Taming Reflection

Aiding Static Analysis in the Presence of Reflection and Custom Class Loaders

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Hela Oueslati and Mira Mezini

CASED

TECHNISCHE UNIVERSITÄT DARMSTADT

"Don't write to closed connections!"

Reflective method calls

```
public class Main {

 public static void main(String[] args) throws Exception {
     Connection c = new Connection();

     Class c = Class.forName( "Evil" );
     Method m = c.getMethod("doEvil", Connection.class);
     m.invoke(null,c);

     c.write("ohoh...");
 }

public class Evil {

 public static void doEvil(Connection c) {
     c.close();
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}
```

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~~hard~~ to analyze statically!

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impossible

~~hard~~ to analyze statically!

Present a pragmatic, partial solution

Important reflective calls

- `Class.forName(String className)`
- `Class.newInstance()`
- `Method.invoke(Object tgt, Object[] args)`
- `Constructor.newInstance(Object[] args)`
- ...

Uses of Reflection

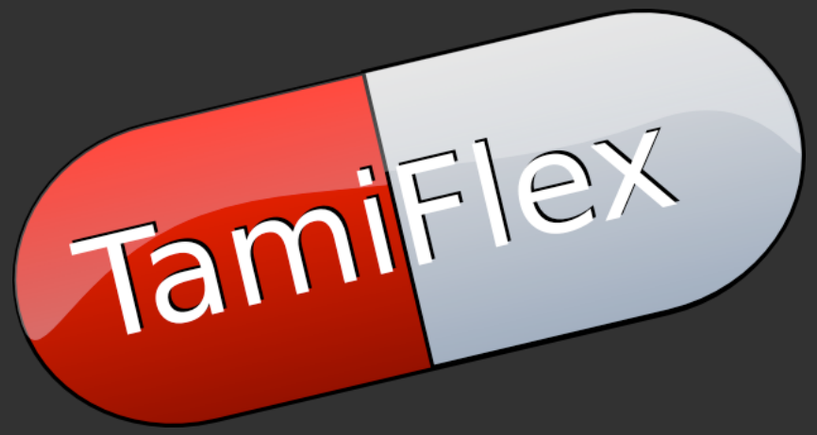
- Extensibility
- Separate Compilation
- Runtime class generation
- "Hacking": call private methods

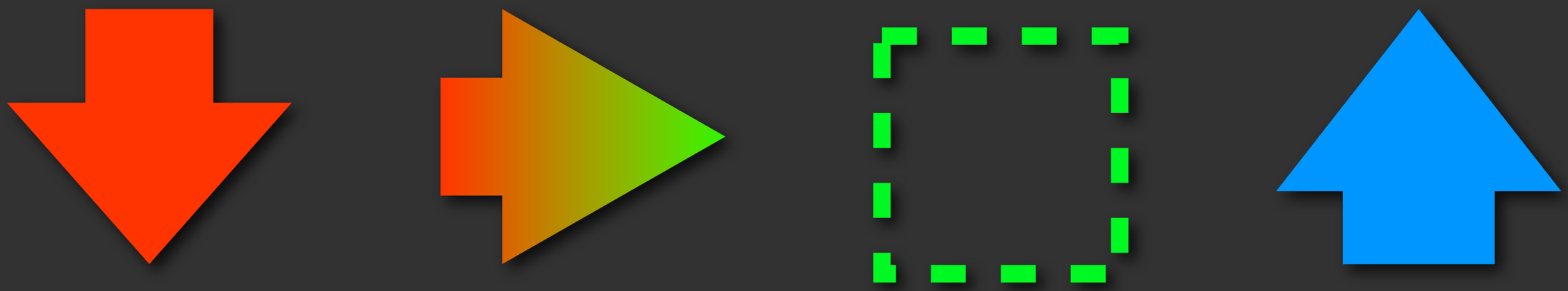
Reflection is...

used a lot

unsound to ignore

often impossible to resolve





Play-Out

Boost

Analyse & Transform

Play-In

Step 1: Play-Out

Play-Out

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 public static void doEvil(Connec
     c.close();
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}
```

```
$ javac Main.java
$ java -javaagent:poa-trunk.jar=out Main

============================================
TamiFlex Play-Out Agent Version trunk
Found 2 new log entries.
Log file written to: out/refl.log
$ cat out/refl.log
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Play-Out

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```

kind of call

Play-Out

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fully resolved target of call

Play-Out

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location of call

Play-Out

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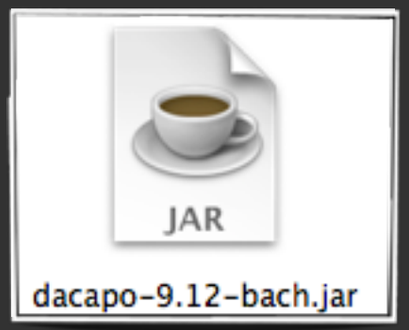
```
$ find out -name \*.class
out/com/apple/java/BackwardsCompatibility.class
out/java/io/BufferedInputStream.class
out/java/io/BufferedOutputStream.class
out/java/io/BufferedReader.class
out/java/io/BufferedWriter.class
out/java/io/ByteArrayInputStream.class
out/java/io/ByteArrayOutputStream.class
out/java/io/Closeable.class
out/java/io/DataInput.class
...
```

Why dump classes?

Why dump classes?

Static analysis needs to know the code

Why dump classes?




```
$ java -jar dacapo-9.12-bach.jar fop
===== DaCapo 9.12 fop starting =====
===== DaCapo 9.12 fop PASSED in 2503 msec =====
```

Static analysis needs to know the code

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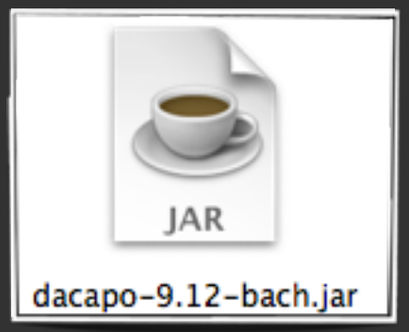


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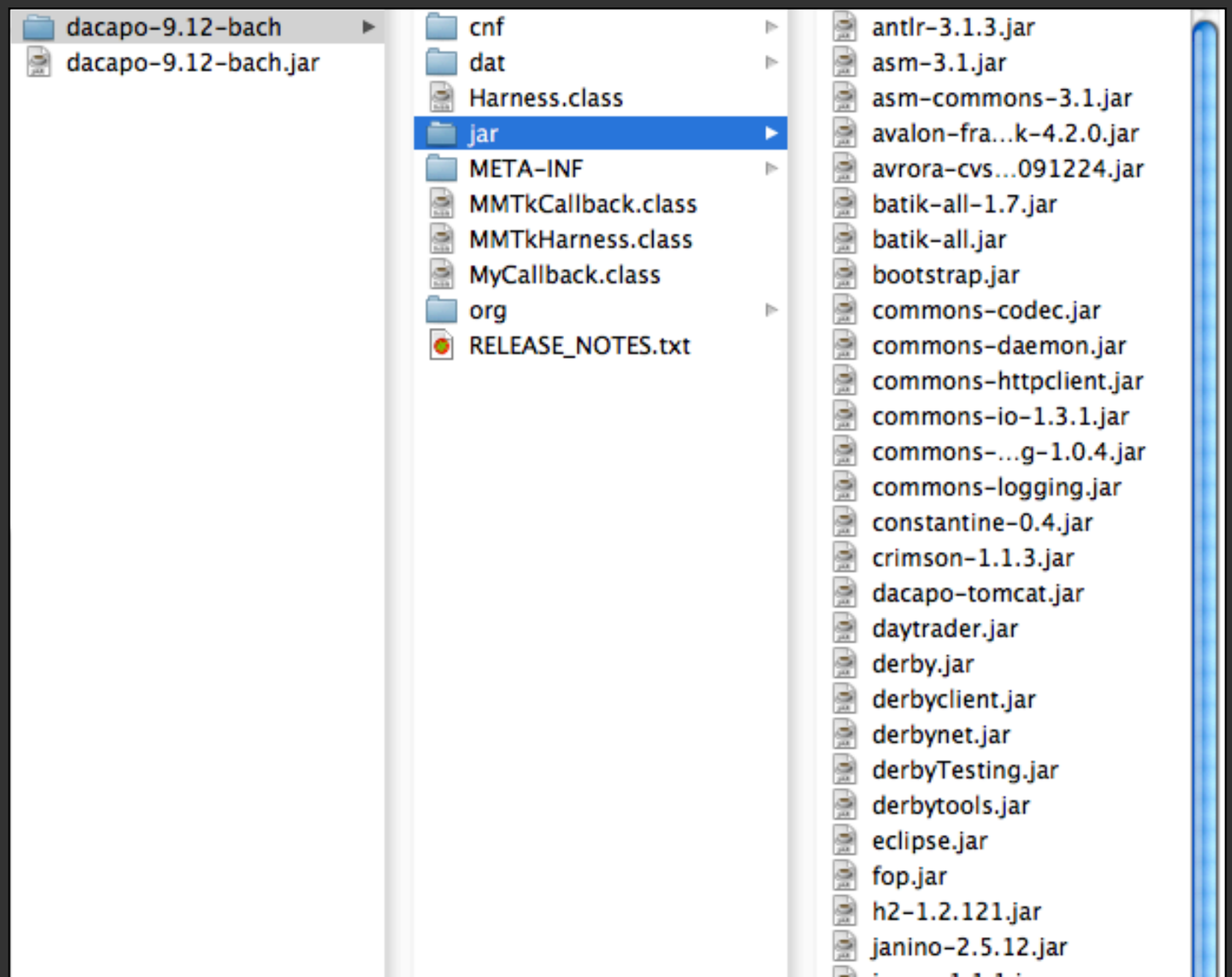
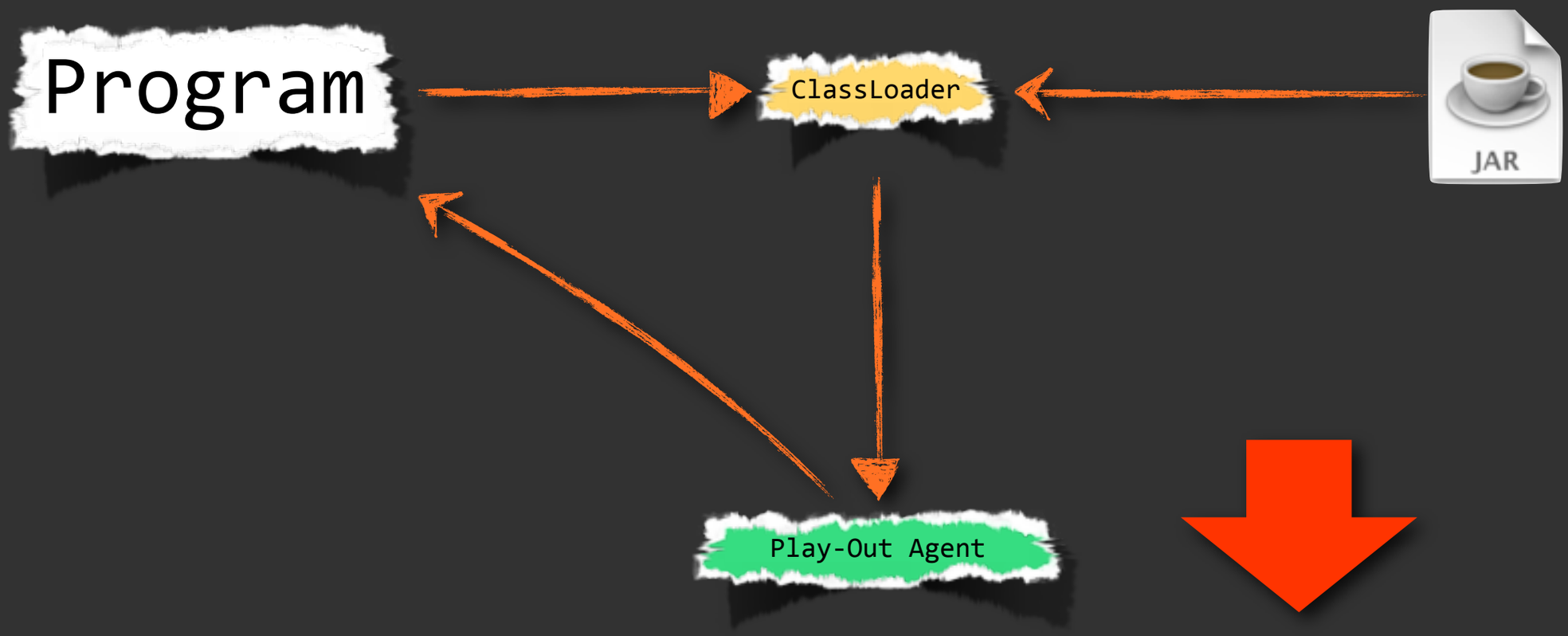
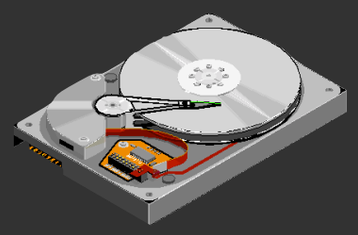


