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Accurate Reification of Complete Supertype Information for Dynamic Analysis on the JVM

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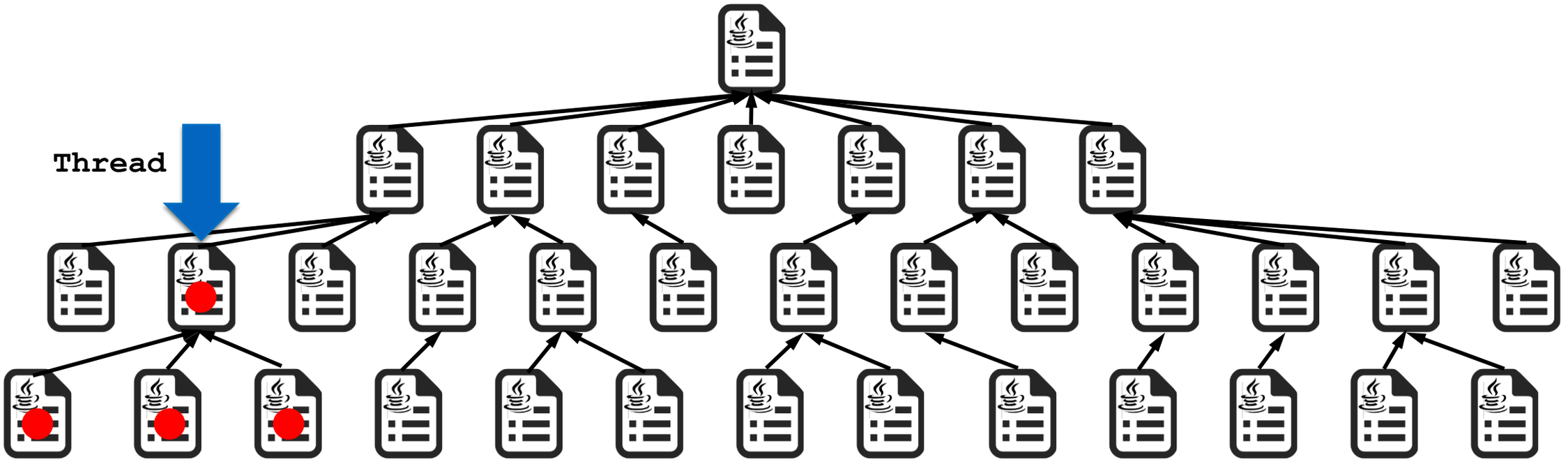
Reflective Information in the JVM

- Any information on a Java class or method available at runtime
  - Provided by the Java Reflection API
    - E.g.: `java.lang.Class`

- **Reflective supertype information (RSI)**
  - Information on all direct and indirect supertypes
    - `public Class<? super T> getSuperclass()`
    - `public Class<?>[] getInterfaces()`
    - Recursively applied

RSI during Instrumentation

- Enables more efficient dynamic analyses
- Example: analysis targeting threads



- Without RSI:

RSI during Instrumentation

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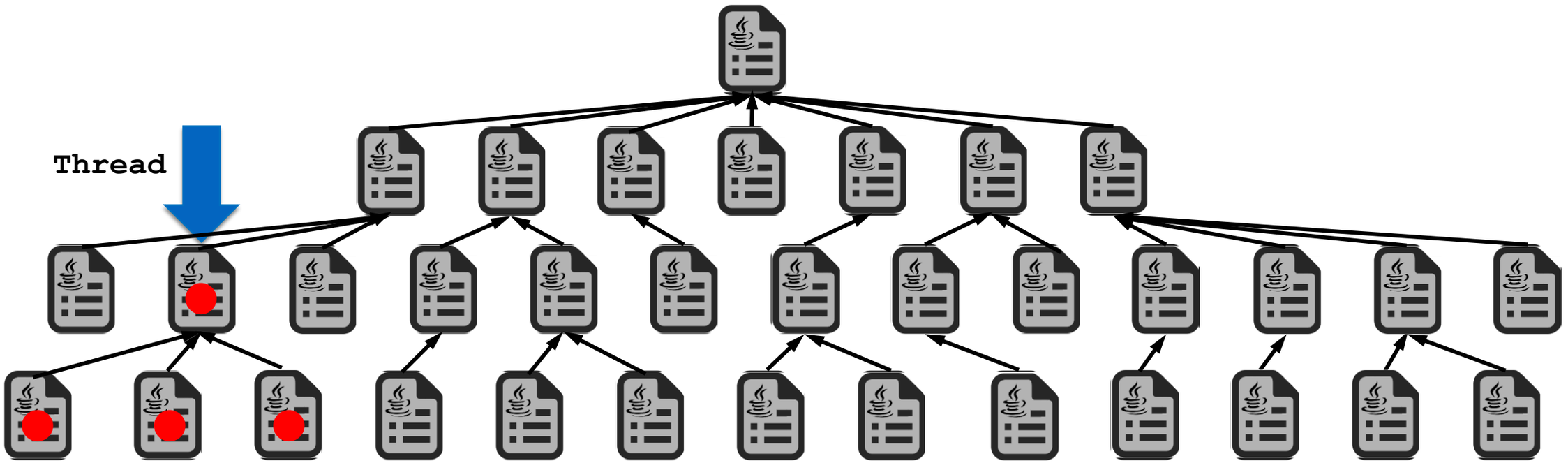

