Introducing *abc*

- why we are building it -

A workbench for AOP research

- Extensions:
  - Parametric introductions
  - Symmetric class composition (Hyper/J, GenVoca)
  - Trace cuts
  - Dataflow pointcuts
- New static checks:
  - Pure aspects
- Optimisations:
  - Eliminate runtime overheads for cflow
  - Avoid closures in around

require extensible frontend

require analysis framework

Requirements

Syntactic changes should be easy
⇒
Generate parser from grammar

jflex + javacup: parser generator

Frontend framework designed for extensibility:
- Changes to environment type
- Augment existing type objects
- Same override on many existing AST classes
- Override in middle of AST inheritance hierarchy

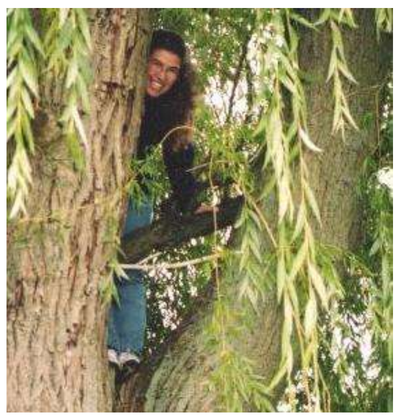
Polyglot:
extensible Java compiler

Backend framework:
- Clean intermediate representation
- Rich set of existing analyses
- Easy to plug in new transformations

Soot:
manipulate classfiles,
3-addr IR for analysis and transformation

abc team

- Chris Allan - Oxford
  (tracecuts)
- Pavel Avgustinov - Oxford
  (test harness, privileged, lexer)
- Aske Simon Christensen - Århus
  (architecture, decl parents, pattern matcher)
- Laurie Hendren - McGill
  (grammar and scanner, initial weaver)
- Sascha Kuzins - Oxford
  (around weaver)
- Jennifer Lhoták - McGill
  (JavaToJimple, initial weaver)



- Ondrej Lhoták - McGill
  (initial weaver, soot class and method handling)
- Oege de Moor - Oxford
  (frontend, intertype weaver)
- Damien Sereni - Oxford
  (cflow optimisations)
- Ganesh Sittampalam - Oxford
  (pointcut matching, advice weaver, optimisations, class and method handling)
- Julian Tibble - Oxford
  (EAJ language extensions)

Suggested schedule

Morning:
introductory talks about abc
(why, what and how)

Afternoon: discuss
- difficult points in language design
- plans for future of AspectJ
- opportunities for ajc/abc collaboration

Plan for the morning

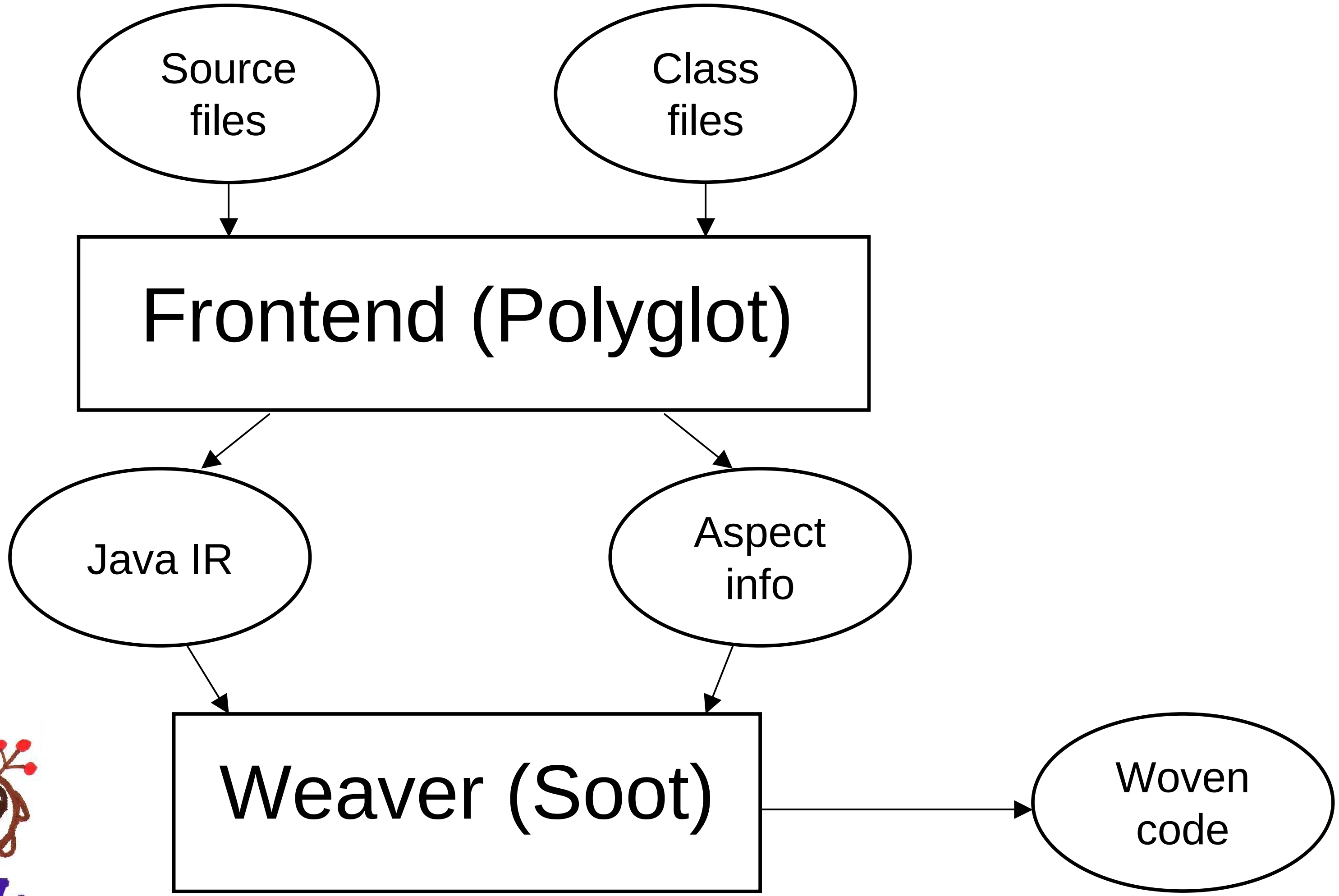
- Architecture (Aske Simon Christensen)
- Scanner and Parser (Laurie Hendren)
- Polyglot and frontend (Oege de Moor)
- Introduction to Soot (Ondrej Lhoták)
- Advice weaver (Ganesh Sittampalam)
- Around weaver (Sascha Kuzins)
- Language extensions (Julian Tibble)
- Current status and plans (Oege de Moor)

abc architecture

Goals

- Focus on extensibility and runtime performance
- Separation between frontend (Polyglot) and backend (Soot)
- Whole-program compiler

