Original Research Paper

Prototyping Rule-Based Expert Systems with the Aid of Model Transformations

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Abstract: The problem of improving efficiency of intelligence systems engineering remains a relevant topic of scientific research. One of the trends in this area is the use of the principles of cognitive (visual) modelling and design as well as approaches based on generative programming and model transformations. This paper aims to describe the implementation and application of model transformations for prototyping rule-based knowledge bases and expert systems. The implementation proposed uses the main principles of the Model Driven Architecture (MDA) (e.g., model types and creation stages) and considers the features of developing intelligent systems. Therefore, the current research employs the following tools: Ontologies for the representation of the computation-independent model; the author’s original notation, namely, the Rule Visual Modelling Language (RVML) to create the platform-independent and platform-specific models; the C Language Integrated Production System (CLIPS) and the Drools Rule Language (DRL) as the programming languages (as the platforms). The approach proposed targets non-programmers (domain experts and analytics) and makes the design process of rule-based expert systems and knowledge bases more efficient. The paper also presents a detailed description of the main elements of the approach including models, transformations and a specialised software (Personal Knowledge Base Designer).

Keywords: Model-Driven Engineering, Expert System, Rules, Ontology, Prototyping, Model Transformations

Introduction

The problem of improving efficiency of Knowledge Bases (KB) and expert systems engineering remains a challenging topic of scientific research and it can be addressed in different ways: By improving the existing approaches or creating a specialized software for automation of the development process (Jackson, 1998; Giarratano and Riley, 2004; Liebowitz, 1998; Luger, 2008; Sahin et al., 2012).

At the same time there exist several main trends to improve the efficiency.

Using the software for ontological and cognitive modeling, CASE-tools (Protégé, OntoStudio, IHMC CmapTools, XMind, FreeMind, TheBrain, IBM Rational Rose, StarUML and etc.), which create graphic models that correspond to the key software abstractions. However, most of these systems do not cover all the creation stages of KBs and ESs and do not provide the completeness of the development process: From the subject domain model to the program codes. In some cases, they can only help obtain graphic images of KB structures. Perhaps, only Protégé is capable of generating a limited set of KB elements, in particular, for CLIPS/COOL.

Using KBs editors and ESs shells (Expert System Designer, Expert System Creator, ARITY Expert Development Package, CxPERT, Exsys Developer, DDTRES and etc.), which are programmer-oriented and allow implementation of a formalized description of the domain concepts and KB structures in a certain Programming Language (PL), but have a low integration capacity with visual modeling systems and knowledge interpretation modules, in most cases supporting one specific PL.
Using integrated frameworks and unified approaches that provide the coverage of all phases of the life cycle of knowledge-based systems and the integration of the first two trends.

It should be noted that this area offers such solutions as AT-TECHNOLOGY (Rybina et al., 2016) and such special methodologies as HeKatE (Nalepa and Ligeza, 2010) and CommonKADS (Schreiber et al., 2000), however, there is a general tendency to target non-programmers (Nofal and Fouad, 2015; Ruiz-Mezcua et al., 2011) and employ conceptual models, including ontologies and semantic nets (Baumeister and Striffler, 2011) and employ conceptual models, including.

At the same time, it remains relevant to expand the set of conceptual models used and further minimize the participation of the programmer in the creation of KBs.

One of the trend in these areas is the use of the principles of cognitive (visual) modelling and design as well as approaches based on generative programming (Czarnecki and Eisenecker, 2000; Czarnecki and Helsen, 2006), in particular, the Model-Driven Engineering (MDE) or the Model Driven Software Development (MDD) and its variants (modifications).

The MDE/MDD is a software design approach that uses the information models as the major artifacts, which, in turn, can be used for obtaining other models and generating programming codes (Sami et al., 2005). This approach enables programmers and non-programmers (depending on the implementation) to create software on the basis of conceptual models.

Thus, the core ideas of the model-driven approach are:

- A model is a key artifact during the development process of software (a formal specification of the function, structure and behavior of a system within a given context)
- The software development process is a sequence (a chain) of transformations of models (from more abstract to less abstract)

To date, the best-known MDE initiatives are the following:

- The Model-Driven Architecture (MDA), which is a registered trademark of the Object Management Group (OMG) (Sami et al., 2005; Djurič et al., 2005; Frankel, 2003; Kleppe et al., 2003; MDA, 2017; Schmidt, 2006). The main idea of the approach is to build an abstract meta-model for the management and exchange of metadata (models) and set the ways of their transformation into a software-supported technology (Java, CORBA, XML, etc.). MDA specifies three default viewpoints on software: Computation independent, platform independent and platform specific. The viewpoint is an abstraction technique for focusing on a particular set of concerns within a system while suppressing all irrelevant details. The viewpoint can be represented via one or more models.
- The Eclipse Modeling Framework (EMF) is an Eclipse-based modeling framework and code generation facility for building tools and other applications based on a structured data model (EMF, 2017). The EMF provides the foundation for interoperability with other EMF-based tools and applications. The heart of EMF is Ecore. Ecore is a special language for description of meta-models (implementation of OMG's Essential Meta-Object Facility, EMOF). The basic tools to work with meta-models and skeletal code generation of software (programming skeletons) are EMF.Core, EMF.Edit, EMF.Codegen
- The Model-Integrated Computing (MIC) has been developed for over two decades at ISIS, Vanderbilt University, for building a wide range of software systems. MIC focuses on the formal representation, composition, analysis and manipulation of models during the design process. It places some models in the center of the entire system life-cycle, including specification, design, development, verification, integration and maintenance (MIC, 2017). MIC provides three core elements: The technology for the specification and use of the Domain-Specific Modeling Languages (DSML); the fully integrated metaprogrammable MIC tool suite and an open integration framework to support formal analysis tools, verification techniques and model transformations in the development process; the three-level representation of the system development process (Application Level, Model-Integrated Program Synthesis Level, Meta-Level)

In the context of the development of rule-based ESs we choose the MDA as the primary approach. This is the most standardized version (initiative) of the MDE, which uses the UML, one of the most common modeling and software design languages.

