VISUAL SOFTWARE MODELLING WITH EXTENDED RULE-BASED MODEL
A Knowledge-based Programming Solution for General Software Design

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Keywords: Rule-based programming, software modelling, knowledge engineering, automated implementation, XTT.

Abstract: Rule-based programming paradigm is omnipresent in number of engineering domains. However, there are some fundamental semantical differences between it, and classic procedural, or object-oriented approaches. Even though, there has been a lot of effort to use rules to model business logic in classic software no generic solution has been provided so far. In this paper a new approach for generalized rule-based programming is given. It is based on a use of advanced rule representation, which includes an extended attribute-based language, a non-monotonic inference strategy, with explicit inference control on the rule level. The paper shows how some typical programming constructions, as well as classic programs can be modelled in this approach. The approach can largely improve both the design and the implementation of complex software.

1 INTRODUCTION

Rule-based programming paradigm is omnipresent in number of engineering domains such as control and reactive system, diagnosis and decision support. Recently, there has been a lot of effort to use rules to model business logic in classic software. However, there are some fundamental semantical differences between it, and classic procedural, or object-oriented approaches. This is why no generic modelling solution has been provided so far.

The motivation of this paper is to investigate the possibility of modelling typical programming structures with an extended forward-chaining rule-based programming. In this paper a new approach for generalized rule-based programming is given. It is based on a use of an advanced rule representation, which includes an extended attribute-based language (Ligęza, 2006), a non-monotonic inference strategy, with explicit inference control on the rule level. The paper shows, how typical programming constructions (such as loops), as well as classic mini-programs (such as factorial) can be modelled in this approach. It presents possibilities of efficient integration of this technique with existing software systems.

The paper is composed of several parts. In Sect. 2 basics of the rule-based programming are given, and in Sect. 3 fundamental differences between software and knowledge engineering are given. Then, in Sect. 4 the extended model for rule-based systems is considered. The application of this model is discussed in Sect. 5. This model could be integrated in a classic software system in several ways, considered in Sect. 6. The research presented in this paper is a work-in-progress. Some directions for the future research as well as concluding remarks are given in Sect. 7.

2 RULE-BASED PROGRAMMING

Rule-Based Systems (RBS) constitute a powerful AI tool (Negnevitsky, 2002) for specification of knowledge in design and implementation of systems in the domains such as system monitoring and diagnosis, intelligent control, and decision support. For the state-of-the-art in RBS see (Liebowitz, 1998; Jackson, 1999; Ligęza, 2006). From a point of view of classical knowledge engineering (KE) a rule-based expert system consists of a knowledge base and an inference engine. The KE process aims at designing and evaluating the knowledge base, and implementing the

J. Nalepa G. and Wojnicki I. (2007).
VISUAL SOFTWARE MODELLING WITH EXTENDED RULE-BASED MODEL - A Knowledge-based Programming Solution for General Software Design.
In *Proceedings of the Second International Conference on Evaluation of Novel Approaches to Software Engineering* , pages 41-47
DOI: 10.5220/0002586600410047

inference engine. The process of building the knowledge base involves the selection of a knowledge representation method, knowledge acquisition, and possibly low-level knowledge encoding. In order to create an inference engine a reasoning technique must be selected, and the engine has to be programmed.

In the formal analysis of RBS (Ligęza, 2006) some important aspects of the design and implementation are identified. The first concerns *rulebase design*, including: the formal logical language of the representation, formal syntax of the representation method, representation expressiveness, which is related to the expressiveness of the underlying logic, and particular rule syntax. The second comes down to the *inference engine implementation*, including: inference strategy, interpreter model, including rule matching method, and conflict resolution algorithm.

In order to design and implement a RBS in an efficient way, the knowledge representation method should support the designer, introducing a scalable *visual representation*. As the number of rules exceeds even relatively very low quantities, it is hard to keep the rule-base consistent, complete, and correct. These problems are related to knowledge-base verification, validation, and testing. To meet security requirements a *formal analysis and verification* of RBS should be carried out (Vermesan and Coenen, 1999). This analysis usually takes place after the design stage. However, there are design and implementation methods, such as the XTT, that allow for on-line verification during the design and gradual refinement of the system.

Supporting rulebase modelling remains an essential aspect of the design process. In this area number of approaches are present. The simplest one consists in writing rules in the low-level RBS language, such as one of *Jess* (`www.jessrules.com`). A more sophisticated approaches are based on the use of some classic visual rule representations. This is a case of *LPA VisiRule*, (`www.lpa.co.uk`) which uses decision trees. Approaches such as XTT (Nalepa, 2004) aim at developing a new language for *visual rule modelling*.