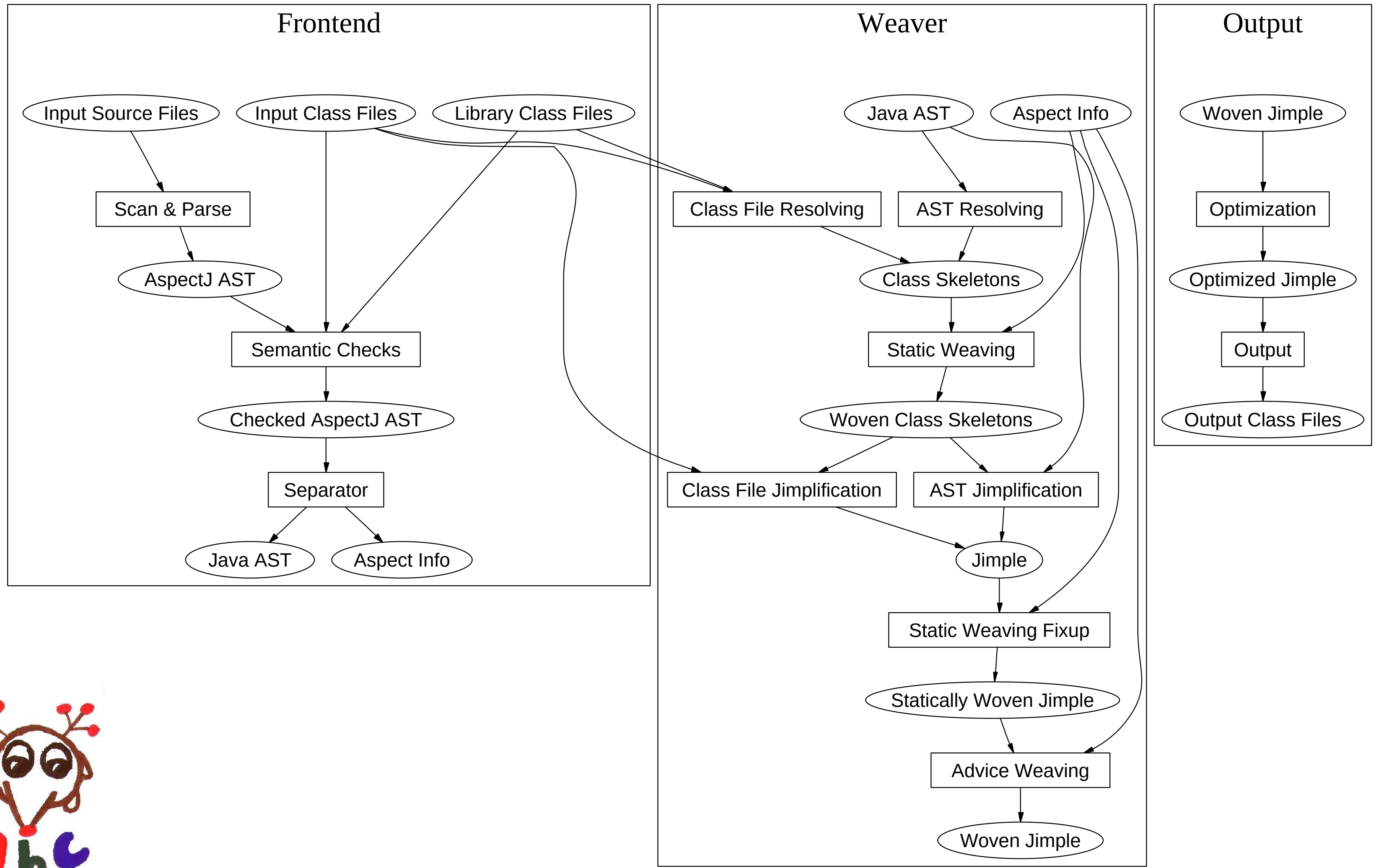
Basic design of the compiler



Aspect Info

- Internal representation of all AspectJ-specific constructs
- All code is put into placeholder methods
- Name mangling for intertype and access
- Categories and real signatures of methods and fields
- Mapping between Polyglot and Soot types

Components of the compiler



The abc scanner and parser

Laurie Hendren and the **abc** team

Challenges

- Unambiguous LALR(1) grammar for the complete AspectJ language that is a natural extension of the Java grammar. (easy to understand and extend)
- Express as much of the language specification in the grammar as possible (for example, differentiate in the grammar where class pattern is required and where a general type pattern is allowed).
- Handle the different sublanguages and associated reserved words in a well-defined manner.

abc Solution Overview

- Jflex-based scanner that is built on top of Polyglot's Java scanner.
- **abc**'s scanner uses state to distinguish between different scanning contexts.
  `abc/src/abc/aspectj/parse/aspectj.flex`
- LALR(1) grammar expressed as a clean extension to Polyglot's base Java grammar (originally defined by Scott Ananian - JavaCup)
  `abc/src/abc/aspectj/parse/java12.cup`
  `abc/src/abc/aspectj/parse/aspectj.ppg`

Scanning AspectJ

- Really three different sublanguages:
  1. normal Java code
  2. aspect declarations
  3. pointcut definitions
- Different sub-languages have different lexical structure, for example
  `if*.*1.Foo+.new(..)`

  Java: reserved("if"), op("*"), op("."), op("*"),float(1.0), id("Foo"), op("+"), reserved("new"), op("("), op("."), op("."), op(")")

  Pointcut: IdPat("if*"), op("."), IdPat("*1"), op("."), Id("Foo"), op("+"), reserved("new"), op("("), op(".."), op(")")

abc Scanner Uses States

- Scanner maintains a stack of states.
- New state is pushed when entry into lexical scope is detected, and the scanner is put into the new state.
- When the end of a lexical state is detected, state is popped from the stack and scanner put into the state now at the top of the stack.
- Four major states, each state has well-defined entry/exit points, and its own lexical structure, including specific reserved words defined for that state.
- A reserved word is easily associated to two different token types, based on current state of the scanner. For example, **`if`** can have two different token types, one for the regular **`if`** and one for the pointcut **`if`**.

Scanner States

Java: Default state, **`aspect`**, **`privileged`**, and **`pointcut`** are reserved words. This state is entered at **`class`** or **`interface`** and exited at matching **`}`**. (finding the matching } requires a nesting counter)

Aspect: Begins at the **`aspect`** keyword and ends at the end of the aspect declaration's body. Has, in addition to above reserved words, **`after`**, **`around`**, **`before`**, **`declare`**, **`issingleton`**, **`percflow`**, **`percflowbelow`**, **`pertarget`**, **`perthis`**, **`pointcut`**, and **`proceed`**.

abc Scanner States (2)

Pointcut: Four contexts in which pointcut expressions may be found:

per clause: **`pertarget ( ..... )`**

declare declaration: **`declare ..... ;`**

body of a pointcut declaration: **`pointcut ..... ;`**

header of an advice declaration: **`after ..... {`**

Reserved words in this state are only: **`adviceexecution`** **`args`**, **`call`**, **`cflow`**, **`cflowbelow`**, **`error`**, **`execution`**, **`get`**, **`handler`**, **`if`**, **`initialization`**, **`parents`**, **`precedence`**, **`preinitialization`**, **`returning`**, **`set`**, **`soft`**, **`staticinitialization`**, **`target`**, **`this`**, **`throwing`**, **`warning`**, **`within`** and **`withincode`**.

abc Scanner States (3)

PointcutIfExpr: inside a pointcut, an if pointcut has a nested expression, same scanning state as Aspect, but state returns to pointcut state at terminating parenthesis.

```
..... if ( ..... ) .....
```

Defining a LALR(1) grammar as Polyglot ext.

1. Define new alternatives to existing rules in the polyglot Java grammar.
2. Define new grammar productions. (sometimes must accept a slightly too large language and then weed)

All new alternatives

⟨*type_declaration*⟩ ::= ⟨*aspect_declaration*⟩

⟨*class_member_declaration*⟩ ::= ⟨*aspect_declaration*⟩
| ⟨*pointcut_declaration*⟩

⟨*interface_member_declaration*⟩ ::= ⟨*aspect_declaration*⟩
| ⟨*pointcut_declaration*⟩

⟨*method_invocation*⟩ ::= 'proceed' '(' ⟨*argument_list_opt*⟩ ')'

Adding alternatives in Polyglot

```
/* add the possibility of declaring an
    aspect to type_declaration */

extend type_declaration ::=
     aspect_declaration:a
        {: RESULT = a; :}
  ;
```

New aspect-specific productions

```
aspect_declaration ::=
   modifiers_opt:a PRIVILEGED modifiers_opt:a1
     ASPECT:n IDENTIFIER:b
     super_opt:c interfaces_opt:d
     perclause_opt:f
     aspect_body:g
  {: RESULT = parser.nf.AspectDecl(parser.pos(n,g),
              true, a.set(a1), b.getIdentifier(),
              c, d, f, g);
  :}
```

aspect_declaration (continued)

```
|  modifiers_opt:a
     ASPECT:n IDENTIFIER:b
     super_opt:c interfaces_opt:d
     perclause_opt:f
     aspect_body:g
   {: RESULT = parser.nf.AspectDecl(parser.pos(n,g),
                    false, a, b.getIdentifier(),
                    c, d, f, g);
   :}
;
```

abc grammar includes pointcuts

⟨*basic_pointcut_expr*⟩ ::=
 '(' ⟨*pointcut_expr*⟩ ')'
| 'call' '(' ⟨*method_constructor_pattern*⟩ ')'
| 'execution' '(' ⟨*method_constructor_pattern*⟩ ')'
| 'initialization' '(' ⟨*constructor_pattern*⟩ ')'
| 'preinitialization' '(' ⟨*constructor_pattern*⟩ ')'
| 'staticinitialization' '(' ⟨*classname_pattern_expr*⟩ ')'
| 'get' '(' ⟨*field_pattern*⟩ ')'
| 'set' '(' ⟨*field_pattern*⟩ ')'
| 'handler' '(' ⟨*classname_pattern_expr*⟩ ')' . . .

(continued)

⟨*basic_pointcut_expr*⟩ ::= . . .
| 'adviceexecution' '(' ')'
| 'within' '(' ⟨*classname_pattern_expr*⟩ ')'
| 'withincode' '(' ⟨*method_constructor_pattern*⟩ ')'
| 'cflow' '(' ⟨*pointcut_expr*⟩ ')'
| 'cflowbelow' '(' ⟨*pointcut_expr*⟩ ')'
| 'if' '(' ⟨*expression*⟩ ')'
| 'this' '(' ⟨*type_id_star*⟩ ')'
| 'target' '(' ⟨*type_id_star*⟩ ')'
| 'args' '(' ⟨*type_id_star_list_opt*⟩ ')'
| ⟨*name*⟩ '(' ⟨*type_id_star_list_opt*⟩ ')'

Specific Patterns

⟨*method_constructor_pattern*⟩ ::=
    ⟨*method_pattern*⟩
| ⟨*constructor_pattern*⟩

⟨*method_pattern*⟩ ::=
    ⟨*modifier_pattern_expr*⟩ ⟨*type_pattern_expr*⟩
    ⟨*classtype_dot_id*⟩
    '(' ⟨*formal_pattern_list_opt*⟩ **')'** ⟨*throws_pattern_list_opt*⟩
| ⟨*type_pattern_expr*⟩ ⟨*classtype_dot_id*⟩
    '(' ⟨*formal_pattern_list_opt*⟩ **')'** ⟨*throws_pattern_list_opt*⟩

Summing up ....

- State-based scanner, plus LALR(1) grammar:
  - clearly defines lexical scopes and associated reserved words
  - naturally handles different sub-languages in AspectJ
  - clean addition to the base Java grammar
  - easy to understand
  - easy to extend
- More detailed scanning/parsing document at: **`http://abc.comlab.ox.ac.uk/doc`**

AspectJ as a Polyglot extension

- the frontend of abc -

Roadmap

- What is Polyglot?
- Brief overview of the AspectJ extension
- Sketch of disambiguation of “this” in ITDs
- Summary

What is Polyglot?

