

Model Execution: An Approach based on extending Domain-Specific Modeling with Action Reports

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Abstract. In this paper, we present an approach to development and application of domain-specific modeling (DSM) tools in the model-based management of business processes. The level of Model-to-Text (M2T) transformations in the standard architecture for domain-specific modeling solutions is extended with action reports, which allow synchronization between models, generated code, and target interpreters. The basic idea behind the approach is to use M2T transformation languages to construct submodels, client application components, and operations on target interpreters. In this manner, M2T transformations may be employed to support not only generation of target platform code from domain-specific graphical language (DSGL) models but also straightforward use of models and appropriate DSM tools as client applications. The applicability of action reports is demonstrated by examples from document engineering, and measurement and control systems.

Keywords: domain-specific modeling, model-driven development, model transformations, modeling tools, document engineering

1. Introduction

Over the last few years, there have been increased efforts within the academic community to improve software engineering through application of software models [33]. In numerous works, there are remarks that the adoption of Model Driven Software Development (MDS) and the Unified Modeling Language (UML) as its main language has only partially achieved the

proclaimed goals related to development productivity and software quality [19], [21]. Some authors consider the unfitness of UML for domain specific problems to be the main reason for this failure. Expecting that an average software engineer uses or thinks in domain independent abstractions might have been unrealistic. Several approaches, including Domain Specific Modeling (DSM) and MDS, still focus on software models, which are sufficiently formal but also understandable to both machines and humans. One of the important goals in the aforementioned approaches is that models should not only be part of the specification but also of the implementation of the corresponding systems.

Software industry experts are more pragmatic in regard to these issues and not determined to use general purpose modeling languages, such as UML, at all costs. They are more focused on developing modeling tools that satisfy requirements for highly specialized production and control systems. Although the quality and usability of these tools are not being questioned, the manufacturers are constantly faced with high costs of development and customization, even for very similar domains. Taking all into consideration, we expect that the software industry will base its highly specialized tools on the DSM architecture to a much greater extent. The following two improvements could be particularly important: (i) better support for the construction of modeling languages and their syntax, including abstract, concrete graphical, and concrete textual syntax; and (ii) better synchronization between meta-models, models, generated code, and target interpreters or "execution machines". Our research is oriented toward the latter improvement, i.e., better synchronization between meta-models, models, generated code, and target interpreters. The aforementioned synchronization is closely linked to model debugging and execution.

The topic of our research presented herein is also present in other domains of application within the field of software engineering. One such domain is software development based on MDS and Computer Aided Software Engineering (CASE) tools. The traditional CASE tools support the creation of platform independent model (PIM) software specifications, their automatic transformation into platform specific model (PSM) specifications, and ultimately the generation of program code. However, it cannot be actually expected that these tools support incremental interpretation of specifications and dynamic changes of the applied meta-models. These requirements may be gradually fulfilled in the evolution of CASE tools into MDS tools by insisting on retaining the complete synchronization between the created PIM models and the generated program code. An example of one such MDS tool, which is developed by the authors of this paper, is the Integrated Information Systems CASE Tool (IIS*Case) [26]. At present, this tool relies on the PIM model of an information system to generate: (i) implementation description of a database schema and (ii) prototypes of the applications supporting operations on that database. In the current version, any modification within the model requires a new generation of the implementation description of the database schema, as well as a new generation of the prototype applications. In this manner, in forward

engineering, there is support for a one-way synchronization. One of the future research tasks includes implementing in IIS*Case the automatic two-way synchronization between the model and the system executing the applications. As opposed to the existing abovementioned approaches to the execution of models created using a DSM tool, our approach supports incremental interpretation of specifications. Each user operation on a model in the DSM tool is directly interpreted in real time, which may be utilized to verify the correctness of the specification. Simulation tools have supported this approach for quite some time, but they set restrictions on the semantics of simulation languages, i.e., meta-modeling is considerably limited. The execution of models whose semantics is not known in advance represents a significantly more complex problem with respect to both the theoretical and practical issues. The most difficult problems are the definition and automatic generation of a target interpreter that supports incremental verification of specifications. Moreover, the goal of our approach, to which we actively direct our efforts, is to support the two-way synchronization by allowing the direct execution of changes on a model. This may be achieved by using operations on the application that represents the result of the incremental specification. There should be support also for the direct extension of a meta-model in real time according to the operations executed on the previously created models.

Our initial application of MDSD, DSM, and model transformation principles is related to complex problems in document engineering, previously presented in [7], [11], [14], [22], [24], [26]. Positive experience with the construction and application of domain specific languages (DSLs), together with problems related to the development of client applications for measurement and control systems, indicated that the Model-to-Text (M2T) transformations in DSM may be significantly improved and utilized in model debugging and execution. By employing extended M2T transformations, namely "action reports", we intend to make possible the use of modeling tools as client applications. Notwithstanding the fact that current techniques for code generation from models have great capabilities, we demonstrate herein the practical value brought by: the introduction of the submodel concept and appropriate operations; the introduction of the transaction concept in the context of (sub)models; and the use of action reports (generators) as synchronization units during the testing of meta-models, models, client applications, and target interpreters. The practical value of introducing submodels, transactions, and action reports, is that M2T transformations, in addition to being employed for the generation of code in a target language, may also be used for expressing semantics of user actions on a PIM, i.e., on the graphical interface of a DSM tool.

In order to refer to the activities related to meta-modeling (Me), modeling (M), interpretation (I), and documenting (D) of model changes and execution flow, we introduce the term/acronym *MeMID activities*. Consequently, the approach to the modeling and development of software systems that includes all of the aforementioned activities is named *the MeMID approach*. When compared to the traditional approach to modeling, the MeMID approach

includes interaction between all of the components in the DSM architecture, incremental specification, and visual representation of all changes within a real system being modeled. We took a pragmatic approach to the issue of model execution, with the goal of having solutions that may be sufficiently understood by a wide range of users and quickly applied in various business domains. The emphasis is placed neither on the definition of syntax of user semantic actions, nor on meta-modeling, but on the definition of action semantics, i.e., on the interpretation of user actions in a DSM tool during their execution and not solely afterwards, during code generation.

Besides the Introduction and Conclusion, the paper contains eight sections. In Section 2, we describe the state of the art and what is expected from DSM for model execution. The description of the concept of action reports and how they differ from code generators may be found in Section 3. In Section 4, we describe Model-to-Application (M2A), Application-to-Model (A2M), and Model-to-Document (M2D) transformations with respect to application generation. In Section 5, we describe usage of submodels and transactions in the testing of a DSL, model, and target framework or interpreter. This is illustrated with examples of using DSM tools for modeling documents, document templates, and modeling systems by documents. In Section 6, we describe how arbitrary user components may be integrated into DSM tools with the goal of visually representing abstract language concepts. In Section 7, we give examples of the synchronization between a client application and modeling tool. Section 8 describes usage of action reports for the purpose of implementing operations on DSM models, the target interpreter, and user applications. Chapter 9 contains a survey of related work, and overview of the current state of technology in the area of model execution.

2. State of the Art and MeMID Activities

There are certain differences between the roles of some elements in the architecture of DSM and UML tools. These roles originate from different perspectives on modeling in domain specific (DSM) and general purpose (UML) tools. On one hand, DSM tools promote unrestricted construction of domain-specific languages tailored to the needs of users in narrow business domains. On the other hand, UML tools promote construction and use of profiles that are tailored to a particular domain but retain basic elements of the UML syntax, as in the case of SysML [34]. Moreover, DSM tools allow rapid construction of any language belonging to the UML group, while UML tools feature a more suitable graphical interface. In DSM tools, a model is completely separated from the target language, i.e., models are fully platform independent. In UML tools, there is an early coupling between a model and the target language. In DSM tools, reverse engineering is regarded as a methodologically inappropriate procedure, while it is indispensable in UML tools for the purpose of synchronizing code and model. Nonetheless, these

observations are fairly general since there are significant differences even between the tools of the same group.

Further evaluation of the state of the art in the area of model execution is done with respect to the aspects of traditional and advanced code generation and execution (Fig. 1). A modeling language is constructed using a dedicated editor, while models are created using the newly constructed language. In the DSM architecture, these steps correspond to meta-modeling and modeling activities. PIMs are transformed into source code in a general purpose programming language. Transformations are done using patterns or navigation languages [15], [30]. The generated source code in some language (e.g., IEC 611.31, C++, Java, and C#) is translated into binary code using a compiler so that it could be executed on the target platform. This DSM use case is marked as Traditional Flow in Fig. 1. In some cases, target platforms are operating systems themselves, but they may often be Run-Time Systems (RTSs) or Execution Machines, which feature a set of functions more suited for the concrete purpose when compared to operating systems. In our opinion, traditional use of DSM tools significantly improves productivity in the system development, but also has serious drawbacks.