Static analysis needs to know the code

Play-out Agent





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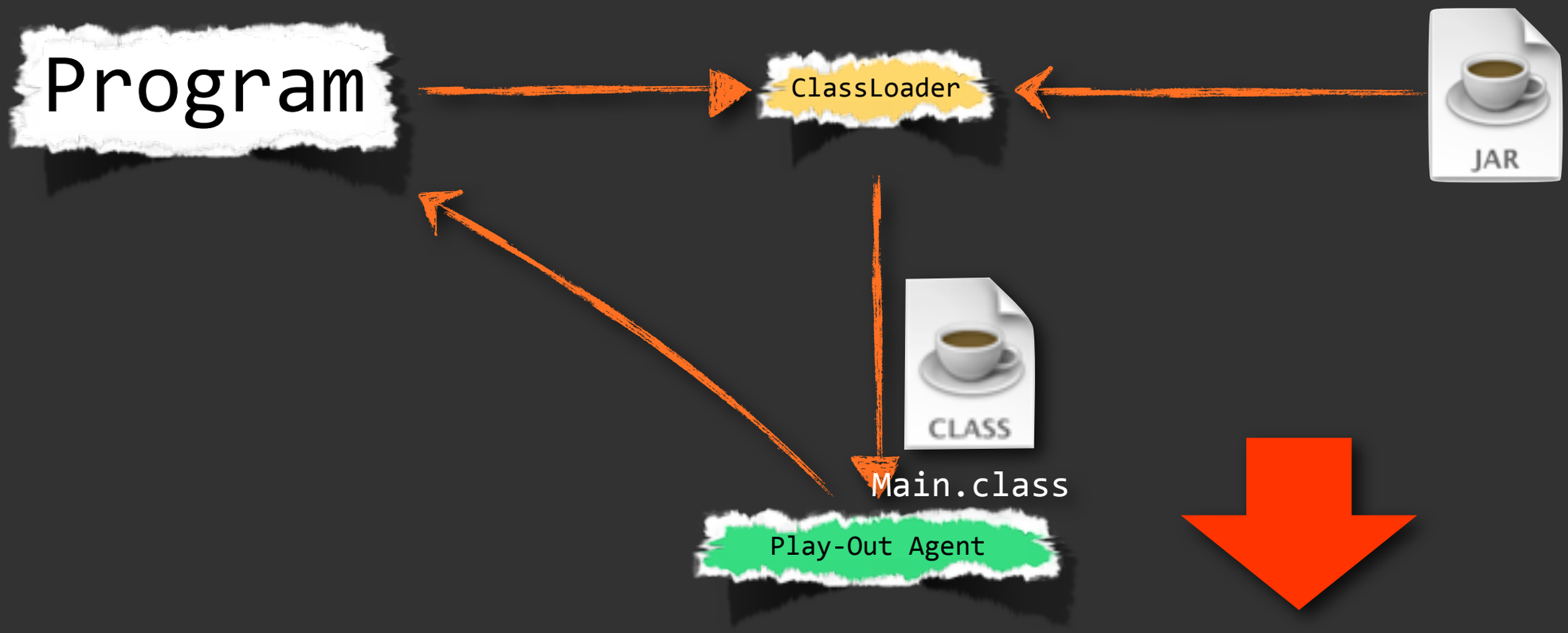
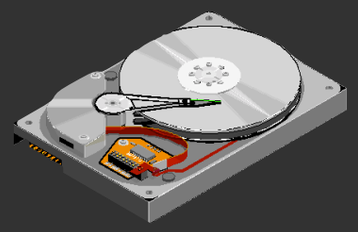
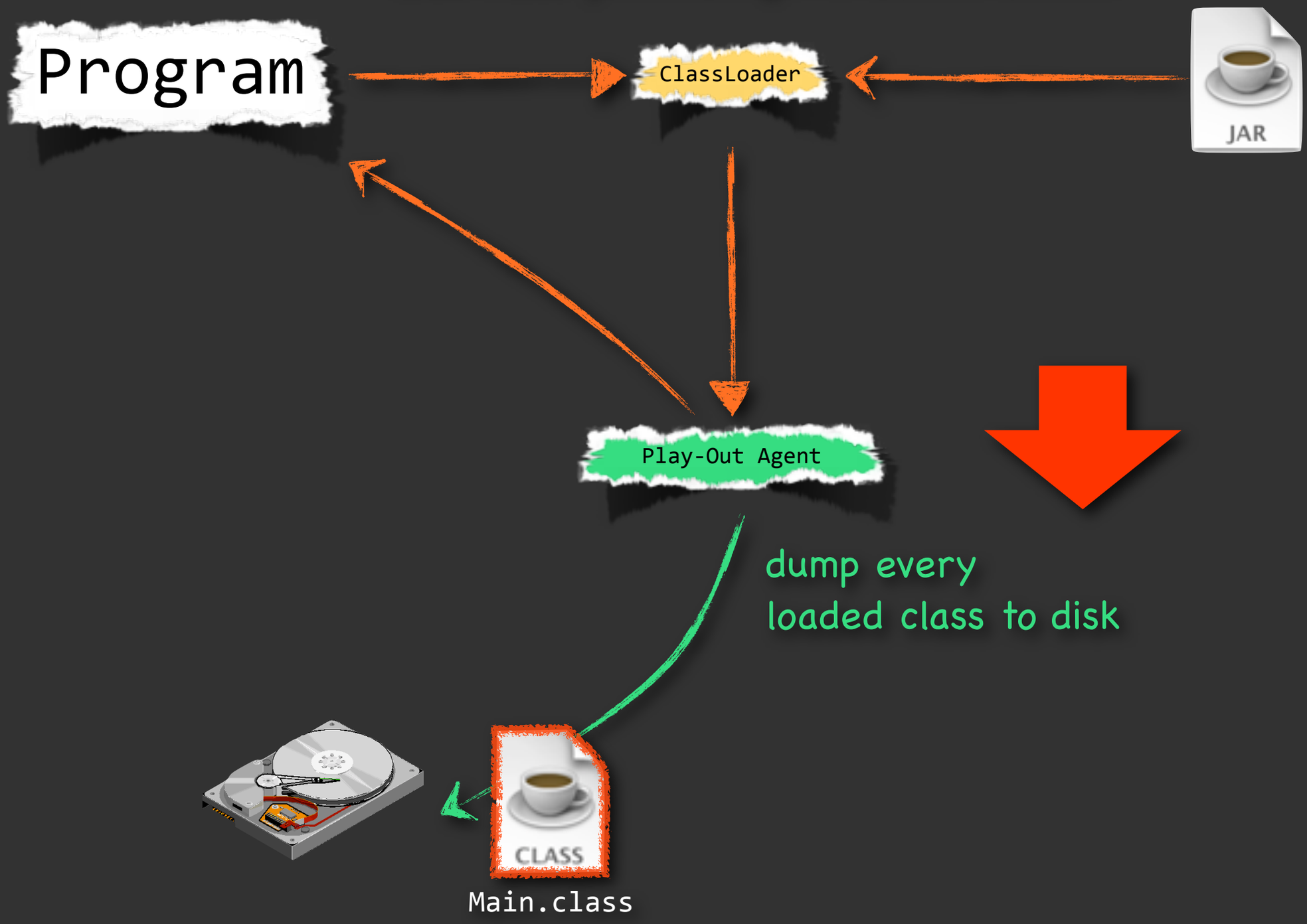




Play-out Agent

load class java.lang.reflect.Method



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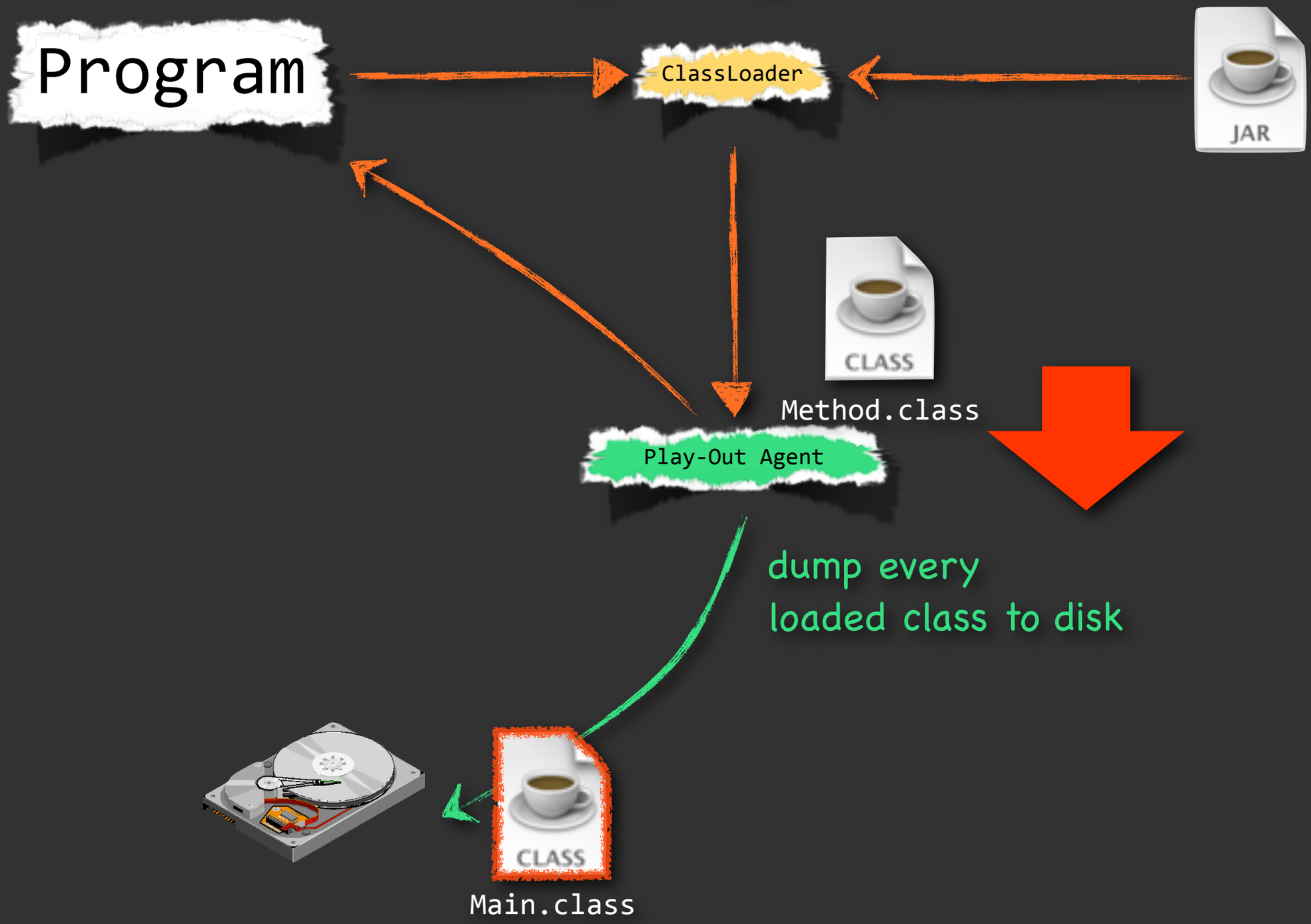

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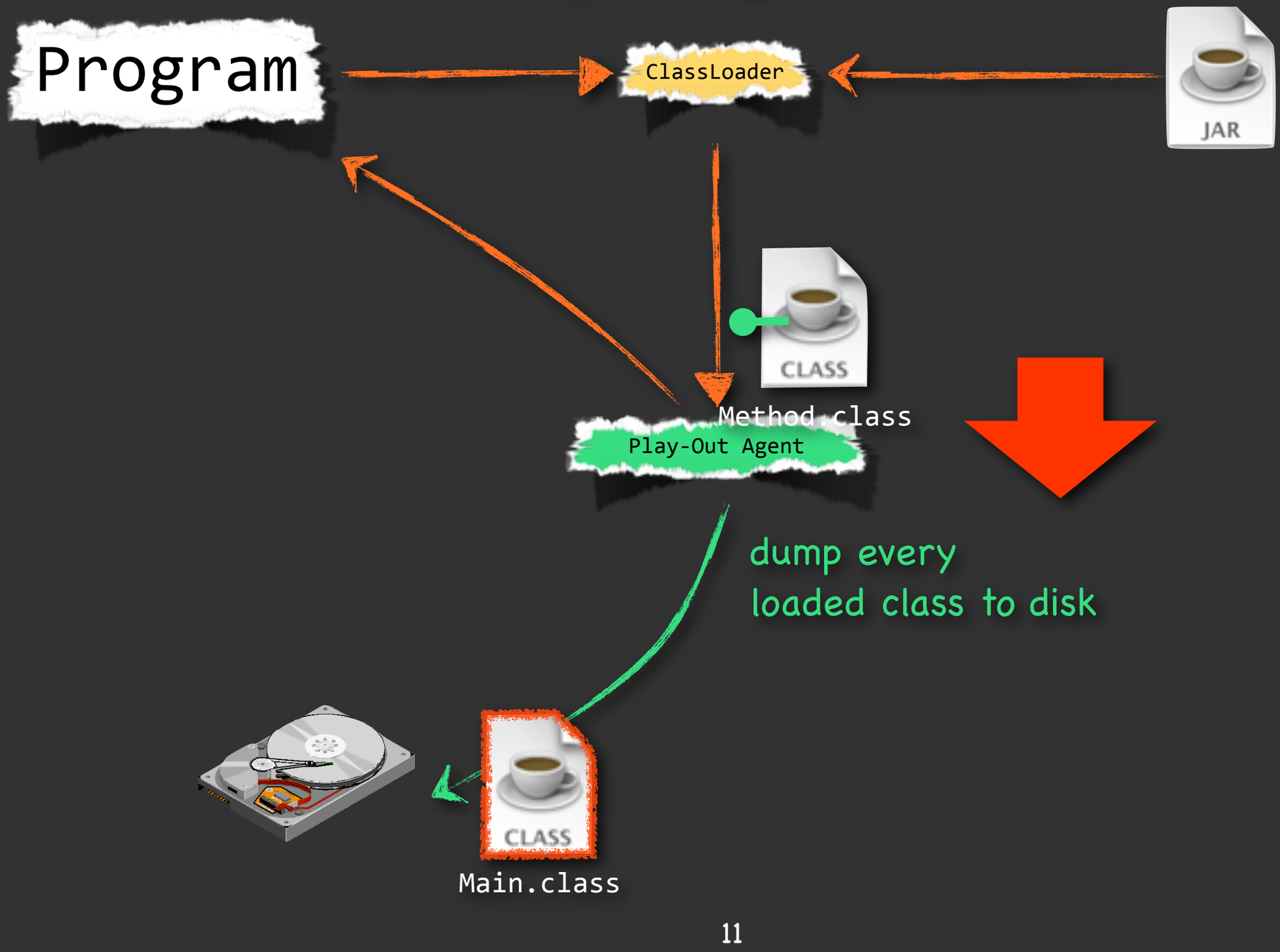

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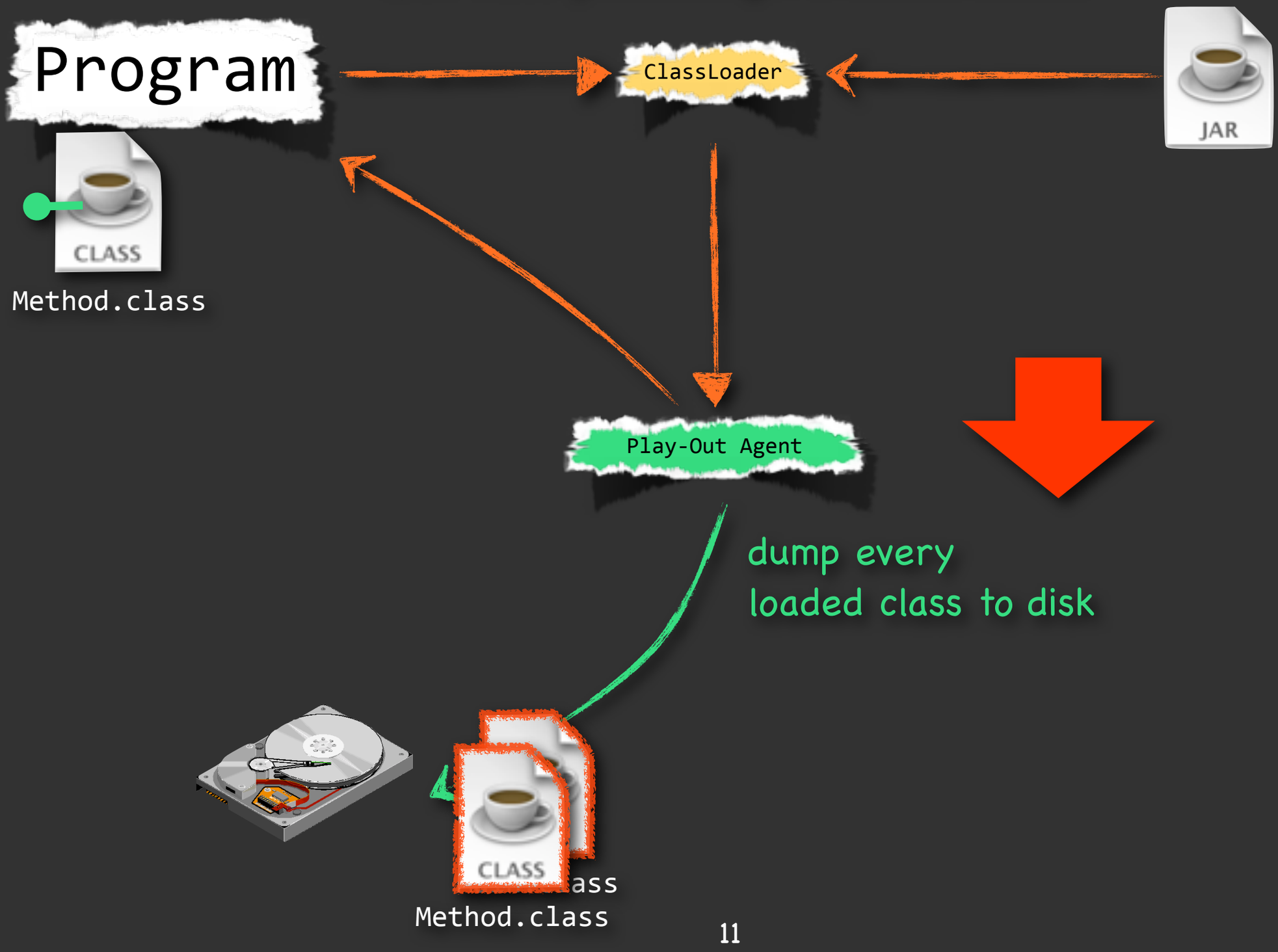

