Tool Support for Design Pattern Recognition at Model Level

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Abstract

Given the rapid rise of model-driven software development methodologies, it is highly desirable that tools be developed to support the use of design patterns in this context. This paper presents such a tool, called LAMBDES-DP, with UML diagrams as the software design models. Its theoretical foundation is a descriptive semantics of UML in first order logic, and the design patterns are formally specified in the same language. The tool uses the LAMBDES system to translate the UML diagrams into their descriptive semantics and invokes the theorem prover SPASS to decide whether the design conforms to a pattern. Our experiments show that our tool has significantly lower rates of false positive and false negative errors compared with existing tools.

1 Motivation and Related Work

Software design patterns are frequently used to share design expertise. They document solutions to commonly occurring design problems. It is widely recognized that their proper use can improve software quality and development productivity [29]. Software tools have been proposed that could spot the use of a pattern within a software system and/or check if a pattern is applied correctly. The prototype tool LAMBDES-DP presented in this paper is distinctive for two reasons. First, it facilitates model-driven development by working at the design level rather than code level. Secondly, it is based on a formalism that has been shown to be applicable to all 23 Gang of Four (GoF) patterns in [10].

Code-level tool support has been much reported [6], with examples including HEDGEHOG [5], FUJABA [24] and PINOT [25], but they all have relatively high error rates. As suggested in [13], this is probably because the level of abstraction is too low. Variations in implementation cannot be expressed systematically, for example, and important dynamic behaviours cannot be determined statically from the code alone.

Kim \textit{et al}. have advanced two separate approaches to design-level tool support, both based on the role-based metamodeling language RBML [13] for specifying patterns. In [14], they translate RBML into a query on a Prolog database representing the UML model, but without explaining how to translate either language into Prolog. In [15, 16], they report a plug-in called RBMLCC for IBM Rational Rose but then apply it to only 7 of the 23 GoF patterns.

Precision is essential for any tool, but the semantics of UML is lacking in this respect. So too is the usual presentation of design patterns: an informal combination of English, to explain basic principles, together with semigeneral UML diagrams and code examples, by way of illustration. So much work has gone into formal alternatives. Examples include the Design Pattern Modeling Language of Mapelsden \textit{et al}. [22], the graphical language LePUS of Eden [7, 8], the use of predicate logic and temporal logic by Taibi [27, 28] and Mikkonen [23], the extension of the UML meta-model and the Object Constraint Language (OCL) by Le Guennec \textit{et al}. [11], and many other works such as [17, 19, 20, 21, 30]. However, only RBML has been incorporated into tools like the one we propose here.

The language we use for specifying design patterns is that of Bayley and Zhu [1, 3]. They use a first-order predicate logic (FOL) language systematically derived from the abstract syntax of UML diagrams in GEBNF (Graphically Extended BNF). Patterns are then predicates on UML diagrams and pattern instantiation is predicate satisfaction. FOL is expressive enough for all 23 GoF patterns and is more readable than its rivals. Better still, in [2], it is used to compose patterns and to formally prove their properties. Note that the alternative of OCL is not designed for the meta-level and even when lifted, it cannot specify the absence of a relationship between classes; see [9] for other problems with OCL.

The remainder of the paper starts with the theoretical foundation of the tool in section 2, followed by a description of the tool LAMBDES-DP and the report on the experiment with it in sections 3 and 4, respectively. Finally, we conclude the paper with a brief discussion of future work in section 5.
2 Theoretical Foundations

2.1 Descriptive Semantics of UML

In [26], the formal semantics of UML is resolved into two aspects: descriptive semantics and functional semantics. The descriptive semantics defines which systems (e.g., software systems) are instances of a model. It does this with a set of FOL statements about the system being modelled in terms of basic modeling concepts such as classes, attributes, methods, inheritances, and associations, etc. A system in the domain is an instance of a model if and only if it satisfies the set of statements.

