Modeling Non-Functional Application Domain Constraints for Component-Based Robotics Software Systems

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Abstract—Service robots are complex, heterogeneous, software intensive systems built from components. Recent robotics research trends mainly address isolated capabilities on functional level. Non-functional properties, such as responsiveness or deterministic behavior, are addressed only in isolation (if at all). We argue that handling such non-functional properties on system level is a crucial next step. We claim that precise control over application-specific, dynamic execution and interaction behavior of functional components – i.e. clear computation and communication semantics on model level without hidden code-defined parts – is a key ingredient thereto.

In this paper, we propose modeling concepts for these semantics, and present a meta-model which (i) enables component developers to implement component functionalities without presuming application-specific, system-level attributes, and (ii) enables system integrators to reason about causal dependencies between components as well as system-level data-flow characteristics. This allows to control data-propagation semantics and system properties such as end-to-end latencies during system integration without breaking component encapsulation.

I. INTRODUCTION AND MOTIVATION

Service robots are complex, heterogeneous, software intensive systems. Recent robotics research trends mainly address isolated capabilities on functional level. Examples include robust perception, mobile manipulation and intuitive human-robot interaction. This already allows to showcase impressive lab prototypes. However, the inter-disciplinary software engineering challenges, i.e. building modular and flexible software architectures covering several product generations that are easy to maintain and that adhere to functional and in particular non-functional requirements, are underestimated and underrepresented. The general need for model-based system engineering techniques within the robotics domain is also recognized by the European SPARC Robotics \cite{1} initiative in its Multi-Annual Roadmap (MAR) \cite{2} as “the “make or break” factor in the development of complex robot systems” – \cite{2}.

Service robotics as a science of integration relies on the combination of individual expertise from various stakeholders involved in the overall development of a robotics software system. In this paper we particularly focus on two distinct expert roles: the robotics experts, i.e. experts of a particular technology domain such as computer vision, mobile manipulation, etc., and application experts for various application domains such as e.g. logistics, agriculture, etc.

Obviously, both experts need to focus on different concerns to build a robotic system. For instance, robotics experts should be able to focus on the functional part of a component without anticipating application specific details, whereas the application domain experts should be able to select the right components and to adjust them on model level according to the application related requirements without the need to investigate nor modify the internal implementation of the individual software parts.

We therefore argue that successful and efficient system engineering strongly relies on a clear separation of concerns allowing for efficient collaboration between all involved stakeholders \cite{3}. Only then the different experts are enabled to fully concentrate on their dedicated expertise, which globally leads to shared and lowered risks, increased robustness and product quality as well as reduced costs, development time, and time to the market.

While several model-based robotics approaches such as RTC \cite{4}, RobotML \cite{5} and BCM \cite{6} already facilitate the description of functional components by robotics experts, the system integration part which is central for application domain experts is currently not systematically addressed in robotics system development (besides of a few promising initiatives such as Rock \cite{7}). Precise control over the dynamic execution and interaction behavior of functional components, i.e. the computation and communication semantics, on model level without hidden (i.e. code-defined) parts is urgently needed to enable the aforementioned separation of concerns between functional component development and application-specific system integration.

Other existing model-based approaches beyond robotics such as OMG MARTE \cite{8}, AMALTHEA \cite{9}, AADL \cite{10} and SysML \cite{11} offer concepts for describing the execution and interaction behavior of components on system level. However, central concepts are often hidden in a freedom-of-choice philosophy offering all kinds of alternative coequal concepts. Moreover, many of the concepts that are lifted to model level are too fine granular (e.g. read and write operations on buffers in MARTE) directing the focus and efforts on minor aspects. In the end, the robotics expert who is mainly interested in functional development is left alone with many system-level design choices, while application domain experts need to understand all the low-level technical details (often on code level) of the functional components. This either leads to refusal of using the model-based ap-
proaches in the first place, or results in non-interoperable, hard to reuse, functional components.

In this paper, we therefore pursue the opposed freedom-from-choice [12] approach by consciously restricting the modeling choices to the crucial concepts and abstractions that are necessary to systematically design and integrate functional components. More precisely, we present a meta-model using Model-Driven Software Engineering (MDSE), which is separated into two parts, each individually addressing the corresponding concerns of the robotics experts and the application domain experts. The two meta-model parts further allow to provide role-specific views with an appropriate abstraction level, and, they are interconnected, thus allowing to ensure system level conformance by means of automated model consistency checks.