There can be found examples of successful use of the MDE approach in the development of database applications (e.g., ECO, for Enterprise Core Objects), agent-oriented monitoring applications (Gascueña et al., 2012; 2014), decision support systems (Baumeister and Striffler, 2015; Shue et al., 2009; Neto et al., 2017), embedded systems (software components) for the Internet (Canadas et al., 2009; Cabello et al., 2009; Distante et al., 2007), including rule-based ESs (Nofal and Fouad, 2014; Shue et al., 2009; Nofal and Fouad, 2015; Ruiz-Mezcua et al., 2011; Canadas et al., 2009).
This paper aims to describe the implementation and application of the MDA/MDE approach and model transformations in prototyping rule-based KBs and ESs. The implementation proposed uses the main principles of the MDA/MDE (e.g., model types and creation stages) and considers the features of developing intelligent systems, in particular, rule-based ESs and KBs through specialization and redefinition of certain models and stages.

In particular, we suggest using the following tools:

- Ontologies and conceptual models in the form of UML class diagrams (Star UML and IBM Rational Rose formats) or mind maps (HMC CmapTools format) to represent a computation-independent model (CIM), that distinguishes this work from similar ones, in particular (Nofal and Fouad, 2014; Shue et al., 2009; Nofal and Fouad, 2015; Ruiz-Mezcua et al., 2011; Canadas et al., 2009).
- The original author’s notation - a Rule Visual Modelling Language (RVML) to improve the visibility of representations of cause-effect relations for designing platform-independent and platform-specific models, that allows us to take into account the specifics of the logical rules formalism, in contrast to (Canadas et al., 2009; Cabello et al., 2009).
- C Language Integration Production System (CLIPS) as a platform model.

We also define the rules of model transformation in accordance with the principles of the MDA/MDE in the context of designing KBs and ESs. The closest works (Canadas et al., 2009; Cabello et al., 2009) use the classical MDE-based scheme for developing applications without taking into account the specifics of the development of knowledge-based systems, in particular, the need for a conceptualization stage or the selection of certain formalism for the knowledge representation.

The approach proposed is implemented in the form of a prototype of the specialized software: Personal Knowledge Base Designer (PKBD, 2017). This software supports the main stages of the development process and it was used in the ESs design to define the causes of damage and destruction of construction materials. This software was also used in the educational process at the Irkutsk National Research Technical University (IrNRTU).

The approach targets non-programmers (domain experts and analytics) and improves the efficiency of the design process of rule-based KBs and ESs.

This paper is organized as follows. The next section presents analysis of the related works; Section 3 contains the problem statement. Section 4 describes the modification and application of the MDA/MDE approach to the automated creation of rule-based KBs and ESs. Sections 5 and 6 demonstrate the implementation and applicability of the approach using an example. Discussion is presented in Section 7 and the concluding remarks are stated in Conclusion.

Related Works

The following several works have been already developed in the area of engineering rule-based KBs and ESs and exploit the principles of the MDA/MDE to a greater or lesser extent. Analysis of those works showed that they can be divided into two groups:

1. The first group includes the works that do not explicitly indicate the use of the MDE methodology and principles, however, they actually use conceptual models to describe the subject domain and some transformations of these models to interpret or generate software codes. In this case, the specialized transformation languages are not used and the main results are presented either in the form of single domain specific applications or problem-oriented shells.

   In particular, Dunstan (2008) presents a method to automatically generate web-based ESs from XML descriptions of the knowledge domain. The case study is university course rules. An XML data definition file is developed featuring common rules and restrictions regarding courses. In this work the generator conception is used and the method is programmer-oriented.

   Nofal and Fouad (2014) describe a tool for developing web-based ESs. The tool utilizes the Semantic Web technology which enables the knowledge engineers and domain experts to define knowledge without having to know anything about programming languages and Artificial Intelligence (AI). The facts of the knowledge can be annotated using the semantic concepts and relations found in WordNet ontology and interpreted in the tool.

   Shue et al. (2009) use the ontology to model the domain knowledge and decision rules to represent operational knowledge. The system described integrates Protege, as a domain KB and the Java Expert System Shell (JESS), as an operational KB, into one complete ES. The case study is corporate financial rating. In this work the generator conception is implemented, so the main results are the JESS and Java program codes. The special transformation languages are not used.

   Ruiz-Mezcua et al. (2011) created an ES development tool for non AI experts. This tool utilizes allows development of the ESs on the basis of knowledge representation models. The models are described in the form of trees and interpreted in the tool. The special transformation languages are not used.

   An approach for the ESs construction on the basis of UML is described in (Touzi and Messaoud, 2009). The approach proposed uses the extension of the CLIPS, called VCLIPS_UML, which is developed in Java and allows one to automatically generate the corresponding
scripts in accordance with the CLIPS language. This approach is oriented to non-programmers.

Kadhim et al. (2013) introduced a tool for constructing rule-based ESs called Diagnosis Domain Tool for Rule-based Expert System (DDTRES), which tool provides a variety of functions to facilitate the development of ESs for practical problems in different diagnosis domains. This system is developed and implemented using the visual PROLOG programming language. Since the tool proposed is a problem-oriented shell, the structure of the domain model is already defined and is filled with the use of data mining methods.

2. The second group contains the works that explicitly use the MDE principles in the context of the EMF or MDA initiatives.

For instance, Canadas et al. (2009) present an MDE for the development of rule-based applications for the Web. Their approach uses ontology to describe the subject domain. In this case, the Conceptual Modeling Language (CML) (instead of UML) is used to describe the ontology (as the Computation-Independent (CIM) and Platform Independent Models (PIM)) as a rule modeling formalism. The implementation was made as a part of the Eclipse Modeling Project (using the Eclipse Modeling Framework); accordingly, model transformations (model-to-model and model-to-code) are described with the aid of the ATLAS Transformation Language (ATL).

The CIM and PIM are not separated and the selection of a possible formalism for knowledge representation is not offered. Ontology and rules are transformed into JESS, which supports the development and deployment of rule-based systems tightly coupled to Java applications. Furthermore, a Web-based architecture is generated from the CML model, enhanced by the interaction and presentation features.