An *extensible* Java compiler

Sample extensions:

- Jif : Java information flow and program partitioning
- PolyJ 2.0 : Java with parameterized types
- JMatch : Abstract iterable pattern matching for Java
- Jx: Nested inheritance in Java
- Jedd: BDD-based analyses
- JPred : Practical predicate dispatch

Produced by Andrew Myers, Nate Nystrom *et al.* at Cornell

How does Polyglot do it?

- Structured as a series of visitors
- Each visitor pass rewrites AST; about 15 such visitors
- Rigorous use of interfaces and factories makes it easy to change type system, environment, ...
- Delegates for overriding members of non-final AST classes (*cf.* intertype decls)

The AspectJ extension

Like any other Polyglot extension, five new packages:

- AST: new ast nodes (89 classes)
- Extension: overrides of existing Java AST nodes (13 classes)
- Parse: new lexer and grammar (2 files)
- Types: new types and type system (8 classes)
- Visit: new passes (35 classes)

- Includes Java/AspectInfo separator
- Many AST classes in pointcut language are light-weight
- The tricky bits are the type rules for ITDs, and the separator into Java & AspectInfo

Example: intertype scope rules

```
public class A {
    int x;
    class B { int x; }
}
aspect Aspect {
    static int x;
    static int y;
    int A.B.foo() {
        class C {
            int x = 3;
            int bar() {return x + A.this.x;}
        }
        return this.x + (new C()).bar() + y;
    }
}
```

Example: intertype scope rules

```
public class A {
    int x;
    class B { int x; }
}
aspect Aspect {
    static int x;
    static int y;
    int A.B.foo() {
        class C {
            int x = 3;
            int bar() {return x + A.this.x;}
        }
        return this.x + (new C()).bar() + y;
    }
}
```

need to disambiguate field references:

- may be a reference to aspect fields,

- local class fields,

- or host (=target) of intertype declaration

Rules:

- no explicit receiver? if it was introduced into environment by the host, give it “**this**” from host.
- explicit “**this**” or “**super**”? if there is no qualifier and we're not inside a local class, it refers to the host. If there is a qualifier Q, and there is no enclosing instance of type Q nested inside the ITD, it refers to the host if the host has an enclosing instance of type Q.

How to disambiguate “*this*”

- Extend *context* type in Polyglot
- Test to determine whether *this* refers to host
- Override *disambiguate* for Polyglot *this*.

New context type

types.Context:

```
public interface AJContext extends Context {
    Context pushHost(ClassType ct, boolean declaredStatic);
                                    // called when entering itd
    ClassType hostClass();          // return target of current itds
    boolean inInterType();          // are we inside an intertype declaration?
    boolean nested();               // are we inside a local class in an intertype declaration?

    // other itd-related members...
    boolean varInHost(String name);
    boolean methodInHost(String name);
    ClassType findFieldScopeInHost(String name);
    ClassType findMethodScopeInHost(String name) throws SemanticException;
    // ... more for advice and declare decls ...
}
```

Does "*this*" refer to host of ITD?

types.AJTypeSystem_c

```
public boolean refHostOfITD(AJContext c, Typed qualifier) {
    if (!c.inInterType())          // if not inside an ITD, cannot refer to a host
        return false;
    if (qualifier == null)         // if there is no qualifier
        return !c.nested();        // it refers to the host if we're not in a local class
    else                           // otherwise look for enclosing instance in host
        return c.hostClass().hasEnclosingInstance(qualifier.type().toClass());
}
```

Override disambiguate

extension.AJSpecial_c *(Special is the Polyglot class to represent "this")***:**

```
public Node disambiguate(AmbiguityRemover ar) throws SemanticException {
    AJContext c = (AJContext) ar.context();
    AJTypeSystem ts = (AJTypeSystem) ar.typeSystem();
    if (!(ts.refHostOfITD(c,qualifier()))) {
        // this is an ordinary special, it does not refer to the host
        return super.disambiguate(ar);
    } else {
        // this is a host special
        AJNodeFactory nf = (AJNodeFactory) ar.nodeFactory();
        HostSpecial_c hs = (HostSpecial_c) nf.hostSpecial(position,kind,
                                                qualifier,((AJContext)c).hostClass());
        return hs.type(type()).disambiguate(ar);
    }
}
```

Frontend summary

- Extensible in all dimensions:
  - syntax, type system, visitors
- Potential merge problems with pure Java compiler only occur in extension dir and type system
- Extensions to *abc* have same structure as *abc* itself

Soot, a Tool for Analyzing and Transforming Java Bytecode

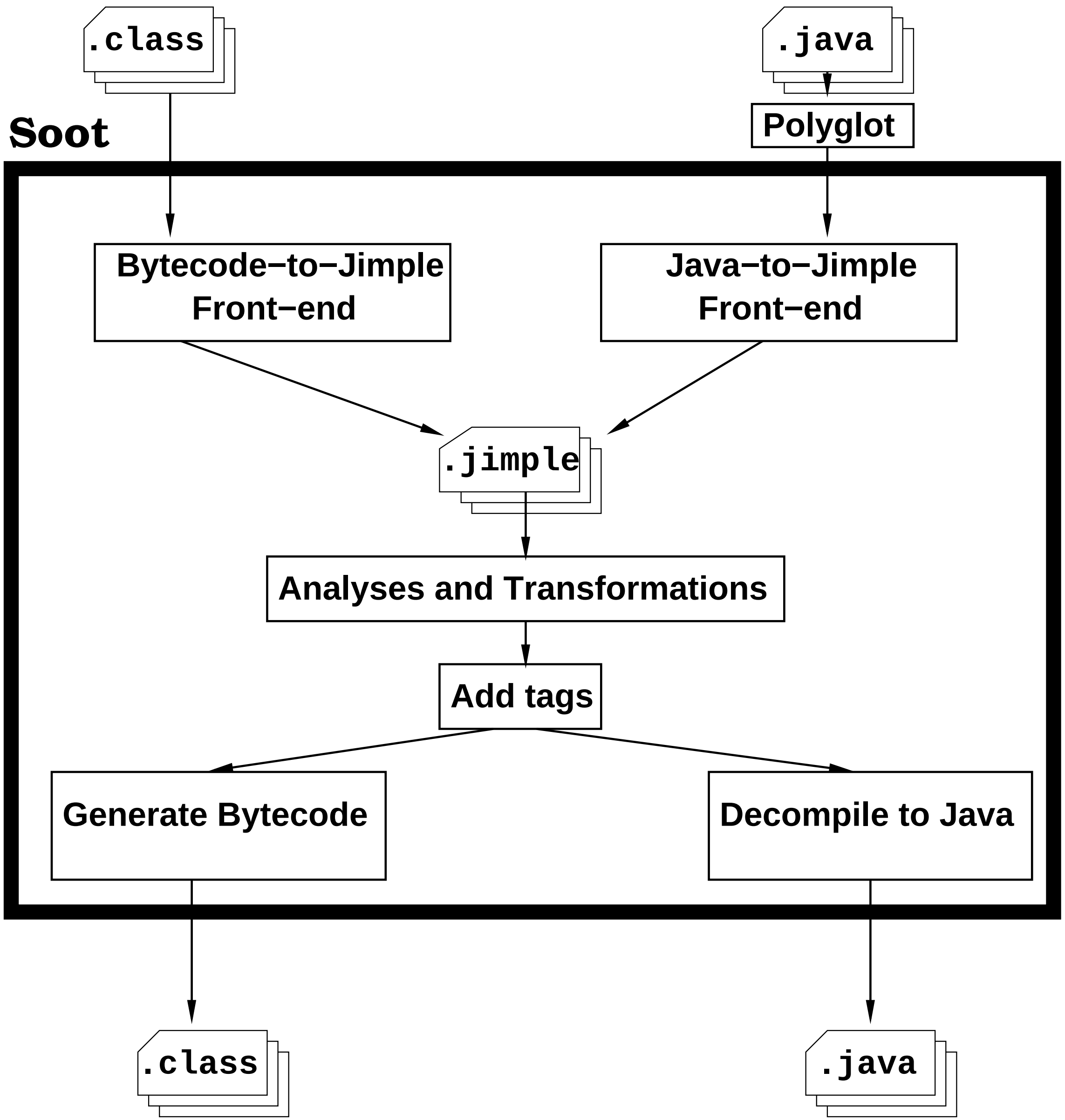
presenter: Ondřej Lhoták, McGill University

Soot toolkit

Soot provides:

- Convenient IRs (mainly Jimple)
- Existing analyses and transformations
- Framework for new analyses, transformations, code generation
- Dava decompiler
- Eclipse plugin for visualization
- Whole-program analysis framework

Soot Overview



Jimple

Jimple is:

- principal Soot Intermediate Representation
- 3-address code in a *control-flow graph*
- a *typed* intermediate representation
- *stackless*

Jimple example

Java:

```
public int bar(int a, int b) {
    return a+b;
}
```

Jimple:

```
public int bar(int, int) {
    Foo this;
    int a, b, $i0;

    this := @this;
    a := @parameter0;
    b := @parameter1;
    $i0 = a + b;
    return $i0;
}
```

Converting bytecode → Jimple → bytecode

- These transformations are relatively hard to design so that they produce correct, useful and efficient code.
- Worth the price, we do want a 3-addr typed IR.

raw bytecode	typed 3-address code (Jimple)
○ each inst has implicit effect on stack	○ each stmt acts explicitly on named variables
○ no types for local variables	○ types for each local variable
○ $>$ 200 kinds of insts	○ only 15 kinds of stmts

Bytecode → Jimple

- Naive translation from bytecode to untyped Jimple, using variables for stack locations.
- splits DU-UD webs (so many different uses of the stack do not interfere)
- types locals (SAS 2000)
- cleans up Jimple

Java → Jimple

- Input: Polyglot AST generated from .java sources
- Compile AST to Jimple
- Generate Jimple methods/classes for implicit Java features (initializers, inner class accessor methods, class literals, assertions)
- Output: Jimple to be analyzed/optimized, eventually converted to bytecode
- Combination of Polyglot, Java-to-Jimple, Jimple-to-Bytecode passes forms a complete Java compiler equivalent to javac.