The basic drawbacks of the traditional approach include: (i) weak synchronization between the generated code, model, and meta-model, which hinders incremental execution of models; and (ii) growth of specifications. As the specification is growing, the model should be executed accordingly, first, as empty, and later as more complex, while for each action on the model there should be a corresponding interpretation in the target RTS.

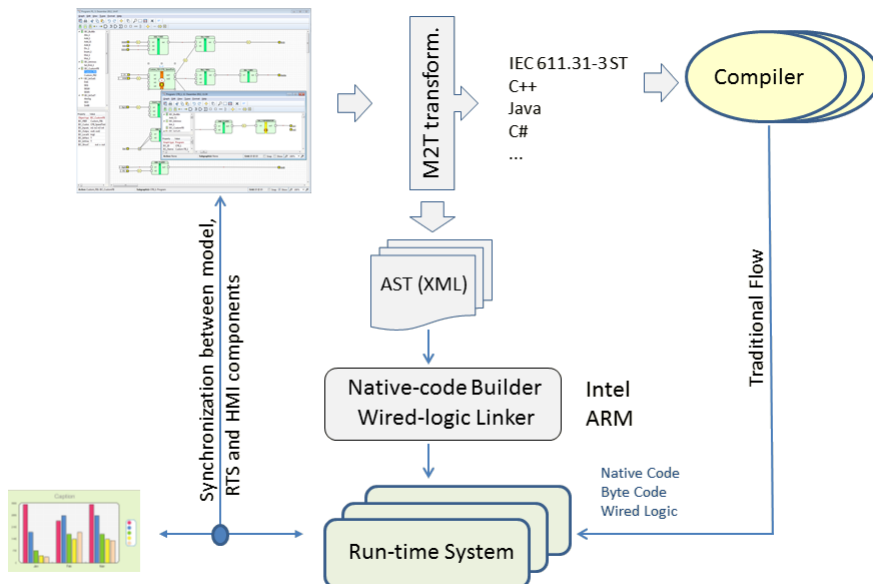


Fig. 1. Traditional and advanced usage of DSM tools

In the traditional approach, which is based on transformations into a general purpose language, the semantics expressed by a PIM may be significantly limited by a transformation to a target general purpose language (GPL). The approach that we propose, which is illustrated herein in Fig. 1 and with several examples tested in practice, includes:

- direct translation of PIM models to binary code tailored to the characteristics of the target RTS and hardware;
- dynamic linking of specifications being executed using increments, which are the result of changes in the model;
- use of action report interpreter within DSM tools, Human-machine interface (HMI) components, and the RTS for the purpose of their synchronization;
- application of arbitrary user components for the visualization of abstract DSL concepts; and
- run-time visualization of the interpretation of specifications within the DSM tool.

As indicated in Fig. 1, at the level of M2T transformations, an extended abstract syntax tree (AST) is generated. It is an Extensible Markup Language (XML) structure, from which it is possible to generate code in binary, assembly, or a general purpose programming language. Depending on the characteristics of the RTS and target hardware, various protocols for dynamic linking of binary code to the RTS are employed. These protocols specify how to exchange data on variables, arrays, user structures, external functions, and values of object instances. If the modeling language is sufficiently rich, there is no need for a host language, and, consequently, for a GPL compiler. We consider this approach especially suitable for target RTSs that support: incremental updating, dynamic linking of binary code, and execution of instructions used to communicate with wired logic controllers. The target system may also be a virtual machine, which executes byte code. We use the term byte code to denote a set of platform independent assembly instructions that are primarily intended to be interpreted by virtual machines. Due to their slow interpretation times, virtual machines are generally not suitable for systems that should have a prompt and time-determined response.

The tracking of model changes presents an important research topic of practical relevance to the Model-Driven Development (MDD) community. In [29], the authors introduce new features of the MetaEdit+ Workbench [30] and present various capabilities for visualizing language concepts of a DSL, including dynamic modification of appearance properties. The MetaEdit+ Workbench is a tool that provides support for various development phases including meta-modeling, modeling, code generation, and simulation of the modeled system. In our approach, we borrow two well-established ideas that are implemented in modern database management systems: transactions and views.

In [27], the authors report the lack of support for model debugging in DSL tools. While most GPL Integrated Development Environments (IDEs) support model debugging because language syntax and semantics are known in advance (and because there is a compiler), the situation concerning DSLs is

substantially more complex. The standard debugging scenario is conceptually restricted by operating systems, target frameworks, and libraries. Therefore, any pragmatic approach featuring even minor improvements related to MeMID activities is going to represent a significant contribution to the testing of domain-specific models.

3. Action Report as an Extended M2T Transformation

An action report is a special M2T transformation formally defined using a language for specifying code generators that, in addition to the description of the model-to-text transformation, contains commands and rules for command invocations during model execution. DSM involves use of reports, also known as generators, to specify how to utilize information from abstract models and to generate code in accordance with a particular concrete syntax [3], [14], [20], [30]. A report is a program whose interpretation yields a textual representation of the semantics expressed in a model. Since transformation languages support model filtering by selection of objects and relations according to a criterion, they should be used to explicitly define a submodel or model view. The need to introduce submodels arises from the fact that, in practice, testing is most of the time focused on a single part of the system and not on the system as a whole.

The purpose of extending report languages and their interpreters is to improve synchronization between a modeling tool, target interpreter and client applications that are not generated by the modeling tool. Therefore, an action report is a report containing synchronization commands. Accordingly, an action report interpreter is an extended code generator that, in addition to reading, may change the state of a model, meta-model, client application and target interpreter. Put in simple terms, an action report features set and get operations for property values. In such role of action reports, it is assumed that every participant in the synchronization has an instance of the action report interpreter.

Relevant characteristics of action reports are divided into three groups: (i) those that are related to modeling tools; (ii) those that are related to target interpreters; and (iii) those that are related to user components for visualizing and documenting actions.

The first group includes the following characteristics: (i) action reports are defined in the context of a submodel; (ii) action reports allow frequent model view changes, i.e., frequent submodel redefinitions; (iii) action reports are executed inside an optimized transaction whose beginning and end are tied to valid model states; and (iv) action reports may execute operations (and be referenced) in the context of both concepts forming a meta-model (modeling language) and objects not part of the meta-model, i.e., any user control.

The second group includes the following characteristics: (i) there are target environments that support model interpretation during specification time, which introduces the need for an operation that would calculate specification

increment between two model states; and (ii) when employing models to manage business processes, action reports may be used to synchronize business activities prior to a switch to a new management model, as well as to incrementally generate documentation and applications that precede the change of the business model.

The third group includes the following characteristics: (i) all the communication between modeling tools and external applications is in the form of textual commands specified in the syntax of a generator language; (ii) action reports are closely related to target interpreter environments, which may vary greatly; (iii) action reports may be called both synchronously and asynchronously, while calling rules define order, frequency, and/or logical conditions related to the call; and (iv) if the target interpreter does not support incremental update during interpretation time, the problem is reduced to the recompilation of the generated code and the use of appropriate debugging tools, which are often part of IDEs.

The role of action reports is illustrated in Fig. 2. They are primarily an interface between the modeling tool, user applications, and target interpreter or debugging environment for the generated code. The interpretation of action reports is performed by special components that are instances of action report interpreters, which are labeled *AR Int* within the little yellow rectangles featured in Fig. 2. The objective is to allow various user groups like meta-modelers, modelers, testers, etc., to use an existing DSM tool as a means of testing the generated code, target interpreter, model and DSL. Action reports are not intended to be used for the description of dynamic characteristics of a system. These characteristics may be completely formally specified through UML state diagrams or equivalent DSLs. Action reports are employed to allow direct use of the existing DSM graphical interface in debugging or testing of the generated code.

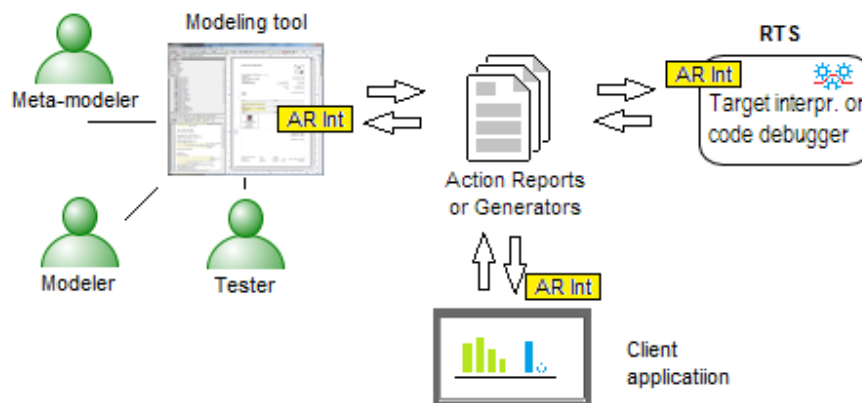


Fig. 2. Action reports and their interpreters

When the modeling language is not sufficiently semantically rich, generators may be temporarily used to describe semantics, i.e., surpass problems caused by the lack of DSL concepts. This scenario is typical particularly for the DSL construction phase.

