Journal of Science and Technology ***49***, *Number 5 (2011) 105-118*

A FORMAL ANALYSIS FRAMEWORK FOR AADL

Stefan Björnander[1], Cristina Seceleanu[2], Kristina Lundqvist[2], Paul Pettersson[2]

[1]*CrossControl AB Kopparlundsvagen 14, 721 30 Vasteras, Sweden*

[2]*School of Innovation, Design, and Engineering Malardalen University, Box 883, 721 23 Vasteras, Sweden*

Received September 30, 2011

ABSTRACT

As system failure of mission-critical embedded systems may result in serious consequences, the development process should include verification techniques already at the architectural design stage, in order to provide evidence that the architecture fulfils its requirements. The Architecture Analysis and Design Language (AADL) is a language designed for modeling embedded systems, and its Behavior Annex defines the behavior of the system. However, even though it is an internationally used industry standard, AADL still lacks a formal semantics and is not executable, which limits the possibility to perform formal verification. In this paper, we introduce a formal analysis framework for a subset of AADL and its Behavior Annex, which includes the following: a denota- tional semantics, its implementation in Standard ML, and a graphical Eclipse-based tool encapsulating the implementation. We also show how to perform model checking of AADL properties defined in the Computation Tree Logic (CTL).

1. INTRODUCTION

Mission-critical embedded systems play a vital role in many applications, like air traffic control and aerospace applications. As system failures may result in serious consequences, the development process should include verification techniques, in order to provide evidence that the system's architecture fulfills its requirements. The architectural design phase is of high practical interest, since architectural mistakes that cause a system to fail certain requirements are hard and expensive to correct in later development phases.

The Architecture Analysis and Design Language (AADL) [1] is a standard of the Society of Automotive Engineers (SAE[1]), and is based on MetaH [2] and UML [1]. AADL is designed for modeling both the hardware and the software of embedded systems. The standard includes several annexes, out of which the Behavior Annex [3] provides means of describing the behavior of the model.

[1]SEA is presented at http://www.sae.org.

Even if appealing and already adopted by industry, AADL still lacks a formal semantics, which is particularly important for the design of mission-critical embedded systems, since failures may cause serious damage to people or valuable assets. Such systems are often required to pass certification processes in order to provide sufficient evidence about their safety. Moreover, AADL models are not executable, which limits the possibility to formally analyze their safety and liveness properties.

Consequently, it is highly desirable to overcome such limitations of AADL. To do so, one has to define AADL formally, as any attempt to achieve formal verification requires a precise mathematical method. It is also beneficial that the analysis techniques based on the semantics are supported by tools that are integrated into an AADL tool chain; this would make it easier for an user with limited knowledge of the underlying formalism, to perform, e.g., model checking of AADL models.

In this paper, we introduce a formalization of the meanings of a subset of AADL and its Behavior Annex in denotational style. Our choice of a denotational style for AADL structures is justified by the simplicity of the semantics models, which is known to improve generality and ease of reasoning [4].

To complete our analysis framework, we also describe the Standard ML implementation that forms the basis of our AADL verification tool, called the ABV tool. See Björnander et al. [5] for a description. The semantics as well as its implementation and CTL verification are illustrated through a small example.

The results of this contribution together with the recently developed verification tool ABV define our AADL formal analysis framework that contains the following:

- A denotational semantics defining a subset of AADL and its Behavior Annex that also include model checking of properties defined in CTL. See Björnander et al. [9] for a complete specification of the semantics.
- The semantics implemented in Standard ML, and a parser translating a model defined in AADL and its Behavior Annex as well as a subset of CTL property specification into a format in Standard ML suitable as input.
- The ABV model checker that encapsulates the semantic implementation and the parser in a graphical user interface based on the Eclipse Framework. With the help of the tool, the user is able to verify a subset of CTL properties of the model without knowledge of the underlying formalism.

The rest of this paper is organized as follows: Section 2 is preliminaries; describing, among other things, the syntax of a subset of AADL and its Behavior Annex. Section 3 defines the information gathering part of the denotational semantics. In Section 4, verification by model checking techniques is described. Finally, Section 5 discusses related work before concluding the paper in Section 6 with conclusions and further work.