Play-out Agent

load class java.lang.reflect.Method

Program

ClassLoader

JAR

CLASS

Method.class

call to
Method.invoke

Play-Out Agent

dump every
loaded class to disk

CLASS

ass

Method.class

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write entry
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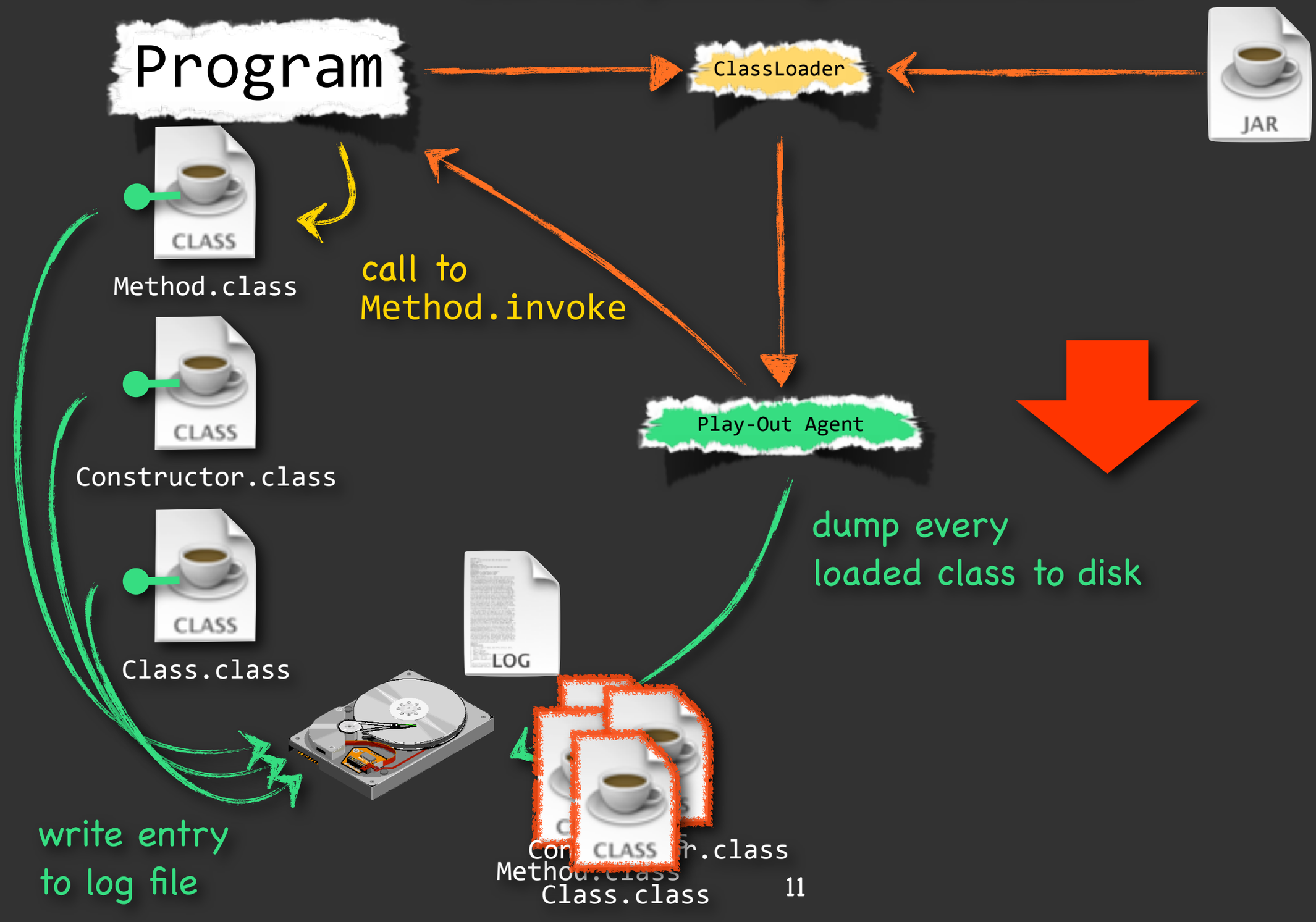
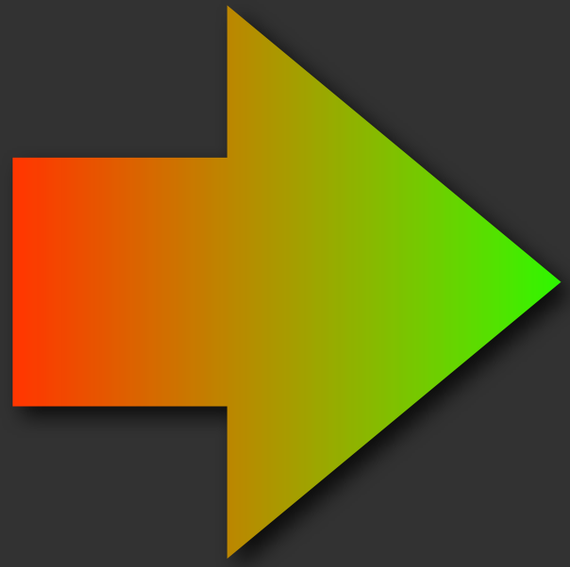