The Web application code is based on the MVC architectural pattern and the Java Server Faces (JSF) framework, producing a set of JavaBeans classes and Java Server Pages (JSP). Further use of the results assumes that the user has programming skills.

Chaur (2004) offers an approach to create rule-based systems based on the concept of the EMF. In particular, the ECore meta-metamodel is used to describe a Rule Meta-Model which defines a conceptual model for representation of domain expert’s knowledge in the form of JESS rules, but a clear description of CIM, PIM and a Platform-Specific Model (PSM) is lacking. In general, the principle of the generator for the JESS platform (oriented to programmers) is implemented.

Cabello et al. (2009) suggest an implementation of the MDA for the PRISMA platform. This tool allows generation of diagnostic ESs (as PRISMA architectural models) on the basis of conceptual models describing various aspects of software: The feature model, the decision tree, the domain conceptual model, the application domain conceptual model and etc. In this case, the first two models are considered as CIM and the rest as PIM. No specialized languages are used to implement the model transformations. The main results are the generated program codes for C# and .NET.

The model transformation is one of the main principles of the MDE/MDE approach and can be considered from different points of view. In particular, (Kleppe et al., 2003; Czarnecki and Helsen, 2006) identified two types of transformations:

- Model-to-Model (M2M)
- Model-to-Text (M2T) and Text-to-Model (T2M)

At the same time, the M2T transformation corresponds to the concept of ‘pretty printing’ in the program transformation and the Model-to-Code (M2C) can be considered as a special case of M2T.

Two types of transformations are identified in (Mens and Gorp, 2006) in accordance with the modeling languages used to describe the source and target models:

- The endogenous transformation is a transformation between models that uses one modeling language
- The exogenous transformation is a transformation between models that uses different modeling languages

The model transformations can also be classified by the transformation direction (Mens and Gorp, 2006):

- A vertical transformation is a transformation where the source and target models reside at different abstraction levels
- A horizontal transformation is a transformation where the source and target models reside at the same abstraction level

The transformations should satisfy the following main requirements (Czarnecki and Helsen, 2006; Gardner et al., 2003; Sendall and Kozaczynski, 2003):

- Completeness: It should allow one to represent any necessary transformation in accordance with the defined models
- Formality: It should allow automatic execution
- Flexibility: It should not depend on a specific subject domain

At present, there exist several research areas related to the implementation of model transformations:

- Using graph grammars (graph rewriting) (Rozenberg, 1999) (e.g., Visual Automated model TRAnsformations (VIATRA2) (Varro and Balogh, 2007), Graph REwriting And Transformation (GREAT) (Balasubramanian et al., 2007), Henshin (Arendt et al., 2010), etc.)
• Using special languages and standards of model transformation (e.g., Query/View/Transformation (QVT) (QVT, 2017), ATL (Jouault et al., 2008), Epsilon (2017), etc.)
• Using declarative and procedural programming languages (Berman et al., 2010)
• Using languages for transforming XML documents (e.g., eXtensible Stylesheet Language Transformations (XSLT) (XSLT, 2017), etc.)

In the context of the MDA approach, it is recommended to use the standard for the M2M transformation called the QVT (Operational, Relational and Core languages). However, a significant drawback of QVT (like all model transformation languages) is the high qualification requirements for a user (developer). In particular, the user should:

• Know the syntax of the specific model transformation language
• Be able to describe transformation rules with the aid of the transformation language
• Know the meta-modelling languages (e.g., MOF, Ecore, KM3, etc.) to define the source and target languages (to support the model transformation process)
• Know and be able to use other languages in addition to the main model transformation languages, for example, the Object Constraint Language (OCL)

Therefore, we decided to make an ‘ad-hoc’ solution and use a direct-manipulation approach (Czarnecki and Helsen, 2006) for description of transformations and a general-purpose programming language (Object Pascal) to provide the internal representation and transformations of the models in the prototype (framework) of the software tool that implements the approach proposed.

The Problem Statement

Analysis of the existing technologies for the development of ESs and KBs (Jackson, 1998; Giarratano and Riley, 2004; Liebowitz, 1998; Luger, 2008; Djurić et al., 2005; Canadas et al., 2009) revealed that they primarily target users with knowledge of software engineering.

Therefore, to apply these technologies, the developer should have programming skills and know at least one programming language for KBs. Similarly, if a programmer develops KBs, then he/she has to study the subject domain model and formalize basic concepts and relations. It is a rare occasion for the same person to have necessary programming skills and be an expert in the subject area.

As a result, we propose to adapt (modify) and apply the MDA approach to the automated creation of rule-based KBs and ESs, including automatic generation of program codes and specifications on the basis of the subject domain models represented in the form of graphics primitives. This type of automation would help minimize the participation of the programmer in the software development process.

We formalize an MDA as follows:

\[ MDA = \left\{ F_{\text{CIM} \rightarrow \text{PIM}}, F_{\text{PIM} \rightarrow \text{PSM}}, F_{\text{PSM} \rightarrow \text{CODE}} \right\} \]

where, \( L = \{UML\}; \text{CIM, PIM, PSM, PDM are corresponding models; } F_{\text{CIM} \rightarrow \text{PIM}}, F_{\text{PIM} \rightarrow \text{PSM}}, F_{\text{PSM} \rightarrow \text{CODE}} \text{ are model transformation rules.} \)

Thus, the main purpose of this paper is to adapt (to specialize) the MDA methodology in the context of the development of rule-based expert systems and knowledge bases, i.e. to define an \( MDA^{\text{RB}_E} \).

\[ MDA^{\text{RB}_E} = \left\{ L^{\text{RB}_E}, F^{\text{RB}_E}, \text{CIM}^{\text{RB}_E}, \text{PIM}^{\text{RB}_E}, \text{PSM}^{\text{RB}_E}, \text{PDM}^{\text{RB}_E}, F^{\text{RB}_E \rightarrow \text{PIM}}, F^{\text{RB}_E \rightarrow \text{PSM}}, F^{\text{RB}_E \rightarrow \text{CODE}} \right\} \]

Thus, it is necessary to define the elements of the \( MDA^{\text{RB}_E} \), including models and rules for the transformation of models in the context of designing rule-based ESs and KBs and implement them in the form of a special tool.

