# P-UML
## *A Pattern Design Language with a Formal Semantics*

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Abstract: This paper presents and fine-tunes the P-UML design language which is a UML profile that better represents the design patterns and guides their instantiation. Then, it focuses on the definition of the formal semantics of this language in Z. The formal semantics allows a designer to prove the syntactic well-formedness of a P-UML design. In addition, it allows the verification of a design pattern's instantiation thanks to the theorem prover Z/EVES.

## 1 INTRODUCTION

Design patterns (Gamma et al., 1995) offer solutions that can be instantiated and composed to produce software faster and with a good quality. When presented in UML, a design pattern is a set of classes with their relationships and their behaviour, designed to solve a recurring problem. However, design patterns are in some cases fairly difficult to understand and reuse especially in complex systems. These difficulties can be alleviated through a design language that is expressive, that guides the user in distinguishing among the variable and fixed parts of the pattern, and that ensures the correct reuse of the design patterns.

Numerous UML-based design languages for patterns have been proposed *cf.* (Fontoura et al., 2001), (Dong, 2002), (Dong et al., 2007), (Sanada and Adams, 2002); (Arnaud et al., 2007). These languages extend UML in order to support patterns' specific concepts and to trace their elements when reused. The fact that these languages are based on UML increases their potential acceptance by designers. However, none of these languages relies on a formal, precise semantics that reinforces the clarity of the language and provides for the verification of pattern reuse.

On the other hand, several researchers have proposed formalizations of patterns. These propositions formalize either the structural (*cf.*, (Taibi T. and Taibi F., 2006), (Kim and Carrington, 2006), (Blazy et al., 2006)) or the behavioural (Dey and Bhattcharya, 2010) aspect of patterns. In addition, some of these works rely on the definition of a new specification language specific for reuse (*cf.*, (Eden et al., 1998), (Taibi T. and Taibi F., 2006), (Dey and Bhattcharya, 2010)), while others use formal languages and methods such as B, Z and Object-Z (*cf.*, (Blazy et al., 2002), (Kim and Carrington, 2004)). Furthermore, these works focus essentially on the formalization of the specific concepts of patterns, without considering their "informal/graphical" representation. We believe that a design language for patterns should: represent visually, clearly and intuitively patterns; formalize the specificities of patterns; and provide for the validation of pattern reuse.

In this paper, we present a formal semantics for our UML-based language, P-UML (Bouassida et al., 2006). The pattern design language P-UML with its precise description facilitates a rigorous reasoning on patterns and their reuse. It distinguishes visually among the roles played by the elements of a pattern and it shows the variability, while guiding potential reuses of the pattern. Moreover, P-UML distinguishes hook and template methods from other methods in a pattern: template methods define abstract and generic behaviour, while hook methods provide their implementation (Pree, 1994). The formal semantics of P-UML is defined in the Z notation. It facilitates the unambiguous understanding of a pattern and ensures correct reuse through the theorem prover Z/EVES.

In the remainder of this paper, we first overview UML-based notations for design patterns. Secondly, we present briefly the P-UML design language. Then, we present its well-formedness rules. Finally we define the P-UML formal semantics by translating its meta-model to a Z specification.

## 2 RELATED WORKS

### 2.1 Pattern Representation Languages

Fontoura et al., (Fontoura et al., 2001) proposed a UML-based notation whose aim is to facilitate pattern instantiation. The notation is composed of an extended class diagram and an adapted activity diagram (called "instantiation diagram"). The extended class diagram is enriched with the tagged values and stereotypes to show the variable parts of a pattern (called *hot-spots*). One limit of this notation is its lack of support for patterns traceability; it does not keep track of the correspondence between the elements of a pattern and the application instantiating it. In addition, it does not express how to compose patterns

The UML profile of Sanada (Sanada and Adams, 2002) aims to be comprehensive and well-defined. It defines four stereotypes for design patterns and three tags. It has the advantage of showing the pattern participant roles. However, it lacks concepts to identify the roles played by reused methods. Similar to the UML profile of Fontoura et al., this notation also does not facilitate patterns composition.

The notation proposed by Dong et al. (Dong, 2002) (Dong et al., 2007) focuses on design pattern composition. It defines new tagged values that are used to hold the pattern name, and the role names of the classes, the attributes and the operations in the pattern. Overall, this notation represents the structure, participant roles and collaborations in a pattern. However, it focuses more on pattern composition than on pattern instantiation in a particular application. For instance, it does not visually distinguish between the hook and template methods in a pattern.