- **Without** RSI:
  - Many classes instrumented
  - Increased overhead

```
if (this instanceof Thread){
    // Do something
}
```

RSI during Instrumentation

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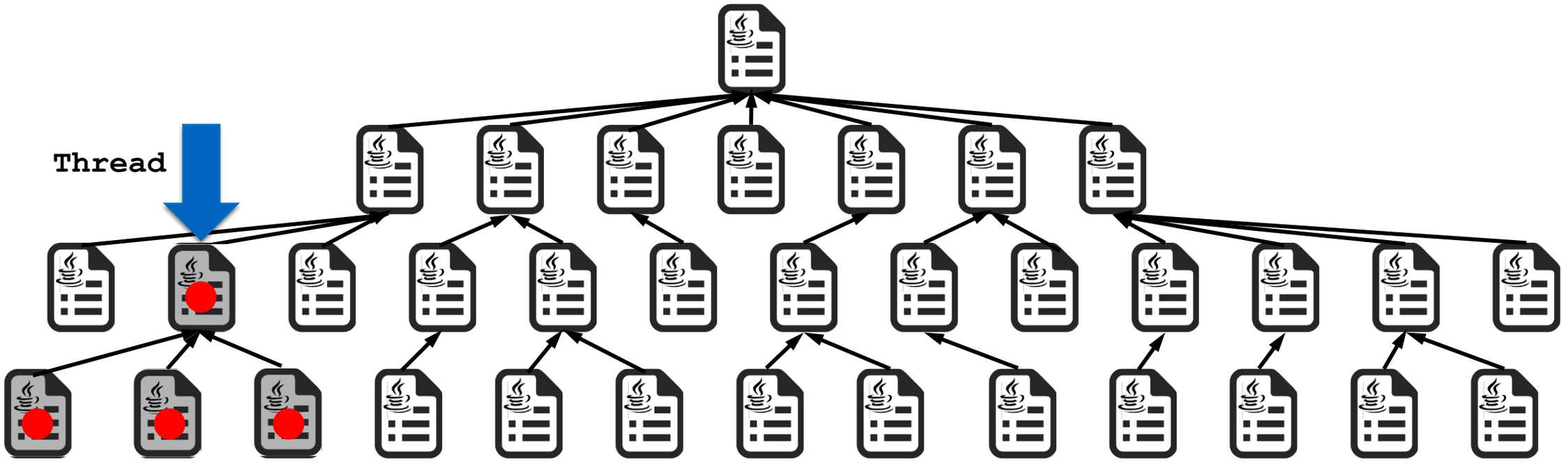
- Example: analysis targeting threads

