WELCOME TO THE TUTORIAL!

Tutorial Team

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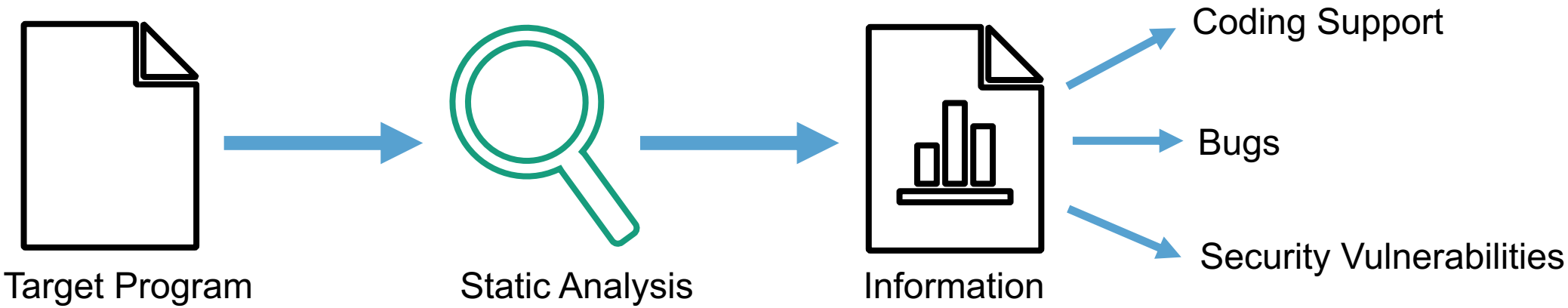
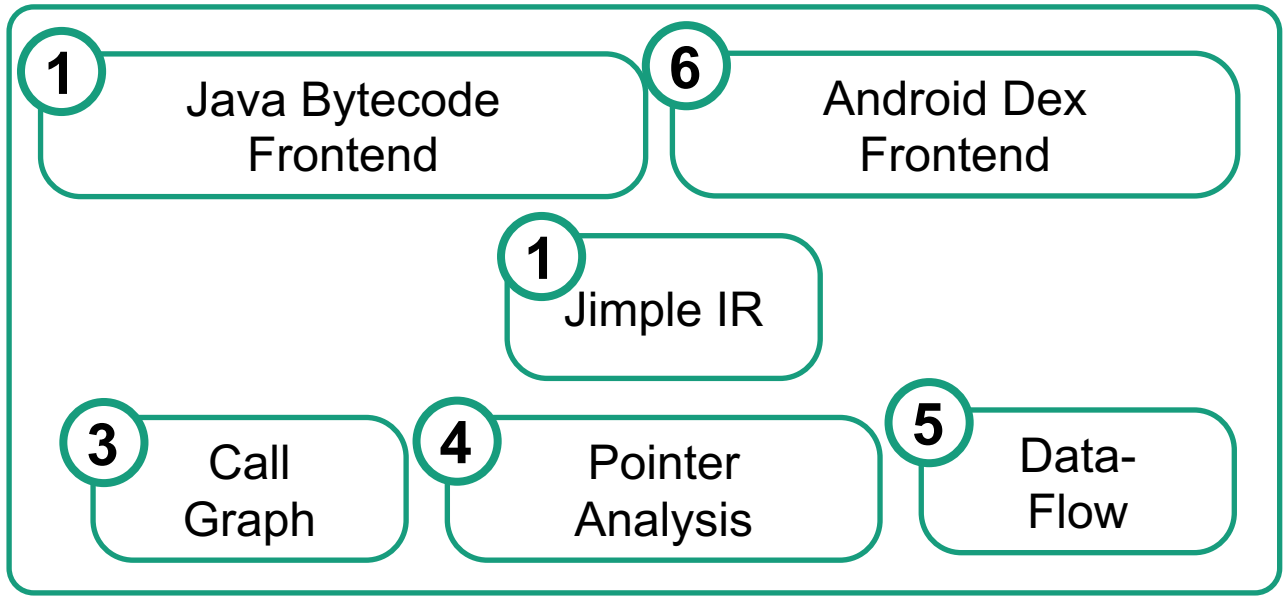
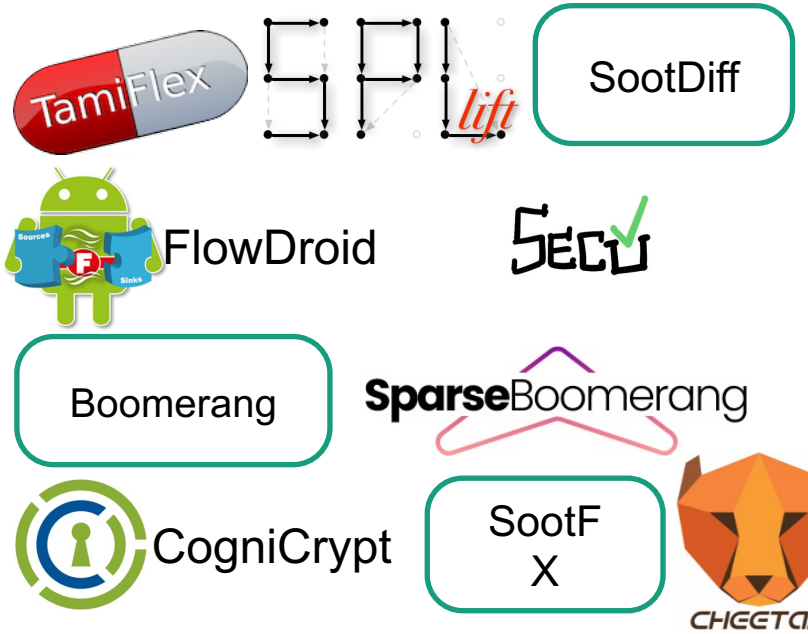
Context: Static Program Analysis

