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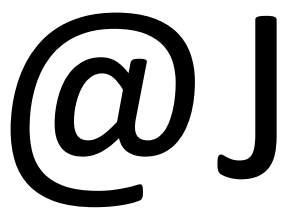

Towards Rapid Development of Dynamic Analysis Tools for the Java Virtual Machine

Walter Binder, Alex Villazón, Danilo Ansaloni, Philippe Moret
University of Lugano, Switzerland

Background

Developing dynamic analysis tools for:

- profiling
- debugging
- testing
- reverse engineering

is difficult and error-prone

➡ time-consuming

➡ **expensive**

Aspect-Oriented Programming

With AOP you can express instrumentations at a higher abstraction level

➡ reduce developing and testing time

➡ **rapid**

Is AOP the silver bullet for dynamic analysis tools?

Overview

- AOP at a glance
- Limitations of prevailing AOP frameworks
- @J features
- Example: LiLa
- Conclusions

AOP at a glance

With AOP you can add arbitrary code *before*, *after* or *around* **any** identifiable execution point:

- method/constructor body
- method/constructor invocation
- field access
- exception handler
- ...

AOP at a glance

To count the number of object allocations:

```
aspect AllocCounter {
  final AtomicLong counter = new AtomicLong();

  after() returning(Object o) : call(*.new(..)) {
    System.out.println("New object allocated: " + o);
    counter.incrementAndGet();
  }
}
```

AspectJ terminology

Join Points are specific execution points:

- field access (read/write)
- call/execute method
- call/execute constructor
- call/execute exception handler

AspectJ terminology

Pointcuts intercept specific join points

```
aspect AllocCounter {
  final AtomicLong counter = new AtomicLong();

  after() returning(Object o) : call(*.new(..)) {
    System.out.println("New object allocated: " + o);
    counter.incrementAndGet();
  }
}
```

AspectJ terminology

Advice is the code executed before/after/around each join point intercepted by a pointcut

```
aspect AllocCounter {
  final AtomicLong counter = new AtomicLong();

  after() returning(Object o) : call(*.new(..)) {
    System.out.println("New object allocated: " + o);
    counter.incrementAndGet();
  }
}
```

AspectJ terminology

Aspects are class-like elements added to Java by AspectJ

```
aspect AllocCounter {
  final AtomicLong counter = new AtomicLong();

  after() returning(Object o) : call(*.new(..)) {
    System.out.println("New object allocated: " + o);
    counter.incrementAndGet();
  }
}
```

Limitations of AOP frameworks

AOP frameworks have not been designed for developing dynamic-analysis tools

Common limitations:

- no data passing between advice bodies
- no execution of custom code at weaving time
- no basic-block level join points

Our goal

Develop a new:

- expressive
- efficient
- portable and compatible
- comprehensive
- easy to use

aspect-oriented instrumentation framework: **@J**

Aspect Tools in Java: @J

@J is:

- an annotation-based aspect language and weaver
- based on AspectJ annotation syntax
- designed for developing dynamic-analysis tools
- compatible with standard Java compilers

@J features

New @J features:

- invocation-local variables
- snippet composition
- basic-block level join points

Invocation-local variables

Invocation-local variables are:

- accessed through public static fields
- annotated with **`@InvocationLocal`**
- mapped to local variables in woven methods

They allow data passing between snippets that are *woven in the **same** method body*

Invocation-local variables

```
public aspect TimeAspect {
    pointcut allCalls() : call(* *.*(..)) && !within(TimeAspect);

    @InvocationLocal
    public static long start;

    before() : allCalls() {
        start = System.nanoTime();
    }

    after() : allCalls() {
        long elapsed = System.nanoTime() - start;
        logExecTime(thisJoinPoint, elapsed);
    }
}
```

Snippets

Snippets are:

1. public static methods with void return type
2. annotated with:
   - **`@BeforeSnippet`**
   - **`@AfterSnippet`**
   - **`@AfterReturningSnippet`**
   - **`@AfterThrowingSnippet`**

Snippets

Snippets look similar to AspectJ advices, but:

- by default, are inlined in the woven code
- cannot be woven around a join point
- support invocation-local variables
- support additional parameters
- can be executed at weaving-time

Snippets

Weave-time executable snippets:

- are not inlined
- are executed at weaving-time
- they can only access static information
- they can change the value of invocation-local variables
- after advice-execution, the weaver inlines the code to initialize these invocation-local variables with the respective values

Basic-block join points

In @J, every basic-block of code is a join point.