We close the action reports introductory section with a remark that the importance of action reports as defined herein may significantly differ depending on the actual context. In some business domains, the feedback that action reports may provide to modeling tools has no relevance. However, when DSLs are used in specification of measurement and control processes, action reports are essential and their use brings numerous advantages [29]. A modeling tool may be used as an HMI by exploiting the feedback from the target interpreter. There may also be different visual representations of a single language concept.

4. M2A , A2M, and M2D Transformations

For the purpose of investigating and verifying practical usability of Model-to-Application, Application-to-Model, and Model-to-Document transformations, we implemented the DVRepLang language for specifying these transformations and a corresponding interpreter [8], [14]. They are part of DVDocIDE [10], a DSM tool for document modeling. M2A/A2M transformations are basically M2T/Text-to-Model (T2M) transformations whose purpose has been described in various papers [30], [34]. M2T transformations have been applied in numerous tools for code generation from models [2], [14], [15], [20]. The motivation for introducing M2A/A2M transformations in our research is differentiating in code generation between: (i) procedures that generate the code for the communication between modeling tools and a target interpreter and (ii) procedures that generate the code to be interpreted or executed on the target interpreter. The procedures that generate the code responsible for the communication are tailored to the characteristics of communication components, i.e., communication frameworks. On the other hand, the procedures that generate the code being interpreted are tailored to the characteristics of the framework and target system. The semantics expressed by the model is interpreted by this target system independently from the manner in which the communication is performed. For example, if both frameworks are inadequate, the communication procedures may generate TCP/IP commands, while the procedures responsible for expressing the semantics of the model may generate code in C++. In this context, the target interpreter is important as a component that verifies model and gives feedback for the potential refinement of both the model and DSL. The reason for introducing the notion of a M2D transformation is a need to extend M2T transformations with procedures for the generation of documentation about the MeMID activities.

The most important characteristics of M2A/A2M transformations include:

- target text is a code in a GPL, DSL, or any textual format interpretable by a modeling tool or a target interpreter;
- target text contains embedded semantic actions like property get and set operations;
- operations may be performed on models inside a repository or locally on visual representations of DSL concepts in the graphical interface of a modeling tool;
- these transformations may include operations on external elements of the presentation that are not part of the modeling tool (see Fig. 3);
- these transformations do not directly modify the meta-model, but are used for the semi-automatic inclusion of user controls that graphically represent language concepts; and
- when there is a discrepancy between the concepts directly supported by the interpreter and those of the DSL, these transformations provide an interface for the communication between the relatively incompatible units.

The most important characteristics of M2D transformations include:

- target text is a specification of document instances in a DSL;
- such specification contains identifiers of layout styles that are used for the document rendering;
- target interpreter, which features an instance of the action report interpreter, utilizes action report definitions as a basis for the identification of rules and conditions for initiating document rendering; and
- M2D transformations include rendering of well-designed documents in the PDF or HTML format in the form of external services.

By introducing these transformations, we satisfy some of the user requirements related to the more agile testing and documenting of DSLs, models, and target interpreters. The ideal environment for the application of these transformations within the MeMID activities is the one that supposes the existence of the “universal interpreter” and does not require interrupting the interpretation during the synchronization of model changes. These “hot” switches to a new version of the model are known as incremental updates. Universal interpreters that are independent of the application domain do not exist. Any generalization of the target interpreter necessarily leads to a greater separation of the language used to describe the problem from the language interpretable by the interpreter. In practice, there is a compromise to solve the widest possible class of problems by upgrading the interpreter so that it could internally translate DSL constructs that are at a high level of abstraction to an optimized set of elementary operations.

With respect to the connectedness of meta-models and models, modern tools vary greatly. Some tools support meta-modeling only through textual syntax and feature weak synchronization between meta-models and models [15]. Other tools consistently support abstract graphical models, graphical DSL constructions, and different visual representations for the same language concept, as well as full synchronization between the meta-models and models [30]. Different visual representations of a single language concept allow animations, i.e., visual presentations of model states during

interpretation [29]. The debugging of DSM models cannot be equated with the debugging inside GPL IDEs. With the GPL-to-assembly transformations, there is a finite, predetermined set of source and target language concepts. On the other hand, in DSM neither the source nor the target language needs to be known in advance. The source language is constructed to meet the domain-specific needs and the target code may substantially depend on the existing libraries and frameworks. One of the approaches to the formation of a stronger logical relationship between debugging environments and modeling tools includes the use of patterns. In this manner, it is generally possible to relate the model to the target code. One disadvantage of the use of patterns is that they need to be created for each combination of a DSL and target platform. The critical issue is how efficient the debugging of the resulting code is when done through a GPL IDE that is logically separated from the meta-modeling tool. This problem is extensively debated and the proving of the language validity is a topic of numerous papers and books [21], [27].

Further discussion of MeMID activities is based upon an assumption that the debugging rules or steps should be defined inside the M2A, A2M and M2D transformations in order to provide the feedback from the target interpreter toward the model.

5. Using Submodels, Transactions, and Action Reports in MeMID activities

Modeling tools usually support the concept of model decomposition, which implies that an object, relation, or role may be linked to a submodel. This allows for a model to be described and expressed at different levels of granularity and sometimes even at different levels of abstraction. During testing, it is necessary to focus on just a subset of elements within the model. In DSM tools, this subset should be defined using a submodel, as a complex object with its own structure, operations, and constraints. Although default operations (insert, delete, connect, and disconnect) and constraints express fundamental dynamics of the system described by that model, they are not sufficient to express the rules for the translation of the model from one consistent state to another. For this reason, modeling tools should include support for the transaction concept. Transaction is defined as an operation that validates a sequence of actions on a model and updates the repository. Similar to the database transaction, it includes a validation of actions in the context of MeMID activities. Therefore, we expect that modeling tools explicitly support defining submodels, similarly to how it is supported in DVDocIDE [10].

The purpose of submodels and transactions is illustrated by an example presented in Fig. 3. The diagram in the left section of the figure features activities A1-A4 that are part of the production of advertisements and related documents. The activity A2 (Standard ad production) is composite and

consists of several activities in the modeling of small advertisements. To model advertisements, we use a DSL named DVAdLang, [5], [11]. The subgraph of the object $A2$, marked with $M4$, is an advertisement model that features a logo, several phone numbers, and an email address. In the upper right section of the figure, there are three models ($M1-M3$) in three consistent states ($S1-S3$), all of them representing the same advertisement. These advertisements states, which are explicitly expressed by their models $M1-M3$, are evaluated in the context of the submodel $SM1$, which does not contain the advertisement title (the yellow rounded rectangle).

With respect to model execution, there are two levels of verification: (i) model verification during design time, done by the modeling tool and in accordance with the meta-model; and (ii) on-demand verification of the code generated from the model, whose form of invocation is explicitly expressed by transactions, i.e., action reports in a M2A transformation (in Fig. 3 marked by $T1$ and $T2$). Successfully completed transactions change the advertisement states while giving a visual representation for each of these states, i.e., they document the changes in the advertisement states using well-designed PDF documents (see the lower section of Fig. 3). Partial verification of a model, herein illustrated by the example of the submodel $SM1$, which is represented by a shaded rectangle with rounded edges, is not directly supported in standard DSM tools. This fact hinders a wider use of DSM tools in certain domains, such as document engineering and incremental specification of measurement and control processes. In the presented example, we implemented this functionality using the incremental document generator DVDocGen [6] as the target interpreter. In this manner, we obtained advertisement images, which are shown in the lower section of Fig. 3. DVDocGen can detect, interpret, and update action reports. The DSM modeling tool needs to interpret only a property value set operation in order to visualize the model execution flow. As opposed to DVDocIDE [10], which is focused on the formal specification of documents, general purpose DSM tools mostly do not support such operations.

Examples 1 and 2 further refer to the contents of Fig. 3 and include: (i) specification of the action report $AR1$, which sets the text property *Font.Underline* in the objects in the modeling tool; and (ii) a generic form of a DSL script, which is an interpretable textual representation of a portion or whole semantics expressed by a model.

Example 1. The action report $AR1$ is defined using DVRepLang [8], [38], a language similar to the MetaEdit+ Reporting Language (MERL) [30]. Both languages are navigation languages for M2T transformations of models into an arbitrary target text. $AR1$, which is presented in Listing 1, is applicable to all models that are of the same type as $M1-M4$ from Fig. 3. It is used to generate, in accordance with the syntax of DVAdLang language, a DSL script from the advertisements models. Besides the code segments that are responsible for a standard M2T transformation, $AR1$ also contains sections for embedded semantic actions.