We pay special attention to non-functional system-level aspects such as an adequate responsiveness of the overall system and deterministic system behavior. As a core contribution in this paper we provide model-based mechanisms for robotics experts to clearly define activation semantics for the concurrent execution of functional blocks within components such that causal dependencies as well as data-flow characteristics (analogous to SDF [13]) between components are made explicit and can be consciously designed by application domain experts on the right abstraction level. Thereby, the abstraction level is chosen high enough to achieve separation of concerns between the corresponding developer roles, but also detailed enough to being able to calculate system-level end-to-end latencies and jitters for chains of interconnected components.

This paper is structured as follows. In the subsequent section II we present a couple of real-world examples paying special attention to non-functional, application related needs. Then, section III presents a formal meta-model including a detailed explanation of the individual core elements. Section IV addresses possible model-editor syntax options based on the presented meta-model. Section V gives some insights into the model-to-text transformations for two selected frameworks, namely ROS and SMARTSoft. Finally, section VI discusses related work, and section VII concludes the paper.

II. Motivating Example

This section presents a system example (see figure 1) consisting of software components which have been used in various real-world scenarios. This example represents a particular set of recurring robotics use-cases with an emphasis on application specific, non-functional, system-level aspects.

Figure 1 presents the navigation scenario with two basic robot capabilities: the fast, local obstacle avoidance (inner loop) and the slower grid-map-based path planning (outer loop). Each of these capabilities is realized by several connected components forming a component-chain between the involved sensors and actuators. The functional concerns are the described functionality, and, in particular, the data exchange between the components.

A key non-functional requirement in this situation is the end-to-end response time for the obstacle avoidance.

Concretely, if a human suddenly jumps in front of an autonomously navigating robot, how long will it take for the robot to react to this event by retrieving a new laser scan, propagating it to the obstacle avoidance component, calculating an evasive maneuver and finally commanding the robot-base? The maximum admissible value for this response time will probably influence the periods at which individual components have to run, and possibly the choice of algorithms.

Now, the selection of that value primarily depends on the kinematics constraints of the actual robot, which may further be constrained by the concrete application (e.g. the acceptable maximum velocity of this robot moving in crowded areas). As these aspects are highly application specific, they need to remain unbound until the corresponding application domain experts provide the according domain knowledge allowing to select adequate values.

Another such sensor to actuator coupling (from here on we call it a "cause-effect chain") is the map-based path planning functionality. How often does the path to a (remote) location need to be re-planned in order to adequately react to structural changes in the environment (such as closed or opened doors)? Again, depending on the expected environments the robot is supposed to operate in, the probability and frequency of changes can only be anticipated by application domain experts providing the according requirements for the re-planning frequency.

Unfortunately, in the current state-of-practice, many details about the execution and interaction behavior are hidden within component implementations which makes it difficult to reason about global execution aspects.

For instance, in ROS the semantic of how incoming messages on a topic are processed is intrinsically tied to the node implementation and cannot easily be changed according to a specific use-case. More precisely, the subscriber callback can directly process an incoming message or store it in a local variable (or buffer) for later processing in a timer callback (which is common pattern in ROS based systems).
In the first case the processing is data triggered, and the latter case corresponds to polling a register. Obviously, there are huge differences in the execution behavior with respect to latency and jitter between both cases. We argue that the adequate execution and interaction behavior of functional components highly depends on the actual application, and thus needs to remain a configurable part for application domain experts. Furthermore, we are convinced that for systems comprising many components this information needs to be lifted to model level to easily understand the overall system behavior.

There are many other comparable examples, e.g., related to tracking, person-following, human-robot interaction, visual servoing, etc. Interestingly enough, a typical service robot, that combines multiple basic capabilities to achieve a certain task often needs to execute several such cause-effect chains in parallel, possibly with completely different requirements. These requirements can range from very strict hard real-time guarantees (e.g. for a robot balancing on two wheels) up to very soft, safety unrelated, average timing estimations (e.g. reaction time in speech interaction). Independent of the guarantee-severity (hard or soft), the important point addressed in this paper is that the mentioned system properties need to be an explicit and adjustable part of the overall system design and not the result of hidden, too early, and un-modifiable decisions inside of component implementations.

