A Parameterized Interpreter for Modeling Different AOP Mechanisms

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ABSTRACT
We present a parameterized interpreter for modeling aspect-oriented mechanisms. The interpreter takes several parameters to cover different AOP mechanisms found in AspectJ, Hyper/J, and Demeter. The interpreter helps our understanding of the AOP mechanisms in two ways. First, its core part represents the common mechanical structure shared by different AOP mechanisms. Second, by reconstructing the existing AOP mechanisms and using parameters to configure the interpreter, we can illustrate the differences and similarities of those mechanisms clearly. This will also be helpful in rapid-prototyping a new AOP mechanism or a reflective AOP system that supports different mechanisms.

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General Terms: Languages
Keywords: AOP, Join point models

1. INTRODUCTION
Mechanisms in aspect-oriented programming (AOP) languages can be characterized by join point models (JPMs) consisting of join points, a means of identifying the join points, and a means of raising effects at the join points. JPMs are important in AOP languages because they can deal with crosscutting concerns elegantly. Crosscutting concerns may not be able to be modularized as aspects without an appropriate JPM. Each of the current AOP languages is based on a few fixed set of JPMs. Many different JPMs have been proposed, and they are still evolving with the aim of better modularization of various crosscutting concerns.
H. Masuhara and G. Kiczales defined a three-part modeling framework that explains a common structure in different JPMs including PA (pointcuts and advice as in AspectJ[2][15]), TRAV (traversal specifications as in Demeter[6]), COMPOSITOR (class merges based on matching relationships as in Hyper/J[27][22]), and OC (open classes as in AspectJ[19]). The modeling framework is derived from a suite of interpreters called Aspect SandBox (ASB)[1][7].

Although the three-part modeling framework clarifies common mechanisms in major JPMs, it does not provide a common design model. The goal of this paper, a follow-up paper to [19], is a conceptual description of the design space of JPMs, executed by capturing essential characteristics and differences concisely. Based on the three-part modeling framework, we propose a parameterized interpreter that takes several parameters to cover different JPMs.

The interpreter helps our understanding of the AOP mechanisms in two ways. First, its core part represents the common mechanical structure shared by different JPMs. Second, by reconstructing the existing JPMs and using parameters to configure the interpreter, we can illustrate the differences and similarities of those mechanisms clearly. This will also be helpful in rapid-prototyping a new JPM or a reflective AOP system that supports different mechanisms.

The remainder of this paper is structured as follows. In section 2, we point out the difficulty of providing a common parameterized interpreter by using examples that show the differences among the four JPMs. We overcome the difficulty, and present the parameterized interpreter in section 3. We also show how the four JPMs are obtained by fulfilling the parameters of the interpreter. In section 4, we evaluate the parameterized interpreter in terms of the efficiency of rapid-prototyping JPMs. In section 5, we discuss extensible AOP using the parameterized interpreter. In section 6, we introduce some related works, and discuss future directions of research. Section 7 concludes the paper.

2. MOTIVATION
Although the previous work pointed out the common struc-
ture shared by different AOP mechanisms[19], the commonality is described in an informal manner. In other words, there has been no single model to capture different AOP mechanisms. Note that, as in the previous work, we refer to an interpreter of a language with an AOP mechanism as a model of the mechanism. In this section, we briefly excerpt a modeling framework with sample programs from the previous work, and then demonstrate how the framework lends itself to no single model.

2.1 Example

Using the following simple figure program, we give a brief explanation of the four JPMs:

class Figure { List element = new LinkedList(); }
class FigureElement { Display display; }
class Point extends FigureElement {
  int x, y;
  int getX() { return x; }
  int getY() { return y; }
  void setX(int x) { this.x = x; }
  void setY(int y) { this.y = y; }
}
class Line extends FigureElement {
  Point p1, p2;
  int getP1() { return p1; }
  int getP2() { return p2; }
  void setP1(Point p1) { this.p1 = p1; }
  void setP2(Point p2) { this.p2 = p2; }
}

This program is written in the ASB core language called BASE\(^1\). In ASB, interpreters of the four JPMs are designed on the BASE interpreter. The above program consists of four classes: Figure, FigureElement, Point, and Line. A figure is comprised of a collection of figure elements. There are two kinds of figure elements: point and line. The definitions of the two classes LinkedList and Display are omitted here. The former is a class for managing figure elements, and the latter is a class for displaying a figure.

