The Soot framework for Java program analysis: a retrospective

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Soot

a compiler framework for Java (bytecode), enabling development of static analysis tools.
Map of Reported Soot Users
Outline

- About Soot
- About Soot’s development
Soot Workflow

- Java source
- Scala source
- Java source
- messages
- Error
- Graphs
- HTML
- Soot
- Eclipse
- javac
- scalac
- JastAdd parser
- Produce Jimple 3-address IR
- Analyze, Optimize and Tag
- Generate Bytecode
- Optimized/transformed class files + attributes
- Java Virtual Machine
- TamiFlex output

class files
The preprocessor e.g. converts field reads into method calls.
The preprocessor e.g. converts field reads into method calls.
More Selected Soot Applications

- Analysis of Concurrent Programs
- Symbolic Execution
- Combined Static and Dynamic Analysis Approaches (static part, plus instrumentation for dynamic analysis)
Part I

About Soot
We start by describing Soot’s features, namely:

- intraprocedural features;
- interprocedural features; and
- getting results out of Soot.
Intraprocedural Features

- Provides three-address code.
- Supports implementing dataflow analyses.
public int foo(java.lang.String) {

    // [local defs]
    r0 := @this; // IdentityStmt
    r1 := @parameter0;

    if r1 != null goto label0; // IfStmt

    $i0 = r1.length(); // AssignStmt
    r1.toUpperCase(); // InvokeStmt
    return $i0; // ReturnStmt

    label0:
        return 2;
}
Connecting with Java source

Each Jimple statement

```java
if r1 != null goto label0; // IfStmt
```

belongs to:
- a SootMethod, e.g. `foo(String)`, and
- a SootClass, e.g. `Foo`,
reflecting the structure of the original source code.

You can also get:
- line number information (if available), e.g. “`Foo.java:72`”.
- original variable names (on a best-effort basis).
Dataflow Analysis Example: “Live Locals”

Question:

At a given program point \( p \), which locals \( v \) will be accessed in the future?

```java
void foo(boolean b) {
    int x = 5, y = 2;

    System.out.println(x);
    if (b) {
        x = bar(y*2);
    } else {
        foo(false);
    }
    System.out.println(x);
}
```
Dataflow Analysis Example: “Live Locals”

Question:

At a given program point \( p \), which locals \( v \) will be accessed in the future?

```java
void foo(boolean b) {
    int x = 5, y = 2;  // {x, y, b}
    System.out.println(x);  // {x, y, b}
    if (b) {
        x = bar(y*2);  // {x}
    } else {
        foo(false);  // {x}
    }
    System.out.println(x);  // {}
}
```
Dataflow Analysis Example: “Live Locals”

Soot’s Eclipse plugin helps you debug your flow analysis.
Interprocedural Features

- Call graph/pointer information
- (Side effect analysis)
- (Reflection)
Why Call Graphs?

Sophisticated static analyses need to answer questions like:

```java
class A {
    bar() {
        /* */
    }
}

class B extends A {
    bar() {
        /* */
    }
}

foo() {
    A o = ...;
    o.bar();
}

"Which methods might o.bar() reach?"
Spark (part of Soot) computes call graph edges, which contain:

- Source method
- Source statement (if applicable)
- Target method
- Kind of edge

<table>
<thead>
<tr>
<th>source m.</th>
<th>source stmt.</th>
<th>target m.</th>
<th>kind</th>
</tr>
</thead>
<tbody>
<tr>
<td>•</td>
<td>•</td>
<td>•</td>
<td>VIRTUAL</td>
</tr>
</tbody>
</table>