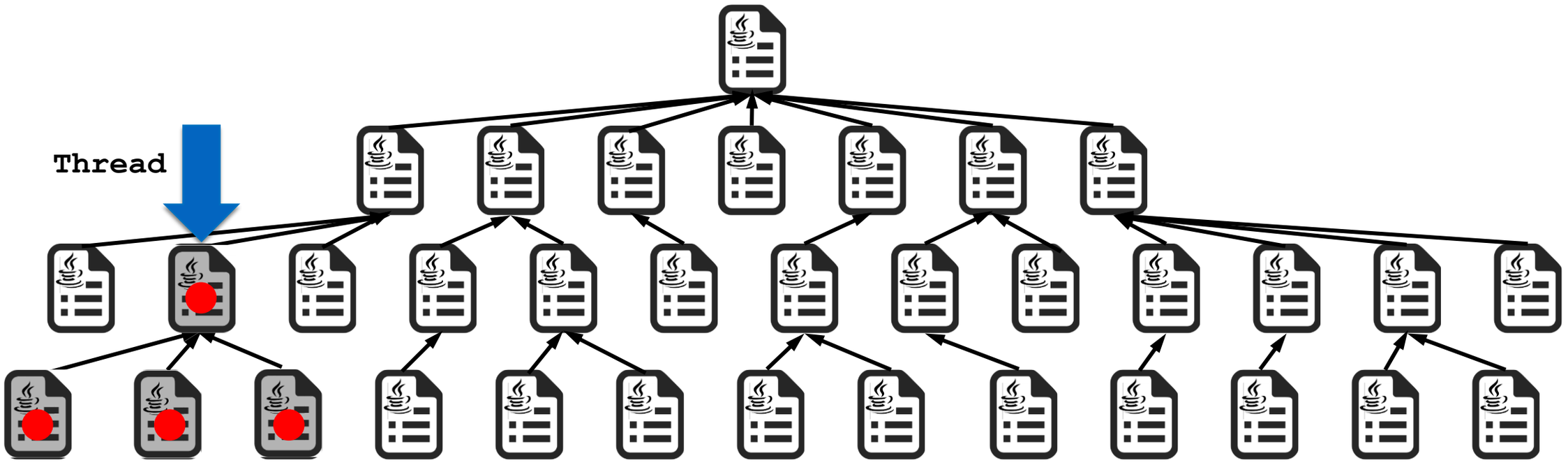


- With RSI:
  - Less classes instrumented
  - Less overhead

```
if (this instanceof Thread){
    // Do something
}
```

RSI during Instrumentation

- Enables more efficient dynamic analyses
- Example: analysis targeting threads



- With RSI:
  - Less classes instrumented
  - Less overhead

Availability of RSI
vs
Full code coverage

RSI during Instrumentation

Instrumentation	Complete RSI available?	Full code coverage?	Classloader namespaces?
Compile-time (e.g., AspectJ [1] compile-time weaver)	✗	✗	✗
Load-time in-process (e.g., AspectJ [1] load-time weaver)	✓	✗	✗
Load-time out-of-process (e.g., DiSL [2])	✗	✓	✗
Our approach (load-time out-of-process)	✓	✓	✓

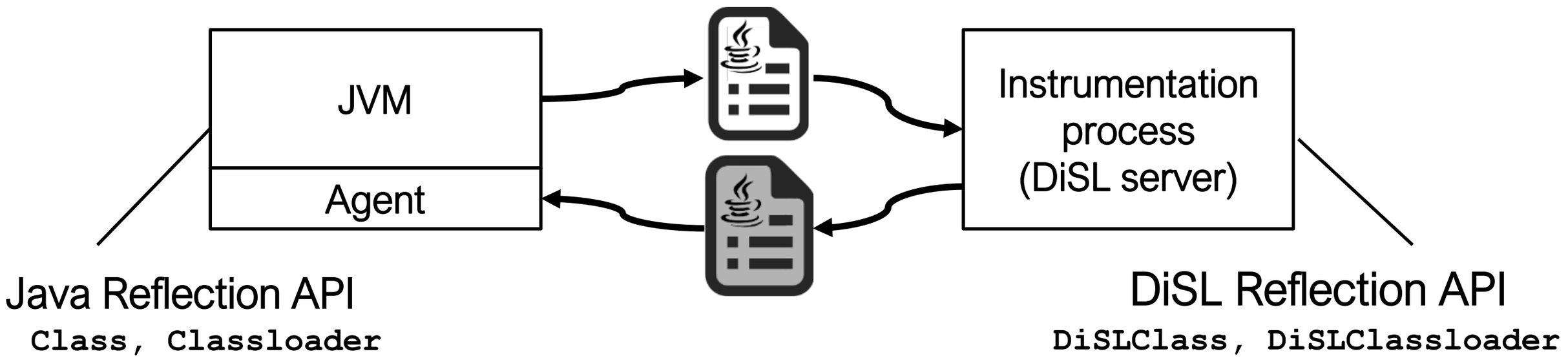
[1] Kiczales et al. *An overview of AspectJ*. ECOOP'01.

[2] Marek et al. DiSL: *A Domain-specific Language for Bytecode Instrumentation*. AOSD'12.

