Concerning Efficient Reasoning in Aspect-Oriented Languages

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Based on work with Curtis C. Clifton and James Noble

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Summary

Problem:
- Efficient reasoning in Aspect-Oriented languages

Approach:
- Use static analysis, identify (non-)interference
Background: Reasoning

- Specification, of:
  - Object state
  - Method:
    - Preconditions
    - Heap effects (postcondition + frame)
    - Control effects

- Verification, of method:
  - Calls
  - Implementation
Tally Specification

public class Tally {
    protected /*@ spec_public @*/ int val = 0;

   /*@ requires true;
    @ assignable this.val;
    @ ensures this.val == \old(this.val + inc);
    @*/
    public void add(int inc) { this.val += inc; }
}

public void testAdd(Tally t) {
    //@ assert t.val == 0;
    t.add(-10);
    //@ assert t.val == -10;
}

Implementation Verification: Heap Effects

```java
public void add(int inc) {
    //@ assert true;
    this.val += inc;
    //@ assert this.val == old(this.val + inc);
}
```
Implementation Verification: Heap Effects

For all normal states, \( \text{pre} \),

\[
\text{if } \mathcal{E}[\text{t.val} = 0](\text{pre}) \\
\text{then let } \text{post} = \mathcal{S}[\text{t.add(-10)}](\text{pre}) \\
\text{in if } \text{normal}(\text{post}) \\
\text{then } \mathcal{E}[\text{t.val} = -10](\text{post}) \\
\text{else } \text{true} \\
\text{else } \text{true}
\]
Implementation Verification: Frame Axiom

//@ assignable this.val;

- Conservative static analysis, accumulates:
  - Assignments
  - Assignable clauses for calls
public void testAddFrame(Tally t, C c, H h) {
    //@ assert t != c;
    //@ assert t.val == 0 && c.val == 7 && h.b;
    t.add(-10);
    //@ assert t.val == -10 && c.val == 7 && h.b;
}
Costs of Reasoning

- Specification effort
- Verification effort for calls
  - Find specification
  - Prove precondition
  - Show frame independent of preserved part
  - Show postcondition implies assertion
Benefits of Reasoning with Contracts

Maintainable despite changes to:
- Implementation
- Subtypes

Modular:
- Only look at small part of program
- Gives scalability
Background: AspectJ

- Features:
  - Law enforcement (declare error/warning)
  - Intertype declarations (adding fields/methods)
  - Advice on dynamic execution events
Background: Advice in AspectJ

- **Join point** = potential dynamic event
  - Call of method / constructor
  - Execution of method / constructor body
  - Get / set of field
- Before advice – run before join point
- After advice – run after join point
- Around advice – run instead of join point
Example: Counting Calls

```java
public aspect C {
    private /*@ spec_public @}*/ int val = 0;

    public pointcut tallyAddCalls() :
        call(* Tally+.add(..));

    before() : tallyAddCalls() { this.val++; }
}
```
Problem: Frame Axiom Invalid?

```java
public void testAddFrame(Tally t, C c, H h) {
    //@ assert t != c;
    //@ assert t.val == 0 && c.val == 7 && h.b;
    t.add(-10);
    //@ assert t.val == -10 && c.val == 7 && h.b;
}
```
Problem Analysis

With before / after advice:

- Calls do more
  - Before advice
  - Call
  - After advice
- Specification doesn’t reflect that
- Verification not designed for it
Example: Buffering Calls

```java
public aspect BufferTally {
    private int tallies = 0;
    void around(int i) :
        call(* Tally+.add(..)) && args(i)
    {
        this.tallies += i;
        if (i == 0 || Math.abs(this.tallies) > 100) {
            proceed(this.tallies);
            this.tallies = 0;
        }
    }
}
```
public void testAdd(Tally t) {
    //@ assert t.val == 0;
    t.add(-10);
    //@ assert t.val == -10;
}
Problem Analysis

With advice:

- Control effects:
  - Replacing call
  - Running it multiple times
  - Not returning (exception, abort)
- Specification doesn’t reflect that
- Verification not designed for it
How to reason efficiently?
- How much of program?
- What changes can be ignored?
- Which changes need how much effort?
Approach -1: Use Semantics Directly

Specification = code

Verification:
- Find applicable advice (Eclipse AJDT)
- Weave (recursively)
- Use semantics
Approach -1: Use Semantics Directly

Benefits:
- Maximally expressive
- Doesn’t restrict programmers

Costs:
- All applicable changes need re-verification
- No abstraction
Approach 0: Functional Advice

- Advice with no heap or control effects

Benefits:
- Base code reasoning unaffected

Costs:
- Useless
Approach 1: “Harmless” Advice
Dantas and Walker (POPL 2006)

- No information flow from advice to base
- Conservative static analysis
- Base code assertions can’t mention advice state
Approach 1: “Harmless” Advice
Dantas and Walker (POPL 2006)

Benefits:
- No annotations needed
- No heap effects on base

Costs:
- No help with control effects
- Loss of expressiveness
  - Some aspects (assertions) can’t be written
- No help with interference among advice
Approach 2: Behavioral Subtyping