```
foo() {
    o.bar();
}
```

```
bar() {
    /* */
}
```
Points-to Analysis

A closely related question:

Could $x$ and $y$ be aliases in:

\[
x.f = 5;
y.f = 6;
z = x.f;
\]

Spark can answer this question with a call to hasNonEmptyIntersection() on points-to sets.
There are many ways to get results out of Soot:

- *abc*: reads Java and AspectJ source, produces Java bytecode.
- *model checking*: generate summaries (in Java bytecode plus modelling primitives) of system environment behaviour.
- *tracematch/race condition detection*: generate error messages or warnings.
- *side-effect information*: generate attributes encoding the information along with the Java bytecode.
Running unaltered versions of Soot

Use Soot as a:
- disassembler to three-address code;
- bytecode optimizer; or
- visualizer for CFGs and analysis results, in Eclipse.
**Extending Soot**

You can write a compiler pass extending Soot, as either a
- **BodyTransformer**, for a intraprocedural analysis; or
- **SceneTransformer**, for a whole-program analysis.

You choose where this pass should run by putting it in a **Pack**.

Use **Maps** or attributes to share analysis results.

We explicitly disallow subclassing of IR statements, based on past experience. (Mixins would be OK).

To run extended Soot, you create a custom main class which calls **soot.Main.main()**.
Part II

About Soot’s Development
Initial release in 1999–2000; Soot 1.0.0 was an intraprocedural Java bytecode analysis framework.
Soot Evolution

Stepwise evolution of key features:

1. Local variable type inference, initially by Gagnon et al; later by Bellamy et al.

2. Call graph information, initially Variable Type Analysis by Sundaresan et al; subsumed by Spark.
Support and Community

- Main agora: Soot mailing list, about 30 messages/month.
- Soot Bugzilla contains some bugs.
- Soot Wiki is good for recording certain types of information.
- Publicly readable Subversion repository; we’d welcome external committers.
Soot is licensed under GNU Lesser General Public License. We recommend choosing a license that works for you.

- McLab (compiler framework for MATLAB) will be released under the Apache 2.0 license.
Documentation

Documentation is critical to framework success.

- API carefully designed.
- Some Javadoc documentation.
- Soot tutorials.
- Soot Survivor’s Guide by Einarsson and Nielsen.
- Plus: Helpful error messages.
Future Improvements for Soot

Some future directions where we’d like to see Soot improvements:

- faster startup and computation time;
- structured interprocedural analysis support;
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Some future directions where we’d like to see Soot improvements:

- faster startup and computation time;
- structured interprocedural analysis support;
Soot does what we expected it to do.
  • a surprise: unsound and incomplete analyses.

Challenges:
  • keeping up with external changes (e.g. in the Java specification);
  • incorporating external extensions into Soot.
Useful Features for Compiler Frameworks

While Soot doesn’t have these features, they are indispensible for compiler frameworks.

- some way of avoiding redundant re-computations, e.g. incremental computation;
- quasiquoting, for easily generating code from templates.
Reflections on Compiler Frameworks

Our suggestions for compiler frameworks and the community:

- make it easy to independently release extensions (non-monolithic structure, like CPAN);
- the community must value software and data releases;
- we need more venues for framework papers.
Reasons for Success

Soot:
- provided the right features at the right time;
- was easy enough to use (availability, license, community).

Key features:
- Jimple intermediate representation;
- Spark pointer analysis toolkit.
Thanks!

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- IBM’s Centre for Advanced Studies, and an Eclipse Innovation Grant.

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**External contributors**

- Ben Bellamy at Oxford (type assigner);
- Torbjörn Ekman at Oxford (Java 5 parser);
- Manu Sridharan, while at Berkeley (demand-driven pointer analysis).
Over the years, we and others have improved Soot:

- a single singleton;
- dealing with partial programs;
- better front-end parsers;
- demand-driven efficiency improvements.
List of Soot Users

- McGill University, 3605, rue de la Montagne, Montreal, QC H3G 2M1, Canada
- Rutgers University, United States
- University of Washington, United States
- University of Alberta, Canada
- Georgia Tech, Atlanta, GA, USA
- Portland State University, Portland, OR 97201, USA
- Imperial College London, United Kingdom
- Rensselaer Polytechnic Institute, Troy, NY 12180, USA
- The Ohio State University Airport, United States
- Allegheny College, 520 N Main St, Meadville, PA 16335, USA
- University of Alabama, United States
- University of Warwick, CV8, UK
- Dortmund University of Technology, August-Schmidt-Straße 4, 44227 Dortmund, Germany
- Kansas State University, Manhattan, KS 66502, USA
- Drexel University, Philadelphia, PA 19104, USA
- Brigham Young University, 350 Clyde Bldg N, Provo, UT 84602, USA
- University of Buenos Aires - Buenos Aires, Capital Federal, Argentina
- University of Waterloo, Canada
- UC Berkeley, Oakland, CA, USA
- University of Maryland
- Hawthorne, NY, USA
- University of Aarhus, Birk Centerpark 15, 7400 Herning, Denmark
- imec Ieper, Ter Waarde 44, 8900 Ypres, Belgium
- MIT, Cambridge, MA, USA
List of Soot Users II

- University of Pittsburgh, Pittsburgh, PA, USA
- Strathclyde University, University of Strathclyde, Glasgow, Glasgow City G4 0, UK
- Uppsala, Sweden
- University of California Davis, United States
- Rocquencourt, France
- Cornell University, Ithaca, NY, USA
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- University of Delaware, Lewes, DE 19958, USA
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- Tel Aviv University, Tel Aviv, Israel
- Haifa, Israel
- University of Alabama, United States
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