-order, version of the Entity-Relationship model is that of a hierarchical (property) hypergraph[7][8]:

- hierarchical : every node and every edge can be a full graph in itself. In other words, any Relation can be considered an Entity in itself, and can hence be used as an argument in another, higher-order Relationship.
- hypergraph: every edge can connect more than two nodes; that is, it is an n-ary "hyperedge"
- property meta data: every node and every edge in the graph has a property data structure attached to it; two (mandatory) parts of those properties are the following meta data:
    - unique node/edge identifier : other relationships in the graph can refer to this node or edge.
    - meta model identifier : each node or edge has a type, indicated by the unique identifier of the graph that models that type.

Often used synonyms for the term "Entity" are: object, concept, atom, primitive. "Relationships" are also called: rules, axioms, constraints, links, expressions. Often used extra meta data is the so-called provenance of a model: who made it? when? what version is it? Etcetera. State of the art formal meta models to represent such provenance are W3C provenance[9], and Dublin Core[10].

Entity-Relation Model

Each "thing" to be modelled will have a number of data structures that represent its properties. That can be done via (possibly nested) key-value pairs, with each key having, a type, a unique identifier (with which

Relationships can refer to it), and a role to play in the “thing” properties. While efficient implementations of those properties can be realised with the rich data structure primitives in computer programming langauges, the meaning of such properties, as just described above, is a hierarchical hypergraph.

A Relationship between Entities is a named directed graph, representing the Role that each Entity plays as an Argument in the Relationship:

- the top node carries the meta data of the Relationship, of which the two major ones are: (i) its unique “identifier ” (with which other Relationships can refer to it), and (ii) the context (all the externally defined Entities and Relationships whose names are being used in the model of this Relationship). Other meta data in the top node are: type and provenance. In addition to the identifier (which in principle should only be computer-readable), models often carry human-readbale names and description strings, possibly in various languages. However, these are not used in linking Entities together into Relationships.
- from the top node, there are Role edges towards each of the Entity nodes that figure as Arguments in the relationship. Each Role edge also has similar meta data properties as the top node, but the most distinguishing one represents the purpose (“role”) of a particular argument in the Relationship. This is formally represented by a specific Relationship in itself.

Each “value” in an Argument has a domain (or “universe of discourse”): the type and the set(s) of possible values that the “key” can have. In other words, that domain brings its own property data structure to each argument. Remark the recurring pattern of “identifiers”, “types” and “contexts”, in the nodes and edges of a hierarchical hypergraph. And also remark that the graph is directed : pointing from the Relationship to the Entities, and down to the latters’ proeprties.

Natural modelling levels of abstraction

“Abstraction” is a key concept in modelling, but it is hard to define axiomatically. Below, three core “meta meta” forms of modelling are described[11]:

- **mereology** – parts: there is already quite some (mature) formalisation available in the state of the art, to structure “Entities’; for example, the Wikipedia article [https://en.wikipedia.org/wiki/Mereology] in the subject has a good overview and pointers to the literature. The key Relationship is has-a (also called, “has-part” or similarly equivalent names), and is-equal.
- **topology** – structure of interconnections between parts: this kind of structural model is a key property of any system, and also here the state of the art insights and formalizations are sufficiently mature to have unambiguous and consistent semantics of formal models, to the extent that it is realistic to develop “standards” and “tools”.

Concretization (or specialization) can be considered as the opposite of abstraction. In this sense, raising the level of abstraction means to get more general purpose while lowering the level of abstraction means to get more specific with respect to e.g. a certain domain. It is only natural that the general purpose (i.e. higher) abstraction levels tend to leave open some semantic variability. For instance, UML (as one representative for general-purpose modeling languages) purposefully defines *“semantic variation points”*. These “semantic variation points” can be fixed by e.g. deriving domain-specific models (in terms of UML by defining UML profiles). In this sense, RobMoSys as well defines several levels of abstractions, with “Hierarchical Hypergraphs” and “Entity-Relation” levels on top, over “Block-Port-Connector” and “RobMoSys composition structures” and down to concrete realizations (sometimes “reference implementations”). Going gown this abstraction hierarchy also means getting more domain-specific and narrowing semantic variability.

Formalization

This section provides formal specifications for the Hierarchical Hypergraphs and for an Entity-Relation model.

Hierarchical Hypergraph

- "a hypergraph H is a pair H = (X,E) where X is a set of elements called nodes or vertices, and E is a set of non-empty subsets of X called hyperedges or edges" Wiki:Hypergraph [https://en.wikipedia.org/wiki/Hypergraph]
- hyperedge: each vertex in the graph can connect more than two nodes
- hierarchy: each node or edge in the graph can be a full graph in itself

Entity-Relation Model

Entity-Relation is a specialization of a Hypergraph. Therefore, Entity-Relation **conforms-to** a Hypergraph.

- **entity**
  - the "things"
  - entity instantiates a node of its meta-model
    - uniquely referencing an element of its meta-model
  - entity has a unique identifier
    - uniquely referencing this primitive
- **relation**
  - n-ary link between primitives
  - relation instantiates a hyper-edge of its meta-model
    - uniquely referencing an element of its meta-model
  - relation has a unique identifier
    - uniquely referencing this relation
- **property**
  - attribute of a primitive or a relation

Basic set of standard relations for linking different levels of abstraction

We do not introduce a RobMoSys specific definition for these relations. Instead, we just use their "common sense definition". The following explanations are just typical "common sense descriptions":

- **is-a**
  - this is inheritance
  - an element of a model derives from an element of a metamodel
- **instance-of**
  - this is often just a synonym for "is-a"
  - one talks of an instance when it is the final element in an inheritance hierarchy. What is considered a final element depends on what parts of the inheritance hierarchy you see.
- **conforms-to**
  - a meta-model is a model that defines the language for expressing a model. A model represents an abstracted representation of an artefact. A model conforms to a meta-model. One model can have multiple models to which it conforms.
- **constraints**
  - this is a particular relation
  - it can be applied to primitives, relations and properties

See next:

* Block-Port-Connector

References

1)

P. P.-S. Chen. The entity-relationship model—Toward a unified view of data. ACM Transactions on Database Systems, 1(1):9–36, 1976.

2)

At more or less the same time, similar developments took place around knowledge representations via "programming languages", such as Lisp or Prolog.

3)

T. Berners-Lee, J. Hendler, and O. Lassila. The semantic web. Scientific American, 284(5):34–43, 2001.

4)

M. L. Minsky. A framework for representing knowledge. In P. H. Winston and B. Horn, editors, The psychology of computer vision. 1975.

5)

R. Reiter. On closed world data bases. In Logic and Data Bases, pages 55–76. 1978.

6)

S. J. Russell and P. Norvig. Artificial Intelligence: A Modern Approach. Prentice Hall, 3rd edition, 2009.

7)

G. Engels and A. Schürr. Encapsulated hierarchical graphs, graph types, and meta types. Electronic Notes in Theoretical Computer Science, 2:101–109, 1995.

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M. Levene and A. Poulovassilis. An object-oriented data model formalised through hypergraphs. Data & Knowledge Engineering, 6:205–224, 1991.

9)

W3C. An overview of the prov family of documents. https://www.w3.org/TR/prov-overview/ [https://www.w3.org/TR/prov-overview/], 2013.

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Dublin Core Metadata Initiative. Dublin core metadata element set. http://dublincore.org/documents/dces/ [http://dublincore.org/documents/dces/].

11)

P. Borst, H. Akkermans, and J. Top. "Engineering ontologies". *International Journal on Human-Computer Studies*, 46:365–406, 1997.

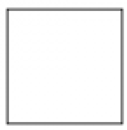
Block-Port-Connector

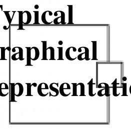
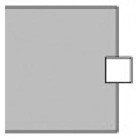
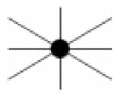
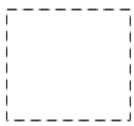
The Block-Port-Connector model is a specialization of the more abstract Hypergraph and Entity-Relation model.

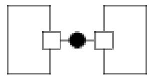
The following generic **relations** have been introduced already: **is-a**, **instance-of**, **conforms-to** and **constraints**. There are two additional (i.e. more specific) relations that need to be introduced:

Relation	Explanation	Typical graphical representation	Typical textual representation
contains	# can be applied to entities and can be applied to relations * this realizes hierarchical composition (nested composition) in a hierarchical composition (i.e. elements are enclosed by another element) * the contained elements are not accessible (in contrast to elements in a collection) * the contained elements cannot exist without the parent * can be refined to composition association in UML	a nested box with solid border or a UML composition arrow	contains(A,a,b,c) contains(B,m,n)
has-a	# can be applied to entities and can be applied to relations * this realizes aggregation * in aggregation, elements remain at the same level * elements linked with has-a can exist independently * can be refined to aggregation association in UML	a nested box with dashed border or a UML aggregation arrow	has-a(A,a,b)

The generic **entity** is refined as follows:

Entity/Relation	Model and Description	Typical graphical representation	Typical textual representation
block	**Model:** * is-a **entity** * possibly has-a property (or many) * possibly has-a port (or many) * possibly contains property (or many) * possibly contains block (or many) * possibly contains collection (or many) * possibly contains connector (or many) * possibly contains relation (or many) **Description:** the only interaction points of a block are ports		block(block-A)

Entity/Relation	Model and Description	Typical graphical representation	Typical textual representation
port	**Model:** * is-a **entity** * has-a internal dock * has-a external dock **Description:** it is the only interaction point over which a block can interact with other blocks; when attached to a block, the internal dock becomes a private to the block (contains) and the external dock becomes public (has-a) **Comment:** In textual representation, access to docks can be represented e.g. like internal-dock(Port-A), external-dock(Port-A)		port(Port-A)
dock	**Model:** * is-a **entity** **Description:** A dock is used to semantically differentiate between the “internal” and “external” sides of a port with respect to the port's parent block. **Comment:** In a graphical representation, the internal dock and the external dock can be highlighted, for example by different colors (be careful, not to start an irrelevant activity in introducing such graphical notions into existing tools which cannot handle that).		dock(Dock-A)
connector	**Model:** * is-a **entity** * connects ports (n-ary relation) **Description:** can connect ports as long as no block boundaries are crossed **Comment:** In graphical representation, the connector itself is represented by a dot. With the connects-relation, star-shaped lines (connects-relations) originate from the dot in the center.		connector(connector-A)
collection	**Model:** * is-a **entity** * possibly has-a entity (or many) * possibly has-a relation (or many) **Description:** A collection can group any combination of entities and / or relations. The enclosement formed by a collection is just a virtual one where the elements are openly accessible (in		collection(collection-C,k,l,m,n)

Entity/Relation	Model and Description	Typical graphical representation	Typical textual representation
	contrast to nesting) A collection can pick any elements out of blocks ignoring block boundaries ⇒ this is particularly useful to specify modeling views **Comment:** In the graphical representation, the dotted box can enclose entities and / or relations where you can cross the dotted line to “enter” the collection		
connects	**Model:** is-a **relation** **Description:** links a dock of a port to a connector (binary relation)		connects(connector-A,external-dock(Port-A))

There is a specific relation between the RobMoSys composition structures and the modeling views as is discussed on the next page. The important point at this level here is to provide a base-level that allows specification of both kinds. The specific part for specifying modeling views is the **collection** definition while all the other specifications are used to define the RobMoSys composition structures.

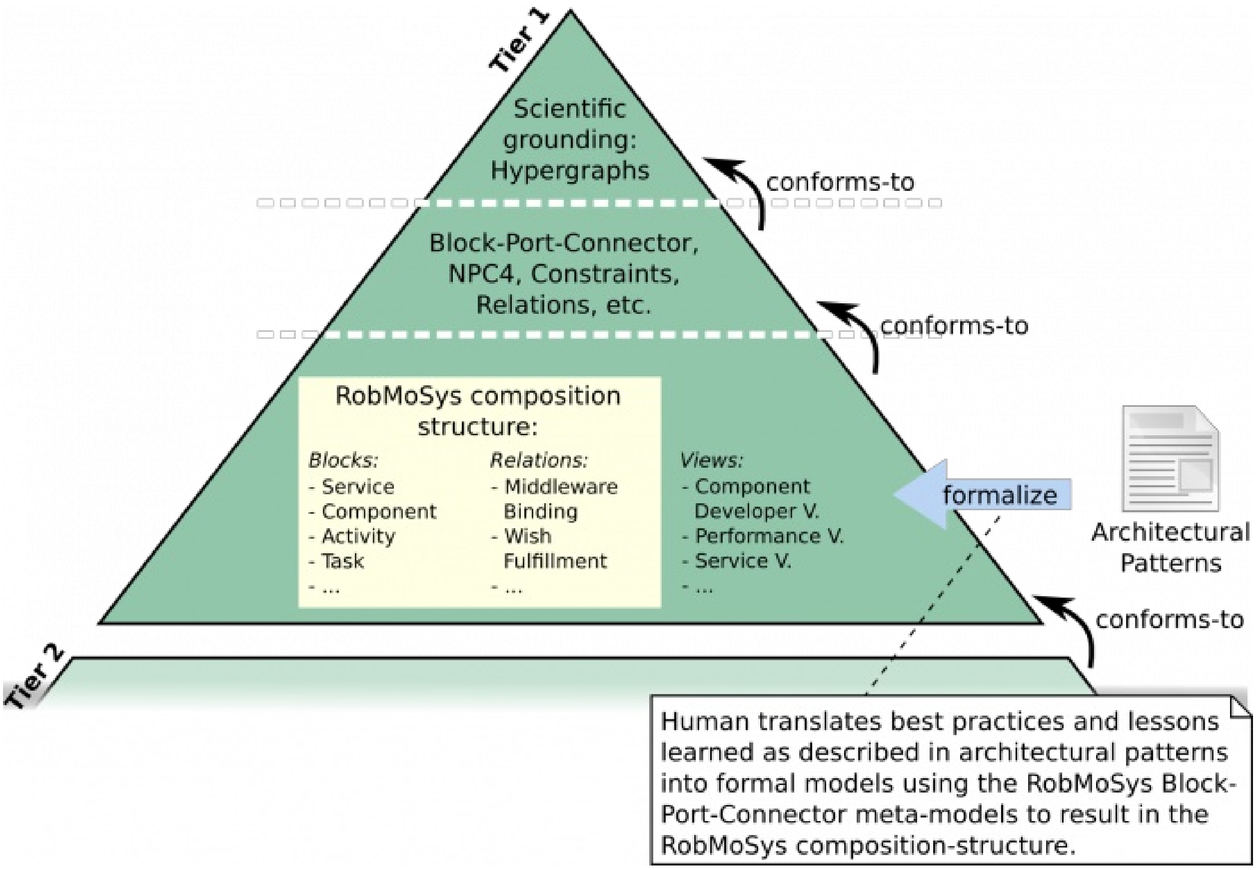
Please note that while **blocks** and **ports** are semantically different, depending on the current role-specific view with according level of abstraction, ports can contain additional structures and thus might appear as blocks on that detailed abstraction level (see service-definition metamodel).

See next

- RobMoSys composition structures

RobMoSys Composition Structures

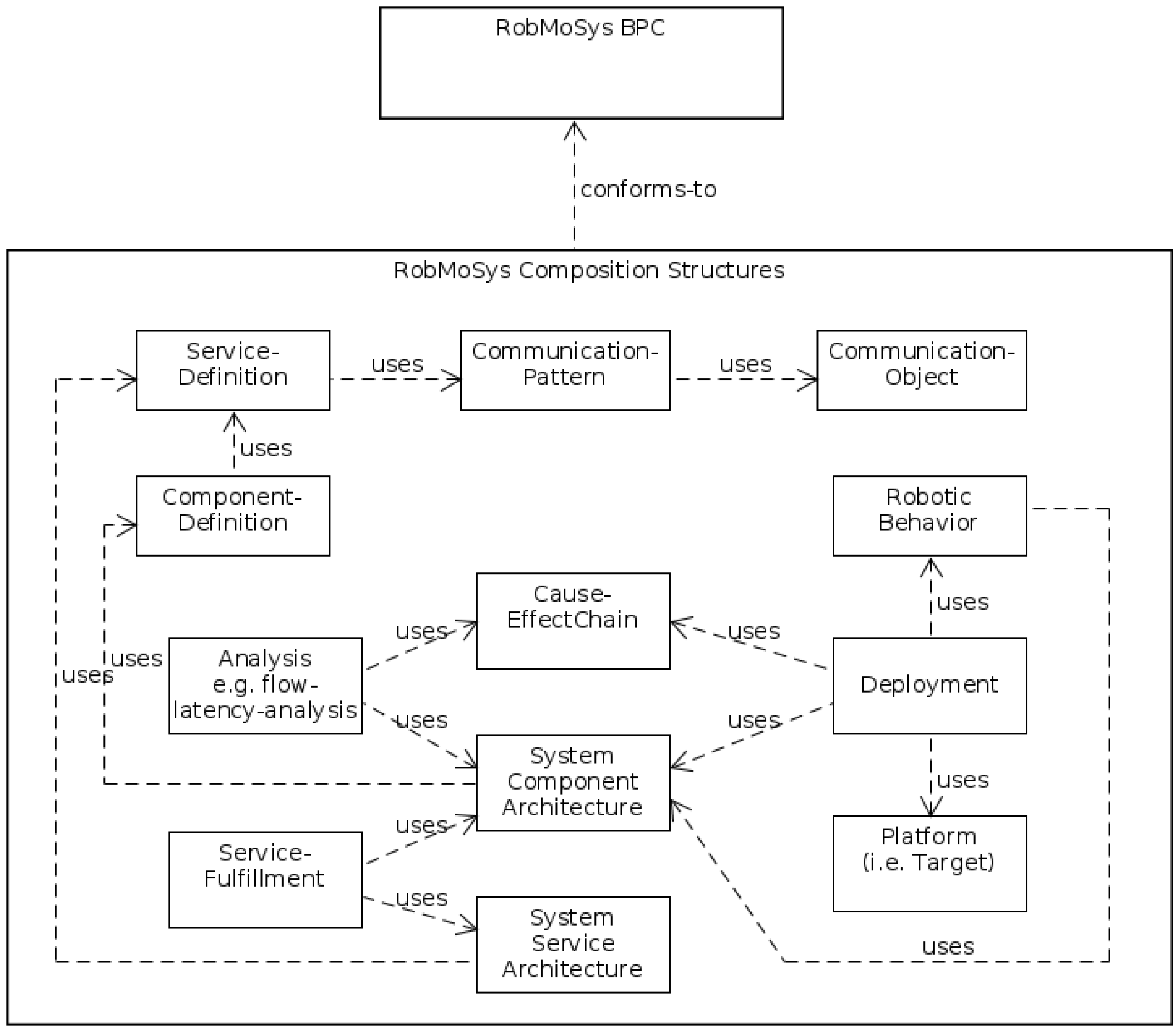
The RobMoSys composition structures is a bottom abstraction layer on Tier 1 (see figure below). This layer defines all the robotics meta-structures that are required to consistently model robotic systems throughout several development phases and thereby supporting different developer roles. The meta-structures follow a general composition-oriented approach where systems can be constructed out of reusable building blocks with explicated properties. In other words, RobMoSys enables the composition of robotics applications with managed, assured and maintained system-level properties via model-driven techniques. This enables communication of design intent, analysis of system design before it is being built and understanding of design change impacts. Therefore, the RobMoSys composition structures adhere to the general block-port-connector meta-structures and can be considered as a further specialization thereof.