Prototyping Rule-Based Expert Systems with the Aid of Model Transformations

According to MDA (Sami et al., 2005; Frankel, 2003; Kleppe et al., 2003; MDA, 2017), the designed software, which includes a description of the basic concepts, the relations between them and methods for processing them, is represented in the form of information models defining the composition, structure and behaviour. Therefore, the process of software development is a gradual transition from abstract information models (i.e., models that do not contain the details of the implementation on a specific technological platform; such models are called logical) to specific information models (i.e., models that contain the details of the implementation on a specific technological platform; such models are called physical) with the subsequent generation (synthesis) of the program codes of a KB and an ES.

Main Stages

The development process of KBs and ESs is presented by a sequence of stages providing the creation and transformation of information models.

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**Stage 1: Building a Model of a Subject Domain**

The main concepts and relations. At this stage, the user creates a Computation-Independent Model (CIM). This model can be implemented in the form of ontology or an UML-model (in particular, as a class diagram). In addition to the concepts and relations of ‘is-part-of’ and ‘is-a’, the relation ‘depends-on’ is introduced; this relation provides a description of cause-and-effect relations. In the case of UML class diagrams, these types of relations are defined by the mechanism of stereotypes. 

A description of the main architectural elements of the ES (such as the ‘input form’; the ‘output form’ etc., which are derived from the ‘border class’; the ‘inference engine’, which is derived from the ‘control’; the ‘knowledge-base’) is also produced at this stage.

The efficiency of this stage can be improved by reusing the existing conceptual models created using various ontological and cognitive editors, such as CASE-tools (e.g., Protégé, CmapTools, IBM Rational Rose Enterprise) (Dorodnykh and Yurin, 2015). Most of the software that supports the MDA approach (e.g., Bold for Delphi) does not realize this stage and only enables development of the software starting at the next stage. In this case, the conceptual model of a subject domain (even presented in the form of ontology (Djurić et al., 2005)) is considered as a Platform-Independent Model (PIM) that describes the main concepts and business logic (that is acceptable for databases). In the case of developing intelligent systems, this stage is necessary and corresponds to the stage of the conceptualization of knowledge. This stage allows transition from a general conceptual model of a subject domain to a knowledge representation model (with logical rules).

**Stage 2: Building Platform-Independent Models (PIMs)**

The models of this stage describe logical rules that stem from the automated transformation of a CIM with the subsequent specification of the results of the automated transformation. In the process of the CIM transformation, the concepts are transformed into the fact templates and rule elements (such as the conditions and actions) and the cause-and-effect relations are transformed into logical rules. In fact, the automated formalization of a subject domain model is carried out.

Visual modelling is one of the main aspects of the MDA approach. MDA traditionally uses a Unified Modelling Language (UML) for building models. It should be noted that applying the MDA approach to develop specific software requires the use of UML extensions (Miguel et al., 2002) that allow one to take into consideration some features of a subject domain (e.g., telecommunication or health), architectures (e.g., real-time access and reliability) and programming languages and formalisms (e.g., Prolog). Because a UML is not intended for illustrative and unambiguous representation of cause-and-effect relations (logical rules), we use the author’s original notation of the ‘Rule Visual Modelling Language’ (RVML) to represent logical rules and furthermore, to serve as a UML.

**Stage 3: Building Platform-Specific Models (PSMs)**

That take into account the features of a certain knowledge representation language (e.g., CLIPS), such as priorities of rules and ‘by default’ values of slots.

**Stage 4: Generating the Code of a KB and an ES**

At this stage, the interpretation of the UML-class diagram (that describes the software architecture) and RVML diagrams is performed. The main results of the interpretation are the program codes and specifications for an interpreter. In the process of interpretation and code generation, the Platform Description Model (PDM) and rules for the transformation of models are used. In this case, a PDM describes the syntax and semantics of the programming languages for which program code is generated.

**Stage 5: Testing**

At this stage, the program codes obtained are tested in a special software (in the interpreter).

It should be noted that the end user (an expert or a system analytic) only designs a CIM, a PIM and part of a PSM. All the transformations of the models and the generation of program codes (with the possibility of modifications) are implemented with a specialized software that includes a PDM.

The described sequence of stages almost coincides with a ‘standard’ MDA approach, but the stage content is redefined on the basis of designs of the rule-based ESs and KBs.

Next, we focus on the models under study.

**Models**

The description of the models and their transformations are important for the MDA/MDE approach.
The Computation-Independent Model

The computation-independent model (CIM) can be presented in the form of ontology (Fig. 1) that includes the subject domain ontology (e.g., the reliability of technical systems) and the ontology of rule-based ESs, which includes the description of the main architectural elements that are necessary for the implementation of the approach proposed. In turn, the subject domain ontology includes the concepts (i.e., the classes and instances) and the relations between them including the basic data types; the classes and properties.

The Platform-Independent and Platform-Specific Models.

A PIM is described with two models and can be represented as follows:

\[ PIM^{RB\cdot ES} = \{ UML^{RB\cdot KB}, UML^{RB\cdot ES} \} \]

where, \( UML^{RB\cdot KB} \) is a model of a KB and \( UML^{RB\cdot ES} \) is a model of an ES architecture.

Representation and Modelling of the ES Architecture

The UML class diagrams with additional classes (e.g., ‘Input From Class’, ‘Output From Class’) that extend the standard classes of ‘Border Class’, ‘Entity’ and ‘Control’ are used for the representation and modelling of the ES architecture.