PA program

PA captures a join point such as a method call, and inserts advice code before/after/around the join point. The following code is an after-advice that implements display updating functionality. The update, which is the method of the Display class, is called after setX, setY, setP1, or setP2 is called.

```java
after (FigureElement fe):
  ( call(void Point.setX(int))
 || call(void Point.setY(int))
 || call(void Line.setP1(Point))
 || call(void Line.setP2(Point)) ) \& target(fe){
    fe.display.update(fe);
}
```

TRAV program

TRAV provides a mechanism that enables programmers to design traversals through object graphs in a succinct fashion. The following code implements the behavior of visiting all the figure elements reachable from a figure:

```java
Visitor counter = new CountElementsVisitor();
traverse("from Figure to FigureElement", fig, counter);
```

The first argument to traverse is called a traversal specification that describes a path to be visited. The second argument is the root object where the traversal starts. The third argument is a visitor that defines behavior at each traversed object. In this case, the program traverses from a root figure object following down through line objects to reach point objects, and counts the elements.

COMPOSITOR program

COMPOSITOR composes independent partial programs. Using COMPOSITOR, the display updating functionality can be designed in two steps. First, we write the following program and relationship:

```java
class Observable {
  Display display;
  void moved() { display.update(this); }
}
; relationship between Point/Line and Observable
match Point.setX with Observable.moved
match Point.setY with Observable.moved
match Line.setP1 with Observable.moved
match Line.setP2 with Observable.moved
```

Next, we compose the original figure program and the above program using the relationship. In the resulting composed program, the specified method of the Point and Line classes are combined with the body of the moved method in the Observable class. The effect is that display.update is called after the execution is complete.

OC program

OC makes it possible to locate method or field declarations for a class outside the textual body of the class declaration. The following code defines draw methods for the different kinds of figure elements in a single DisplayMethods class – it modularizes the display aspect of the system. Graphics is a class for drawing graphics.

```java
class DisplayMethods {
  void Point.draw() { Graphics.drawOval(...); }
  void Line.draw() { Graphics.drawLine(...); }
}
```

2.2 Three-part modeling framework

Although the four JPMs are drastically different, there are some points of commonality. The three-part modeling framework shows the core semantics of these JPMs by modeling the weaving process. The framework defines the process of weaving as taking two programs and coordinating them into a single combined computation. A critical property of the framework is that it describes the join points as existing in the result of the weaving process rather than residing in either of the input programs.

The framework explains each JPM as an interpreter that is modeled as a tuple of nine parameters:

\((X, X_{JP}, A, A_{ID}, A_{EFF}, B, B_{ID}, B_{EFF}, META)\).

\(A\) and \(B\) are the languages in which the respective programs \(p_A\) and \(p_B\), input to the interpreter, are written. \(X\) is the result domain of the weaving process, which is the third language of a computation. \(X_{JP}\) is a join point in \(X\). \(A_{ID}\) and \(B_{ID}\) are the means, in the languages \(A\) and \(B\), of identifying elements of \(X_{JP}\). \(A_{EFF}\) and \(B_{EFF}\) are the means, in the languages \(A\) and \(B\), of affecting semantics at the identified join points. \(META\) is an optional meta-language for

\(1\)While this is a Scheme-based object-oriented language, we use a Java-like syntax for readers’ easier understanding.
Table 1: Three-part modeling framework

<table>
<thead>
<tr>
<th>PA</th>
<th>TRAV</th>
<th>COMPOSITOR</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>program execution</td>
<td>traversal execution</td>
<td>composed program</td>
</tr>
<tr>
<td>X_JP</td>
<td>method calls</td>
<td>arrival at each object</td>
<td>declarations in X</td>
</tr>
<tr>
<td>A</td>
<td>c, m, f declarations</td>
<td>c, f declarations</td>
<td>c, m, f declarations</td>
</tr>
<tr>
<td>A_ID</td>
<td>m signatures, etc.</td>
<td>c, f signatures</td>
<td>c, m, f signatures</td>
</tr>
<tr>
<td>A_EFF</td>
<td>execute method body</td>
<td>provide reachability</td>
<td>provide declarations</td>
</tr>
<tr>
<td>B</td>
<td>advice declarations</td>
<td>traversal spec.&amp;visitor (=A)</td>
<td>OC m declarations</td>
</tr>
<tr>
<td>B_ID</td>
<td>pointcuts</td>
<td>traversal spec.</td>
<td>(=A_ID)</td>
</tr>
<tr>
<td>B_EFF</td>
<td>execute advice body</td>
<td>call visitor&amp;continue</td>
<td>(=A_EFF)</td>
</tr>
<tr>
<td>META</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>