The figure (above) shows an exemplary list of possible composition structures (highlighted with the yellow background color), which can be clustered into (a) specializations of **blocks** and (b) specializations of **relations**. One of the central structures defined by RobMoSys is a consistent and rich enough **component model** that considers the interaction with related structures around the component model (such as e.g. the definition of communication services and the binding to different middlewares). These structures are described below in separate pages. An interesting point is that RobMoSys by purpose does not aim at one huge meta-model that covers all robotics aspects at once. Instead, RobMoSys foresees the definition of modeling views that cluster related modeling concerns in dedicated views, while at the same time connecting several views in order to be able to define model-driven tooling that supports the design of consistent overall models and to communicate the design intents to successive developer roles and successive development phases. In this sense, composition does not only apply to designing robotics software but is also applied to designing the modeling tools, thus making them easily extensible and composable.

Overview of RobMoSys composition structures

The figure below provided an overview of the RobMoSys composition structures (i.e. the **RobMoSys Metamodels**). Each block in the figure represents a separate Metamodel that is individually described in a separate page (see below). There are high-level relations between the metamodels that are depicted with the **uses** keyword.



The next pages individually describe the RobMoSys metamodels in a human-readable notation using the general definitions of block-port-connector. There is a straightforward way to transform this representations using a dedicated modeling technology as described here.

Each metamodel (presented next) addresses two main modeling needs namely **structure** and **interaction**. **Structure** defines the structural relations (such as **has-a** and **contains**) between the individual model elements. Structure can often be directly translated into a modeling technology such as Ecore. **Interactions** define the important interaction relations (using **port**, **connector** and **connects**) between specific model elements. In contrast to structure, interactions are often transformed into software APIs (e.g. through code generation) and must not always be visible on model level.

See next:

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

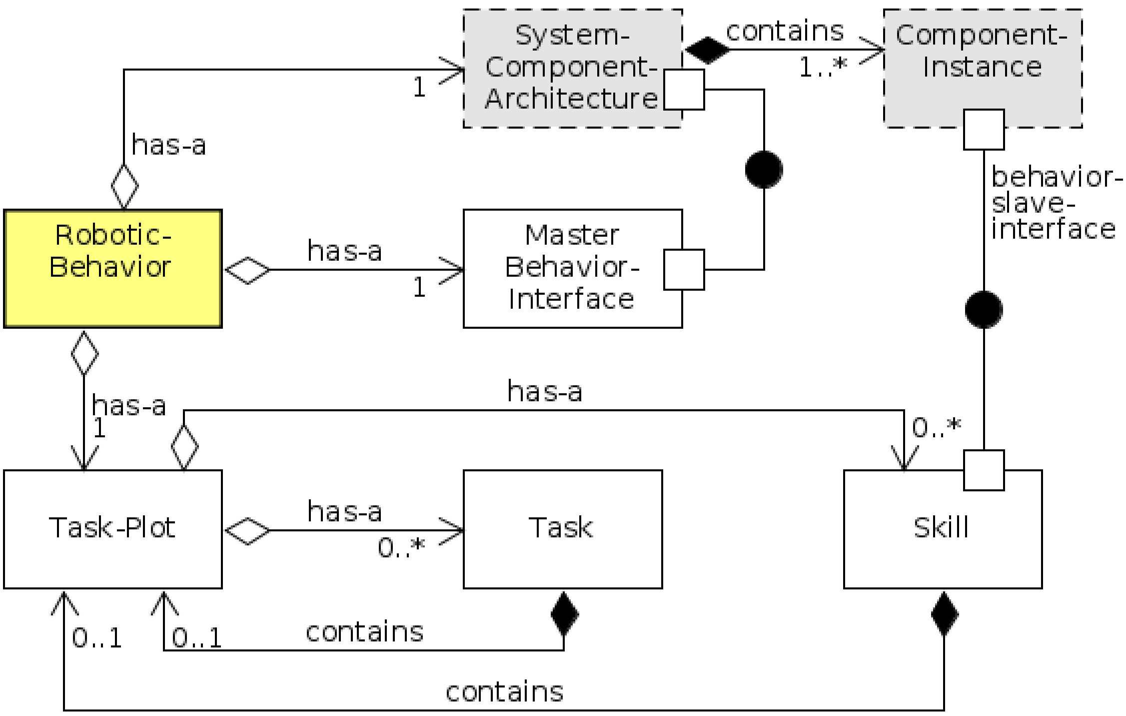
See also:

- RobMoSys Views

Robotic Behavior Metamodel

The Robotic Behavior Metamodel is one part of the RobMoSys Composition Structures that is responsible for specifying the overall run-time behavior of a robot acting in real-world environments.

The Robotic Behavior Metamodel defines structures for modeling task-plots of a robot (see figure below). Task-plots define sequences of tasks required to achieve certain goals at run-time. Each task itself can contain another task-plot. This introduces hierarchy into the task-plot modeling where high level tasks (such as e.g. making-coffee) are refined into lower level tasks (such as e.g. approach the kitchen, operate the coffee machine and bring the coffee back to the customer). At the lower end of the abstraction hierarchy, tasks eventually operate (i.e. to coordinate and configure) according software components that do the actual “work” of a task. In this sense, tasks are passive, they just delegate the work to components in the system and await the results (i.e. success or failure). The interaction between task-plots and components is over skills. In this sense, a skill abstracts the technical coordination interface of a component and makes it accessible for task-plots. A skill by itself might “inject” additional task-plots. This feature is particularly useful for modeling alternative behaviors in case of contingencies in the overall behavior. For example, a skill commanding a navigation component to approach a room might get the result that the navigation component failed to do so (e.g. due to a blocked hallway). In this situation, the according skill might inject an alternative strategy, namely to first go to another location and to try the current task later (or whatever other strategy might be appropriate here).



A service robot is a physical entity that needs to cope with the physical constraints of the real-world. For instance, actions of the robot, once performed, might be irreversible and always can fail. This also means that at each point in time, the control hierarchy on the robot must be clear. Simply speaking, a robot cannot decide in parallel to go to left and to right at the same time (for most of the robots, this is physically impossible). In consequence, there is typically only one entity on each robot that is responsible for executing the robotic behavior models namely the sequencer (see this page [http://www.servicerobotik-ulm.de/drupal/?q=node/86] for further details on sequencing).

For the interaction between the behavior model and the software components in a system, the robot behavior uses the “Master-Behavior-Interface”. Each component in the system by default implements the counter part “Slave-Behavior-Interface” (not displayed in the figure). Therefore, the robot-behavior depends on the system-component-architecture for the interaction with the according component-instances.

One existing realization of the robotic behavior meta-model is SmartTCL [http://www.servicerobotik-ulm.de/drupal/?q=node/84]. SmartTCL [http://www.servicerobotik-ulm.de/drupal/?q=node/84] conforms to the above presented meta-model and can be used as an initial software baseline already now.

See next:

- Deployment Metamodel

See also:

- System Component Architecture Metamodel

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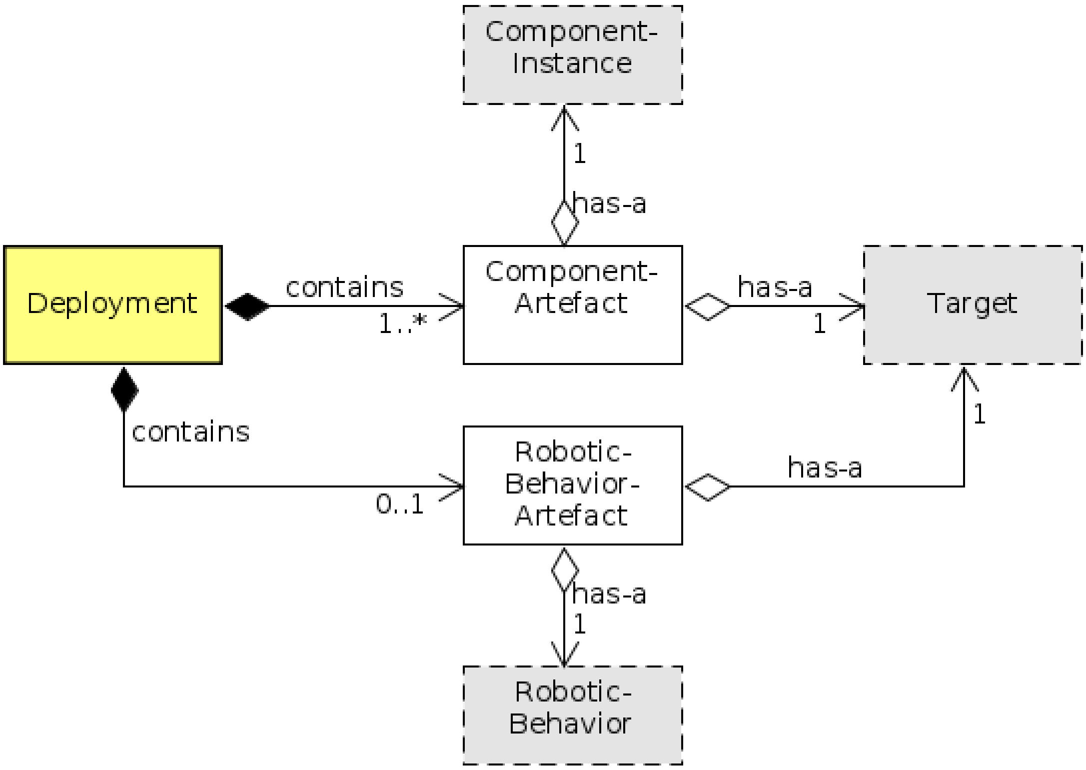
modeling:metamodels:behavior · Last modified: 2017/06/23 18:16
http://www.robmosys.eu/wiki-sn-01/modeling:metamodels:behavior

Deployment Metamodel

The Deployment Metamodel (see figure below) is part of the overall RobMoSys Composition Structures. This meta-model links (i.e. interfaces between) the three meta-models, namely System Component Architecture, Platform and Robotic Behavior.



The main concerns of this meta-model are to define artefacts and to assign them to selected targets. This meta-model is inspired by the UML deployment model. There are two artefact types namely component-artefacts and robotic-behavior-artefacts. Component-artefacts represent typically the precompiled binary form of component-instances (including generated ini-files and start scripts). The robotic-behavior-artefact is the physical representation of the robotic-behavior model (often this is an interpretable model).

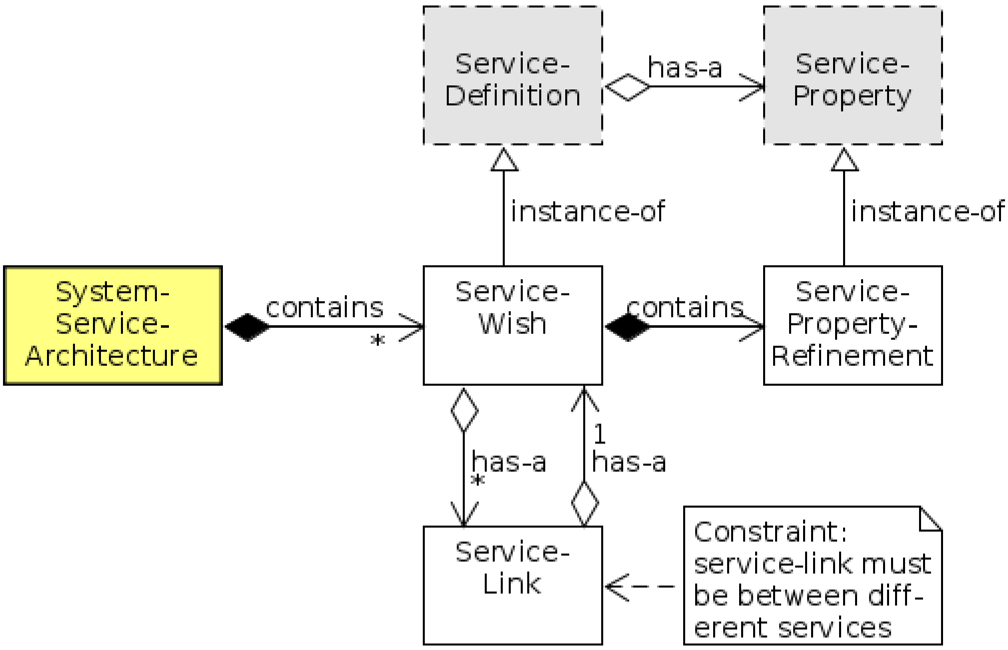
Depending on the used modeling tool, the deployment meta-model could also be connected with the actual deployment action that copies the component and robotic-behavior artefacts to the according target platforms. However, this is a matter of tooling and is independent of the deployment meta-model as such.

See also:

- Platform Metamodel
- System Component Architecture Metamodel
- Robotic Behavior Metamodel

System Service Architecture and Service Fulfillment Metamodels

The System Service Architecture Metamodel is a particularly useful meta-model for System Architects. This meta-model allows the definition of service-based reference architectures for specific (sub-)domains on Tier 2. This meta-model depends on service-definitions and itself can be used to check “conformance” of a system-component-architecture to this service-based reference architecture. Checking this conformance is one of the main concerns of the service-fulfillment meta-model (see the following section below).



The System Service Architecture Metamodel specifies service-wishes which are component-independent definitions of service-requirements for a set of systems. Moreover, links between service-wishes specify component-independent inter-service dependencies (i.e. a service-wish might depend on the existence of another service-wish).

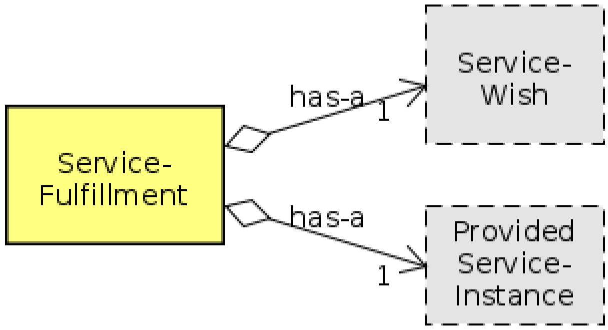
For example, a set of recurring services for a navigation stack (such as localization, mapping, path-planning, obstacle-avoidance, etc.) can be specified in advance independent of a concrete system and independent of concrete implementations in software components. In addition, it can be specified that a path-planning service typically depends on the existence of a localization service which itself depends on a mapping service, etc.

In addition, a service-wish can instantiate several service-properties which allow definition of specific Quality-of-Service (QoS) attributes. Examples for such attributes can be found here.

Please note, that the definition of service-based reference architectures seldom defines all services of one concrete system. Instead, a service-based reference architectures typically defines only the recurring services for (or from) a set of systems.

Service Fulfillment Metamodel

The Service Fulfillment Metamodel maps the service-wishes from a system-service-architecture (see above) with the provided-service-instances from a system-component-architecture. This mapping of service-wishes to provided-service-instances is called service-fulfillment. This is a powerful meta-model that allows definition of domain-specific de-facto standard architecture and thus considerably increases reuse of recurring specifications and at the same time fosters competition on implementation level (conforming to modeled reference architectures).



While the Service Fulfillment Metamodel directly depends on the two meta-models “System Service Architecture” (see above) and “System Component Architecture”, the order of usage of these two models is not strict. For instance, an existing (i.e. fully specified) system-component-architecture can be used to check whether it conforms to a later (or independently) defined system-service-architecture. Or, a specified system-service-architecture can be used upfront to select conforming components (from a component repository) for a current (i.e. new) system-component-architecture under development. Of course, all the intermediate options are also possible with partial specifications of system-service-architectures and system-component-architectures with intermediate checking of conformance.

An interesting option for this meta-model is to use constraint solvers to automatically pre-select existing component-definitions from a component repository according to the specified system-service-architecture. This is a powerful mechanism that considerably improves efficiency in designing new systems.

See next:

- System Component Architecture Metamodel

See also:

- Service-Definition Metamodel

Acknowledgement

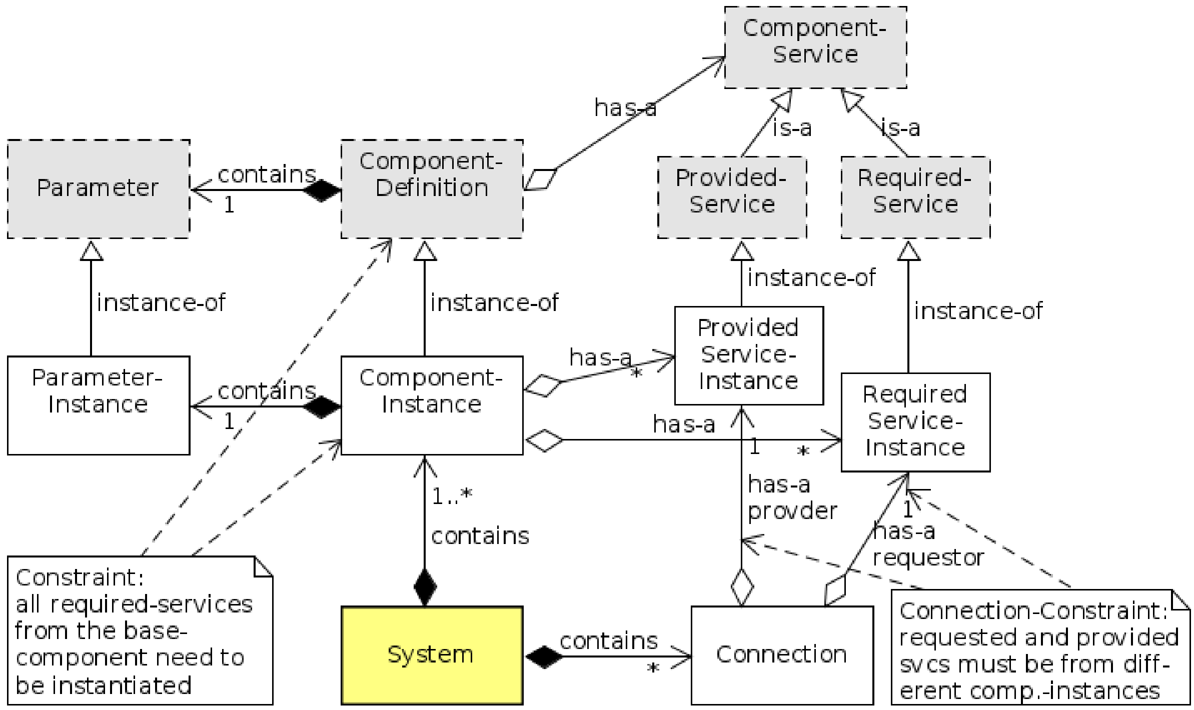
This document contains material from:

- Stampfer2017 Dennis Stampfer, “Contributions to Composability using a System Design Process driven by Service Definitions for Service Robotics,” 2017. (unpublished work)
- Lotz2017 Alex Lotz, “Managing Non-Functional Communication Aspects in the Entire Life-Cycle of a Component-Based Robotic Software System,” 2017. (unpublished work)
- Lutz2017 Matthias Lutz, “Model-Driven Behavior Development for Service Robotic Systems: Bridging the Gap between Software- and Behavior-Models,” 2017. (unpublished work)

System Component Architecture Metamodel

The System Component Architecture Metamodel depends on the Component-Definition Metamodel as part of the RobMoSys Composition Structures.