The following equations give the main concepts of \( UML^{RB\cdot ES} \):

\[
\begin{align*}
<UML\cdot RB\cdot ES> &= <Class> + \\
<Class> &= <Border\ Class> | <Entity> | <Control> \\
<Border\ Class> &= <Input\ Form\ Class> | <Output\ Form\ Class> \\
<Output\ Form\ Class> &= \text{Results form} | \text{Explanation form} \\
<Control> &= \text{DROOLS interpreter} | \text{CLIPS interpreter}.
\end{align*}
\]

Representation and Modelling of Logical Rules

The RVML-notation (RVML, 2017) (which is based on the UML) is used for the platform-independent modelling of logical rules (Fig. 2). This notation allows description of the cause-and-effect relations and abstraction from the features of programming languages for rule-based KBs.

In addition, the specification of certain elements of the notation (such as the Priority (P) and the Certainty Factor (CF)) provides the means to create a PSM, especially for a CLIPS.
The structure of a PIM in the form of a concept card is presented in Fig. 3.

**The Platform Model**

The C Language Integrated Production System (CLIPS) was selected as a platform model. The following equations give the main elements of the CLIPS in the EBNF:

\[
<\text{CLIPS}> = <\text{template}()>^*, <\text{fact}()>^*, <\text{rule}()>^*
\]

\[
<\text{template}> = \text{(deftemplate } <\text{template-name}> [<\text{optional-comments}>] [<\text{slot-definition}>^*])
\]

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Transformation of the Models

Thus, it is necessary to implement a sequence of exogenous vertical transformations:

• The M2M-transformation for $F_{\text{PB}_{\text{ES}}\rightarrow\text{PIM}}$,
• The M2M-transformation for $F_{\text{PIM}\rightarrow\text{PSM}}$,
• The M2C-transformation for $F_{\text{PSM}\rightarrow\text{CODE}}$.

The following is a fragment of the transformation rules in the EBNF:

\[
<\text{Transformation}> = <\text{Transformation rule}> \{<\text{Transformation rule}>\}.
\]

\[
<\text{Transformation rule}> = \text{Rule} \text{ name} \{<\text{Source model element}> \text{,} <\text{Result}>\}.
\]

\[
<\text{Source model element}> = <\text{ONT D element}> | <\text{ONT RB ES element}> | <\text{UML RB KB element}>.
\]

\[
<\text{Result}> = <\text{UML RB ES element}> <\text{UML RB KB element}> <\text{CLIPS element}> <\text{GUI element}>.
\]

where $<\text{ONT D element}>$, $<\text{ONT RB ES element}>$, $<\text{UML RB KB element}>$, $<\text{CLIPS element}>$, $<\text{GUI element}>$ are the elements of the domain ontology, the ontology of rule-based ESs, the UML-models of rule-based ESs, the rules (RVML) (Miguel et al., 2002), the CLIPS-models and the models of a Graphic User Interface (GUI), respectively.

Then, we use the following transformation rule templates:

\[
F_{\text{PB}_{\text{ES}}\rightarrow\text{PIM}} = \{\text{Rule} \text{ UML RB KB*-TO-CLIPS}, \text{Rule} \text{ UML RB KB*-TO-CLIPS}\}.
\]

\[
F_{\text{PIM}\rightarrow\text{PSM}} = \{\text{Rule} \text{ UML RB KB*-TO-CLIPS}, \text{Rule} \text{ UML RB KB*-TO-CLIPS}\}.
\]

\[
F_{\text{PSM}\rightarrow\text{CODE}} = \{\text{Rule} \text{ UML RB KB*-TO-CLIPS}, \text{Rule} \text{ UML RB KB*-TO-CLIPS}\}.
\]

Rule UML RB KB*-TO-CLIPS: $<\text{UML RB KB element}>, <\text{CLIPS element}>$.

Rule UML RB ES-TO-GUI: $<\text{UML RB ES element}>, <\text{GUI element}>$.

These are the transformation rules we employ:

• ONT D-TO-UML RB KB:

  Rule Class-Template $\{<\text{Class}>\}$.
  Rule Object-Fact $\{<\text{Object}>\}$.
  Rule Fact-UML RB KB: $\{<\text{Fact UML RB KB}>\}$.
  Rule Cause-Rule $\{<\text{Depends on}>, <\text{Rule UML RB KB}>\}$.
  Rule Property-Slot $\{<\text{Property}>, <\text{Slot}>\}$.
  Rule Value $\{<\text{Property value}>, <\text{Slot value}>\}$.

• ONT RB ES-TO-UML RB ES:

  Rule Form-UML $\{<\text{Form}>, <\text{Border Class}>\}$.
  Rule Knowledge_base-UML RB ES $\{<\text{Knowledge base}, <\text{Entity}>\}$.
  Rule Interpreter-UML RB ES $\{<\text{Interpreter}, <\text{Control}>\}$.

• UML RB KB*-TO-CLIPS:

  Rule Template-CLIPS $\{<\text{Template UML RB KB}>, <\text{template}>\}$.
  Rule Fact-CLIPS $\{<\text{Fact UML RB KB}>, <\text{fact}>\}$.
  Rule Rule-CLIPS $\{<\text{Rule UML RB KB}>, <\text{rule}>\}$.
  Rule Slot-CLIPS $\{<\text{Slot UML RB KB}>, <\text{Slot value}>\}$.
  Rule Value-CLIPS $\{<\text{Value UML RB KB}>, <\text{Value}>\}$.

• UML RB ES-TO-GUI:

  Rule Border Class-GUI $\{<\text{Border Class}, <\text{GUI Border Class}>\}$.
  Rule Entity-GUI $\{<\text{Entity}, <\text{GUI Entity}>\}$.
  Rule Entity-GUI $\{<\text{Control}, <\text{GUI Control}>\}$.

The elements of the models can be represented in a (Table 1).

The model transformation rules are implemented with an imperative programming language.
Table 1: A fragment of a table of mapping of models’ elements (CIM to PIM and PIM to CLIPS and DRL)

| CIM elements       | PIM elements                                   | CLIPS elements               | DRL elements               |
|--------------------|-----------------------------------------------|------------------------------|----------------------------|
| Class              | TemplateFact (name, description)              | (deftemplate name “description” | declare name               |
| Property type      | Slot (description, value)                     | (slot name)                  | name                       |
| Property value     | Slot value                                    | (default value)              |                            |
| Property type      | Slot type                                     | (type datatype)              | : datatype                  |
| Relationship       | Rule (nodal element)                          | (defrule name)               | rule ”name” salience 0     |

Implementation

The approach proposed was implemented in the form of a research prototype of software known as the Personal Knowledge Base Designer (PKBD, 2017).