Listing 1. The AADL syntactic rules.

\+ one or ore, * zero or more, ? zero or more

Model ::= Sysem+ SystemImpl

System ::= **system** *Identifier Features? Annex?* **end ;**

Features ::= **features** *Feature+*

Feature ::= Identifier **: in event port;**

| *Identifier* **: out event port;**

SystemImpl ::= **system implementation** *Identifier .*
Identifier Subcomponents? Connections
end ;

Subcomponents ::= **subcomponents** *Subcomponent+*

Subcomponent ::= Identifer **: system** *Identifier* ***;***

Connections ::= **connections** *Connection*

Connection ::= **event port** *Identifier . Identifier* **->**
Identifier . Identifier **;**

2. PRELIMINARIES

In AADL, there are two kinds of systems: the *system* that defines the port interface and an optional behavior annex, and the *system implementation* that defines the subcomponents and the port connections between them. In this paper, we have chosen a subset of the AADL model that includes at least one system and exactly one system implementation, which occurs at the end of the definition. The subcomponents of the system implementation are instances of earlier defined systems (equivalent to objects and classes in object-oriented languages) and the connections are made between input and output ports of the subcomponents, not the systems. The syntax of our AADL subset is given in Listing 1.

In order to increase the expressiveness of AADL, it is possible to add *annexes*. One of them is the Behavior Annex [6, 7] that models an abstract state machine [8]. Each component of the model describes its logic by defining a behavior state machine, which consists of the parts *State Variables, Initializations, States,* and *Transitions.* The corresponding syntax is given in Listing 2.

CTL is a branching-time temporal logic, that is, it models time as a tree structure with a non-determined future. There are several different paths; any one of them may be realized. There are several quantifiers and operators available in CTL; among them, the universal, *all*, and existential, *exists*, quantifiers over paths together with the *global* and *eventually* path-specific operators.

In an AADL model, identifiers are bound to values that need to be stored for further use. Therefore, we need to utilize the data types *list*, *table*, *set*, and *tree* to holds the values. See Björnander et al. [9] for their complete semantic definitions.

Listing 2. The *Behavior Annex* syntactic rules.

```
Annex ::= annex Identifier {** StateVariables?
          Initializations? States? Transitions? **} ;
StateVariables ::= state variables StateVariable+
StateVariable ::= Identifier : integer ;
StateVariable ::= states State+
State ::= Identifier : initial state ;
        | Identifier : state;
Initializations ::= initializations Action+
Transitions ::= transitions Transition+
Transition ::= Identifier - [ Expression ] -> Identifier ;
             | Identifier - [Expression ] -> Identifier
             { Action+ }
Action ::= Identifier := Expression ;
        | Identifier !;
Expression ::= Identifier
             | Expression ArithmeticOperation Expression
ArithmeticOperation ::= + | - | * | / |
```

3. THE SEMANTICS OF AADL STRUCTURAL ELEMENTS

In this section, we define the semantics of the subset of AADL and its Behavior Annex described in Section 2. We formalize the meaning of the latter by constructing mathematical objects, called *denotations* (see functions in Listing 4 and 5). The denotational semantics consists of the mathematical models of meanings *(model* [[*S SI*]] in Listing 4 and *system* [[S_1 S_2]] and *system*[[**system** *I SB* **end** ;]] in Listing 5) and the corresponding semantics functions, respectively *(model* : Model → Table in Listing 4 and *system* : System → Table in Listing 5).

In the approach we have chosen, the semantics can be divided into three phases: information gathering, state space generation, and state space tree evaluation. This section describes the information gathering phase briefly, since it is a rather straightforward process. The other phases are described in more detail in Section 4.

Formally, an AADL system is a tuple $\langle S, s_0, I, Var, P_{in}, P_{out}, T\rangle$ where S is a non-empty finite set of states and $s_0 \in S$ is a compulsory initial state. *Var* is a possible empty finite set of state variables. P_{in} and P_{out} are the possible empty finite sets of input and output ports, respectively. $I \subseteq (Var \times Expr) \cup P_{out}$ is a possible empty set of initializations. $T \subseteq (S \times Expr \times S \times A) \cup P_{out}$ is a possible empty set of transitions, where $A \subseteq (Var \times Expr) \cup P_{out}$ is a possible empty action set and *Expr* is made up by a state variable, a constant value or an arithmetic expression. The input port expression is of Boolean type.