The functional semantics, in contrast, actually defines these basic modeling concepts, perhaps with axioms on the dynamic behaviour of systems or perhaps by mapping each system to an element of a denotational semantics domain. Then a collection of systems can be regarded as a domain if and only if it satisfies the axioms of the functional semantics. LAMBDES-DP is related only to the descriptive semantics, as we shall see later.

\[
\text{Domain } D = \{ \text{AbstractClassXX, ConcreteClassXX} \}
\]

Figure 1. Descriptive Semantics of UML

As shown in Figure 1, the definition of descriptive semantics of UML models consists of four sets of rules, which we summarise from [26].

A. Signature Rules.

UML is defined by a metamodel that specifies the types of model elements and the relationships between them. The metamodel determines the signature of the FOL language in which sentences are constructed. The signature rules define a mapping \( S \) from a metamodel \( M \) to a signature \( \Sigma = S(M) \) so that statements representing the descriptive semantics of models are \( \Sigma \)-sentences. This means that predicate and constant symbols are generated for metaclasses, metattributes and metaenumeration values. For example, \( \text{Class(Book)} \) means the model element Book is a class, and \( \text{isAbstract(Book, true)} \) means that the class Book is abstract.

A \( \Sigma \)-sentence is a property of the systems in the modeling domain \( D \). Thus, \( \Sigma \)-sentences are evaluated on systems in \( D \). A satisfaction relationship \( \models \) between \( D \) and \( \Sigma \)-sentences can be defined as usual such that a \( \Sigma \)-sentence \( \varphi \) is true on a system \( s \) in \( D \), written \( s \models \varphi \), when the system \( s \) has property \( \varphi \).

B. Axiom Rules.

A metamodel also defines the inter-element relationships that must be satisfied by all models. These axiom rules define a mapping \( A \) from metamodel \( M \) to a set of axioms \( A(M) \) in the \( \Sigma \)-sentences. For example, some of these rules state that the set of diagram elements is partitioned into disjoint sets according to the metaclasses they belong to, such as Association, Operation, Class, etc.

C. Translation Rules.

A model states the existence of certain types of elements in the modeled system as well as their properties and interrelationships. The translation rules define a translation mapping \( T \) from model \( m \) into a set of \( \Sigma \)-sentences such that a system \( s \) is an instance of a model \( m \) if and only if all \( \Sigma \)-sentences in \( T(m) \) are true on system \( s \). For example, a sentence \( C(id) \) is generated for each identifier \( id \) of concrete type \( C \).

D. Hypothesis Rules.

These also define a mapping \( H \) from models to sets of \( \Sigma \)-sentences. However, they reveal the context in which models are used, and their application is specific to the modelling context, which here is software design. Suppose the model contains a number of elements of the same concrete type. Then one example of the rules says they are all distinct, another says that the system contains no more than these.

Let \( L_M \) be a modeling language, say UML, defined by a metamodel \( M \). Then \( DES(L_M) = \langle S, A, T, H \rangle \) represents the descriptive semantics and is defined as follows.

Definition 1 (Descriptive semantics of models)

The descriptive semantics of a model \( m \) in \( L_M \) defined by DES, written \( [m]_{DES} \), is the set \( A(M) \cup T(m) \cup H(m) \) of \( \Sigma \)-sentences, where \( \Sigma = S(M) \). A system \( s \) in domain \( D \) is an instance of model \( m \) under the definition of DES, written \( s \models_{DES} m \), if \( s \models [m]_{DES} \).

A tool LAMBDES was reported in [26]. It implements these rules for UML class, sequence and state machine diagrams. For example, Figure 3 shows some of the formulae in SPASS format generated from the UML diagram in Figure 2. These only specify the two classes, however. Fourteen more formulae specify properties of the two operations, six more give the generalisation relationship, and three more link the operations to their classes.
2.2 Specification of Design Patterns

In Bayley and Zhu’s approach to the formal specification of design patterns \([1, 3]\), a pattern is a first-order predicate \(p\) on UML models. A design model \(m\) conforms to the pattern denoted by \(p\), if the evaluation of \(p\) on model \(m\) is true.

For example, here is the specification of the Template Method pattern taken from \([3]\).