III. ECore Meta-Model for Component Definition and System Configuration

This section presents an ecore meta-model (shown in figure 2) which separates the individual concerns for component development and system integration. It is worth noting that the presented meta-model is inspired by fully fledged robotics (meta)-models such as SMART MARS [14]. However, on the one hand, it has been simplified to focus on essential concepts for efficiency and clarity reasons, and, on the other hand, it has been extended with additional concepts to address concerns related to interconnected components with the aforementioned cause-effect chains.

There are several other component meta-models such as RobotML [5], BRICS Component Model (BCM) [6], RTC [4], GCM from OMG MARTE [8], etc. which provide similar core items such as a Component, an In- and OutPort, an IDL for the definition of communicated data, a Connection and often a ComponentInstance. These meta-model root-elements are not supposed to be reinvented here, instead, we encourage to map them onto the according original items of an already existing meta-model wherever possible.

A. Component-Definition Meta-Model

The left part of figure 2 addresses the robotics expert view. The core element is the definition of a Component including a name, which serves as a unique identifier in the later component pool. The main purpose of a Component is to provide clearly specified means of communication (using In- and OutPorts) between the internal functionality (realized as Tasks) and other components in the system[1]. In-/OutPorts represent typed, 1 to n, publish-subscribe communication semantics. In SOA terminology, an OutPort is a publisher and resp. a service provider, whereas an InPort is a subscriber and resp. a service requestor. This communication semantics can be mapped onto many popular middlewares such as the Data Distribution Service (DDS) [16], onto other component models such as the Flow-Port from the OMG MARTE [8] specification, or even directly onto existing (robotics) frameworks such as ROS, SMARTSOFT and others. InPorts additionally support the definition of CompoundInPorts, which allow to define advanced SDF [13] composition strategies (such as HSDF). It is worth noting, that we do not (yet) include other communication semantics such as request-response. There are many valid use-cases where components are only acting on request. However, such components typically are not part of tightly coupled cause-effect chains between sensors and actuators, and thus can easily coexist alongside with the extensions presented here.

At this point it is worth noting that we do not (yet) support hierarchical components (i.e. components of components). There are several approaches in the robotics domain such as RTC [4] or outside robotics such as MARTE [8] providing hierarchical component models. In this paper we chose a flat component representation focusing on the imminent problems first before generalizing and extending the model semantics. However, we might extend our meta-model in future work accordingly.

Tasks represent concurrent functionalities inside a Component thereby clustering (independent) functional aspects, thus allowing to implement more complex Components that can provide several (independent) OutPorts. This is particularly useful for sophisticated libraries such as, for instance, OpenRAVE[2]. The main concern of a Task is to (continuously) generate data for one or several OutPorts. Thereby, a Task might internally use any kind of HW API (i.e. for sensors or actuators). For its computation a Task can depend (strictly or optionally) on data arriving from one or several InPorts. Please note that InPorts can be shared by several Tasks. However, each OutPort must be served by exactly one distinct Task. This is an important aspect for the configuration of interconnected components in cause-effect chains (see below). Furthermore, two different Task-types are distinguished. PreemptiveTasks can be executed in parallel (allowing e.g. to utilize multicore CPUs). In case that PreemptiveTasks share data inside a component, it is assumed that the component developer implements suitable mutual exclusion mechanisms. CooperativeTasks are executed pseudo-parallel (they are internally sequenced), thus preventing race-conditions even if accessing unprotected shared data.

One of the particularly interesting aspects is the optional definition of ActivationConstraints. ActivationConstraints are used to express intrinsic requirements on ac-

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1 Please note that the description of further important component’s orchestration mechanisms such as component parametrization and the component’s lifecycle automaton [15] are considered out of scope in this paper.
2 OpenRAVE: [http://openrave.org/](http://openrave.org/)
tivation characteristics of a Task. Application-specific activation characteristics (such as configurable timers, or the synchronicity of data received on one or several InPorts) should be left open for later configuration by the application domain expert who is responsible for system integration (see subsection III-B). ActivationConstraints can be used by robotics experts though, for instance, to express strict and unmodifiable constraints on execution characteristics, which might be due, for instance, to an internal HW trigger (e.g. a sensor providing data with a fixed frequency). Other use-cases for specifying ActivationConstraints during component development include internally used algorithms requiring specific activation-frequency ranges (e.g. for a PID controller).