This part is unchanged in abc.

Jimple → Bytecode

- A naive translation introduces many spurious stores and loads.
- Two approaches (CC 2000),
  - aggregate expressions and then generate stack code; or
  - perform store-load and store-load-load elimination on the naive stack code.

Weaving example – source

```
public class Foo {
    public int foo(int x, int y, int z) {
       return bar(x, y, z);
    }
    public int bar(int a, int b, int c) {
        return a+b+c;
    }
}
aspect A {
    before(Foo x) :
    call(int bar(int,int,int)) && target(x) {
        System.out.println(x);
    }
}
```

Weaving example – original bytecode

```
public int foo(int x, int y, int z)
0:    aload_0
1:    iload_1
2:    iload_2
3:    iload_3
4:    invokevirtual    Foo.bar (III)I (7)
7:    ireturn
```

Weaving example – weaving by hand

```
public int foo(int x, int y, int z)
0:     invokestatic        A.aspectOf ()LA; (14)
3:     aload_0
4:     invokevirtual       A.before$0 (LFoo;)V (20)
7:     aload_0
8:     iload_1
9:     iload_2
10:    iload_3
11:    invokevirtual       Foo.bar (III)I (9)
14:    ireturn
```

Weaving example – ajc weaving

```
public int foo(int x, int y, int z)
0:     aload_0
1:     iload_1
2:     iload_2
3:     iload_3
4:     istore            %4
6:     istore            %5
8:     istore            %6
10:    astore            %7
12:    invokestatic      A.aspectOf ()LA; (52)
15:    aload             %7
17:    invokevirtual     A.ajc$before$A$124 (LFoo;)V (56)
20:    aload             %7
22:    iload             %6
24:    iload             %5
26:    iload             %4
28:    invokevirtual     Foo.bar (III)I (37)
31:    ireturn
```

Weaving example – original Jimple

```
public int foo(int, int, int)
{
    Foo this;
    int x, y, z, $i0;

    this := @this;
    x := @parameter0;
    y := @parameter1;
    z := @parameter2;
    $i0 = this.bar(x, y, z);
    return $i0;
}
```

Weaving example – woven Jimple

```
public int foo(int, int, int)
{
    Foo this;
    int x, y, z, $i0;
    A theAspect;

    this := @this;
    x := @parameter0;
    y := @parameter1;
    z := @parameter2;
    theAspect = A.aspectOf();
    theAspect.before$0(this);
    $i0 = this.bar(x, y, z);
    return $i0;
}
```

Weaving example – bytecode from Jimple

```
public int foo(int x, int y, int z)
0:     invokestatic       A.aspectOf ()LA; (14)
3:     aload_0
4:     invokevirtual      A.before$0 (LFoo;)V (20)
7:     aload_0
8:     iload_1
9:     iload_2
10:    iload_3
11:    invokevirtual      Foo.bar (III)I (9)
14:    ireturn
```

Intraprocedural analyses and transformations

- local packer (“register allocation” on bytecode locals)
- copy propagation
- constant propagation
- common subexpression elimination
- partial redundancy elimination
- dead assignment elimination
- unreachable code elimination
- branch simplification

Law of Demeter benchmark

In method lawOfDemeter.objectform.Pertarget.fieldIdentity:

- ajc: 616 locals
- ajc+Soot: 3 locals
- abc: 3 locals

Law of Demeter benchmark

In method lawOfDemeter.objectform.Pertarget.fieldIdentity:

- ajc: 616 locals 45.9 seconds
- ajc+Soot: 3 locals 14.1 seconds
- abc: 3 locals 1.0 second

Adding analyses and transformations

Soot provides tools:

- control flow graphs
- def/use relationships
- fixed-point flow analysis framework
- method inliner

These are useful to have available for:

- weaving itself
- optimizing woven code

Dava decompiler

```
public int foo(int x, int y, int z)
{
    A.aspectOf().before$0(this);
    return this.bar(x, y, z);
}
```

- Dava decompiles bytecode with strange aspect-generated control flow that breaks other decompilers.
- Dava is integrated with Soot and abc.
  We could produce annotated decompiled output (e.g. comments showing pointcuts).

Eclipse plugin

- Soot can be run as a plugin from Eclipse.
- Soot includes a tagging framework to communicate analysis information to Eclipse for visualization. (CC2004, eTX2004)
- Could be used to communicate aspect-specific information.

Whole-program analyses

- CHA call graph
- VTA – more precise call graph (OOPSLA2000)
- Spark: context-ins. points-to and call graph (CC2003)
- Paddle: BDD based framework for context-sensitive:
  - points-to analysis
  - call graph analysis
  - cflow analysis
  - type analysis (`instanceof` checks)
  - side-effect analysis (aspect purity)
  - escape analysis (`thisJoinPoint[StaticPart]`)

Advice weaving

Ganesh Sittampalam

Overview

- Match - produce mapping :

  application sites → advice + dynamic residue

- Prepare application sites

- Weave "inside-out" (i.e. in reverse precedence order)

Pointcut separation

- Restrict containing class
  - e.g. `within(…)`
  - Does include nested classes
- Restrict containing method
  - e.g. `withincode(…)`
  - Doesn’t include classes lexically within the method
- Specific join point
  - e.g. `call(…)`

Translating pointcuts

```
execution(int Foo.foo(char))
   ➔ withinmethod(int Foo.foo(char)) && execution()
```

```
execution(Foo.new(int))
  ➔ withinconstructor(Foo.new(int)) && execution()
```

```
adviceexecution() ➔ withinadvice() && execution()
```

```
staticinitialization(Foo)
   ➔ within(Foo) && withinstaticinitialization() && execution()
```

```
preinitialization(Foo.new(int))
    ➔ withinconstructor(Foo.new(int)) && preinitialization()
```

```
call(int Foo.foo(char)) ➔ methodcall(int Foo.foo(char))
```

```
call(Foo.new(int)) ➔ constructorcall(Foo.new(int))
```

Initialization

```
initialization(Foo.new(int))
   ➔ withinconstructor(Foo.new(int))
   && classinitialization()
```

```
initialization(Foo.new())
   ➔ (withinconstructor(Foo.new())
       && classinitialization()))
   || interfaceinitialization(Foo)
```

```
initialization(Foo.new(..))
   ➔ (withinconstructor(Foo.new(..))
       && classinitialization()))
   || interfaceinitialization(Foo)
```

Pointcut preprocessing

- Inline named pointcuts
  - requires “private” pointcut variables

```
pointcut bar(int x) : args(x,..)
bar(*) ➔ private(int x) { args(x,..) }
```

- Convert to DNF
  - to correctly handle alternative bindings

```
(this(x) || target(x)) && if(x instanceof Foo)
  ➔ (this(x) && if(…)) || (target(x) && if(…))
```

- Lift pointcuts from cflow and per clauses into special advice declarations
  - look for CSE and counter opportunities with cflow pointcuts

Restructuring

- Move `new+invokespecial` together
  - Needed for constructor call matching
- `foo()` ➔ `a0 = foo()`
  - If `foo()` returns a value we want to bind
- Restructure `return` statements in body so that there is just one at the end
  - For execution pointcuts
- Inline `this(…)` calls in constructors
  - For initialization and preinitialization weaving

Matching

- Shadows categorised as:
  - Whole body (execution, initialization etc)
  - Individual statement (method call, field set, field get etc)
  - Pair of statements (constructor call)
  - Exception handler
- Iterate through all weavable classes
  - At each shadow, try all pointcuts

Finding method call shadows

```
…
if (stmt instanceof InvokeStmt) {
    InvokeStmt istmt=(InvokeStmt) stmt;
    invoke=istmt.getInvokeExpr();
} else if(stmt instanceof AssignStmt) {
    AssignStmt as = (AssignStmt) stmt;
    Value rhs = as.getRightOp();
    if(!(rhs instanceof InvokeExpr)) return null;
    invoke=(InvokeExpr) rhs;
} else return null;
SootMethodRef methodref=invoke.getMethodRef();
…
```

Dynamic residues

- Mini-language roughly corresponding to structure of pointcuts
- Used to generate runtime code
  - decide whether advice should execute
  - bind values to pass to advice
- Also used to signal static results
  - “Match failed”
  - “This always matches”
- Easy to improve residues using analysis results