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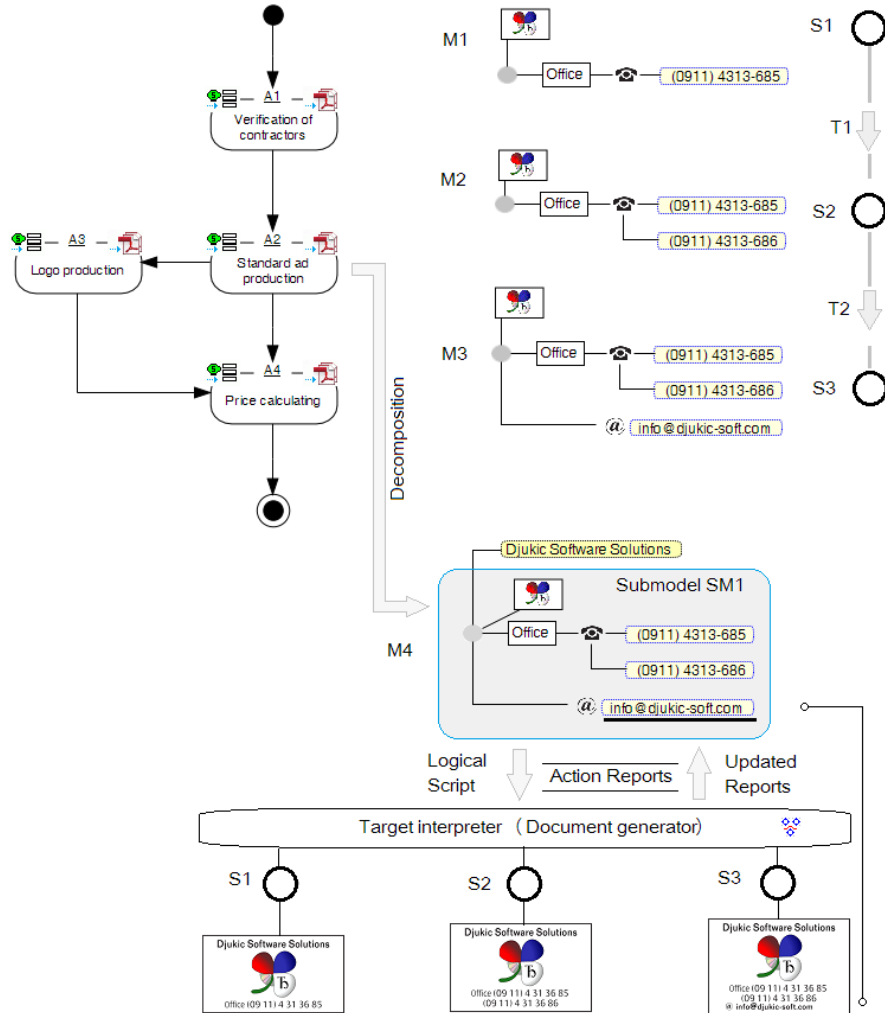


Fig. 3. Submodels, transactions, and testing of models and the target interpreter

Listing 1. Action report example

```

Report 'AR1'
CALL_TYPE = event; /*interval,cyclic,event*/
foreach >ContentUnit {
do .()
{'<'type '>'
if type = 'LOGO' then
  ID ',' :Alignment; ',' :Height;
else :Value; endif
newline
dowhile ~Phones in> Phone connections~Phone rings in.()}
    
```

```
{
  '<' type '>' :Value; newline
  ACTION_BEGIN
  '<STATE>'objID
  :Font.Underline=true;
  ACTION_END
}
```

The existing syntax of DVRepLang, which is used for M2T transformations, is extended with: (i) `CALL_TYPE` command for the declaration of conditions or intervals for the exchange of action reports with the target interpreter, and (ii) `ACTION_BEGIN` and `ACTION_END` primitives, which mark a report code section related to synchronization. In Listing 1, the new language commands are marked in bold.

Example 2. During the interpretation of the *AR1* report from Example 1, a DSM tool generates target text. In this particular case, it is a DSL script in the DVAdLang syntax, which is featured in Listing 2. The definition of action reports is inserted into the `<AR_META>` tag. This definition is required by the target interpreter during the whole synchronization process done with the modeling tool and client applications.

Listing 2. Embedded definition of an action report in the DSL script

```
<AR_META>="REPORT AR1..."
<CU>Initial DSL script
<STATE>S1
<CU>Increment for S2 (Transaction T1)
<STATE>S2
<CU>Increment for S3 (Transaction T2)
<STATE>S3
```

The `<STATE>objID` commands in a DSL script in the target language explicitly denote states, and define transitions and semantic action during model execution. During the interpretation of each `<STATE>` command, a client application or document generator finds an action definition within the `<AR_META>` tag and executes that action while informing the modeling tool about the interpretation state. In this example, the property-setting operation `Font.Underline=true` (marked by `ACTION_BEGIN` and `ACTION_END`) is called.

Semantic action of synchronization through an action report may be arbitrarily complex. It may include incremental specification and rendering of documents inside MeMID activities. In this particular example, since the target interpreter is a document renderer, the semantic action represents both a proof of model execution and a rendered documentation about model testing. For the visualization of the execution of document models and business process models, very fast document generators are required [4]. An example of one such simulation that follows the life cycle of documents is presented in a video clip [5].

6. User Application and Modeling Tool

In a typical DSM scenario, HMI components of a user application are generated or parameterized from models. User applications are not utilized in modeling but are products of modeling that are obtained in the automatic generation of source code. In environments where DSM is being applied, users often have their own framework and HMI components whose layout and functionality are too complex to be specified using editors for meta-modeling. Therefore, it is useful to allow simple integration and use of external HMI components in DSM tools. This integration does not only include exchange of values according to the scenario described in the previous section, but also implies use of external HMI components for visual representation of abstract DSL concepts. In the following discussion, we restrict ourselves to the pragmatic approach that utilizes action reports and common properties of visualization elements in the DSM tool and HMI components.

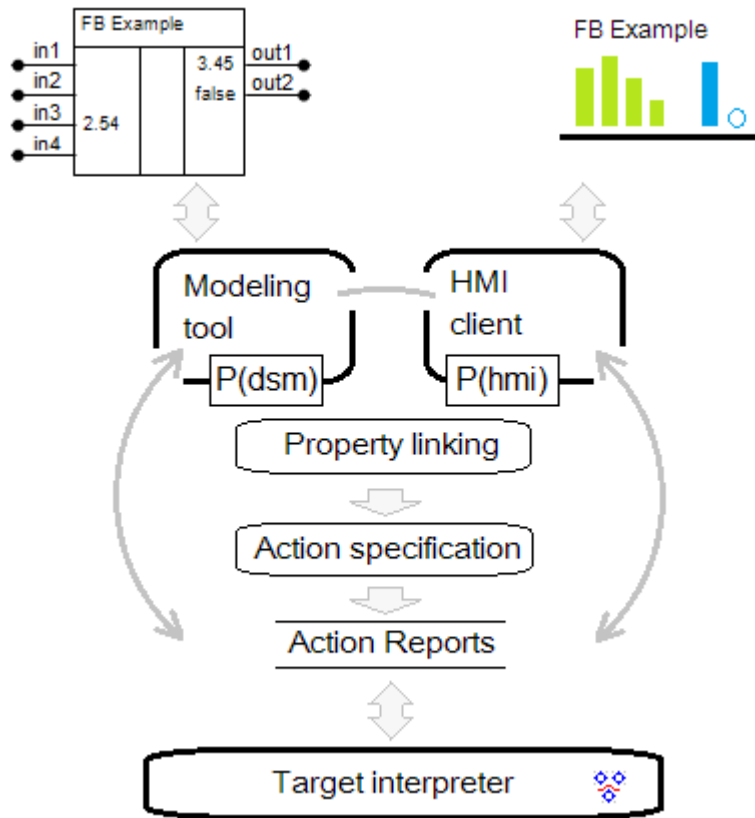


Fig. 4. Editor of common properties, action specifications, and synchronization

In Fig. 4, we illustrate an approach to the integration of user HMI components into DSM tools. In the upper left corner of Fig. 4, there is a function block object in a default visual representation created using a DSM tool. In the upper right corner of the same figure, there is a user HMI component that in the form similar to a bar chart shows input and output values of variables associated with the function block. The output variable *out2* is of the bool type, so it is represented in the HMI component as an empty circle when its value is *false*, or as a filled circle when its value is *true*. Both the DSM tool and the HMI component support reading and changing the property values in several ways, e.g., mouse operations and using a text editor. The $P(dsm)$ label denotes properties defined using the DSM tool, while the $P(hmi)$ label denotes properties belonging to the HMI component. The integration procedure consists of three steps: (i) property linking (also shown in Fig. 4), in which the semantically equivalent properties are found between the two visual representations, irrespectively of the actual form of visualization; (ii) defining user actions on the elements of the graphical representation when certain semantic actions should be executed (labeled *Action specification* in Fig. 4); and (iii) defining the semantics of actions using a language for action reports.