Table 2: X-ASB parameters

<table>
<thead>
<tr>
<th>Three-part model</th>
<th>X-ASB parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>[eval-program], [computation-at-jp]</td>
</tr>
<tr>
<td>X_JP</td>
<td>[register-jp]</td>
</tr>
<tr>
<td>A</td>
<td>pgm-a</td>
</tr>
<tr>
<td>A_ID</td>
<td>[lookup-a]</td>
</tr>
<tr>
<td>A_EFF</td>
<td>[effect-a]</td>
</tr>
<tr>
<td>B</td>
<td>pgm-b</td>
</tr>
<tr>
<td>B_ID</td>
<td>[lookup-b]</td>
</tr>
<tr>
<td>B_EFF</td>
<td>[effect-b]</td>
</tr>
</tbody>
</table>

Figure 1: Weaving process

We illustrate the outline of the X-ASB parameterized interpreter. The heart of the weaving process is the coordination at join points where the two programs A and B meet. The type of join points is registered by the register-jp parameter. Each coordination given as the computation-at-jp parameter is executed using the four parameters lookup-a, effect-a, lookup-b, and effect-b. The eval-program parameter is the body of an interpreter in which procedures specified by the computation-at-jp parameter are called. The following code shows the core part of the interpreter.

```scheme
(define weave
  (lambda (pgm-a pgm-b)
    (register-jp)
    (eval-program pgm-a pgm-b)))
```

3. PARAMETERIZED INTERPRETER

To tackle the problem pointed out in section 2, we present a single model that captures different AOP mechanisms, in the form of a parameterized interpreter written in Scheme. The interpreter, extensible ASB (X-ASB), consists of the core part and various sets of parameters. The former represents the common mechanical structure of the four JPMs PA, TRAV, COMPOSITOR, and OC. The latter clarifies the differences and similarities of those JPMs. Each JPM can be obtained by providing parameters to the interpreter.

3.1 Core part and the sets of parameters

Table 2 and Figure 1 show the relation between the parameters of the three-part modeling framework and those of X-ASB. The elements enclosed by brackets are procedures. The X-ASB parameters provided as procedure signatures expose the programming interfaces for JPM developers.

parameterizing the weaving process. A weaving process is defined as a procedure that accepts $p_A$, $p_B$, and META, and produces either a computation or a new program. Table 1 summarizes the three-part modeling framework[19]. In Table 1, single letters 'c', 'm', and 'f' are abbreviations for class, method and field, respectively.

2.3 Problem to be tackled

In the three-part modeling framework, the weaving process consists of three operations: 1) generating a join point; 2) applying $A_{ID}$ and $B_{ID}$ to identify elements in $p_A$ and $p_B$ matching the join point; 3) using $A_{EFF}$ and $B_{EFF}$ to produce the proper effects from the matching elements. These steps are illustrated by the following code skeleton written in Scheme.

```scheme
(lambda (pA pB)
  (let ((jp <generate a join point>))
    (effect-A (lookup-A jp pA))
    (effect-B (lookup-B jp pB))))
```

As pointed out in [19], the differences among the four JPMs make it difficult to design a single parameterized procedure of this form. For example, $B_{EFF}$ controls execution of $A_{EFF}$ in PA. As a consequence, the four JPMs are designed as individual interpreters in ASB. Although the three-part modeling framework identified a common structure among different AOP mechanisms as shown in Table 1, the commonality is given in an informal manner. There has been no single model that captures all the different AOP mechanisms.

3. PARAMETERIZED INTERPRETER

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Table 2: X-ASB parameters

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<thead>
<tr>
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<th>X-ASB parameter</th>
</tr>
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<tbody>
<tr>
<td>X</td>
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</tr>
<tr>
<td>X_JP</td>
<td>[register-jp]</td>
</tr>
<tr>
<td>A</td>
<td>pgm-a</td>
</tr>
<tr>
<td>A_ID</td>
<td>[lookup-a]</td>
</tr>
<tr>
<td>A_EFF</td>
<td>[effect-a]</td>
</tr>
<tr>
<td>B</td>
<td>pgm-b</td>
</tr>
<tr>
<td>B_ID</td>
<td>[lookup-b]</td>
</tr>
<tr>
<td>B_EFF</td>
<td>[effect-b]</td>
</tr>
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Figure 1: Weaving process

We illustrate the outline of the X-ASB parameterized interpreter. The heart of the weaving process is the coordination at join points where the two programs A and B meet. The type of join points is registered by the register-jp parameter. Each coordination given as the computation-at-jp parameter is executed using the four parameters lookup-a, effect-a, lookup-b, and effect-b. The eval-program parameter is the body of an interpreter in which procedures specified by the computation-at-jp parameter are called. The following code shows the core part of the interpreter.

```scheme
(define weave
  (lambda (pgm-a pgm-b)
    (register-jp)
    (eval-program pgm-a pgm-b)))
```

```scheme
(define eval-program
  (lambda (pgm-a pgm-b)
    ( <iterate the following steps
      - get the next program element
      - generate a join point
      - call computation-at-jp>)))
```
(define computation-at-jp
  (lambda (jp)
    <mediate the following according to the JPM type>
    (effect-a (lookup-a jp))
    (effect-b (lookup-b jp)))))