The System Component Architecture Metamodel (see figure below) is the platform-independent specification of a software system consisting of instantiated components. This means that selected component-definitions are instantiated and initially wired (i.e. connected). Please note, that at this point individual components can still be distributed over (i.e. deployed to) different target platforms (i.e. PCs) without affecting this model.



An instantiated component also instantiates its (internal) structures such as the definition of parameters and the component's provided/required services. By instantiating parameters, it is possible to define system-specific and application-related parameter values (i.e. parameter refinement) that differ from the default parameter values in the original component-definition. It is important to notice that a component-instance cannot instantiate any structures that have not been defined in the component-definition (base-model). Moreover, all the required services of a component-definition also need to be instantiated within the derived component-instance. This can be easily supported by modeling tools that can pre-generate component-instance models (using so called proposal-providers) out of selected component-definitions. This is an important functional constraint that allows checking that each required service also is connected to an according provided service of another component-instance in the system. Finally, a Connection defines initial wiring between provided and required services of different components. It is worth mentioning that this initial wiring can be dynamically changed at run-time (if needed) using the dynamic wiring pattern.

At this point, it is also worth mentioning that at the moment a system is built from components as basic building blocks. In future versions of this meta-model the hierarchical definition for systems-of-systems (i.e. composite components) will be introduced. Composite components will be introduced as an extension to the *current meta-model that allows building systems out of sub-systems which again can be built out of yet other sub-systems and so forth.*

See next:

- Deployment Metamodel

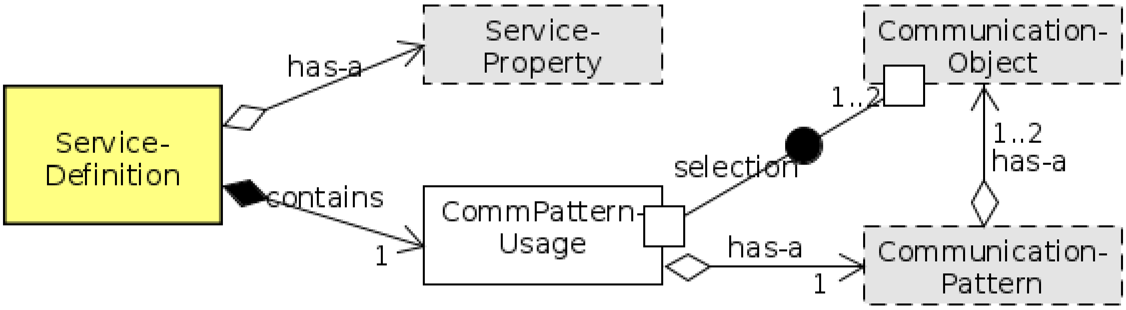
See also:

- Component-Definition Metamodel

Service-Definition Metamodel

The Service-Definition Metamodel is one of the core composition structures of RobMoSys.

A Service allows interaction (i.e. regular exchange of information) between software components. A Service consists of service-properties (defined in an external metamodel) and a communication-pattern-usage. The communication-pattern-usage selects a certain Communication Pattern with a pattern-specific selection of according number of communicated data-structures (i.e.Communication Objects).

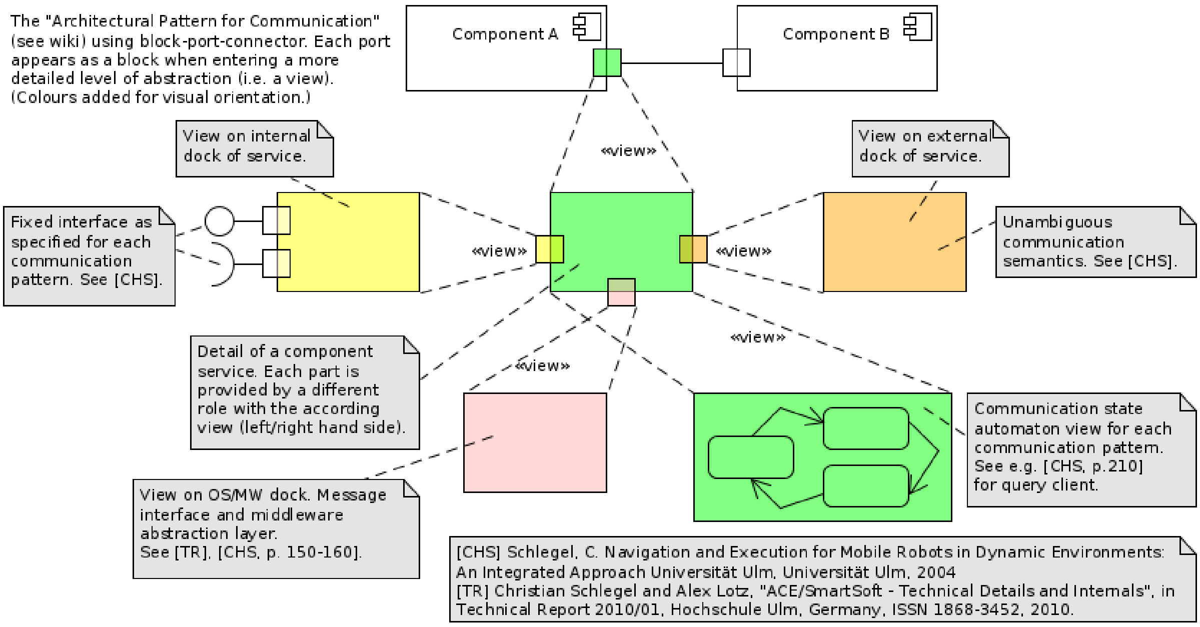


The service-definition is used as a base meta-model for component-definition and for service-architecture. The relation between these three service-related meta-models form a service triangle (see the example of a Service Triangle).

Views of a Service

A service can be graphically represented as a port of a component (just like in UML). However, depending on the current role-specific view with an according level of abstraction, a service “port” can reveal additional details that are not visible (i.e. hidden/encapsulated) for another role. The more detailed view enrolls additional internal structures of the port and the port itself might appear as a block for that role (see figure below). This is a useful pattern to provide different levels of abstraction, each adequate for the according developer role (with certain responsibilities and concerns).

This pattern can be applied recursively, where the ports of the currently more detailed view can again contain additional internal structures (not visible for the current role). For instance, a the “external” port of a service (see orange block on the right in the figure below) provides sufficiently detailed and stable communication semantics between interacting components (defined through a selected Communication Pattern). Second, the “internal” port of a service provides a clear API towards implementation within a component (also defined as part of the Communication Pattern). Third, the “bottom” port of a service provides a generic middleware abstraction layer that allows using any general purpose communication middleware without affecting the communication semantics (see Communication Objects).



References:

- Christian Schlegel. “Navigation and Execution for Mobile Robots in Dynamic Environments: An Integrated Approach”. *Dissertation*. University of Ulm, 2004.PDF [http://www.hs-ulm.de/users/cschlege/_downloads/phd-thesis-schlegel.pdf]
- Christian Schlegel and Alex Lotz, “ACE/SmartSoft - Technical Details and Internals”, in *Technical Report 2010/01*, Hochschule Ulm, Germany, ISSN 1868-3452, 2010. PDF [http://www.zafh-servicerobotik.de/dokumente/ZAFH-TR-01-2010-ISSN-1868-3452.pdf]

See next:

- Component-Definition Metamodel

See also:

- Communication-Pattern Metamodel
- Communication-Object Metamodel
- Service Triangle
- Service Design View

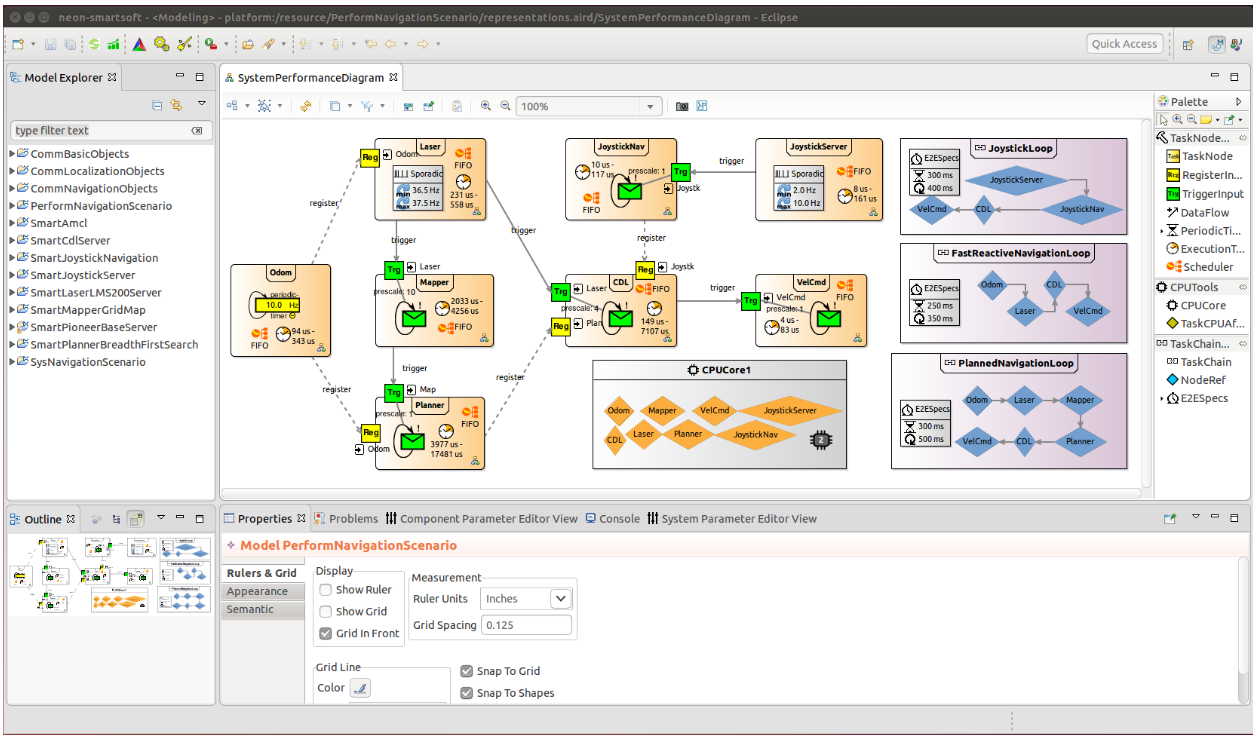
Cause-Effect-Chain and its Analysis Metamodels

The Cause-Effect-Chain meta-model and the according Analysis Metamodel are two parts of the overall RobMoSys Composition Structures. See also Architectural Pattern for Stepwise Management of Extra-Functional Properties.

The main concern in these meta-models is to specify application-specific (often non-functional) system properties. This is considered as an important aspect in RobMoSys, which is however sparsely addressed in robotics research. One of the core publications that addresses this issue for a narrowed problem domain, namely for designing causal dependencies and overall end-to-end delays in a system, can be found here:

- Alex Lotz, Arne Hamann, Ralph Lange, Christian Heinzemann, Jan Staschulat, Vincent Kesel, Dennis Stampfer, Matthias Lutz, and Christian Schlegel. “Combining Robotics Component-Based Model-Driven Development with a Model-Based Performance Analysis.” In: IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR). San Francisco, CA, USA, Dec. 2016, pp. 170–176. LINK [http://dx.doi.org/10.1109/SIMPAR.2016.7862392]

This publication also provides an initial version of a meta-model that is used as first version in RobMoSys for addressing the overall problem domain.



An open-source reference implementation of according model-driven tooling (see above figure) is publicly available within the sourceforge git repository [https://sourceforge.net/p/smart-robotics/smartmdsd-v3/ci/master/tree/]. Further information thereto can be found here [http://www.servicerobotik-ulm.de/drupal/?q=node/83].

Later versions of the initial meta-model will be extended throughout the run-time of the RobMoSys project to address a broader problem domain.

Acknowledgement

This document contains material from:

- Stampfer2017 Dennis Stampfer, “Contributions to Composability using a System Design Process driven by Service Definitions for Service Robotics,” 2017. (unpublished work)
- Lotz2017 Alex Lotz, “Managing Non-Functional Communication Aspects in the Entire Life-Cycle of a Component-Based Robotic Software System,” 2017. (unpublished work)
- Lutz2017 Matthias Lutz, “Model-Driven Behavior Development for Service Robotic Systems: Bridging the Gap between Software- and Behavior-Models,” 2017. (unpublished work)

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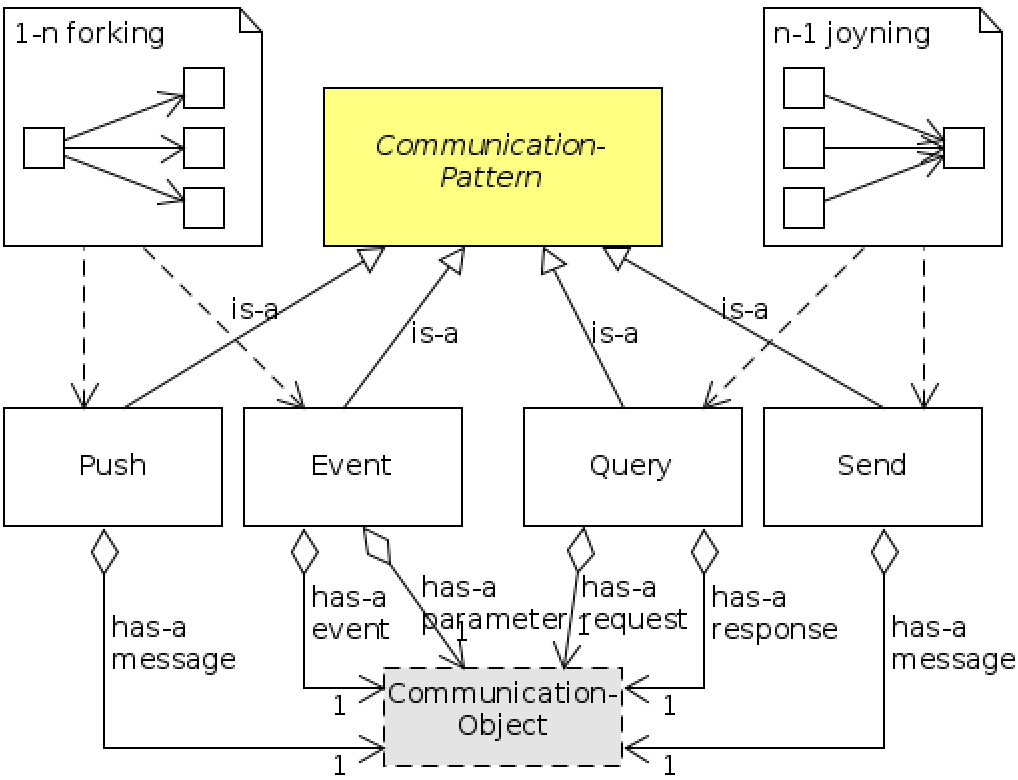
modeling:metamodels:performance · Last modified: 2017/06/23 18:16
http://www.robmosys.eu/wiki-sn-01/modeling:metamodels:performance

Communication-Pattern Metamodel

Communication Patterns specify the communication semantics for the definition of Services.

- The metamodel of the RobMoSys communication patterns is fully conformed by the SmartSoft communication patterns
- Thus, at this moment, the semantics of the RobMoSys communication patterns is specified by the according SmartSoft documents (see details below)
- Therefore, the SmartMDSD Toolchain already now allows to use RobMoSys compliant communication patterns and also is an example of how to realize their metamodel with Ecore
- See also Conformance of SmartSoft to RobMoSys composition structures



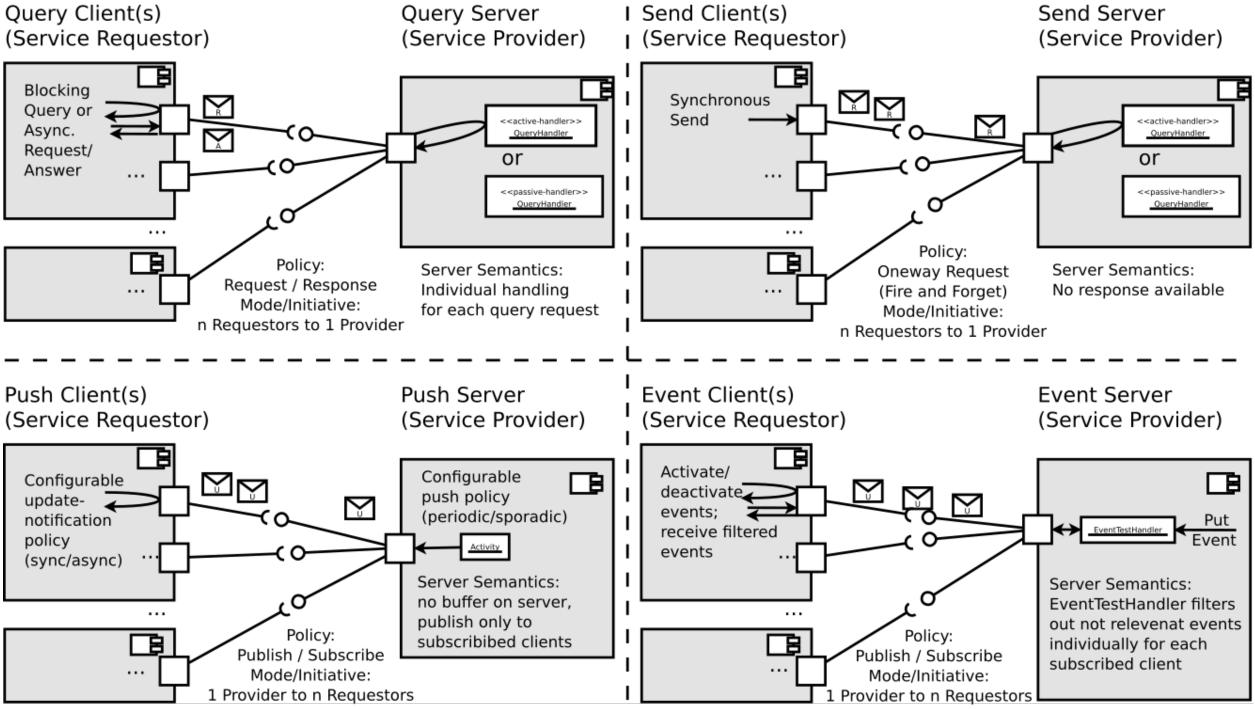
Component Communication Patterns

The four communication patterns (see table below) define the basic set of recurring communication semantics that proved to be sufficient for all robotics use-cases for inter-component communication.