Step 2: Boosting



Booster transforms program into statically analyzable version

```
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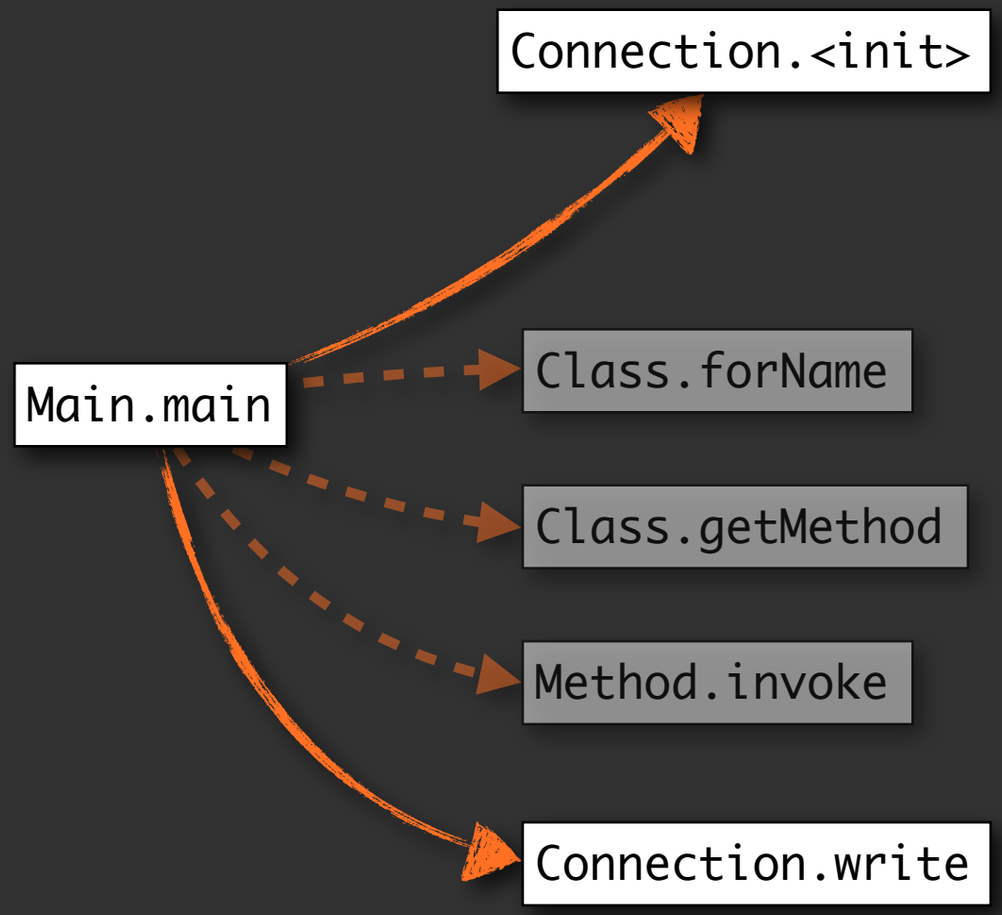

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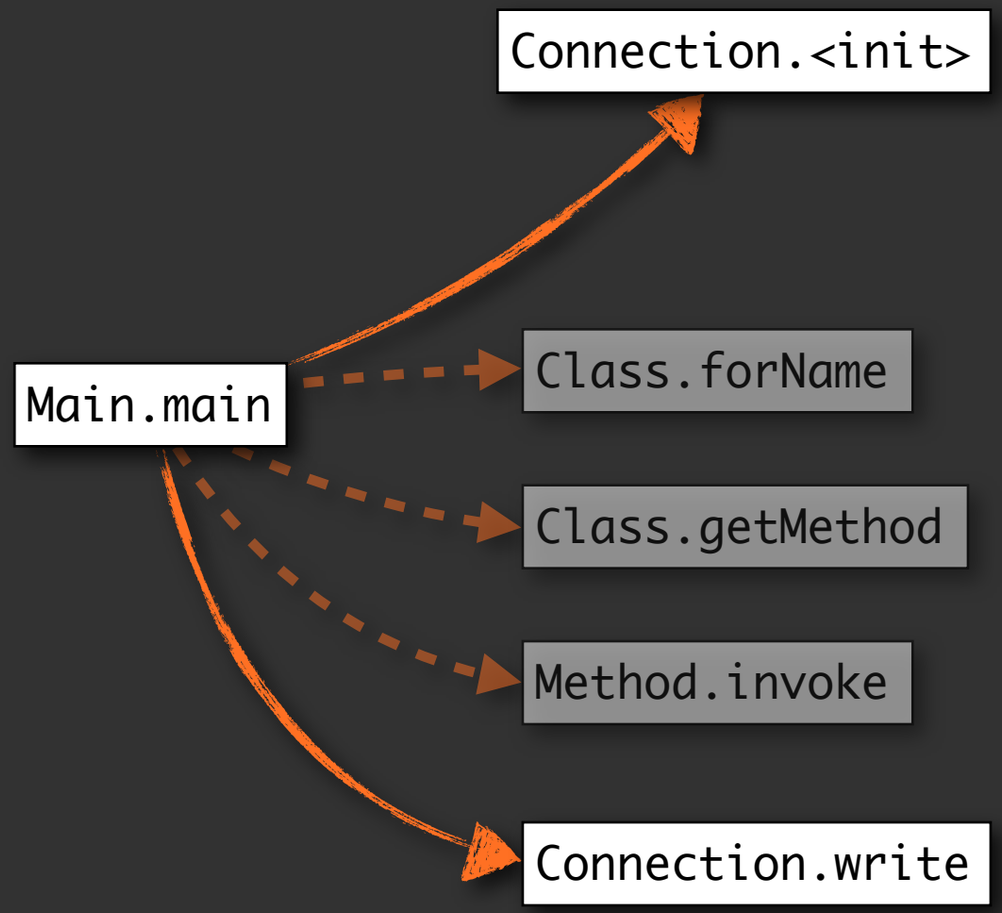


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public class Main {

   public static void main(String[] args) throws Exception {
      Connection c = new Connection();

      Class cl;
      if(args[0].equals("Evil"))
          cl = Evil.class;
      else {
          TamiFlexRT.warnClassForName(args[0]);
          cl = Class.forName(args[0]);
      }

      Method m = cl.getMethod("do"+"Evil", Connection.class);

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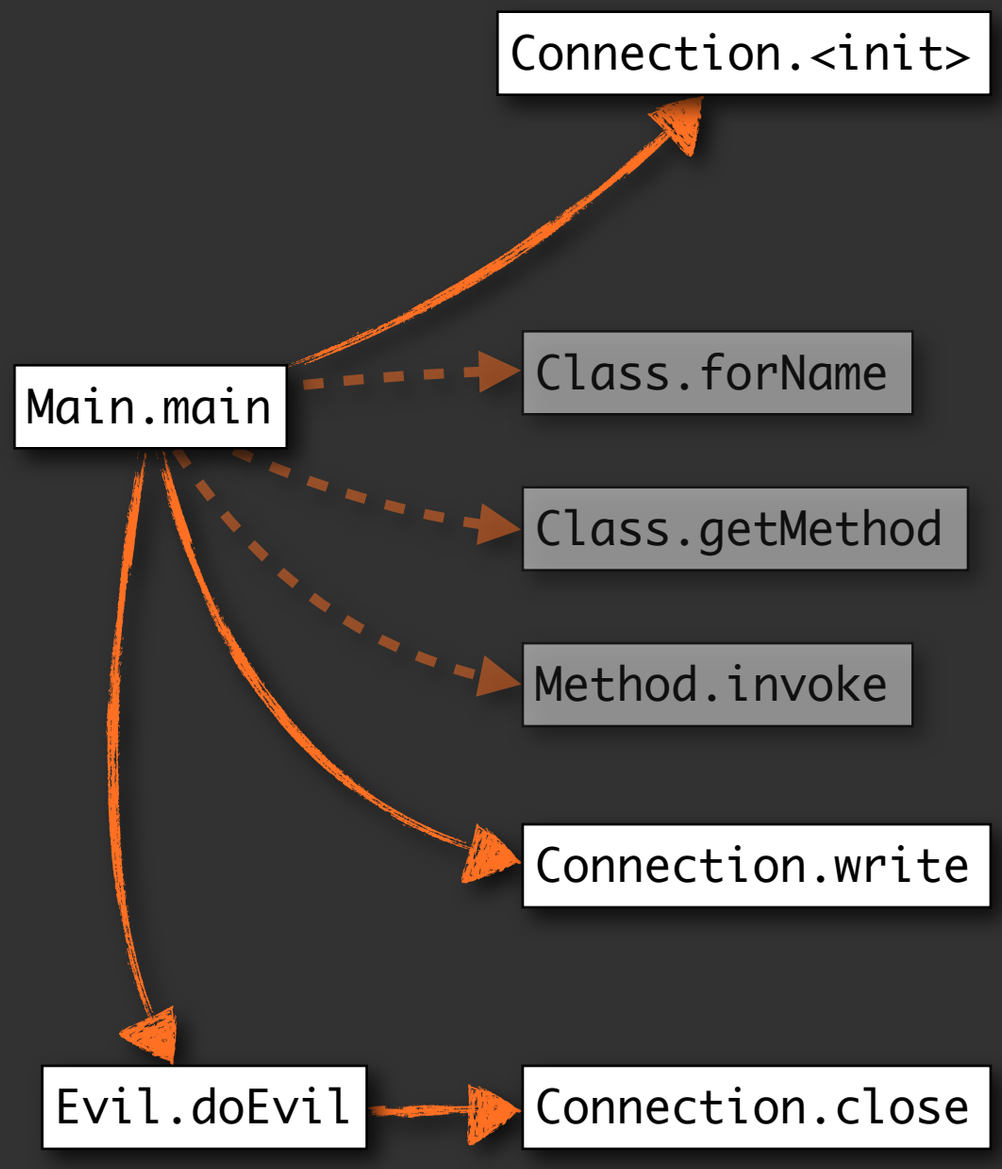

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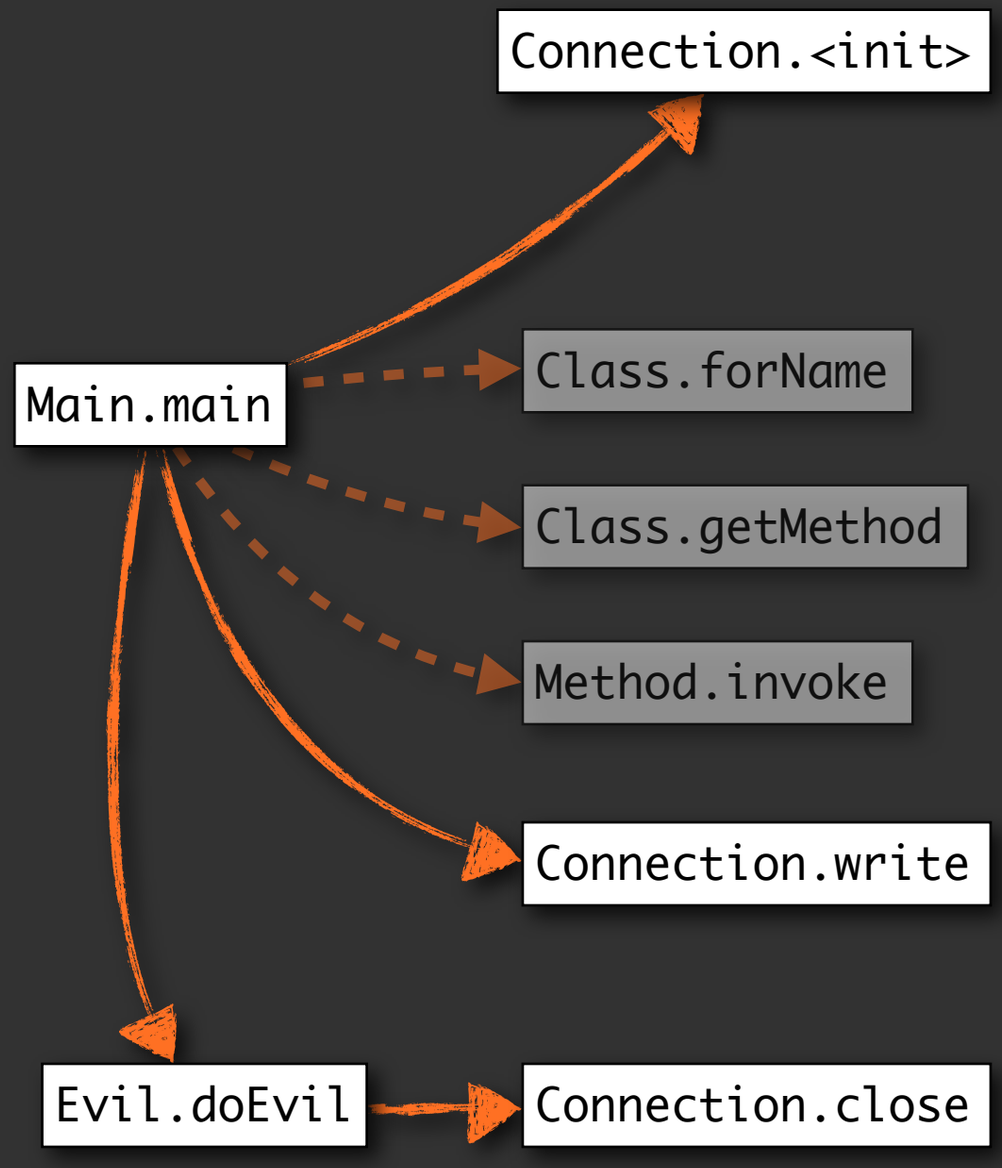
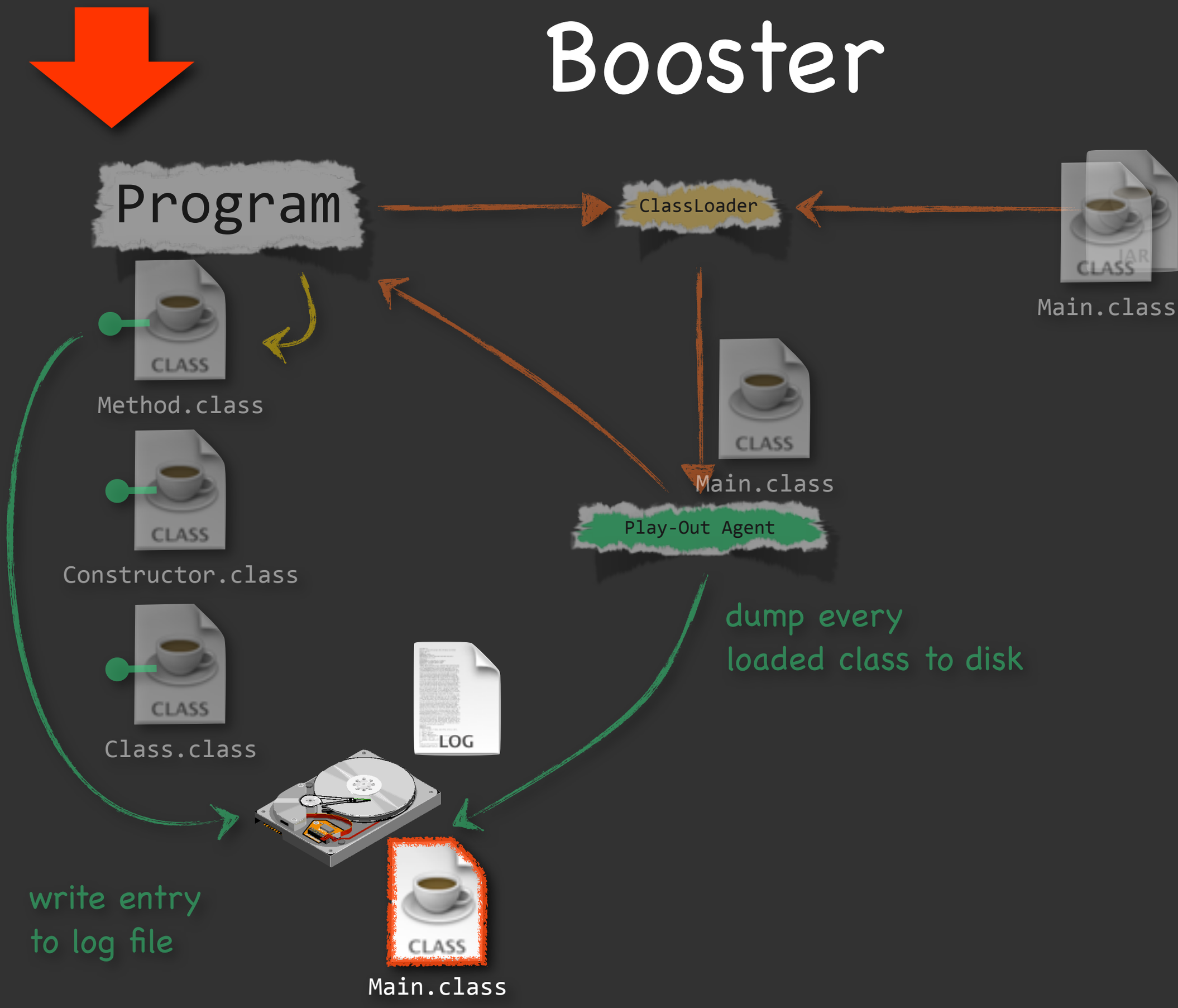


Booster

- Implemented on top of Soot
- Operates on 3-address code (Jimple) generated from bytecode
- Input: class files recorded by play-out agent
- Emits class files of "boosted" program
- Some nitty-gritty details with respect to the use of non-standard class loaders (see paper)

Booster


Program
ClassLoader
CLASS
JAR
Main.class