@J provides:

- customizable basic-block analysis algorithm
- customizable matching properties
- customizable data properties
- clear low-level interface to BCEL

Example: LiLa

```
@J
public class LiLa {
    @InvocationLocal
    public static long start; // stores starting time of listener execution

    @InvocationLocal
    public static boolean needsProf; // stores result of static analysis

    @Pointcut( "execution(* java.util.EventListener+.*(..))" )
    void listenerExec() { }

    @BeforeSnippet( pointcut = "listenerExec"; execute = true; order = 1; )
    public static void analyzeNeedsProfiling( JoinPoint.StaticPart jpsp) {
        needsProf = isInterfaceMethod(jpsp); // not shown here
    }
...
}
```

Example: LiLa

```
@J
public class LiLa {
...
    @BeforeSnippet( pointcut = "listenerExec”; order = 2; )
    public static void takeStartTime() {
        if (needsProf) start = System.nanoTime();
    }

    @AfterSnippet( pointcut = "listenerExec && this(listener)"; )
    public static void takeEndTimeAndProfile( JoinPoint.StaticPart jpsp,
                                              java.util.EventListener listener) {
        if (needsProf) {
            long exectime = System.nanoTime() - start;
            if (exectime >= THRESHOLD_NS)
                profileEvent(jpsp, listener, exectime); // not shown here
        }
    }
...
}
```

Example: LiLa

```
class ExampleListener implements ActionListener {
    public void actionPerformed(ActionEvent e) {
        doSomething();
    }

    public void notDeclaredInInterface() {
        doSomethingElse();
    }
...
}
```

Example: LiLa – woven code

```
class ExampleListener implements ActionListener {
    // representing actionPerformed
    private static final JoinPoint.StaticPart jpsp1 = ...;
...
    public void actionPerformed(ActionEvent e) {
        long start = 0L;
        boolean needsProf = true;
        if (needsProf) start = System.nanoTime();
        try {
            doSomething();
        } finally {
            if (needsProf) {
                long exectime = System.nanoTime() - start;
                if (exectime >= LiLa.THRESHOLD_NS)
                    LiLa.profileEvent(jpsp1, this, exectime);
            }
        }
    }
}
```

Example: LiLa – optimized code

```
class ExampleListener implements ActionListener {
    // representing actionPerformed
    private static final JoinPoint.StaticPart jpsp1 = ...;
...
    public void actionPerformed(ActionEvent e) {
        long start = System.nanoTime();
        try {
            doSomething();
        } finally {
            long exectime = System.nanoTime() - start;
            if (exectime >= LiLa.THRESHOLD_NS)
                LiLa.profileEvent(jpsp1, this, exectime);
        }
    }
}
```

Example: LiLa – woven code

```
class ExampleListener implements ActionListener {
    // representing notDeclaredInInterface
    private static final JoinPoint.StaticPart jpsp2 = ...;
...
    public void notDeclaredInInterface(ActionEvent e) {
        long start = 0L;
        boolean needsProf = false;
        if (needsProf) start = System.nanoTime();
        try {
            doSomethingElse();
        } finally {
            if (needsProf) {
                long exectime = System.nanoTime() - start;
                if (exectime >= LiLa.THRESHOLD_NS)
                    LiLa.profileEvent(jpsp2, this, exectime);
            }
        }
    }
}
```

Example: LiLa – woven code

```
class ExampleListener implements ActionListener {
    // representing notDeclaredInInterface
    private static final JoinPoint.StaticPart jpsp2 = ...;
...
    public void notDeclaredInInterface(ActionEvent e) {
        doSomethingElse();
    }
}
```

Ongoing research

1. Buffered snippets:
   - we already have a programming model for buffered advices integrated with AspectJ
   - support buffered snippets and their composition with inlined and weave-time executable snippets
2. New case-studies:
   - CProf, Senseo, MemoryLeak, CC Profiling, ...
3. Bytecode level join points
4. Collection of low-level metrics

Conclusion

- AOP simplifies the development of DA tools
- AspectJ lacks important features
- @J: annotation-based aspect language ad weaver
- Some new features:
  1. invocation-local variables
  2. snippet composition
  3. weave-time executable snippets
  4. basic-block level join points

Thanks!

Questions?