The interpreter takes the two programs pgm-a/pgm-b as arguments that correspond to A/B in Table 1. The register-jp procedure registers join point types that include information needed for coordination at specific join points. For example, a method-call join point type (abbreviated as call-jp in this paper) is registered in PA. When the execution of the eval-program procedure arrives at a point that requires a weaving, it generates a join point instance from its type and calls the computation-at-jp procedure. In PA, the eval-program procedure evaluates the original program (pgm-a), generates a call-jp instance when the eval-program procedure evaluates the method-call expression, and calls the computation-at-jp procedure that executes an advice body (pgm-b) using information contained in the call-jp instance. The computation-at-jp parameter that handles the call-jp can be designed as follows.

;; The first version
(define eval-exp ;called from eval-program
  (lambda (exp env)
    (cond
      ((method-call-exp? exp)
        (computation-at-jp::call-jp
          (lambda (jp)
            (execute-advice (lookup-advice jp)
              (lambda ()
                (execute-method (lookup-method jp) jp))))))
      (else
        (eval-exp exp env))))

The four procedures lookup-method, execute-method, lookup-advice, and execute-advice correspond to the X-ASB parameters lookup-a, effect-a, lookup-b and effect-b, respectively. lookup-method and lookup-advice searches the method declaration and the advice declarations related to the call-jp; execute-method executes the method body; and execute-advice executes the advice bodies. In this case, only the after-advice is available.

### 3.2 Registration of join point type

A join point type registered by the register-jp parameter is strongly related to the computation-at-jp parameter. For example, the computation-at-jp::call-jp procedure is affected by the call-jp join point. If we want to add a new kind of join point such as a field-set join point, we must define a new kind of computation-at-jp such as the computation-at-jp::fset. Although the first version of the computation-at-jp procedure shown above gives a guideline applicable to JPM designs, its reusability is still limited. In order to make the computation-at-jp procedure reusable, it is necessary to enrich the data structure that a join point holds. The following jp defines the structure of a join point:

(define-jp
  (jname
    (jtype
      (jparam
        (jparam
          (effect-a
            (effect-b (lookup-b effect-b)))))
    (jcondition
      (jparam
        (jparam
          (effect-a
            (effect-b (lookup-b effect-b)))))
    (jcontrol
      (jparam
        (jparam
          (effect-a
            (effect-b (lookup-b effect-b)))))))

The jp structure consists of five elements: the first element computation-strategy shows a weaving policy such as computation-at-jp::call-jp, the second element lookup-a, the third element effect-a, the fourth element lookup-b, and the fifth element effect-b correspond to parameters in Table 2. The elements specific to a certain join point type can be added to the jp structure. For instance, the call-jp join point in PA is defined below. This join point includes the name of the method being called, the object that is the target of the call, and a list of the arguments to the call:

(define-struct (call-jp jp) mname target args)

A set of join point types must be registered using register-jp. The following is the code for registering the call-jp join point type.

(define-struct jtype (jname generator))
(define register-jp
  (lambda ()
    (register-one-jp
      'call-jp
      (lambda (mname target args)
        (make-call-jp
          'b-control-a
          lookup-method execute-method
          lookup-advice execute-advice
          mname target args))))

A join point type is defined by the jtype structure, which in turn has two elements: the jname element shows the name of the join point type, and the generator is a procedure that instantiates a join point from the jp structure. The register-one-jp procedure, an X-ASB library procedure, registers one join point type. Using the library procedure, it is possible to add a new kind of join point type and its related computation.

### 3.3 Computation at a join point

Using the jp structure, we give a new design of the computation-at-jp parameter. This is more modular than the first version.

When an interpreter arrives at a point specified by the registered join point type, the interpreter generates a join point instance using the generator defined in the jtype structure, and executes the following computation-at-jp procedure, which dispatches a process according to a computation strategy. In the case of the call-jp join point, the computation-at-jp::b-control-a library procedure is executed. It is not necessary to define a new kind of computation-at-jp whenever we add a new kind of join point type. We can reuse the computation-at-jp::b-control-a library procedure if the join point type is based on PA.