The values of a system are formally defined in Listing 3. As there can only be one system implementation, its subcomponents are stored in the subcomponent list.

Listing 3. The Values of a System

Connection	=	Integer × Identifier × Integer × Identifier
Expression	=	*value* Value + *identifer* Identifier + *eq* (Expression × Expression) + *add* (Expression × Expression) +
Action	=	*assign* (Identifier × Expression) + *send* Identifier
Transition	=	Identifier × Expression × Identifier × List
System	=	Integer × Table × List × List
Value	=	*state* Integer + *boolean* Boolean + *integer* Integer + *action* Action + *transition* Transition + *system* System

In an AADL model, identifiers are bound to values that need to be stored for further use. In order to store these values, several tables and lists are needed:

- The system table holds the systems of the model. The information of each system is stored in the tuple *(state, symbol-table, initJist,transdist),* where *state* is the current state of the annex (initialized to zero, representing the initial state), *symbol-table* holds the input and output ports of the system as well as states and state variables of the annex, *init-list* holds the list of initializations, and *transdist* holds the list of transitions. For each system, its tuple is associated with the name of the system in the system table.
- The subcomponent table and subcomponent list hold the subcomponents of the system implementation. They hold the same subcomponents, the table is used to look up states and states variable in the CTL property specification (see Section 2) and the list is used to keep track of connections between the subcomponents.
- The connection list holds the connections between the subcomponents. In order to identify the sending and receiving subcomponents, it uses the index in the subcomponent list above.
- The local system table. Each system has a symbol table, holding the input and output ports as well as the states and state variables of the behavior annex. Each system also holds a local initialization list and transition Listing This information is originally stored for each system and copied to the subcomponents instantiating the systems.

For each syntactic rule in Section 2, one corresponding semantic rule is defined. The semantic rules of this section work in a way similar to a traditional compiler; they gather information that is stored in the structures listed above. Due to limitation of space, we confine our self to showing the *model* (Listing 4) and *system* (Listing 5) rules in this paper. See Björnander et al. [9] for the complete definitions of the rules.

Listing 4. The *model* semantic function

model : Model → Table

model $[\![S \quad SI]\!]$ =

let system_table = system S **in**

system_impl SI system_table

Listing 5. The *system* semantic function

system : System → Table

system $[\![S_1 \quad S_2]\!]$ =

let *system_table*$_1$ = *system S*$_1$ **in**

let *system_table*$_2$ = *system S*$_2$ **in**

table_merge system_table$_1$ *system_table*$_2$

system $[\![\text{system I SB end ;}]\!]$ =

table_set I (system_body SB) table_empty

All observably distinct elements have distinct denotations in form of semantic functions, which ensures the soundness of the set of semantic rules. The semantic functions are structure-preserving functions, in such that each morphism of the semantic model is a denotation of an architectural element, which ensures the completeness of the same rule set.

4. VERIFICATION BY MODEL CHECKING

In this section, we describe the verification of CTL properties of AADL models. The main difference between this section and Section 3 is that in Section 3 semantic rules were used to gather information about the model, while we, in this section, utilize that information to perform model checking.

The main idea is to generate a state space tree (a state space is the sum of the states of all the annexes of the system; technically: a subcomponent list) that becomes traversed with regard to the CTL property specification.