Pattern Name	Interaction Model	Description
Send	Client/Server	One way communication
Query	Client/Server	Two way request/response

Pattern Name	Interaction Model	Description
Push	Publisher/Subscriber	1-n distribution
Event	Publisher/Subscriber	1-n asynchronous condition notification

The figure below provides a schematic overview of the communication semantics.



The following list of core references provides detailed descriptions of communication patterns:

- Christian Schlegel. "Navigation and Execution for Mobile Robots in Dynamic Environments: An Integrated Approach". *Dissertation*. University of Ulm, 2004.PDF [http://www.hs-ulm.de/users/cschlege/_downloads/phd-thesis-schlegel.pdf]
- Christian Schlegel and Alex Lotz, "ACE/SmartSoft - Technical Details and Internals", in *Technical Report 2010/01*, Hochschule Ulm, Germany, ISSN 1868-3452, 2010. PDF [http://www.zafh-servicerobotik.de/dokumente/ZAFH-TR-01-2010-ISSN-1868-3452.pdf]

Coordination and Configuration Patterns

The four coordination and configuration patterns (see table below) provide recurring semantics that proved to be sufficient for robotics use-cases related to behavior coordination (which requires run-time coordination and configuration of several components in a system from the skill and task level). Therefore, each component in a system should by default implement the slave part of each of the four patterns. In addition, there is typically one specific component per system that implements the master part of the patterns and that is responsible to centrally coordinate the robot behavior (see Robot Behavior Coordination [http://www.servicerobotik-ulm.de/drupal/?q=node/86] for further details). The SmartTCL [http://www.servicerobotik-ulm.de/drupal/?q=node/84] language conforms to the RobMoSys composition structures and can be used already now for Robot Behavior Coordination [http://www.servicerobotik-ulm.de/drupal/?q=node/86].

Pattern Name	Interaction Model	Description
Parameter	Master/Slave	Run-time configuration
State	Master/Slave	Lifecycle management and mode (de-)activation
Dynamic Wiring	Master/Slave	Run-time connection re-wiring
Monitoring	Master/Slave	Run-time monitoring and introspection

Pattern Name	Interaction Model	Description

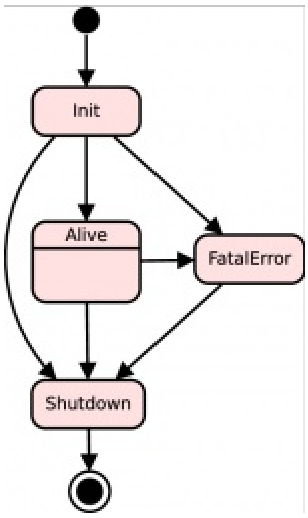
Parameter

The Parameter pattern allows run-time configuration of components. The following links provide further details:

- Parameter Definition [http://www.servicerobotik-ulm.de/toolchain-manual/html/ch02s02s03.html]
- Parameter Usage in a Component [http://www.servicerobotik-ulm.de/toolchain-manual/html/ch02s03s02.html#UsingToolchain_ComponentDevelopmentView_CompModeling_CompParar

State

The state management of a component is one of the central patterns for run-time coordination of components. On the one hand, state management is about the generic lifecycle state-automaton (see figure on the right) that each component implements by default and that allows coordinated handling of the component's start-up and shutdown procedures as well as the component's fatal-error mode. In addition, component's individual run-time modes can be specified as explained in the following reference:



- Christian Schlegel, Alex Lotz and Andreas Steck, “SmartSoft - The State Management of a Component”, in *Technical Report 2011/01*, Hochschule Ulm, Germany, ISSN 1868-3452, 2011. PDF [http://www.zafh-servicerobotik.de/dokumente/ZAFH-TR-01-2011-ISSN-1868-3452.pdf]

Dynamic Wiring

Dynamic Wiring is used to increase run-time robustness and flexibility by dynamically changing the wiring between components. Additional details can be found here:

- Christian Schlegel. “Navigation and Execution for Mobile Robots in Dynamic Environments: An Integrated Approach”. *Dissertation*. University of Ulm, 2004.PDF [http://www.hs-ulm.de/users/cschlege/_downloads/phd-thesis-schlegel.pdf]

Monitoring

Run-time Monitoring and Introspection of components is an important aspect in robotics that requires dedicated interaction mechanisms. The following reference provides details of a concrete realization:

- Alex Lotz, Andreas Steck, and Christian Schlegel. “Runtime Monitoring of Robotics Software Components: Increasing Robustness of Service Robotic Systems”, in *International Conference on Advanced Robotics (ICAR '11)*, Tallinn, Estonia, June 2011. IEEE-Link [http://ieeexplore.ieee.org/document/5174736/?tp=&arnumber=5174736]

See next:

- Service-Definition Metamodel

See also:

- SmartSoft Baseline
- Communication Pattern View
- Component Metamodel

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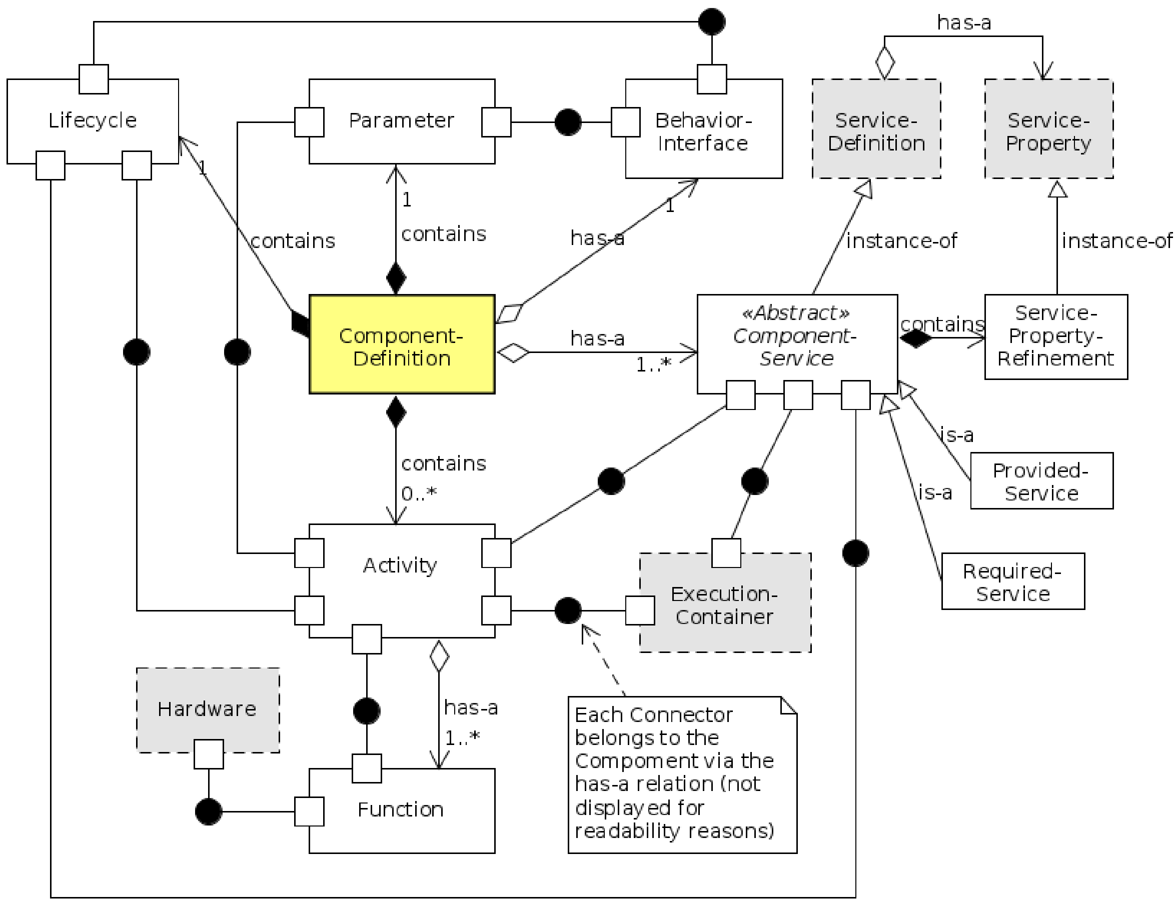
Component-Definition Metamodel

A Component-Definition Metamodel is one of the core composition structures of RobMoSys.

The Component Metamodel (shown in the figure below) combines two complementary concerns namely **structure** and **interaction**. Individual blocks define the main entities of a component (including the component root element itself, highlighted with the yellow background color). For specifying **structure**, the blocks are connected using either the **contains** or the **has-a** relation (as defined in block-port-connector). For specifying **interaction**, the blocks are additionally connected using dedicated **ports**, **connectors** and **connections** (as also defined in block-port-connector). Moreover, two blocks (highlighted with the gray background color and dashed border-line) represent model elements that are defined in a separate metamodel (described in the next pages).



A component **contains** one **Parameter** structure, one **Lifecycle** state automaton and **has-a Behavior Interface**. The **Parameter** structure can be a Metamodel (or a DSL) by itself and the **Behavior Interface** allows run-time coordination and configuration from a higher robotics behavior coordination layer (see JOSER2016[1] for further details on both elements). The **Lifecycle** state automaton coordinates the different operational modes of a component. Some generic modes are for example *Init*, *Shutdown* and *Fatal-Error* (see TR2011[2] for more details).

The next core element of a Component is the **Activity** which is an abstract representation of a thread. A Component can define several Activities (depending on the component-internal functional needs). An Activity is independent of a certain thread realization and can be later mapped to a certain implementation by the selection of an according target platform. Moreover, an Activity provides a wrapper for the **Functions**. This is important for gaining control over execution characteristics of a component. This also considerably increases the flexibility (i.e. adjustability) of the component with respect to adapting the component to the different needs of various (at this point even unforeseen) systems.

A **Function** represents a functional block that can be designed using any preferred engineering methodology. From the component's internal point of view, a **Function** needs to be integrated into an **Activity** in order not to prematurely define any computational models that are not really relevant from the local functional point of view but might considerably restrict the compositionality of this component in different systems (see SIMPAR2016[3] for an example). In some cases, a **Function** might need to interact with specific hardware devices (such as e.g. sensors or actuators).

The last element of a Component is a **Service**. A Component can have several *required* and/or *provided* **Services**. A **Service** is the only allowed interaction point of a component to interact with other (not yet known) components. The definition of a service is described in a separate metamodel. Moreover, a **Function** interacts with the component's services over the surrounding **Activity** only. Again, this is important to gain control over execution characteristics as argued above.

See next:

- System Service Architecture Metamodel
- System Component Architecture Metamodel

See also:

- Service-Definition Metamodel
- Communication-Pattern Metamodel
- Component Development View

References

1)

Dennis Stampfer, Alex Lotz, Matthias Lutz, Christian Schlegel. “The SmartMDSD Toolchain: An Integrated MDSD Workflow and Integrated Development Environment (IDE) for Robotics Software”. In *Journal of Software Engineering for Robotics (JOSER 2016)*, Online [https://joser.unibg.it/index.php?journal=joser&page=article&op=view&path%5B%5D=91]

2)

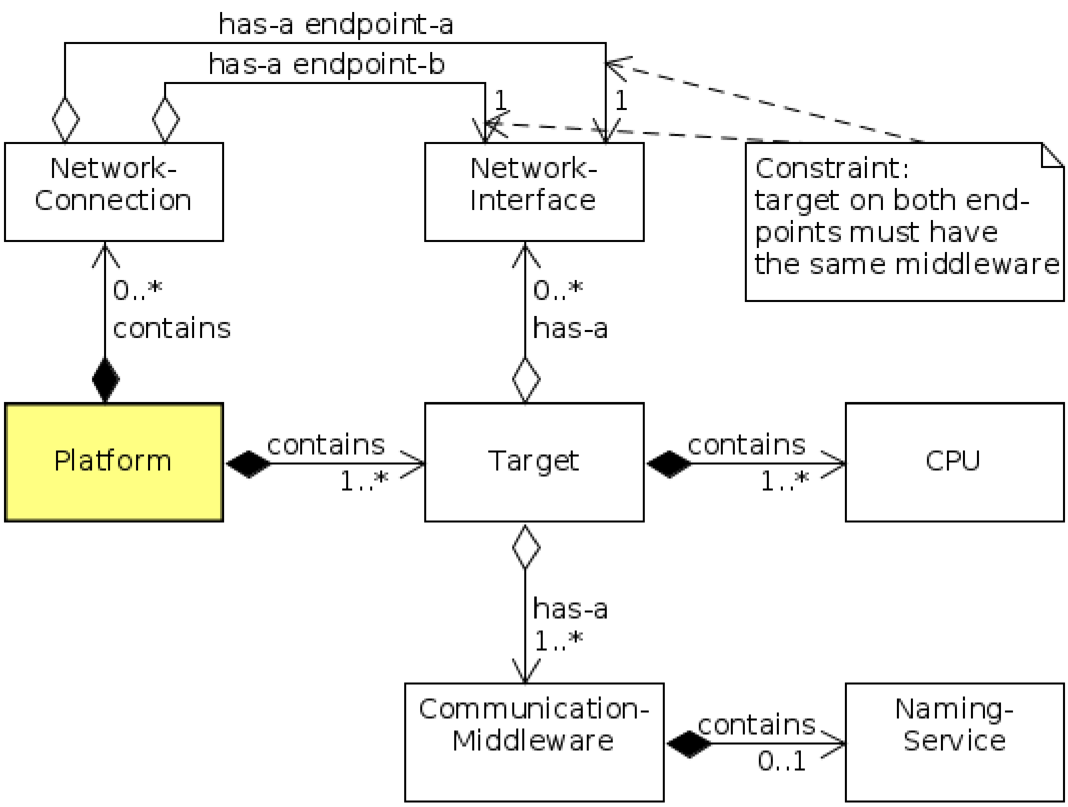
Christian Schlegel, Alex Lotz and Andreas Steck, “SmartSoft - The State Management of a Component”, in *Technical Report 2011/01*, Hochschule Ulm, Germany, ISSN 1868-3452, 2011. PDF [http://www.zafh-servicerobotik.de/dokumente/ZAFH-TR-01-2011-ISSN-1868-3452.pdf]

3)

Alex Lotz, Arne Hamann, Ralph Lange, Christian Heinzemann, Jan Staschulat, Vincent Kesel, Dennis Stampfer, Matthias Lutz, and Christian Schlegel. “Combining Robotics Component-Based Model-Driven Development with a Model-Based Performance Analysis”. In *IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR 2016)*. San Francisco, CA, USA, 2016. DOI [https://doi.org/10.1109/SIMPAR.2016.7862392]

Platform Metamodel

The Platform Metamodel (see figure below) is one part of the overall RobMoSys Composition Structures. It defines the target platforms on the robot where the software components are later deployed to. Please note that the current version of the Platform Metamodel is reduced to the most basic elements that are sufficient for deploying and executing software components. However, further versions of this metamodel might be extended to reveal additional details.



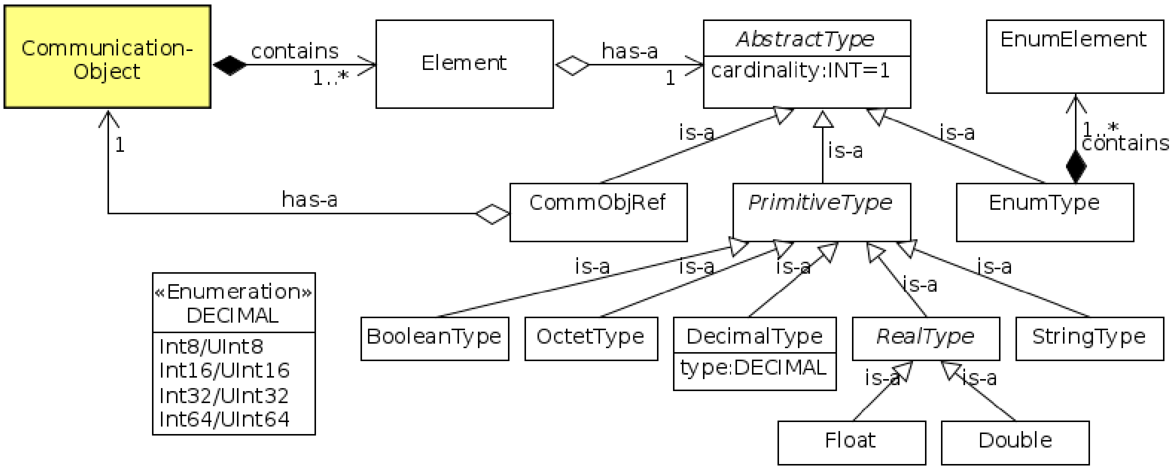
The two core elements of the platform meta-model are the targets and the network-connections. A target is basically a PC on the robot. Each target (i.e. a PC) has several CPUs and can have several network-interfaces. In addition, a target can use a specific communication-middleware (optionally with a middleware-specific naming-service). A network-connections links two network-interfaces and requires (as a constraint) that both connected targets use the same communication-interface (otherwise the components from the two targets would not be able to communicate).

See also:

- Deployment Metamodel

Communication-Object Metamodel

Communication Objects define data structures that are communicated through services between components. The definition of communication objects requires primitive data types such as Int, Double, String, etc. and complex data types (i.e. composed data types). The figure below shows a simple metamodel of communication objects. A fully fledged communication objects modeling language that conforms to this metamodel is the SmartSoft communication object DSL [http://www.servicerobotik-ulm.de/toolchain-manual/html/ch02s02s02.html].



Typically, communication middlewares such as e.g. CORBA or DDS provide an *Interface Definition Language (IDL)* that allows specification of communication structures. RobMoSys requires a middleware-independent language. The SmartSoft communication object DSL [http://www.servicerobotik-ulm.de/toolchain-manual/html/ch02s02s02.html] provides a fully fledged Xtext-based language that is compliant to the metamodel in the figure above and that can be used already now for the definition of services.