The target interpreter, which is shown in the lower section of Fig. 4, executes the current specification, i.e., interprets the model and action reports. In the context of the target interpreter, it is not important whether the action reports were created by a DSM tool or user application. The role of the target interpreter is to fetch the values of some properties from the current state of the interpretation, update the action report, and send it back. The communication may also go in the opposite direction. Based on the state of the real system, the target interpreter detects the conditions when the semantic actions, whose structure and content are represented by the previously defined action reports, should be called. In this manner, the state of the model within the DSM tool or the state of the user application may be updated. Modifications in the model are not restricted only to setting new values of some properties, but they may be arbitrarily complex and include any operation that is supported within the graphical interface of the DSM tool, HMI components, and user application containing those HMI components.

In the context of the example from Fig. 4, Listing 3 illustrates what is executed by the action report interpreter featured in the target interpreter.

Listing 3. Structure of the semantic action for synchronization

```
ACTION_BEGIN  
:in3='2.54'  
ACTION_END
```

The value of the *in3* property is set to *2.54* and the updated action report is sent back to: (i) the modeling tool for the purpose of modifying interface properties and (ii) the HMI client application for the purpose of setting the values for visualization controls. Report exchange is performed periodically

or on a certain event that is not time dependent, according to the role of an external HMI component. This approach to the synchronization between the HMI components and target interpreters is not supported within the general purpose DSM tools, so the testing is performed using DVRepLang and DVDocIDE, which are DSM tools for document engineering.

7. DSM and Action Reports vs. UML in the Domain of Measurement and Control Systems

Software models are widely used in the manufacturing of measurement and control systems (MCSs), as well as in processes that are automated by these systems. In the field of MCS, there are numerous specifications and solutions that were created in previous decades without significant use of standardized modeling languages. There are several important reasons why UML has not become widely adopted in the MSC industry:

- UML is a graphical language that is not intuitive for domain-specific problems;
- there is a discrepancy between abstract models and a target language that is used in model implementation;
- UML cannot be used to easily transform submodels of abstract specifications into various target languages; and
- UML tools offer limited possibilities when it comes to model execution.

Some of the aforementioned restrictions, which used to impede the full-fledged application of UML in the MCS industry, have been overcome, however many practical issues still remain. MSC solutions have to satisfy rigorous requirements related to low system resources consumption, precision, execution speed, and reliability of control programs. Application of abstract UML models was not attractive to domain experts in spite of potential benefits that could be expected in software development from such an approach. Practical experience of domain experts shows that the gap between an ontology and the linguistic concepts of UML that describe the meaning increases with the specialization of a production environment.

DSM languages and tools have become more prominent as a result of trying to avoid numerous issues that arise from using GPLs to model domain-specific problems. The goals of DSM are to completely formally describe a data structure and process using domain-specific concepts and to generate code from abstract models while using all the capabilities of a target environment. One particularly beneficial effect of using DSM tools, especially those that support access to their repositories through a web service, could be a move from domain-specific to domain modeling. This means that, in some business domains, a problem solution based on DSM may be made available to users from similar domains by offering: (i) a set of domain specific languages for modeling different aspects of a system; (ii) libraries containing abstract model transformations for various target environments (concrete programming languages, interpreters, and hardware languages);

(iii) a predefined set of constraints for different contexts of use; and (iv) concepts for describing model variations and the customization of services to a concrete environment that are both formal and simple for users.

7.1. Applying Action Reports to Models of Car Control Systems

The example given below illustrates the application of action reports in the synchronization of complex services and actions in a simplified version of a car control system. The DSL that is featured in Fig. 5 was constructed starting from the Real-time Object-oriented Modeling Language (ROOM) [35], whose numerous variations are used in the automotive industry. The basic concepts of this language include objects (Actor, External client port, External server port, and Switch) and relations (Binding and Visualization). These language concepts are sufficient for describing driver's interaction with car devices, command processing, state indications on a display, and the feedback between the current car speed and the way the system reacts on driver's commands and states of different sensors.

The model shows a collection of external client ports, such as gas pedal, brake pedal, rotation counter, engine thermometer, and fuel state indicator. These mostly analogue devices are connected through sensors to controllers or external server ports, from which measured values are forwarded to display components (for speed, rotation, temperature, and fuel level). Switches that turn engine and cruise control (tempo limiter) on and off are connected to gas and speed controllers. This abstract model of a car control system has two units. The first unit includes objects that read values and forward them to controllers. The other unit contains objects that are used to display values. In the development of car control systems, a practitioner would have the following expectations from DSM:

- to be able to extend the language and graphical representations of concepts (meta-modeling);
- to be able to describe any complex control system using diagrams and to test such models (modeling);
- to connect a model to analogue devices, external applications, or HMI components that support advanced graphics;
- to generate code for different target systems and controllers; and
- to automatically document each test case in a readable format (PDF).

Such expectations are well founded because across different industries there are many software solutions that satisfy the majority of these requirements to some extent. At the moment, connecting to external applications, and documenting of test cases are areas that still need significant improvement. This example is generally focused on illustrating the use of HMI components with the advanced Windows Presentation Form (WPF) graphics [39]. The advertisement example featured in Section 5 illustrates how documents are generated during the testing of models.

Model Execution: An Approach based on extending Domain-Specific Modeling with Action Reports

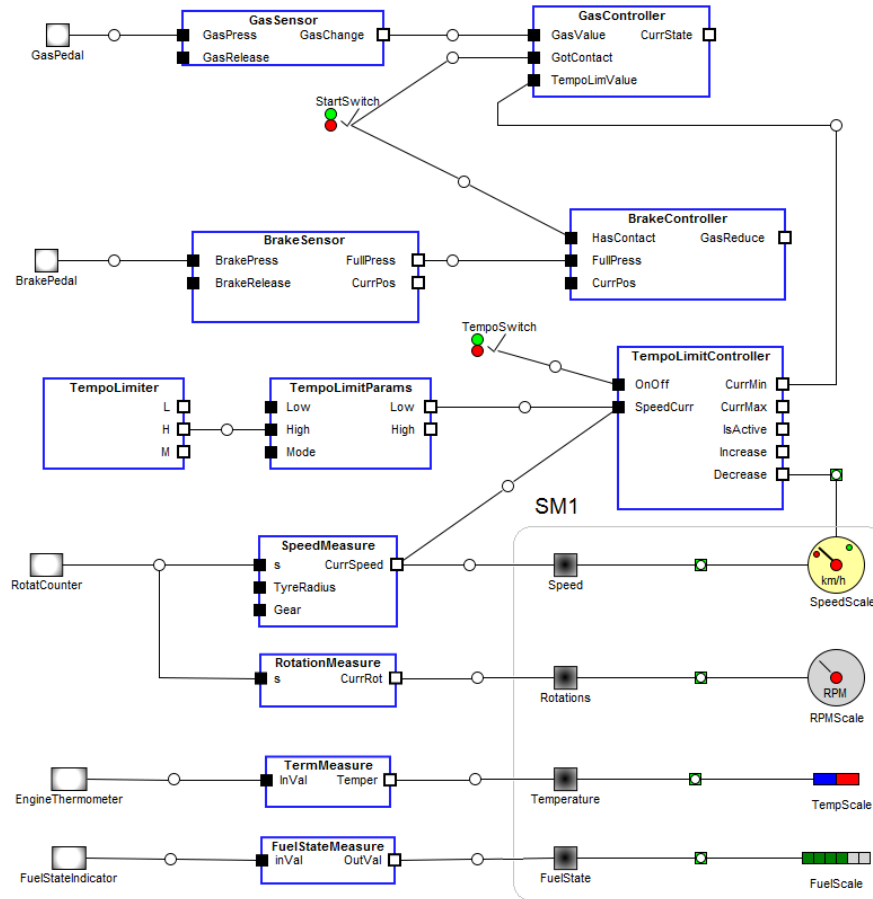


Fig. 5. Car control system as specified in a DSL

HMI components or user applications are connected to a model in two ways (see Fig. 6). In the first scenario, HMI instances are generated from models, while some of the properties are set according to the model state. In this case, graphical components are implemented using WPF. In the second scenario, HMI components are default visual representations of linguistic concepts that are used for modeling. In both cases, linking of model elements and visual representations is based on property linking (see Fig. 4) and using action reports. All external server ports that correspond to different types of scales, such as speed, rotations, temperature, and fuel state featured in Fig. 5, are implemented as web services. These services are used to retrieve the latest state and forward a new value. All scales that are located to the right side of the SM1 submodel are implemented using the WPF components. In the existing DSM tools, the aforementioned functionality dedicated to connecting DSM and HMI components may be achieved only indirectly,

because these tools do not include an implementation of action report interpreters. The indirect method involves using APIs to access the repository of DSM tools with the goal of creating objects and setting property values.



Fig. 6. HMI components as created in WPF

In Listing 4, we present a code generator for the model featured in Fig. 5. It is a MERL report that generates code for web service calls.