4.1. Generation

In this section, we generate the state space tree that is initially made up of one single node holding the initial state space; that is, the subcomponent list in its initial state. Then *traverse-subcomponent-list* (Listing 7) traverses the subcomponents and for each subcomponent *traverse_transition_list* (Listing 8) traverses the transitions. For each transition that can be taken, *execute_transition* (Listing 9) updates the state space so that the transition is taken and creates a new sub tree with the new state space as root value. Then it attaches the sub tree as a child tree to the main tree. Finally, it calls *generate^tree* (Listing 6) which recursively continues to create sub trees until no more transitions can be taken. However, in order to prevent infinite tree generation the generation becomes aborted if a previous state space reoccurs

Listing 6. The *generate_tree* semantic function

```
generate_tree : List × List × Set × Tree → Tree
generate_tree subcomp_list conn_list set1 main_tree =
    if not (set.exists subcomp_list set1) then
      let set2=set_add subcomp_list set1 in
      let sub_tree1 = tree_create subcomp_list in
      let subcomp_list2 = traverse_connection_list
        conn_list subcomp_list in
      let sub_tree2 = traverse_subcomponent_list
        subcomp_list2 conn_list set2 sub_tree1 in
        tree_add_child sub_tree2 main_tree
     else main_tree
```

Listing 7. The *traverse_subcomponent_list* semantic function

```
traverse_subcomponent_list : Integer × List ×
                                  List × Set × Tree → Tree
traverse_subcomponent_list ints_index subcomp_list
                                 conn_list set tree1 =
    if inst_index < (list.size subcomp.list) then
       let system (state, symbol_table, init_list,
            trans_list) = list_get inst_index subcomp_list in
       let tree2 = traverse_transition_list trans_list
                inst_index subcomp_list conn_list set tree1
       in traverse_subcomponent_list (inst_index + 1)
            subcomp_list conn_list set tree2
      else tree1
```

4.2 Evaluation

When the state space tree of section 4.1 has become generated, it becomes evaluated against the CTL property specification. The *evaluate_children* (Listing 10) and *evaluate_tree* (Listing 11) semantic functions call each other alternately. Initially, *evaluate_tree* is called with the root node; it calls *evaluate_children* for its children, which in turn calls *evaluate^tree* for each of the children. These alternately calls continue until the property specification has been satisfied or a leaf in the tree has been reached.

The evaluate_tree traverses the children of the root node of a tree. If there are no children, we have reached a leaf of the tree. Different values are returned depending of the *depth* operator.

In case of the global operator, the property has to hold for each node on the path from the root node to the leaf. Therefore, the and operator is applied to the node property values, and true is returned at the end of the path. In case of the eventually operator, it is enough that one property holds for the path from the root node to the leaf node. Therefore, the or operator is applied to the node property values and false is returned at the end of the path.

Listing 8. The *traverse_transition_list* semantic function

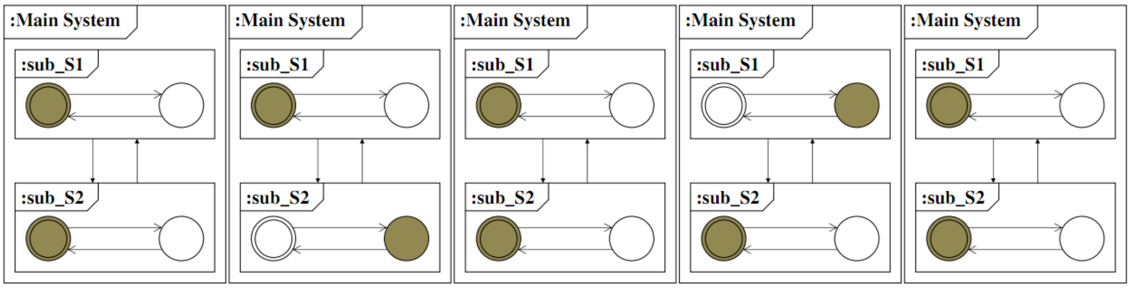
```
traverse_transition_list :  List × Integer × List × List ×
                                Set × Tree → Tree
traverse_transition_list trans_list ints_index subcomp_list
                                conn_list set tree1 =
    if  (list.size trans_list) > 0  then
        let (head, tail) = list_split trans_list in
        let tree2 = execute_transition head inst_index
                    subcomp_list conn_list set tree1 in
                    traverse_transition_list tail inst_index
                          subcomp_list conn_list set tree2
        else tree1
```

If the root node of the tree has one child, we simple evaluate it by calling evaluate_tree. However, if it has more than one child, we need to examine the quantifier. In case of the all quantifier, the property has to hold for all child nodes, why we apply the and operator between the property value of the first child node and the evaluation of the rest of the children. In case of the exists quantifier, the property has to hold for only one of the children, why we instead apply the or operator.