At some point the communication object needs to be serialized (i.e. marshalled) into a middleware-specific representation. The following references provide details for how this can be achieved for a CORBA-based and a message-based middlewares:

- Christian Schlegel. "Navigation and Execution for Mobile Robots in Dynamic Environments: An Integrated Approach". *Dissertation*. University of Ulm, 2004.PDF [http://www.hs-ulm.de/users/cschlege/_downloads/phd-thesis-schlegel.pdf]
- Christian Schlegel and Alex Lotz, "ACE/SmartSoft - Technical Details and Internals", in *Technical Report 2010/01*, Hochschule Ulm, Germany, ISSN 1868-3452, 2010. PDF [http://www.zafh-servicerobotik.de/dokumente/ZAFH-TR-01-2010-ISSN-1868-3452.pdf]
- Dennis Stampfer, Alex Lotz, Matthias Lutz, and Christian Schlegel. "The SmartMDSD Toolchain: An Integrated MDSD Workflow and Integrated Development Environment (IDE) for Robotics Software". In *Journal of Software Engineering for Robotics*, Special Issue on Domain-Specific Languages and Models for Robotic Systems, Vol 7, No 1 (2016). PDF [https://joser.unibg.it/index.php?journal=joser&page=article&op=view&path%5B%5D=91]

See next:

- Communication-Pattern Metamodel
- Service-Definition Metamodel

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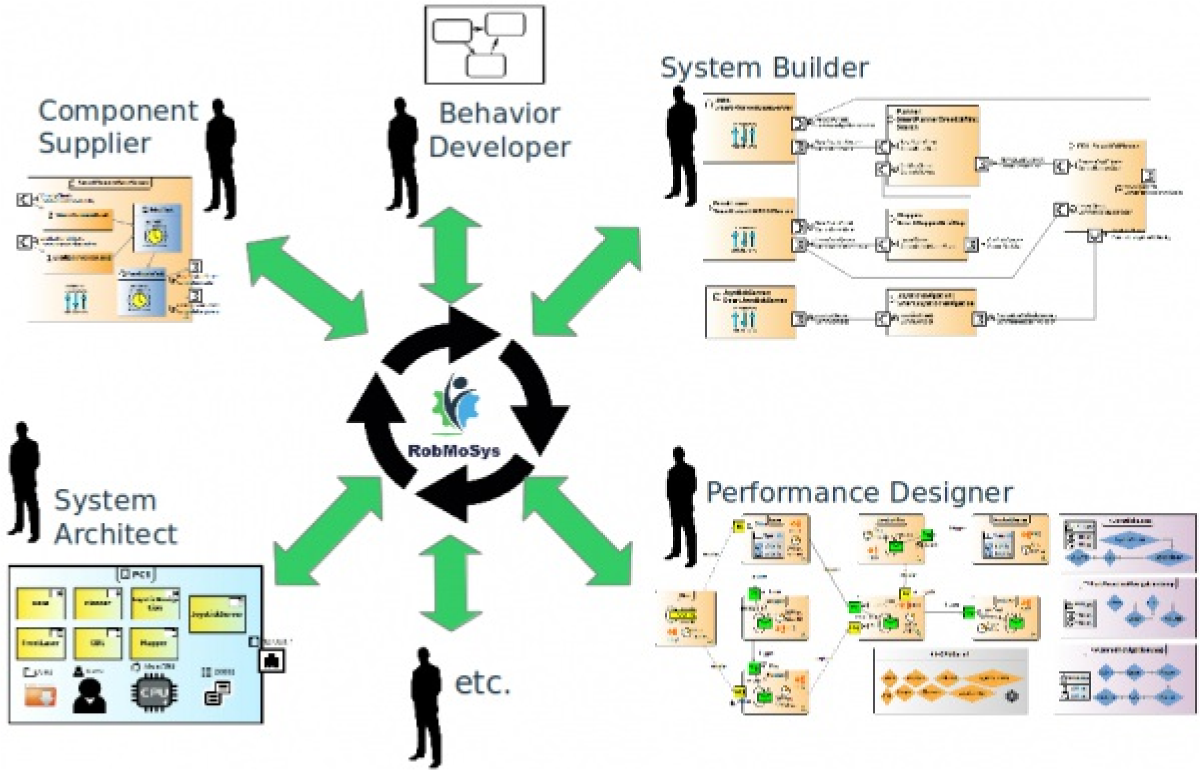
RobMoSys Views

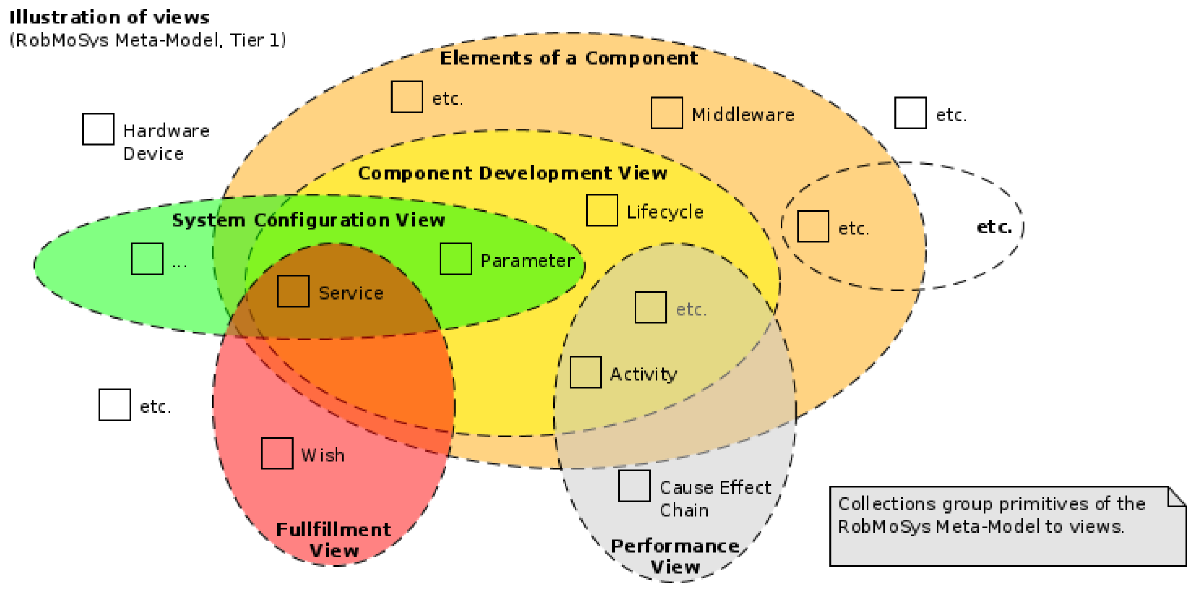
Roles in the Ecosystem come with specific views. The benefit of a view to a role is to present only what is relevant for the role's responsibility, thereby hiding the complexity that is not relevant for that role, but is still relevant for the whole system in the end. The system in the end consists of many concrete models based on the RobMoSys Composition Structures. These elements are contributed by roles that work through views and interact such that the contributed elements are composable to form a system. As a result, the individual role can focus on its responsibility and expertise alone, while working decoupled from other roles. This is enabled by the RobMoSys Composition Structures.



Each role that participates in the ecosystem uses a dedicated view to focus on its responsibility and expertise.

The concept of “views” groups basic primitives of the RobMoSys composition strucures. A view is related to a role and establishes the link between primitives in the RobMoSys composition strucures and the RobMoSys roles.

A role has a specific view on the system at an adequate abstraction level using relevant elements only. A view is not only in the sense of a perspective where one only sees a part of the system but does not see the rest, even if it is there. Instead, a view shows an excerpt of the whole system that can be viewed independently of the other parts. These other parts might even not exist at the time of having the view on the system, because it is composed to other parts to form the complete system later.



Example: Consider a closed book. The view of a front cover is a certain perspective on the book. Even though only the front cover is visible, the whole book is lying there. The book also consists of its pages and the back cover which are not visible, even if they are there. It, however, makes perfect sense to only look at the back cover of a book, its content pages or even the individual chapters separately (an excerpt of the book) as both the front page and the back page can be designed differently (separation of roles) and then be put together.

List of Views

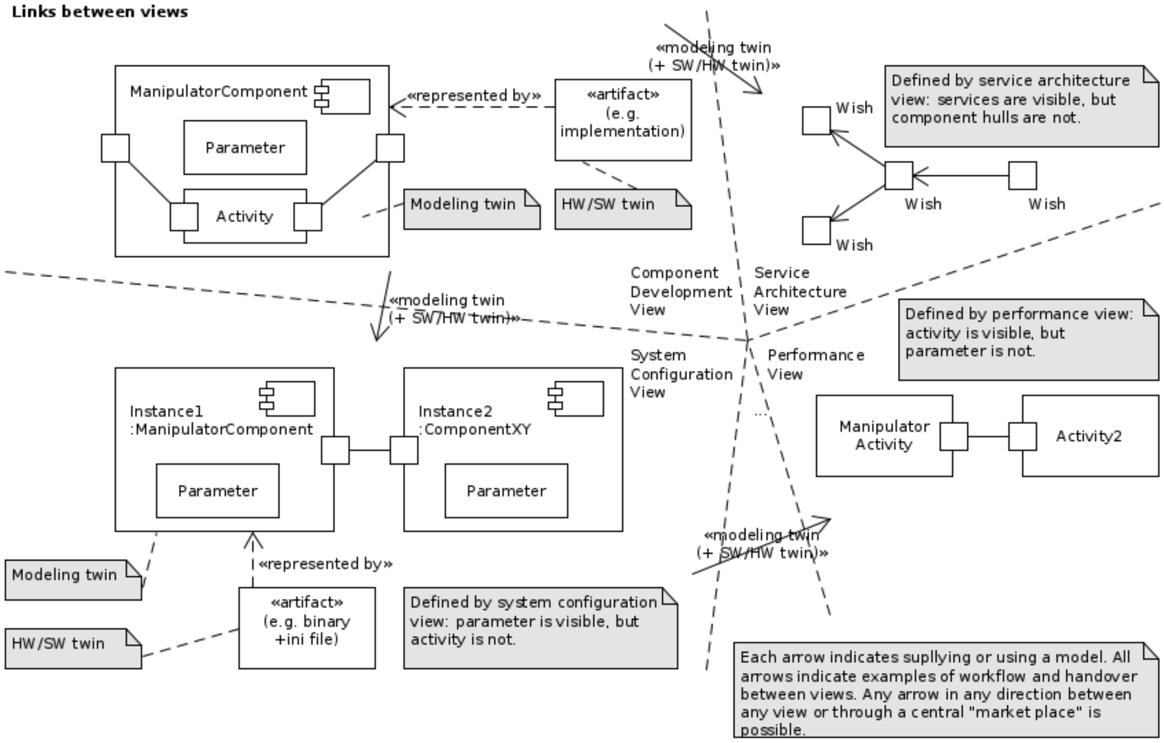
(alphabetical order)

- 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
- …

Links Between Views: Example 1

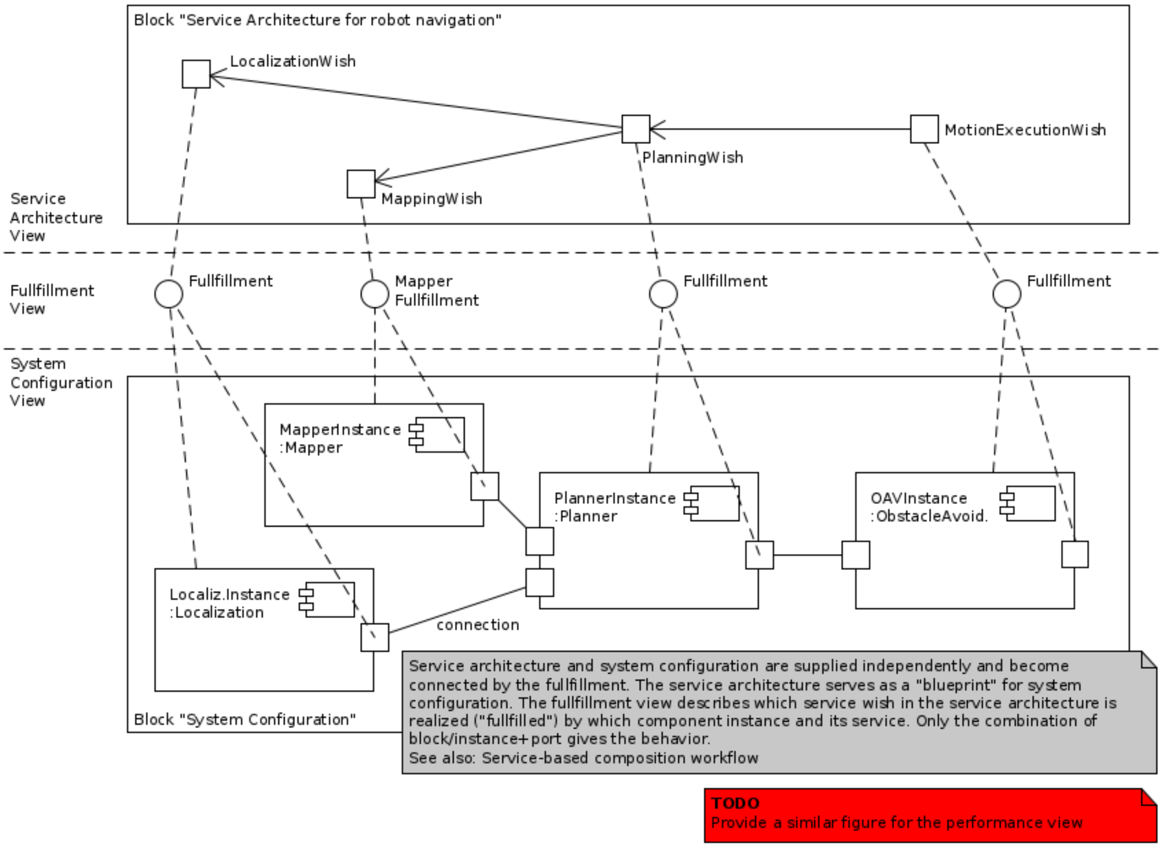
The figure below illustrates the link between several views. The Modeling Twin is handed over between one view to the next. There is no strict order in the sense of a strictly order value chain. Instead, the interactions form a network of collaborating roles consisting of various bilateral interactions between suppliers and consumers.



Links Between Views: Example 2

The figure below illustrates an example where two views are connected by a third view. The service architecture can serve as a blueprint for system configuration.

Two views are linked by a third view



See also

- Views in the RobMoSys Glossary
- Views in RobMoSys Composition Structures
- Views in the PC domain analogy
- Roles in the Ecosystem

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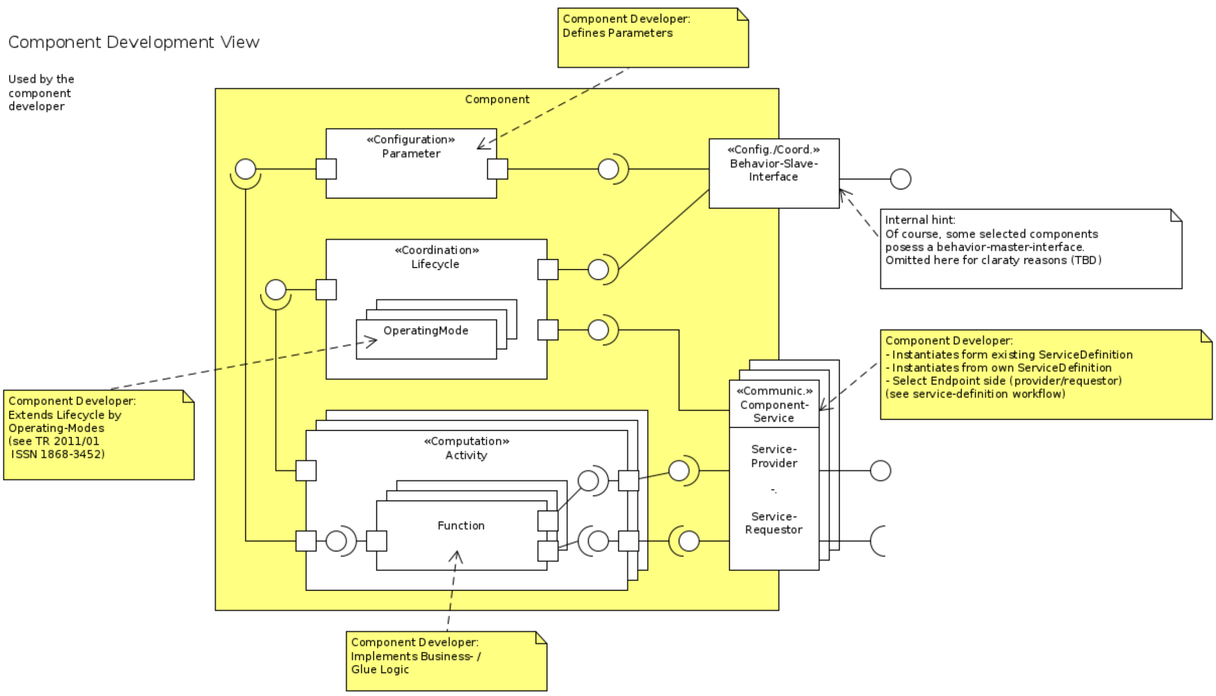
Component Development View

The component developer view clusters elements of the Component Metamodel that are relevant to the Component Supplier.

The component development view (shown in the figure below) needs to be rich enough and provide sufficient structures such that this model can serve as a consistent baseline for all the successive development steps (such as e.g. system composition/configuration) that rely on proper component models. At the same time, the component development view should avoid definition of too many low level details that are more related to internal knowledge that is not required for supporting composition with respect to the surrounding models. In this way, the component development view always is a trade-off between providing enough structures where needed and leaving enough design freedom for the internal realization.



The only interaction point of a component with other components is through services. Therefore, a component can specify several provided and/or required services. A special kind of service is the behavior-interface which is used by the behavior coordination layer to coordinate this component at run-time (i.e. to set propper configurations, to activate/deactivate certain component modes, etc.). Therefore, the behavior-interface interacts with the component's internal parameter structure and the component's lifecycle state automaton which also defines the component-specific run-time modes.

The component's services interact within a component with Activities and the component's Lifecycle. The component's Lifecycle affects the lifelines of services and the activation/deactivation of Activities.

Regarding a component's Services, as long as the component is initializing (during start-up) or as long as a component is in a fatal-error mode, then the provided services might be physically available but not ready to properly offer a service (i.e. not able to answer query requests).

The next component-internal structural element is an Activity, which is an abstract representation of a task (or more precisely of a thread). An activity wraps a functional block which by itself is passive and only gets active by the execution environment of its parent Activity. This is an effective decoupling of the design and implementation of functional parts within a component and the execution of the functions. This even allows configuration of the execution characteristics for individual functions even after the component has been fully implemented and shipped to e.g. a system builder and without affecting the component's internal implementation.

As mentioned above, it is important that a structural model provides enough details that are required to communicate the structural knowledge of a component to other developer roles as well as to provide a sound foundation for the later development steps. In this respect, it is equally important to mention which parts have been omitted on purpose in order not to intermix the responsibilities and concerns that become relevant in later development steps. The most important parts that have been omitted on purpose are: (1) the mapping of services to a particular communication middleware (which is the responsibility of another developer role) (2) the mapping of Activities to a particular execution container such as Windows/Linux threads, or QNX/RTAI real-time threads (again a responsibility of another developer role) and (3) the definition of the services by themselves (which might be the responsibility of domain experts).