B. System Configuration Meta-Model

The right part of figure 2 addresses the application domain expert’s view. The main concern here is the initialization of ComponentInstances and the definition of initial Connections between In- and OutPorts. In future work we plan to link the system configuration model with a deployment model (such as e.g. in [14]) and a simple platform definition model which altogether embody the overall system integration step.

The novel parts in the meta-model are the late binding of the ActivationSource for each corresponding Task reference and the definition of CauseEffectChains. There is an interesting interdependency between the specification of ActivationConstraints in the component definition model and the corresponding selection of an ActivationSource in the system configuration model. The ActivationSource enables application domain experts to select specific execution characteristics for a Task considering the predefined boundaries in the according ActivationConstraints.

There are three different types of ActivationSources. One is the DataTrigger denoting that each incoming data message on the referenced InPort directly triggers the execution of the associated Task. In other words, the Task synchronously reads data from the referenced InPorts. By definition, we allow at most for one InPort with DataTrigger semantics per Task. All other InPorts are asynchronously read with register semantics at the time instant of the Task’s activation. Please note, that by using CompoundInPorts it is possible to define more complex data triggered activation schemes involving several InPorts (such as homogeneous SDF [13], or respectively AND- and OR-activation semantics [17]).

Another option is to use a PeriodicTimer as ActivationSource for a Task. In this case all referenced InPorts are asynchronously read with register semantics at periodic Task activation.

The third ActivationSource type is Sporadic. Its main use-case is the backwards compatibility for already implemented components whose hard-coded Task activation behavior is unmodifiable on model level.

Next, a CauseEffectChain is defined by a list of OutPort references. This is sufficient to unambiguously derive all relevant model elements contained in the cause-effect chain, namely the Connections, the InPort to Task dependencies as well as the Task to OutPort dependencies. One of the main concerns of the CauseEffectChain is to define a relationship between the overall E2ELatencySpecs and the involved ActivationSources. The individual ActivationSources can be chosen such that both requirements are satisfied, those coming from the enclosing component (defined by the according ActivationConstraints) and those coming from the involved CauseEffectChain (defined by the corresponding E2ELatencySpecs).

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3 Some frameworks such as SMARTSOFT additionally allow for dynamic (re-)wiring at run-time, which is out of scope in this discussion.
IV. DSLs AND MODEL CHECKS

A meta-model as presented in the previous section is the foundation in a modelling initiative which formalises domain knowledge by specifying domain specific vocabulary with the involved structures and relations. In addition, further aspects such as an intuitive model editor with easily understandable representation, as well as an unambiguous mapping into code by model-to-text transformations (see overview in figure 3) are important factors for the overall acceptance and usefulness of a modeling tool.

This subsection presents an exemplary graphical notation for the component definition according to the EPackage ComponentDefModel in figure 2 which is the view of robotics experts. The model editor is demonstrated using the ObstacleAvoidance and the Base components (see figure 4). The graphical editor is based on the Eclipse Sirius plugin whose graphical notation is inspired by UML. In fact, another possibility is to directly profile UML as e.g. demonstrated by RobotML [5].

The interesting parts are the dashed lines between InPorts and the Tasks as well as between the Tasks and the OutPorts. This way, the functional dependency of a Task to input data as well as the responsibility of that Task to provide results on a certain OutPort are clearly specified. This allows to implement functionally complete and compilable code without already binding the exact run-time communication semantics.

In case the changeable flag is set to false (see e.g. PoseUpdateTask in figure 4), this indicates that the provided ActivationConstraints are fix and can not be changed any more during system configuration. This way it is possible to express strict requirements which should not be changed by application domain experts. If in addition, both values of maxActFreq and minActFreq are equal, this indicates a fix (i.e. unmodifiable), periodic update frequency.

B. System Configuration Model

Figure 5 shows an excerpt of the navigation scenario (presented in section III) using an Xtext based DSL according to the EPackage SystemConfigModel in figure 2 which defines the high level view for application domain experts.

For the presented DSL, there are several factors in favor for a textual representation rather than graphical. For
instance, the model in figure 5 references lots of already existing elements: Components, Tasks and In-/OutPorts. Therefore, Xtext allows to implement powerful code completion mechanisms using scope providers and content assist to e.g. generate higher level model elements including their child elements (such as a ComponentInstance with its TaskRefs).

