SPECIFICATION AND INSTANTIATION OF DOMAIN SPECIFIC PATTERNS BASED ON UML

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Abstract: Domain-specific design patterns provide for architecture reuse of reoccurring design problems in a specific software domain. They capture domain knowledge and design expertise needed for developing applications. Moreover, they accelerate software development since the design of a new application consists in adapting existing patterns, instead of modeling one from the beginning. However, some problems slow their expansion because they have to incorporate flexibility and variability in order to be instantiated for various applications in the domain.

This paper proposes new UML notations that better represent the domain-specific design patterns. These notations express variability of patterns to facilitate their comprehension and guide their reuse. The UML extensions are, then, illustrated in the process control system context using an example of an acquisition data pattern.

1 INTRODUCTION

Reusable design patterns can be classified as general or domain-specific. General patterns (Gamma et al., 1994) support horizontal reuse, that is, they can be used in a variety of application domains. Due to the fact that general patterns are too abstract, their use can result in systems that do not correspond to reality. Moreover, their instantiation remains a difficult task since it is hard to determine in which context or in which part of the system the patterns can be used (Port, 1998). On the other hand, a domain-specific design pattern captures particular software domain knowledge, and thus supports vertical reuse. It offers a flexible architecture with clear boundaries, in terms of well-defined and highly encapsulated parts that are in alignment with the natural constraints of the domain (Port, 1998).

In fact, while horizontal reuse is widely spread, Prieto-Diaz (Prieto-Diaz, 1993) states that vertical reuse which benefits from a high quality domain experience can result in more significant improvement in the development cycle-time and better software quality.

However, domain-specific patterns suffer from representation problems since they have to express certain concepts specific to patterns such as their flexibility and their reuse traceability, which can not expressed with UML. These reasons motivated several works on domain-specific patterns representation (Kim et al., 2004) (Montero et al., 2005) (Couturier, 2005) (Díaz et al., 2008). They propose new notations based on UML to facilitate patterns specification. However, none of them distinguishes between the extensions used in pattern instantiation from those used in pattern specification, which reduces their expressivity. Moreover, these notations lack clarity since they do not focus on the identification of the elements, the structure and the roles played by the elements of a pattern. In addition, they do not guide the user when adapting a pattern to a specific application since they do not identify the elements that may differ from one pattern instantiation to another.

This paper proposes new UML extensions for domain-specific design patterns. It has two-fold objectives. Our first objective is to cope with the representation of patterns at the specification level. At this level, our design language offers the following advantages: (i) it is expressive since it facilitates the comprehension of design patterns instantiation and guides a designer in deriving a particular application, (ii) it shows variability since it differentiates the fixed parts from the optional and variable parts in the pattern (iii) it allows domain related constraints definition.

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Our second objective is patterns expression at the instantiation level. In fact, when several patterns are instantiated to design an application, our profile identifies clearly the elements belonging to each design pattern in order to ensure the traceability. Moreover, it avoids ambiguity when composing patterns by showing the role played by each pattern element.

The remainder of this paper is organized as follows. Section 2 overviews currently proposed design languages and their extensions. Section 3 presents our proposition to represent an UML profile for domain specific design patterns. Section 4 illustrates the design language through the definition of the acquisition data pattern for the process control system. Section 5 concludes the paper and outlines future work.

2 RELATED WORK

Design patterns have mostly been described using natural language, complex mathematical or logic based formalisms (Eden et al., 1999) (Mikkonen, 1998) which are not easily understood by an inexperienced designer. This leads to complications in incorporating design patterns effectively into the modelling of a new system. To remediate to this difficulty, the solution is using an expressive visual notation based on UML to specify patterns. This improves the pattern specification quality because UML allows to easily visualise, define and document the artefacts of the system under development.

Several works for pattern representation based on UML have been proposed.

Kim et al., (Kim et al., 2004) propose a Role Based Modeling Language (RBML). This language is interested only on representing patterns at the specification level. It specifies patterns using a structure of roles. Each role is associated with a UML metaclass that is called its base. The properties expressed in a role define a subset of the base metaclass instances. For example, a role whose base is the Classifier metaclass expresses properties that define a subset of UML classifiers (instances of Classifier). Properties in a classifier role can be expressed in structural feature roles or behavioral feature roles specifying respectively the attributes and operations of conforming classifiers.

