Efficient temporal pointcuts through dynamic advice deployment

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Outline

1. Trace matching - state of the art
2. Making use of dynamic aspect deployment
3. The case of pure AspectJ
4. Problems / Future work
Trace matching

What is it?

Watch an application’s execution trace and when some pattern occurs, do something.
### Trace matching

**Tools and formalisms**

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All use automata, all except PQL and Tracecuts use finite automata even.
Static approaches taken so far

What has been optimized \textit{statically} so far?

- Minimization of the generated automata
  - Might mean to minimize NFA ! (PSPACE complete)
- Optimization of data structures [ATB+06]
- Specialization w.r.t. base program [SGA04]
- Sophisticated memory management [AAS+05, Bod05]

Brought trace matching from \textit{infeasible} to \textit{feasible}.

Our goal here: Close the efficiency gap between those and plain Java/AspectJ programs.
Trace matching

What does it look like?

A temporal specification:

*Whenever a enumerator $e$ is claimed for a collection $c$, do not modify $c$ while $e$ is in use.*
Trace matching
What does it look like?

As a tracematch:

```java
tracematch(Vector c, Enumeration e) {
    sym create after returning(e):
        call(Enumeration+.new(..)) && args(c);
    sym next before:
        call(Object Enumeration.nextElement()) && target(e);
    sym update after:
        vector_update() && target(c);

    create next* update+ next
    {
        throw new ConcurrentModificationException();
    }
```

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Trace matching
How does it work?

General evaluation strategy:

- Generate a (possibly finite) state machine according to the spec.
- Run that state machine along the actual execution trace.
- Events are triggered by advice.
- When we hit a final state, “blow the horn”.

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Trace matching
Evaluation by example

0 → 1 → 2 → 3

true → false → false → false
Trace matching
Evaluation by example

- 0
  - create
- 1
  - update
- 2
  - next
- 3

true \quad c = c_1, i = i_1 \quad false \quad false

create(c=c_1,i=i_1)

Executed pieces of advice: 1
Trace matching
Evaluation by example

create(c=c1,i=i1) next(i=i1)

Executed pieces of advice: 3
Trace matching
Evaluation by example

\[ true \quad c = c_1, i = i_1 \quad false \quad false \]

create\((c=c_1, i=i_1)\)  next\((i=i_1)\)  next\((i=i_1)\)

Executed pieces of advice: 5
Trace matching
Evaluation by example

create(c=c1, i=i1) next(i=i1) next(i=i1) update(c=c1)

true  \[ c = c1, i = i1 \]
false  \[ c = c1, i = i1 \]

Executed pieces of advice: 7
Trace matching - state of the art
Making use of dynamic aspect deployment
The case of pure AspectJ
Problems / Future work

Current (static) optimization efforts
Common performance issue

Trace matching
Evaluation by example

\[ \begin{align*}
\text{create} & : c = c_1, i = i_1 \\
\text{update} & : c = c_1, i = i_1 \\
\text{next} & : c = c_1, i = i_1
\end{align*} \]

Executed pieces of advice: 9

true

create(c=c_1,i=i_1) next(i=i_1) next(i=i_1) update(c=c_1) next(i=i_1)
Matching today and in the future

Approach today:
Always match on everything. Works of course, but can be slow.

More clever approach:
At any time only match on what you are interested in!
How to tackle the problem

How can we do a better job?

1.) Statically remove loops. (sound for “non-overlapping” symbols)
Removing the loops

0 → 1 → 2 → 3

create update next

true false false false
Removing the loops

create(c=c1,i=i1)

true c = c1, i = i1 false false

Executed pieces of advice: 1
Removing the loops

create(c=c1,i=i1) next(i=i1)

true \quad c = c1, i = i1 \quad false \quad false

Executed pieces of advice: 2
Removing the loops

\[ \text{create}(c = c_1, i = i_1) \quad \text{next}(i = i_1) \quad \text{next}(i = i_1) \]

**Executed pieces of advice:** 3
Removing the loops

\[ \text{create}(c=c_1, i=i_1) \quad \text{next}(i=i_1) \quad \text{next}(i=i_1) \quad \text{update}(c=c_1) \]

Executed pieces of advice: 4
Removing the loops

true  \quad c = c_1, i = i_1 \quad c = c_1, i = i_1 \quad c = c_1, i = i_1
create(c=c_1,i=i_1) \quad next(i=i_1) \quad next(i=i_1) \quad update(c=c_1) \quad next(i=i_1)

Executed pieces of advice: \quad 5
Let’s get dynamic

How can we still do better?