The profile proposed by Arnaud et al. (Arnaud et al., 2007) covers three views: functional, dynamic and static. The functional view is materialized by a use case diagram. This diagram begins the instantiation process and any designer reusing a pattern has to select a functionality variant from the use case diagram. The dynamic view is modelled by the sequence diagram as defined in UML 2.0. The static view, modelled by a class diagram, is based on the use of packages. In fact, design patterns are presented with very elementary separated packages which contain one or two classes. Each package is relative to one use case. This may complicate the diagram and makes its comprehension difficult. Moreover, the class diagram proposed by Arnaud et al. does not show the pattern participant roles, nor does it express hook and template methods.

In summary, none of the proposed languages shows simultaneously the pattern participants, their roles, the meta-patterns and the hot-spots. In addition, none of them has a formal semantics making the design language clear and non ambiguous.

### 2.2 Design Pattern Formalizations

The formalization of design patterns has been treated either by defining a new language or by translating them to existing formal languages.

As an example of works that propose the definition of a new specification language specific for pattern reuse, we find Taibi (Taibi T. and Taibi F., 2006) who proposes the formalization of patterns using a Balanced Pattern Specification Language (BPSL) that uses both First Order Logic (FOL) and Temporal Logic of Actions (TLA) in order to specify the structural as well as behavioural aspects of patterns. Another example adopting this approach is the work of Dey (Dey and Bhattcharya, 2010) who proposes FSDP (Formal Specification of Design Pattern). The FSDP language formalizes the textual content of the UML class diagram. Thus, the classes, methods and attributes are represented, and the behaviour is represented through relationships, association and cardinality of the participating classes. This work combines the work of Taibi (Taibi T. and Taibi F., 2006) and (Dong, 2002), thus it formalizes the roles that pattern participants play in a composition. This formal language represents only the structure; however the interactions which are modelled through the sequence diagram and method calls are ignored.

On the other hand, other researchers used existing formal languages and methods such as B and Object-Z to specify patterns (*cf.*, (Blazy et al., 2002), (Kim and Carrington, 2006)). Among these works, Kim et al., (Kim and Carrington, 2004) formalizes patterns using Object-Z. For this, they rely on the meta-model of patterns, expressed in UML. Thus, each pattern is considered as a pattern role model. In fact, the role describes the pattern participants which could be: a class, an attribute, an operation and a relationship between classes. Note that, since the role meta-model is formalized in Object-Z, then the consistency constraints which must be respected are formalized.

This approach was improved in Kim et al. (Kim and Carrington, 2006) where the authors were interested in the validation of pattern reuse. For this purpose, they transform, automatically, the role meta-model defined in Object-Z to an Ecore model and then implement it using the Eclipse Modeling Framework (EMF). Thus, patterns are deployed in a design model by developing a role binding model that maps pattern entities to the design model entities. When a pattern is reused in a design model, the corresponding constraints must be preserved to make the pattern deployment valid. These constraints, defined using Object- Z, are implemented as a plug-in for Eclipse.

Blazy et al. (Blazy et al., 2002) formalize design patterns with the B method. Each pattern is specified with a unique abstract machine that is proved with the Atelier B. This work is extended in (Blazy et al., 2006) where an approach for the specification of instantiations and compositions of design patterns with others is proposed. The instantiation mechanism is implemented in B by the inclusion of machines: the machine corresponding to the pattern is included in the machine corresponding to the instantiation of the pattern. The composition is treated through three levels (juxtaposition, composition with inter-pattern links and unification) according to whether or not there exist links between the composed patterns. In the three cases, composition is achieved by the inclusion mechanism of B: all the machines representing the composed patterns are included in the machine representing the composition, called the composition machine. One of the limits of this approach is that a pattern is specified by a single abstract machine. As a consequence, one can find big and complicated machines, which impede their comprehension. Another limit is that the composition of several instances of the same pattern was not treated by this approach.

## 3 THE PATTERN DESIGN LANGUAGE: P-UML

The design language P-UML extends UML to enrich UML diagrams, in order to show pattern participant roles (e.g., observer, subject) and participant relationships. The extensions allow us to set apart core pattern classes from concrete and application classes. In addition, they identify the methods that play important roles in the pattern. Moreover, they put the attention on pattern hot-spots and variations through the meta-patterns (e.g., hook and template methods). Finally, they distinguish among the elements belonging to different design patterns, when they are combined in a design.