**Components**
- \(AbstractClass \in \text{classes}\)
- \(templateMethod \in \text{AbstractClass.opers}\)
- \(others \subseteq \text{AbstractClass.opers}\)

**Static Conditions**
- \(templateMethod.\text{isLeaf}\)
- \(templateMethod \notin others\)
- \(\forall o \in others . \neg o.\text{isLeaf}\)

**Dynamic Conditions**
- The template method calls the non-leaf operations.
  \(\forall o \in others . \text{callsHook}(templateMethod, o)\)

The static conditions relate to the class diagram and the dynamic conditions relate to the sequence diagram. Here, \(\text{classes}\) denotes the set of classes in the class diagram. If \(C\) is a class then \(C.\text{opers}\) denotes the set of operations of class \(C\). If \(o\) is an operation then \(o.\text{isLeaf}\) is true when \(o\) is not redefined in a subclass. So the static conditions stipulate that there must be a class \(AbstractClass\) with a non-redefined operation \(templateMethod\) that calls a set \(others\) of separate redefined operations.

The predicate \(\text{callsHook}(op, op')\) in the dynamic conditions is defined as \(\exists C \in \text{subs}(C') \cdot \text{calls}(op, C.\text{opers})\), where \(\text{calls}(op, op')\) denotes that the sequence diagram has messages \(m\) and \(m'\) in \(\text{messages}\), the set of messages, such that \(m\), labeled with operation \(op\), calls \(m'\), labeled with operation \(op'\).

The mix of maths and text forming the specification above is meant to be read as a single (commented) predicate in which the variables \(AbstractClass, \text{templateMethod}\) and \(others\) are existentially quantified and the four conditions are conjoined together into a single predicate on those three variables. The general form for the predicate is

\[
\exists v_1 : T_1 \exists v_2 : T_2 \cdots \exists v_n : T_n \cdot (Pr_s \land Pr_d)
\]

where \(Pr_s\) and \(Pr_d\) are the static and dynamic conditions as predicates and the \(v_i : T_i\) are the variables free in \(Pr_s\) and \(Pr_d\).

The evaluation of a predicate \(p\) on a model \(m\) in the context of an assignment \(\alpha\) \(^1\) is written \(\text{Ev}_{\alpha}(m, p)\), is the truth value of \(p\) when the free occurrences of each variable \(x\) in \(p\) are replaced by \(\alpha(x)\). If \(\text{Ev}_{\alpha}(m, p) = true\), we say that model \(m\) satisfies predicate \(p\) under the assignment \(\alpha\) and write \(m \equiv_\alpha p\). When there is no free variable in the predicate \(p\), its truth value is independent of the assignment so the subscript \(\alpha\) can be omitted.

Finally, we must translate this syntax into that of the LAMBDES tool. The translation is fairly straightforward as both languages use the same basic concepts of object-orientation. For Template Method, we get the following:

\[
\text{formula}(Class(\text{UMLClass}_3))
\]

\[
\text{formula}(\text{Class}(\text{UMLClass}_6))
\]

\[
\text{formula}(\text{not}(\text{equal}(\text{UMLClass}_3, \text{UMLClass}_6)))
\]

\[
\text{formula}(\text{forall}(\{x\}, \text{implies}(\text{Class}(x),
\text{or}(\text{equal}(x, \text{UMLClass}_3), \text{equal}(x, \text{UMLClass}_6))))).
\]

\[
\text{formula}(\text{isAbstract}(\text{UMLClass}_3, \text{bTrue}))
\]

\[
\text{formula}(\text{isAbstract}(\text{UMLClass}_6, \text{bFalse})).
\]

\[
\text{formula}(\text{visibility}(\text{UMLClass}_3, \text{public})).
\]

\[
\text{formula}(\text{visibility}(\text{UMLClass}_6, \text{public})).
\]

\[
\text{formula}(\text{Name}(\text{UMLClass}_3, \text{M_AbstractClassXX})).
\]

\[
\text{formula}(\text{Name}(\text{UMLClass}_6, \text{M_ConcreteClassXX})).
\]

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\(^1\)An assignment \(\alpha\) is a mapping from free variables in \(p\) to elements in model \(m\).

**2.3 Bridging the Semantic Gap**

Although FOL is used both in the descriptive semantics of UML diagrams in \([26]\) and in the formal specification of patterns in \([1, 2, 3]\), the universes of discourses are different. To bridge the semantic gap, the translation mentioned above, which turns predicates on UML models into predicates on software systems, must meet the following correctness requirement.