1.) Statically remove loops.

2.) Use dynamic advice deployment: At any time, only use those pieces of advice that are necessary.
Dynamic deployment

Deployed pieces of advice: \{ create \}
Dynamic deployment

\[
\begin{align*}
0 \xrightarrow{\text{create}} 1 \xrightarrow{\text{update}} 2 \xrightarrow{\text{next}} 3
\end{align*}
\]

\begin{align*}
\text{true} & \quad c = c_1, i = i_1 & \text{false} & \quad \text{false}
\end{align*}

create(c=c_1, i=i_1)

Deployed pieces of advice: \{ create, update(c=c_1) \}

Executed pieces of advice: 1
Dynamic deployment

Create(c=c1, i=i1) next(i=i1)

Deployed pieces of advice: \{ create, update(c=c1) \}

Executed pieces of advice: 1
Dynamic deployment

create(c=c1, i=i1) next(i=i1) next(i=i1)

Deployed pieces of advice: \{ create, update(c=c1) \}

Executed pieces of advice: 1
Dynamic deployment

create(c=c1, i=i1) next(i=i1) next(i=i1) update(c=c1)

Deployed pieces of advice: \{ create, next(i=i1) \}

Executed pieces of advice: 2
Dynamic deployment

true  \quad c = c_1, i = i_1  \quad c = c_1, i = i_1  \quad c = c_1, i = i_1

create(c=c_1,i=i_1)  \quad \text{next}(i=i_1)  \quad \text{next}(i=i_1)  \quad \text{update}(c=c_1)  \quad \text{next}(i=i_1)

Deployed pieces of advice: \{ create \}

Executed pieces of advice: 3
Went down from 9 updates in the unoptimized version over ...

... 5 updates after removal of loops ...

... to 3 updates updates through dynamic deployment.

So: Use of dynamic deployment yields potential for 40% speedup here! And that only for one pair of participating objects!
Algorithmic approach

Algorithms involved are simple and can be calculated statically:

1. For each state, calculate relevant symbols, i.e. symbols which exists on outgoing non-loop edges.
2. In the matching advice, insert deploy/undeploy commands based on that information.
3. Generally, instance-based deployment should yield way better results.
Optimality

Can we still do any better?
Optimality

Can we still do any better?

... probably not.

Reason: At any point in time, we know that all which is done needs to be done.
But what about...?

Right, so what about Stack machines or Petri nets?

(may be used for context-free or counting expressions)

For both, reachability is decidable.

- Pushdown systems: use “p-automata”. Low polynomial overhead. [EHRS00]
- Petri nets: use “coverability graph”. Exponential overhead. [May81, EN94]
Why using trace matching at all?

“I don’t like those strange formalisms. Can we not do the same with plain AspectJ?”
"I don’t like those strange formalisms. Can we not do the same with plain AspectJ?"

No! We cannot...
Pure AspectJ

```java
aspect SafeEnum {

    after(Vector c) returning(Enumeration e):
        call(Enumeration+.new(..)) && args(c) {
            if (in state 0) {
                // take transition to state 1,
                // storing c and e
            }
        }

    before(Vector c):
        vector_update() && target(c) {
            if (in state 2 for object c) {
                // take transition to state 3 for c
            }
        }

    // advice for 3rd symbol "next" here
}
```

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Problems / Future work

- How expensive is dynamic deployment?
- Undeploy vs. disable advice
- Does VM support really buy us anything?

Thank you for your attention.
Adding Trace Matching with Free Variables to AspectJ.
In *OOPSLA ’05, San Diego, California, USA*, October 2005.

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J-LO - A tool for runtime-checking temporal assertions.

Efficient algorithms for model checking pushdown systems.

J. Esparza and M. Nielsen.
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Ernst W. Mayr.
An algorithm for the general petri net reachability problem.

Robert O’Callahan Simon Goldsmith and Alex Aiken.
Light-Weight Instrumentation From Relational Queries Over Program Traces.

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