Dynamic residue construction

- “pre” residue from aspect
  - hasAspect check for per advice
- Residue from pointcut
- Residue from advice spec (before, after etc)
- “post” residue from aspect
  - aspectOf for getting aspect instance

Weaving

- Insert nops around the instruction(s) representing the shadow
  - Take care to fix up exception ranges and gotos correctly
- Advice gets inserted just inside the nops
- Advice gets woven “inside-out”

Around Weaving in abc

Objectives

- Avoid heap allocations
- Inlining not as the general strategy
  - to avoid code duplication
- Keep code in original classes
  - to avoid visibility problems

The starting point

- Around advice → advice method
  - same return type
  - arguments matching the advice formals
    - plus arguments for thisJoinpoint etc.
- `proceed` statement → call to dummy method
- Dynamic residue AST
  - includes all the bindings
  - (can fail)

Review: Closure strategy

- closure interface:

```
public interface AroundClosure$1 {
  public [ret-type] proceed([arg-type] arg1, ...);
}
```

- advice method:

```
[ret-type] adviceMethod$1(AroundClosure$1 closure,
                              [arg-type] arg1, ...) {
  ...
  [ret-type] result=closure.proceed(arg1’, ...);
  ...
  return result;
}
```

Review: Closure strategy (2)

- Closure instantiation

```
public class ShadowClass {
   public void shadowMethod() {
        AroundClosure$1 closure=new
                AroundClosure$1$Implementation$1();
        ...store additional information...
        Aspect.aspectOf().adviceMethod$1(closure, arg1, ...);
   }
   ...
}
```

- Closure implementation

```
public class AroundClosure$1$Implementation$1 implements AroundClosure$1 {
   public [ret-type] proceed([arg-type] arg1, ...) {
        ... do what the shadow did...
   }
}
```

Avoiding the closure (1)

- Using the object itself
  - simply add an interface to the class of the shadow

```
public class ShadowClass implements AroundClosure$1
{
  public [ret-type] proceed([arg-type] arg1, ...) {
      ...do what the shadow did...
  }
  public void shadowMethod()  {
      Aspect.aspectOf().adviceMethod$1(this,
            arg1, ...);
  }
}
```

Avoiding the closure (2)

- Problem: The same advice can apply multiple times within the same class
- Solution: the shadow ID

Shadow ID

```
public class ShadowClass implements AroundClosure$1 {
   public [ret-type] proceed(int shadowID, [arg-type] arg1, ...) {
        switch(shadowID) {
        case 0:
               ... do what the first shadow did...
        case 1:
               ... do what the second shadow did...
        }
   }
   public void shadowMethod() {
        Aspect.aspectOf().adviceMethod$1(this, 0, arg1, ...);
   }
   public void anotherShadowMethod() {
        Aspect.aspectOf().adviceMethod$1(this, 1, arg1, ...);
   }
}
```

Shadow ID (2)

- Problem: inheritance
  - subclasses may need to implement the same interface, but this overrides the original implementation of the superclass

- Solution: unique shadow ID, super() call

Shadow ID (3)

```
public class ShadowClassExt extends ShadowClass
                                   implements AroundClosure$1 {
   public [ret-type] proceed(int shadowID, [arg-type] arg1, ...) {
        switch(shadowID) {
        case 2:
                ... do what the shadow did...
                break;
        default:
                super(shadowID, arg1, ...);
        }
   }
   public void anotherShadowMethod() {
        Aspect.aspectOf().adviceMethod$1(this, 2, arg1, ...);
   }
}
```

Static methods

- Problem: shadows in static methods.
  - which object instance do we pass as the closure?
  - ideas:
    - create a temporary instance
    - use a singleton instance

Static Class ID

- Solution: the static class ID.
  - assign a unique integer ID to each class
  - implement a static proceed method where necessary.
  - pass this ID to the advice method
  - transform each proceed call into a switch statement

Static Class ID (2)

- static proceed method, unique id

```
public class ShadowClass implements AroundClosure$1 {
  public static[ret-type] proceed_s(int shadowID,
                               [arg-type] arg1, ...) {
      switch(shadowID) ... as before ...
  }
  public static shadowMethod() {
      Aspect.aspectOf().adviceMethod$1(null, 0,
            1, arg1, ...);
  }
}
```

Static Class ID (3)

```
[ret-type] adviceMethod$1(AroundClosure$1 closure, int shadowID,
   [arg-type] arg1, ...) {
   ...
   closure.proceed(shadowID, arg1, ...);
   ...
}
```

```
[ret-type] adviceMethod$1(AroundClosure$1 closure, int shadowID,
   int staticClassID, [arg-type] arg1, ...) {
   ...
   switch (staticClassID) {
   case  0: closure.proceed(shadowID, arg1, ...); break;
   case  1: ShadowClass.proceed_s(shadowID, arg1, ...); break;
   ...
   }
   ...
}
```

Static Class ID (4)

- This method for the static cases can also be used for the non-static cases
- Tests indicate that this method is slightly faster

Transferring joinpoint context

- abc adds arguments to the advice method and the proceed method to carry the context
  - no heap allocations
- Problem: advice can apply to different joinpoints with different context
- Solution: add enough arguments to handle all the cases

Transferring joinpoint context (2)

- Mapping types
  - all reference types: Object
  - simple types are mapped to themselves
    - int-like types (short, byte, boolean and char) are mapped to int
  - (possibility of using exact reference types to avoid casts)
- This approach does not need boxing/unboxing for simple types

Transferring joinpoint context (3)

```
public class Foo {
    public static void main(String args[]) {
        new Foo().bar1("test");
        new Foo().bar2(1.0d);
    }
    public void bar1(String s) {}
    public void bar2(double d) {}
}
aspect Aspect {
    void around(): call(void *.bar*(..)) {
        proceed();
    }
}
```

Transferring joinpoint context (4)

```
public class Foo {
    public static void proceed$1(int shadowID,
       java.lang.Object contextArg1,
       double           contextArg2,
       java.lang.Object contextArg3)  {

       switch (shadowID) {
            case 0: ((Foo)contextArg1).test2(contextArg2);
                return;
            case 1: ((Foo)contextArg1).test1(contextArg3);
                return;
        default: throw new RuntimeException();
        }
    }
    public static void main(java.lang.String[] r0) {
        Foo target1 = new Foo();
        Aspect.aspectOf().adviceMethod$1(1, 1, target1, 0.0, "test");
        Foo target2 = new Foo();
        Aspect.aspectOf().adviceMethod$1(0, 1, target2, 1.0, null);
        return;
    }
    ...
}
```

Transferring joinpoint context (5)

```
class Aspect {
   final void adviceMethod$1(int shadowID,
        java.lang.Object contextArg1,
        double           contextArg2,
        java.lang.Object contextArg3)
   {
        ...
        Foo.proceed$1(shadowID,
               contextArg1,
               contextArg2,
               contextArg3);
        ...
        return;
   }
   ...
}
```

Binding context

- When skipping the advice, the advice formals must be ignored
- The Skip Flag indicates this to the proceed method

Skip Flag

- Example program

```
public class Foo
{
   public static void main(String args[])
   {
       new Foo().bar(0);
   }
   public void bar(int i) {}
}
aspect Aspect
{
    void around(int intArg):
        call(void *.bar*(..)) &&
        args(intArg) &&
        target(Foo)
    {
        proceed(intArg);
    }
}
```

Skip Flag (2)

```
public class Foo {
   public static void proceed$0(
        int intArg, // advice formal
        int shadowID, boolean skipFlag,
        java.lang.Object contextArg1, int contextArg2 ) {

        int arg;
        switch(shadowID) {
            case 0:
                if (skipFlag)
                    arg=contextArg2; // unbound case
                else
                    arg=intArg;      // bound case

                Foo callTarget=(Foo)contextArg1; // never bound
                callTarget.bar(arg);
                break;
            default:  throw new RuntimeException();
        }
   }
   ...
}
```

Skip Flag (3)

```
public class Foo {
   ...
   public static void main(String args[])    {
        Foo foo=new Foo();
        int i=0;
        if (foo instanceof Foo) {
               // residue passed
               Aspect.aspectOf().adviceMethod$0(…);
        } else {
               // residue failed
               proceed$0(
                     …,
                      true,  // skip flag
                     …);
        }
   }
   public void bar(int i) {}
}
```

Alternative bindings

```
aspect Aspect {
    void around(String s): call(void *.foo*(..)) &&
        (args(s,..) ||  args(.., s))
    {
        proceed("new");
    }
}
public class Foo {
   public static void main(String args[]) {
       new Foo().foo("string", new Integer(0));
       new Foo().foo(new Integer(0), "string");
   }
   public void foo(Object ob1, Object ob2) {
       System.out.println(ob1 + ", " + ob2);
   }
}
```

Output:

```
new, 0
0, new
```

Alternative bindings (2)

```
public class Foo {
    public static void main(String args[]){
       Foo foo=new Foo();
       Object arg1="string";
       Object arg2=null;
       String adviceFormal;
       int bindMask=0; // initialization
       label_0: {
           if (arg1 instanceof String) {
               adviceFormal=arg1;
               bindMask|=0; // removed by optimizer
           } else {
               if (arg2 instanceof String) {
                   adviceFormal=arg2;
                   bindMask|=2; // set bit 1
               } else  { // skipped case
                   bindMask=1; // set skip flag
                   adviceFormal=null;
                   proceed_s$0(adviceFormal, 0, bindMask, foo, arg1, arg2);
                   break label_0;
               }
           }
           Aspect.aspectOf().adviceMethod$0(
               adviceFormal, null, 0, 1, bindMask, foo, arg1, arg2);
       }
   …
}
```