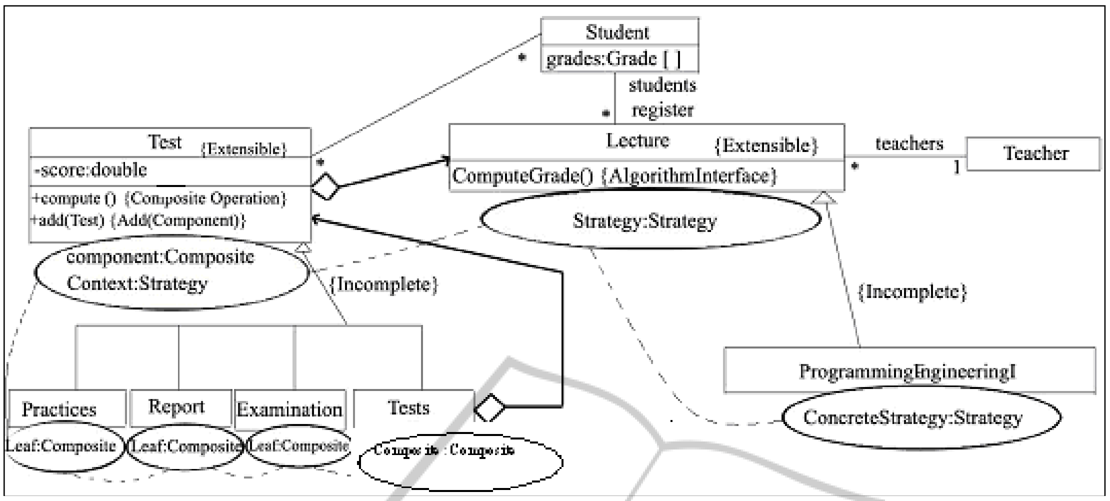
P-UML models a design through a class diagram that describes the static architecture of a pattern through the following extensions:

– An ellipse in in the bottom of a class indicating the pattern name and the role through which this class participates in the pattern.
– An association between ellipses joins the elements of the same pattern to show the participants of a pattern and their dependencies.
– A dashed line joins a hook and a template method.
– The classes of the pattern core are highlighted and stereotyped “core”. Note that a core class is a class essential for the pattern (the classes subject and observer are core classes in the Observer pattern. The other pattern classes which are concrete classes are not highlighted and they are stereotyped “concrete” (e.g., The ConcreteSubject and ConcreteObserver classes in the Observer pattern) On the other hand, all the application classes are not stereotyped and thus they can be easily distinguished from the others.
– Each association which is fundamental in the pattern is drawn with a highlight.
– Each fundamental method is tagged with its role in the pattern.
– The tag *virtual* associated to a circle filled in gray in front of a method name indicates that the method code varies from one implementation to another.
– The tag *extensible* inside a class indicates that the class has an extensible interface, i.e., a reuse may add attributes and/or methods.
– The UML constraint *incomplete* on a generalization relation indicates that the pattern provides only a sample of subclasses and that the user may add other subclasses to reuse it.

Besides the class diagram, P-UML also proposes an extension of the UML sequence diagram to describe possible interactions between various object instances of the class diagram; the reader is referred to (Bouassida et al., 2006) for more details.

### 3.1 P-UML Example

Figure 1 shows the class diagram of an application (inspired from (Sanada and Adams, 2002)) to manage courses in a university. This application, modelled in P-UML through our editor P-UML Tool (Bouassida et al., 2006), instantiates and It combines the patterns Strategy and Composite. The classes



Design example represented with P-UML.

*Test*, *Practices*, *Report*, *Examination*, and *Tests* participate in the Composite pattern. The objective is to show that a Composite (the class *Tests*) delegates its behaviour to its components (the class *Test)*. Besides playing the role of *Component,* the class *Test* also plays the role of *Context* in the *Strategy* pattern. The classes *Practices*, *Report*, *Examination* are concrete classes since they play the role of a leaf.

In Figure 1, the roles played by each class are represented in ellipses attached to the classes. On the other hand, the pattern participants are linked with the dashed lines. Note also that the roles played by each method, which is essential to the pattern are shown in Figure 1. For example, the method Add(Test) plays the role of the Add() method; that is, it adds components to the composite class.