**Definition 2** (Correctness of translation) Let \(p\) be a predicate on models, \(p'\) be a predicate on systems. The predicate \(p'\) is a correct translation of \(p\), if for all models \(m\), we have \(m \equiv p \iff \forall s \in D \cdot (s \equiv ([m] \Rightarrow p'))\). □

Once a specification \(Spec(P)\) of pattern \(P\) is correctly translated into \(Spec'(P')\) then, given a design model \(m\) represented in UML diagrams, we can decide whether the design \(m\) conforms to pattern \(P\) by proving or disproving the logic statement \([m] \Rightarrow Spec'(P')\) in FOL. For example, the translated specification of Template Method pattern can be deduced from the LAMBDES formulae that describe the class diagram in Figure 2.

The following theorems state that if we can prove \([m] \Rightarrow Spec'(P)\) in FOL for model \(m\) and pattern \(P\), then every system that is an instance of \(m\) must conform to \(P\). (Actually, Theorem 2 states this and 1 is preparatory.) Together,
these provide the solid foundation required for us to use a theorem prover to check pattern conformance.

**Theorem 1** Suppose that $\text{Spec}'(P)$ is a correct translation of the formal specification $\text{Spec}(P)$ of pattern $P$. For all design models $m$ and systems $s \in D$, if $s$ is an instance of model $m$ and $m$ conforms to a pattern $P$ as specified in $\text{Spec}(P)$, we have that $(s \models \text{Spec}'(P))$.

**Proof.** By Definition 1, if $s$ is an instance of model $m$ then $s \models m$, which is equivalent to $s \models [m]$. By Definition 2 and the condition that $\text{Spec}'(P)$ is a correct translation of $\text{Spec}(P)$, then $m \models \text{Spec}(P)$ implies that for all $s \in D$, $s \models [m] \Rightarrow \text{Spec}'(P)$. By the consistency theorem of FOL, and $s \models [m]$ we have that $s \models \text{Spec}'(P)$. □

If $\text{Spec}(P)$ is a correct translation of the formal specification of $\text{Spec}'(P)$, as in Theorem 1, then by Definition 1, for all models $m$, we have $m \models \text{Spec}(P)$ if and only if $[m] \Rightarrow \text{Spec}'(P)$ holds. Thus, the above theorem can be equivalently stated as follows.

**Theorem 2** Suppose that $\text{Spec}'(P)$ is a correct translation of $\text{Spec}(P)$. For all models $m$, if $[m] \Rightarrow \text{Spec}'(P)$ is true in FOL, then, for all systems $s \in D$, we have $s \models m$ implies $s \models \text{Spec}'(P)$. □

### 3 LAMBDES and LAMBDES-DP

In [26], a prototype software tool called LAMBDES (Logic Analyser of Models/Metamodels Based on DEscriptive Semantics) was reported. It translates UML models into FOL systems and facilitates reasoning about models through logical inference. The tool LAMBDES-DP presented in this paper is an extension of LAMBDES with facilities to support reasoning about the conformance of models to design patterns.

LAMBDES is integrated with two other software tools: StarUML ², a UML modelling tool that allows the user to edit a diagram and export it in the XMI format that LAMBDES uses as input, and SPASS ³, an automated theorem prover for FOL with equality, which reads in LAMBDES output.

SPASS input is a logic system in a text file of four parts:

1. **Description**: background information;
2. **Signature**: declarations of the functions, predicates and constant symbols of the logic system;
3. **Premises**: a list of formulas as the premises of the logic inference;
4. **Conjectures**: a list of formulas to be proved.

For any input, the execution of SPASS may terminate with a proof, terminate with a failure to prove or else run forever without producing any results, because inference in FOL is NP-hard.

A major function of LAMBDES is to translate a UML model and a metamodel into a FOL system. Figure 4 shows the structure and workflow of LAMBDES. Many of the components represent the sets of rules that form the descriptive semantics. Signature mapping and axiom mapping are implemented in the Signature Generator and the Axiom Generator, respectively, and both take the metamodel as the input. To reason about the properties of a metamodel, the Domain Generator generates a set of auxiliary constants and formulas to populate the domain of discourse. Translation and hypothesis mappings are implemented in the Formula Generator and the Hypothesis Generator, respectively. They take a UML model in XMI format and a modeling context as input, respectively. Using a GUI, users can decide which hypothesis rules are to be applied.