Alternative bindings (3)

```
public class Foo {
   public static void proceed_s$0(String s, int shadowID, int bindMask,
       Object contextArg1, Object  contextArg2, Object contextArg3) {
       …
       Object arg1;
       Object arg2;
       if (bindMask==1) { // skip case
          arg1=contextArg2;
          arg2=contextArg3;
       } else  {
          arg1=contextArg2; // first assign the default context
          arg2=contextArg3;
          switch ((bindMask & 2) >> 1) { // then overwrite the bound value
       case 0: arg1 = s; break;
            case 1: arg2 = s; break;
            default: throw new RuntimeException();
          }
       }
       Foo foo(Foo)contextArg1; // never bound
       foo.foo(arg1, arg2);
       …
   }
}
```

Local and anonymous classes

- Problem: `proceed` in local/anonymous classes
  - can occur at an arbitrarily deep nesting level
- Solution: All relevant parameters of the advice method are stored as dedicated fields in each class at the outermost nesting level
- Classes at a deeper nesting level refer to the enclosing outermost class

Advice execution

- Around-advice applying to the execution of around-advice
- Weaving is done as described
- Problem: once an advice method has been woven into, it itself cannot be woven anymore
- Solution: topological sort of graph of applications

Circular advice execution

- Detected by topological sort
- Once an advice method has been woven into, use closure approach
  - closure simply implements interface of that advice method
- Closures or similar construct necessary

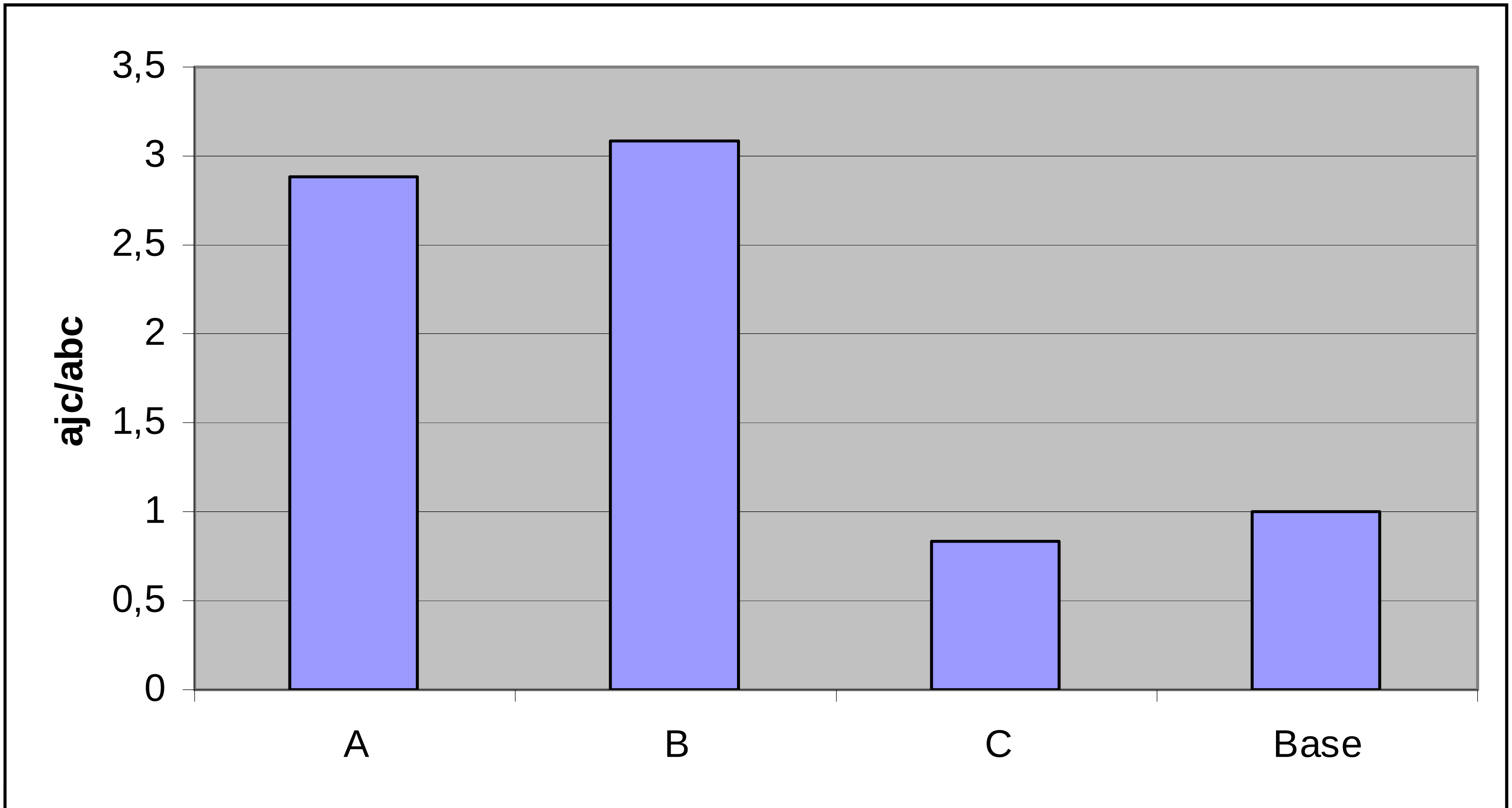
Closures

- Dedicated fields for all values
  - no Object array
- Actual shadow is moved to static method inside of original class
- No closure creation if residue fails

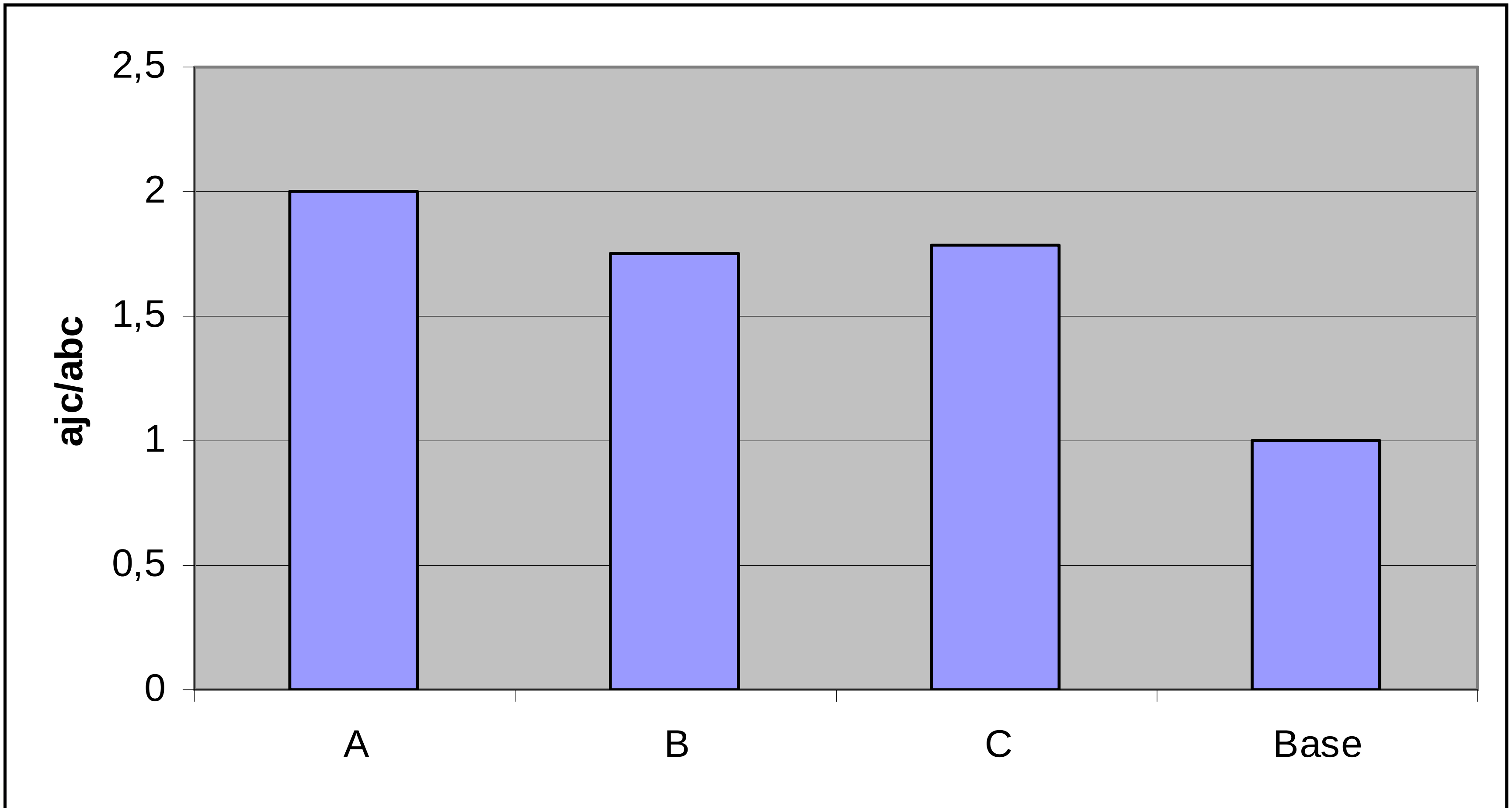
Benchmarks – Nullptr

```
aspect Nullptr {
    pointcut methodsThatReturnObjects():
        ...
    Object around():
        methodsThatReturnObjects(){
        Object lRetVal = proceed();
        if(lRetVal == null)
            System.err.println(
                        "Null return value: " + thisJoinPoint);
        return lRetVal;
    }
}
A: pointcut methodsThatReturnObjects():
        call(* *.*(..)) && !call(void *.*(..));
B: pointcut methodsThatReturnObjects():
        call(Object+ *.*(..));
C: pointcut methodsThatReturnObjects():
        call(Object+ *.*(..)) && !within(lib.aspects..*);
```

