Integrating AADL within a multi-domain modeling framework

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Abstract

**DUALLY** is a framework that allows architectural languages interoperability through automated model transformation techniques. Any transformation among ADLs is defined in **DUALLY** by passing through A0 that is an extensible semantic core set of modeling elements. In this paper we describe the integration of AADL and the corresponding OSATE tool-set in **DUALLY**. Once AADL is hooked to A0, it is automatically integrated with the network of languages already integrated in **DUALLY**. In particular, we show how it is possible, in an easy way, to obtain a UML specification and to model check AADL and behavioral annex specifications through LTSA.

1. Introduction

Increasingly, Architecture Description Languages (ADLs) [1] are defined by stakeholder concerns [2]. The large amount of possibly different stakeholder (e.g., a developer, a domain expert, a maintainer) implies a variety of different needs, requirements and domain specific information to be incorporated into an architectural language. Obviously, it is impossible to capture all such domain concerns with a single, narrowly focused notation and building a “universal” notation for modeling software architectures is impractical. This is one of the major causes of the flourishing of different ADLs.

While a unique language for modeling all such concerns is not reasonable, the software architecture community has created a quite clear boundary between those core architectural concepts shared among most software architecture languages, and other modeling elements that are domain- or analysis- specific. This observation is one of the leitmotif of **DUALLY** [3], an automated framework that allows architectural languages and tools interoperability. Given any number of architectural languages and tools, **DUALLY** allows interoperability among them through automated model transformation techniques. Any transformation among ADLs is defined in **DUALLY** by passing through what we refer to as A0, a semantic core of architectural concepts, providing the infrastructure upon which to construct semantic relations among different ADLs. It acts as a bridge among the different architectural languages to be related together. Extensibility mechanisms are provided by **DUALLY** in order to augment A0 with domain specific concerns. For instance, A0 could be extended with performance concerns by obtaining an Aperf0 or it can be extended with real-time concerns by obtaining an AWT. Therefore, A0 is the root of a hierarchy tree that allows **DUALLY** to support the horizontal abstraction [4], i.e., an abstraction that takes place at a same level of definition and emphasizes certain system concerns or complementary viewpoints.

In this paper we analyze the feasibility in integrating AADL [5] and the corresponding OSATE tool-set in **DUALLY** following a multi-domain approach. The integration is performed in a scalable, time-saving and effective way. In fact, the number of transformations is linear and adding AADL means just to relate it to A0 or to one of its extensions (without the need to relate AADL with each ADL previously integrated). This process is time-saving since we need only to relate AADL to A0. This process is effective since the software architect neither needs to be skilled in model transformation techniques nor needs to know all the notations within **DUALLY**. We show how AADL (and its behavioral annex), once integrated in **DUALLY**, can be transformed into both a UML profile for SA modeling [6] and Darwin/FSP [7]. Thanks to the integration with Darwin/FSP we can, in an easy way, model check AADL behavioral specification through the Darwin/FSP LTSA tool [7].

The paper is structured as follows: Section 2 describes how **DUALLY** can be used as a multi-domain modeling framework. Section 3 presents the integration of AADL in **DUALLY** and Section 4 shows how AADL models can be automatically transformed to UML and Darwin/FSP models. In Section 5 we present related work, while Section 6 concludes the paper highlighting future research directions.

2. **DUALLY** as a multi-domain modeling framework

**DUALLY** [3] allows different formal ADLs and/or UML-based languages and tools for software architecture modeling to interoperate. The interoperability is implemented via model transformation and passing through A0, a semantic core of architectural concepts, acting as a central pillar of the
model transformation network. $A_0$ becomes the staging point for the complete and consistent migration for architectural information across any number of description technologies already integrated within DUALLY (in the form of meta-models or profiles), by means of the process we call DUALLYzation. $A_0$ has been defined as general as possible to ensure that DUALLY is able to potentially represent and support any kind of architectural representation (i.e., formal ADLs or UML-based languages). $A_0$ is a MOF compliant meta-model whose main elements are the concept of component, connector, interface, channel, architectural type, property and group. Please refer to [3] for further details about $A_0$ and its meta-model.