CLASS
Method.class
CLASS
Main.class
Play-Out Agent
CLASS
Constructor.class
CLASS
Class.class
LOG
dump every
loaded class to disk
write entry
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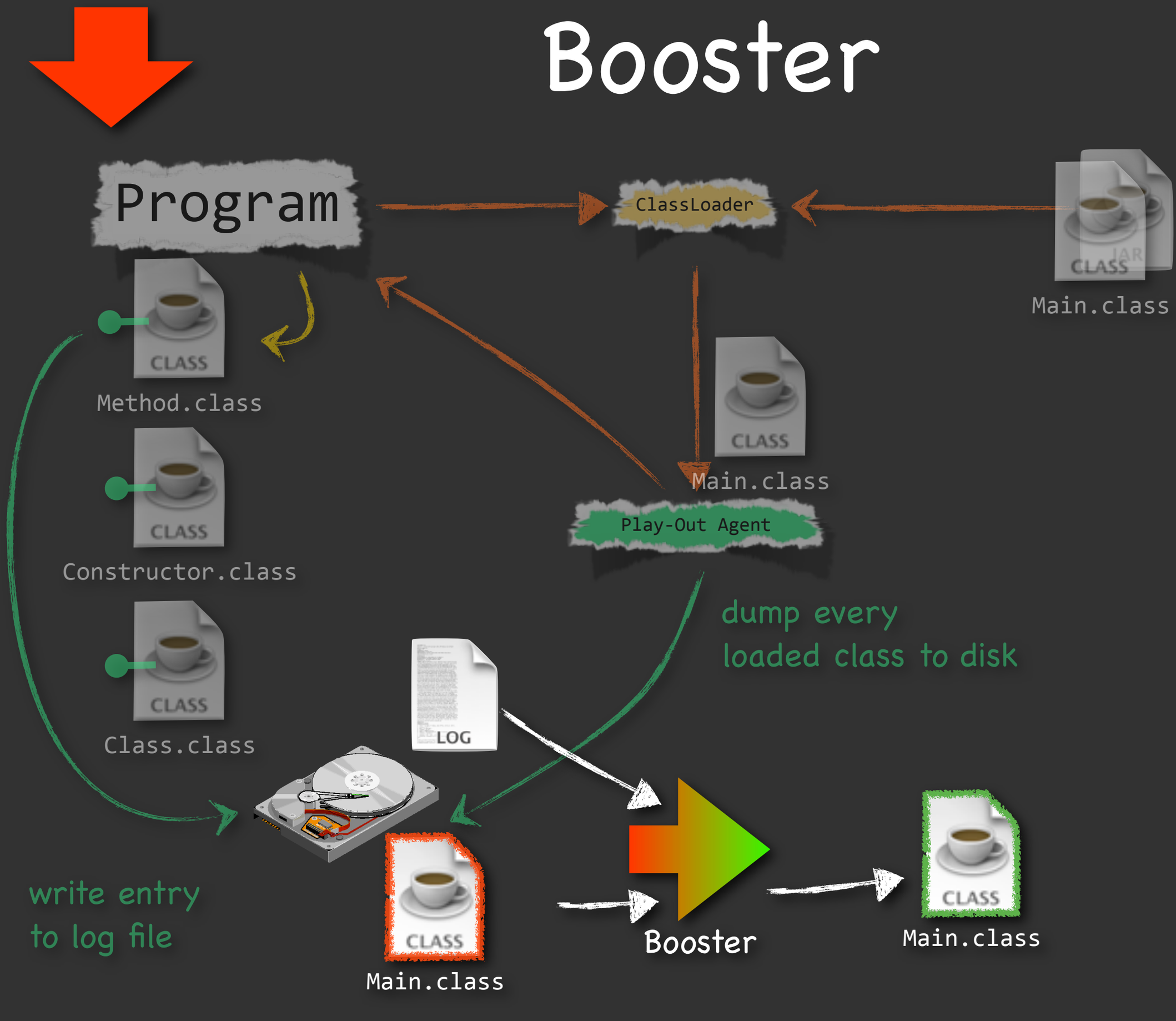
CLASS
Main.class

Booster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Booster

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Static Analysis

Booster

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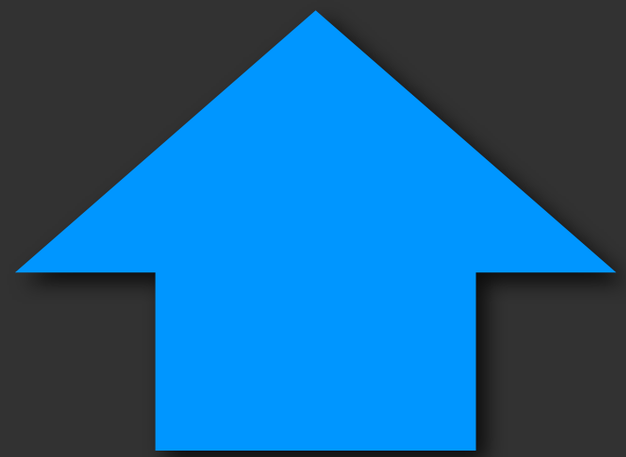
Static Analysis



Step 3: Play-In

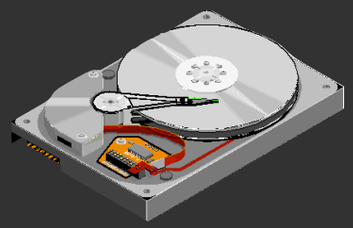
Play-in Agent

load from somewhere, or generate

load class Main

Program

Custom ClassLoader



Main.class

Play-In Agent

Play-in Agent

load from somewhere, or generate

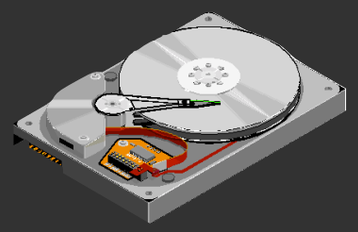
load class Main

Program

Custom ClassLoader

JAR

Play-In Agent



CLASS

Main.class

Play-in Agent

load from somewhere, or generate

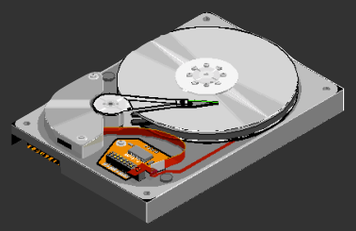
load class Main

Program

Custom ClassLoader

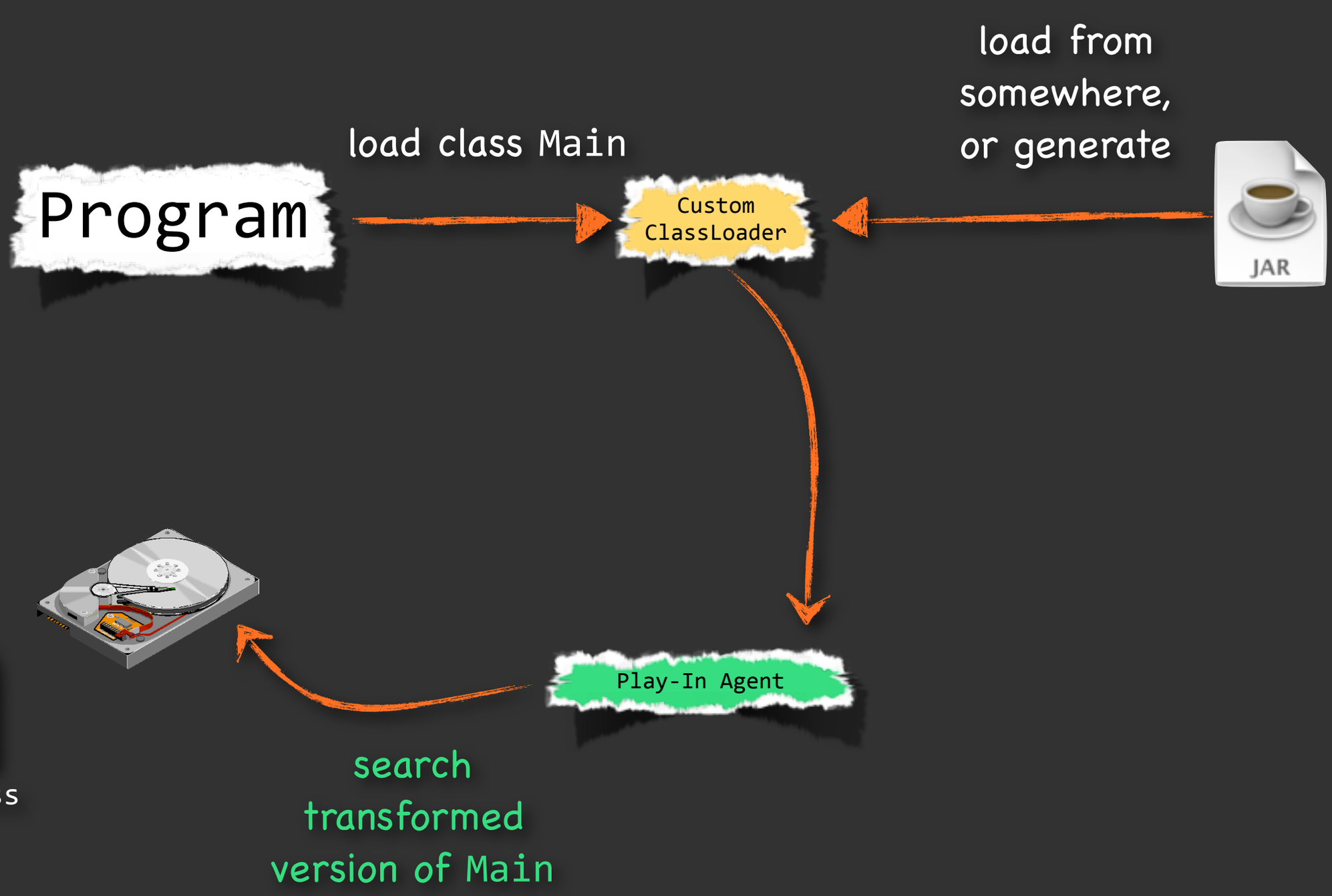
Main.class

Play-In Agent



Main.class

Play-in Agent



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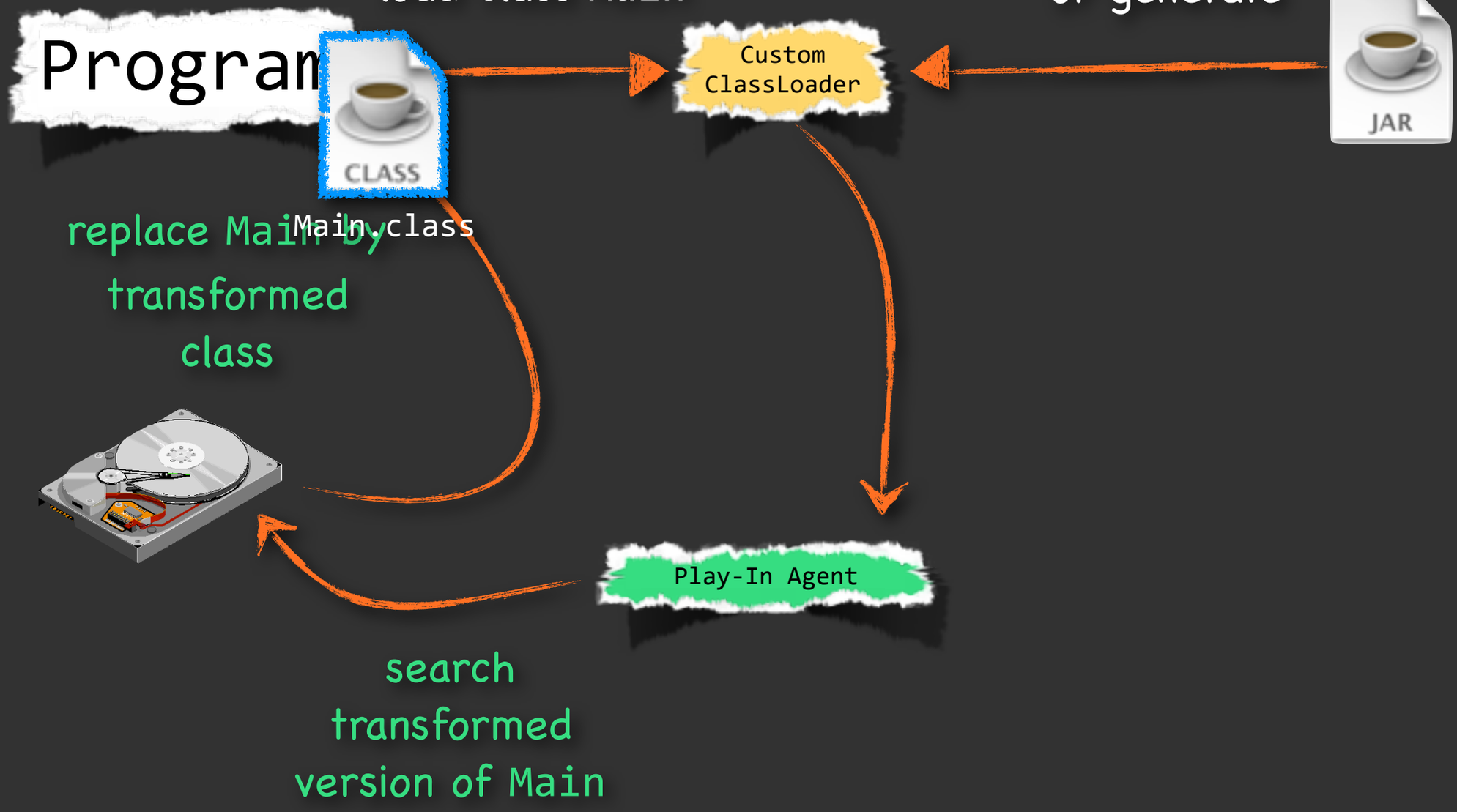
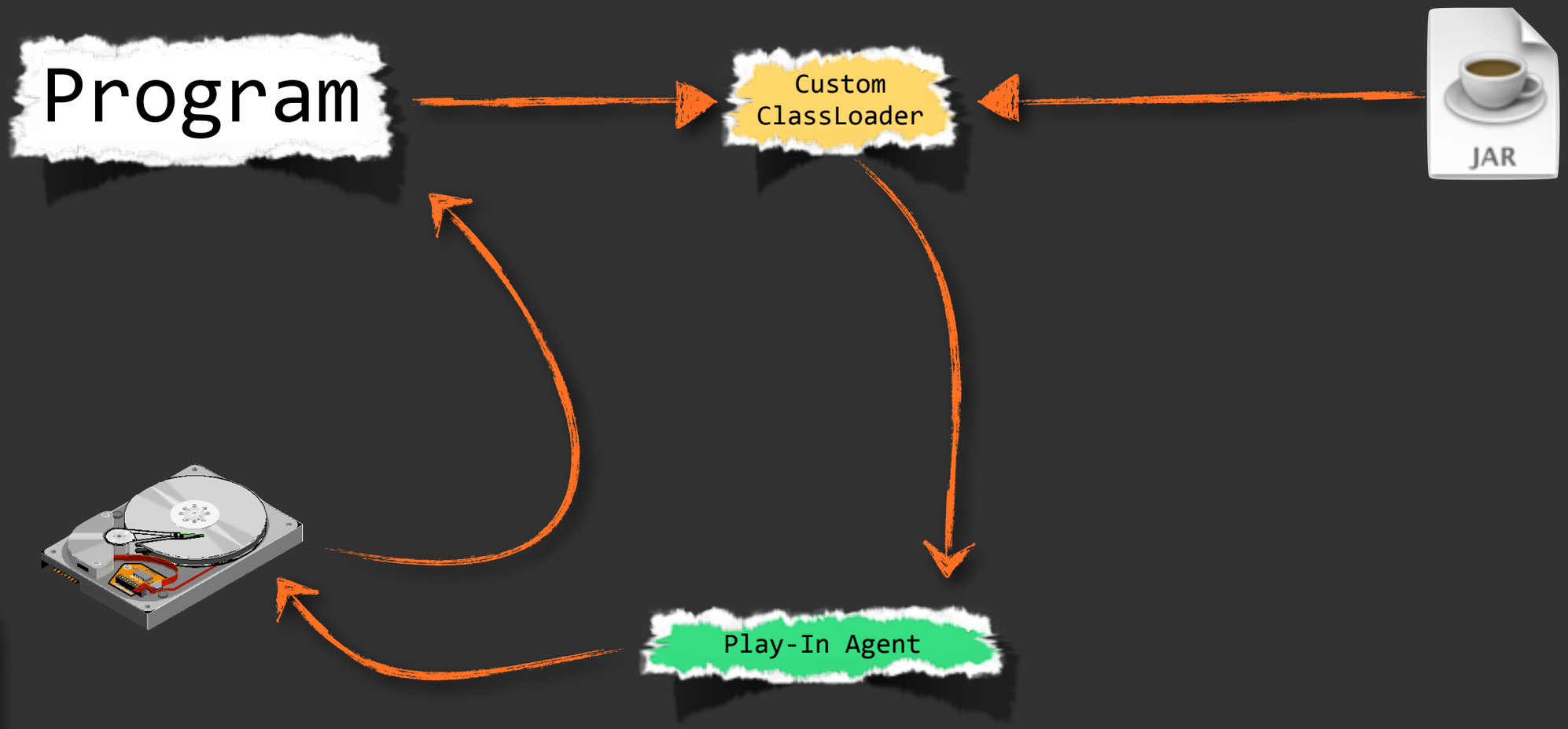


Just when
we thought