Benchmarks – Nullptr (2)



Benchmarks (2) - Closures



Future work

- Obvious optimizations
  - unused arguments, conditionals, table-switch etc.
- Adaptive inlining
  - post processing step
- Optimization of advice execution cycles
  - reduce likelihood of closure creation

Extending abc

Aspect *Bench* Compiler

- abc...
  - ...is designed to provide a workbed for research and investigation
  - ...therefore must be flexible and extensible
- We ensured that it is by extending it

Layout of an extension

- 3 small extensions
- 2 ½ weeks coding (no prior experience with the codebase)
- ~1000 lines of code
- In self-contained directory structure

- **eaj** – (Extended AspectJ)
  - **ast** – new polyglot ast nodes
  - **visit** – new polyglot passes
  - **parse** – new scanner, parser extensions
  - **weaver** – backend extensions

Layout of an extension

- *ExtensionInfo* is sub-classed for each extension.
  - Calls a new scanner and an extended parser
  - Creates factories for creating Polyglot AST nodes and type objects
  - (Re)Orders the passes of the compiler

The Cast Pointcut

- Defines a new shadow join point encompassing each explicit or implicit cast, and a pointcut to match it
- Syntax:

  `cast (` *`TypePattern`* **`)`**

  matches all casts to a type matching the *TypePattern*

The Cast Pointcut

- For example

```
pointcut int_to_short(int x) :
    cast(short) && args(x);
```

- matches a cast from an `int` to a `short` and binds `x` to the original `int`

Check bounds with Cast Pointcut

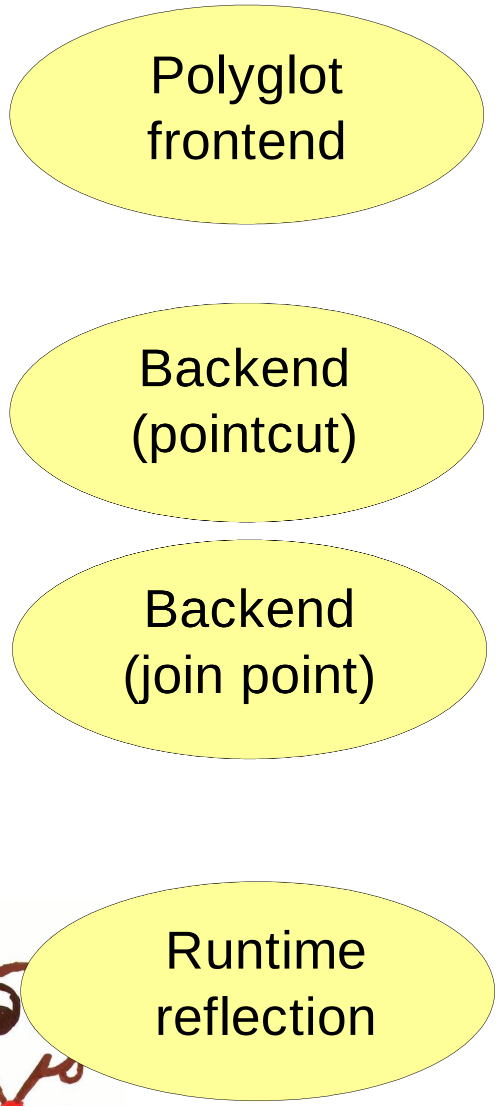
```
import uk.ac.ox.comlab.abc.eaj.lang.reflect.CastSignature;

aspect BoundsCheck
{
    before(int x) :
        cast(short) && args(x)
    {
        CastSignature s = (CastSignature)
            thisJoinPointStaticPart.getSignature();

        if (x > Short.MAX_VALUE || x < Short.MIN_VALUE) {
            System.out.println(
                “Warning: information lost casting “ +
                x + “ to a “ + s.getCastType().getName());
        }
    }
}
```

Check bounds with Cast Pointcut

```
class LoseInformation
{
    public static void main(String[] args)
    {
        int x = 50000;
        short y;

        y = (short) x;
    }
}
```

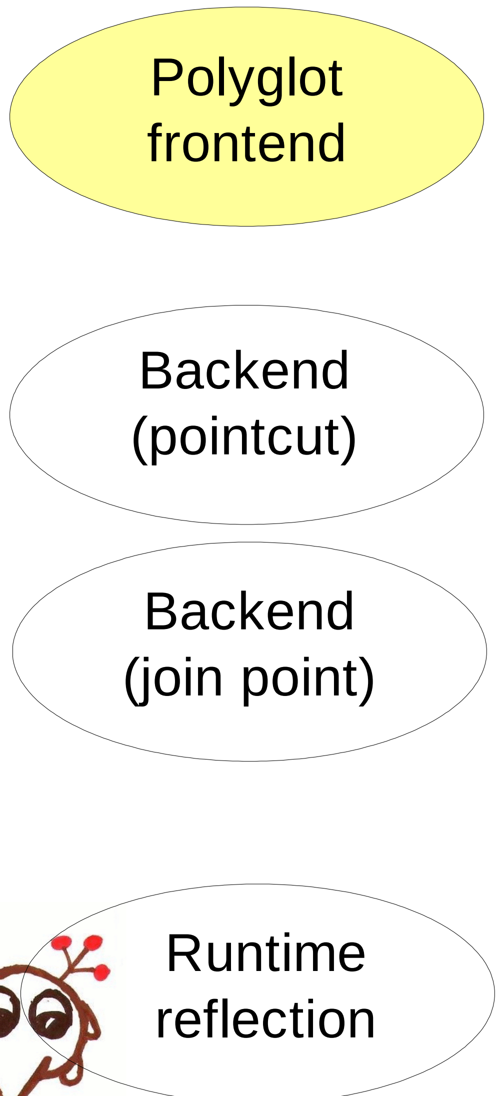
```
$ java LoseInformation

Warning: information lost casting 50000 to a short
```

Implementing the Cast Pointcut



- Frontend
  - New polyglot AST node: *PCCast*
- Backend
  - Cast pointcut class
  - Cast shadow join point class
- Runtime
  - Cast signature

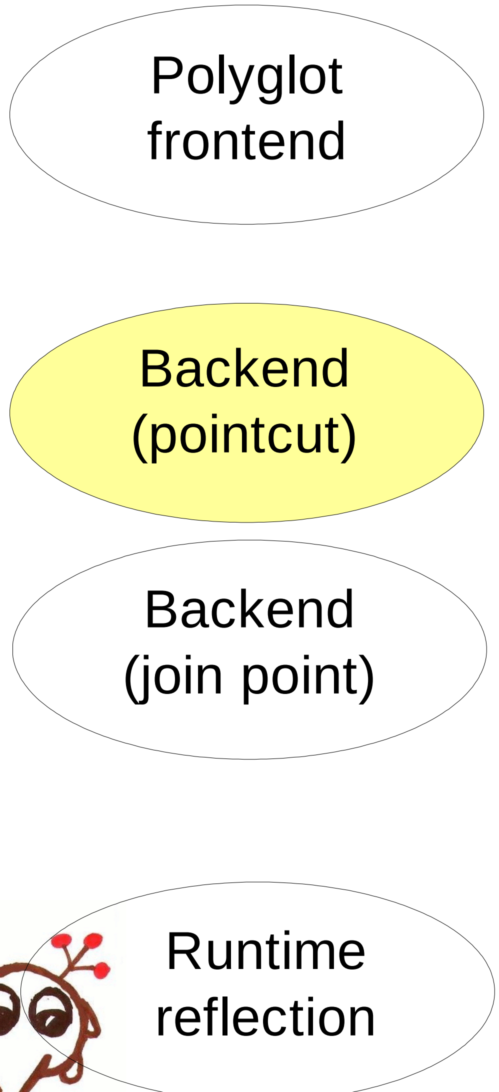
Implementing the Cast Pointcut



- Create a polyglot AST node which stores the *TypePattern*

```
Class PCCast_c extends Pointcut_c
               implements PCCast
{
  protected TypePatternExpr type_pattern;
    .
    .
    .
  public abc.weaving.aspectinfo.Pointcut makeAIPointcut()
  {
    return new
      abc.eaj.weaving.aspectinfo.Cast
         (type_pattern.makeAITypePattern(), position());
  }
}
```