This software includes main modules with the following purposes:

- Designing and modelling; these modules are intended to create an application model and include a model editor, a model checker and modules for importing and exporting models
- Code generation; this module generates the program codes, including specifications for the interpreter and CLIPS codes
- Interpretation and control; these modules provide execution, including the interpretation and access to model elements and the interaction between the data level and the graphical user interface

The software provides full support for stages 1 and 2 of the proposed approach and partial support for stages 3-5.

Consider an example of application of the proposed approach for the development of a KB and an ES for the definition of the causes of damage and destruction of construction materials in petrochemistry.

The main cause of damage and destruction of a construction is degradation processes. The processes of degradation (Berman and Nikolaichuk, 2007) are the objective physical-chemical processes conditioned by both different technological processes and structural, manufacturing and maintaining irregularities which cause damages and destruction of materials and parts, failures of mechanical and petrochemical systems (or apparatus) and emergencies. Each process of degradation is characterized by a mechanism and kinetics. A mechanism of degradation is a set of properties of the technological object and effecting factors. A kinetics is a set of micro-and (or) macroscopic phenomena resulting from accumulating elementary movement acts. A description of kinetics includes: Events; event parameters; functional relations (if it is possible) for the definition of event parameters at a specified moment of time. In the field of safety the degradation processes are called hazardous processes.

According to the approach proposed, in order to develop a KB and an ES for definition of the causes of damage and destruction of construction materials, it is necessary to design conceptual models of the basic concepts of the subject domain that will be a CIM:

Stage 1

Building a CIM using a model of the dynamics of technical states (Berman and Nikolaichuk, 2007) by the experts. The main result of this stage is the subject domain concepts and relations.

In particular, a fragment of a CIM (Fig. 4) describes a mechanism of a degradation process (exist-mech), events (exist-event), a construction material (material), a technological environment, etc. At the same time, the «association» relation denotes the existence of relations between concepts that can be interpreted as cause-and-effect relationships.

Stages 2 and 3

Building a PIM includes the definition of cause-and-effect relationships in the form of logical rules. In addition, the ES architecture is created on the basis of the transformation of a CIM. Depending on the element type of the CIM, the concepts are transformed to templates for facts and rules (Fig. 5) for further modifications by the user with consequent destining specific rules (Fig. 6).

In addition to the PIM for a KB, a PIM for the ES is formed. The PIM for the ES includes a description of the main GUI forms and this model is created on the basis of a rule chain analysis. In particular, the following rules (forming the PIM for a KB) were obtained:

1. IF the water is under pressure of 3-4 MPa AND the temperature is approximately 300°C AND there are chlorine ions AND there is dissolved oxygen THEN the technological environment is active
2. IF we have low-alloy steel THEN the construction material is sensitive
3. IF the construction material is sensitive AND the technological environment is active with properties
Alternation AND incident object is a pipe into pipe AND a constant mechanical stress with high cycle frequency exists THEN the event is corrosion AND the mechanism is local corrosion \( (C_f = 0.6) \) AND the mechanism is corrosion cracking \( (C_f = 0.9) \).

Fig. 4: A fragment of a CIM in the form of a UML class diagram (IBM Rational Rose)

Fig. 5: An example of a template for a rule (RVML) (Dorodnykh and Yurin, 2015)

Fig. 6: An example of a specific rule (RVML) (Dorodnykh and Yurin, 2015)
These rules form a chain of logical inference that does not require any additional information (i.e., this chain uses the contents of the working memory and the initial data entered by the user). The PIM for the ES (the architecture) corresponding to this chain includes the following software components:

- The initial data input form that provides the input information on the technological environment, the stresses, the investigated object and the material
- The inference machine (this element is a part of the ES and is hidden from the user)
- The output form that provides the publication of the results of the logical inference
- The output form that provides an interpretation of the results obtained (it shows activated rules and modified, added and deleted facts)

Stage 4
Generating a code and specifications, including:

- The CLIPS code

Specifications of the ES for the interpreter, which provides the generation of the user interface for the creation, reading, updating and deleting (CRUD) of the KB elements (Fig. 7) and the interaction between software components.

Fig. 7: An example of a PKBD GUI (Dorodnykh and Yurin, 2015)

Fig. 8: An example of a GUI: Initial facts preview
Stage 5

Testing a KB and an ES is carried out by an expert by means of logical inferences (Fig. 8 and 9). It is possible to return to one of the previous stages in accordance with the results of the testing.

Efficacy Evaluation

The results obtained (the approach and the software) were verified on the basis of the Irkutsk National Research Technical University (IrNRTU). The case study involved 60 students, who graduated from the Popov Cybernetics Institute, where they completed training in CASE-tools, Means of Information Technologies and Programming Technologies. As a result, the students know the basic concepts of software design, UML, knowledge management and expert systems.

The main objectives of the case study were: (1) to assess the complexity of the development of knowledge bases of expert systems using our approach and the software developed (UML-modeling + PKBD). Denote this approach as A1; (2) to compare A1 with the complexity of the KBs development under different conditions:

- Without UML-modeling, but with the use of the software for knowledge base design, in particular, ClipsWin (2017) – a free and simple CLIPS editor for Windows (this is just a pure programmer’s approach, denote this approach as A2)
- UML-modeling + other software for knowledge base design, in particular, ClipsWin (denote this approach as A3)
- IBM Rational Rose (2017) is chosen as a UML-modeling tool which is widely used when creating non-specialized software

There are 20 variants (tasks) for the design of static expert systems for solving problems of diagnosing or prognosis in different subject areas. Some constraints were imposed on the characteristics of subject area models and knowledge bases (on the tasks), in particular:

- The number of subject area entities: 5-10
- The number of properties of subject area entities: 3
- The number of connections between subject area entities: 5-10
- The number of cause-effect relations (generalized rules): 3-4
- The number of instances of cause-effect relations (possible concrete rules): 10-15

Using the constraints provides multiple repetitions of the tasks and their time compactness. The time criterion is used (the time required to perform certain stages of development of expert systems) to assess the complexity.