Listing 4. MERL report that generates web service calls

```
Report 'External Server Ports'
$mUrl = :VusualURL;
foreach .External Server Port;
{
  filename :CodeTargetFolder;1 :Name; '.h' write
  '#ifndef C_' :Name; '_HEADER_H_' newline
  '#define C_' :Name; '_HEADER_H_' newline
  newline
  '#include "GenericServerPort.h"'
  class C' :Name; ' : CGenericServerPort' newline
  '{
  public:'
  newline
  ' C' :Name; '(int mCurrVal) : CGenericServerPort(currVal)
  {
    //TODO: ???
  }' newline
}
```

```
' virtual~C' :Name; '(void) {
}'
newline
do ~ValueOnPort;~UsedFor;. ()
{
  ' int Get' type '()'
  {
    ';
    ' String mUrl = "' $mUrl 'Get' type '"';
  }
  newline
}
' void On' :Name; 'Update(int currVal)
{'
newline
do ~ValueOnPort;~UsedFor;. ()
{
  ' String mUrl = "' $mUrl 'Set' type
do :()
{
  '?' type='m_'type;
}
';'
newline
}
};'
do ~Server~Server. ()
{
  if :IsSensor;='T' then
newline ' C' :Name; '& m_' :Name; ';'
  endif
}
newline

'#endif'
newline
close
}
endreport
```

From the model, we generate web service addresses and HTTP GET requests that read and set the current speed. An excerpt from the code that was generated using the aforementioned report is presented in Listing 5.

Listing 5. An excerpt from the generated code for calling web services

```
#ifndef C_Speed_HEADER_H_
#define C_Speed_HEADER_H_
#include "GenericServerPort.h"
class CSpeed : CGenericServerPort
{
public:
```

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```
CSpeed(int mCurrVal) :
CGenericServerPort(currVal)
{
    //TODO: ???
}
virtual~CSpeed(void) {
}
int GetSpeedScale()
{
    String mUrl = "http://localhost:13216/
CarDashWebService.asmx/GetSpeedScale";
}
void OnSpeedUpdate(int currVal)
{
    String mUrl ="http://localhost:13216/
CarDashWebService.asmx/SetSpeedScale?
ScaleName=m_ScaleName?MinValue=m_MinValue?
MaxValue=m_MaxValue?Precision=m_Precision?
CurrValue=m_CurrValue";
};
CSpeedMeasure& m_SpeedMeasure;
#endif
```

7.2. Applying Action Reports to Function Block Diagrams

In this subsection, we present another practical example that highlights our experience in the application of GPLs and DSLs in measurement and control systems. The example involves using DSM tools to construct and apply a graphical language for the description of function block diagrams according to the IEC 611.31 specification [18].

The IEC 611.31 specification features five parts, two of which, structured text and function block diagrams, are especially important in the subsequent discussion. Structured text (ST) is a textual GPL with a syntax similar to that of Pascal and with features similar to those of C++, but containing certain language concepts that provide some benefits when applied to MCSs. A function block diagram (FBD) is a graphical GPL that may be used to specify flows in measurement and control processes by diagrams. In practice, numerous tools for specifying FBDs (modeling MCSs using FBDs) are used. A common characteristic of ST and FBD languages is the fact that the syntax is fixed in advance. For that reason, in most tools, algorithms for generating code from the model are hard-coded. The main shortcoming of tools for modeling using FBD is the fact that domain-specific problems are modeled using general purpose language concepts that are often not compatible with the models in real systems. For modeling activities, experienced IEC 611.31 programmers and companies are often hired, however, their productivity in actual projects cannot be readily predicted. In order to point out possible solutions to the aforementioned problems, in the provided example we applied the DSM approach which includes the following activities:

- applying DSM tools in the construction of a IEC 611.31 language,
- specifying code generators and action reports using a M2T transformation language,
- generating ST and native code from models; and
- interpreting models where incremental updating is supported.

For the construction of the IEC 611.31 graphical GPL, we used the MetaEdit+ modeler. In Fig. 7, there is an example of FBD, which is further used to explain main concepts of the language. The language features objects of the following types: function block (1), type convertor (2), distributor (3), input and output connectors (4), and connectors of logical pages (5). Function block (FB) has three subtypes: built-in FB (1.1), intrinsic FB (1.2), and external FB (1.3). Each function block has ports through which it exchanges input and output values with other objects. In the process of language construction, we defined several variants of concrete graphical syntax, model constraints, and diagnostics for incorrect operations and inconsistent model states. We selected the textual IEC 611.31 (ST) and Abstract Syntax Tree (AST) to be our target languages. In line with the example from the introduction (Fig. 1), our intention was to generate GPL specifications in the IEC 611.31 ST syntax from model, together with native code for Intel and ARM processors that is optimized for the target domain, by using AST as input structure for native code generation. Since in both cases a target interpreter is required to execute a model, for that purpose we used a special RTS that executes segments of native code. As native code generation is closely related to compiler construction, to this end, we relied on various industry and academic solutions and experiences.

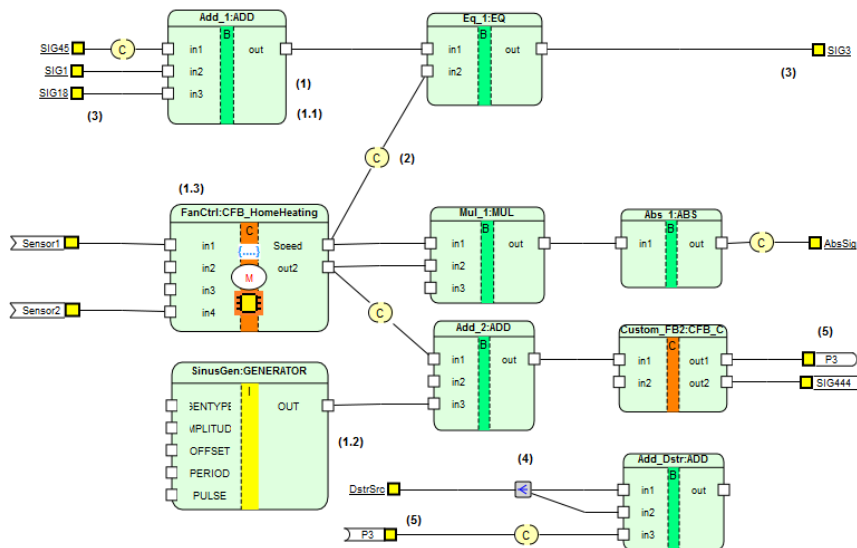


Fig. 7. A FBD example in IEC 611.31

In Listings 6 and 7, we give short excerpts from the generator of ST code, as well as the end result related to the model in Fig. 7. Generators were written in MERL. The ST code generator iterates through all Custom FBs and checks whether they are macros. In the case they are macros, it calls a generator that retrieves the code defined by the macro. In the case they are not macros, by relying on properties, it retrieves definitions of input (VAR_INPUT ... END_VAR) and output (VAR_OUTPUT ... END_VAR) signals, as well as internal variables (VAR ... END_VAR). Whenever a function block is declared as a macro, its graphical representation is changed so that a circled letter M appears in the center of the symbol (see Fig. 7). The body of the Custom FB is retrieved from the :IEC_StructText; property.

Listing 6. Excerpt from the generator of ST code

```

report '_IEC_CodeForCustomFB'
foreach .IEC_CustomFB;
{
  if :IEC_IsMacro; = 'T' then
    do decompositions
    {
      subreport '!IEC_STCode' run
      newline
    }
  else
    'FUNCTION_BLOCK ':IEC_CustomFBName; newline
    $p = ''
    do :IEC_Inputs; {$p = 'T'}
    if $p = 'T' then
      'VAR_INPUT' newline
      do :IEC_Inputs;
      {
        ' ':IEC_PortName; ':' :IEC_DataType;
        if :IEC_Default; <> '' then
          ' := ' :IEC_Default;
        endif ';';
        newline
      }
      'END_VAR' newline
    endif
    $p = ''
    do :IEC_Outputs; {$p = 'T'}
    if $p = 'T' then
      'VAR_OUTPUT' newline
      do :IEC_Outputs;
      {
        ' ':IEC_PortName; ':' :IEC_DataType;
        if :IEC_Default; <> '' then
          ' := ' :IEC_Default;
        endif ';';
        newline
      }
    }
  }
}

```