![Figure 1. DUALLY conceptual view](Image 406x283 to 510x356)

As shown in Figure 1, the semantic mappings (and the corresponding generated transformation) relates an architectural language representation MM1 (via a meta-model/profile) to the $A_0$ meta-model (as well as M1 to $A_0$). Transformations are defined between a meta-model/profile and the $A_0$ meta-model. Model-to-model transformations are then automatically instantiated by executing a higher-order transformation, thus providing the possibility to automatically reflect modifications made on a model designed with a language to one or even all of the other languages connected with DUALLY. The semantic correctness of the generated transformations can be checked by providing properties that must hold while passing from the source to the target models [3].

$A_0$ has been defined as extensible in order to give the possibility to software architects to customize it for each specific domain. These kinds of extensions are realized by means of the inheritance mechanism. Each element of the $A_0$ meta-model can be extended.

As shown in Figure 2, ADLs can be “hooked” to the DUALLY framework at each level of specialization of $A_0$. We call DUALLYzed an ADL hooked with DUALLY. The level 0 is $A_0$ and a generic ADL, e.g., ADL$_y$ in figure, can be DUALLYzed directly to $A_0$. Figure 2 shows also ADL$_x$ and ADL$_z$ DUALLYzed at level 1 and level 2, respectively. As previously seen, each transformation between two ADLs is performed always through $A_0$ or one of its extensions.

![Figure 2. Hierarchy of domain specific extensions of $A_0$](Image 55x410 to 296x552)

If two ADLs are hooked at the same $A'$, where $A'$ is $A_0$ or an extension of $A_0$, it is clear that the transformation will be defined on elements of $A'$. Whereas, if two ADLs are hooked on two different versions of $A_0$, $A''$ and $A'''$ respectively, the transformation will be based on elements of $A'$ that is the first common “ancestor” of $A''$ and $A'''$. Thus, typically there exists a set of elements that cannot be translated from one ADL to a different one. The dimension of this set depends on the similarity of the pair of ADLs. The existence of these elements is unavoidable. In fact ADLs could be specific of two different domains and could contain domain specific aspects. However, DUALLY provides synchronization mechanisms such that changes made on a specific (generated) model can be propagated back to the others when closing the round-trip journey.

![Figure 3. Hierarchy of domain extensions of $A_0$ instantiated on the illustrative example](Image 316x283 to 510x356)

In the context of what illustrated in Figure 2, this paper describes an attempt to realize an instance of the hierarchy, by considering the DUALLYzation between AADL and its behavioral annex, Darwin/FSP, and the UMLCC profile for software architecture modeling, and by passing through a common extension named $A_{behavior}$ (as shown in Figure 3).

### 3. Integrating AADL in DUALLY

This section presents the mappings between AADL (along with its behavior annex) and the $A_0$ meta-model. A mapping refers to semantic links among meta-models elements, and describes a transformation relationship between (AADL and $A_0$) architectural concepts and vice versa. The mapping is
implemented via a weaving model and its logic will be reflected upon the automatically generated transformations at the modeling level. Due to space limitations, we focus on the most relevant elements of AADL and their counterparts in the $A_0$ meta-model only.

### 3.1. Mapping core AADL concepts.

AADL components can be divided into software, hardware and system architecture. Since the concepts of $A_0$ focus on software architecture and this work is meant to abstract from AADL low-level specificity, we restrict our experimentation only on software and system AADL categories. Nevertheless, we had to pay special attention to the concept of AADL Device; in [8], a device is defined as a generic entity “that interfaces with the external environment of an application system” and that can be considered as both a software and an execution platform component. So, in order to complete our approach and cover all possible software entities of AADL, we consider also the concept of device during the mapping process.

**Software component implementations.** Each software component meta-class (namely AADL ProcessImpl, ThreadImpl, ThreadGroupImpl and DataImpl) is mapped to the generic $A_0$ SComponent. The promotion of these kinds of components to a generic entity is one of the means by which we manage to abstract from AADL specificity. However, this may cause a round-trip problem, i.e., while transforming an $A_0$ model into an AADL one, an SComponent can be transformed either into a process, a thread or some other AADL component; this problem could be avoided by extending the generated transformations so that model synchronization is performed during the round-trip, instead of creating a new AADL model. We are currently investigating this and other similar issues. Also ThreadGroup is mapped to an SComponent because in AADL it natively serves to logically collect threads into a single, coarse-grained entity. Both a ThreadGroup and its internal threads are thus grouped into a single $A_0$ component.

