ASPECT-ORIENTED DOMAIN SPECIFIC LANGUAGES FOR ADVANCED TRANSACTION MANAGEMENT

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Abstract: Transaction management has some known drawbacks, which have been researched in the past, and many solutions in the form of advanced transaction models have been proposed. However, these models are too difficult to be used by the application programmer because of their complexity and their lack of separation of concerns. In this paper we address this by letting the application programmer specify advanced transactions at a much higher abstraction level. To achieve this, we use the software engineering techniques of Aspect Oriented Programming and Domain-Specific Languages. This allows the programmer to declare advanced transactions separately in a concise specification which is much more straightforward.

1 INTRODUCTION

In current-day module-based software development, software is built by decomposing the problem domain into different modules. However, given any decomposition of a sufficiently large problem domain, not all of its concerns can be modeled in separate modules. Some concerns will be scattered throughout the entire system, crosscutting different modules (Tarr et al., 1999). Transaction management is one of those concerns because to use transactions, the programmer must add transaction demarcation code: code which starts and ends transactions, and which indicates which data accesses occur within the scope of what transaction. Code for transaction demarcation is therefore not just contained in one module. Instead, transaction demarcation code is spread out into different modules.

Aspect-Oriented Programming (AOP) addresses the issue of such cross-cutting concerns (Kiczales et al., 1997) by introducing the concept of aspects. In AOP a concern is either implemented in a component, or in an aspect. A concern is called a component if it can be encapsulated cleanly into a module, and if it cannot be encapsulated cleanly into a module, it is called an aspect. (All concerns which are components are often called the base aspect or base code.) AOP allows the programmer not only to reason separately about the aspects, but also to specify them separate from the normal modules. This is achieved by specifying the code pertaining to an aspect in a separate aspect file, in a special aspect language. Once all modules and aspects are defined, a special tool, called an aspect weaver, combines these into executable code.

Proposed approaches that captured transaction management with aspects all elaborated in an object-oriented setting and start by assuming that transaction boundaries coincide with method boundaries, i.e. that transactions are started when a method starts executing and ended when the method ends. However, these approaches are limited, as they structurally restrict themselves to only implement classical transaction processing.

A known issue with classical transactions is that it has been developed to treat small units of work, which only access a few data items. As a result, as transaction time grows, and the number of data items accessed in one transaction becomes larger, the performance of the system will drop significantly (Gray and Reuter, 1993). To increase application performance, and to address some additional requirements, advanced transaction mechanisms (ATMS) have been developed, mostly between 1981 and 1997. An impressive number of alternate ATMS can be found in the literature, and two books have been published about the subject (Elmagarmid, 1992; Jajodia and Kershberg, 1997).

Our research focuses on bringing the known ad-
vantages of separation of concerns through AOP to
the field of ATMS. The goal is to be able to express
the transactional properties of the application in a
separate aspect, in domain-specific aspect languages.
Such a separate specification then allows us to tailor
the aspect-specific languages specially to the domain
of the problem at hand, in this case the ATMS being
used. As a result, the application programmer writes
more concise and intentional aspect declarations, i.e.
transactional specifications.

In this paper we start with an introduction to
ATMS, then briefly discuss a published formal model
for them. We then detail our contribution by first pre-
senting the general aspect language we defined for
ATMS: KALA, and second giving an overview of the
different aspect languages for specific ATMS.

2 ADVANCED TRANSACTION
MODELS

As said above, a large number of alternate ATMS can
be found in the literature, therefore we do not provide
a full overview here. Instead we briefly describe two
models here: Nested Transactions and Sagas.

A first example is the best-known ATMS: nested
transactions (Moss, 1981). Nested transactions al-
low for hierarchically structured transactions, where
a child transaction also has access to the data used by
its parent transaction, and this recursively to the root
transaction. Furthermore, when a child transaction
commits its data, this is not committed to the data-
base, but instead to its parent, which is now respon-
ible for committing this data.

A second example ATMS, Sagas (Garcia-Molina
and Salem, 1987), is tailored towards long-lived trans-
actions. Sagas split these into a sequence of atomic
sub-transactions, which should either be executed
completely or not at all. Splitting the long-term trans-
actions releases locks earlier, which increases con-
currency. However, to rollback the Saga extra work
needs to be done: compensating actions must be
executed to undo the effects of already committed
sub-transactions. Hence, the application programmer
should define a compensating transaction for each
sub-transaction, which performs a semantical com-
pensation action. To rollback a Saga, the TP Monitor
aborts the currently running sub-transaction, and sub-
sequently runs all required compensating transactions
in reverse order.

Besides the models we discussed above, we have
evaluated a large set of ATMS, and have concluded
that each ATMS usually focuses on a small subset
of the issues of classical transaction management.
No overall system has been developed which treats a
large number of the identified shortcomings of classi-
cal transactions. However, a formal model that covers
many ATMS has been developed, that can serve as the
basis for an overall system, and we discuss this next.