Contribution

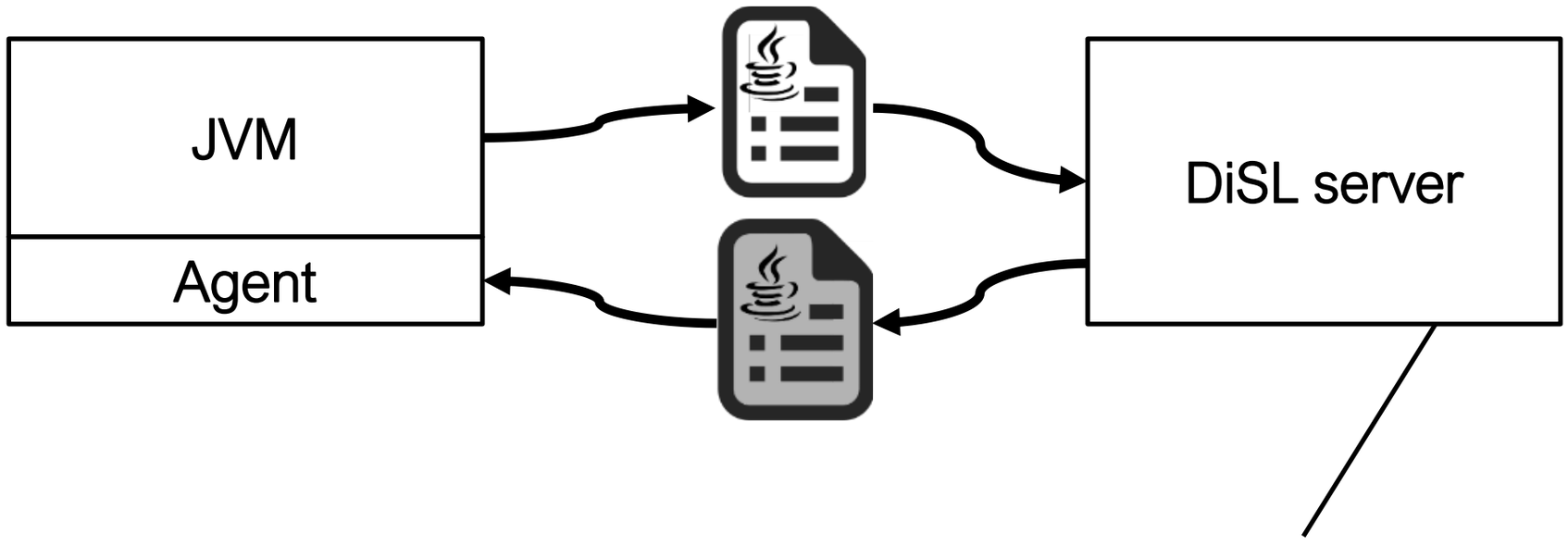
- We present a new technique to **accurately reify complete RSI** in a **separate instrumentation process**
  - Reification of classloader namespaces
  - Complete RSI available upon instrumentation of any class
  - Works with full code coverage
- Implemented in DiSL

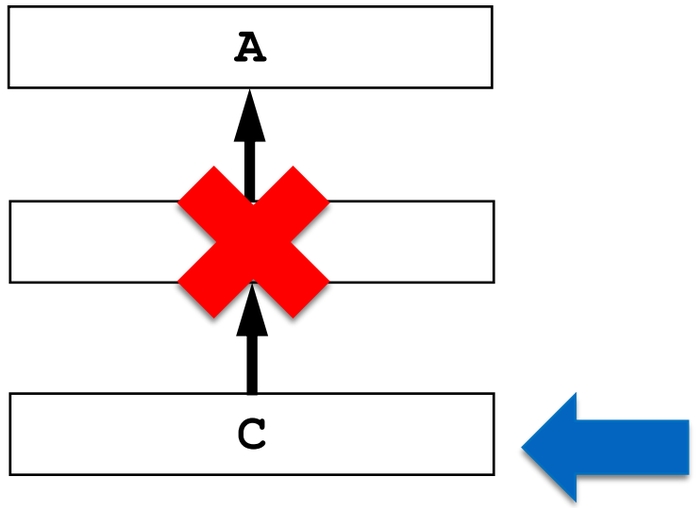
DiSL Reflection API




```
public interface DiSLClassLoader {
    long getID();
    DiSLClass forName(String fullyQualifiedClassName);
    boolean isBootstrapLoader();
    boolean isApplicationLoader();
    ...
}

public interface DiSLClass {
    String getName();
    DiSLClassLoader getClassLoader();
    DiSLClass getSuperclass();
    Stream<DiSLClass> getInterfaces();
    Stream<DiSLClass> getSupertypes();  // All direct and indirect supertypes
    ...
}
```

Forced Loading of Supertypes





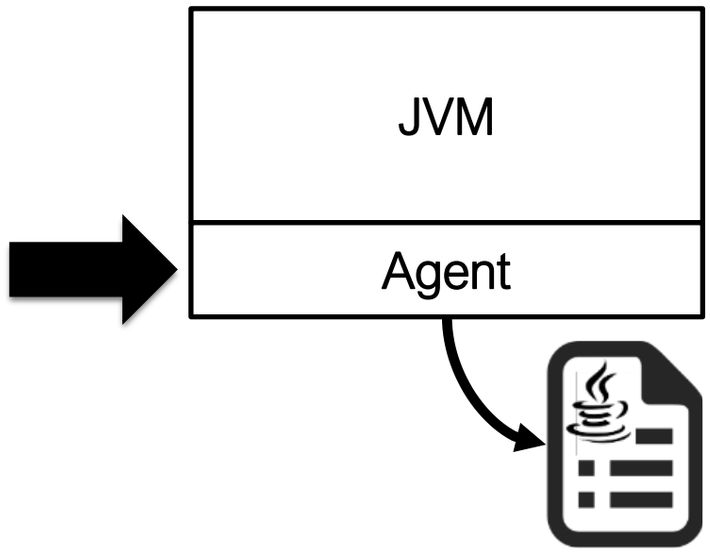
- JVM may load subtypes before supertypes