### 3.2 P-UML Well-Formedness Rules

The P-UML well-formedness rules are syntactic rules that guarantee the construction of a "correct" design. These rules are necessary since using new UML extensions may generate, in some cases, inconsistencies (e.g., if a concrete class inherits a core class, since concrete classes can be omitted in a pattern instantiation).

**Rule C1:** The fundamental association, which is highlighted, can join only core classes. Thus, none of its association ends can be an application class.

**Rule C2:** Each class stereotyped "core" must have a corresponding object in the sequence diagram also stereotyped "core". Moreover, each class stereotyped "concrete" must have a corresponding object in a sequence diagram also stereotyped "concrete".

**Rule C3:** The fundamental method cannot be omitted in a pattern instantiation.

**Rule C4:** The fundamental classes cannot be omitted but the pattern concrete classes can be omitted. Note, also, that their number could be extended.

**Rule C5:** The tag extensible exists only in pattern classes (core or concrete) and it does not exist in application classes.

## 4 P-UML FORMAL SEMANTICS

P-UMLwas initially proposed in (Bouassida et al., 2006) as a graphical and semi-formal language. It needed a formal semantics providing for a means to "reason" about a P-UML specification and to verify several properties like the correct instantiation of a pattern.

In order to specify the semantics and syntax of P-UML, we used the Z language (Meisels, 2004). The choice of Z is motivated by the intuitive notation of Z, its expressive power which covers all elements in P-UML, its maturity as a formal notation, and the availability of its theorem prover Z-EVES (Meisels, 2004).

To formalize the semantics of P-UML, we first define a set *Name* as the domain of the names of all classes, attributes, operations, parameters and associations: *[Name]*. In addition, we define the visibility of a P-UML attribute (private, public, protected) through the following type:

*Visibilitykind ::= private | public | protected.*

A P-UML type has a name and a finite set of attributes and operations.

╲*PUMLType* ╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲

‖*name:Name*
‖*attributes:⎵ PUMLAttribute*
‖*operations:⎵ PUMLOperation*
╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲

*PUMLAttribute* and *PUMLOperation* represent, respectively, attributes and operations of a P-UML class. Each attribute *PUMLAttribute* is described with the following schema:

╲*PUMLAttribute*╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲
‖*name: Name*
‖*type: Classifier*
‖*visibility: VisibilityKind*
╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲

The *PUMLOperation* is described by the following schema:

╲*PUMLOperation*╲╲╲╲╲╲╲╲╲╲╲╲╲
‖*name: Name*
‖*parameters:* seq *PUMLParameter*
‖*visibility: VisibilityKind*
‖*isAbstract: Boolean*
‖*PatInstance: PatName*
‖*PatRoleOp: RoleOp*
‖*TemplateOp: Boolean*
‖*HookOp: Boolean*
‖*VirtualOp: Boolean*
‖*FundamentalOp: Boolean*
╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲
‖≜ *p1, p2:* ran *parameters* ⎵ *p1.name=p2.name*ℕ*p1=p2*
╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲

This pattern is composed of the following *Boolean* attributes: *TemplateOp*, *HookOp*, *FundamentalOp*. In addition, it contains *PatRoleOp* to specify the role played by the fundamental operation in the pattern instance *PatInstance.* This latter is drawn from the *PatName* free type: listing all design patterns:

*PatName* ::≪ *NONE* ⎵ *Composite* ⎵ *Observer*
⎵ *AbstractFactory* ⎵ *Builder* ⎵ ...

and the *PatRoleOp* is drawn from the *RoleOp* free type listing all pattern elements' roles:

*RoleOp* ::≪ *None* ⎵ *Operation* ⎵ *OperationImp* ⎵ *ADDComponent* ⎵ *Construct* ⎵ *BuildPart* ⎵ *Factorymethod* ⎵ *Clone* ⎵ *StaticInstance* ⎵ ...

