Adding Trace Matching with Free Variables to AspectJ

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Introduction

AspectJ: An Aspect-Oriented Extension of Java

- Define patterns on run-time events
- Match patterns to events at run-time
- Execute extra code when matching events occur

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Tracematches

Match whole *execution histories*, not just events

AspectJ Lingo

Join Point = event (call, execution, field set / get)

Pointcut = pattern on join points

Advice = extra code to run

AspectJ: Advice

```
aspect Autosave {
   int count = 0;
   after(): call(* Command.execute(..))
        { count++; }

   after(): call(* Application.save()) || call(* Application.autosave())
        { count = 0; }

   before(): call (* Command.execute(..))
        { if (count > 4)
             Application.autosave(); }
}
```

AspectJ: Join Points

enter call Command.execute()

  enter execution Command.execute()

    (…)

  exit execution Command.execute()

exit call Command.execute()

enter call Application.save()

  enter execution Application.save()

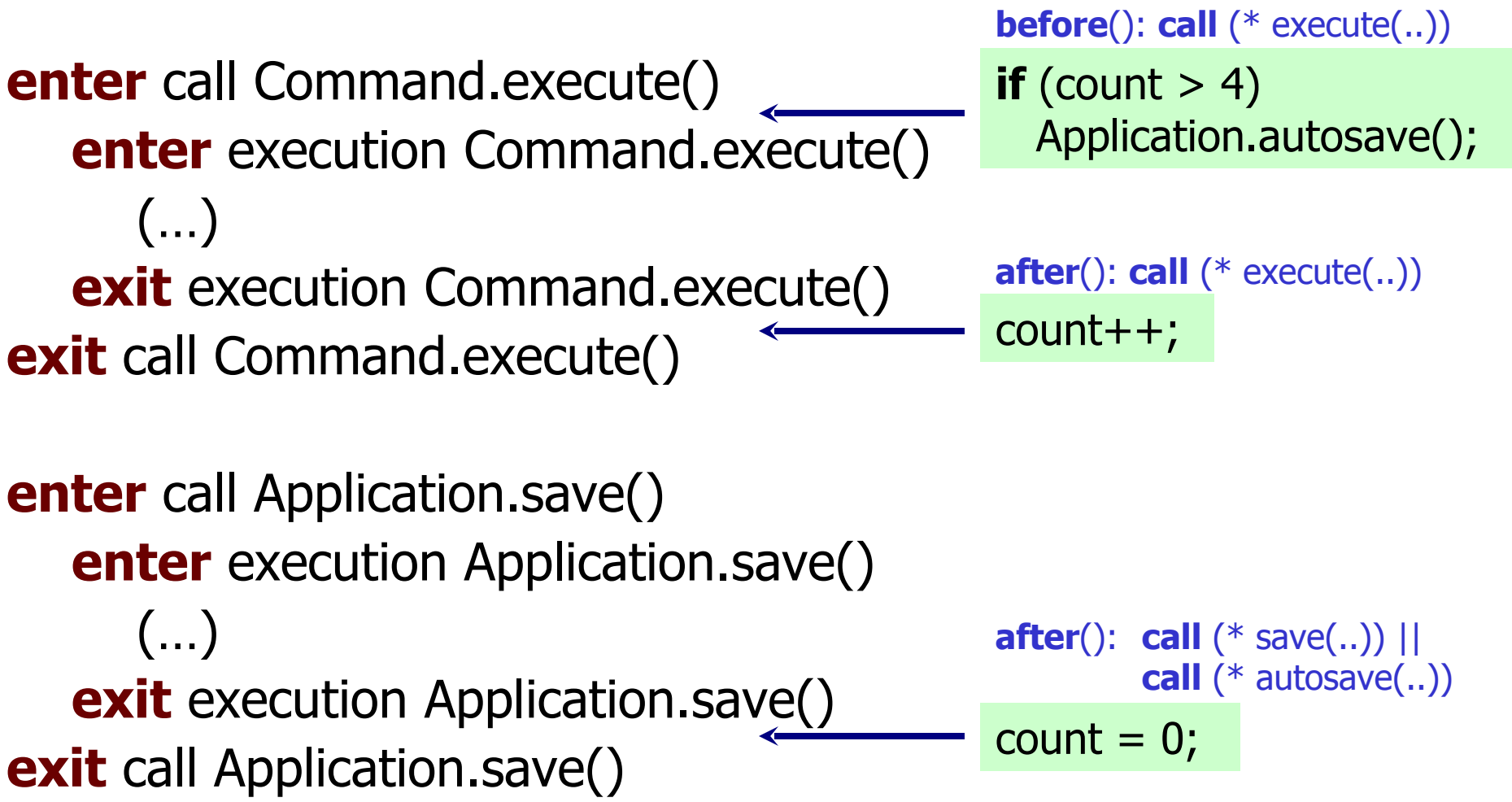
    (…)

  exit execution Application.save()

exit call Application.save()

```
Command c;
(…)
c.execute();
Application.save();
```