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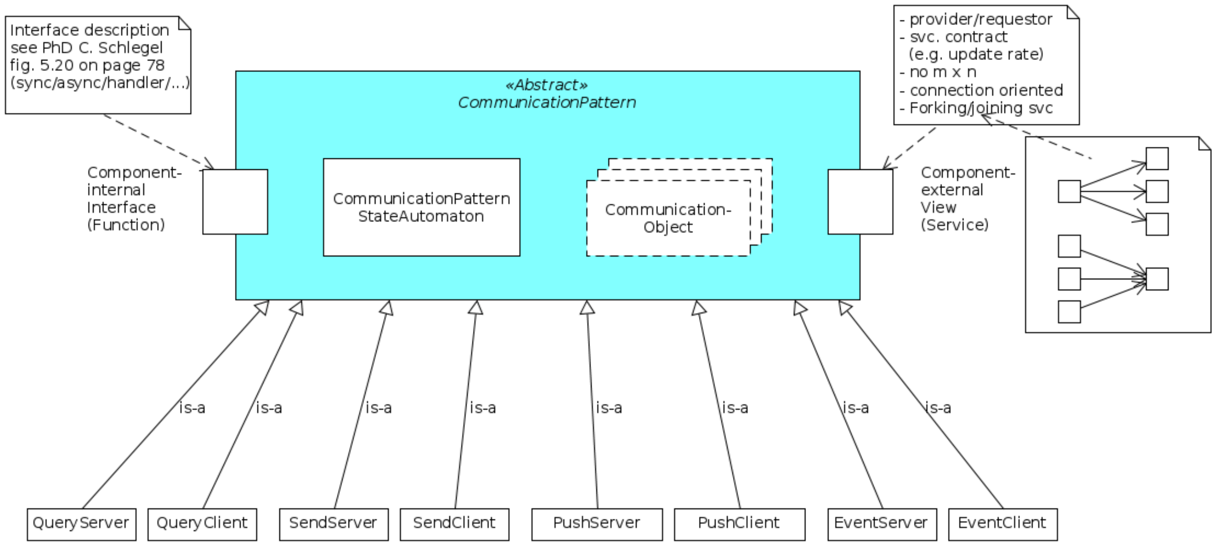
Communication Pattern View

The communication pattern view clusters elements of the communication pattern metamodel that defines a fixed and stable set of recurring communication semantics.

This set of recurring communication semantics is defined for the robotics domain independent of an underlying communication middleware which can be flexibly selected in another development phase.



It is important to have a fixed set of a few (e.g. around four) communication patterns that efficiently support composition through unambiguous communication semantics and clearly defined communication interfaces. In addition, the mapping to different communication middlewares becomes possible over a generic middleware abstraction layer that is part of each communication pattern.

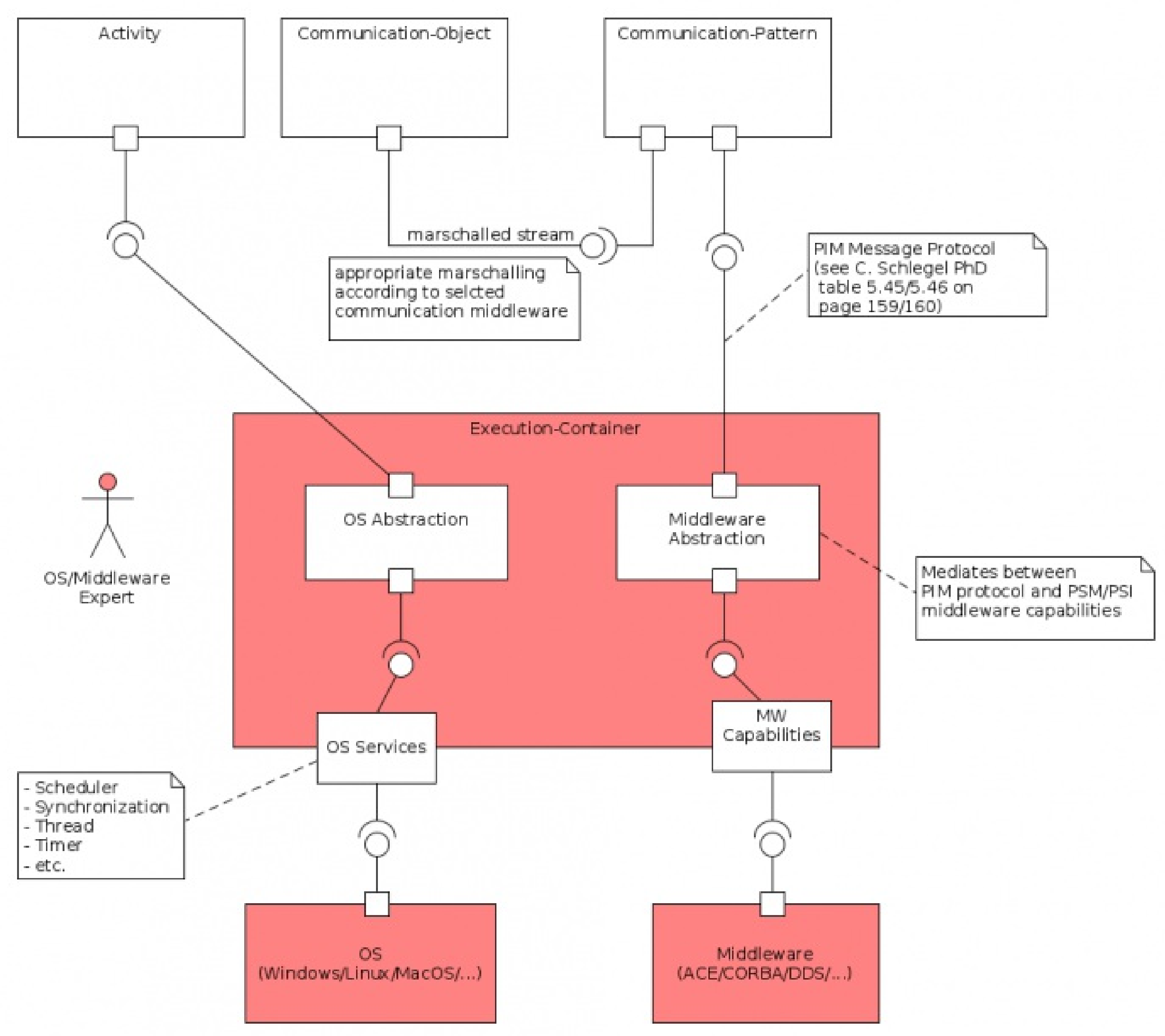
See also:

- communication pattern metamodel

Execution Container View

The Execution Container View shows the mapping from platform independent models (such as components and services) into concrete platforms (i.e. Operating Systems and Communication Middlewares).

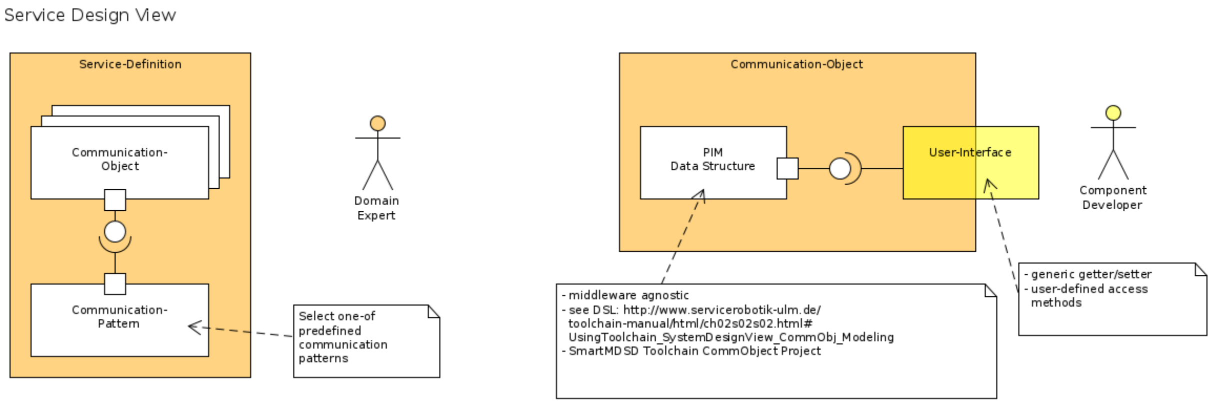
A component (see Component Metamodel) is at first independent of an actual execution environment. The actual mapping towards a communication middleware and an operating system (OS) is done in a later development step (such as e.g. the deployment step). For example, during the deployment phase of component to a specific platform, an accordingly used operating system and communication middleware become known which can then be mapped to the so far independent component.



At this point an Activity becomes a certain implementation of a thread (such as e.g. a Windows thread or an RTAI real-time thread). Also, the actual marshaling (i.e. the serialization technique for the communicated data structures) and the used communication environment are selected. This should not affect the possible functional constraints of a component and different communication middlewares should be usable (as long as there are no specific constraints such as e.g. a specific real-time requirements for communication, which then should be complied with).

Service Design View

The service design view clusters elements of the Service Metamodel that are relevant to the Service Designer.



A service definition (shown on the left in the figure) comprises of a selection of a communication pattern and a selection of a communication object. A communication object is a data structure that is communicated between a service provider and a service requestor. The exact direction of communication is defined by the communication pattern (see also Communication Pattern View). The communicated data structure is independent of the underlying communication middleware that is linked in another development phase as explained in the preceding section above.

Tier 2: Examples of Domain Models

RobMoSys allows the definition of domain-specific models and structures at composition Tier 2. To illustrate this concept, RobMoSys defines the following extendable content for Tier 2.

- Flexible Navigation Stack
- Active Object Recognition
- Motion Stack
- Perception Stack
- etc.

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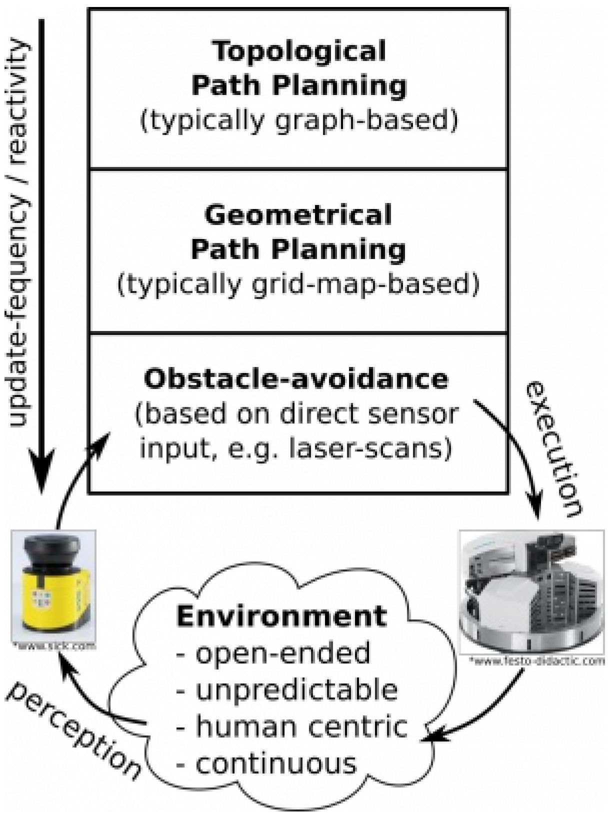
Flexible Navigation Stack

The flexible navigation stack is a set of components specifically related to provide a flexibly applicable navigation capability for a service robot. This navigation stack can be used on various robot platforms with different kinds of sensors and is able to deal with unstructured and dynamic environments of variable scale. The focus hereafter is to emphasize the general design choices and architectural decisions of the navigation stack components. After that, the following section provides some technical details and references for the concrete open-source components that can be used already now, e.g. with the Robotino3 platform.



The figure on the right illustrates the three main levels of the navigation stack. These levels describe the shared responsibilities between different parts of the navigation stack. These responsibilities are assigned top down according to the subsidiarity principle (as explained next).

The bottom level defines components (a full list is provided further below) related to the fast and reactive obstacle-avoidance navigation loop. This loop ensures that regardless of where the robot has to move next, this movement will not cause a collisions and the robot will not be commanded to execute a physically invalid movement considering the robot's kinematic and dynamic constraints. Therefore this loop will only command navigation values that never lead to a collision even if these commands might not directly lead towards the next goal (e.g. because of the need to avoid a suddenly appeared obstacle in between). In consequence this loop might lead to a globally non-optimal, yet collision-free, navigation.

On the middle level, a geometric path planner calculates intermediate way-points based on a grid-map of the current environment. The planner relies on this map, which is updated during the navigation to accommodate for changes in the environment. Localization components need to estimate the current position of the robot within that maps. Several existing path-planning algorithms (using A* for example) allow the generation of intermediate way-points to be individually approached by the lower obstacle-avoidance level. In contrast to the lower obstacle-avoidance level, this intermediate geometric path planing level has a global view on the mapped environment. This is useful to e.g. avoid local minima (by generating intermediate way-points around them). It is worth mentioning that this intermediate level does typically not generate full trajectories (to be exactly executed by the lower level), but spares intermediate way-points. Sparse line of sight intermediate way points as a result from geometric path planning enables a clear separation of concerns between the two lower levels and avoids several disadvantages with respect to wasting resources (due to e.g. too frequent need for path re-planning) continuous velocity changes and too tight (i.e. inflexible and hardly exchangeable) coupling with the lower level.

In some cases, even the intermediate level is not sufficient. For instance, if a robot needs to navigate in an entire building consisting of several floors, maybe connected over elevators, then building a single huge grid map becomes complicated, too inefficient and too resource consuming. In these cases, it is rather reasonable to calculate several smaller grid-maps (e.g. one for each level or room in the building) and to concatenate these grid-maps in a topological map (which is typically a graph). The responsibility of this top level is to provide a logical plan how to navigate through the separated maps, e.g. through levels or rooms of a building.

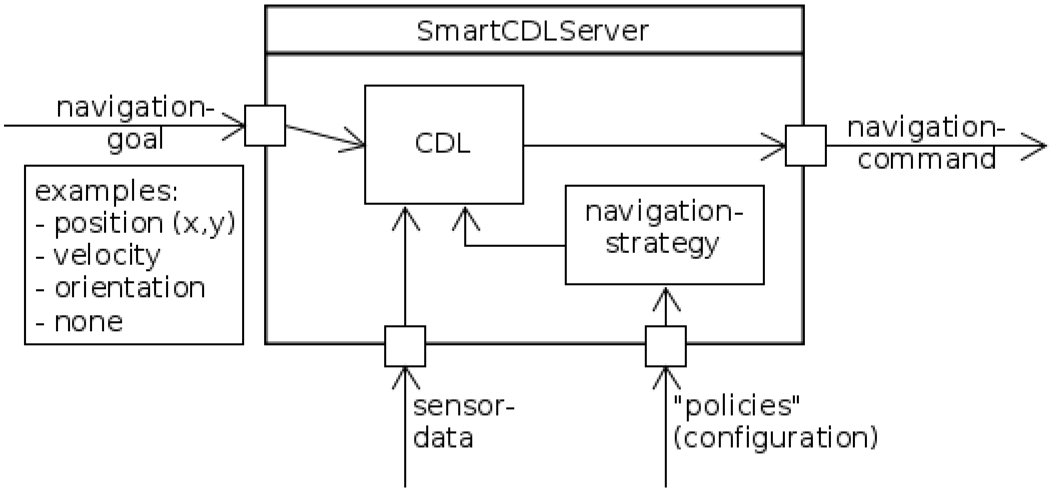
The separation of the navigation components into these three levels has several advantages. The levels can be composed to individual navigation solutions best fitting the needs of the application or the current environment a robot is navigating in. According to these needs the size of the stack can be changed, with the bottom level being the most versatile and configurable one. For instance, some scenarios might require to manually command a robot using a joystick. In that case, both upper levels would be replaced by a simple joystick driver component, while the collision avoidance level still validates the navigation commands. In other scenarios, a robot might always navigate in a single map only. For that the geometrical path-planner on the middle level (without the topological path planner on top) is fully sufficient. Of course, there are also scenarios where all three levels are needed. Even in these latter cases, components on the individual levels can be flexibly exchanged (even at run-time, while moving) by alternatives because of a clear separation of responsibilities on each level and due to the clear interfaces between the levels.

The SmartSoft navigation components and the Robotino3 robot platform

The SmartSoft environment provides a set of flexible navigation components for all thee levels (as explained above). These components are ready for immediate use and can be downloaded from the SmartSoft Sourceforge repository [https://sourceforge.net/p/smartsoft-ace/code/HEAD/tree/trunk/src/components/]. The following list of references provide documentation for the three core navigation components:

- SmartCdlServer [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__SmartCdlServerGroup.html]: this is the main obstacle-avoidance component that uses the Curvature Distance Lookup (CDL) [http://ieeexplore.ieee.org/document/724683/][1) approach in its core
- SmartPlannerBreadthFirstSearch [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__SmartPlannerBreadthFirstSearchGroup.html]: this is geometrical path-planning component using a breadth-first-search algorithm
- SmartMapperGridMap [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__SmartMapperGridMapGroup.html]: this component calculates up to date occupancy grid maps

The SmartCdlServer [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__SmartCdlServerGroup.html] component (see figure below) deserves some further explanations. In a nutshell, this component receives laser-scans and next goals (which can be either a position, velocity, orientation or even undefined). Based on these inputs, the internal CDL algorithm calculates a set of collision-free navigation-commands. Each of these navigation-commands is equally valid, the selection of one “appropriate” one is performed upon a configurable navigation-strategy. For example, one strategy might try to maximize the overall velocity, another might try to stay in the middle of a hallway, yet another strategy might try reaching the next goal closest possible (often the default strategy). This separation between the general obstacle-avoidance and the definition of different strategies adds flexibility with respect to applicability of this component in different scenarios.



There is a list of further components related to different sensor types and robot platforms whose generated documentation can be found here [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__componentGroup.html].

A packaged set of several components for immediate use, including those from the navigation stack with the Robotino3 platform can be downloaded from here [http://wiki.openrobotino.org/index.php?title=Smartsoft].

Another application that uses this navigation stack in a structured and coordinated fleet environment using e.g. Robotino3 robots is described in the ETFA2016 paper [http://ieeexplore.ieee.org/document/7733602/][2].

Moreover, as one of the further baselines in RobMoSys, the SmartSoft navigation components can be used with the PAL Robotics Tiago platform within the Gazebo simulation.

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1)

Christian Schlegel. "Fast local obstacle avoidance under kinematic and dynamic constraints for a mobile robot". In *IEEE International Conference on Intelligent Robots and Systems (IROS)*. Victoria, Canada, 1998. DOI: 10.1109/IROS.1998.724683 [https://doi.org/10.1109/IROS.1998.724683].

