Domain Knowledge as an Aspect in Object-Oriented Software Applications

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1 Introduction

The complexity of software domains is steadily increasing and knowledge management of businesses is becoming more important. The real-world domains of many software applications, such as e-commerce, the financial industry, television and radio broadcasting, hospital management and rental business, are inherently knowledge-intensive. Current software engineering practices result in software applications that contain implicit *domain knowledge* tangled with the *implementation strategy*. An implementation strategy might result in a distributed or real-time application, or in an application with a visual user interface or a database, or a combination of above. Domain knowledge consists of a conceptual model containing *concepts* and *relations* between the concepts. It also contains *constraints* on the concepts and the relations, and *rules* that state how to infer or "calculate" new concepts and relations [23]. There is a strong analogy between the rules and constraints on the one hand, and *Business Rules* on the other. Business Rules are defined on a *Business Model*, analogous to the conceptual model of the domain knowledge.

A first problem is that real-world domains are subject to change and businesses have to cope with these changes in order to stay competitive. Therefore, it should be possible to identify and locate the software's domain knowledge easily and adapt it accordingly while at the same time avoiding propagation of the adaptations to the implementation strategy. Similarly, due to rapidly evolving technologies, we should be able to update or replace the implementation strategy in a controlled and well-localized way. A second problem is that the development of software where domain knowledge and implementation strategy are tangled is a very complex task: the software developer, who is typically a technology expert but not a domain expert, has to concentrate on two aspects of the software at the same time and manually compose them. This violates the principle of *separation of concerns* [8] [21] [11], which states that the implementation strategy should be separated from other concerns or aspects such as domain knowledge. In short, the tangling of domain knowledge and implementation strategy makes understanding, maintaining, adapting, reusing and evolving the software difficult, time-consuming, error-prone, and therefore expensive.

2 Examples of Domain Knowledge in Software Applications

To clarify our above description of domain knowledge, two small representative case studies that are used in this research are briefly presented here. They are both based on existing industrial applications, but scaled down without reducing the inherent complexity related to this research topic. The first case study is an e-commerce application for an online book and cd shop [22]. The second case study is an application for the management and support of planning television programs for broadcast companies. These cases provide a balanced combination of domain knowledge and implementation strategy: in e-commerce applications there are obviously technological challenges such as transactions, replication, remote procedure calling and concurrency, whereas the second case study has to deal with a visual user interface and persistency.

2.1 e-Commerce

The domain of the first application contains for example the obvious concepts customer, shopping cart, product (of which book and cd are specializations), customer profile, and some obvious relationships between them. Constraints on this static domain model are for example "a customer can buy at most 10 products at the same time" or "if the purchased products are shipped, the order cannot be cancelled". Related to calculating the price of an order there are a number of rules such as "if a customer has previously bought 10 products, he or she is entitled to a 10% discount on the next order", "if it is Christmas, everybody gets a 5% discount" and "if a customer's last purchase was a cd in the category of classical music, then he or she gets a discount of 15% on the next classical music cd". It becomes interesting when one thinks of the possible interferences of these rules and constraints and how to deal with them. What happens when a customer who has already purchased more than 10 products orders something during Christmas?

2.2 Broadcast Planning

In the domain of broadcasting there are concepts such as transmission (a time slot in the schedule), program (concrete program to be broadcasted), contract (for programs that were purchased), tape, snap (a rebroadcast), trailer (announcement for a number of programs), group of programs, chain of programs, and so on. Again, there are relationships between these concepts, some more obvious than others. Constraints limit the scheduling of these concepts, for example stating that "a snap should always be scheduled after its original" and that "the contract should be valid for the period in which the program will be broadcasted". When a scheduled entity is moved in the program schedule a number of rules become active, such as "if the anchor of a chain of programs is moved, the entire chain has to be moved". Again, the rules and constraints interact: if the rules dictate that other programs have to be moved as a result of the move of a program, all the constraints have to be checked on these programs as well.

3 Domain Knowledge as an Aspect

According to the technical problem described earlier, the domain knowledge and the implementation strategy of software applications should be represented as separated as possible. Although this principle can and should be applied throughout the entire software development life cycle, we concentrate on representing domain knowledge and implementation strategy separately at the implementation level. Our research hypothesis is: *Domain knowledge is an aspect, and using knowledge representation technologies for expressing it explicitly and separately from the implementation strategy, which is expressed in a standard (object-oriented) programming language, will improve software understandability, software maintenance and software reuse.* After decomposing follows composition or weaving in order to obtain an operational software application that exhibits the desired behaviour. Since weaving is a knowledge-intensive process (as is also shown in [25]) we will investigate the advantages of using the same knowledge representation language as meta-language for guiding the composition.

Although it is difficult to test subjective properties such as improved understandability, it was already shown in [27] that an explicit model of the domain knowledge achieves exactly this. Furthermore, we will show that the separation of domain knowledge and implementation strategy reduces the propagation of changes from the one part to the other, thus facilitating maintenance. Finally, the AOSD community among others, promotes decomposing parts of the software into loosely coupled and independently evolvable components because it improves reusability.

The following two subsections elaborate on representing domain knowledge separately and composing it with the implementation strategy respectively.