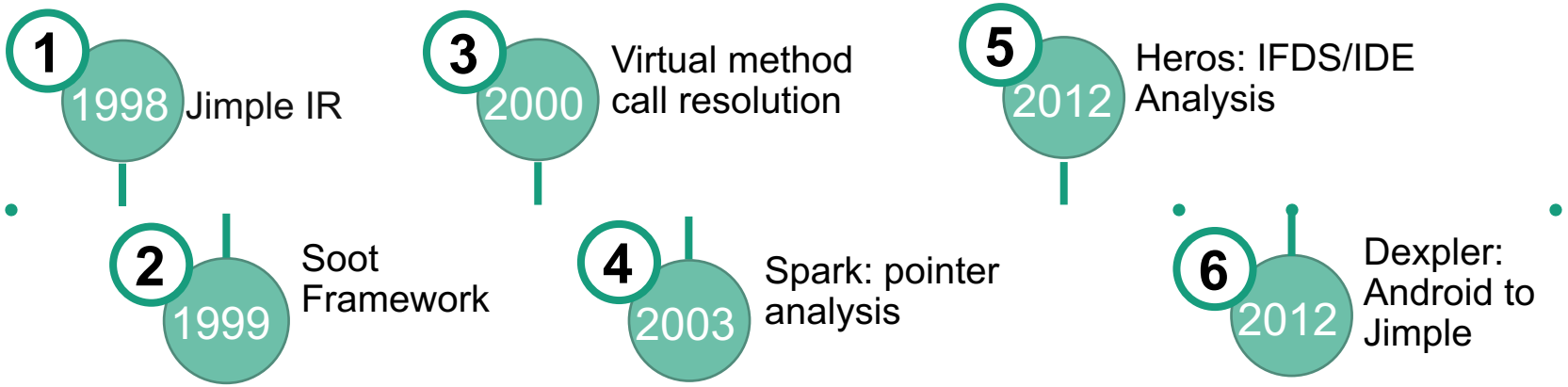


SootUp is a redesign of the **Soot** static analysis framework.