While RBS found wide range of industrial applications in „classic AI domains" e.g. decision support, system diagnosis, or intelligent control, the technology did not find applications in the mainstream software engineering – due to some fundamental differences between knowledge and software engineering.

3 SOFTWARE AND KNOWLEDGE ENGINEERING

Rule-based systems (RBS) constitute today one of the most important classes of the so-called Knowledge Based Systems (KBS). Building real-life KBS is a complex task. Since their architecture is fundamentally different from classic software, typical Software Engineering approaches cannot be applied efficiently. Some specific development methodologies, commonly referred to as *Knowledge Engineering* (KE), are required.

What makes KBS distinctive is the separation of knowledge storage (the knowledge base) from the knowledge processing facilities. In order to store knowledge, KBS use various knowledge representation methods, which are *declarative* in nature. In case of RBS these are *production rules*. Specific knowledge processing facilities, suitable for particular representation method being used, are selected then. In case of RBS these are logic-based inference engines.

The knowledge engineering process, involves two main tasks: knowledge base design, and inference engine implementation. Furthermore, other tasks are also required, such as: knowledge base analysis and verification, and inference engine optimization. The performance of a complete RBS should be *evaluated* and *validated*. While this process is specific to expert systems, it is usually similar in case of other KBS.

What is important about the process, is the fact that it should *capture* the expert knowledge and *represent* it in a way that is suitable for processing (this is the task for a knowledge engineer). The actual structure of a KBS does not need to be system specific – it should not „mimic" or model the structure of the real-world problem. However, the KBS should capture and contain knowledge regarding the real-world system. The task of programmers is to develop processing facilities for the knowledge representation. The level at which KE should operate is often referred to as *the knowledge level* (Newell, 1982). It should be pointed out, that in case of KBS there is no single universal engineering approach, or universal modelling method (such as UML in software engineering). Different classes of KBS may require specific approaches, see (Ligęza, 2006; Torsun, 1995).

Software engineering (SE) is a domain where a number of mature and well-proved design methods exist; furthermore, the software development process and its life cycle is represented by several models. One of the most common models is called *the waterfall model* (Sommerville, 2004). In the software engineering process a number of development roles can be identified: users and/or domain experts, system analysts, programmers, testers, integrators, and end users (customers). What makes this process different from knowledge engineering is the fact that systems analysts try to *model* the *structure* of the real-world information system in the structure of computer software system. So the structure of the software corresponds, to some extent, to the structure of the real-world system. Then programmers encode and implement the model (which is the result of the system analysis) in some lower-level programming language.

The important difference between SE and KE, is that the former tries to *model* how the system *works*, while the latter tries to capture and *represent* what is *known* about the system. The knowledge engineering approach assumes that information about how the system works can be inferred automatically from what is known about the system (Nalepa, 2005).

The fundamental differences between the KE and SE approaches include:

- declarative vs. procedural point-of-views,
- clear semantic gaps in the SE process, between the requirements, design, and implementation,
- the application of gradual abstraction as the main approach to the design of KBS.

The solution introduced in this paper aims at integrating a classic KE methodology of RBS with SE. The model considered here, based on the XTT method could serve as an effective bridge between SE and KE.

4 EXTENDED RULE-BASED MODEL

The approach considered in this paper is based on an extended rule-based model. The model uses the *XTT* knowledge method with certain modifications. The XTT method was aimed at forward chaining rule-based systems. In order to be applied to general programming it is modified in several aspects. Furthermore, it proved to be robust and highly effective combining features of *decision tables* and *decision trees* (Nalepa, 2004).

4.1 XTT – Extended Tabular Trees

The *XTT* (*EXtended Tabular Trees*) knowledge representation (Nalepa, 2004; Nalepa and Ligęza, 2005a), has been proposed in order to solve common design, analysis and implementation problems with RBS. In this method three representation levels are addressed:

- *visual* – the model is represented by a hierarchical structure of linked extended decision tables,
- *logical* – tables correspond to sequences of extended decision rules,
- *implementation* – rules are processed using a Prolog representation.

A1		An	-X	+Y	H
a11		a1n	x1	y1	h1
am1		amn	xm	ym	hm

Figure 1: A single XTT table.

On the visual level the model is composed of extended decision tables. A single table is presented in Fig. 1. The table represents a set of rules, having the same attributes.