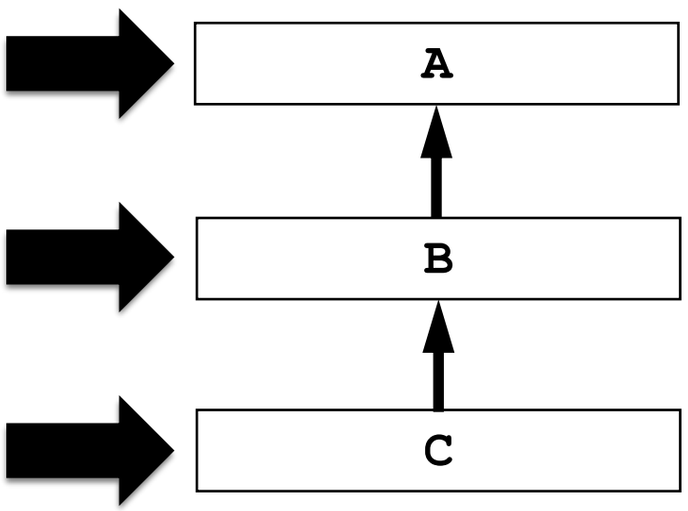
```
public interface DiSLClass {
    String getName();
    DiSLClassLoader getClassLoader();
    DiSLClass getSuperclass();
    Stream<DiSLClass> getInterfaces();
    Stream<DiSLClass> getSupertypes();
    ...
}
```

- Solution: force loading of supertypes

Forced Loading of Supertypes

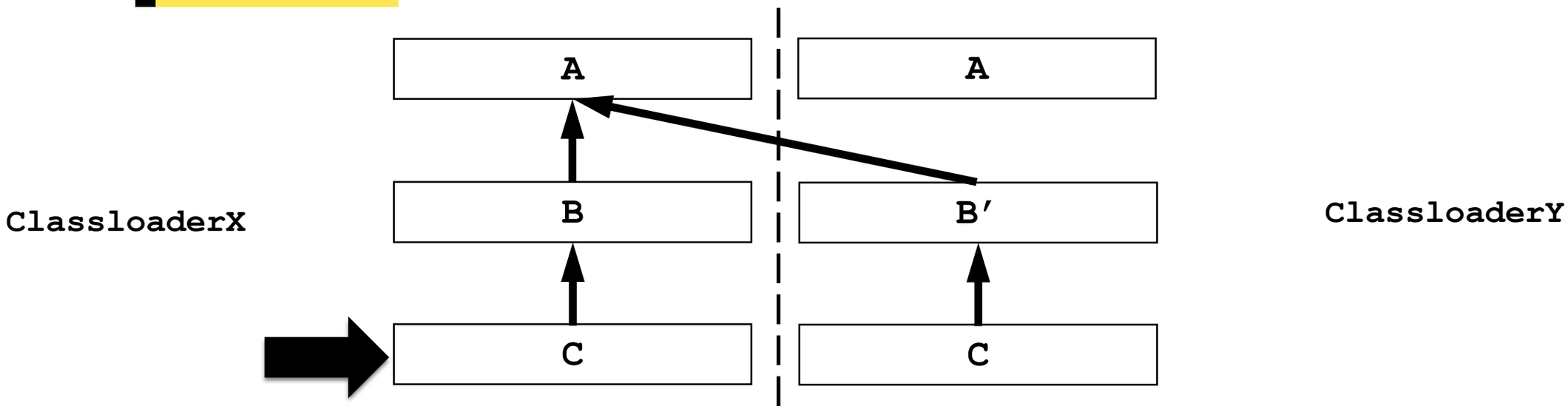
```
input  : b  original byte array of the loaded class
         l  defining classloader of the loaded class
output : B_c  instrumented byte array of the loaded class

1  callback onClassLoad(B_c b, L l) begin
2      STRING s_s ← superclass(b)
3      P p_s ← < s_s, loadAndGetClassloaderID(s_s, l) >
4      𝒫 p_i ← ()
5      𝒮 s_i ← interfaces(b)
6      foreach s_j ∈ s_i do
7          P p_j ← < s_j, loadAndGetClassloaderID(s_j, l) >
8          p_i ← p_i ‖ (p_j)
9      end
10     return instrumentRemotely(b, id(l), p_s, p_i)
11 end

12 function loadAndGetClassloaderID(STRING s, L l) begin
13     return id(classloader(loadClass(s, l)))
14 end
```