This approach treats domain patterns as templates where the parameters are roles. The constraint templates are used to specify semantic properties associated with features that conform to structural and behavioral feature roles. The RBML defines well the properties that must be instantiated by each application in the pattern domain, but it does not focus on expressing variability. Moreover, RBML does not offer mechanisms for patterns composition in a domain.

Unlike the previous work, the UML profile proposed by Arnaud (Arnaud et al., 2007) focuses on the variability expression in the functional, dynamic and static views. The functional model fragment (use case diagram) is the entrance point for the instantiation process, where the application designer selects a functionality variant. However, the use case diagram is too abstract and can not be used as an input model for the patterns instantiation. In fact, the use case diagram is at a high level of abstraction and thus the designer cannot identify, for example, the optional attributes or methods according to its needs. Thereby, this profile is not very expressive and it makes the patterns composition more difficult since the static view of a pattern is decomposed into very elementary separated packages which contain one or two classes. Each package is relative to one use case of the functional diagram.

Overall, currently proposed UML based design languages for patterns are more interested in the patterns specification level than in the instantiation one. Moreover, they do not express variability nor composition aspects. Thus, they do not offer an expressive notation guiding the designer in pattern instantiation.

3 DOMAIN-SPECIFIC DESIGN PATTERNS PROFILE

In the present work, we offer UML extensions (OMG (b), 2007) distinguishing between domain-specific design patterns representation at the specification and instantiation levels. At the specification level, our profile facilitates the pattern instantiation through the expression of pattern variability and the definition of the constraints to be fulfilled when the designer adapts the patterns according to its needs. At the instantiation level, our profile offers extensions for comprehension, traceability and composition purposes through the identification of the roles played by each pattern element in the application instantiating it.

In the following, we present some UML 2.1.2 (OMG, 2007) basic concepts expressing the variability in the static and behavioral views. Then, we show our UML extensions to represent domain-specific design patterns.

In the class diagram, the generalization relationship represents variation points which are defined by an abstract class and a set of subclasses that constitute the different variants. At least, one of these subclasses is chosen in a pattern instantiation. There are two types of UML constraints that can be applied on the generalization relation:

- {incomplete}: this constraint indicates that the design provides only a sample of subclasses and that the user may add other subclasses in an instantiation.
- {xor}: this constraint indicates that the designer must choose one and only one variant among the presented subclasses during the instantiation.

In addition, the interface concept allows to express variability since the designer can choose a particular interface realization among the various possibilities.

In the sequence diagram, an interaction sequence can be grouped into an entity, called combined fragment. This latter defines a set of interaction operators, particularly (**alt**: alternative) and (**opt**: optional) operators. The interaction operator (**alt**) indicates that a set of interactions are alternative. It is used with an associated guard that informs the user that only one set of interactions will be chosen. While the interaction operator (**opt**) indicates that a set of interactions represents an optional behavior that can be omitted in a model instance.

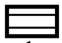
Domain-specific design pattern are generic designs intended to be specialized and reused by an application. For this reason, in addition to the UML variability concepts, we need new notations distinguishing the commonalities and differences between applications in the pattern domain. Moreover, we need new concepts for the explicit representation of the pattern elements roles in order to trace back to the design pattern from a complex design diagram.

In the next section, we describe the extensions that we propose to take into account these new concepts.

3.1 Extensions for Specifying Design Patterns

In this section, we propose new stereotypes showing the optional and fundamental elements participating in a pattern and assisting the designer in pattern reuse. Thus, the class diagram Metamodel is extended with the following stereotypes:

• **Stereotype <<*optional*>>** (applied to the *Feature* UML Metaclass): This stereotype is used to specify optional features in UML class diagram. When an attribute (or method) is stereotyped optional, then it can be omitted in a pattern instance.
Each method or attribute which is not stereotyped <<optional>> means that it is an essential element that plays an important role in the pattern.