A rule can be read as follows:

$$IF\ (A11 \in a11) \wedge \ldots (A1n \in a1n)\ THEN$$
$$retract(X = x1), assert(Y = y1), do(H = h1).$$

It includes two extensions compared to classic RBS:

- non-atomic attribute values, used both in conditions and decisions,
- non-monotonic reasoning support, with dynamic assert, retract operations in decision part.

Every table row corresponds to a decision rule. Rows are interpreted from the top row to the bottom one. Tables can be linked in a graph-like structure. A link is followed when rule (row) is fired.

There are tools (see (Nalepa, 2004; Nalepa and Ligęza, 2005b))which support the design process using the above visual model. They are capable of defining attributes, creating linked XTT tables, and last but not least running the inference process. There is also an ongoing research to make these tools cover functionality presented in Sect. 4.2.

On the logical level a table corresponds to a number of rules, processed in a sequence. If a rule is fired and it has a link, the inference engine processes the rule in another table. The rule is based on a *attributive language* (Ligęza, 2006).

It corresponds to a *Horn* clause:

$$\neg p_1 \vee \neg p_2 \vee \ldots \vee \neg p_k \vee h$$

where p is a literal in SAL (set attributive logic) (see (Ligęza, 2006)) in a form:

$$A_i(o) \in t$$

where $o \in O$ is a object referenced in the system, and $A_i \in A$ is a selected attribute of this object (property),

$t \subseteq D_i$ is a subset of attribute domain A_i. Rules are interpreted using a unified knowledge and fact base, that can be dynamically modified during the inference process using Prolog-like assert/retract operators in rule decision.

Rules are implemented using Prolog-based representation (see (Nalepa and Ligęza, 2006)). Rule representation uses Prolog terms, which is a very flexible solution. However, it requires a dedicated meta-interpreter (Covington et al., 1996; Bratko, 2000).

This model has been successfully used to model classic rule-based expert systems. For the needs of general programming described in this paper, some important modifications are proposed.

4.2 XTT Enhancements

Considering the use of XTT for general applications, there have been several extensions proposed regarding the base XTT model. These are: *Grouped Attributes*, *Attribute-Attribute Comparison*, *Not-Defined Operator*, *Link Labeling*, *Scope Operator*, *Multiple Rule Firing*. Applying these extensions constitute the *XTT Plus* (or XTT+ for short).

Grouped Attributes provide means for putting together some number of attributes to express relationships among them and their values. As a result a complex data structure, called a *group*, is created which is similar to constructs present in programming languages (i.e. C language structures).

A group is expressed as:

$$Group(Attrinbute1, Attribute2, \ldots, AttributeN)$$

Attributes within a group can be referenced by their name: $Group.Attribute1$ or position within the group: $Group/1$. An application of such Grouped Attributes could be expressing spatial coordinates: $Position(X,Y)$ where *Position* is the group name, X and Y are attribute names.

The *Attribute-Attribute Comparison* concept introduces powerful mechanism to the existing XTT comparison model. In addition to comparing an attribute value against a constant (*Attribute-Value Comparison*) it allows for comparing an attribute value against another attribute value.

The *Attribute-Value Comparison* can be expressed as a condition:

```
if (Attribute OPERATOR Value) then ...
```

where `OPERATOR` is a comparison operator i.e. equal, greater then, less than etc., while *Attribute-Attribute Comparison* is expressed as a condition:

```
if (Attribute1 OPERATOR Attribute2) then ...
```

where `OPERATOR` is a comparison operator or a function in a general case:

```
if (OPERATOR(Att1,...,AttN)) then ...
```

The proposed *Not-Defined* (N/D) operator checks if a value for a given attribute has been defined. It has a broad application regarding modelling basic programming structures, i.e. to make a certain rule fired if the XTT table can be executed for the first time.

The *Link Labeling* concept allows to reuse certain XTTs, which is similar to subroutines in procedural programming languages. Such a reused XTT is executed in several contexts. There are incoming and outgoing links. Links are labeled, if control comes from a labeled link it has to be directed through an outgoing link with the same label. There can be multiple labeled links for a single rule then. If an outgoing link is not labeled it means that if a corresponding rule is fired the link will be followed regardless of the incoming link label. Such a link (or links) might be used to provide control for exception-like situations or making a set of XTTs reusable.

The graphical *Scope Operator* provides a basis for modularized knowledge base design. It allows for treating a set of XTT as a certain *Black Box* with well-defined input/output. Outside the given scope only conditional attributes for the incoming links and conclusion attributes for the outgoing links are visible.