;; The Second version
(define computation-at-jp
  (lambda (jp)
    (let ((strategy (jp-computation-strategy jp)))
      (cond ((b-control-a? strategy)
              (computation-at-jp::b-control-a
               (lambda (jname target args)
                 (make-call-jp
                  'b-control-a
                  lookup-method execute-method
                  lookup-advice execute-advice
                  mname target args))))))

(define computation-at-jp::b-control-a
  (lambda (jp)
    (let* ((lookup-a (jp-lookup-a jp))
            (effect-a (jp-effect-a jp))
            (lookup-b (jp-lookup-b jp))
            (effect-b (jp-effect-b jp)))
      (effect-b (lookup-b jp)
        (lambda ()
          (effect-a (lookup-a jp) j))))))
that is as modular as possible because information needed is more reusable than the first version. This version can be join point instance.

3.4 Library for pointcut designator

The pointcut mechanism is important and useful for effective AOP although all JPMs do not presume the mechanism. X-ASB provides library procedures for designing pointcut designators and pointcut evaluations.

The structure of a pointcut designator is defined as follows:

```
(define-struct pcd (pname evaluator))
```

A pointcut designator consists of two elements: the `pname` shows the name of a pointcut designator, and the `evaluator` is a boolean procedure that checks whether a current join point is an element of a pointcut set. The `evaluator` procedure is called from the `lookup-b` parameter.

Below is the code for registering a call pointcut designator that includes a type of return value, a class name, a method name, and parameters of the method. The `register-one-pcd` procedure, an X-ASB library procedure, registers one pointcut designator. The procedure has two arguments: the first is the name of the pointcut designator, and the second is an evaluator. In this case, the registered evaluator checks whether the method name of a join point is equivalent to the name specified by the call pointcut designator.

```
(define-struct (call-pcd pcd)
  (rtype cname mname params))

(define register-jp
  (lambda ()
    (register-one-pcd
      'call-pcd
      (lambda (ptc jp)
        (if (call-pcd? ptc)
            (and (eq? (call-pcd-mname ptc) (call-jp-mname jp))))))))
```

In PA, the `lookup-advice` procedure, which checks call pointcut conditions, uses the pointcut evaluator registered by the above code.

<table>
<thead>
<tr>
<th>PA</th>
<th>TRAV</th>
<th>COMPOSITOR</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>X</code></td>
<td>[eval-program]</td>
<td>[eval-program]</td>
<td>[eval-program]</td>
</tr>
<tr>
<td><code>X_{JP}</code></td>
<td>[lookup-b]</td>
<td>[lookup-b]</td>
<td>[lookup-b]</td>
</tr>
<tr>
<td><code>A</code></td>
<td>c, m, f declarations</td>
<td>c, m, f declarations</td>
<td>c, m, f declarations</td>
</tr>
<tr>
<td><code>A_{ID}</code></td>
<td>[lookup-fields]</td>
<td>[lookup-decl]</td>
<td>[lookup-decl]</td>
</tr>
<tr>
<td><code>A_{EFF}</code></td>
<td>[provide-next-arrival]</td>
<td>[provide-decl]</td>
<td>[provide-decl]</td>
</tr>
<tr>
<td><code>B_{ID}</code></td>
<td>traversal spec. &amp; visitor</td>
<td>(= <code>A</code>)</td>
<td>(lookup-oc-decl)</td>
</tr>
<tr>
<td><code>B_{EFF}</code></td>
<td>[execute-visitor]</td>
<td>(= <code>A_{ID}</code>)</td>
<td>[lookup-oc-decl]</td>
</tr>
<tr>
<td><code>META</code></td>
<td>B control A</td>
<td>traversal</td>
<td>oc</td>
</tr>
</tbody>
</table>

Table 3: Application of the X-ASB parameterized interpreter

The updated version of the `computation-at-jp` procedure is more reusable than the first version. This version can be commonly used by PA, TRAV, COMPOSITOR, and OC. The idea of join point type is essential in designing a JPM that is as modular as possible because information needed at the `computation-at-jp` parameter is encapsulated in a join point instance.

### 3.5 Design of the four JPMs

Table 3 shows the application of the X-ASB parameterized interpreter. Table 3 corresponds to the three-part modeling framework as follows: a parameter in the framework corresponds to a procedure that designs an X-ASB parameter, and the `META` parameter in the framework corresponds to the computation strategy in X-ASB. Although there are no `META` parameters in the framework except `COMPOSITOR`, the existence of these parameters is assumed implicitly in the framework. For example, the `META` parameter in PA can be regarded as the `b-control-a` computation strategy. The concept of a computation strategy is important to making the design of the `computation-at-jp` parameter reusable. Moreover, this concept resolves the problem pointed out in section 2.3.