**Software component types.** AADL software component types are mapped to SAtype in $A_0$, along with the related properties and features (whose mappings will be explained later in this section). Thus, AADL ProcessType, ThreadType, ThreadGroupType and DataType are mapped to $A_0$ SAtype. In case the source AADL concept can contain nested AADL entities, the target $A_0$ element is SAnestedType. The only difference between an SAtype and an SAnestedType is that is it allowed to define a subarchitecture within the latter one. Component types can be hierarchically structured in AADL through the “extend” structural reference.

**System.** In the specification of AADL, a system component is defined as an assembly of software and execution platform components. From an abstract point of view, it can be considered as a generic, coarse-grained component. Consequently, we mapped SystemImpl and SystemType to $A_0$’s SSystem and SStructuredType, respectively.

**Device.** An AADL device can be considered as a low-level software component executing on a processor that accesses the physical device. A device represents also the software that access and manage the underlying physical device. In the mapping process we linked AADL DeviceImpl and DeviceType meta-classes to $A_0$’s SComponent and SAtype.

**Features.** An AADL feature (i.e., Port, PortGroup, Parameter, Subprogram and ComponentAccess) is part of a component type and represents its point of interaction with other components of the system. Based on this definition of AADL features, we mapped them to $A_0$ SInterface. Moreover, ports and port groups directions are linked to the “direction” attribute of the target $A_0$ SInterface, while other auxiliary attributes (like properties) are related to the corresponding $A_0$ properties. The “direction” attribute of an AADL ComponentAccess can be either provided or required. In the former case the direction of the corresponding SInterface is out, while in the latter one is in.

**Connections.** AADL port connections are mapped to SChannel in $A_0$ if the connected elements are not contained within each other. Another mapping links AADL port connection and SAbinding. It is guarded with an OCL condition that is evaluated true if one of the connected elements is nested within the other one. So, similarly to the mapping between component implementations, this mapping links many different kinds of connections (e.g., DataConnection, EventConnection,EventDataConnection) into a single, generic $A_0$ entity reaching a higher level of abstraction. If the source AADL port connection is a DataConnection, then its “connectionTiming” attribute is mapped into an $A_0$ Property initialized with the corresponding value (i.e., delayed or immediate). ParameterConnection, DataAccessConnection and SubprogramCall are linked to either SChannel or SAbinding in the same manner of port connections.

**Properties.** AADL Property is mapped to $A_0$ Property, the corresponding “value” feature is also linked to the PropertyValue meta-class in the $A_0$ meta-model. The types of AADL properties are also mapped to either an $A_0$ primitive type or a predefined $A_0$ SAtype, accordingly to the type of the source AADL property. Bridging the concept of property set to $A_0$ consisted in linking the PropertySet meta-class of AADL to $A_0$ Group and setting the “members” reference of the latter to the property declarations contained by the AADL property set.

**Package.** An AADL Package is defined as a construct to organize collections of component declarations into separate units. In the $A_0$ meta-model the concept of Group is semantically close to that of AADL package, so we mapped it (either it is public or private) to $A_0$ Group. This mapping helps producing $A_0$ models with different namespaces and designed in a modular way.
Modes. Modes and mode transitions are managed as well and, since their concepts intersect with that of behavior, their mapping is described in the following section.

3.2. Mapping behavioral concepts

The AADL behavioral annex is composed of three main sections: states, composite states and transitions declaration. The AADL behavioral annex contains also sections to declare state variables, their initialization and auxiliary connections to component ports. They are not part of this presentation because their semantics is not represented in $A_0$. Therefore, such elements are not mapped to any member of the $A_0$ meta-model.

The AADL BehaviorAnnex meta-class is mapped to a StateDiagram in $A_0$ and the contained references to states and transitions are mapped to the ownedState and owned-Transitions references, respectively.

AADL State and CompositeState are both mapped to $A_0$ State. In case the source AADL element is a composite state, there is also a link to an inner $A_0$ StateDiagram and the references to its contained elements is mapped as well. However the concept of history in a composite state is ignored because there is no semantic counterpart in $A_0$. An AADL state corresponds by default to a State in $A_0$. However, if the type of the AADL state is initial, then the mapping refers to InitialState in $A_0$, and if it is complete or return, the mapping refers to FinalState.

Transition in AADL corresponds to $A_0$ Transition and the condition of the guard is mapped to the “guard” attribute in $A_0$. The label attribute in the $A_0$ transition corresponds to the action of the AADL transition and both source and destination state attributes are mapped to the corresponding source and target attributes of $A_0$’s state. This will help in preserving the topology of the AADL behavioral specification into $A_0$ state diagrams. Real-time aspects like delays, computations or timeouts are not considered during the mapping process so that they will be abstracted out while passing to $A_0$ models.