The *evaluate_tree* semantic rule evaluates the property of the root node of the tree and compares it with the children. In case of the *global* operator, the property has to hold for the root node and all the nodes on the path to the leaf nodes. In case of the *eventually* operator, it is enough if the property holds for one of them.

The *evaluate_node* semantics rule calls *evaluate_node*, which is relative simple and therefore has been omitted due to space limitations.

Example 1. Let us investigate the AADL model of Listing 12 and 13 (originally introduced in [5]). There are two subcomponents: *subsystem1* and *subsystem2*. For each subcomponent, *traverse_transition_list* traverses the transactions and, for each transition that is ready to be taken, calls *execute_transition*. Finally, *execute_transition* calls *generate-tree* recursively with the new child node as parameter in order to attach child nodes recursively. That is, each taken transitions represent a new state space that is dealt with by *generate-tree* as it was the initial state space. This call chain continues until no more transitions are ready to be taken or until a previous state space reoccurs (Fig. 1) for an illustration of the process.



(a) Initial State (b) State 2 (c) State 3 (d) State 4 (e) Final State

Figure 1. The Main System States

5. RELATED WORK

The approach we feel is closest to ours is Olveczky et al. [10]. The authors have defined a translational semantics from AADL into their object-oriented language Maude, which includes components, port connections, and the Behavior Annex.

Listing 9. The *execute_transition* semantic function

```
execute_transition :  Value × Integer × List × List ×
                                  Set × Tree → Tree
execute_transition trans_value ints_index subcomp_list1
                                  conn_list set main_tree =
   let  transition (source_state, guard_expr,
          target_state, action_list)=trans_value in
   let record1 = table_get inst_index subcomp_list in
   let system (state, symbol_table1, init_list,
                                      trans_list) = record1 in
   let (boolean is_guard, symbol_table2) =
                              evaluate guard_expr symbol_table1 in
      if (state = sourceState) and is_guard then
          let symbol_table3 = traverse_action_list
             init_list symbol_table2 in
          let record2 = system (target_table,
               symbol_table3, init_list, trans_list)
          let subcomp_list2 = list_set inst_index
               record2 subcomp_list1 in
               generate_tree subcomp_list2 conn_list
                           set main-tree
      else main-tree
```

The AADL components and their subcomponent instances are translated into Maude classes and objects. Maude is capable of simulations and model checking of Linear Temporal Logic (LTL) [11] on embedded systems. However, they have chosen an AADL subset that differs from the subset of this paper.

An approach that is also close to ours is the formal semantics defined by Boz-zano et al. [12]. It is centered on the concept of components. For each component, its type, interface, and implementation are given. The component interaction is described by a finite state automaton [8]. Their work includes model checking. However, it is centered around detection of errors, as opposed to the semantics of this paper that focuses on system behavior.

Another interesting approach is Yang et al. [13]. The authors introduce a formal semantics for the AADL Behavior Annex using Timed Abstract State Machine (TASM) [14]. They give the semantics of the AADL default execution model and formally define some aspects of the Behavior Annex. In their translation, each behavior annex is mapped into a TASM main machine. However, even though TASM is a user-friendly and powerful simulation tool, it does not support model checking. Instead, they propose further mapping of the TASM state machine into UPPAAL [15].

We finally mention Abdoul et al. [16] that presents an AADL model transformation providing a formal model for model checking activities and covers the three aspects structure, behavior description, and execution semantics. The authors extend the AADL meta model in order to improve the system behavior and they define a translation semantics into the IF language [17], which is a language for simulation of systems and processes. However, the system behavior is not defined in the Behavior Annex, but rather in the IF internal format.