The main contribution of this paper is to provide a process for designing JPMs. Using X-ASB, we can design JPMs explicitly as follows: 1) design a type of join point using the `register-jp` parameter, which includes the four parameters `lookup-a`, `effect-a`, `lookup-b`, and `effect-b`; 2) coordinate the computation at the join point using the `computation-at-jp` parameter; and 3) design a weaving process using the `eval-program` parameter in which the `computation-at-jp` is called. The registration of a join point type and coordination using the type are essential in the parameterized interpreter X-ASB. Based on X-ASB, interpreters of the four JPMs can be designed as follows (see Figure 2):

- **PA**: The `eval-program` procedure executes program `pA`, and calls the `computation-at-jp` procedure upon evaluating a method-call expression, a point related to the `call-jp` join point. The `computation-at-jp` procedure weaves the method execution of the program `pA` and the advice execution of the program `pB` using `lookup-method`, `execute-method`, `lookup-advice`, and `execute-advice`. These procedures are registered in the `call-jp` join point;

- **TRAV**: The `eval-program` procedure traverses program `pA` provided as an object graph, and calls the `computation-at-jp` procedure upon reaching a point related to the `arrival-jp` join point, an arrival at the node that satisfies the traversal specification. The `computation-at-jp` procedure weaves the program `pA` (class, field declarations) and the program `pB` (traversal specifications and visitor) by executing the visitor method that refers to the fields of the program `pA`. The `computation-at-jp` procedure uses the four pro-
4. EVALUATION

X-ASB is effective for rapid-prototyping JPMs. In this section, we evaluate how rapidly we can model JPMs using X-ASB.

Table 4 shows the code size for developing the four JPMs. The code is categorized into four parts consisting of register-jp (and related parameters: lookup-a/b, effect-a/b), computation-at-jp (to be exact, a sub-procedure such as computation-at-jp::b-control-a), eval-program, and base. The base part includes the BASE interpreter and X-ASB library procedures except computation-at-jp. The code size A, the summation of the first three parts, indicates the LOC (Line of Code) specific to each JPM. The code size B shows the total LOC of each JPM weaver. The labor for introducing a new JPM can be estimated by the expression $A/B \times 100$. As shown in the table, we have only to add 10 - 30 % new code to develop a new JPM. Although the code for defining the register-jp parameter and the computation-at-jp parameter is relatively small excluding PA, the size of the eval-program is large. It is not necessarily easy to design this parameter because it determines the overall behavior of the weaver.

Next, we evaluate the labor for extending an existing JPM. Table 5 shows the code size for extending PA. We have only to add 48 LOCs and 42 LOCs in order to add fset-jp/fset-pcd (a field-set join point and pointcut designator) and fget-jp/fget-pcd (a field-get join point and pointcut designator), respectively. The labor for extending PA can be estimated by the expression $B/(A+B)+100$. As shown in the table, we have only to add about 20 % new code to add
Table 4: LOC for developing each JPM

<table>
<thead>
<tr>
<th>Part</th>
<th>PA</th>
<th>TRAV</th>
<th>COMPOSITOR</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. register-jp</td>
<td>16</td>
<td></td>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td>2. computation-at-jp:xx</td>
<td>5</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>3. eval-program</td>
<td>16</td>
<td></td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>4. base</td>
<td>16</td>
<td></td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>A: sum of 1-3</td>
<td>154</td>
<td>183</td>
<td>259</td>
<td>71</td>
</tr>
<tr>
<td>B: sum of 1-4</td>
<td>537</td>
<td>537</td>
<td>537</td>
<td>537</td>
</tr>
<tr>
<td>A/B (%)</td>
<td>22.3</td>
<td>25.4</td>
<td>32.5</td>
<td>11.7</td>
</tr>
</tbody>
</table>

Table 5: LOC for extending PA

<table>
<thead>
<tr>
<th>Part</th>
<th>original PA</th>
<th>add fset-jp</th>
<th>add fget-jp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. register-jp</td>
<td>16</td>
<td>44</td>
<td>38</td>
</tr>
<tr>
<td>2. computation-at-jp:xx</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. eval-program</td>
<td>4</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>sum of 1-3</td>
<td>A:154</td>
<td>B:48</td>
<td>B:42</td>
</tr>
<tr>
<td>B/(A+B) (%)</td>
<td>23.8</td>
<td>20.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: JPM design layer

<table>
<thead>
<tr>
<th>Layer Purpose</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>level 1 introduction of new JPMs</td>
<td>[eval-program] [computation-at-jp] [register-jp]</td>
</tr>
<tr>
<td>level 2 extension of existing JPMs</td>
<td>[computation-at-jp] [register-jp]</td>
</tr>
</tbody>
</table>