The assessment was carried out in the following stages (Jackson, 1998):

- Conceptualization (including building the conceptual model)
- Formalization (including the transformation of the key concepts and relations to some formal knowledge representation language)
- Programming (including the transformation of formalized knowledge into a working program)

The main results of the conceptualization and formalization stages are the conceptual models of the subject areas presented in the form of UML class diagrams. The main results of the implementation stage are syntactically corrected program codes of the knowledge bases, checked to ensure their adequacy and consistency.

For each variant (task) three results describing the time used were obtained, the average of their values is presented in Table 2 and Fig. 10.
Table 2: The results of evaluation of the time used

| Variant (Task) | UML-modeling with the aid of IBM Rational Rose, min. | Designing with the aid of knowledge base A1: IBM PKBD, min. | A2: IBM rational rose + PKBD, min. | A3: IBM rational rose + ClipsWin, min. | Relative difference, % |
|---------------|--------------------------------------------------|--------------------------------------------------|---------------------------------|---------------------------------|------------------------|
| 1             | 10.89                                            | 7.2                                             | 18.09                           | 41.29                           | 30.4                   |
| 2             | 8.36                                             | 7.1                                             | 15.46                           | 32.86                           | 24.5                   |
| 3             | 8.58                                             | 8.3                                             | 16.88                           | 36.46                           | 27.88                  |
| 4             | 9.36                                             | 5.83                                            | 15.19                           | 26.82                           | 17.46                  |
| 5             | 11.25                                            | 5.52                                            | 16.77                           | 64.41                           | 53.16                  |
| 6             | 10.78                                            | 4.6                                             | 15.38                           | 43.8                            | 33.02                  |
| 7             | 6.6                                              | 15.82                                           | 22.42                           | 68                              | 61.4                   |
| 8             | 10.95                                            | 7.56                                            | 18.51                           | 57.23                           | 46.28                  |
| 9             | 7.37                                             | 7.2                                             | 14.57                           | 54.71                           | 47.34                  |
| 10            | 12.58                                            | 6.6                                             | 19.18                           | 42.7                            | 30.12                  |
| 11            | 8.69                                             | 5.5                                             | 14.19                           | 38.01                           | 29.32                  |
| 12            | 8.36                                             | 6                                               | 14.36                           | 45.22                           | 36.86                  |
| 13            | 10.64                                            | 7.42                                            | 18.06                           | 44.31                           | 33.67                  |
| 14            | 10.66                                            | 10.23                                           | 20.89                           | 50.57                           | 39.91                  |
| 15            | 10.01                                            | 7.56                                            | 17.57                           | 55.5                            | 45.49                  |
| 16            | 10.92                                            | 8.96                                            | 19.88                           | 49.42                           | 38.5                   |
| 17            | 8.14                                             | 8.36                                            | 16.5                            | 45.59                           | 37.45                  |
| 18            | 11.55                                            | 18                                              | 29.55                           | 47.43                           | 35.88                  |
| 19            | 11.85                                            | 5.2                                             | 17.05                           | 43.28                           | 31.43                  |
| 20            | 9.12                                             | 7.44                                            | 16.56                           | 40.95                           | 31.83                  |

The resulting average value of the relative difference: **48.2**

![Bar chart](image)

Fig. 10: The results of evaluation of time used

Let us highlight the features of performing the work at various stages for different approaches:

A2: The ClipsWin has functional limitations when it comes to manual editing of codes. This obstacle stipulated application of the additional text editor, Programmer's Notepad, at the implementation stage.

In particular, first, the description of the code in an external text editor (using the copying and pasting of
individual blocks of a code) is carried out and then the resulting code is imported into ClipsWin, which carries out the syntax check. In practice, using this scheme, the creation of knowledge bases took one and a half time less.

A3: This approach provides the greatest time performance and uses IBM Rational Rose Enterprise for conceptual modeling of the subject area. The greatest time performance is caused by the manual transfer of the obtained conceptual models into (due to the absence of the function of automatic code generation for the knowledge base on the basis of conceptual models).

The analysis of the effectiveness of the approach proposed by the time criteria showed that the effectiveness of the development of knowledge bases by the A1 can be increased by 60.3% Vs. A3 and by 48.2% Vs. A2 on average due to the automatic code generation based on conceptual models, which in turn allows:

- Increase of the effectiveness of using the results of the conceptualization and formalization stages in the form of UML class diagrams, considering them not as static images, but as a basis for the automatic formation of the program codes in accordance with the ideology of a model-driven approach
- Reduction of the risk of design errors by enabling rapid prototyping knowledge bases and getting their program codes
- Elimination of programming errors (hand coding errors) by automatically transferring the elements of the conceptual models into CLIPS language constructs

**Discussion**

In accordance with the problem statement, we proposed an approach for developing ESs and KBs based on the MDA/MDE principles and redefined its main elements, in particular: Models (CIM, PIM, PSM, PDM) and the main stages. Methodologically, this approach is a combination of:

- The classical methodology for the development of ESs and KBs (Jackson, 1998; Giarratano and Riley, 2004; Liebowitz, 1998; Luger, 2008), that forms a chain of steps: Identification, conceptualization, formalization, implementation and testing
- The MDE-based methodology (Sami et al., 2005; Djurić et al., 2005; Frankel, 2003; Kleppe et al., 2003; MDA, 2017; Schmidt, 2006), that forms a chain of steps: The creation of CIM, PIM, PSM and code generation (or model interpretation)

This combination is a qualitative difference between this work and similar ones (Table 3) and it allowed us to transfer the MDE principles in the field of knowledge engineering and will provide the use of the methodology proposed when creating other types of ESs, for example, case-based (by means of redefining PIM) or to extend the list of supported programming languages (by adding new PSMs).