Since AADL modes are considered states in the behavioral annex, then the Mode meta-class is also mapped to State $A_0$. Similarly, the ModeTransition meta-class is mapped to $A_0$ Transition.

It is important to note that elements that cannot be mapped are stored by the DUALLY framework so that these parts of the model can be retrieved when coming back to the source notation in a round-trip scenario. In fact, it is unacceptable to use a transformation technique supporting the horizontal abstraction [4] that loses the parts of the model that cannot be translated from one ADL to another.

3.3. Model transformations generation

Once the semantic links between AADL and $A_0$ metamodels have been designed and implemented via a weaving model, model-to-model transformations can be automatically generated. We generate two transformations from the weaving model: (i) $Addl2A_{0}$ and (ii) $A_{0}2Addl$. The former takes as input an AADL model and produces an $A_0$ one, while the latter performs the opposite task. In the following we will focus on the generation (and subsequent execution, see Section 4) of $Addl2A_{0}$ only, presenting how DUALLY can be exploited to either raise AADL’s level of abstraction (via UML) or formally verify it (via Darwin/FSP). The logic of the $Addl2A_{0}$ reflects that of the the weaving models.

However, there are some concepts peculiar of the AADL language whose mapping has to be handled by advanced constructs in the $Addl2A_{0}$ model transformation; thus we need to manually refine $Addl2A_{0}$ in order to correctly preserve their semantics also in $A_0$. Each peculiar AADL concept and a high-level description of how we handle it in the model transformation are described below:

Inheritance between implementations: AADL allows the definition of hierarchies also at the implementation level. In this case all the features, properties and flows of a super-component are also implicitly defined in its sub-components. This creates a semantic mismatch between AADL and $A_0$ because in $A_0$ only hierarchy among type elements (e.g., SArype) are allowed. To overcome this issue, we instructed the $Addl2A_{0}$ transformation in order to “simulate” AADL implementations hierarchy so that if an AADL implementation component $C_1$ extends another component $C_2$, then in $A_0$ all the features and properties of $C_2$ are replicated into the component $C_1$. The various connections to and from $C_2$ are replicated as well into $C_1$.

Behavior communication actions: one of the aim of our work is to verify AADL models via LTSA. In FSP two transitions synchronize if they have exactly the same action name (e.g., $p$). Whereas, in AADL, transitions synchronize if they are coupled by the $p!$ (sender) and $p?$ (receiver) notation. The $Addl2A_{0}$ model transformation is modified so that for each couple of actions, the corresponding action names are stripped to $p$.

4. Illustrative Example

To illustrate the execution of the DUALLY transformations we decided to consider a Flight Control System (FCS, taken from [9]) and to model its behavior through the OSATE AADL editor. This model mainly focuses on the autopilot and status display system. From a high-level perspective, it is composed of a LAN network connecting two main subsystems: a NAP_system that comprises a network of sensors and actuators managed by a navigation controller and an HCI_system that represents the Human Control Interface (HCI) that manages the moving map display and takes input from the pilot for autopilot parameters. Due to space limitation, we present the HCI_system only; its internal structure is represented in Figure 4.
The HCI_System has a standard computing architecture: there are a processor and a memory component bound by a bus and devices connected to the processor via a dedicated bus. Display shows the moving map, and the status of the aircraft, while Pilot_Console is used to set the autopilot configuration and turn on/off the autopilot system through a toggle switch. The software part of the system is composed of a main process (P_HCI) containing two concurrent threads:

1) T_Screen_Disp: periodically updates the display device with the current position of the aircraft; it is also triggered if the pilot either inputs configuration data or switches on/off the system;