Furthermore, the definition of a CauseEffectChain is mainly based on a list of concatenated OutPort references. A scope provider in combination with a validation check ensures that only those successive OutPort references can be chosen which really are reachable from the current OutPort reference in the list (through according Connection and the dependency specifications within the corresponding component). Furthermore, as there might be lots of involved components (20 and more) in a typical system, graphical notations tend to become cumbersome with lots of crossing lines for e.g. the Connections. Even so, textual representations can also get lengthy, it still is easier to distribute a textual model over several files.

A model-editor additionally supports the editing process by on-the-fly checking the syntax according to the metamodel specification and by additionally running semantic evaluation checks (see figure 3). For the former, Xtext allows to implement element-based Validation Rules which display error- or warning-messages attached to a corresponding textual element in the editor. For the latter semantic evaluation, there are two main realization possibilities. One is to use an external 3rd-party tool such as e.g. pyCPA [18] or SymTA/S [17], for analyzing worst-case latencies along cause-effect chains whose input can be directly generated from the Xtext model (we plan to demonstrate this in our future work). Another option is to directly implement semantic interpretation rules as part of the model editor and to display their results in the Outline view of the Xtext model (as shown in figure 6).

For example, the FastReactiveNavigationLoop in figure 5 defines a cause-effect chain consisting of four components: (1) a Base component providing odometry, (2) a Laser component providing laser-scans, (3) an ObstacleAvoidance component and (4) again the Base component receiving velocity commands. For each Task within these components an individual ActivationSource can be selected. This way, the Tasks form a concatenated chain whose links are either synchronously connected using the DataTriggered activation source or asynchronously connected using e.g. the TimedTrigger activation source. Thereby, all successive Tasks with the DataTriggered activation source implicitly follow the update frequency from the preceding Task. Along the chain, this frequency can be subdivided by an optional prescaler as is demonstrated by the Mapper component in figure 6 subdividing the incoming frequency of 40 Hz from the Laser component by 10 in order to get an adequate frequency of 4 Hz. It is worth noting that since there is a 1-to-1 relationship between Tasks and OutPorts one might be tempted to combine both modeling elements, e.g. by including the Task semantics into the OutPort. However, a Task additionally serves as a functional block for the InPorts which might be independent from the OutPort as e.g. is demonstrated by the Base component in figure 4.

Tasks in a chain using PeriodicTimers can either run at a higher update frequency than the input data, thus potentially
using old values for several task-cycles (see oversampling in figure 5), or at a lower update frequency, thus skipping some intermediate values (see undersampling in figure 6). Depending on the current application, over- or under-sampling might be acceptable or not. The important point is that this information is available for the application domain expert, thus enabling him to find the right balance between the different selection options of the individual ActivationSources. For example, the expert could decide to use a DataTriggered activation source with prescale 4 instead of the PeriodicTimer for the OATask in the ObstacleAvoidance component (see figure 5). This would result in a triggering of the OATask each 4th incoming laser-scan, thus again getting an update-frequency of 10 Hz, however, now synchronously without sampling effects due to scheduling.

V. M2T Code-Generation

One of the remaining elements in figure 3 which is not yet discussed is the model-to-text transformation (i.e. the code generation). Model-to-text transformations implement the actual grounding of the meta-model into the code. At the moment, lots of valuable algorithms for robotics are implemented as libraries (often embedded in ROS nodes or enveloped by SMARTSOFT components). Therefore, we consider it illusory (at least in the near future) to describe all necessary low level details in an overall model, and to completely generate ready to use components by simply pushing a button. Instead, we focus on modeling essential parts related to structured system integration and generate glue-code (e.g. using the generation-gap pattern) to link with existing implementations.

Successful code generation heavily relies on a generic interface (dashed line) between the functional code (component’s inner area) and the framework glue-code (component’s gray container).

In order to ease the migration of already existing components, we support both, top-down and bottom-up development. Top-down refers to designing new components which can be adjusted during system configuration on model level without modifying their functional code. Bottom-up refers to existing component implementations where we express their implemented execution and communication behavior with our model.