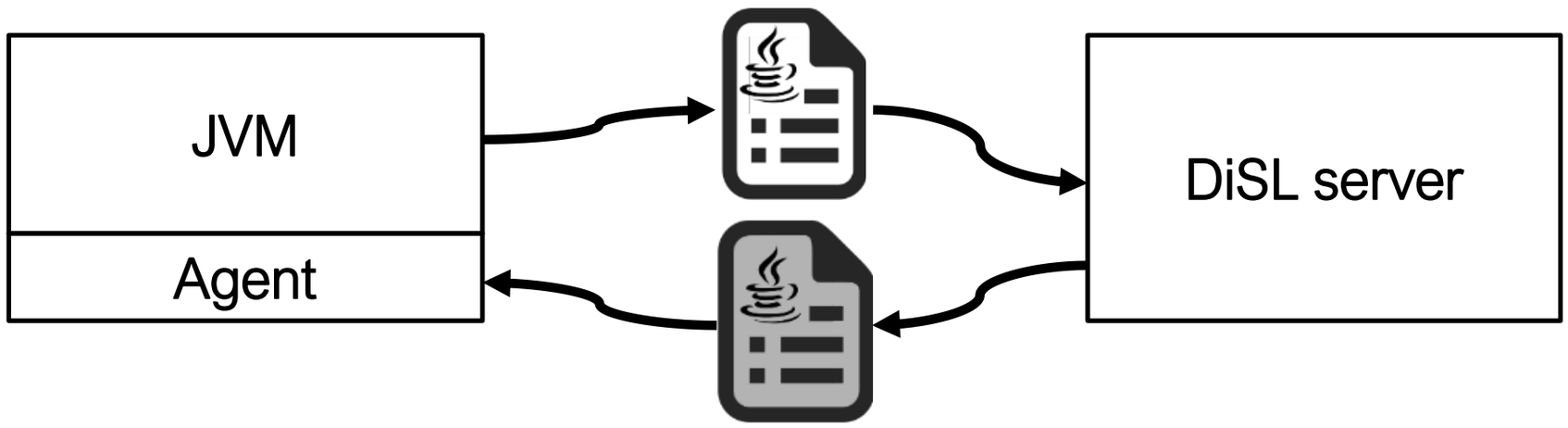


Triggers instrumentation of *s*

Classloader Namespaces




```
<C, ClassloaderX>
<B, ClassloaderX>