we were
done...

generated classes
may bear
randomized names!

Play-in Agent



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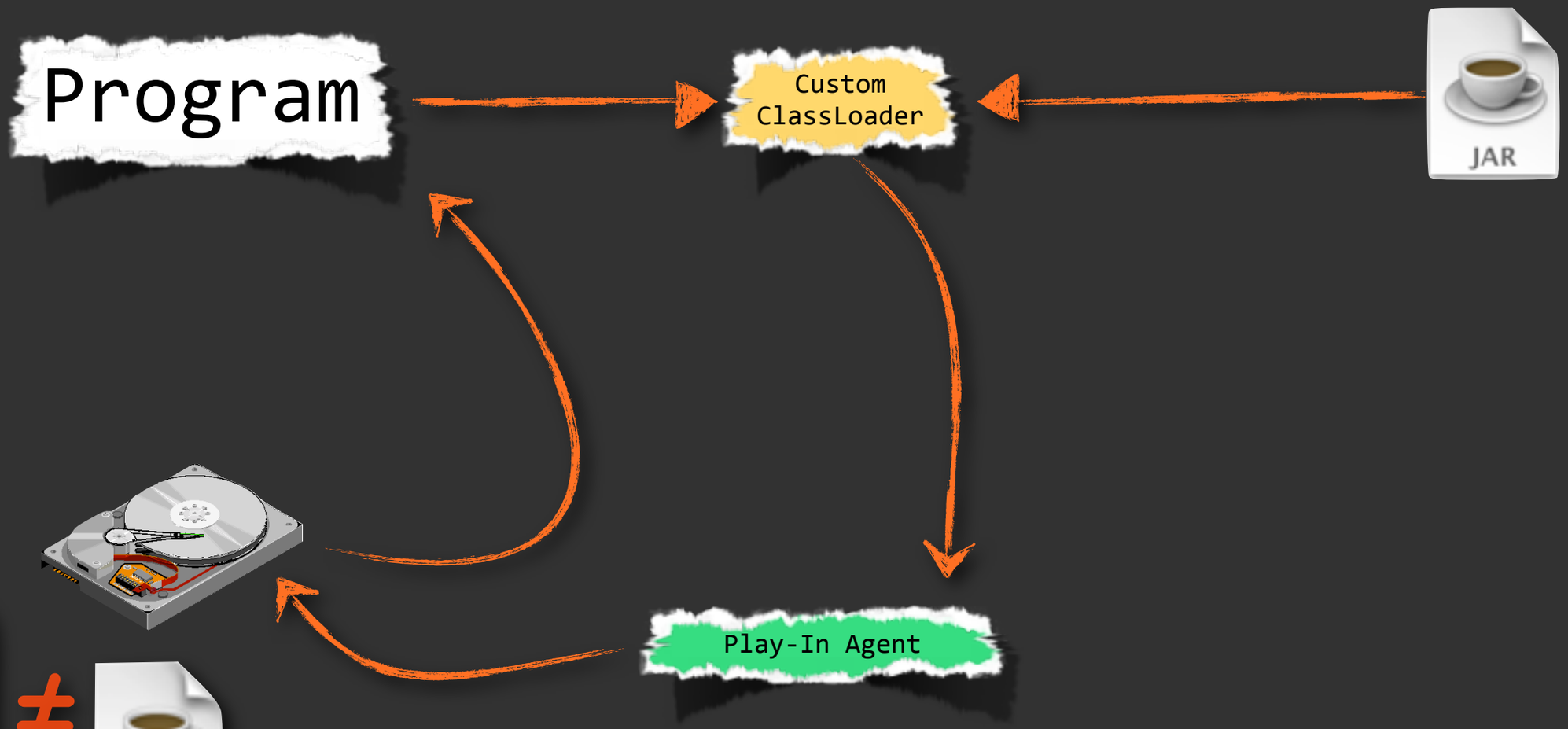

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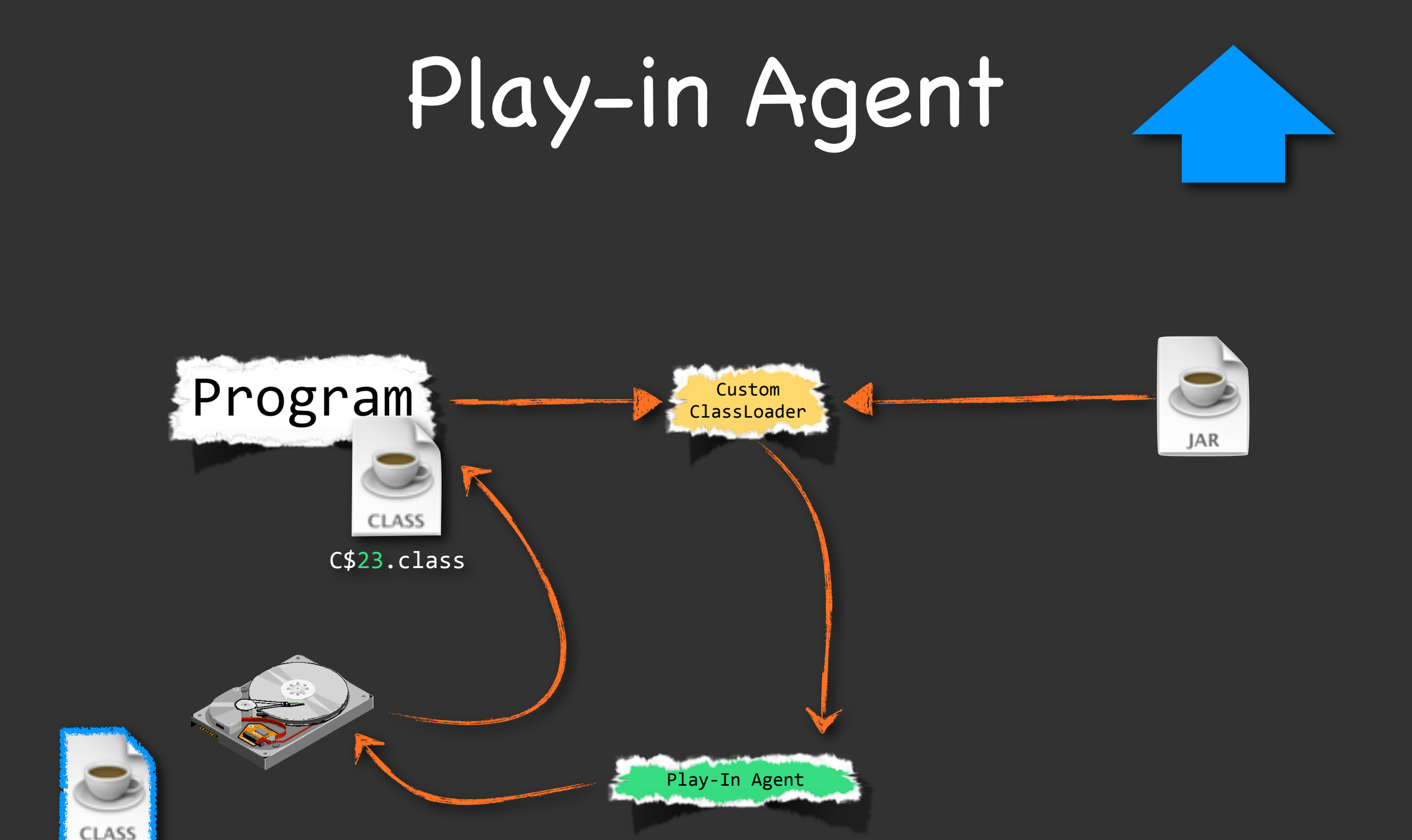
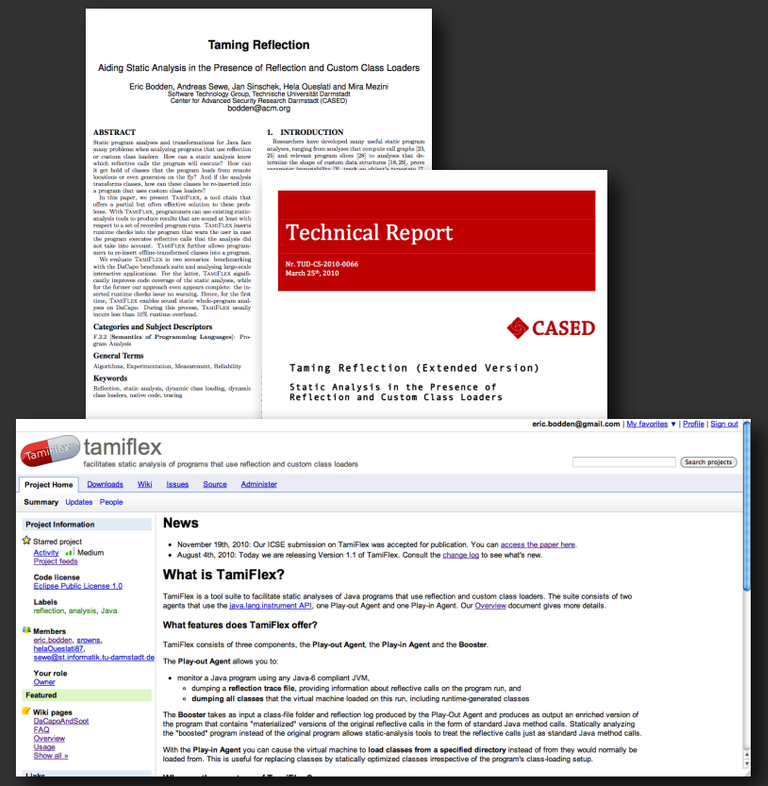


Solution

- Normalization: replace randomized name by normalized name
  - in the log, the binaries, everywhere...
- Quite involved: classes to normalize may be interdependent
- Details in the paper
- More details in our Tech Report
- Yet more details in the source



Evaluation

Evaluation

How can this be sound?

Evaluation

How can this be sound?

It's not!
But it's sound**er**!

Evaluation

How can this be sound?

It's not!
But it's sound**er**!
It's "representative"!

Correctness

static call graph ⊇ U{recorded call graph} ?

Correctness

static call graph ⊇ U{recorded call graph} ?

computed with Soot/Spark

recorded with JVMTI agent

Correctness

static call graph ⊇ U{recorded call graph} ?

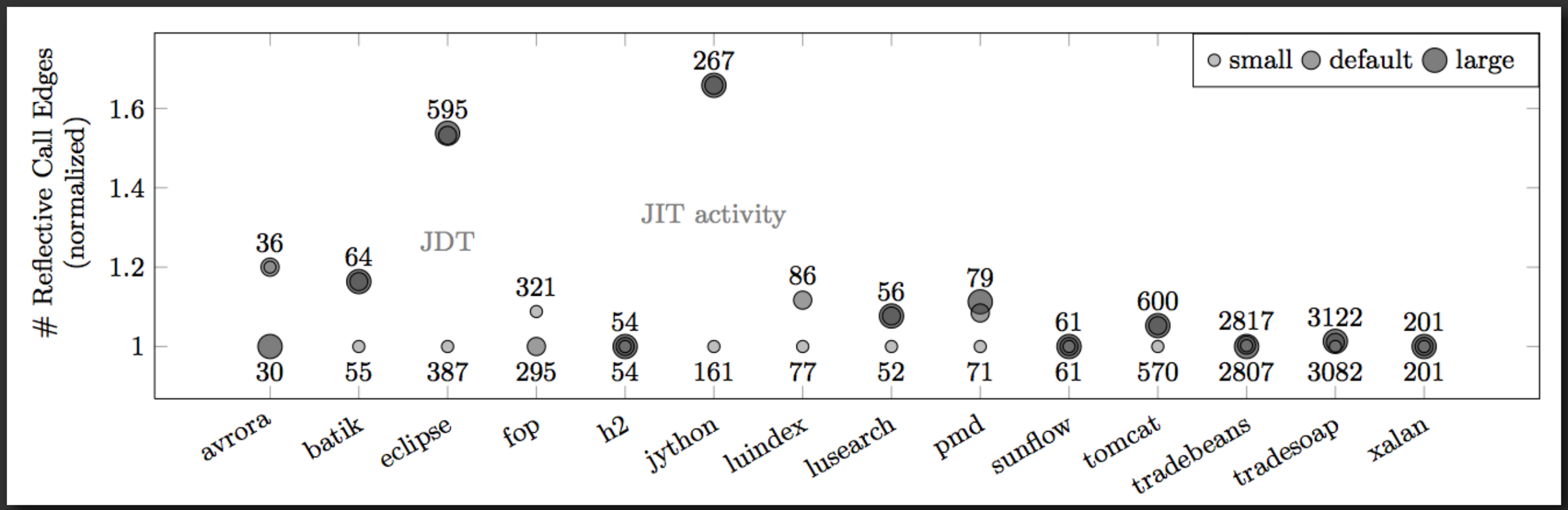
computed with Soot/Spark

recorded with JVMTI agent

Yes!

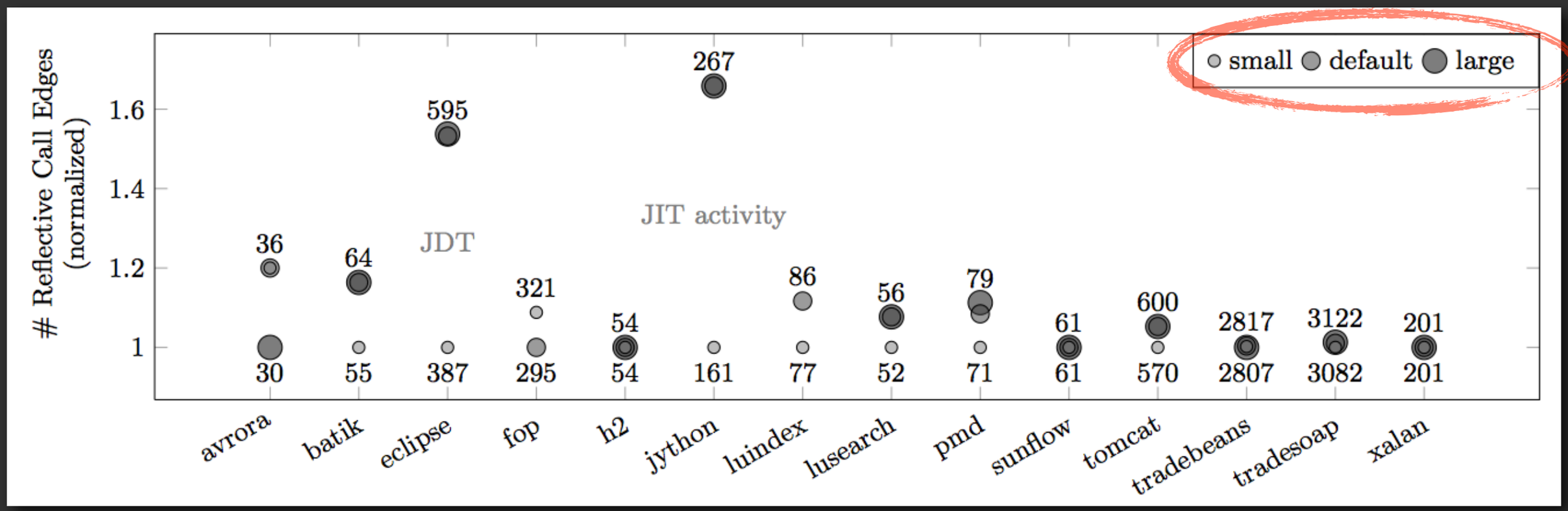
(call graphs are representative;
tested with Lhotak's Call-graph comparison tool ProBe)