• **Stereotype <<*mandatory*>>** (applied to the UML Metaclasses: *Class*, *Association, Interface, Lifeline and ClassAssociation*): This stereotype is used to specify a fundamental class or relation (association, aggregation,…) that must have at least one instance in a specific application model. A fundamental element in the pattern is drawn with a highlighted line like this class .
Each relation or class which is not highlighted means that it is an optional element, except the generalization relation that permits to represent variant elements.

• **Stereotype <<*extensible*>>** (applied to the UML Metaclasses: *Class, Interface and ClassAssociation*): This stereotype is inspired from {extensible} tagged value proposed in (Bouassida et al., 2006). It indicates that the class interface may be extended by adding new attributes and/or methods. Moreover, two properties related to the extensible stereotype are proposed, in order to specify the type of features (attribute or method) that may be added by the designer.

- *Extensible Attribute* tag: It takes the value *false*, to indicate that the designer cannot add new attributes when he instantiates the pattern. Otherwise, this tag takes the value *true*.
- *Extensible Method* tag: It indicates if the designer may add new methods when he instantiates the pattern. The default value is *true*.

• **Stereotype <<*variable*>>** (applied to the *Operation* UML Metaclass): This stereotype has the same meaning with the {variable} tagged value proposed in (Bouassida et al., 2006). It indicates that the method implementation varies according to the pattern instantiation.

Note that the designer can add constraints describing properties inherent to the pattern domain. These constraints are expressed in OCL (Object Constraint Language) (OMG (a), 2003).

3.2 Extensions for Instantiating Design Patterns

Some of the existing notations, such as a UML profile (Dong & Yang, 2003), provide support on how to keep trace of the pattern when instantiated. These notations focus only on generic design patterns for which it is difficult to recognize the pattern instance when it is composed with others in a particular design. Thus, it is essential to hold the pattern name and the role played by each element (class, attribute and method) in the instantiation.

However, a domain specific pattern is instantiated in the scope of a domain. Therefore, it is easy to retrieve the pattern-related information even after the pattern is applied or composed with other patterns. We assume that omitting both the name and the role of pattern attributes and operations will not create any ambiguity. For this reason, we propose to present only the pattern name and the roles of the classes in order to avoid having overloaded models. In fact, pattern-related information should be minimized in the class and sequence diagrams for readability.

We propose to define two new stereotypes for the explicit visualization of patterns in an application design:

- <<***Pattern Class***>> stereotype: It is applied to the *Class* UML metaclass in order to indicate that it is an instantiated pattern class and not originally defined by the designer. Two properties, relative to this stereotype, are defined:
  - *patternName* tag : indicates the pattern name,
  - *participantRole* tag : indicates the role played by the class in a pattern instance.

This stereotype allows to eliminate any confusion when patterns are composed. That is, when two or more classes represent the overlapping part of the composition, the proposed stereotype shows the roles that these classes play in each pattern.

- ***<<Pattern Lifeline>>*** stereotype: It is applied to the Lifeline metaclass in order to distinguish between the objects instantiated from the pattern sequence diagram and those defined by the designer. This stereotype has the same properties than <<patternClass>> stereotype.

4 CASE STUDY

To illustrate our profile, we have chosen the process control systems domain. In fact, applications in this domain monitor and control the values of certain variables through a set of components that work together to achieve a common objective or purpose (Reinhartz-Berger et al., 2009). Application areas within this domain include engineering and industrial control systems, financial derivation-tracking products, and so on. They perform several processes among which: the data acquisition and the data control processes. We focus in this paper on representing a pattern for the data acquisition process using our UML profile. Then, at the instantiation level, the pattern is reused through an example of an industrial control application. Due to space limitation, only the extensions to the UML class diagram are illustrated.

4.1 Pattern Specification

The variety within the process control system domain is quite large. Applications in the domain defer in the number of the observed elements, the number and type of controlled values and sensors, whether the history of measurements is recorded or not, etc (Reinhartz-Berger et al., 2009).
Nevertheless, all applications in the process control domain should define at least one sensor to acquire data from the environment. A sensor is defined as a device that measures or detects a physical phenomenon. This detected measure is usable for command ends. The sensors can be classified according to their functioning principle. Some applications use passive sensors and others use active sensors.