Soot: A Brief History







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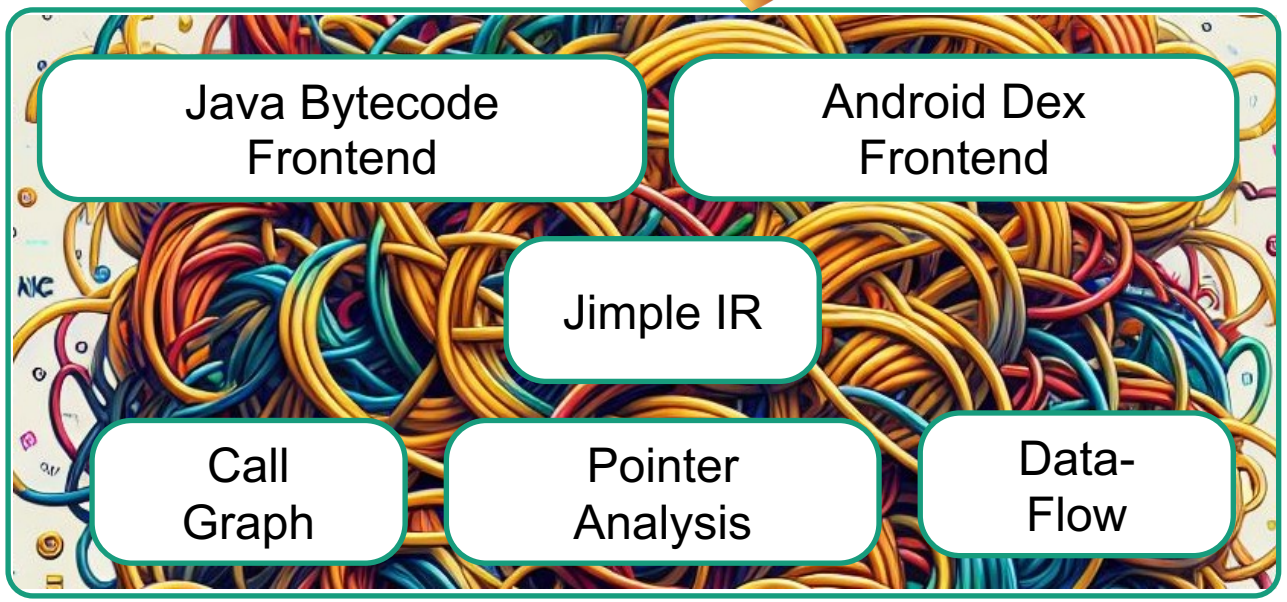
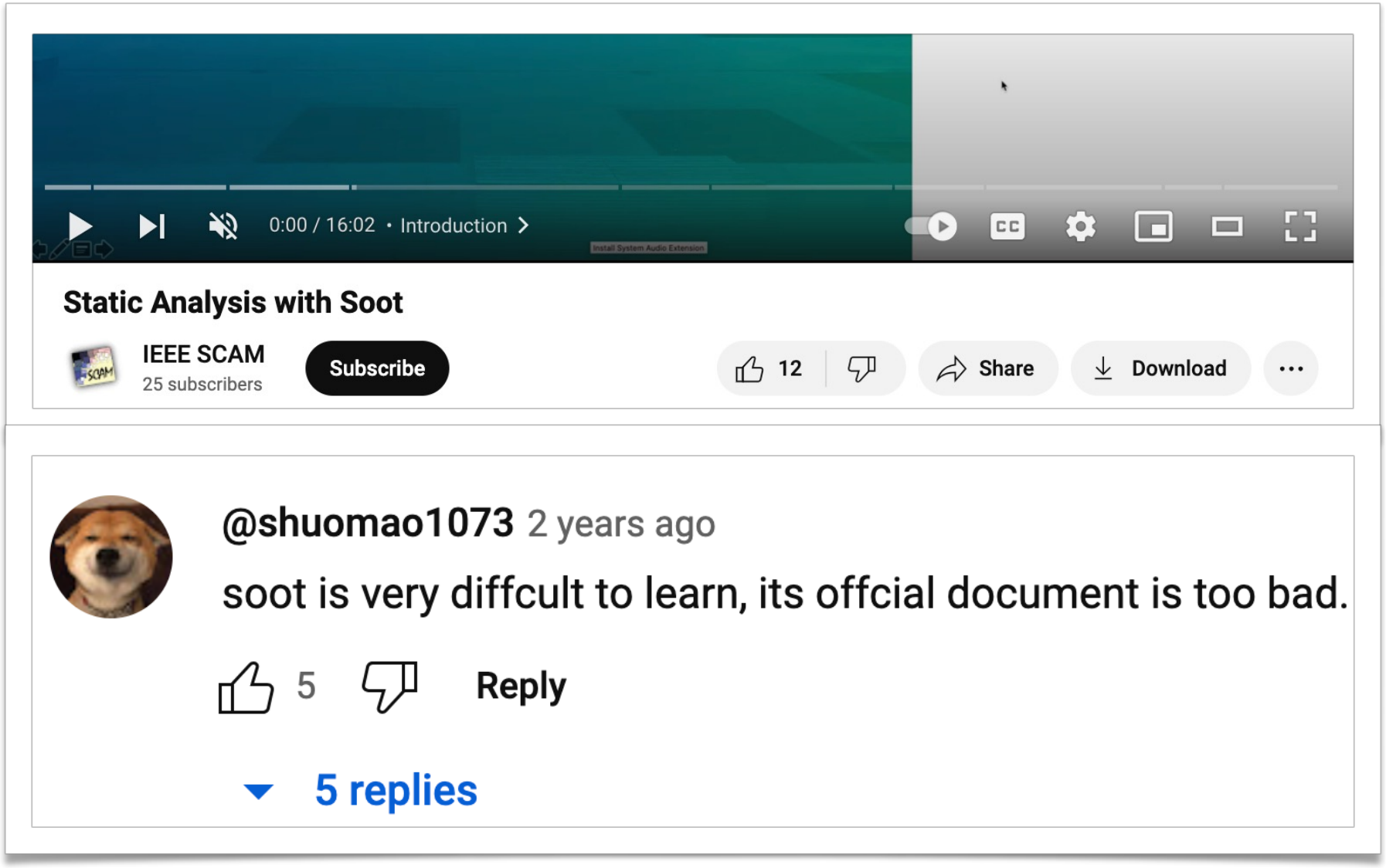
Soot: Strengths & Drawbacks