Scope Operators make the knowledge base more scalable and it provides modularity. Furthermore it allows rule management at the scope level, managing a given scope, or set of scopes. This includes checking rule consistency within a given scope.

Since multiple values for a single attribute are already allowed, it is worth pointing out the the new inference engine being developed treats them in a more uniform and comprehensive way. If a rule is fired and the conclusion or assert/retract use a multivalue attribute such a conclusion is executed as many times as there are values of the attribute. It is called *Multiple Rule Firing*. This behavior allows to perform aggregation or set based operations easily.

5 MODELLING SOFTWARE WITH RULES

The XTT+ can be applied in other domains than RBS. The section presents typical programming constructs developed using the XTT+ model.

5.1 Basic Programming Structures

Two main constructs considered here are: a *conditional statement*, and a *loop*. Programming a conditional with rules is both simple and straightforward,

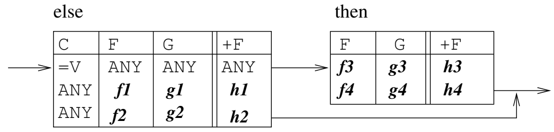

Figure 2: A conditional statement.

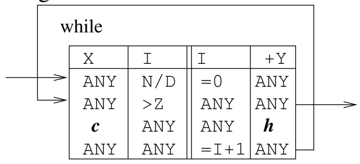

Figure 3: A loop statement.

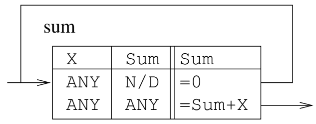

Figure 5: Sum implementation.

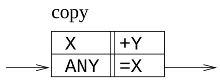

Figure 6: Copying elements of a set.

since a rule is by definition a conditional statement. In Fig. 2 two table system is presented. The first row of the `else` table represents the main conditional statement using attribute `C`, while the remaining rows implement the statements executed on attributes `G` and `F` when the condition is not met. If the condition is met, then the other table, simply called `then` is executed.

A loop can be easily programmed, using the dynamic fact base modification feature. In Fig. 3 a simple system implementing the *for*-like loop is presented. In the XTT table the initial execution, as well as the subsequent ones are programmed. The `I` attribute serves as the index. In the body of the loop the value of the decision attribute `Y` is modified depending on the value of the conditional attribute `X`. The loop ends when the index value is greater then `Z`. This could be easily generalized into the *while* loop.

5.2 Simple Programming Cases

A set of rules to calculate a factorial is given in Fig. 4. An argument is given as attribute X. The calculated result is given as Y. The iterative algorithm is implemented which uses S attribute as a counter.

Since an attribute can be assigned more than a single value (i.e. using the assert feature), certain operations can be performed on such a set (It is similar to aggregation operations regarding Relational Databases). An example of sum function is given in Fig. 5. It adds up all values assigned to X and stores the result as the value of *Sum* attribute. The logic behind is as follows. If *Sum* is not defined then make it 0 and loop back. Than, the second rule is fired, since *Sum* is already set to 0. The conclusion is executed as many times as values are assigned to X. If *Sum* has a value set by other XTTs prior to the one which calculates the sum, the result is increased by this value.

Assigning a set of values to an attribute based on values of another attribute is given in Fig. 6. The given XTT populates Y with all values assigned to X. It uses the XTT assert feature.

Using XTT even complex task such as browsing a tree can be implemented easily. A set of XTTs finding successors of a certain node in a tree is given in Fig.7. It is assumed that the tree is expressed as group of attributes $t(P,N)$, where N is a node name, and P is a parent node name. The XTTs find all successors of a node which name is given as a value of attribute P (it is allowed to specify multiple values here). A set of successors is calculated as values of F. The first XTT (labeled *tree1*) computes immediate child nodes of the given one. If there are any child nodes control is passed to the XTT labeled *tree2*. It finds child nodes of the children computed by *tree1* and loops over to find children's children until no more child nodes can be found. The result is stored as values of F.

6 MODEL INTEGRATION

The XTT+ has been discussed on the conceptual level of the visual representation. Two approaches to provide a runtime environment are considered.

The first one consists in generating native code in

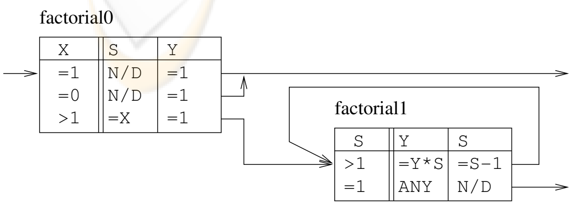

Figure 4: Factorial implementation.