3 FORMALIZING ATMS WITH
ACTA

The ACTA formalism (Elmagarmid, 1992) was cre-
ated as a common framework in which it is possi-
ble to specify different ATMS. We will now give an
overview of ACTA, and use nested transactions as a
running example of an advanced model.

In ACTA, an ATMS is formally defined by stating
three kinds of axioms that constrain and modify the
transaction history. This transaction history, as de-
defined in ACTA, consists of a sequence of operations
of the different transactions on the database.

The first kind of axiom on transaction histories are
dependencies: a dependency places a relationship be-
tween two transactions, defined in terms of the opera-
tions of these transactions. An example dependency is
the commit dependency (Tj CD Tj): if transactions
Tj and Tfj commit, Ti must commit before Tj. In
nested transactions, if Tp is a parent transaction and
Tc a child transaction, then (Tp CD Tc).

The second kind of axioms defined by ACTA are
view definitions, which allow different transactions to
concurrently work on the same data as if they were
the same transaction. In the example this is specified
by defining the view of Tc to contain Tp.

The third kind of axioms are delegation: one trans-
action Ti delegates the responsibility for committing
or aborting a specified number of its operations to an-
other transaction Tj. In nested transactions, if a child
transaction Tc commits, its effects are delegated to its
parent Tp.

A wide variety of ATMS have been formally de-
scribed in ACTA, have been published. These de-
scriptions are quite complicated and lengthy: for ex-
ample, nested transactions is defined using nineteen
axioms, which are not that straightforward, as can be
seen in (Elmagarmid, 1992).

4 FROM ACTA TO ASPECT: THE
LANGUAGE KALA

Having the ACTA formal model at our disposal is an
important asset: we can use this model as a guideline
for the implementation of a TP Monitor and for the
definition of the aspect language for advanced trans-
action models. This will then allow us to support a
wide variety of advanced transaction models. As a
full discussion of the TP Monitor is outside of the
scope of this paper, we will instead focus here on the aspect language for advanced transaction models.

Our aspect language, called KALA (Kernel Aspect Language for ATMS), which, together with the corresponding aspect weaver, allows for the specification of transactional properties of Java methods. These specifications are highly similar, but not identical to the ACTA specifications of transaction models. In KALA, a programmer declaratively annotates the transactional properties of a method, primarily using the concepts which are defined in ACTA: dependencies, view, and delegation. Additionally, two extra concepts are required in KALA: naming of transactions and life-cycle management. We discuss these before treating dependencies, view and delegation.

4.1 Naming

To be able to refer to transactions within a KALA program, two naming schemes are required: first a static scheme for compile-time naming and second a dynamic scheme for run-time naming.

In the static scheme, a transaction coincides with a method definition, and is therefore named by giving the full class name and the method signature, separated by a dot. This already allows us to write our first KALA program, below, in which we declare the method with signature increment(int) of the class utility.Counter transactional.

```java
utility.Counter.increment(int) {} name {self <this.ident.toString() + this.count>};
```

Within one transaction specification, the programmer needs to be able to refer to other transactions that will run concurrently to be able to define dependencies, views and delegation relations between them (as defined in 3). To allow this, we also provide a dynamic naming scheme, at runtime. When a transactional method starts, it can register itself globally under a certain name, and all running transactional methods can use this name to refer to it. This is achieved in KALA by adding a name statement to the transactional properties, which binds a transaction identifier to a key (a Java expression enclosed between angular brackets). Lookup is performed, by using an alias statement. In such a statement, an expression referring to a dynamic name is resolved to an already running transactional method.

A reserved name is the pseudo-name self, which always refers to the current transaction.

As an example of naming, suppose our counter object has a unique identifier (contained in the instance variable ident) and we wish to register the increment transactional method using this name and the current count (contained in the instance variable count). This is performed by the following KALA program:

```java
utility.Counter.increment(int) {
    name {self <this.ident.toString() + this.count>};
}
```

4.2 Transaction Life-Cycle Management

Transactions are started and ended by the underlying application as it executes. However, ACTA, as a formal model, does not involve itself with this. ACTA restricts itself to verifying if the resulting transaction history complies to the axioms. In going from formal model to an implementation, we have to consider how we can ensure that transactions are started and ended when necessary.

As transactions coincide with methods, the main part of the responsibility for transaction life-cycle management lies in the control flow of the underlying application: at some points a transactional method will be called, resulting in the beginning of a transaction, and when the method ends, the transaction will also end. However, in addition to the transactions started by the application, some models, require secondary transactions to automatically run when their dependencies are satisfied. In Sagas, for example, these are compensating transactions which run at rollback, i.e. these methods are executed at that time.