Listing 10. The *evaluate_children* semantic function

```
evaluate_children :  TreeProp × List × WidthOp ×
                     DepthOp → Boolean
evaluate_childre TP child_list quantifier operator =
    case (list_size  child_list) of
        0 => case operator of
                global => true
                | eventually => false
        | 1 => evaluate_tree TP (list.get 0 child.list)
                         quantifier operator
        | default => let (head, tail) = list.split
                            child.list in
        case quantifier of
             all => (evaluate_tree TP head
                  quantifier operator) and
                  (evaluate_children TP tail
                  quantifier operator)
            | exist => (evaluate_tree TP head
```

```
                  quantifier operator) or
                  (evaluate_children TP tail
                  quantifier operator)
```

Listing 11. The *evaluate_tree* semantic function

```
evaluate_tree :  TreeProp × Tree × WidthOp ×
                 DepthOp → Boolean
evaluate_tree PS tree quantifier operator =
    case operator  of
        global => let (single subProp) = PS in
            (is_true (evaluate_prop_spec subProp tree))
           and (evaluate_children PS
           (tree_get_children tree) quantifier operator)
        | eventually => let (single subProp) = PS in
            (is_true (evaluate_prop_spec subProp tree))
            or (evaluate_children PS
           (tree_get_children tree) quantifer opertor)
```

Listing 12. The main System.

```
system implementation MainSystem.impl
      subcomponents
            subsystem1: system Subsystem1;
            subsystem2: system Subsystem2;
      connections
            event   port     subsystem1.CriticalLeave →
                             subsystem2.CriticalEnter;
            event   port     subsystem2.CriticalLeave →
                             subsystem1.CriticalEnter;
end MainSystem.impl;
```

Listing 13. The Subsystem.

```
system Subsystem1
      features
            CriticalEnter: in event port ;
            CriticalLeave: out event port ;
      annex SubsystemAnnex1
```

```
        {**
                initializations
                        CriticalLeave ! ;
                states
                        Waiting : initial state ;
                        Critical: state ;
                transitions
                        Waiting – [CriticalEnter?] → Critical;
                        Critical – [true] → Waiting
                                        {CriticalLeave !;}
        **};
end Subsystem1;
```

Listing 13. The Subsystem.

```
system Subsystem1
        features
                CriticalEnter: in event port ;
                CriticalLeave: out event port ;
        annex SubsystemAnnex1
        {**
                initializations
                        CriticalLeave ! ;
                states
                        Waiting : initial state ;
                        Critical: state ;
                transitions
                        Waiting – [CriticalEnter?] → Critical;
                        Critical – [true] → Waiting
                                        {CriticalLeave !;}
        **};
end Subsystem1;
```

6. CONCLUSION AND FURTHER WORK

In this paper, we have presented a formal analysis framework including a de- notational semantics for a subset of AADL and its Behavior Annex [9], and an implementation of the semantics in Standard ML. The framework is completed by our recently developed graphical Eclipse-based tool [5] that performs model checking of CTL properties, in a user-friendly way.

We have given precise meaning in denotational style for a subset of AADL and its Behavior Annex, with a straightforward implementation in Standard ML. This contribution provides an expressive enough formal framework for the formalization of the AADL constructs that we have looked at. An advantage of our approach is the fact that the implementation in Standard ML maps the elements of the semantic model straightforwardly.

There are several ways to continue the work of this paper. One obvious approach is to optimize the algorithms behind the semantics when it comes to state space generation and property specification evaluation. It is possible to evaluate the state space “on the fly”; that is, the evaluation taking place during the state space generation. A technique that has proven efficient in other model- checking tools, including SPIN and UPPAAL.

Another interesting extension of the semantics is to add time annotation to the transitions in order to perform real-time model checking.

Acknowledgment. This research work was partially supported by swedish research council (vr), and the swedish foundation for strategic research via the strategic research center progress.