2) T_Pilot_Input: a background thread that waits for the pilot to input a new configuration or hits the toggle switch and transmit this information to T_Screen_Disp and to the NAP_system. If the system is off, the configuration is sent also to T_Screen_Disp only. A sketch of its internal behavior is shown in the following listing.

```
thread implementation T_Pilot_Input.PowerPC_G4
properties
  Dispatch_Protocol => Background;
annex behavior_specification {**
    state variables
    aux : Nav_Types::Position.GPS;
    states
    s_Off : initial complete state;
    s_On : complete state;
    s1, s2, s3, s4, s5 : state;
    transitions
    s_Off [AP_Position_In?]-> s2;
    s2 [->] s_Off [AP_Position_Out_Disp!];
    s_Off [AP_Toggle_In?]-> s1;
    s1 [->] s_On [AP_Toggle_Out!];
    s_On [AP_Toggle_In?]-> s3;
    s3 [->] s_Off [AP_Toggle_Out!];
    s_On [AP_Position_In?(aux)-> s4;
    s4 [->] s5 [AP_Position_Out_Disp!(aux)];
    s5 [->] s_On [AP_Position_Out_Nav!(aux)];
**};
...}
end Pilot_Input_Thread.PowerPC_G4;
```

Listing 1. Behavior of T_Pilot_Input

The whole HCI_System is composed of 10 hardware/software components, 21 ports (event, data and event/data), 19 connections (port connections and bindings). The behavioral descriptions comprise 14 states and 16 transitions.

Applying the 

transformation introduced in Section 3.3 we obtain the 

representation of the HCI_System containing 6 SComponents (hardware ones have been abstracted), 21 SInterfaces and 14 connections. The behavioral part contains the same number of elements as the AADL one.

From now on, we can exploit the transformations generated from past 

zations in order to obtain models conforming to other notations. Our intention is to produce both a UML model and a Darwin/FSP specification of the HCI_System (as pointed out before, UMLCC and Darwin/FSP are already integrated in 

). In the case of UMLCC, we execute the corresponding 

transformation to produce its Darwin/FSP counterpart. The output specification is composed of two sub-models: the first one conforms to Darwin and describes the static configuration of the software components, it is conceptually similar to the UMLCC diagram in Figure 5; the second one is an FSP model and can be imported into the corresponding LTSA tool. Figure 6 graphically represents the behavior of T_Pilot_Input.

```
Figure 4. AADL model of the HCI system.
```

```
Figure 5. UML model of the HCI_System.
```

```
Figure 6. FSP specification of T_Pilot_Input.
```

One of the key features of LTSA is that it allows to compose the various behavioral description in order to analyze the system as a whole. So, the HCI_System resulted in a
main labeled transition system composed of 126 states and 459 transitions. In addition, transforming an the HCI_System model from AADL to FSP allowed us to check if the composed behaviors are in a deadlock. The result is negative, i.e. there are no deadlocks in the initial AADL specification. Moreover, customized properties may be checked on the produced FSP specification, like reachability analysis. LTSA provides also a facility to simulate the system, this helps to get an interactive idea on its functioning.

5. Related Work

Related work mainly regards automatic derivation of model transformations and semantic integration. The authors of [10] present ModelCVS, in which semantic links are defined between ontologies, that will serve as a basis for the generation of model transformations. Dually differs since it implies the A0-centered star topology and the preliminary step of meta-model lifting is not performed.

The role of Dually’s A0 is similar to the Klaper language in the field of performability. Grassi et al. in [11] propose the Klaper modeling language as a pivot meta-model within a star topology. However in the Klaper-based methodology model transformations are not “horizontal” and model transformations are not derived from semantic bindings: they must be manually developed.

In the field of software architectures, the ACME initiative [12] is famed for being one of the very first technologies to tackle the interoperability problem. Differently from Dually, it is neither MOF compliant nor automatized. Further on, a programming effort (rather than graphically designed semantic links) is needed every time a notation must be related to the ACME language.

Finally, the Eclipse project named Model Driven Development integration (MDDi0) presents an interesting approach based on the concepts of model bus and semantic bindings, but it is still in a draft proposal state.

6. Conclusions and further work

This paper presented as Dually can be considered a multi-domain modeling framework. This is possible thanks to extension mechanisms of Dually that allows us to extend it with domain specific concerns. The paper presents also the Duallyzation of AADL and then the enabled transformations among AADL, UML, and Darwin/FSP.

As future work we plan to better investigate the use of Dually as a multi-domain modeling framework. In fact, one limitation of the current Dually implementation is that the only relation among different Dually extensions is the inheritance and that the allowed inheritance is only the “single inheritance”. In order to deal with this limitation we are following three different ways: (i) allowing the “multi inheritance” (i.e., to build a Dually extension by extending two or more different extensions of A0), (ii) investigating the definition of model transformations also among Dually extensions and (iii) investigating on merging techniques to build a new Dually extension from already existing Dually extensions.

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References