To support this, we have added the option to start secondary transactions automatically through the use of the autostart statement. Combining such an autostart with the required dependency statements, which we will see below, will ensure that the automatic transactions run when required. With the autostart statement a transactional method will be called which will run in a new thread, with a set of given transactional properties.

A second life-cycle operation is the termination of transactions. This is required because due to the complex interactions of different transactions in ATMS, when a transaction ends its name and dependencies may still be required. When these are no longer needed, the transaction can be stopped and removed from the system by means of the terminate statement.

4.3 Dependencies, Views and Delegation

Dependencies, views and delegation are concepts of ACTA which are represented as statements in KALA. These statements can be performed at begin, commit or abort time and therefore are grouped in begin, commit or abort blocks, as can be seen in the example describing a nested transaction below:

```java
AClass.nestedMethod() {
    alias [parent < [...] > ]
    begin { dep(self wd parent, parent cd self);}
```
In this example, the transaction corresponding to the method AClass.nestedMethod() is declared to be a child of another transaction, by using the extends keyword. (As in 4.3 we have omitted the Java code that determines the parents’ name)

At compile-time a DSL takes a domain-specific program, such as the one above, and generates the equivalent KALA program. In the above case, the result is the KALA program in section 4.3.

A more complicated example is the DSL which was constructed to describe Sagas. An example of such a Saga specification is given below. It is a money transfer method which is divided into three steps, each a method which is called by the transfer method. In this code we declare the Saga and its steps. Also, each step, except for the last, defines a compensation step. Compensation steps are defined through the use of the comp keyword, which takes as argument a static name, as defined in 4.1, and a list of actual parameters for that method.

As an illustration of the advantage of using a DSL, we include the KALA program for the second method only. We can not include the full KALA program due to lack of space. Suffice it to say that the full program is over four times the size of the code shown here, and has the same complexity.

In this code, we see how this step obtains references to the saga and to other transactions and names itself, before defining a compensating transaction. At begin and commit time, dependencies are placed between these, to ensure correct compensation when required.

It is clear that the KALA code above is more complex than the definition in the saga language, while in effect describing the same thing. This clearly shows how the use of a DSL has raised the level of abstraction to the level of the concepts available in the ATMS, further reducing complexity of usage.
5.2 Open set of language features

Instead of implementing a DSL compiler for each ATM from scratch, we have chosen for a modular approach that can exploit the common language features of the different DSLs. The division of a ATM specific DSL into modular and reusable language features is hampered because the effects of these language features are scattered in the resulting KALA program. For example, take the four basic language features of the Saga DSL: name (denoting the step name), saga, step and comp, which should correspond with four modules. As we have seen in 5.1, each step results in a single KALA transaction.

When modularizing the saga language definition, the step and its compensation description are separated into two modules, each module yielding a partial transaction description. When the two language features are combined into single language, the two partial descriptions must be combined together to a single KALA transaction. However, the name of a compensating transaction is not confined to just one step, but it is present in different steps, i.e. each step is linked to other steps. This entails that the comp module needs to invasively change different steps with additional dependencies for the compensating actions, which hampers the division of the DSL into reusable modules. In order to separate these different language features into reusable modules, a system supporting such invasive composition is required.

Keeping both the modularity and invasive composition requirements in mind, the Linglet Transformation System (LTS) (Cleenewerck, 2003) seemed the most appropriate system. In LTS a language implementation is divided into smaller reusable components, each defining a small language feature. The languages in LTS are constructed by composing these modular and reusable language components (called linglets) together. In LTS, for each of the four basic language features of the Saga DSL (name, saga, step and comp) a linglet is built. With these four language features the Saga DSL can be specified through composition. This composition is achieved by customizing the linglet definitions with other linglets. Also, these linglets have been reused when building the RCS DSL, which is an extension of the Saga DSL.

In total, we have built four DSLs: one for classical transactions, and three for the ATMS mentioned here, of which we have shown two, out of a set of seven different language components.

6 CONCLUSIONS

Advanced transaction models address shortcomings in the classical transaction model, but are difficult to use for the application programmer due to their complexity and the lack of separation of concerns. Application programmers need detailed knowledge of the advanced transaction models to use them in their software and must spread the configuration information for these models throughout the code.

In this paper, we reduced this complexity by providing a open family of domain-specific languages, each of which tailored for one specific ATMS. These languages allow the application programmers to declaratively state the transactional properties at a high level of abstraction, in a specification separate from the base application.

To reach this goal, we used Domain-specific languages and Aspect-Oriented Programming. As a result, two contributions have been made: the implementation of an aspect language, KALA, to express advanced transaction models and the development of an open set of language features to raise the abstraction level of KALA to concepts found in ATMS.

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REFERENCES