AspectJ: Matching



Trace Matching

Tracematches match on the entire execution history of the program

Related Work:

Walker and Viggers
Douence *et al*
Bockisch *et al*
Bodden and Stolz
Martin *et al*
Goldsmith *et al*

Contributions:

- Trace matching with free variables
- Semantics of tracematches
- Implemented in the *abc* compiler
- Eliminating memory leaks

Traces

```
enter call Command.execute()
    enter execution Command.execute()
        (…)
    exit execution Command.execute()
exit call Command.execute()

enter call Application.save()
    enter execution Application.save()
        (…)
    exit execution Application.save()
exit call Application.save()
```

Trace =

sequence of join point **enter** / **exit** events

Example: Autosave

```
tracematch() {

    sym save after:
            call ( * Application.save() )
        || call ( * Application.autosave() );

    sym action after:
        call ( * Command.execute() );


    action [5]
        { Application.autosave(); }

}
```

Example: Autosave

```
tracematch() {

    sym save after:
            call ( * Application.save() )
        || call ( * Application.autosave() );

    sym action after:
        call ( * Command.execute() );

    action [5]
        { Application.autosave(); }

}
```

Symbols = pointcuts

Pattern = regexp over symbols

Matching

```
sym action after:
   call ( * Command.execute() );
```

exit call Command.execute()

```
sym save after:
   call (* Application.save())
|| call (* Application.autosave())
```

exit call Application.save()
exit call Application.autosave()

action [5]

The pattern matches traces:

ending with 5 events matching action

with *no* events matching save in between

Matching with Free Variables

```
tracematch(Subject s, Observer o) {

    sym create_observer
        after returning(o):
            call ( Observer.new(..) )
        && args (s);

    sym update_subject after:
            call ( * Subject.update(..) )
        && target (s);

    create_observer update_subject *
        { o.update_view(); }

}
```

Matching with Free Variables

```
tracematch(Subject s, Observer o) {

    sym create_observer
        after returning(o):
            call ( Observer.new(..) )
        && args (s);

    sym update_subject after:
            call ( * Subject.update(..) )
        && target (s);

    create_observer update_subject *
        { o.update_view(); }

}
```

```
o = new Observer(s);
```

```
s.update(..);
```

Matching with Free Variables

create_observer binds the Observer o and Subject s
update_subject binds the Subject s

```
create_observer  update_subject *
```

Matches a trace if there is a *consistent* binding of o and s
each symbol must bind s to the same value

There can be several such bindings:

run the body once for each set of bindings

After an update to *s*, the body is run for each *o* observing *s*

Example: DB Connection Pooling

```
public aspect DBConnectionPooling {

pointcut connectionCreation(String url, String uid, String password) : …;
pointcut connectionRelease(Connection connection) : …;

    Connection tracematch
        (Connection connection, String url, String uid, String password) {

        sym get_connection1 after returning(connection):
            connectionCreation(url, uid, password);

        sym get_connection2 around(url, uid, password):
            connectionCreation(url, uid, password);

        sym release_connection before:
            connectionRelease(connection);

        get_connection1 release_connection get_connection2
            { return connection; }

    }
…
```

Example: DB Connection Pooling

```
public aspect DBConnectionPooling {
    ...
    Connection tracematch
        (Connection connection, String url, String uid, String password) {
        sym get_connection1 after returning(connection):
            connectionCreation(url, uid, password);
        sym get_connection2 around(url, uid, password):
            connectionCreation(url, uid, password);
        sym release_connection before:
            connectionRelease(connection);
        get_connection1 release_connection get_connection2
            { return connection; }
    }
    void around() : connectionRelease(*) { /* Do Nothing */ }
}
```

Semantics and Implementation

Matching Semantics
No Free Variables

```
tracematch () {
  sym F before: call(* f());
  sym G before: call(* g());
  F G +   { }
}
```

Filter out all events that do not match any symbol in the tracematch

The last event must match a symbol

```
enter call f();
enter call f();
enter call g();
enter call g()
```

The tracematch applies if:

some *suffix* of the *filtered* trace is matched by a word in the pattern

~~enter call f();~~
enter call f();
enter call g();
enter call g()

matched by

F;
G;
G

Matching Semantics
Free Variables

```
tracematch (Object x) {
  sym F before: call(* f()) && target(x);
  sym G before: call(* g()) && target(x);
  F G +   { }
}
```

Apply *all* possible substitutions, then match as before

Trace	Filtered, x=o	Filtered, x=q
o.f()	o.f()	~~o.f()~~
q.f()	~~q.f()~~	q.f()
o.g()	o.g()	~~o.g()~~
q.f()	~~q.f()~~	q.f()
o.g()	o.g()	~~o.g()~~