## 4.1 P-UML Class Formalization

A P-UML pattern class is described by the following PUMLClass schema in Z:

╲*PUMLClass*╲╲╲╲╲╲╲╲╲╲╲╲╲╲
‖*name: Name*
‖*PatRoleCl:* ⎵ *RoleClass*
‖*PatInstance:* ⎵ *PatName*
‖*attributes:* ⎵ *PUMLAttribute*
‖*operations:* ⎵ *PUMLOperation*
‖*extensible: Boolean*
‖*isAbstract: Boolean*
╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲╲
‖**[C1]** ≜ *a1, a2: attributes* ⎵ *a1.name = a2.name* ℕ *a1 = a2*
‖**[C2]** ≜ *op1, op2: operations* ⎵ *op1 = op2*
‖ ℕ *op1.name = op2.name*
‖ *op1.visibility = op2.visibility*
‖ *op1.parameters = op2.parameters*
‖**[C3]** ≜ *op: operations* ⎵ *op.TemplateOp = True* ℕ *op.HookOp* = ‖*False*
‖**[C4]** ≜ *op: operations* ⎵ *op.HookOp = True* ℕ *op.TemplateOp* = ‖*False*
‖**[C5]** ≜ *op: operations* ⎵ *op.FundamentalOp = True*
‖ ℕ *op.PatInstance = Composite*
‖ ‿*op.PatRoleOp = Operation* ‗ *op.PatRoleOp =* ‖*ADDComponent*⁀
‖ ‗ *op.PatInstance = Observer*
‖ ‿*op.PatRoleOp = Update* ‗ *op.PatRoleOp = Attach*
‖ ‗ *op.PatRoleOp = Dettach* ‗ *op.PatRoleOp = GetState*
‖ ‗ *op.PatRoleOp = SetState* ‗ *op.PatRoleOp = Notify*⁀
‖ ‗ *op.PatInstance = State*
‖ ‿*op.PatRoleOp = Request* ‗ *op.PatRoleOp = Handle*⁀
‖ ‗ *op.PatInstance = Adapter*
‖ ‿*op.PatRoleOp = Request* ‗ *op.PatRoleOp = SpecificRequest*⁀
‖ ‗ *op.PatInstance = AbstractFactory*
‖ ‿*op.PatRoleOp = CreateProductA* ‗ *op.PatRoleOp =* ‖*CreateProductB*⁀
‖ ‗ *op.PatInstance = Builder*
‖ ‿*op.PatRoleOp = Construct* ‗ *op.PatRoleOp = BuildPart*⁀
‖ ‗ *op.PatInstance = FactoryMethod op.PatRoleOp =* ‖*Factorymethod*
‖ ‗ *op.PatInstance = Prototype*
‖ ‿*op.PatRoleOp = Clone* ‗ *op.PatRoleOp = Operation*⁀
‖ ‗ *op.PatInstance = Singleton*
‖ ‿*op.PatRoleOp = StaticInstance* ‗ *op.PatRoleOp =* ‖*SingletonOperation*⁀
‖ ‗ *op.PatInstance = Bridge*
‖ ‿*op.PatRoleOp = Operation* ‗ *op.PatRoleOp = OperationImp*⁀
‖ ‗ *op.PatInstance = Decorator op.PatRoleOp = Operation*
‖ ‗ *op.PatInstance = Proxy op.PatRoleOp = Request*
‖ ‗ *op.PatInstance = Flyweight*
‖ ‿*op.PatRoleOp = Operation* ‗ *op.PatRoleOp = GetFlyweight*⁀
‖ ‗ *op.PatInstance = ChainOfResponsibility op.PatRoleOp* = ‖*HandleRequest*
‖ ‗ *op.PatInstance = Command*
‖ ‿*op.PatRoleOp = Execute* ‗ *op.PatRoleOp = Action*⁀
‖ ‗ *op.PatInstance = Interpreter op.PatRoleOp = Interpret*
‖ ‗ *op.PatInstance = Iterator op.PatRoleOp = CreateIterator*
‖ ‗ *op.PatInstance = Mediator op.PatRoleOp = Operation*
‖ ‗ *op.PatInstance = Memento*
‖ ‿*op.PatRoleOp = SetMemento* ‗ *op.PatRoleOp = CreateMemento*
‖ ‗ *op.PatRoleOp = GetState* ‗ *op.PatRoleOp = SetState*⁀
‖ ‗ *op.PatInstance = Strategy*
‖ ‿*op.PatRoleOp = AlgorithmInterface*
‖ ‗ *op.PatRoleOp = ContextInterface*⁀
‖ ‗ *op.PatInstance = TemplateMethod*

```
‖          ⌣op.PatRoleOp = Templatemethod ⌐ op.PatRoleOp =
‖PrimitiveOperation⌢
‖    ⌐ op.PatInstance = Facade     op.PatRoleOp = Operation
‖    ⌐ op.PatInstance = Visitor
‖          ⌣op.PatRoleOp = VisitConcreteElement
‖        ⌐ op.PatRoleOp = Accept  ⌐ op.PatRoleOp = Operation⌢
‖[C6]  ≙ op: operations ⎵ op.FundamentalOp = False
‖   ℕ op.PatRoleOp = None     op.PatInstance = NONE
⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
⤡⤡⤡⤡⤡
```