OO Analogy:
- Around advice ~ overriding method
- Proceed ~ super call

Behavioral Subtyping:
- Advice obeys specification of all it advises
Approach 2: Behavioral Subtyping

Benefits:
- Verification of base code independent of advice

Costs:
- Quantification limits in practice
- Re-verify advice when advise more
- Much advice outside this paradigm (e.g., Buffering)
Approach 3: Limits on Advice

- Gudmundson and Kiczales (2001)
- Griswold \textit{et al.}'s XPIs (2005-6)
- Aldrich's Open Modules (2005)

Idea:
- Advice only on declared pointcuts
Approach 3: Limits on Advice

Benefits:
- Some code can’t be advised
- Enables negotiation
- No limits on expressive power

Costs:
- Extra annotation / code
- No help where advice can be applied
- No help finding interference among advice
Similar Approaches

- Composition Filters: no execution advice
- HyperJ: limits quantification
- Larochelle et al.: hide join points
- Ossher: confirm or deny advice application
- Lopez-Herrejon, Batory: limit quantification
- Cottenier et al.: limit quantification
- Rajan-Leavens: no obliviousness (not AOP)
Approach 4: Weave Specifications

- Specify:
  - Object state and methods
  - Aspect state and advice
    - Heap effects
    - Control effects
  - Weave specifications
Approach 4: Weave Specifications

Benefits:
- More abstract than code
- Allows changes in methods and advice

Costs:
- Lack of expressiveness?
- Weaving specifications is hard / expensive
Optimizations for Weaving Specifications

- Inapplicable advice ignored
- Spectator advice ignored:
  - Want
    \[ \text{Advice} \circ \text{Call} \equiv \text{Call} \]
  - Problem: soundness
- Other advice:
  - Advice \circ \text{Call} \equiv \text{weave(Advice, Call)}
  - Problem: expense
Where the Composition is Done
(Clifton 2005)

- Client utilities:
  client weaves into call semantics

- Implementation utilities:
  implementation of method weaves into its specification
Approach 4a: Optimization via Effect Analysis

- Advice A *heap interferes with* code C iff: A writes a field that C reads
- Efficiency: only look at signatures

Can apply to both:
- Advice vs. base code
- Advice vs. other advice
Effect on Specification Composition

- Want non-interference to imply:
  \[ \text{weave(ensures } P, \text{ ensures } Q) \cong \text{ ensures } P \&\& Q \]  
  (modulo control effects)

- For spectators, projection onto base fields can ignore advice’s effects
Potential Cost:
Overly Conservative Analysis

- Even spectators will have side effects

```java
private int val = 0;
before() : tallyAddCalls() { this.val++; }
```
Concern Domains (Clifton 05) (Clifton, Leavens, Noble 07)

- Declare **concern domains** (heap partitions)
- Declare write effects (and control effects)
- Uses readonly types
- Type/effect analysis detects potential interference
- Sound for checking possible interference
Concern Domains
Partition the Heap

Domain of Main

Domain of an Aspect

Domain of another Aspect
Example MAO Class with Concern Domains

```java
public class CDTestTally<Owner> {
    @writes({"Owner"})
    public void testAdd(Tally<Owner> t) {
        //@ assert t.value == 0;
        t.add(-10);
        //@ assert t.value == -10;
    }
}
```
Example MAO Aspect with Concern Domains

```java
@readonlyDomains({"Other"})
@depends({ @varies({"Owner", "Other"}) })
public aspect CDBufferTally<Owner, Other> {
    private int tallies = 0;
    @writes({"Owner"})
    void around(int i)
        : call(* Tally<Other>+.add(..)) && args(i) {
            this.tallies += i;
            if (i == 0 || Math.abs(this.tallies) > 100) {
                proceed(this.tallies);
                this.tallies = 0;
            }
        }
}
```
Checking Spectators in MAO

A spectator aspect:
- Only has surround advice:
  - Only writes its home concern domain (Owner)
  - Does not change arguments or results
  - Does not interrupt program flow:
    - No explicit exception throwing
    - Proceeds exactly once
- Control effect guarantees enforced
- Heap effect guarantees proved sound
Analysis of Concern Domains

Benefits:
- Spectators can be ignored
- Sound for detecting heap (non-)interference

Costs:
- Declaring effects of methods and advice
- Other concern domain annotations
- Restrictions on assertions
Related Work in Static Analysis

Rinard, Salcianu, Bugrara (FSE ’04):
- Control flow analysis and global pointer + escape analysis
- More fine-grained than concern domains
- Considers interference
- But it’s a whole-program analysis
Summary

Goals:
- Reasoning efficiency
- Practicality

Approaches could be combined?
- Applicability (AJDT)
- Declared limits (XPIs, OMs)
- Heap partitions / effects (MAO)
- Specification of advice, weaving specifications
- Other static analyses + annotations
Future Work

- Implement and do case studies
- Integrate MAO’s concern domains and JML’s data groups [Leino98]
  - Problem: data groups can overlap
  - Benefit: less syntax, plug into other tools
Conclusions

- Around advice like overriding method
- But often used to change behavior
- So refinement isn’t a complete solution
- Efficient reasoning by:
  - Limited applicability
  - Specifications of advice
  - Weaving specifications
  - Effect analysis (concern domains)