```
        'END_VAR' newline
    endif

    $p = ''
    do :IEC_LocalVars; {$p = 'T'}
    if $p = 'T' then
        'VAR' newline
        do :IEC_LocalVars;
        {
            ' ':IEC_PortName; ':' :IEC_DataType;
            if :IEC_Default; <> '' then
                ' := ' :IEC_Default;
            endif ';'
            newline
        }
        'END_VAR' newline
    endif
    :IEC_StructText; newline
    endif
    if :IEC_IsMacro; = 'F' then
        'END_FUNCTION_BLOCK' newline newline
    endif
}
endreport
```

The resulting ST code is produced by calling the generator, which translates the whole model and associated submodels. Generation of Custom FBs is only one segment of the translation process. In the generated code, after the `PROGRAM` keyword, there is the name of the model featured in Fig. 7, followed by the definitions of all the input and output ports or signals. Input and output signals are translated into input and output variables of the corresponding types, while external signals are translated into external variables. At the end of the code excerpt, there is the body of the ST program, which contains a description of the relations defined by the model. The code in the line `Add_1_out := ADD(INT_TO_UDINT(SIG45), SIG1, SIG18);` indicates that the *out* port of the FB instance *Add_1* is modified by adding *SIG45*, *SIG1*, and *SIG18*, where *SIG45* was previously converted from INT to DINT.

Listing 7. Generated ST code

```
PROGRAM Example_with_all_language_concepts
VAR_INPUT
    DstrSrc:INT;
    SIG1:UDINT := 7;
    SIG18:UDINT := 21;
    SIG45:INT := 10;
END_VAR
VAR_OUTPUT
    AbsSig:USINT;
```

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```
SIG3:BOOL;
END_VAR
VAR_EXTERNAL
  SIG444:REAL;
  Sensor1:INT;
  Sensor2:INT;
END_VAR
VAR
  Abs_1_out :INT;
  Add_1_out :UDINT;
  Add_2_out :REAL;
  Add_Dstr_out :INT;
  Eq_1_out :BOOL;
  Mul_1_out :INT;
  SinusGen:GENERATOR;
  Custom_FB2:CFB_Commands;
  FanCtrl:CFB_HomeHeating;
END_VAR

  Add_1_out := ADD(INT_TO_UDINT(SIG45), SIG1, SIG18);
  Eq_1_out := EQ(Add_1_out, INT_TO_UDINT(FanCtrl.Speed));
  SinusGen(1, 1.0, 5.0, 10.0, 2.0);
  Add_2_out := ADD(INT_TO_REAL(FanCtrl.out2), 55.9,
SinusGen.OUT);
  Custom_FB2(Add_2_out, 46.0);
  FanCtrl(Sensor1, 9, 10, Sensor2);
  Mul_1_out := MUL(FanCtrl.Speed, FanCtrl.out2, 40);
  Abs_1_out := ABS(Mul_1_out);
  AbsSig := INT_TO_USINT(Abs_1_out);
  SIG3 := Eq_1_out;
  Add_Dstr_out := ADD(DstrSrc, DstrSrc, REAL_TO_INT
(Custom_FB2.out1));
  SIG444 := Custom_FB2.out2;

END_PROGRAM
```

By constructing the language and using the IEC 611.31 ST generator, we have achieved two important goals that can be accomplished neither by modeling tools that focus only on FBDs nor by UML tools. The first goal was to construct a language that could be easily transformed into a DSL in order to satisfy some domain-specific requirements. The second goal was to transform abstract models into an arbitrary target language, as well as into native code, For some FBs, it is possible to generate code according to some syntax, e.g., to that of VHDL, that would initialize wired-logic controllers. In Fig. 7, such a FB is shown with a processor symbol in the middle. Submodels of a model are transformed into even more different languages. Since DSM tools do not support explicit declaration of a submodel, we achieved this by introducing the `IsWired` property to FBs and writing a generator that utilizes that property.

From the user's point of view, in addition to fast and complete specification of a modeling language, it is also very important how models are verified.

Numerous tools support model verification but only for complete specifications. Our approach is based on the following idea: each specification, from an empty model to the most complex specification, should be interpreted simultaneously with the modeling process. We refer to such model execution as the interpretation with incremental updating. Similar approaches may be found within simulation tools, such as Simulink [36] or LabView [23]. However, in those cases, the semantics of a modeling language is fixed in advance, which significantly simplifies the whole process. Because of the restrictions associated with language construction, model execution using these tools cannot be considered as a full-fledged MeMID activity.

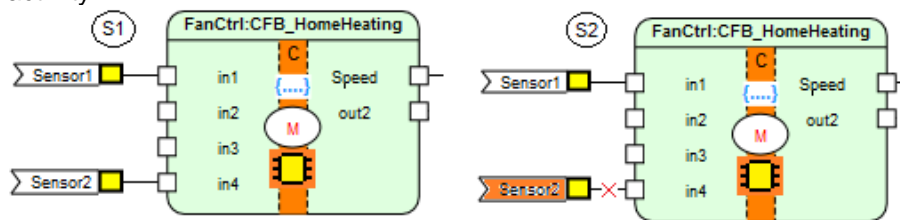


Fig. 8. Incremental update of a MCS

In the rest of this section, we present a practical example of using incremental updating and action generators in a typical MeMID activity. In Fig. 8, two states of a model for fan control, $S1$ and $S2$, are depicted as submodels of the model featured in Fig. 7. The state of the model $S1$ corresponds to the state of a real system when Sensor 1 ($T1$) is functioning normally. The state of the model $S2$ corresponds to the state of the real system when sensor $T1$ is being repaired or replaced. This is the case when a problem with rotation speed of a fan may occur due to a thermometer malfunction. In the model, thermometer replacement is defined as a complex transaction that is made of various MeMID activities. It is also possible for an external application that is synchronized with the model or interpreter to display an image which shows that the installation is in progress. Sensor change is recorded in a document that contains information about the location, time, and identifier of the replaced sensor. In order to better understand the example featured in Fig. 8, it may be worth consulting the specification of function block diagrams in accordance with the IEC 611.31 specification [18] and watching a video clip [9] that demonstrates the construction of a DSL and model execution in a target interpreter.

According to the MeMID scenario, a sensor replacement procedure and documenting of the replacement include the following actions:

- An action report that simulates the replacement is executed. It changes the model from state $S1$ to state $S2$ and sets an appropriate image in a client application.
- An action report that generates a service order in PDF format is executed. All specifications are in various DSLs.

- *Sensor 1 (T1)* is detached from the function block and a default value that corresponds to the temperature which is measured by some other thermometer is assigned to the input *i1* ($i1=21^{\circ}\text{C}$). The transaction is then confirmed by the model. Using this information, a code update is generated for a target interpreter. This update is only an increment and not a complete program.
- A service person replaces the sensor.
- In the simulator, the model changes to the previous state and checks the functioning of a new sensor (*Sensor 1* is reattached to *i1*).
- The model is connected to the real system and returns to interpreting from the previous state.
- An action report that generates the documentation about the changes in the system during sensor replacement is executed.

Documenting model changes, as a part of the MeMID activity, is partially covered in the example featured in Section 5. When action reports are used in documenting results of the testing of a MCS, they retain a similar structure. They feature nested commands that contain a DSL script or functions which return document content increment.

The aforementioned examples illustrate one advanced scenario of applying DSM tools in specialized production environments. While DSM tools support meta-modeling and modeling well, when it comes to the transformation of submodels to certain target languages, their use in complex MCSs is limited. The main reason is the way how they synchronize with external applications and their poor support for logical connection of actions in a real system to operations on models. General purpose DSM tools are less user-friendly for modeling when compared to specialized CASE tools or applications for modeling measurement and control systems. Efficient use of DSM tools also requires improvement of their graphical interfaces. In the following section, these improvements are described as user operations on models.

8. Action Reports and Operations on Model

DSM tools are usually more advanced in terms of concepts when compared to CASE tools and applications used to model MCSs. On the other hand, dedicated CASE tools and applications have better suited graphical interfaces that support drawing of models considerably closer to the specific standards of a particular business domain. In previous sections, we demonstrated how DSM tools may be improved for the purpose of supporting: (i) model execution and (ii) usage of DSM tools as client applications for monitoring, i.e., surveillance of states in a real system [9]. In this section, we explain how the graphical interface of a DSM tool may be improved for the purpose of its more efficient utilization in specific application domains.

Using action reports for formal specification and implementation of three groups of operations constitutes the basis for the improvement of DSM tools. The first group includes operations that accelerate the construction of a DSL and different visual representations of language concepts in a DSM tool by relying on the existing user HMI components. The second group includes operations used to define the behavior of the graphical interface for basic user operations: insert, delete, connect, disconnect, update, move, etc. The third group includes operations on submodels. With some minor extensions, navigation languages for M2T transformations could support all three groups of operations.

The general structure of reports used to define operations of the first group, i.e., those used to transfer a part of the definition of an external HMI component to a meta-model, is presented in Listing 8. As previously discussed, the DSM tool and user application need to include instances of an action report interpreter capable of interpreting specified actions.

Listing 8. General structure of reports defining operations that transfer definitions of external HMI components to meta-models

```
ACTION_BEGIN
  ObjectDef | RelDef | RoleDef | PropDef
ACTION_END
```

Operations used to define the behavior of the graphical interface should provide expected spatial arrangement of model elements during all kinds of user actions. One method of defining the behavior of a graphical interface is to apply structural patterns in the way that we used them to define document layout. In Listing 9, we present only some of the typical patterns, while a more detailed description of grammar rules and examples may be found in [14]. Each pattern consists of an ordered (OL) or unordered list (UL) of elements, which represent objects and relations in a DSM model. Validation or customization of the model according to the specified patterns is performed during the execution of user operations (insert, delete, connect, etc.). Semantic actions that perform validation according to the patterns are executed using action reports. During this process, rules of spatial layout and structural rules are translated into topological properties of model elements.