Operational Semantics

- Matching: Run an automaton for the pattern alongside the program
  - The automaton accumulates *bindings*
  - When a final state is reached, execute the body of the tracematch for each binding

Operational Semantics = Declarative Semantics

- Implemented in the *abc* compiler for AspectJ

Implementation Issues

Memory Usage

A naive implementation would suffer memory leaks:

Objects bound in matching cannot be reclaimed by GC

Use *weak references* to store bindings whenever possible

Some tracematches can still cause memory leaks

Compiler warning

Static analysis of the pattern to detect this

Performance : DB Connection Pooling

DBConnectionPooling :

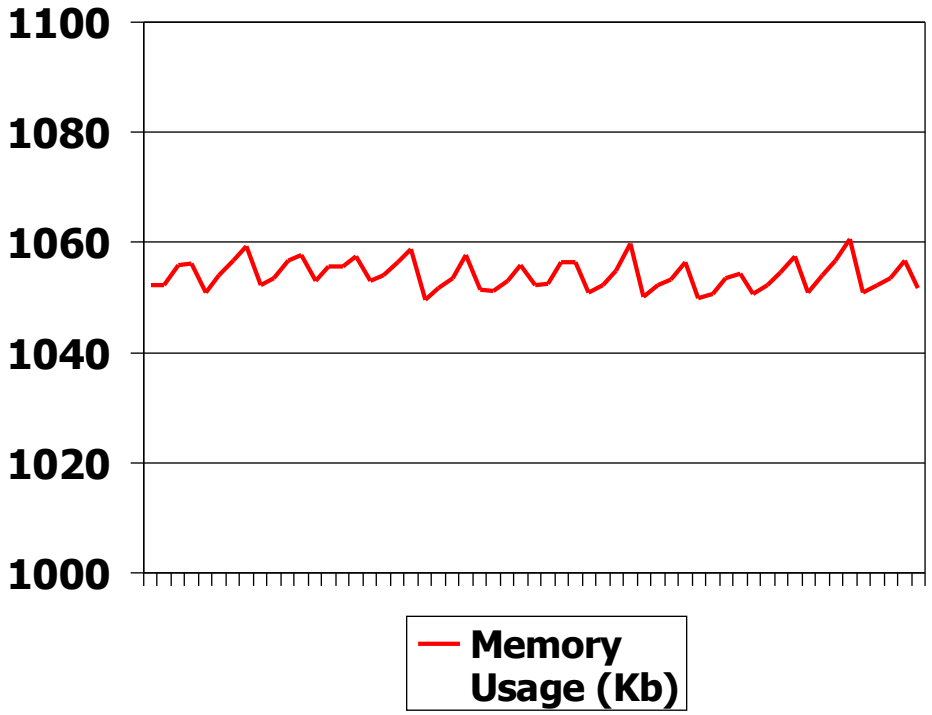
Pure Java (no pooling)	6.0s
with hand-coded pooling aspect	1.0s
with pooling tracematch	1.2s

DB Connection Pooling AspectJ (Laddad, *AspectJ in Action*)	DB Connection Pooling Tracematch
77 LOC (47 implementing pool)	21 LOC

Performance: Memory Usage

Memory usage:

JHotDraw with SafeIterators tracematch



No space leaks

Eliminating space leaks is *essential* to achieve good performance

Related Work

	PURPOSE			PATTERNS			IMPLEMENTATION		
	fault finding	functionality	AspectJ	variables	filtering	context-free	semantics	leak busting	static match
Walker&Viggers	+/-	+	+	-	-	+	-	-	-
Douence et al	+/-	+	-	+	-	-	-	-	-
Bockisch et al	+/-	+	-	+	-	+	-	-	-
Bodden & Stolz	+	-	+	+	-	-	+	+	-
Martin et al	+	-	-	+	-	+	-	-	+
Goldsmith et al	+	-	-	+	-	+	-	-	+
This paper	+/-	+	+	+	+	-	+	+	+/-

Conclusion

- Tracematches
  - Match patterns on execution history
  - Free variables to bind state
- Future work: optimising tracematches
- Tracematches are implemented as an extension of the *abc* compiler

get abc 1.1! **http://aspectbench.org**

PTQL and Tracematches

```
tracematch (Object x) {
  sym A after: call(* a()) && target(x);
  sym B after: call(* b()) && target(x);
  sym C after: call(* c()) && target(x);
  A B C   { }
}
```

```
SELECT *
FROM   MethodInvoc('*.a') A
       JOIN MethodInvoc('*.b') B
         ON A.receiver = B.receiver
       JOIN MethodInvoc('*.c') C
         ON B.receiver = C.receiver
```

o.a(); q.a(); o.b(); q.b(); q.c(); o.c()

PTQL query has 2 solutions
tracematch applies twice

o.a(); o.c(); o.b(); o.c()

Tracematch does not apply, PTQL query does