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; }
}
```

Call Verification: Heap Effects

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

Implementation Verification: Heap Effects

```
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, *pre*,

if $\mathcal{E}$[[t.val == 0]](*pre*)

then let *post* = $\mathcal{S}$[[t.add(-10)]](*pre*)

in if normal(*post*)

then $\mathcal{E}$[[t.val == -10]](*post*)

else *true*

else *true*

Implementation Verification: Frame Axiom

//@ **assignable this**.val;

- Conservative static analysis, accumulates:
  - Assignments
  - Assignable clauses for calls

Call Verification: Frame Axioms

```
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

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

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

   before() : tallyAddCalls() { this.val++; }
}
```

Problem: Frame Axiom Invalid?

```
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

```
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;
} } }
```

Call Verification: Control Effects

```
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

Problem Summary

- 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 *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

    Advice ∘ Call ≅ Call
  - Problem: soundness
- Other advice:
  - Advice ∘ Call ≅ *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:
  weave(**ensures** *P*, **ensures** *Q*)
  $\cong$ **ensures** *P && Q*
  (modulo control effects)

- For spectators, projection onto base fields can ignore advice's effects

Potential Cost: Overly Conservative Analysis

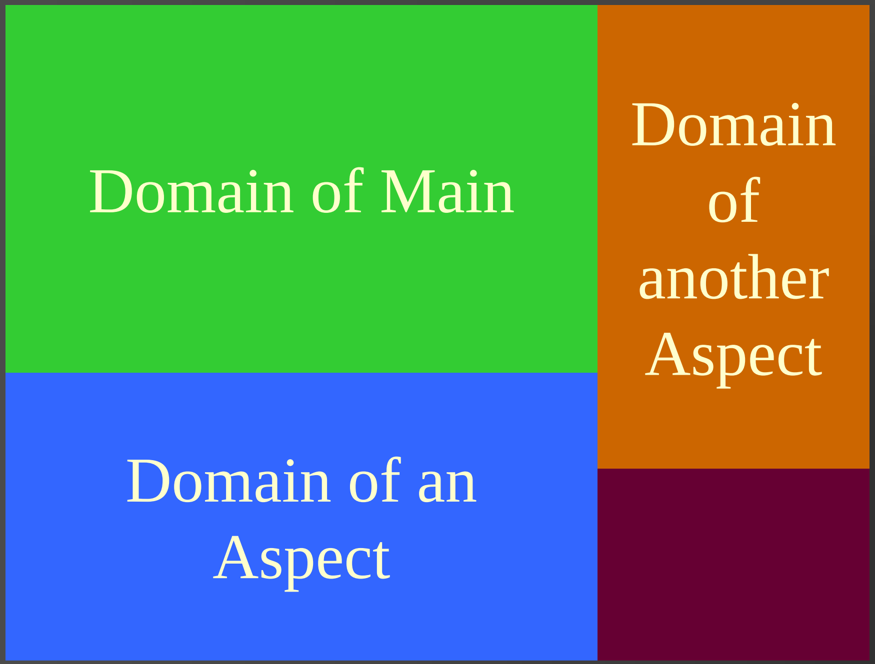
- Even spectators will have side effects

```
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



Example MAO Class with Concern Domains

```
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

```
@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)