Listing 9. Pattern examples

```
PATTERN A UL(B,C,D) END
// The A element consists of three elements, which may appear
in any order.
PATTERN A OL(B,C,D) END
// The A element consists of three elements, which may appear
only in the specified order.
PATTERN A UL(B,C,D) isLeftOf(C,D) END
// The A element consists of three elements, but the C element
must appear before the D element.
```

```
PATTERN A UL(B,C,D) isLeftOf(C,D) isBelow(D,B) END
// The A element consists of three elements, but the C element
must appear to the left of the D element while the D element
must appear above the B element.
PATTERN A UL(B,C[3..5],D) END
// The B element appears exactly once, the C element appears
from three to five times, while the D element appears exactly
once. The elements may appear in any order.
PATTERN A OL(B*,OL(C,D)) END
// The B elements must appear first for any number of times,
followed by the C element and the D element, respectively.
PATTERN A UL(B*,C*,D*) END
// The elements B, C, and D may appear for any number of times
in any order.
```

The third group of operations, whose semantics may be expressed through action reports, is used to: (i) construct submodels and carry out all operations on (sub)models without the need for the execution of low-level API functions on the repository; and (ii) define transactions.

The construction of submodels and corresponding operations is similar to the definition of views in relational databases or the definition of complex objects in object databases. We focus on operations that could significantly improve MeMID activities when the modeling tool is linked to the target interpreter via action reports. Therefore, we give an overview of the selected operation set:

- **CreateSubmodel** (listOfElems) – creates a submodel based on the specified list of objects, connections, relations, roles, and properties from an existing model;
- **SetCurrentSubm** (m_ID) – sets one of the defined submodels as the current one;
- **DeleteSubmodel** (m_ID) – deletes the submodel definition;
- **AddModel** (m_1,m_2) – joins two submodels into one without modifying any relations;
- **Subtract** (m_1,m_2) – removes *m_2* from the existing composite model *m_1*;
- **Multiply** (m_1,n) – creates a new model by repeating the model *m_1* *n* times;
- **Intersection** (m_1,m_2) – returns a model containing intersecting element from *m_1* and *m_2*;
- **Union** (m_1,n) – joins two models without repeating elements having same identifiers;
- **SimDifference** (m_1,m_2) – finds a symmetric difference between the two models;
- **Remove** (objType|relType) – removes objects or relations of the specified type from the submodel; and
- **Clone** (objType|relType|roleType) – clones the complete model or just object, relations, roles, and properties of the specified type or matching the specified pattern.

We used DVDocIDE, a DSM tool for document modeling, to test usage of action reports and patterns as means of a more efficient DSM modeling of documents and their templates. We used DVQL [25], a command/query language for documents, to implement operations on submodels. In order to verify usefulness of these operations in general purpose DSM tools, the latter should be considerably extended. This issue is also one of the topics of our future research.

9. Related Work

Over the last few years, Executable UML has been a recurring topic in both the academic and engineering community [32]. Numerous papers and practical solutions extend its usability for simulations and model execution [17], [23], [36]. However, it seems that the transfer of very narrow specialized knowledge to web services (Cloud computing) is advancing more rapidly as opposed to the use of UML tools for the domain-specific problems. In the academic community, much of the model transformation research relies on the OMG's specification Query/View/Transformation (QVT) [28]. The specification consists of three interrelated languages: (i) Relations, (ii) Core and (iii) Operational Mapping. Atlas Transformation Language (ATL) [2] by the Eclipse Foundation [15] is an example of a model-to-model (M2M) transformation language in accordance with the QVT standard. Among the commercial tools, one of the best known transformation languages is MetaEdit+ Reporting Language (MERL) [30]. It is a language mainly focused on model-to-text (M2T) transformations. It partially supports transformations that conduct synchronization between the model, client applications, and target interpreter. By minimally extending MERL to allow specification and interpretation of action reports, it would be possible to synchronize applications that feature disparate user interfaces, and target interpreters or "execution machines" [1], [4], [6], [24], [31], [38].

In [20] and [27], the authors present ideas and solutions for domain-specific model transformations and debugging. Our consideration of code generators differs slightly from the one presented in [20]. We believe that template-based M2T transformations are complex, insufficiently flexible, and complicated to be implemented within the HMI components and target interpreter of models.

In [16], the authors present a translational and an interpretational approach to execution of domain-specific models. These approaches are based on explicit definition of semantics for execution of each model. The translational approach relies on generating code that should be compiled and then executed, while the interpretational approach relies on model interpretation by a target interpreter. The disadvantage of the former approach is that it is unsuitable for simulations and rapid prototyping. On the other hand, the latter approach is considerably more suitable for both rapid prototyping and incremental update of an active system. The authors recognized the

necessity of the use of transactions and logging of all model changes for the purpose of backtracking. They resolve the issue of the synchronization between a model and the execution engine by relying on the concurrent access to configuration files used by the DSM editor and execution machine. From their simple example implemented using Eclipse EMF, it seems that the application of their idea is limited to less complex cases. In our approach, which is based on the use of M2T transformations, there are slight extensions of existing navigational languages for M2T transformations and two logically independent execution engines: a report interpreter and a target interpreter of models.

In [37], the authors describe the OMG's approach to standardization of UML model execution, which involves using Action Semantics, i.e., explicit definition of execution rules at the level of the UML meta-model. The goal of this standardization is to allow: (i) software independent specification of actions on UML models; and (ii) execution of UML models. Their approach is based on the following three abstractions: meta-model, execution model (UML model), and actions. The semantics of actions is defined, but not the concrete syntax, because it depends on the target language used in code generation from a model. Because this approach requires knowledge about UML meta-modeling, it seems unlikely that it will be widely applied in domain specific problems, particularly for modeling measurement and control systems.

Among numerous tools for modeling measurement and control system that may be used in the extension of DSM tools, or for better illustration of action reports and use of modeling tool as client applications, the following two stand out: Simulink [36] and IbaLogic [17]. Simulink is a tool primarily aimed at drawing function block diagrams. It features a large library of function blocks that may be customized and supports generation of source code in the C language. In the context of the MeMID activities, Simulink does not adequately support meta-modeling and generation of documentation about model execution. IbaLogic is a tool for modeling measurement and control systems that employs structured text and function block diagrams according to the IEC 611.31 specification, where a function block model is also an execution model. This tool supports linking to various run-time systems that may interpret or execute a model. However, meta-modeling and code generation for different programming languages are not supported. Owing to the featured implementation of a set of basic operations on models, it supports: (i) every version of the incremental update for a target system during interpretation; and (ii) visualization of the state of a real system within the modeling tool.

10. Conclusion

In this paper, we present the first practical results and foundations of an approach aimed at further improvement of DSM tools. Our objective is to

better automate the MeMID activities: meta-modeling, modeling, testing of models, generated code, and interpreter, and generation of documentation about test cases. In the areas of document engineering and development of measurement and control systems, the action report approach allows us to specify the following procedures within abstract models: (i) the process of documenting model validation; and (ii) in the context of certain business rules and procedures, the synchronization of actions on a model to the state of the real system. Owing to this, action reports are especially effective when combined with DSM tools that, instead of relying on patterns, conduct M2T transformations by using a dedicated target language and interpreter. In production systems where business procedures are specified both precisely and formally, there is also a need to document each action on the model or to execute each action on the model by relying solely on the previously generated and authorized document. By using action reports, it is possible to synchronize not only the different components that are part of the MeMID activities but also the heterogeneous business and control processes, which feature complex business rules and operation of arbitrary control systems.

Our future research directions include: (i) construction of a language for the description of constraints on presentation elements (graphs), which in turn would simplify the customization of meta-modeling and modeling tools for different domains of application; (ii) construction of M2T transformations, i.e., code generators that would produce binary or assembly code for different processors by starting from abstract models; and (iii) conceptualization of run-time systems that would interpret abstract models, which in turn would be transformed into different target languages, software logic or wired logic. The ultimate goal of our research is to support, to the greatest extent possible, the MeMID scenario, which consists in using modeling tools as client applications to manage business and control processes. The approach presented in this paper was created to be focused on the domain of application and provide pragmatic support to users. For these reasons, its application capabilities may not be fully generic. However, the goal of developing the approach is not primarily oriented to this end, but to provide the foundation for a quality support to users in the domain of monitoring the measurement and control processes. At present, our approach supports modeling and executing models of measurement and control systems. We expect that our ideas, examples, and practical solutions presented in this paper are going to contribute to a better use of DSM tools as client applications for the monitoring of measurement and control processes.

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