```



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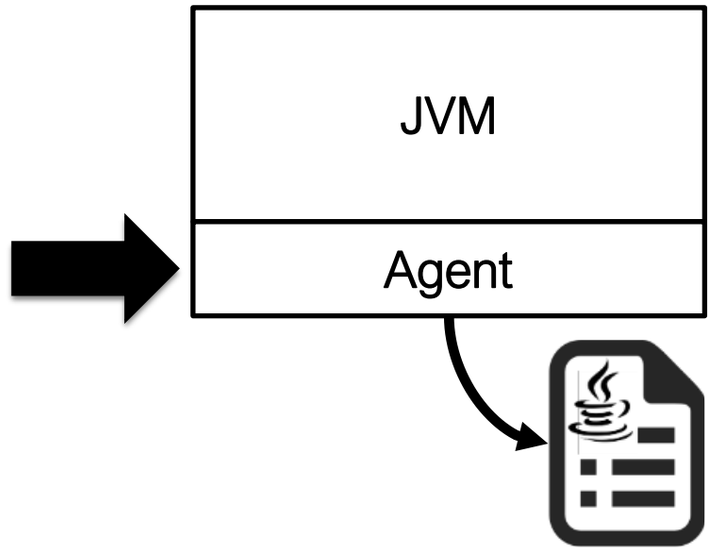
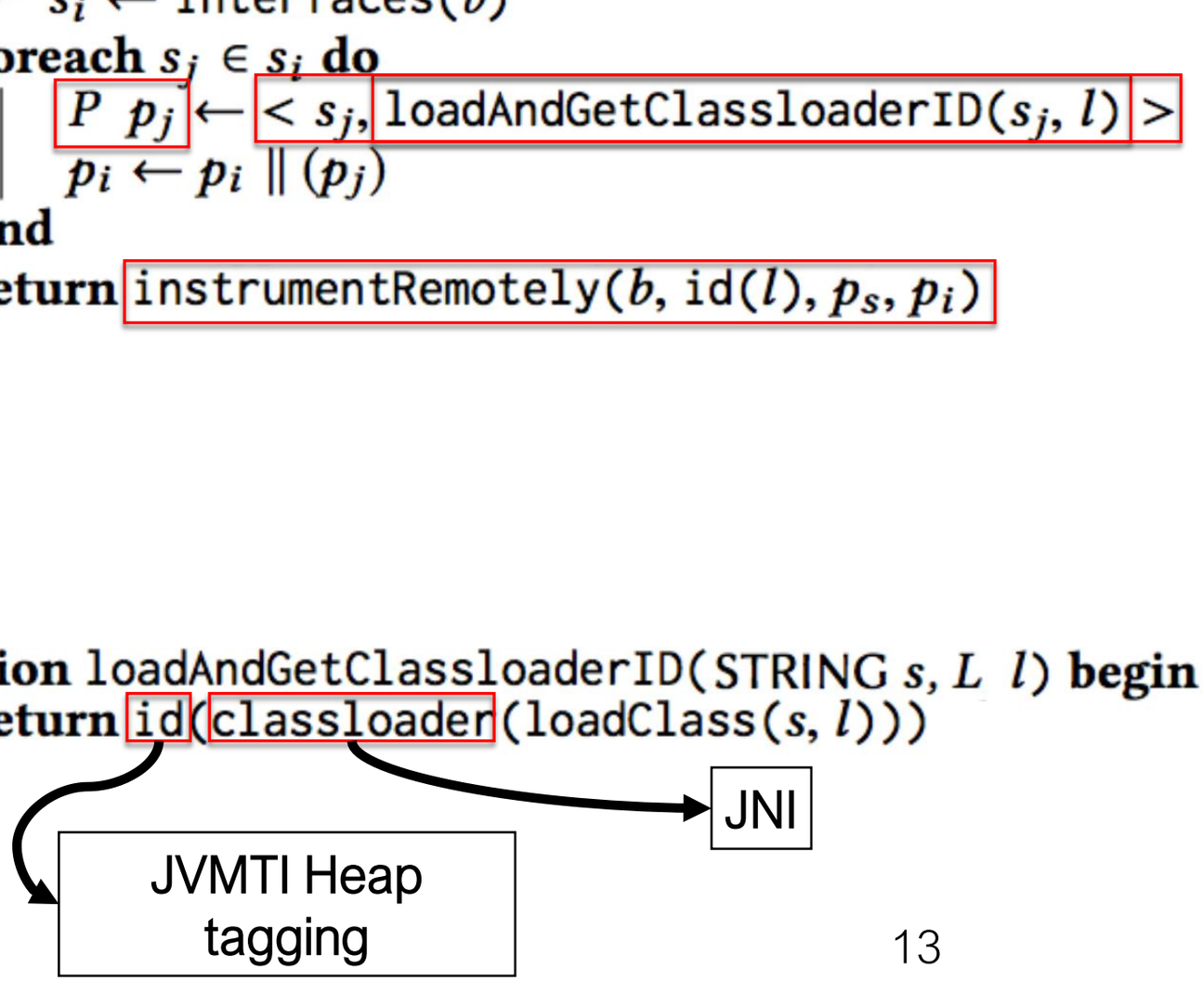