The PUML class has a name, attributes, operations, and it must verify six invariants: [C1] and [C2] ensure the attribute and method names in the same class must be different; [C3] and [C4] ensure that we can not have the same operation in a certain class that takes the value Hook and Template at same time; and [C5] and [C6] ensure that each basic method in PUML is labeled with its role in the pattern through the tag {Name-pattern: role-method}". Note that, this is useful in patterns instantiation. In fact, it specifies the name of the the fundamental method of this pattern.

In addition, a P-UML class adds the following attributes: *extensible*, *PatRoleCl* and *PatInstance*. They indicate, respectively, the ability to add attributes or methods to the class labeled "*extensible*", the role played by the class participating in the pattern and the pattern name. The *PatRoleCl* is defined as a free type listing all possible roles:

*RoleClass* ::≪ *Component* ⎵ *composite* ⎵ *Leaf* ⎵ *Abstractfactory* ⎵ *ConcreteFactory1* ⎵ ...

## 4.2 P-UML Relationships Formalization

In this section, we give some examples of UML relationship formalization. Each PUMLAssociation is described as follows:

```
  ⤡PUMLAssociation⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
‖name: Name
‖e1, e2: AssociationEnd
‖AssocOblig: Boolean
  ⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
‖[C7] ≙ ae1, ae2: AssociationEnd
‖   ℕ ae1 = ae2
‖        ae1.rolename = ae2.rolename
‖          ae1.attachedClass = ae2.attachedClass
‖          ae1.multiplicity = ae2.multiplicity
‖[C8] ≙ e1, e2: AssociationEnd
‖   ℕ e1.associationTyp ⊙ ⏟aggregation
composition⏞
‖        e2.associationTyp = none
⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
```

This schema reuses the *UMLAssociation* schema as defined in (Ali, 2010). It defines two invariants: [C7] ensures the uniqueness of the names of the association ends; and [C8] ensures, in the case of an aggregation or a composition, that only one end of the association has the type aggregation or composition.

Each *PUMLGenralization* is described as follows:

```
  ⤡PUMLGeneralization ⤡⤡⤡⤡⤡⤡⤡⤡
‖super: PUMLClass
‖sub: PUMLClass
‖Incomplete: Boolean
  ⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
‖super.attributes    sub.attributes    super.operations
‖sub.operations
  ⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
```

## 4.3 PUML Class Diagram Formalization

A PUML class diagram is defined by the schema *PUMLClassDiagram*. This schema states respectively the set of classes and relationships (e.g., generalization, association, aggregation ...etc). This schema is defined as follows:

```
  ⤡PUMLClassDiagram ⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
‖classes: ⎵ PUMLClass
‖associations: ⎵ PUMLAssociation
‖gen: ⎵ PUMLGeneralization
  ⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
‖[C9]  c1, c2: classes ⎵ c1.name = c2.name ℕ c1 = c2
‖[C10]  ≙ a1, a2: classes ⎵ a1.name = a2.name ℕ a1 =
a2
‖[C11]  # classes ∕ 2      # associations ∕ 1
‖[C12]  ≙ c: classes
‖   ℕ ⌣c.PatInstance = ⏟Composite⏞
‖         c.PatRoleCl = ⏟composite⏞
‖       ⌐ c.PatRoleCl = ⏟Leaf⏞
‖       ⌐ c.PatRoleCl = ⏟Component⏞⌢
‖     ⌐ ⌣c.PatInstance = ⏟Strategy⏞
‖           c.PatRoleCl = ⏟strategy⏞
‖         ⌐ c.PatRoleCl = ⏟Context⏞
‖         ⌐ c.PatRoleCl = ⏟ConcreteStrategy1⏞⌢
‖     ⌐ ⌣c.PatInstance = ⏟Observer⏞
‖           c.PatRoleCl = ⏟observer⏞
‖         ⌐ c.PatRoleCl = ⏟Subject⏞
‖         ⌐ c.PatRoleCl = ⏟ConcreteObserver⏞
‖         ⌐ c.PatRoleCl = ⏟ConcreteSubject⏞⌢     ....
⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡⤡
```

A PUML class diagram must satisfy four constraints: [C9] and [C10] ensure uniqueness of class names and associations (Ali, 2010); [C11] ensures that a class diagram is composed of at least two classes linked by an association (Ali, 2010); and [C12] ensures that each class (participant) is labeled with its role in the pattern :{Pattern-Name, Participant- role}. This is useful when instantiating patterns. It specifies the name of the pattern in which the class participates and the role of this class.