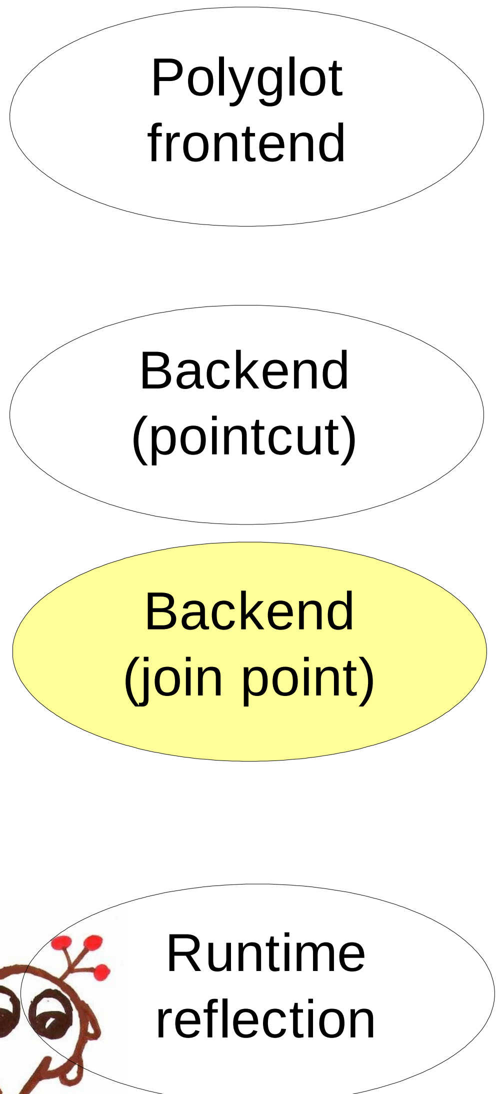
Implementing the Cast Pointcut



- The cast pointcut matches cast join points if they cast a type matching a *TypePattern*

```
class Cast extends ShadowPointcut
{
  private TypePattern type_pattern;
    .
    .
    .
  protected Residue matchesAt(ShadowMatch sm)
  {
    if (! (sm instanceof CastShadowMatch)) return null;
    Type cast_to = ((CastShadowMatch) sm).getCastType();

    if (!getPattern().matchesType(cast_to)) return null;
    return AlwaysMatch.v;
  }
}
```

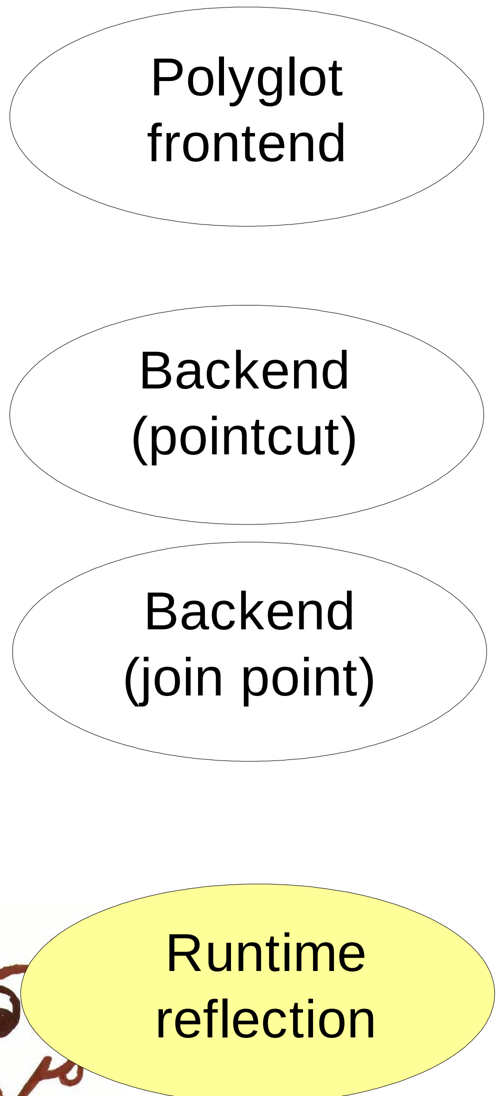
Implementing the Cast Pointcut



- Casts only occur on the right-hand-side of assignments in Jimple

```
class CastShadowMatch extends StmtShadowMatch
{
  private Type cast_to;
    .
    .
  public static CastShadowMatch(MethodPosition pos)
  {
    if (!(pos instanceof StmtMethodPosition)) return null;
    .
    .
    if (!(rhs instanceof CastExpr)) return null;
    Type cast_to = ((CastExpr) rhs).getCastType();

    return new CastShadowMatch(pos.getContainer(),
                               stmt, cast_to);
  }
}
```

Implementing the Cast Pointcut



- *CastSignature,* in the runtime library, allows the retrieval of the type of a cast at runtime
- The information needed by the runtime is encoded by the compiler in the same way that ajc does

Future extensibility

- AspectJ
  - When making compiler extensions you often want to change a class in the compiler source.
  - If you do, this leads to maintenance problems.
  - If you don't, you may have to subclass whole class hierarchies.
  - A possible solution is to use Intertype declarations.

abc summary

- where we are and where we're going -

abc and abcTests.xml

abcTests.xml includes
all of ajcTests.xml, plus
new tests

running abc on abcTests.xml:

865	passed
19	failed (9 from ajcTests.xml)
103	skipped

reasons for failure:

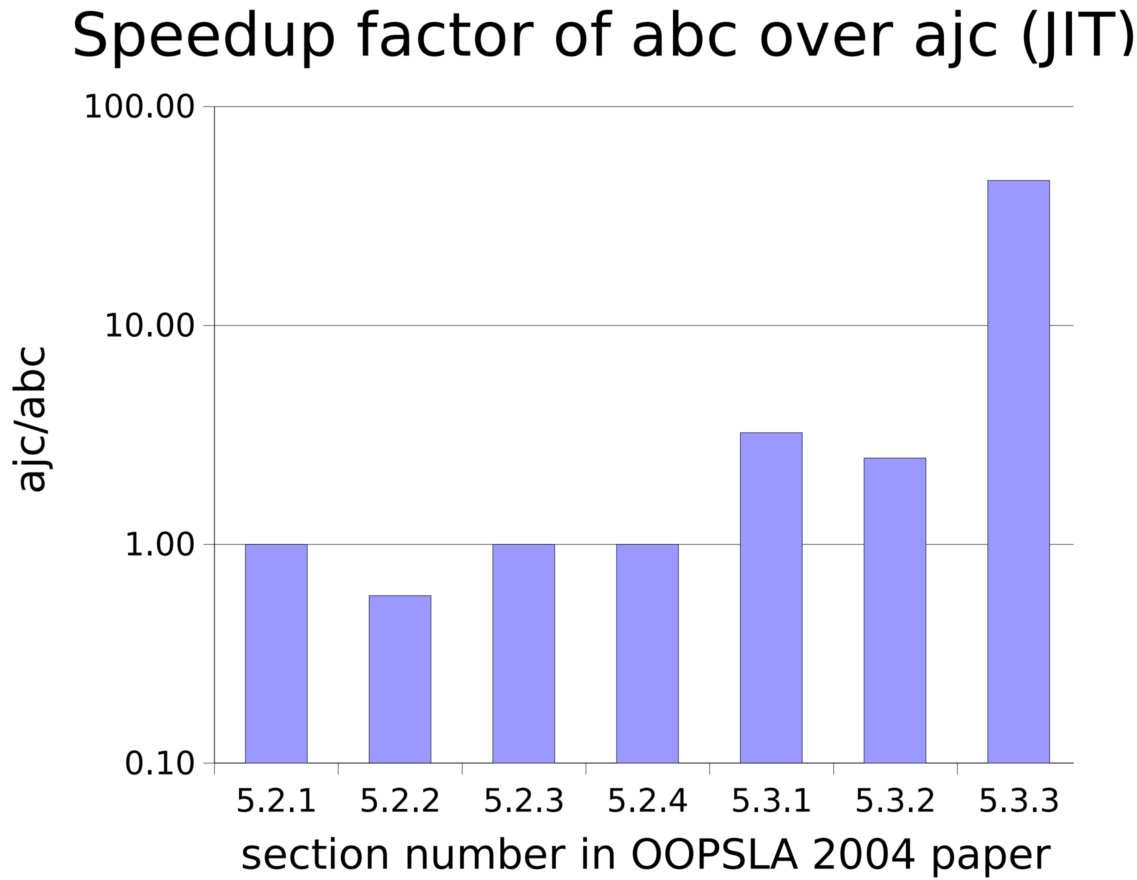
9	abc bugs
6	polyglot bugs
1	javaToJimple/soot bug
3	queries for ajc

reasons for skip:

18	no incremental compilation for aspects & aspect-aware classes
34	options
9	not compiled by javac
2	package dir mismatch
34	“known limitation” of ajc
6	scanner

skipped options: incremental, usejavac, strict, X0codesize, extdirs
skip compile attribute: aspectpath

Initial performance experiments



5.2.2 discrepancy due to architecture-specific JIT optimisations

Development plans

eliminate bugs

improve compilation speed

Java 1.5 support

*J tagger for performance measurement

Dava support for decompiling AspectJ to Java

visualisation in Eclipse

Future optimisations & analyses

- Further around optimisations:
  - smart cycle breaking, inliner
- Interprocedural analysis for eliminating cflow overheads
- Test for pure aspects
- Slicer for AspectJ

Future language extensions

- Semantic pointcuts:
  - predicted cflow
  - dataflow pointcuts
  - tracecuts
- Feature composition
  - CCC/Plainway ideas integrated with AspectJ