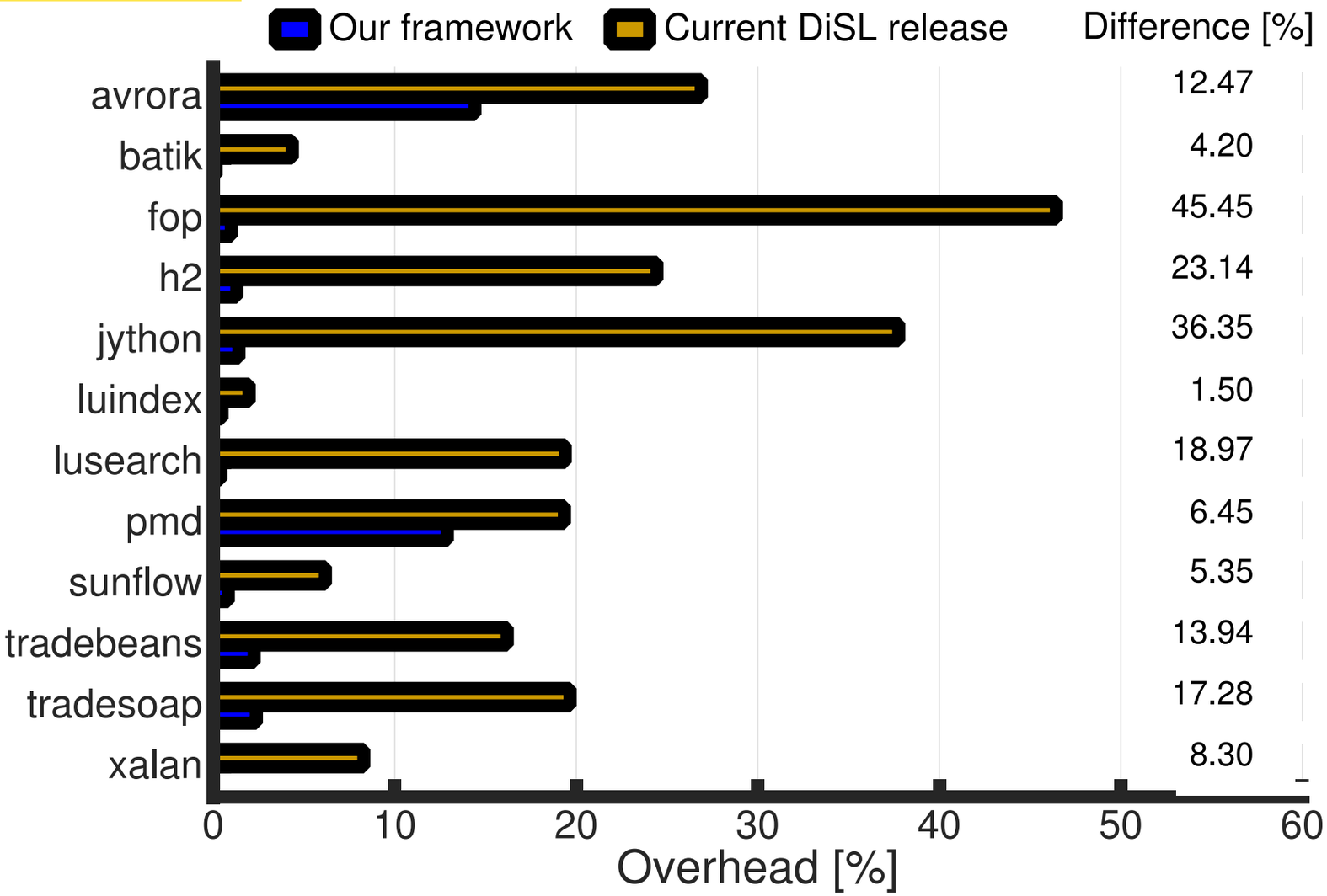


Evaluation

- Task profiling on DaCapo benchmarks [3]
- Target: subtypes of `Runnable` and `Callable`
- Comparison between:
  - AspectJ (load-time in-process instrumentation)
  - DiSL without Reflection API
  - DiSL with Reflection API
- Metrics:
  - Overhead
  - Code coverage

[3] Blackburn et al. *The DaCapo Benchmarks: Java Benchmarking Development and Analysis*. OOPSLA'06.

Evaluation - Overhead



- High overhead without DiSL Reflection API
  - Average overhead: 19%

- Reduced overhead with DiSL Reflection API
  - Average overhead: 3%
  - Difference: 16% (average) – 45% (max)

Evaluation – Code Coverage

Benchmark	# tasks AspectJ	# tasks DiSL	difference (DiSL - AspectJ)	% coverage AspectJ
avrora	8	9	1	88.89
batik	1	3	2	33.33
eclipse	139	368	229	37.77
fop	0	3	3	0
h2	34	35	1	97.14
jython	2	4	2	50.00
luindex	2	2	0	100
lusearch	33	33	0	100
pmd	253	507	254	49.90
sunflow	66	101	35	65.35
tomcat	2737	3083	346	88.78
tradebeans	34	37	3	91.89
tradesoap	34	37	3	91.89
xalan	1733	1733	0	100

- Tasks in Java class library not detected by AspectJ
  - Only 71% of tasks profiled by AspectJ

Limitations

- Incompatible with analyses making use of JVMTI heap tagging
  - Possible solution:
    weak-key identity-based hash tables
    instead of heap tagging
- RSI currently not available for fields, method receivers, and arguments
  - Huge memory footprint and slow startup

Conclusions

- New technique to reify RSI in a separate instrumentation process
  - Instrumentation process aware of classloader namespaces
  - Accurate and complete RSI available for each loaded class
  - Reconciling complete RSI and full code coverage
- Integrated into DiSL
- Significant overhead reductions in type-specific instrumentations

Thank you for the attention

- DiSL: **`https://disl.ow2.org`**

- Andrea Rosà

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