2)

Matthias Lutz, Christian Verbeek and Christian Schlegel. "Towards a Robot Fleet for Intra-Logistic Tasks: Combining Free Robot Navigation with Multi-Robot Coordination at Bottlenecks". In *Proc. of the 21th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, Berlin, September 6-9, 2016. Electronic ISBN: 978-1-5090-1314-2, DOI: 10.1109/ETFA.2016.7733602 [https://doi.org/10.1109/ETFA.2016.7733602]

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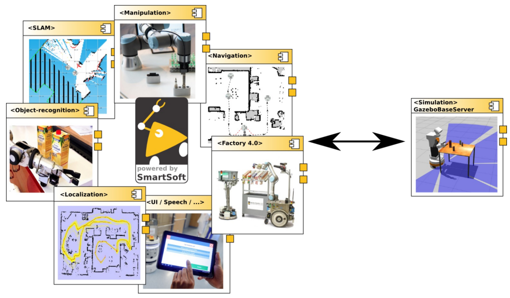
Tools and Software Baseline

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

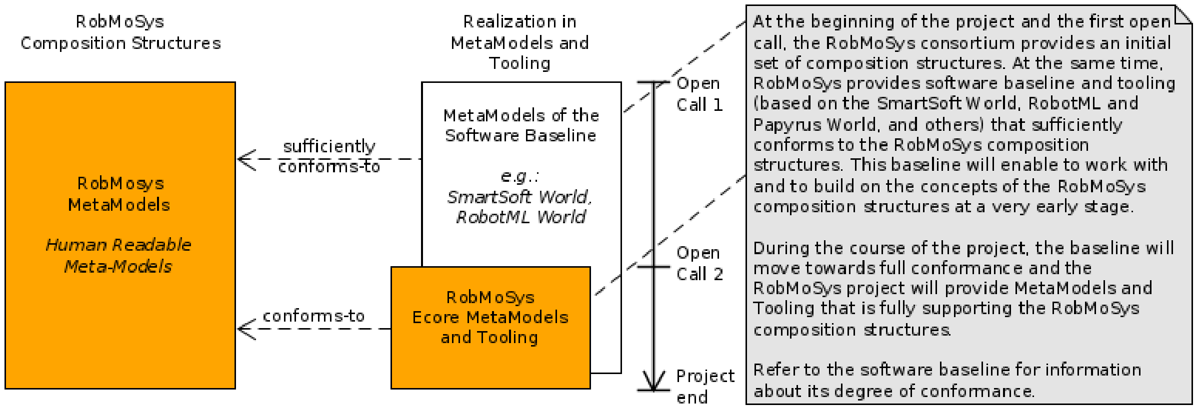
- Roadmap of Tools and Software
- Development Environments and Tools
  - SmartSoft World
  - Papyrus for Robotics
  - to be extended

Tier 3: Existing Building Blocks and Scenarios

- Components
  - SmartSoft Components
- Scenarios and Systems
  - Gazebo/Tiago/SmartSoft Scenario

Roadmap of Tools and Software

The RobMoSys project makes a software baseline available to early work with concepts of RobMoSys composition structures. This includes already existing metamodels and tooling, for example from the The SmartSoft World and Papyrus4Robotics World.



See also

- Roadmap of MetaModeling
- Conformance of SmartSoft to RobMoSys composition structures

baseline:roadmap · Last modified: 2017/06/23 18:16
http://www.robmosys.eu/wiki-sn-01/baseline:roadmap

The SmartSoft World

SmartSoft is an umbrella term for concepts and tools to build robotics systems. The SmartSoft approach [http://www.servicerobotik-ulm.de/drupal/?q=node/19] defines a systematic component-based robotics software development methodology and according model-driven tools [http://www.servicerobotik-ulm.de/drupal/?q=node/20] that support different developer roles in a collaborative design and development of robotic software systems. The SmartSoft World includes (a non-complete list):

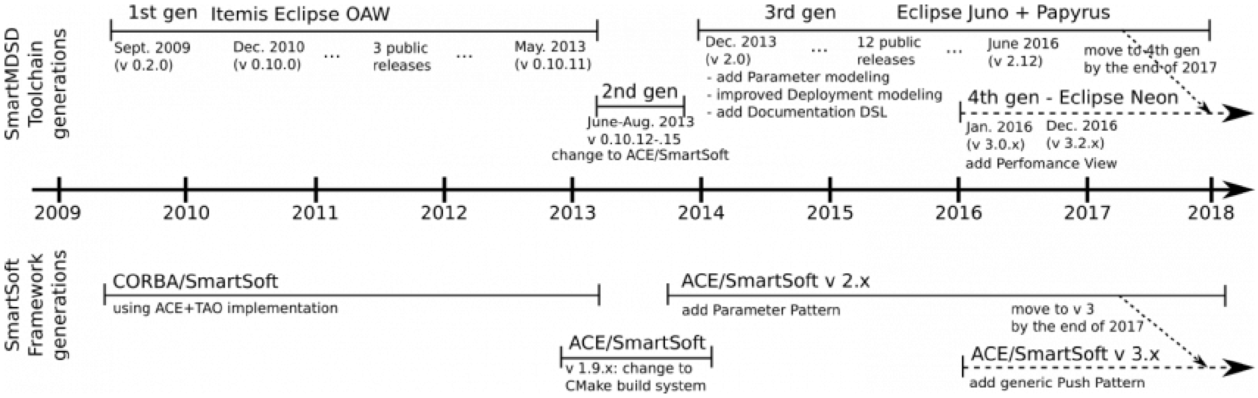
- The **SmartMDSD Toolchain**: an Integrated Development Environment (IDE) for robotics software development using model-driven software development.
- The **SmartMARS Meta-Model**: It defines the structures behind the service-oriented and component-based approach.
- The **SmartSoft Framework and implementation**: two exchangeable reference implementations (current: **ACE** middleware, former: **CORBA** middleware) and execution containers for several platforms and operating systems.
- A **repository with open source** **software components** for immediate reuse to compose new applications (sensor access, skills, task sequencing, knowledge representation, etc.). They have been built with the SmartSoft technologies and tools.

There are two main technology clusters in SmartSoft that adhere to the RobMoSys structures. One is the SmartSoft robotics framework that provides a C++ library for programming robotics software components independent of the underlying communication middleware. The other technology is the SmartMDSD Toolchain that directly implements the RobMoSys metamodels and conforms to the RobMoSys structures. It serves as a baseline for model-driven tooling.

SmartSoft is officially supported by FESTO Robotino [http://www.festo-didactic.com/int-en/learning-systems/education-and-research-robots-robotino/robotino-for-research-and-education-premium-edition-and-basic-edition.htm] (see also Robotino Wiki [http://wiki.openrobotino.org/index.php?title=Smartsoft]).

SmartMDSD Toolchain and the SmartSoft Framework

The SmartMDSD Toolchain has been introduced in 2009 and has been continuously refined and extended in various public releases and three generations since then. The figure below shows the main generations of the SmartMDSD Toolchain and the SmartSoft robotics framework.



Productive Releases

The 3rd generation of the SmartMDSD Toolchain (version 2.x) and the SmartSoft framework (version 2.x) are the current productive versions that – among others – are used by FESTO Robotino.

See also:

- Installation instructions [http://www.servicerobotik-ulm.de/drupal/?q=node/22]
- User Manual [http://www.servicerobotik-ulm.de/toolchain-manual/html/]
- Video Tutorials [https://www.youtube.com/playlist?list=PLJxdA4EZjZiWSlC4R_ChwH_UIcWXWJ8Te]

Next-Generation Technology Preview

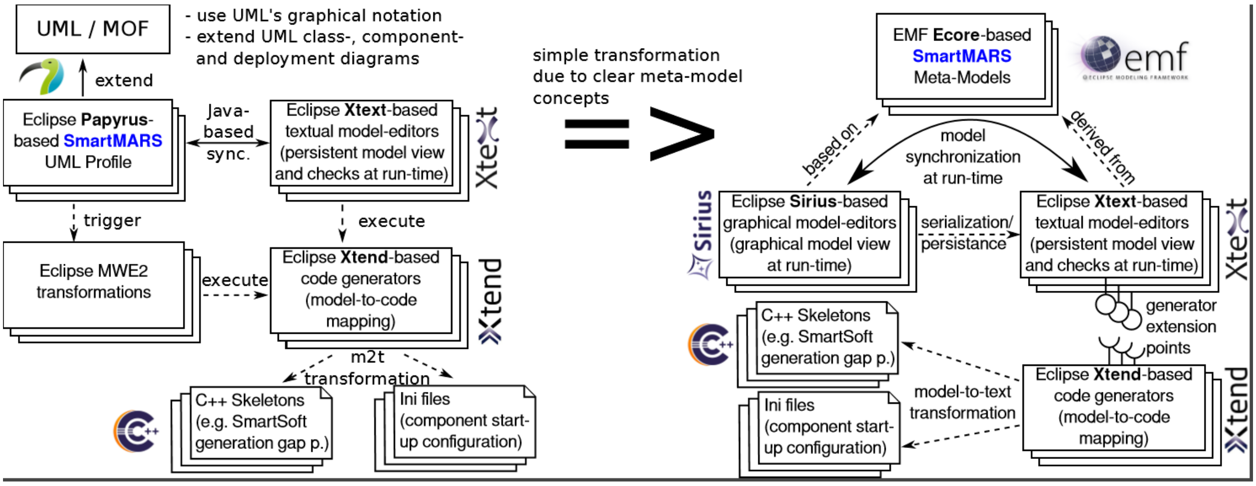
A novel 4th generation for the SmartMDSD Toolchain (version 3.x) and the SmartSoft framework (version 3.x) are currently under development with a strong focus on specifically conforming to the RobMoSys structures. Both technologies are scheduled to be released and productively used by the end of 2017.

See also:

- Introduction to the Technology Preview/Toolchain version 3.x and SmartSoft Framework [http://www.servicerobotik-ulm.de/drupal/?q=node/83]
- Screencast [https://www.youtube.com/watch?v=JIYPJXmop3U]

Eclipse Modeling Tools

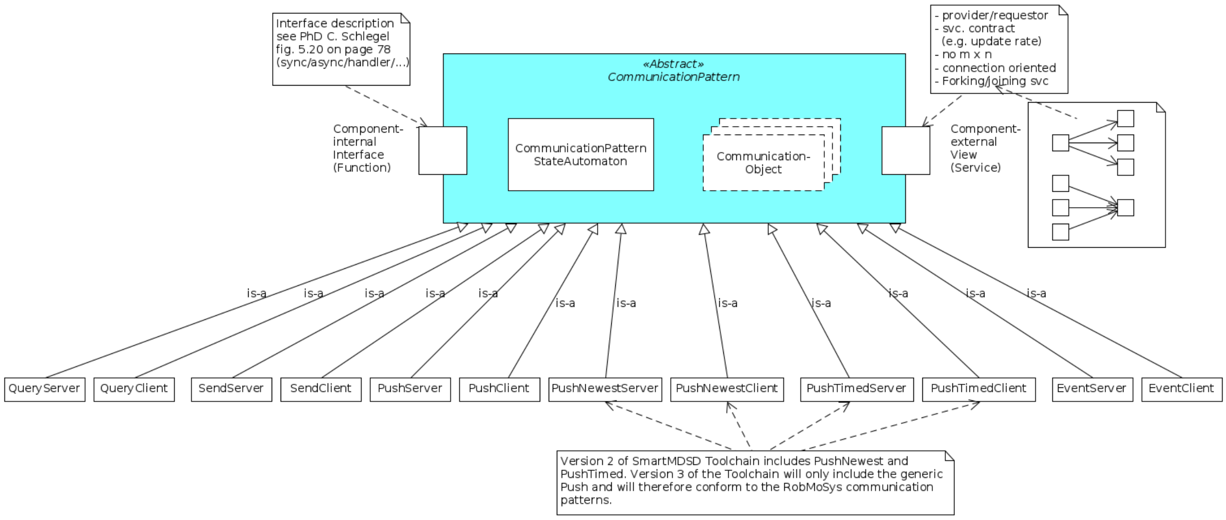
The SmartMDSD Toolchain has been using various Eclipse Modeling technologies. It started in 2009 with the Itemis Open-Architecture Ware (OAW), then between 2013 and 2016 used Xtext, Xtend and UML Papyrus and is currently moving towards using the latest Eclipse Modeling technologies based on latest Xtext, Xtend and Sirius plugins. The figure below provides a schematic overview of the Eclipse technologies used for version 2.x and the transformation with the recent Eclipse technologies for version 3.x.



Overall, the SmartMDSD Toolchain provides various textual and graphical model editors as well as code generators to generate glue-logic for the SmartSoft framework and to generate configuration files.

Conformance to RobMoSys Composition Structures

The SmartSoft software baseline is continuously evolving to match the latest developments in robotics software engineering methods. While many current SmartSoft structures already now fully conform to the RobMoSys definitions, there are some necessary refinements that are summarized below.



Further differences between the current SmartMARS Metamodel and the RobMoSys composition structures will be described in the same way here.

Licenses: SmartSoft is open source

All SmartSoft framework versions are licensed under the LGPL v3 license. The SmartMDSD Toolchain v2.x uses the LGPL v2.1 license. The SmartMDSD Toolchain v3.x uses a plugin-based mix of licenses as depicted below. The SmartSoft components come in GPL/LGPL (see individual component).

Plugin Name	Author	License
org.ecore.component	HSU (Alex Lotz)	LGPL
org.ecore.system	HSU (Alex Lotz)	LGPL
org.ecore.deployment	HSU (Alex Lotz)	LGPL
org.xtext.commObj	HSU (Alex Lotz)	LGPL
org.xtext.component	HSU (Alex Lotz)	LGPL
org.xtext.system	HSU (Alex Lotz)	LGPL
org.xtext.deployment	HSU (Alex Lotz)	LGPL
org.xtext.param.[definition/compusage/sysusage]	HSU (Alex Lotz)	LGPL
org.sirius.component.design	HSU (Alex Lotz)	LGPL
org.sirius.system.design	HSU (Alex Lotz)	LGPL
org.sirius.deployment.design	HSU (Alex Lotz)	LGPL
org.sirius.tools	HSU (Alex Lotz)	LGPL
org.project.creation.wizards	HSU (Alex Lotz)	LGPL
org.robotics.update.site	HSU (Alex Lotz)	LGPL
org.xtend.smartsoft.generator	HSU (Alex Lotz)	LGPL
org.ecore.performExtension	HSU (Alex Lotz)	BSD
org.ecore.performance	HSU (Alex Lotz)	BSD
org.xtext.performance	HSU (Alex Lotz)	BSD

Plugin Name	Author	License
org.sirius.performance.design	HSU (Alex Lotz)	BSD
org.ecore.[symtaBase/symtaConfig]	HSU (Alex Lotz) + Bosch (Vincent Kessel)	BSD
org.xtext.[symtaBase/symtaConfig]	HSU (Alex Lotz) + Bosch (Vincent Kessel)	BSD
org.xtend.symta.generator	HSU (Alex Lotz) + Bosch (Vincent Kessel)	BSD
action.symtaProject.Run	HSU (Alex Lotz) + Bosch (Vincent Kessel)	BSD

Separation of Levels and Concerns in SmartSoft

SmartSoft provides implementations for the individual levels listed in Separation of Levels and Separation of Concerns:

Level	Available/Accessible in the SmartSoft World
Mission	SmartTCL HL Interface
Task Plot	SmartTCL Task Block
Skill	SmartTCL Skill Block
Service	Service Definitions: - Communication Object (data structure) - Communication Patterns (comm. semantics) SmartSoft Components
Function	C++ Library (libOpenRave)
Execution Container	SmartTask
OS/Middleware	ACE, CORBA, DDS, Linux, Windows, iOS
Hardware	UR5, Sick, ARM, x86, Robotino, Segway, MARS

Robotics Behavior in SmartSoft

SmartTCL [http://www.servicerobotik-ulm.de/drupal/?q=node/84] (and the concept of Dynamic State Charts [http://www.servicerobotik-ulm.de/drupal/?q=node/87]) are realizations of the Architectural Pattern for Task-Plot Coordination (Robotic Behaviors)

SmartSoft Terminology

To be extended

Communication Object

- A self-contained entity to hold and access information that is being exchanged via services between components in SmartSoft.
- Communication objects are ordinary C++-like objects that define the data structure and implement middleware-specific access methods and optional user access methods (getter and setter) for convenient access.
- See also the RobMoSys definition for Communication Objects

Communication Pattern

Communication Patterns are a set of few but sufficient characteristics for the exchange of information over services for component interaction in SmartSoft. Communication patterns are fix set of software patterns defining recurring communication solutions for robotics software components. SmartSoft provides communication patterns for the sake of composability, for example *send*, two-way *request-response*, and *publish/subscribe* mechanisms on a timely or availability basis. SmartSoft communication patterns are an implementation of the Architectural Pattern for Communication

Framework

Abstracts away platform-specific details such as independence of a particular operating-system (OS) and communication middleware by providing a unified and platform independent API.

Quality of Service

Quality of Service (QoS) defines the ability of a system to meet application-specific customer needs and expectations while remaining economically competitive. (see Wikipedia service-quality)

Further Resources

All about the SmartSoft World can be found at http://www.servicerobotik-ulm.de [http://www.servicerobotik-ulm.de]. Selected links:

- Getting started with SmartSoft [http://www.servicerobotik-ulm.de/drupal/?q=node/7] provides an overview and starting point
- Use SmartSoft and Gazebo to run the PAL robotics Tiago [http://www.servicerobotik-ulm.de/drupal/?q=node/91] in simulation

Selected Publications

- Dennis Stampfer, Alex Lotz, Matthias Lutz, and Christian Schlegel. “The SmartMDSD Toolchain: An Integrated MDSD Workflow and Integrated Development Environment (IDE) for Robotics Software.” In: Journal of Software Engineering for Robotics (JOSER): Special Issue on Domain-Specific Languages and Models in Robotics (DSLRob) 7.1 (2016). ISSN 2035-3928, pp. 3–19. LINK [https://joser.unibg.it/index.php?journal=joser&page=article&op=view&path%5B%5D=91]
- Alex Lotz, Arne Hamann, Ralph Lange, Christian Heinzemann, Jan Staschulat, Vincent Kesel, Dennis Stampfer, Matthias Lutz, and Christian Schlegel. “Combining Robotics Component-Based Model-Driven Development with a Model-Based Performance Analysis.” In: IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR). San Francisco, CA, USA, Dec. 2016, pp. 170–176. LINK [http://dx.doi.org/10.1109/SIMPAR.2016.7862392]
- Matthias Lutz, Dennis Stampfer, Alex Lotz, and Christian Schlegel. “Service Robot Control Architectures for Flexible and Robust Real-World Task Execution: Best Practices and Patterns.” In: Workshop Roboter-Kontrollarchitekturen, co-located with Informatik 2014. Vol. P-232. GI-Edition: Lecture Notes in Informatics (LNI). ISBN: 978-3-88579-626-8. Stuttgart: Bonner Köllen Verlag, 2014. LINK [https://www.gi.de/service/publikationen/lni/gi-edition- proceedings- 2014/gi-edition-lecture-notes-in-informatics-lni-p-232.html]

See also: Further Publications [http://www.servicerobotik-ulm.de/drupal/?q=node/15] and Technical Reports [http://www.servicerobotik-ulm.de/drupal/?q=node/18] in context of SmartSoft.