The LAMBDES system also allows the users to specify which conjectures are to be proved so that a wide range of logical analyses on models and metamodels can be supported. The Conjecture Generator takes input from a text file and generates the conjectures to be proved. It then combines these with the descriptive semantics of the model as the signature and premise parts to form the input to SPASS.

LAMBDES-DP, on the other hand, is LAMBDES extended with a repository of all 23 patterns in GoF, translated from their formal specifications in [3]. If the model has no sequence diagram then only the components and static conditions are used for the conjecture. Otherwise, the dynamic conditions are included too. The Conjecture Generator and the GUI are different from the original LAMBDES tool. This allows the pattern specifications in the repository to be merged with the descriptive semantics of models to form input to the SPASS theorem prover as the conjectures to be proved. The changes are shown in the shadowed box in Figure 4.

[Figure 4. Structure of LAMBDES-DP]

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² URL: http://staruml.sourceforge.net/en/
³ URL: http://spass.mpi-inf.mpg.de/
4 Experiments

We have conducted some preliminary experiments to see how well LAMBDES-DP recognizes design patterns in UML models.

There are two types of errors in pattern recognition. A false positive error occurs when a design is incorrectly recognized as an instance of a pattern because the specification of the pattern is not restrictive enough to rule out incorrect uses. In contrast, a false negative error occurs when a design is incorrectly rejected as an instance of a pattern because the specification is too restrictive to take into account some valid uses. Moreover, inference in FOL is NP-hard. If the theorem prover cannot prove a statement within the time and memory space available, we regard the design as not conforming to the pattern; i.e. our use of the tool in this experiment is conservative. This may cause false negative errors. These two types of errors are measured by precision (the rate of false positives) and recall (the rate of false negatives), respectively.

Two sets of design instances were produced manually from the diagrams in the GoF book [10].

Set 1 (Class Only): contains a class diagram for each of the 23 patterns in the book.

Set 2 (Class + Seq): contains class and sequence diagrams for the only 6 patterns in the book that contain both.

Table 1 gives an overview of these design instances. Each row records the number of elements in the model and in its generated descriptive semantics. The columns for the model show the number of classes (CL), operations (OP), inheritance relations (IH), aggregations (AG), life-lines (LL), messages (MG), and the total number of elements (SUM). The columns for the semantics show the numbers of constants (CN), function/predicate symbols (SB) and formulas (FM).

There are two reasons why we didn’t use design models from real software systems. First, they are difficult to acquire, as for most open-source projects, only the source code is widely available. Secondly, the informal descriptions of patterns are so ambiguous that it is often debatable [6] whether a pattern should be found in a system or not. Using the examples from the original GoF book [10] avoids such controversies.

The experiments consisted of four steps:

1. Use StarUML to produce design instances as UML diagrams and export them as XMI representations.
2. Use LAMBDES to convert these XMI representations to FOL;
3. Use LAMBDES to check these FOL representations for consistency errors, revising them until there are no more errors;
4. For each pattern, use LAMBDES-DP to determine if the model conforms to (i.e. implies the specifica-

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Table 1. Overview of Design Instances
design models from industry. We note that some code level tools use an intermediate representation of the source code in FOL, e.g. [4, 12, 18], so we will consider integrating our approach with that. Finally, we will enrich the design pattern repository with variants of some patterns and add tool support for pattern composition.

Acknowledgment

The work reported in this paper is partly supported by The Reinvention Center through the funding of Undergraduate Student Scholarship Project to R. Amphlett and the China Scholarship Council’s funding of L. Shan’s visit to Oxford Brookes University. The authors are grateful to Prof. Zhi Jin of Peking University and the members of the Applied Formal Methods research group at Oxford Brookes University for valuable discussions.

References

[10] E. Gamma, R. Helm, R. Johnson, and J. Vlissides. Design Patterns - Elements of Reusable Object-Oriented Software. Addison-Wesley, 1995.