- Jimple IR
  - Local vars instead of stack in bytecode
  - No nested scopes, explicit control-flow
- Call Graph algorithms
  - CHA, RTA, DTA, VTA
- SPARK pointer analysis framework
  - Whole program
  - Context- and flow-insens.
- Heros Data-Flow Analysis framework
  - IFDS/IDE

Frequently extended to support new features → Suboptimal Design

“Soot is very difficult to learn”



DFG Deutsche Forschungsgemeinschaft
German Research Foundation

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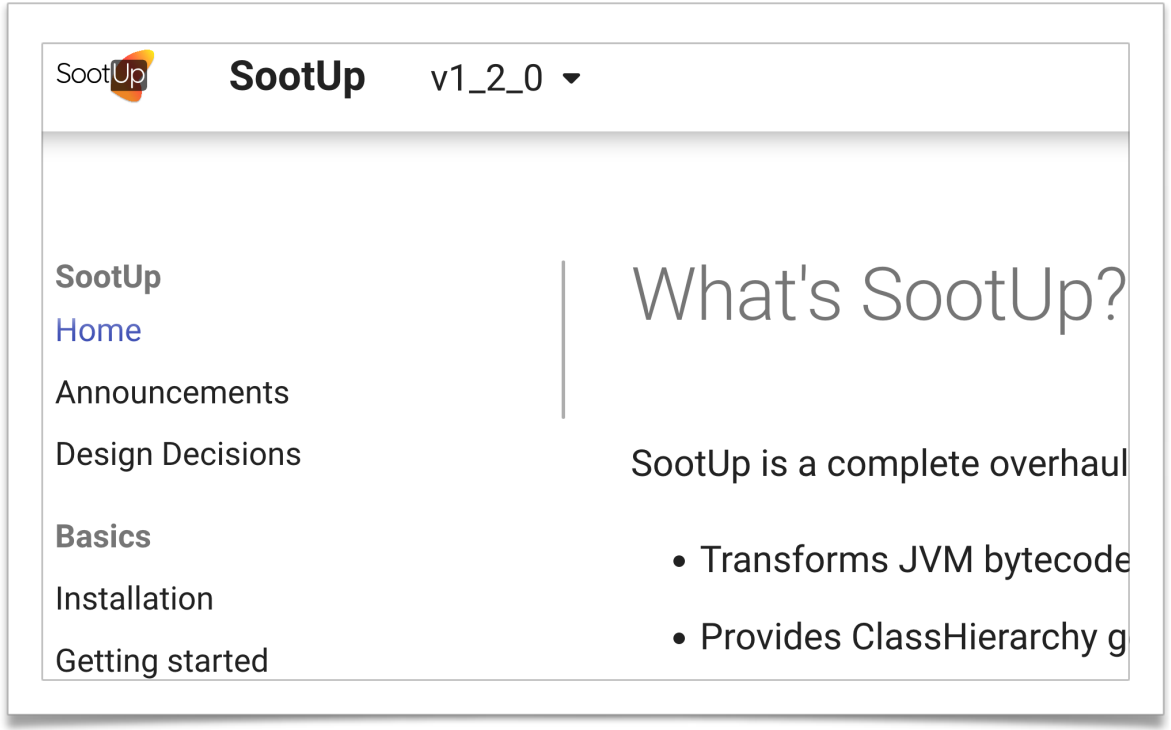
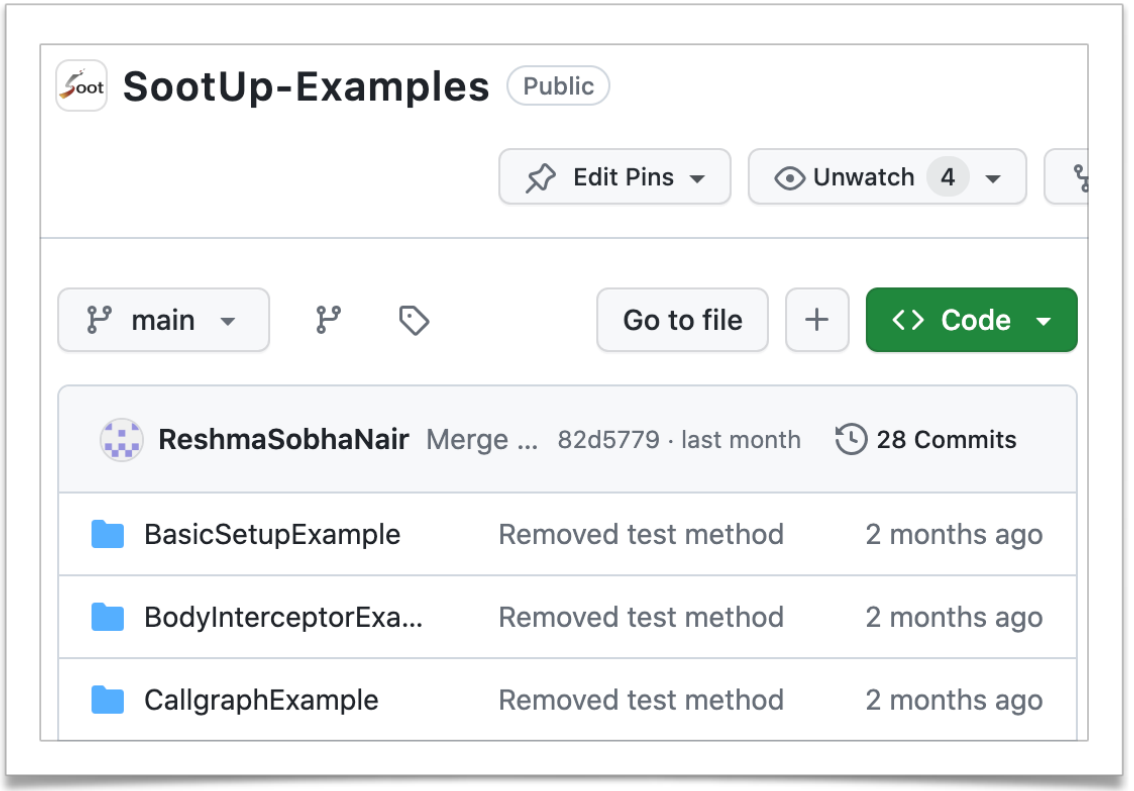
SootUp aims to be beginner friendly