Papyrus4Robotics

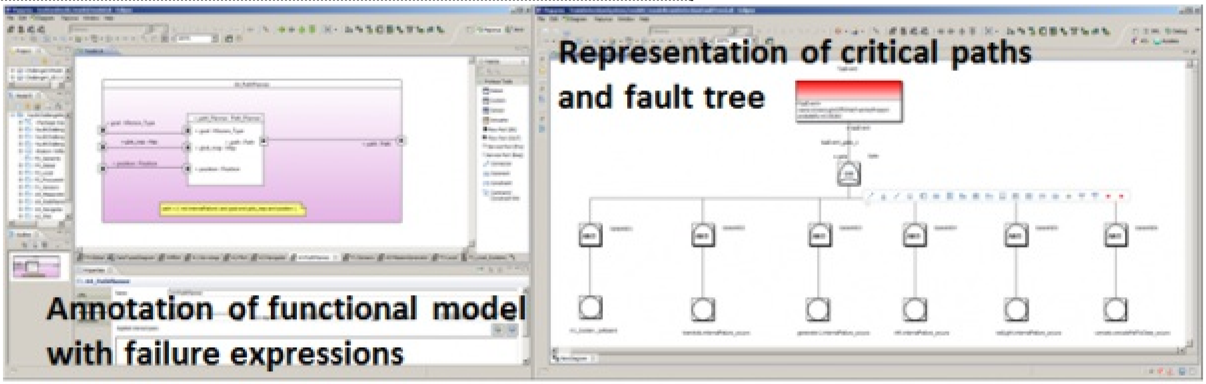
Presentation

Papyrus is an industrial-grade open source Model-Based Engineering tool. It is based on standards and supports Model-Based Design in UML, SysML, MARTE, fUML, PSCS/SM, FMI 2.0 and many more. Papyrus has been used successfuly in industrial projects and is the base platform for several industrial modeling tools—read more about Papyrus Use Case Stories [https://eclipse.org/papyrus/testimonials.html].

To address the robotics domain according to the RobMoSys methodology and structures, a set of Papyrus-based DSLs and tools are being collected under the Papyrus4Robotics umbrella.

It is important to emphasize that RobMoSys-compliant software baselines are not in competition. Indeed, RobMoSys aims, as one of its primary goals, at the realization of a virtual integration platform built upon existing tools and standards for the development of robotic systems.

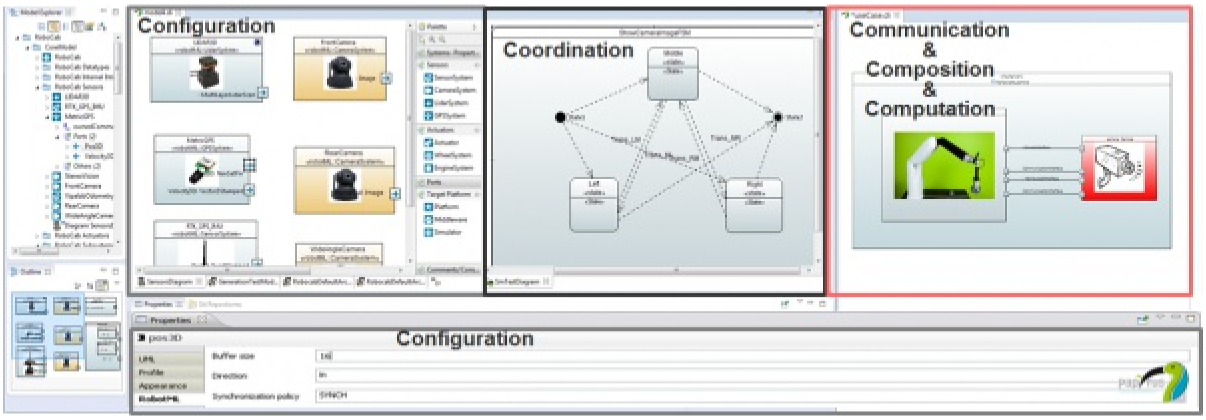
Concretely, this means that the RobMoSys approach and structures can enable model exchange and collaborative development between, e.g., safety engineers and system integrators who use different RobMoSys-compliant software baselines. As an example, SmartSoft and its large set of software components can be used to define the system's functional architecture. Then, a safety module in Papyrus4Robotics can be used to perform dysfunctional analysis on the architecture's key components, including Hazard Analysis and Risk Assessment (HARA), Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). Model-based safety analysis would be enabled by the following components. A dedicated modeling view; a DSL with the main safety concepts for robotics, e.g., various hazards and safety requirements as specified by ISO standards 10218-1/2 (industrial robots), 15066 (collaborative industrial robots) and 13482 (personal care robots); a set of analysis and report generation modules. Read the Aldebaran's use case story [https://eclipse.org/papyrus/resources/aldebaran-usecasestory.pdf] to find out more on this subject.



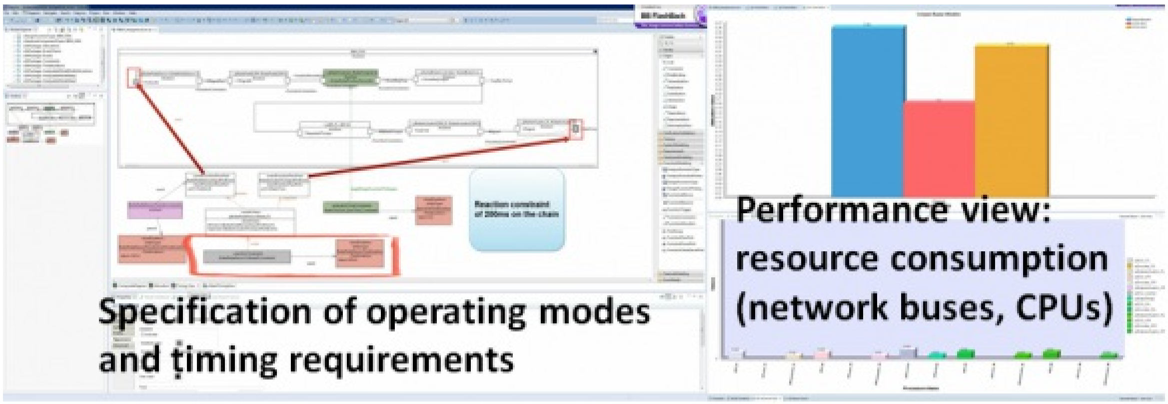
Realization and tools

Papyrus4Robotics uses UML/SysML as underlying realization technology. The platform uses the UML profile mechanism to enable the implementation of Domain-Specific Languages (DSLs) that assist RobMoSys's ecosystem users in designing robotics systems.

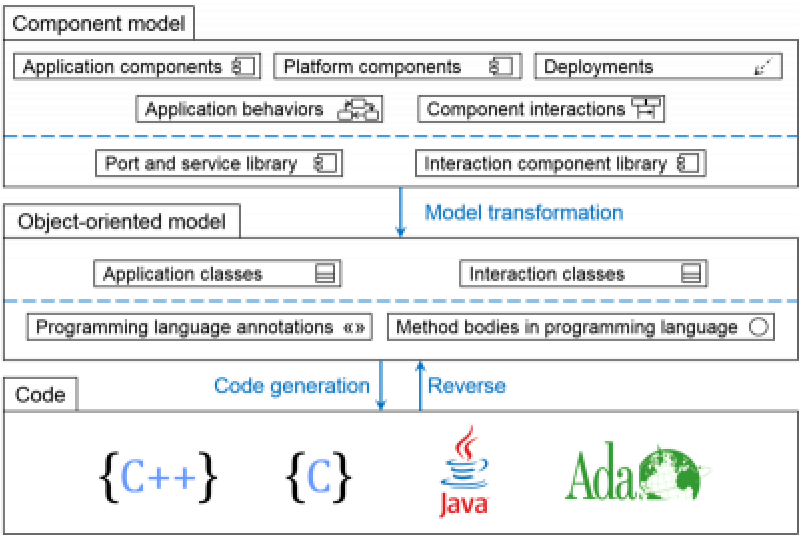
RobotML is a DSL specifically oriented to modeling and design of mobile manipulation robotic systems. **RobotML** conforms to RobMoSys's foundational principles of separation of roles and concerns. It provides several **view points**, including (but not limited to) those for the definition of State Machines, Hardware and Software components , Controllers and Environment. RobotML domain models allow for the representation of the system's architecture, control and communication aspects and span across all 5C concerns of Computation, Coordination, Coordination, Configuration and Composition.



Further modeling views are provided by additional components of Papyrus4Robotics. For example, the **performance view** is featured by Papyrus Architect, a Papyrus4Robotics module dedicated to explore quality attributes of architectures, with a focus on timing properties in real-time applications of embedded (robotic) systems. It leverages the MARTE (Modeling and Analysis of Real-Time Embedded systems) DSL for the specification of system architecture (functional/physical) and of timing properties. The performance view addresses the problem of evaluating the performance of candidate architectures with respect to attributes like hardware resource utilization.



In addition to DSLs and modeling, Papyrus4Robotics also features code-generation capabilities. Papyrus Designer [https://wiki.eclipse.org/Papyrus_Software_Designer] supports code generation from models of SW including embedded and real-time and DDS-based distributed systems as potential targets. In Designer, the generation starts from a model that includes the definition of software components, hardware nodes and deployment information. The latter consists of a definition of the instances of components and nodes and an allocation between these. Code generation is done by a sequence of transformations steps. The model transformation takes care of some platform specific aspects (e.g. communication mechanisms or thread allocation), based on non-functional properties.



RobotML includes generators that transform RobotML-compliant models into code for robotic middlewares (e.g., Orocos-RTT [http://www.orocos.org/rtt]) or simulators (e.g., MORSE [https://www.openrobots.org/wiki/morse/]).

Conformance to the RobMoSys structures

Some modeling concepts in Papyrus4Robotics are already aligned with the RobMoSys definitions. However, further refinement and alignment of meta-models is in process and scheduled to be released and productively used by the end of 2017.

Separation of Levels and tool coverage

Papyrus4Robotics provides implementations for the individual levels listed in Separation of Levels and Separation of Concerns

Level	Corresponding DSL or Tool in Papyrus4Robotics
Task Plot	RobotML State Machine
Skill	RobotML Inteface
Service	RobotML operation (defined in the Skill interface) Software Component representation in Papyrus Designer
Function	C++ library (e.g., libOpenRave, etc.)
Execution Container	Task and resource representation in Papyrus Designer
OS/Middleware	DRM::SRM in UML MARTE
Hardware	DRM::HRM in UML MARTE, RobotML's sensors and actuators

Platform workbenches in the context of RobMoSys

One major project's focus is on models, software and tools that are generically useful for all possible robotic systems and applications. This includes systems and applications that can, e.g., pass certification, monitor their resource usage at runtime, or form systems-of-systems with just a reconfiguration of the available models.

Building such systems and applications require multi-disciplinary competences (beyond robotics) and sets of platform tools that support best-practices established in near and mature engineering-centric domains, such as automotive or aerospace.

Possible modeling workbenches enabled by the RobMoSys's software baselines are for example SmartMDSD Toolchain, the Papyrus4Robotics set of modeling tools. There are many more existing modeling tools that can be made conformal to the RobMoSys's baseline. In a robotics ecosystem multiple users provide models by using these workbenches and these models are interfaced over the RobMoSys's baseline.

Some workbenches allow for many different kinds of analysis that are strongly related to good practices to employ during the development process—as recommended by **experts** in the complex and critical systems design domain (read Annex 1 of D5.1 to find out more). This includes (and is not limited to):

- verification and co-simulation activities (e.g., based on the FMI 2.0 standard) during early stage of design, thanks to the definition of a model of computation (MoC) on system level;
- handling safety and security aspects as soon as possible and not as an afterthought;
- checking whether the amount of reserved resources (hardware/software) is adequate to meet given performance criteria (e.g., respect of time constraints on end-to-end latencies)

It is unrewarding to define one single modeling workbench that covers all aspects of design, analysis and synthesis (i.e. code-generation). Instead, because platform tools conform to the RobMoSys structures, models can be exchanged from one modleing workbench to another to cover all the design needs of the ecosystem users at all the phases of development.

Resources

- Installation procedure
  - Papyrus [https://eclipse.org/papyrus/]
  - Papyrus RobotML [https://eclipse.org/papyrus/components/robotml/1.2.0/]
  - Papyrus Software Designer [https://wiki.eclipse.org/Papyrus/Designer/getting-started]
- Documentation and tutorials
  - Papyrus Documentation [http://www.eclipse.org/papyrus/documentation.html]
  - Papyrus RobotML Documentation [https://eclipse.org/papyrus/components/robotml/1.2.0/]
  - Papyrus Software Designer User Guide [https://wiki.eclipse.org/index.php?title=Papyrus_Software_Designer&redirect=no]
- Videos
  - Model driven safety assessment for robotics [https://www.youtube.com/watch?v=CnklgQ7tWns]
  - Modeling and safety assessment for Nao [https://www.youtube.com/watch?v=-k1xWJr4wg0]
  - More videos on Papyrus Companions [https://www.youtube.com/channel/UCxyPoBlZc_rKLS7_K2dtwYA]
- Selected publications
  - Selma Kchir, Saadia Dhouib, Jérémie Tatibouet, Baptiste Gradoussoff, Max Da Silva Simoes, RobotML for industrial robots: Design and simulation of manipulation scenarios. ETFA 2016: 1-8
  - Nataliya Yakymets, S. Dhouib, Hadi Jaber, Agnes Lanusse, Model-driven safety assessment of robotic systems. IROS 2013: 1137-1142
  - Saadia Dhouib, Selma Kchir, Serge Stinckwich, Tewfik Ziadi, Mikal Ziane, RobotML, a Domain-Specific Language to Design, Simulate and Deploy Robotic Applications. SIMPAR 2012: 149-160

SmartSoft Components

A collection of SmartSoft components is readily available under Open Source Licenses. They have been developed using the SmartMDSD Toolchain and are available for immediate reuse.

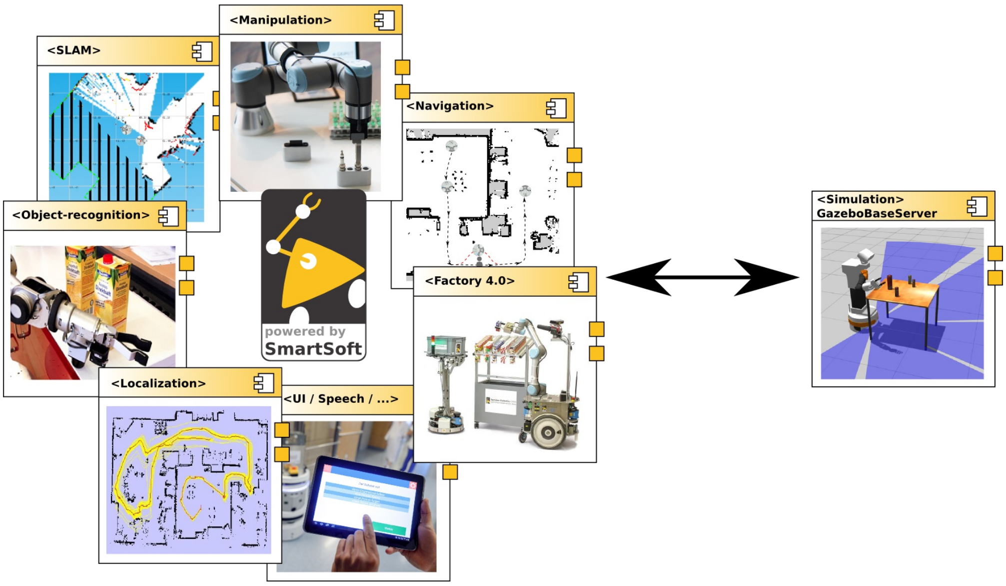
List of available components [http://www.servicerobotik-ulm.de/drupal/doxygen/components_commrep/group__componentGroup.html]

baseline:components:smartsoft · Last modified: 2017/06/23 18:16
http://www.robmosys.eu/wiki-sn-01/baseline:components:smartsoft

Gazebo/Tiago/SmartSoft Scenario

This scenario contributes to the Pilot “mobile manipulation for assistive robotics in a domestic environment or in care institutions”.

The robot platform Tiago from Pal-Robotics is accessible in the SmartSoft World. A scenario was set up in which you can use the SmartSoft navigation stack and SmartTCL for behaviour coordination to move Tiago around in the Gazebo simulator.



The Tiago robot platform in simulation can be used with the SmartMDSD Toolchain as available software for the open calls where we emphasize: “do not re-invent in open call projects but build on existing technologies and tools”.

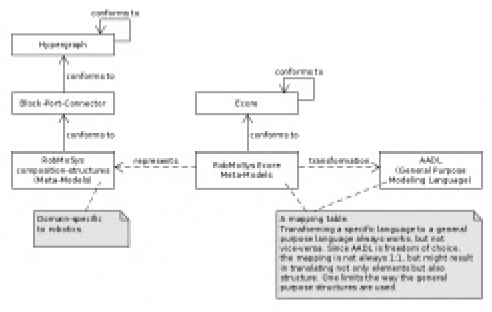
The scenario includes:

- Navigation Stack: obstacle avoidance (CDL), recording maps with Gmapping, localization, path planning
- SmartTCL for behavior coordination to move Tiago around in the gazebo simulator

The models and components to run the Pal-Robotics Tiago using SmartSoft/SmartMDSD Toolchain within Gazebo are available including documentation and tutorial at http://www.servicerobotik-ulm.de/drupal/?q=node/91 [http://www.servicerobotik-ulm.de/drupal/?q=node/91]

Other Approaches in the RobMoSys Context

RobMoSys follows a reuse-oriented approach. This means that reinvention should be kept to a minimum and existing approaches should be used wherever possible. The following list provides some common approaches that are considered relevant within the RobMoSys context.



- General Purpose Modeling Languages (SysML/UML) and Dynamic-Realtime-Embedded (DRE) domains (AADL, MARTE, etc.)
- Robotics Approaches (ROS, YARP, RTC, etc.)
- Middlewares (DDS)

General Purpose Modeling Languages and Dynamic-Realtime-Embedded domains

SysML, SoaML, AADL, MARTE and others are flexible general purpose modeling approaches for systems. They favor freedom of choice. While they often provide different modeling views, these views are not connected such that overall system consistency can be ensured throughout all potential development phases. This hinders separation of roles that is required for successful system composition and therefore is in contrast with the overall needs for modeling in RobMoSys.

The focus of RobMoSys is on composability and consistency of the different views such that the different roles contribute in a consistent and composable way to the system under specification and development. This requires more elaborate structures to connect the different views in a consistent way. This can be achieved via superordinated meta-model structures and via model-to-model transformations.

Of course, the structures of RobMoSys will be inspired by, for example, the above approaches wherever appropriate. The RobMoSys structures might enable linking the different modeling views of the mentioned modeling approaches.

For example, AADL requires more abstract, yet consistent, modeling views on top, while other approaches such as SysML might be subprofiled, thus providing more detailed, yet again consistent, robotic-specific views underneath. Many of the (meta-model) structures and abstractions in RobMoSys focus on transformations (and exchange of knowledge) between well known and widely accepted modeling views.

Within the context of UML the term *"semantic variation point"* has been coined to express the purposeful semantic ambiguity for certain UML elements. Because UML is a general purpose modeling language, this semantic ambiguity makes sense and can be narrowed within the derived domain-specific models using e.g. the UML profile mechanism. Moreover, even the domain-specific models can still expose some semantic variability that is closed within concrete realizations (e.g. through code generation or reference implementations). In this sense, RobMoSys as well offers different levels of abstraction for modeling where the higher levels (such as e.g. the block-port-connector) are more general purpose (leaving open some semantic variability) and lower (i.e. domain-specific) abstraction levels (such as e.g. the RobMoSys composition structures) that narrow this semantic variability.