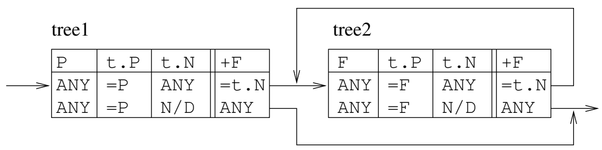

Figure 7: Finding successors in a tree.

an object-oriented language such as Java. This solves both the practical implementation as well as runtime problem. This solution is used in products such as *JBoss Rules* (formerly *Drools*). However, it does has a major drawback: the object-oriented semantics is very distant from the declarative rule semantics of XTT+. This instantly unveils a *semantic gap* which turns out to be a major limitation during the implementation and testing of the system. Furthermore, while a translation from XTT+ to object-oriented if fairly simple, a reversed one is complicated.

The second approach is based on using a high level Prolog representation of XTT. Prolog semantics includes all of the concepts present in the XTT+. It has the advantages of flexible symbolic representation, as well as advanced meta-programming facilities (Covington et al., 1996; Bratko, 2000). The XTT+-in-Prolog solution is based on the Prolog implementation, presented in (Nalepa and Ligęza, 2006). In this case a term-based representation is used, with an advanced meta interpreter engine provided. There are two ways of the integration of the Prolog-based XTT+ model with a Java application. The first one consists in linking the Prolog-based XTT+ interpreter with a Java application using Prolog-to-Java interface provided for some advanced Prolog implementations, such as SWI (`www.swi-prolog.org`). In this approach the SWI Prolog JPL interface is being used to communicate from the Prolog programs with Java objects. Another one relies on the idea of embedding the whole interpreter in a Java application, with use of Java-based Prolog interpreters. So far the *JIProlog* (`www.ugosweb.com/jiprolog`) has been considered.

Furthermore, the integration could be considered on an architectural level. The idea is to use the Mode-View-Controller (MVC) pattern (Burbeck, 1992). In this case the XTT+ would be used to build the application logic *model*, where-as other parts of the application, mainly the interface could be built with object-oriented languages such as Java. The application logic interfaces with object-oriented components. These components provide means for interaction with environment which is user interface and general input-output operations. It is also possible to extend the model with arbitrary code. There are several scenarios possible regarding interactions between the model and the environment. In general, they can be subdivided into output and input *schemas*. These schemas provide *view* and *controller* functionalities.

The *input schema* takes place upon checking conditions required to fire a rule. A condition may require input operations. A state of such a condition is determined by the data from the environment. Such a data could be user input, file contents, a state of an object, a result from a function. The input operation could be blocking or non-blocking providing basis for synchronization with environment. The input schema acts as the *controller* regarding the MVC approach.

The *output schema* takes place if a conclusion regards an output operation. In such a case the operation regard general output (i.e. through user interface), spawning a method or function, setting a variable etc. A conclusion also carries its state which is true or false depending on whether the output operation succeeded or failed respectively. If the conclusion fails, the rule fails as well. The output schema acts as the *view* regarding the MVC approach.

7 CONCLUDING REMARKS

Rule-based programming paradigm plays an important role in number of engineering domains. The fundamental semantical differences between it, and classic programming approaches do not allow for using it to model business logic in classic software.

In the paper the research in the field of knowledge and software engineering is presented. The research aims at the unification of knowledge engineering methods with software engineering. The paper presents a new approach for generalized rule-based programming called XTT+. It is based on the use of advanced rule representation, which includes an extended attribute-based language, a non-monotonic inference strategy, with explicit inference control.

The original contribution of the paper consists in the extension of the XTT rule-based systems knowledge representation method, into XTT+, a more general programming solution; as well as the demonstration how some typical programming constructions and classic programs can be modelled in this approach. Furthermore XTT+ is fully integrable with existing object-oriented programming languages such as Java. The integration is provided based on the Model-View-Controller concept. Future work will be focused on representation extensions and use cases. The original XTT has been applied to control systems, and selected security systems. The application of XTT+ will be also extended towards business rules systems, with richer semantics.

In its current stage, XTT+ can successfully model number of programming constructs and approaches. This proves XTT+ can be applied as a general purpose programming environment. However, the research should be considered an experimental one, and definitely a work in progress.

ACKNOWLEDGEMENTS

The paper is supported by the *HEKATE* Project funded from 2007–2008 resources for science as a research project.
Research supported from AGH University Grant No.: 11.11.120.44

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