## 5 VERIFICATION OF PATTERN REUSE

The formal semantics of P-UML allows us to verify several properties of an application instantiating patterns. In order to illustrate the verification of syntactic correctness of a pattern, we next present the inscription system. In the verification process, we used the Z/Eves theorem prover (Meisels, 2004).

We have translated the application of Figure 1 to Z based on a set of instantiation axioms. Next, we give our verification process composed of three steps:

*Step 1: Instantiation of P-UML elements:*

To illustrate this step, we give an extract of the Z axioms to instantiate a set of elements:

*Score: PUMLAttribute*
*Score.name = score*
*Score.type = double*
*Score.visibility = private*

*Computer: PUMLOperation*
*Computer.name = computer*
*Computer.visibility = public*
*Computer.parameters =*
*Computer.isAbstract = False*
*Computer.PatInstance = Composite*
*Computer.PatRoleOp = Operation*
*Computer.TemplateOp = True*
*Computer.HookOp = False*
*Computer.VirtualOp = False*
*Computer.FundamentalOp = True*

*Add_Test: PUMLOperation*
*Add_Test.name = addTest*
*Add_Test.visibility = public*
*Add_Test.parameters =*
*Add_Test.isAbstract = False*
*Add_Test.PatInstance = Composite*
*Add_Test.PatRoleOp = ADDComponent*
*Add_Test.TemplateOp = True*
*Add_Test.HookOp = False*
*Add_Test.VirtualOp = False*
*Add_Test.FundamentalOp = True*

*test: PUMLClass*
*test.name = Test*
*test.PatRoleCl = ⟨Component Context⟩*
*test.PatInstance = ⟨Composite Strategy⟩*
*test.attributes = ⟨Score⟩*
*test.operations = ⟨Computer Add_Test⟩*
*test.isAbstract = False*
*test.extensible = True*
*computegrade: PUMLOperation*
*computegrade.name = ComputeGrade*
*computegrade.visibility = public*
*computegrade.parameters =*
*computegrade.isAbstract = True*
*computegrade.PatInstance = Strategy*
*computegrade.PatRoleOp = AlgorithmInterface*
*computegrade.TemplateOp = False*
*computegrade.HookOp = True*
*computegrade.VirtualOp = False*
*computegrade.FundamentalOp = True*

*lecture: PUMLClass*
*lecture.name = Lecture*
*lecture.PatRoleCl = ⟨strategy⟩*
*lecture.PatInstance = ⟨Strategy⟩*
*lecture.attributes =*
*lecture.operations = ⟨computegrade⟩*
*lecture.isAbstract = True*
*lecture.extensible = True*
programIng: PUMLClass
programIng.name = ProgrammingIngineeringI
programIng.PatRoleCl = ⟨ConcreteStrategy1⟩
programIng.PatInstance = ⟨Strategy⟩
programIng.attributes =
programIng.operations =
programIng.isAbstract = False
programIng.extensible = False

Due to space limitations, the classes *Examination*, *Report* and *Tests* are not presented, they are similar to the class *Lecture*.

*g: PUMLGeneralization*
*g.super = test*
*g.sub = tests*
*g.Incomplete = True*
*a: PUMLAssociation*
*a.e1.attachedClass = test*
*a.e2.attachedClass = lecture*
*a.e1.multiplicity.upper* = 0
*a.e1.multiplicity.lower* = 100
*a.e2.multiplicity.upper* = 1
*a.e2.multiplicity.lower* = 100
*a.e1.associationTyp = aggregation*
*a.e2.associationTyp = none*

Note that g1, g2, g3 are also generalizations defined similarly to the generalization g. and a1 is an association defined similarly to a.