Effectiveness: How much does log-file quality depend on program input?



Dacapo "bach" release

Effectiveness: How much does log-file quality depend on program input?



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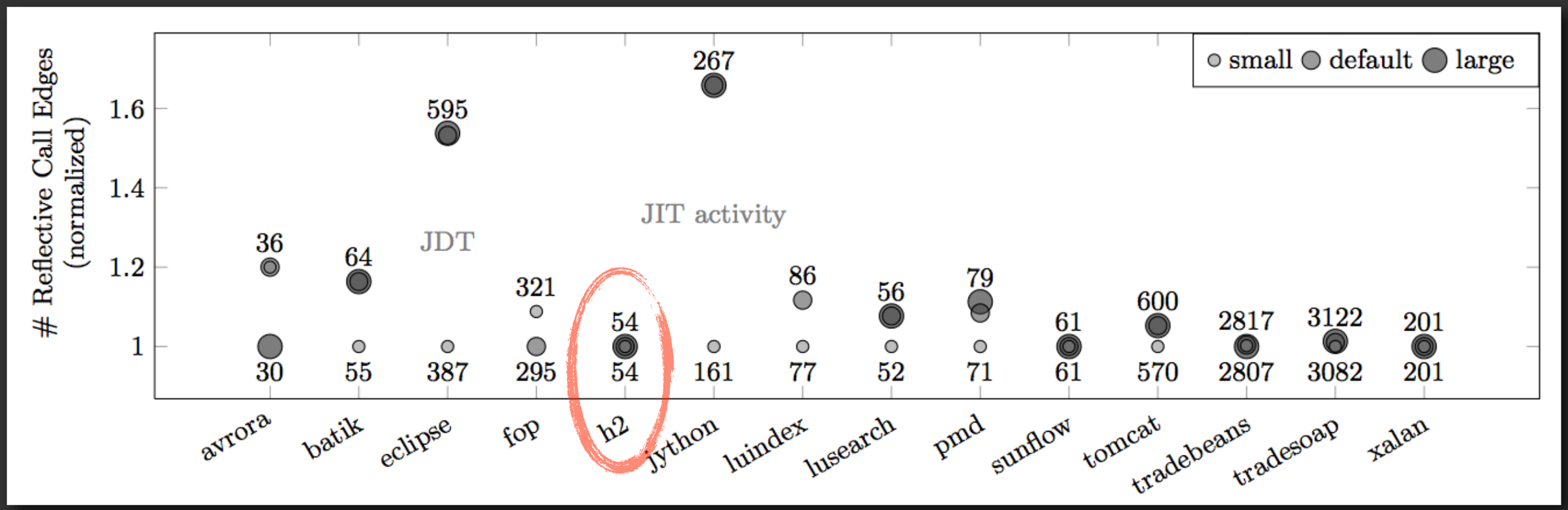

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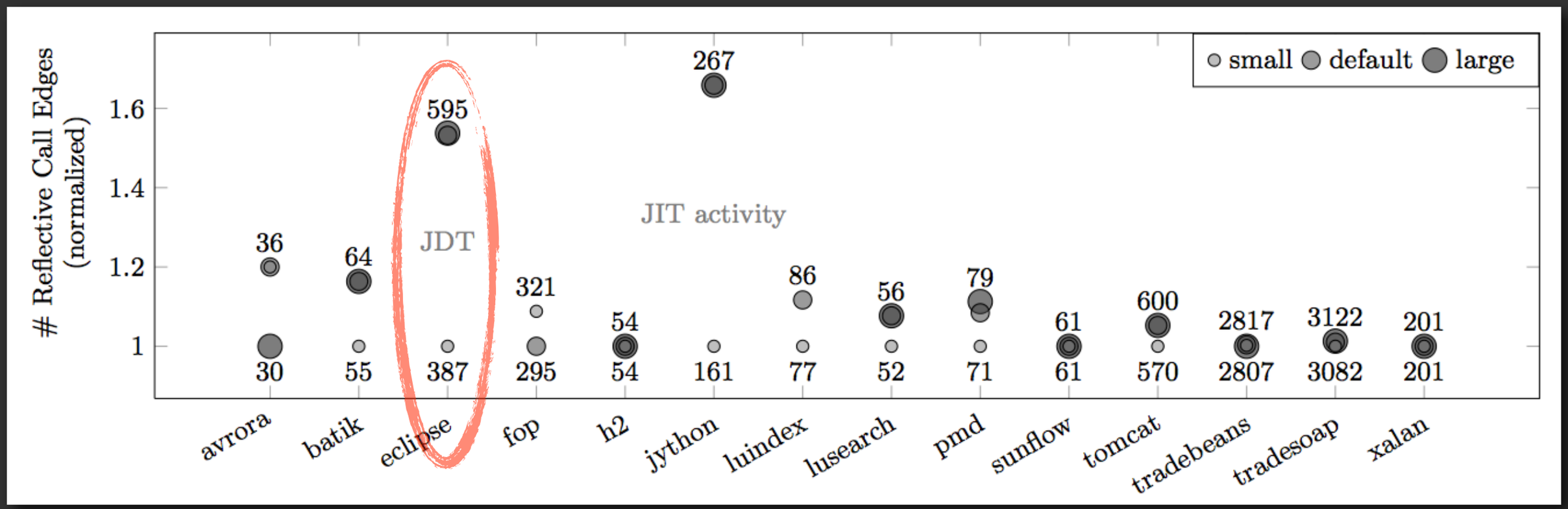

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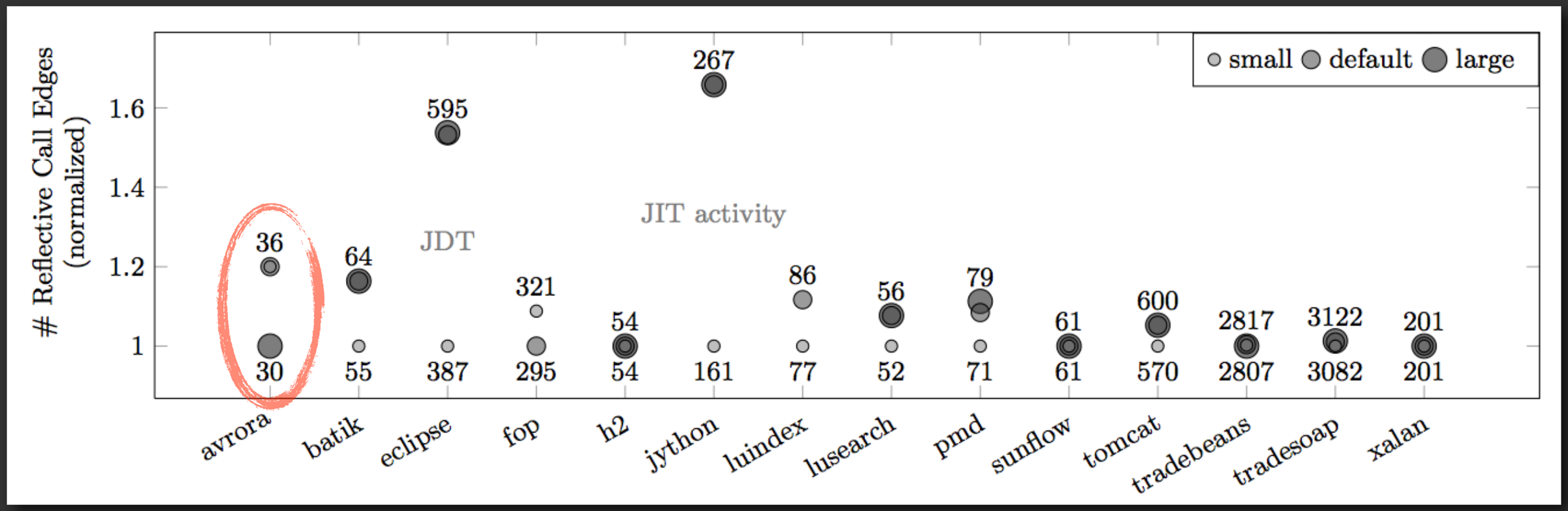

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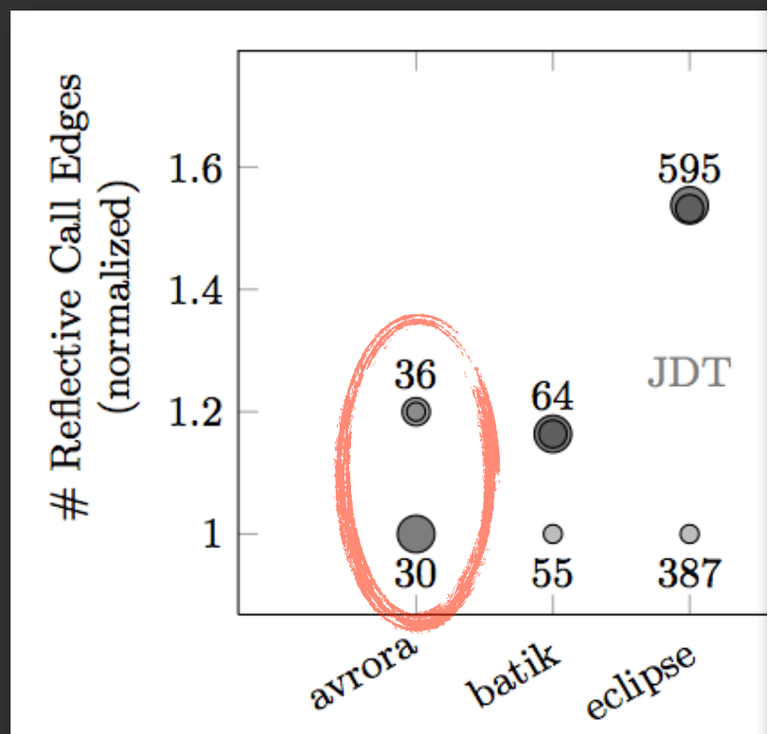
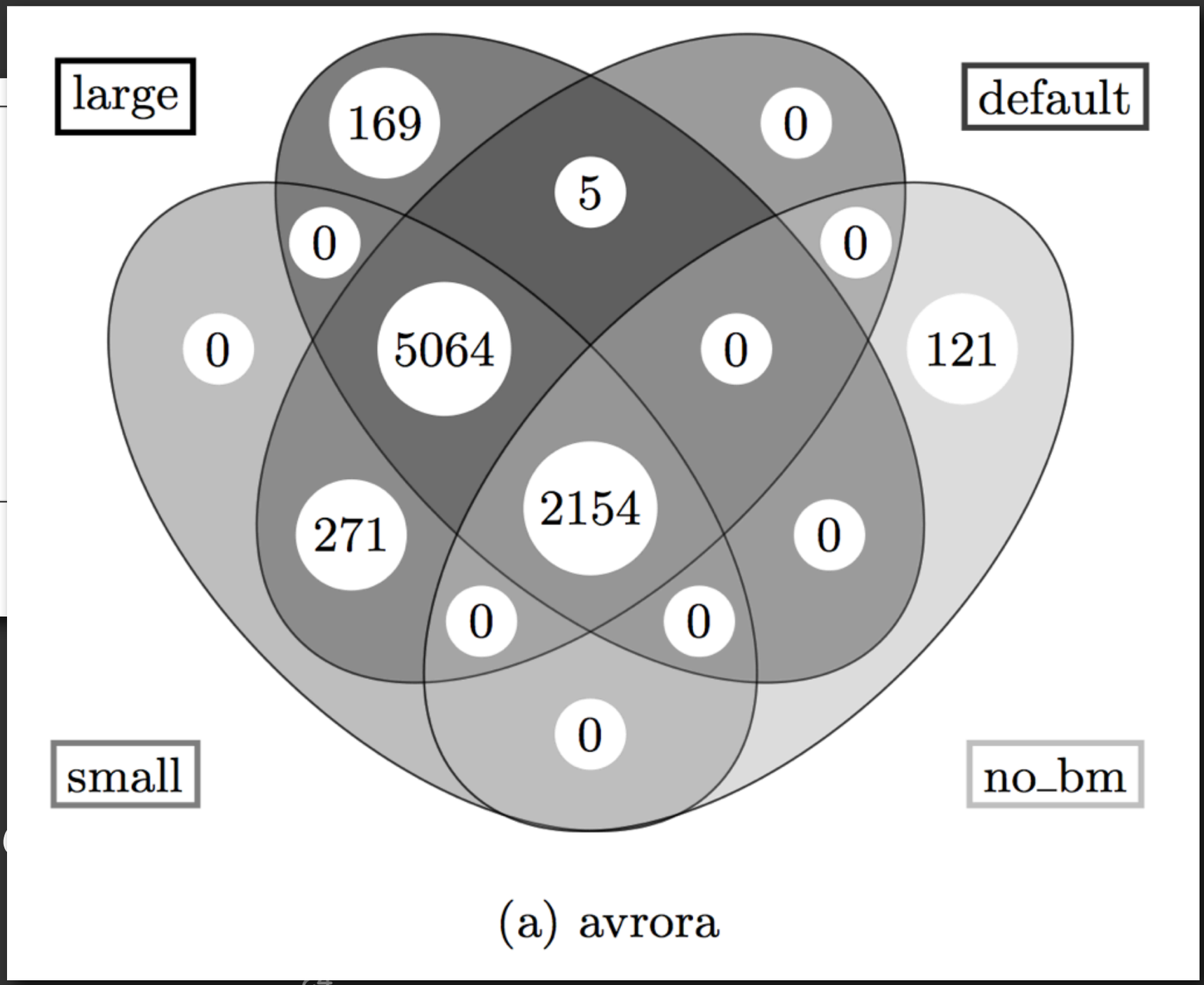
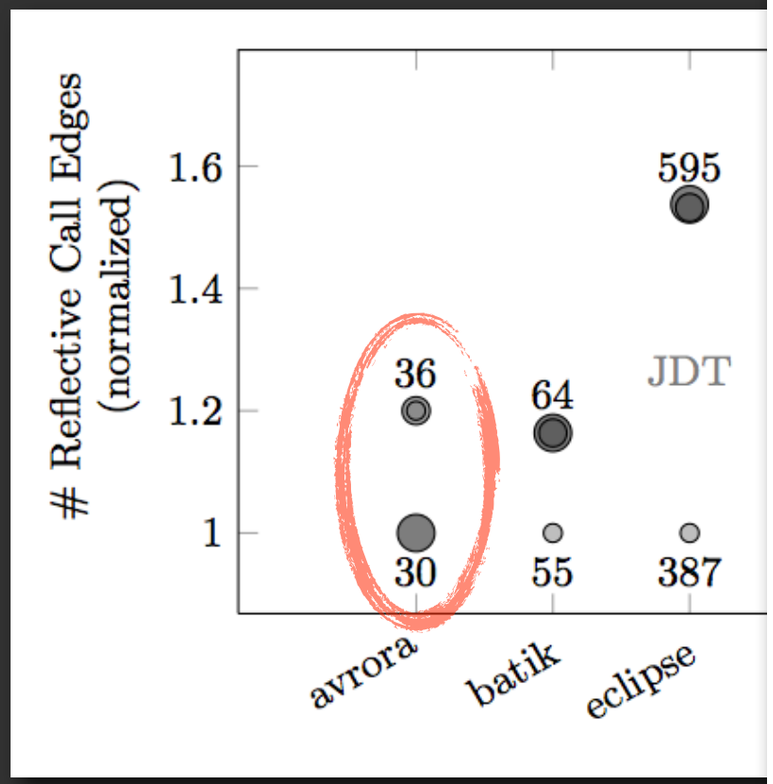
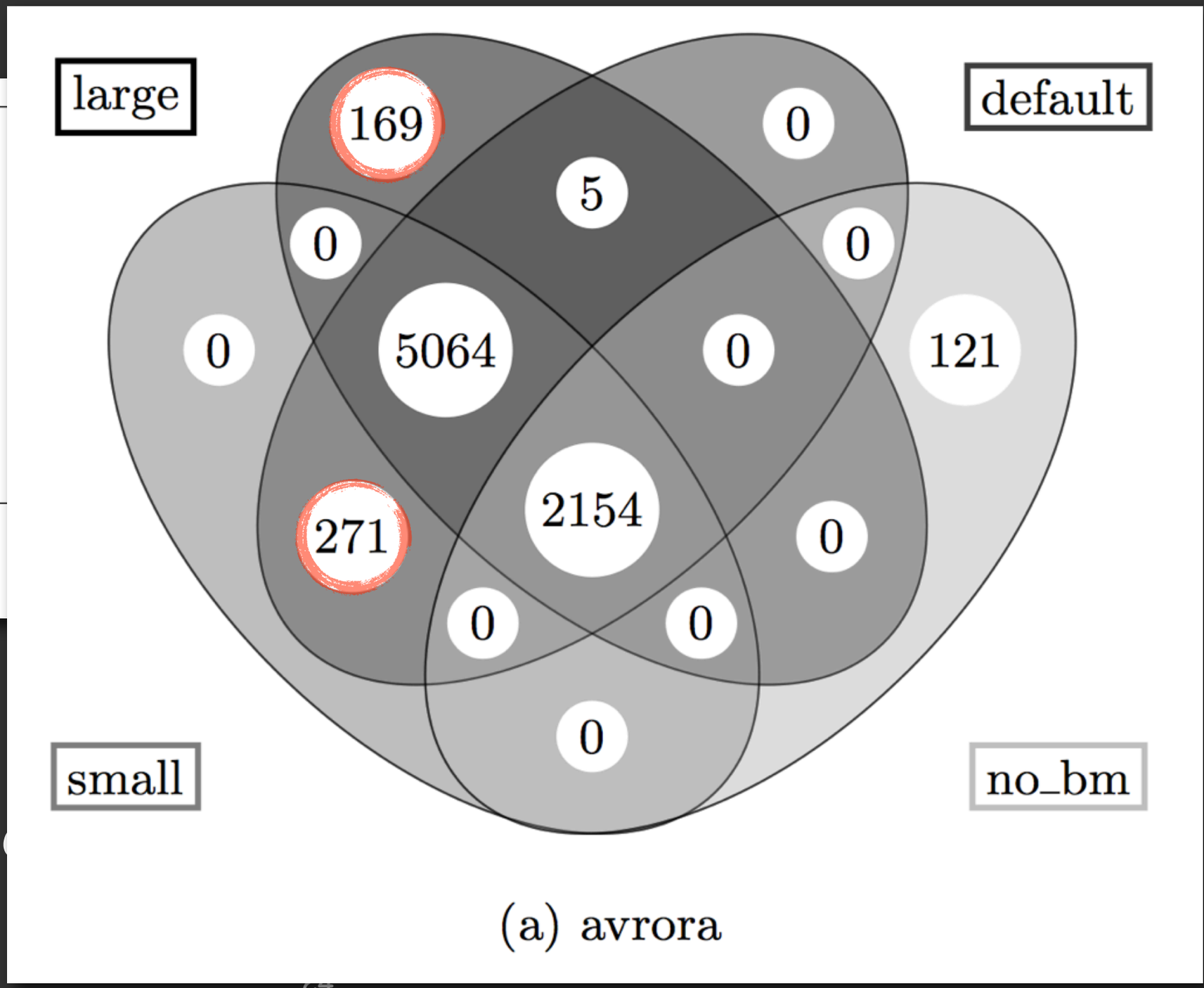




(a) avrora

Effectiveness: How much does log-file quality depend on program input?





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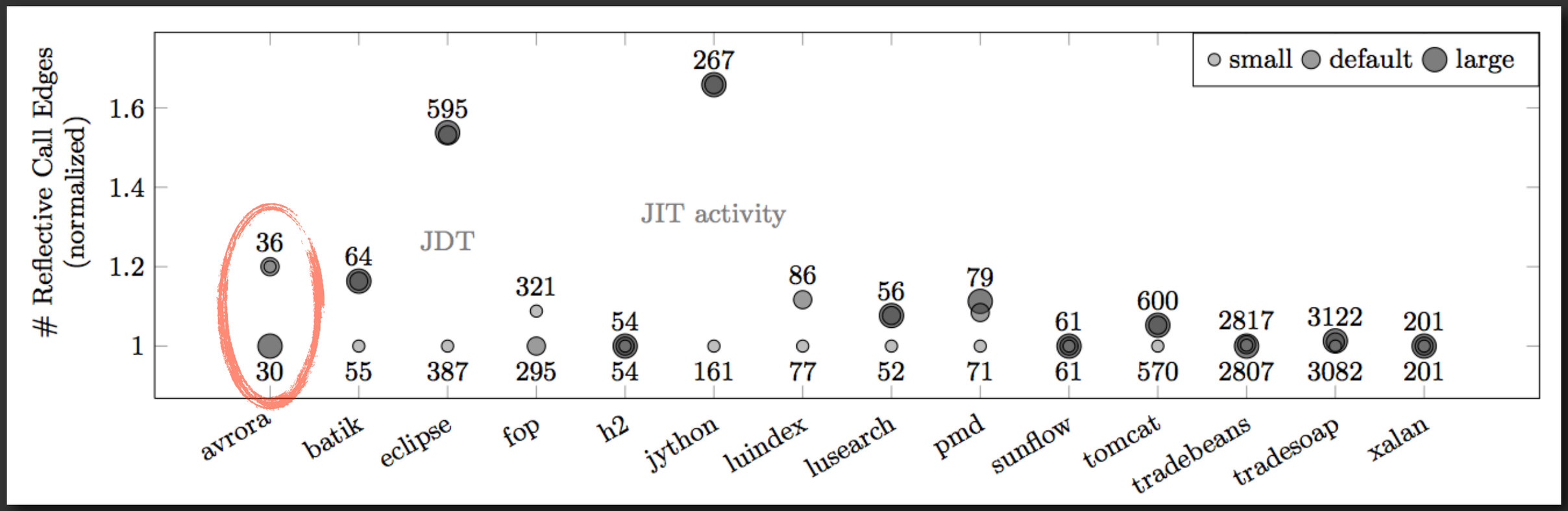
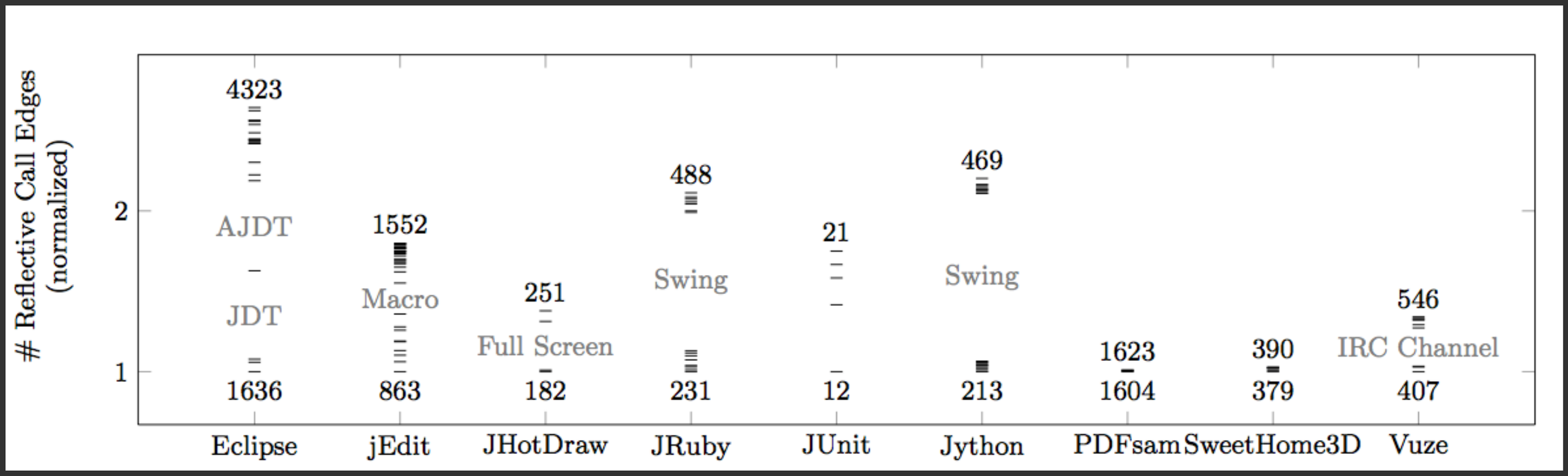
Effectiveness: How much does log-file quality depend on program input?



Can now safely use static analyses on DaCapo: Warnings never triggered!

Effectiveness: How much does log-file quality depend on program input?



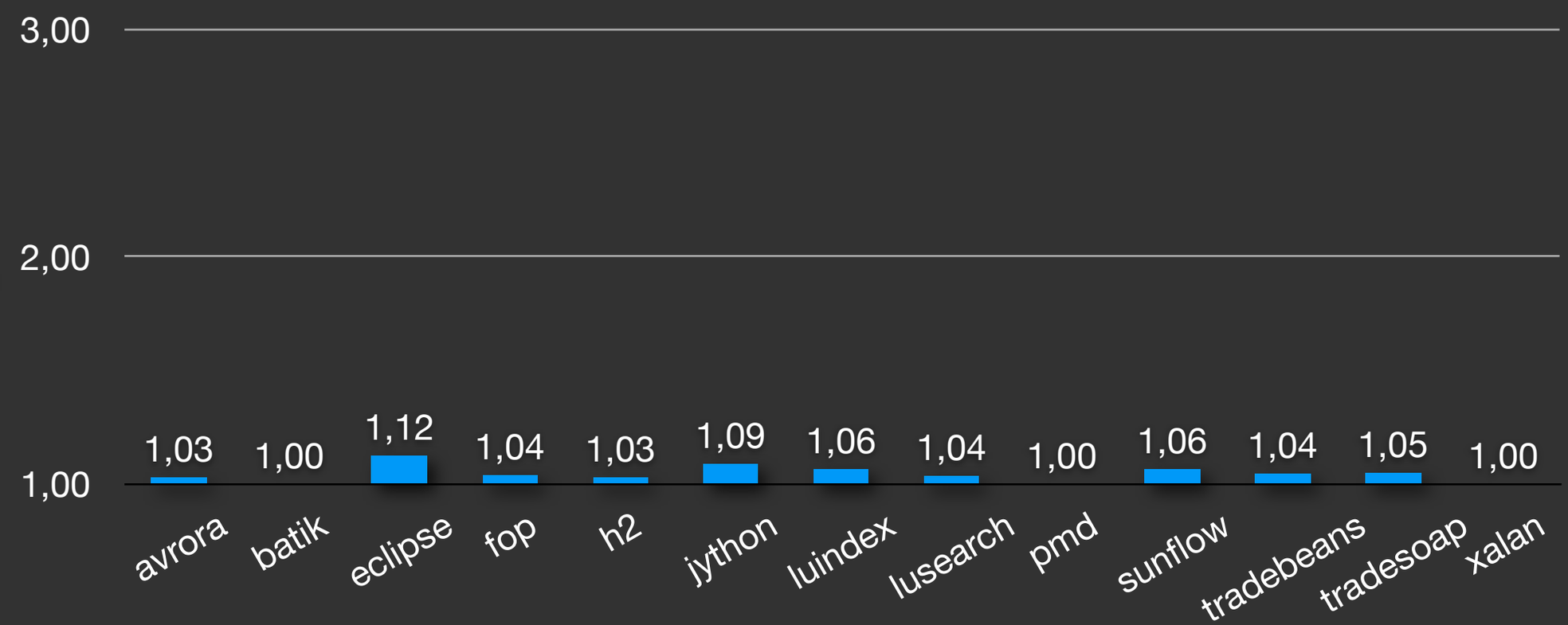
Other prominent programs/frameworks

Effectiveness: How much does log-file quality depend on program input?

Approach requires good "feature coverage