Table 7: Metaobject protocols for AOP

<table>
<thead>
<tr>
<th>Metaobject protocol</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>register-one-jp</td>
<td>register a computation strategy</td>
</tr>
<tr>
<td>lookup-strategy</td>
<td>search a computation strategy</td>
</tr>
<tr>
<td>register-one-ppc</td>
<td>register a pointcut designator</td>
</tr>
<tr>
<td>lookup-ppc</td>
<td>search a pointcut designator</td>
</tr>
<tr>
<td>extract-ppc</td>
<td>extract a pointcut information</td>
</tr>
<tr>
<td>extract-pointcut</td>
<td>extract a pointcut information</td>
</tr>
</tbody>
</table>

From the evaluation in section 4, we can observe the following: it is relatively easy to design the register-jp parameter and the computation-at-jp parameter; and it is not easy to design the eval-program parameter. We believe that reflection for AOP should be limited to adding new kinds of join point types, pointcut designators, and computation strategies. That is, parameters such as eval-program should not be the target of reflection. Developing a new eval-program carries a cost equal to that of developing a new interpreter. Table 6 reflects this observation.

5.2 Metaobject protocols

Table 7 shows metaobject protocols for AOP. These protocols extend the two parameters computation-at-jp and register-jp. The three protocols register-one-ppc (register a join point type) and register-one-ppc (register a pointcut designator) correspond to intercession. The five protocols lookup-strategy (search a computation strategy), lookup-ppc (search a join point type), extract-ppc (extract information of a join point instance), lookup-pointcut (search a pointcut designator), and extract-pointcut (extract a pointcut information) correspond to introspection. The thisJoinPoint variable in AspectJ corresponds to the extract-ppc protocol. A reflective interpreter supporting the metaobject protocols is under construction.

Most aspect-oriented features can be designed by run-time metaobject protocols[25]. It is interesting to explore the relationships between reflective OOP languages and reflective AOP languages. We think that reflective AOP languages should expose metaobject protocols based on JPMs because they are essential to AOP.

5.3 Validity of the metaobject protocols

It is necessary to evaluate the validity of the metaobject protocols from the viewpoint of generality. We have examined how existing research on JPM extensions can be explained using these protocols. We believe that they are generic protocols that can explain almost all the current JPM extensions.

Table 8 shows the relation between existing studies and metaobject protocols. There are investigations that have
6. RELATED WORK

There are two approaches for developing AOP languages that support multiple JPMs[12]. The first approach is to provide a single general-purpose AOP language that can design various special-purpose meta-level transformations. The second approach is to provide an AOP language with domain-specific aspect libraries.

This paper focuses on the first approach based on the three-part modeling framework. There are several works related to the first approach. E. Tanter et al. propose a versatile AOP kernel that supports core semantics[26]. J. Gray and S. Roychoudhury propose an approach that uses a program transformation system as the underlying engine for weave construction[10]. Their long-term research goal, a framework for language and platform-independent weaving, is similar to our goal. R. Lämmel proposed a general method to extend the language in a way that it supports a form of superimposition just in the sense of AOP. In the extended language, a programmer can superimpose additional or alternative functionality (aka advice) onto points along the execution of a program[17]. The AspectBench Compiler (abc)[3] is a workbench that facilitates experimentation with new language features and implementation techniques. The abc is designed to be an extensible framework for implementing AspectJ extensions. X-ASB is an interpreter that can model not only AspectJ-like JPM such as PA but also other kinds of JPMs.

There are several AOP language systems adopting the second approach. M.Shonle, K.Lieberherr, and A.Shah propose an extensible domain-specific AOP language, XAspect, which adopts plug-in mechanisms[23]. Adding a new plug-in module, we can use a new kind of aspect-oriented facility. CME (Concern Manipulation Environment)[5], the successor of Hyper/J, adopts an approach similar to XAspect.

M. Mezini and K. Ostermann claim that join point interception (JPI) alone does not suffice for modular structuring of aspects[21]. They propose Caesar, a model of AOP with a higher-level module concept on top of JPI. Caesar enables reuse and componentization of aspects. There are two kinds of aspect components. One is a component that designs aspecual facilities as in the meaning of Caesar. Another is a component that designs meta-level transformations. Both of these components are important for extensible AOP. The second kind of aspect component establishes a foundation for new types of aspect-oriented features, and the first kind of aspect component gives a variety of aspecual features on the foundation. If we can write both kinds of components using the same base language, the above two approaches may be integrated. That is, the first approach (general-purpose AOP language with meta-level transformations) and the second approach (aspect library) corresponds to reflective AOP languages and associated reflective components, respectively.