Figure 1 represents the data acquisition pattern at the specification level. As indicated in this figure, the different types of sensors present variants for the sensor abstract class.

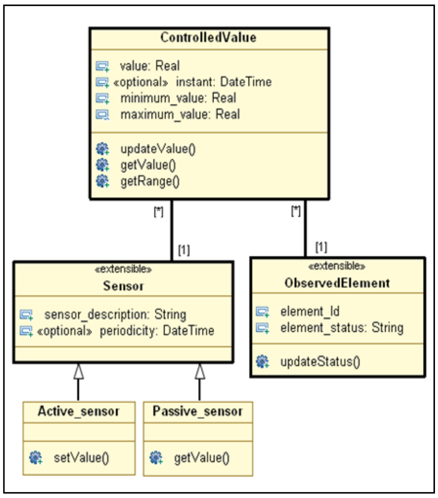


Figure 1: Specification of the data acquisition pattern.

An active sensor takes the transmission initiative of its current value (push mechanism). It must be able to transmit a signal setValue to one object or to a group of objects in order to update the value of a measure. While a passive sensor, it can transmit its value only on demand of an operator (pull mechanism). It must have a method getValue to read the current value.

In addition, a process control application should have at least one observed element and at least one *ControlledValue* class. An *ObservedElement* class represents the description of a physical element that is supervised by one or more sensors. It has an identity and status attributes specifying the evolution of its status according to the variation of the controlled values. Thus, the *ControlledValue* class has an attribute named *Value* containing the final value captured by the related *updateValue ()* method, two attributes specifying its range constraints and at least one operation for getting these ranges. The range constraints define the minimum and the maximum values for which the system does not detect an anomaly. The *ControlledValue* class has also an optional attribute named *Instant* containing the last time at which the value was produced.

4.2 Pattern Instantiation: An Example

The purpose of the water level control of an industrial regulation system is to monitor and control the water levels in tanks, ensuring that the actual water level of $tank_i$ is always in the closed range [Low-level, High-level] (Reinhartz-Berger et al., 2009). If a problem occurs and some of the tanks do not satisfy their boundary constraints, the system tries to resolve the problem internally, for example, by rebooting the system. However, if the problem cannot be resolved internally, the system requires a special treatment of an external exception handler.

The actual levels of the different tanks are measured by boundary sticks sensors. Each acquired measure is characterized by a value, a minimum value and a maximum value of the desired water level in the tank. When the water height in the tank reaches its low (or high) desirable limit, the filling (or emptying) faucet is activated to inject water into the tank (or to drain water from the tank).

Figure 2 illustrates the data acquisition process of the water level control application. The design of this application is facilitated by the reuse of the pattern specification example. In fact, the designer instantiates first the elements that play a significant role in the data acquisition pattern (drawn with a highlight line in Figure 1) and substitutes them by specific elements adapted to the context of the water level control application. This application controls one type of elements (tanks) and monitors one type of controlled value, which is the water height in tanks, through the boundary sticks passive sensors. The passive sensor variant is chosen because all sensors used in this application can not publish their values spontaneously.

After that, the optional elements are identified in order to determine those that can be omitted. For example, the instant optional attribute is omitted since the time of the measured water heights is not recorded in this application.

Moreover, the pattern name and its role are indicated by using respectively the tagged values *patternName* and *participantRole* of the stereotype <<patternClass>>. For example, the instantiated class *Tank* plays the role of an *ObservedElement* in the data acquisition pattern. Thus, the *patternName* tag value is *AcquisitionData* and the *participantRole* tag value is *Observed Element*.

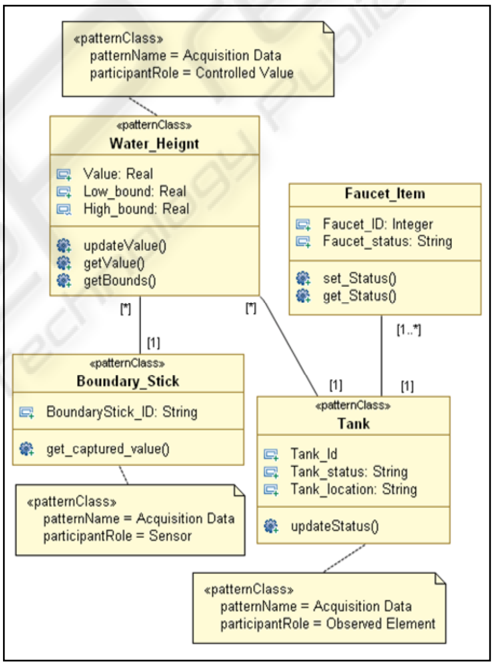


Figure 2: Example of data acquisition pattern instantiation.