In turn, the software (PKBD), which is implemented in the form of a shell, can be used by both programmers and non-programmers to create ESs and the generated codes of KBs can be used in other applications.

The main area of application of the proposed approach and software is the rapid prototyping of rule-based ESs and KBs on the basis of conceptual models.

The approach presented has some limitations: it helps create rule-based ESs and KBs only and does not enable the creation of ESs and KBs in the form of embedded components for intelligent systems. In future, we plan to eliminate these limitations:

- To provide the generation of program codes of embedded ESs for applications
- To extend support for programming languages and formats of conceptual models
- To specify the RVML in order to improve its expressiveness (for example, to define fuzziness, etc.) and ability to describe other knowledge representation formalisms
- To develop the web-oriented version of software (shell) to support the distributed user interaction through Internet when creating ESs and KBs

The results of testing of the approach and software proposed showed their high efficiency caused by the automatic code generation and the simplicity of the examples (tasks) with limitations. We expected that the superiority might be lost when solving more complex problems.

The main differences between the present work and those considered above are the following (Table 3):

- An explicit use of the MDE approach principles, including the identification of conceptual models of varying degrees of abstraction (CIM, PIM, PSM) and the consequent transformation of these models (in relation to the first group of works)
- A combination of conceptions of a generator (for the synthesis of KB codes) and an interpreter (for the synthesis of PSM specifications)
- A combination of the MDE-based and ES-based methods for the development of ESs, that allows further expansion of the set of supported knowledge formalisms (for example, for case-based ESs)
- Usage of RVML to describe PIM and PSM
- Usage of CLIPS and the Drools Rule Language (DRL) as platforms

DOI: 10.3844/jcssp.2018.680.698
Table 3: A brief comparison of some works that describe the creation of KBs and ESs on the basis of a MDE approach (SD – Subject Domain, DCM - Domain Conceptual Model)

| Criterion/Work | Dunstan et al. (2008) | Nofal and Fouad (2014; 2015) | Shaw et al. (2009) | Ruiz-Meza et al. (2011) | Touazi and Mesnoued (2009) | Kadhimi et al. (2013) | Canadas et al. (2009) | Chaur (2004) | Cabello et al. (2009) | Our |
|----------------|-----------------------|-----------------------------|-------------------|-------------------------|---------------------------|----------------------|---------------------|--------------|---------------------|-----|
| Conceptual models used | XML, WorldNet ontology XML, Ontology (OWL, Protege) | Ontology, Tree, UML | – Ontology, Rule models | Conceptual models, Ontology (OWL, UML, Mind Maps) | – Decision Tree, Dynamic Tree, DCM, Applied UML, RVML, Mind Maps | – PRISMA | – PRISMA, CLIPS, DRL, DSL, MDD-based + ES-based, 3 transformations | – PRISMA, C# .NET, MDD-based, 3 transformations | – PRISMA | – PRISMA |
| Methodology | HTML, Perl, Prolog | Own, JESS, Java | Own, Own, Own | Own, CLIPS, Prolog, JESS, Java | JESS, Java | JESS, Java | JESS, Java | PRISMA, C# .NET | MDD-based, 2 transformations | PRISMA, C# .NET, Mind Maps |
| Universality | No, SD university courses, Yes, Shell | No, SD: corporate financial rating | Yes, Shell | Yes, Shell | Yes, Shell | No, SD: Shell, diagnostics | Yes, EMF | Yes, EMF | No, SD: diagnostics | Yes, Shell |
| Special language and standard used | (Ad-hoc) | (Ad-hoc) | (Ad-hoc) | (Ad-hoc) | (Ad-hoc) | (Ad-hoc) | (Ad-hoc) | (ATL) | (ECore) | (Ad-hoc) |
| Non-programmers | – | + | – | + | + | – | – | – | + | + |

Conclusion

The paper describes the specialization and implementation of the MDA/MDE approach for the prototyping rule-based ESs and KBs. The specialization include: The use of ontology as the CIM, the use of the Rule Visual Modelling Language (RVML) notation to create the PIM and the PSM and the use of CLIPS and DRL as the PDM. The problem statement, basic elements of the modified approach and formalized descriptions of the models and transformations are considered.

The approach proposed is designed for non-programmers: Experts and system analytics who can only develop two information models: A CIM (ontology) and PIMs (models of a rule-based KB and ES). In this case, it is possible to automate the PIMs’ creation with automated analyses of conceptual models (UML class diagrams) (Dorodnykh and Yurin, 2015). According to the MDA/MDE approach, other models are either integrated into the software that implements the approach or they are created automatically up to the testing stage. At the testing stage, the user can check the developed KB for completeness and validity.

The benefits of the approach proposed in comparison with the standard method of ES development (Jackson, 1998; Giarratano and Riley, 2004; Nofal and Fouad, 2014) are as follows:

- A significant reduction of time for the implementation stage and the elimination of programming errors through automatic code generation
- A reduction of time for the identification, conceptualization and formalization stages due to the use of an ontology and cognitive graphics

The approach proposed is implemented in the form of a research prototype of software that is intended for the rapid development of prototypes of rule-based KBs and ESs. The main advantages of the personal knowledge base designer are listed below:

- Built-in editor of models
- Integration with IBM Rational Rose (in terms of imports of UML-models)
- Generation of CLIPS and DRL code and specifications for the interpreter
- Usage of models at runtime

The approach and software proposed were used for the development of the ES for defining the causes of damage and destruction of construction materials (Berman et al., 2015) and they were also used in the educational process at the Irkutsk National Research Technical University (IrNRTU).

Acknowledgement

The reported study was partially supported by RFBR (research projects No. 15-07-03088, 15-07-05641, 16-37-00041).

Author’s Contributions

Alexander Yurievich Yurin: He devised the main conceptual ideas, designed the research plan, made an implementation and experiments.
Nikita Olegovich Dorodnykh: He made model transformations and experiments.
Olga Anatolievna Nikolaychuk: She built models and made a formalization.
Maksim Andreevich Grishenko: He made an implementation.

Ethics
This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

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