3.1 Separating and Representing Domain Knowledge

Object-oriented programming languages are the state of the art today for expressing the procedural nature of implementation strategy. In domain knowledge on the other hand, the network of concepts and relations suggests the use of a frame-based knowledge representation [19]. For expressing the constraints and rules in the domain knowledge, and for checking the constraints and chaining the rules, a rule-based system is ideal.

After a literature study of hybrid knowledge representation systems containing representation mechanisms for both frames and rules [9], the following minimal set of features for representing domain knowledge was decided upon:

- basic frame-based representation, with frames having slots that can contain values or rules (specifying how to infer values), and daemons that watch the slots and trigger rules when slots are accessed or changed
- prototype-based frames, as in KRS [17]
- a mixture of forward and backward chaining rules

We will further investigate if a constraint checker or truth maintenance systems is required. If possible, an existing system will be reused, but given the context in which it has to operate it is more likely that we will implement a light-weight knowledge representation system with the above features.

3.2 Composing Domain Knowledge and Implementation Strategy

Whereas the aforementioned suite of technologies achieves the desired separation or decomposition of explicitly described domain knowledge from the implementation strategy, it does not consider the composition of the two in order to achieve a working software application. Since the structural part of the domain knowledge should be mapped onto the implementation strategy and the operational part should be dynamically inserted in very specific places in the implementation strategy, we will look at *Aspect-Oriented Software Development* technologies [3] because they achieve exactly this. In these technologies, *aspects* such as error handling, error reporting, persistence and so on, are expressed in an *aspect language* separate from the implementation strategy. A *weaver* composes the aspect with the implementation strategy which results in an executable program. A weaver uses *join points* which indicate dynamic places in the implementation strategy where the aspect should be inserted. We believe that in some cases the "weaving" of domain knowledge and implementation strategy will be quite straightforward, but that in others it will benefit from applying ideas if not actual techniques from aspect-oriented programming. An original contribution of this research is to consider *domain knowledge as an aspect* [6] [7]. We are currently investigating the suitability of existing AOSD technologies for composing domain knowledge with implementation strategy. The goal is to come up with a required set of features to achieve this. The next step in the research project is establishing a symbiosis between the selected knowledge representation system (KRS) and the object-oriented programming language (OOPL) for facilitating the composition of domain knowledge and implementation strategy.

AOSD technologies Currently we are investigating the state of the art in AOSD technologies such as HyperJ [20], AspectJ[15], Composition Filters [4] and Demeter [16]. The goal is to find out how well they support composing domain knowledge and implementation strategy using the small case studies explained above. The result will be a set of necessary features that are required for composing domain knowledge and implementation strategy. Since it is very likely that this set will contain features from the different approaches – some AOSD approaches have different capabilities that complement each other well – we predict that no single approach will be most suitable.

Symbiosis between a KRS and an OOPL For enabling the composition of domain knowledge and implementation strategy, the symbiosis between the chosen knowledge representation system and the object-oriented programming language will have to be investigated. Research on symbiosis between two object-oriented languages is already conducted in [24]. A similar configuration was already successfully developed at our computer science department, more specifically logic meta-programming [25] [28] where a logic language serves as a meta-language to reason about object-oriented base code, which can be used for example to enforce architectural or design choices in the code [29]. Moreover, a simple prototype of a forward-chaining rule-based meta-language for an object-oriented base language was also developed for reasoning with design knowledge for interactively supporting framework reuse [18].

4 Related Work

Apart from the aforementioned technologies and approaches that will be actively (re)used in this research project, some other work is also relevant.

GeoObjects is a project we were involved in together with an industrial partner specialized in producing and maintaining digital geographic data to be used in Geographic Information Systems. In this project we delivered a means for describing quality constraints, used for checking the well-formedness of the geographic data, in an application independent, modular and declarative way on a conceptual model of the geographic data. This representation of the quality constraints is translated by means of a code generator into a classical programming language which has access to the actual geographic data via API calls [26] [5].

There is some work done on *Business Rules*, where rules and constraints are modelled separately from the core application at the specification level. At the design and implementation level *patterns* are provided for making the business rules as reusable and maintainable as possible [14] [2]. However, the business rules are still tangled in the implementation strategy and not expressed declaratively. We still need to look into approaches such as *CommonRules*[13] and *Business Rule Beans*[12].

There are other efforts that advocate the explicit modelling of domain knowledge. The *framework for requirements models (RMF)* represents real-world knowledge explicitly in the requirements specification [10]. In [1] the authors argue that conventional software engineering and knowledge engineering are complementary and both essential for developing the increasingly larger systems of today. They propose a single common life-cycle methodology. These approaches, however, do not offer support at the implementation level.

5 Conclusion

This paper describes work in progress that advocates the use of knowledge-based techniques in object-oriented software engineering. In particular, we aim to make domain knowledge of software applications explicit and separate it from the implementation strategy. The latter is typically and suitably expressed in an object-oriented programming language. For representing domain knowledge we investigated frame-based and hybrid knowledge representation systems from AI. For composing domain knowledge and implementation strategy in order to obtain an operational software application, we are inspired by Aspect-Oriented Software Development. We believe that a symbiosis between the knowledge representation language and the object-oriented programming language is crucial as a vehicle for enabling the composition of domain knowledge and implementation strategy.

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