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
Selected Soot Applications

- Compile-time deallocation (Cherem and Rugina)
- Elimination of array bounds checks (many, including Qian, Hendren and Verbrugge)
- Test adequacy for DB-driven applications (Kapfhammer and Soffa)
Outline

- About Soot
- About Soot’s development
Part I

About Soot
Soot Workflow

- **Java source**
  - javac

- **Scala source**
  - scalac

- **Java source**

- **Eclipse**
  - class files

- **Soot**
  - JastAdd parser
  - Produce Jimple 3-address IR
  - Analyze, Optimize and Tag
  - Generate Bytecode

- **TamiFlex**
  - output

- **Java Virtual Machine**
  - Optimized/transformed class files + attributes
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

```
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).
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() {
        /* */
    }
}
```

"Which methods might `o.bar()` reach?"
Call Graphs in Soot

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>

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

```java
bar()
{
    /* */
}
```
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.
Running unaltered versions of Soot

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

Initial release in 1999–2000; Soot 1.0.0 was an intraprocedural Java bytecode analysis framework.
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.
- Soot Survivor’s Guide by Einarsson and Nielsen.
- Plus: Helpful error messages.
Some future directions where we’d like to see Soot improvements:

- faster startup and computation time;
- structured interprocedural analysis support;
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- 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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Chris Goard  Nomair Naeem  Raja Vallée-Rai
Richard Halpert  Matthias Perner  Clark Verbrugge
Dev Process & Community

Reflections & Conclusions
External contributors

- Ben Bellamy at Oxford (type assigner);
- Torbjörn Ekman at Oxford (Java 5 parser);
- Manu Sridharan, while at Berkeley (demand-driven pointer analysis).
Notable Changes in Soot

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
- Paris, France
- University of Delaware, Lewes, DE 19958, USA
- Radboud University, Comeniuslaan 4, 6525 HP Nijmegen, The Netherlands
- University of Geneva, Rue du Général- Dufour 24, 1211 Genève 4, Switzerland
- University Medical Center Utrecht, 3584 CX Utrecht, The Netherlands
- Victoria University of Wellington, Rutherford House Level 5/23 Lambton Quay, Pipitea 6011, New Zealand
- Tel Aviv University, Tel Aviv, Israel
- Haifa, Israel
- University of Alabama, United States
- École Polytechnique, Montreal, QC, Canada
- University of Sannio, UniversitÃ del Sannio di Benevento, Piazza Guarrazzi, 1, 82100 Benevento, Italy
- UC Irvine School of Humanities, University Dr, Irvine, CA 92697, USA
- Vienna University of Technology, Karlsplatz 13, 1040 Vienna, Austria
- University of Hull, Scarborough, North Yorkshire YO11, UK
- EPFL, 1015 Ecublens, Switzerland
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- Syracuse University, Syracuse, NY 13210, USA