Play-Out

Play-In



Related Work

- Partial evaluation
  Braux & Noyé, PEPM 1999

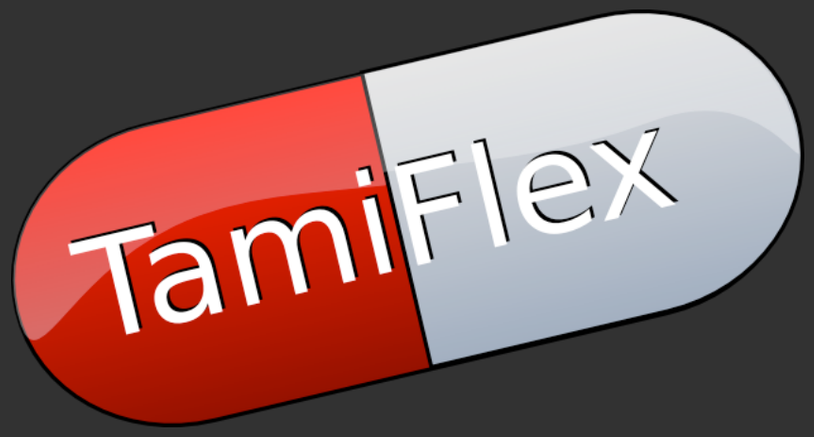
- String analysis
  Christensen et al., SAS 2003
  Livshits et al., APLAS 2005

- Application extraction
  Tip et. al, TOPLAS 2002

- "Finding the code"
  Bessey et. al (Coverity), CACM 2010

Related Work

- Online Call-Graph Construction
  Hirzel et al., TOPLAS 2007
- Blended Analysis
  Dufour et al., ISSTA 2007
- Runtime type inference in ~~P~~Ruby
  Furr et al., OOPSLA 2009



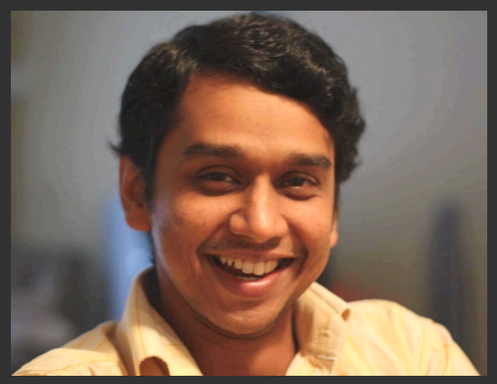
http://tamiflex.googlecode.com/

First external users

Cheng Zhang, SJTU

Play-out, Soot, Play-In

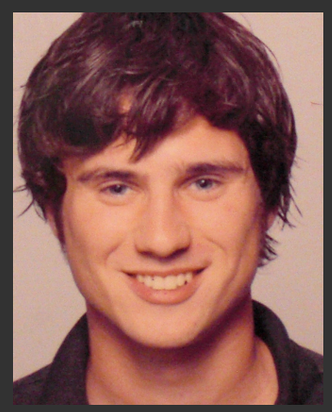
Call frequency analysis



Saswat Anand, Georgia Tech

Play-out, Soot

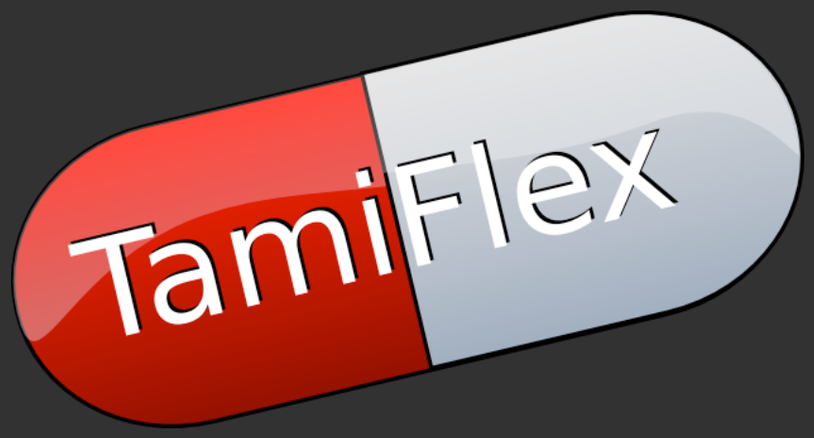
Points-to, Symb. Exec.



Jochen Huck, KIT

Play-out, Soot

Side-Effects, Dominance



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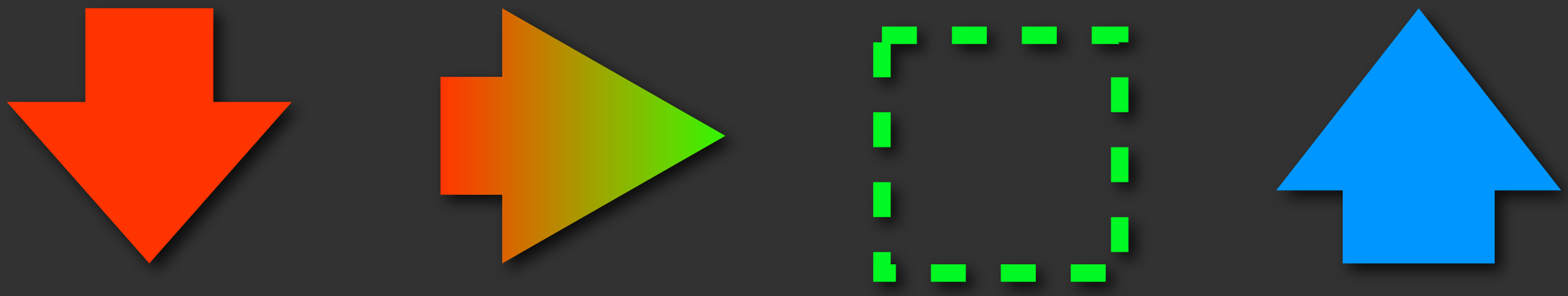

Play-Out Boost Analyse & Transform Play-In

Correct Effective Efficient

TamiFlex

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July 17th-21st, 2011, Toronto

Record number of submitted & accepted papers

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