Finally, specific elements related to the designed application are added. New attributes (or methods) can be added only for the pattern classes stereotyped <<extensible>> and tagged with extensibleAttribute (or extensible-Method). Notice that in the water level control application, a *Location* attribute characterizing the Tank class is added since the corresponding *ObservedElement* class in the pattern is declared extensible. In addition, the class *Faucet_item* is added. This class is characterized by the faucet-ID attribute and faucet-Status attribute indicating if a faucet is opened or closed.

5 CONCLUSIONS

This paper presented a UML profile for domain-specific design patterns. The proposed extensions allow distinguishing clearly between the different parts constituting the pattern in order to guide the designer in determining the variable elements that may differ from one application to another. It allows also to identify, easily, design patterns when they are applied to model a particular application in the pattern domain. The paper illustrated the proposed profile through the data acquisition pattern for the process control system domain.

Our future works include the definition of a process for the creation and specification of domain-specific design patterns through the unification of the existing applications in the domain. This allows to reduce the costs of domain patterns engineering activities and to improve their profitability.

REFERENCES

Arnaud N., Front A.and Rieu D., Expression et usage de la variabilité dans les patrons de conception, Revue des sciences et technologies de l'information, série : Ingénierie des Systèmes d'Information, vol. 12/4, pp. 21-24, 2007.

Bouassida N., Ben-Abdallah H., Extending UML to guide design pattern reuse, Sixth Arab International Conference On Computer Science Applications, Dubai, 2006.

Díaz P., Aedo I., Beth Rosson M., Visual representation of web design patterns for end-users, Proceedings of the working conference on Advanced visual interfaces, pages 408-411, 2008.

Couturier V., Pattern analysis for the cooperative information system engineering, Revue Lavoisier, ISSN 1262-1137, vol. 11, no 4, pages 141-175, 2005.

Dong J. and Yang S., Visualizing design patterns with a UML profile, proceedings of IEEE Symposium on Human Centric Computing Languages and Environments, pp: 123-125, 2003.

Eden A.H., Gil J., Hirshfeld Y., Yehudai A., Towards a mathematical foundation for design patterns, Technical report, dept.of information technology, U.Uppsala, 1999.

Gamma E., Helm R., Johnson R.E, Vlissides J., Design patterns: Elements of Reusable Object-Oriented Software, Addison-Wesley Edition, 1994.

Kim D.K., France R., Ghosh S., A UML-based language for specifying domain-specific patterns, Journal of Visual Languages and Computing, 15 (2004) pp. 265–289, 2004.

Mikkonen T., Formalizing Design Patterns, Proc. 20th International Conference on Software Engineering—ICSE, pp. 115–124, 1998.

Montero S., Díaz P., Aedo I., A Semantic Representation for Domain-Specific Patterns, Springer-Verlag Berlin Heidelberg, vol 3511, pages 129-140, 2005.

OMG (a), UML 2.0 OCL specification, 2003

OMG (b), Unified Modeling Language (UML) Infrastructure: v2.1.2, formal/2007-11-04, 2007.

Port D., Derivation of Domain Specific Design Patterns. USC Center for software engineering, 1998.

Prieto-Diaz R., Status report: software reusability, IEEE Software 10 (3) pp. 61–66, 1993.

Reinhartz-Berger I., Sturm A., Utilizing domain models for application design and validation, Information and Software Technology, vol 51, pages 1275-1289, 2009.

Yacoub S. M., Ammar H., Pattern-Oriented Analysis and Design: Composing Patterns to Design Software Systems, Published by Addison-Wesley Professional, August 2003.