REFERENCES

1. P. H. Feiler, D. P. Gluch, and J. J. Hudak - The Architecture Analysis and Design Language (AADL): An Introduction, Society of Automotive Engineers, Tech. Rep. CMU/SEI-2006-TN-011, 2006.
2. S. Vestal and J. Krueger - Technical and Historical Overview of MetaH, Honeywell Technology Center, Tech. Rep. MN 55418-1006, 2000.
3. The SAE Technical Standards Board - The annex behavior specification, SAE International, Tech. Rep. AS5506, 2007.
4. C. Elliott - Denotational design with type class morphisms (extended version), LambdaPix, Tech. Rep. 2009-01, March 2009. [Online]. Available: http://conal.net/papers/type-class-morphisms
5. S. Björnander, C. Seceleanu, K. Lundqvist, and P. Pettersson, “ABV - A Verifier for the Architecture Analysis and Description Language (AADL),” in *ICECCS ’11: Proceedings of the Sixth IEEE International workshop on UML and AADL*, 2011.
6. R. B. Franca, J. P. Bodeveix, M. Filali, J. F. Rolland, D. Chemouil, and D. Thomas - The AADL behaviour annex - experiments and roadmap, In: *ICECCS*. IEEE Computer Society, 2007, pp. 377-382.
7. P. Feiler and B. Lewis - SAE Architecture Analysis and Design Language (AADL) Annex Volume 1, Society of Automobile Engineers, Tech. Rep. AS5506/1, 2006.
8. E. Borger and R. Stark - Abstract State Machines - A Method for High-level System Design and Analysis, Springer-Verlag Berlin And Heidelberg Gmbh and Co. Kg, 2003.

9. S. Björnander, C. Seceleanu, K. Lundqvist, and P. Pettersson - The architecture analysis and design language and the behavior annex: A denotational semantics, Malardalen University, Technical Report ISSN 1404-3041 ISRN MDH- MRTC-251/2011-1-SE, January 2011.
10. P. C. Olveczky, A. Boronat, and J. Meseguer - Formal Semantics and Analysis of Behavioral AADL Models in Real-Time Maude, In: Formal Techniques for Distributed Systems, Joint 12th IFIP WG 6.1 International Conference, FMOODS 2010 and 30th IFIP WG 6.1 International Conference, FORTE 2010, Amsterdam, The Netherlands, June 7-9, 2010. Proceedings, ser. Lecture Notes in Computer Science, J. Hatcliff and E. Zucca, Eds., vol. 6117. Springer, 2010, pp. 47-62.
11. B. Banieqbal, H. Barringer, and A. Pnueli (Eds.) - Temporal Logic in Specification, Springer-Verlag, 1987.
12. M. Bozzano, A. Cimatti, J.-P. Katoen, V. Y. Nguyen, T. Noll, M. Roveri, and R. Wimmer - A model checker for AADL, In: Computer Aided Verication, 22nd International Conference, CAV 2010, Edinburgh, UK, July 15-19, 2010. Proceedings, ser, Lecture Notes in Computer Science, T. Touili, B. Cook, andP. Jackson, Eds., vol. 6174. Springer, 2010, pp. 562–565. [Online]. Available:http://dx.doi.org/10.1007/978-3-642-14295-6.
13. Z. Yang, K. Hu, D. Ma, and L. Pi - Towards a formal semantics for the AADL behavior annex, in DATE. IEEE, 2009, pp. 1166–1171.
14. M. Ouimet and K. Lundqvist - The TASM Toolset: Specification, Simulation, and Formal Verification of Real-Time Systems, In: Computer Aided Verification, 19th International Conference, CAV 2007, Berlin, Germany, ser. Lecture Notes in Com-puter Science, vol. 4590. Springer, July 2007, pp. 126–130.
15. G. Behrmann, A. David, and K. G. Larsen - A Tutorial on UPPAAL, In: 4th Inter-national School on Formal Methods for the Design of Computer, Communication, and Software Systems (SFM-RT04), vol. 3185. Springer-Verlag, 2004.
16. T. Abdoul, J. Champeau, P. Dhaussy, P. Y. Pillain, and J.-C. Roger - AADL execution semantics transformation for formal verification, In *ICECCS*. IEEE Computer Society, 2008, pp. 263–268. [Online]. Available: http://dx.doi.org/10.1109/ICECCS.2008.24
17. M. Bozga, S. Graf, and L. Mounier - IF-2.0: A validation environment for component-based real-time systems, Lecture Notes in Computer Science, vol. 2404, 2002.

Corresponding author:

Stefan Björnander

CrossControl AB Kopparlundsvagen 14, 721 30 Vasteras, Sweden

Email: *stefan.bjornander@crosscontrol.com*