Domain-specific aspect-oriented extensions are important. They are necessary not only at the programming stage but also at the modeling stage. An approach for supporting domain-specific aspect-oriented modeling is proposed in [9]. Logic programming facilities and queries using these facilities will be useful for defining domain-specific pointcuts[29]. If reflective AOP languages can expose program execution information held in weavers, and programmers can use this information when they define pointcuts, the pointcuts will be enriched.

7. CONCLUSION

This paper proposes the parameterized interpreter X-ASB for modeling different JPMs. X-ASB will be helpful in rapid-prototyping a new AOP mechanism or a reflective AOP system that supports multiple JPMs. We believe that X-ASB guides language developers in modular JPM designs.

8. ACKNOWLEDGEMENT

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9. REFERENCES


APPENDIX

Common

(define weave
  (lambda (pgm-a pgm-b)
    (register-jp)
    (eval-program pgm-a pgm-b)))

(define-struct jp (computation-strategy
  lookup-a effect-a lookup-b effect-b))

(define-struct pcd (pname evaluator))

(define computation-at-jp
  (lambda (jp)
    (let ((strategy (jp-computation-strategy jp)))))

(define computation-at-jp::b-control-a
  (lambda (jp)
    (let* ((lookup-a (jp-lookup-a jp))
           (effect-a (jp-effect-a jp))
           (lookup-b (jp-lookup-b jp))
           (effect-b (jp-effect-b jp)))
      (effect-b (lookup-b jp) jp
        (lambda ()
          (effect-a (lookup-a jp) jp))))))

(define computation-at-jp::relationship
  (lambda (jp)
    (let* ((lookup-a (jp-lookup-a jp))
           (effect-a (jp-effect-a jp)))
      (effect-a (lookup-a jp) jp))))

PA weaver

Body

(define pa::weave
  (lambda (pgm)
    (weave (extract-org-pgm pgm)
      (extract-advice-decls pgm))
    (extract-org-pgm extracts an original program
    extract-advice-decls extracts advice declarations)))

Join point type, pointcut designator

(define-struct (call-jp jp) (mname target args))

(define-struct (call-pcd pcd)
  (rtype cname mname params))

(define register-jp
  (lambda ()
    (register-one-jp
      'call-jp
      (lambda (mname target args)
        (make-call-jp
          'b-control-a
          lookup-method execute-method
          lookup-advice execute-advice
          mname target args)))))

(define lookup-method
  (lambda (jp) <lookup a method>))

(define execute-method
  (lambda (method jp) <execute the method>))

(define lookup-advice
  (lambda (jp) <lookup advices that match pointcut conditions
  using pointcut evaluator 'call-pcd>))

(define execute-advice
  (lambda (advices jp thunk) <execute advices>))

Program evaluator

(define eval-program
  (lambda (org-pgm advice-decls)
    <evaluate expressions by calling eval-exp>))

(define eval-exp
  (lambda (exp env)
    (cond
      ((method-call-exp? exp)
        (call-method
          (method-call-exp-mname exp)
          (eval-exp
            (method-call-exp-obj-exp exp) env)
          (eval-rands
            (method-call-exp-rands exp) env))
      (other expressions are ommitted))))

(define call-method
  (lambda (mname obj args)
    (computation-at-jp
      (jtype-generator (lookup-jp 'call-jp))
      mname obj args)
    (lookup-jp searches a registered join point type))

COMPOSITOR weaver

Body

(define compositor::weave
  (lambda (pgm-a pgm-b)
    (weave pgm-a pgm-b)))

Join point type

(define-struct (matching-jp jp)
  (pgm seed relationships))

(define register-jp
  (lambda ()
    (register-one-jp
      'matching-jp
      (lambda (pgm seed relationships)
        (make-matching-jp
          'relationship
          lookup-decl provide-decl
          lookup-decl provide-decl
          pgm seed relationships))))

(define lookup-decl
  (lambda (jp) <lookup a declaration to be merged>))

(define provide-decl
  (lambda (decl jp) <add the declaration to a merged program>))

Program evaluator

(define eval-program
  (lambda (pgm-a pgm-b)
    (let loop
      ((pgm (make-program '()))
        (seeds (compute-seeds pgm-a pgm-b)
          (relationships (get-relationships)
            <compute seeds, all possible compositions of declarations>)
          (take a seed, and determine whether the seed should be merged>)
          (if so, generate a matching join point, and call computation-at-jp>
            (computation-at-jp
              (jtype-generator (lookup-jp 'matching-jp))
              pgm (car seeds) relationships)
            (loop pgm (cdr seeds) relationships))
            pgm))))