Z/EVES generates automatically a set of axioms. Each axiom has a goal and defines a theorem. For example, the axiom $axiom185 defines a new theorem:

**theorem** axiom *axiom$185*
*Add_TestHookOp = False*

*Step 2: Instantiate the PUML class diagram (Figure 2):*
In order to Instantiate the P-UML class diagram, we use the following schema:

```
 ⟍InitPUMLClassDiagram ⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍
‖PUMLClassDiagram
 ⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍
‖classes = ⎵test   lecture   programIng   tests
examination   ‖report⎵
‖associations = ⎵a   a1⎵
‖gen = ⎵g   g1   g2   g3⎵
 ⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍⟍
⟍⟍
```

Classes, associations and gen are the set of elements of the P-UML example presented in section 3.2.

*Step 3: Applying initial theorem:*
After the instantiation of the P-UML class diagram, we animate with Z/EVES the theorem "*VerifConsistency ClassDiagram*". It ensures that the P-UML model is correct and that it is a valid pattern instantiation.

**theorem** *VerifConsistencyClassDiagram*
⎵ *PUMLClassDiagram*
ℕ *InitPUMLClassDiagram*

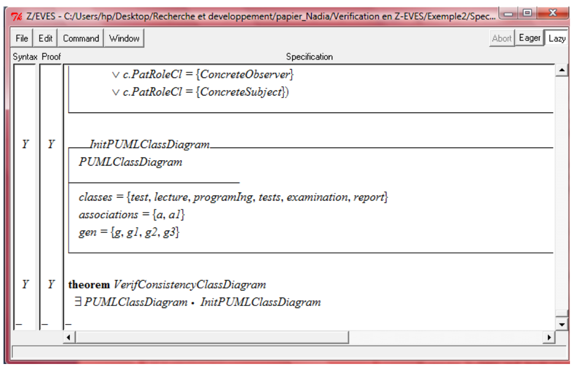
Using Z/EVES, the proof of this theorem needs the following commands:

1. *Invoke*
2. Use the set of generated axioms.
- *Use $axiom164*
- *Use $axiom165*

...

3. *Rewrite*
4. *Prove by reduce*

Figure 2 shows the theorem to be proven and Figure 3 shows it after the proof was successfully done, which proves that our example of Figure 1 is a good instantiation of design patterns.



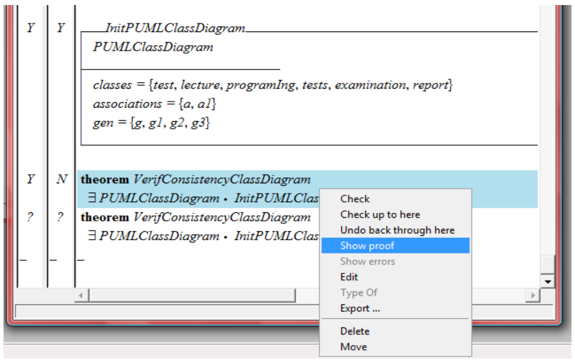
```
Z/EVES - C:/Users/hp/Desktop/Recherche et developpement/papier_Nadia/Verification en Z-EVES/Exemple2/Spec...
File  Edit  Command  Window                                   Abort  Eager  Lazy
Syntax Proof                     Specification
              ∨ c.PatRoleCl = {ConcreteObserver}
              ∨ c.PatRoleCl = {ConcreteSubject})

Y     Y     InitPUMLClassDiagram
            PUMLClassDiagram

            classes = {test, lecture, programIng, tests, examination, report}
            associations = {a, a1}
            gen = {g, g1, g2, g3}

Y     Y     theorem VerifConsistencyClassDiagram
             ∃ PUMLClassDiagram • InitPUMLClassDiagram
```

Figure 1: Theorem before proof.



```
Y     Y     InitPUMLClassDiagram
            PUMLClassDiagram

            classes = {test, lecture, programIng, tests, examination, report}
            associations = {a, a1}
            gen = {g, g1, g2, g3}

Y     N     theorem VerifConsistencyClassDiagram
             ∃ PUMLClassDiagram • InitPUMLClas
?     ?     theorem VerifConsistencyClassDiagram
             ∃ PUMLClassDiagram • InitPUMLClas
```

Figure 2: Theorem after the proof.

## 6 CONCLUSIONS

This paper overviewed proposed UML-based notations for design patterns and it proposed a new notation (P-UML) that distinguishes among the different parts in the pattern structure. Then, it defined the formal semantics of the P-UML class diagram with the formal notation Z.

Our future work includes formalizing the behaviour of P-UML through the specification of the P-UML sequence diagram. In addition, we are looking into testing the formalization of P-UML through different examples.

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