VI. Related Work

In the last decade, component-based frameworks for robotics have become the norm. They mostly focus on implementing functional blocks and abstracting over communication middlewares. However, as argued in the introduction, structured system integration allowing to precisely control the dynamic execution and interaction behavior of functional components on model level, according to application specific needs and without hidden code-defined parts is one of the hot research topics.

Some initial works within the robotics domain address parts of the aforementioned problem. For instance, systematic component development and structured system integration relies on a clear separation of concerns as is also recognized in the BRICS project as the 5Cs [6] (computation, communication, configuration, coordination and composition). Separating concerns means to systematically structure the model representations, as e.g. demonstrated in RobotML [5], by separating models in packages related to communication, behavior, architecture, and deployment. Precise concepts for addressing these concerns are, however, still under discussion and we see our activation semantics as a concrete contribution in this direction.

Successful code generation relies on a generic interface (see figure 7) between the generated framework glue-code (e.g. for ROS or SMARTSOFT) and the provided functional code. It is a matter of framework capabilities whether the glue code is generated from the beginning during component design providing according configuration options (e.g. using the parameter specification in SMARTSOFT), or whether the glue-code is afterwards generated based on the system configuration model as it is typically the case for ROS nodes. In any case, the main concern for code generation is to preserve model semantics with respect to the designed execution and communication behavior.
be integrated with commonly used robotic frameworks. Our approach has, so far, been applied to both ROS [19] and SmartSoft [14].

An approach closer to our concepts can be found in the Architecture Analysis and Design Language (AADL) [10]. In particular, [20] describes how flows in AADL can be used to model activation semantics similar to ours, using appropriate port types (i.e., queued or sampled), and thread types (aperiodic with trigger, for DataTriggered semantics, and periodic for TimeTriggered). It also supports attributes such as deadlines for end-to-end latency analysis using the OSAE2 tool, as also demonstrated for robotics in [21].

Furthermore, AADL allows modeling many additional orthogonal aspects, e.g., the functional behavior inside components using threads, function calls, etc., or details of the execution platform consisting of data buses, CPUs, etc. While this renders AADL very powerful, it is left open how these different concepts addressing different concerns are to be used for system design. As a consequence, the average user might have difficulties to adequately use AADL which threatens its practical usefulness. According to our experience, smaller models that focus on a coherent set of system engineering concerns are of higher practical usefulness since they are far more comprehensive. Ultimately, coherency along with simplicity is key to practically achieve separation of concerns in model-based design, and thus to cope with system complexity.

The only robotics initiative that we are aware of following a similar “freedom from choice” approach is the “oroGen” tool from the Robot Construction Kit (Rock) [7]. In particular, it distinguishes time and data-triggered activation of components. This is a pre-requisite for a precise analysis, but effect chains as such are not provided by oroGen. The other concepts are compatible, however, so they would certainly be a straightforward addition to oroGen’s underlying component model.

Finally, we would like to note that formally specified activation semantics can also be supported in a “freedom of choice” model, of course. Examples include UML’s port behavior state machines, or RTC’s execution semantics [4]. However, our approach differs in that we intentionally limit the modeling choices to a small set of activation semantics sufficient to ease integration and checking.

VII. Conclusions and Future Works

In recent years robotics technologies have become an integral part of everyday life, sometimes embedded in products such as car driving-assistants and sometimes more apparent as smart home-cleaning devices. The public expectations for future robotics technologies are high. Robotics research fosters these expectations by presenting impressive lab prototypes, yet, until now only a few (rather simple) examples have been realized as products. We believe that one of the main reasons is a general lack of appropriate software engineering methods for systematic integration allowing to cope with the vast complexity as is common in autonomous robotic systems.

This paper provides a meta-model which clearly separates different concerns from component developers and system integrators enabling them to collaboratively design and develop component-based robotic software systems. This separation of concerns is achieved: (i) by enabling component developers to focus their engineering efforts on functional concerns, without presuming any system-level application-specific details, and (ii) by enabling system integrators to fully understand and adjust the execution and communication semantics of components on model level according to application-specific requirements, without the need to investigate or adapt internal implementations.

We thereby carefully balanced between the freedom-of-choice and freedom-from-choice [12] philosophies by providing as much design-freedom as possible for the individual developers while restricting their design-choices where needed to ensure interoperability, reusability, and overall system consistency.

To this effect, the presented work provides a contribution for making the step from function-driven system-level coding towards structured, application-specific, and model-driven system integration.

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