- Dedicated web page for:
  - Up-to-date documentation
  - Tutorials



- Dedicated repository with running examples



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Development Process

- Actively maintained at Github
- No breaking changes through CI 

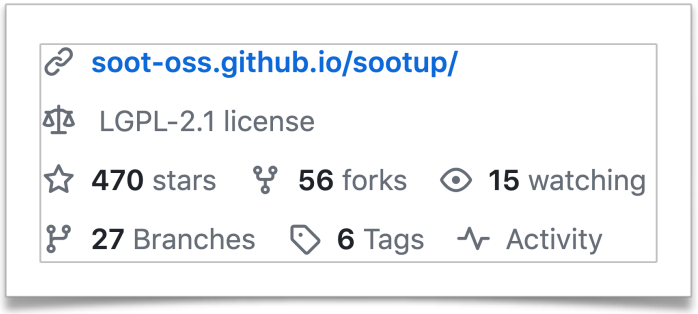
- High code coverage through systematic testing 

- Up-to-date documentation & tutorials 

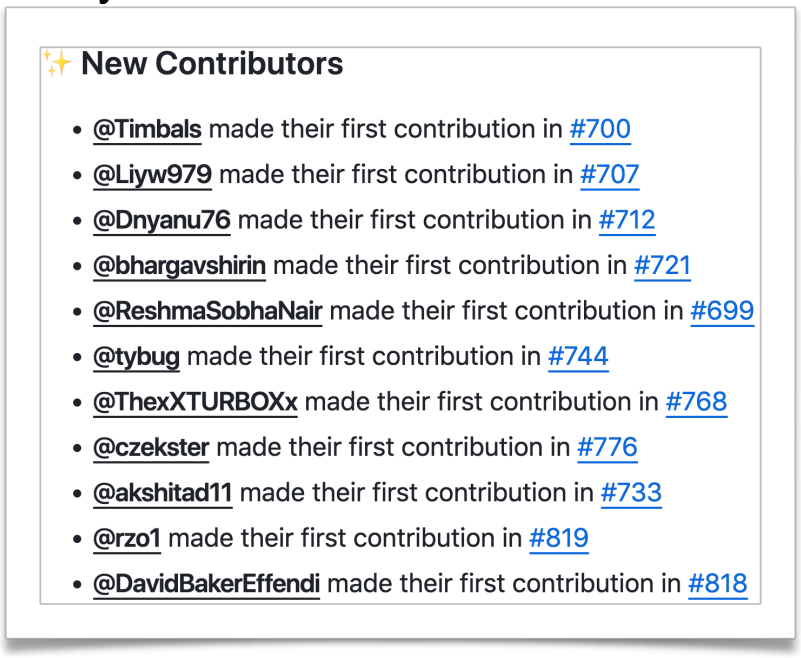
- Released at Maven Central 

Building a User Base

- Already an active user base



- Many outside contributors



- In Labs:
  - SootUp is used in our static analysis course at Paderborn University

- Hackathons (CTF):
  - 1st SootUp Hackathon, at UPB in May 2023
  - 2nd SootUp Hackathon, at UPB in June 2024

- Today: SootUp Tutorial!

Tutorial Program

What's next?

- Technical Introduction
- Exercise 1: Get to know the API
- Live Demo: Call Graph Construction
- Exercise 2: Taint analysis with SootUp and Heros
- Closing

TECHNICAL INTRODUCTION

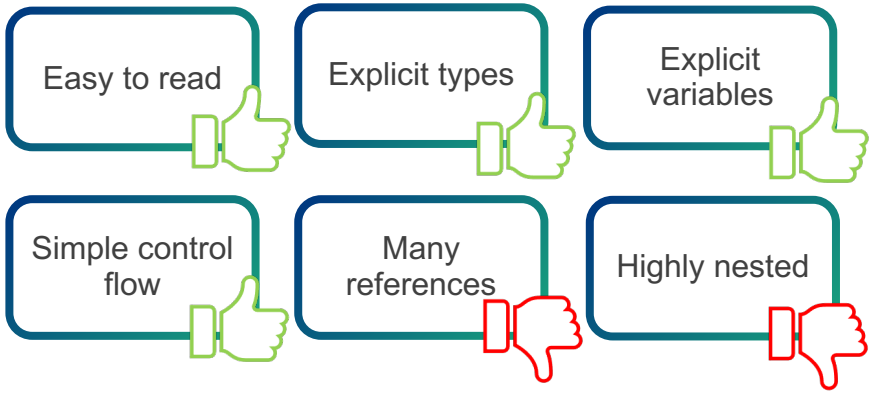
Source Code vs Bytecode vs Jimple

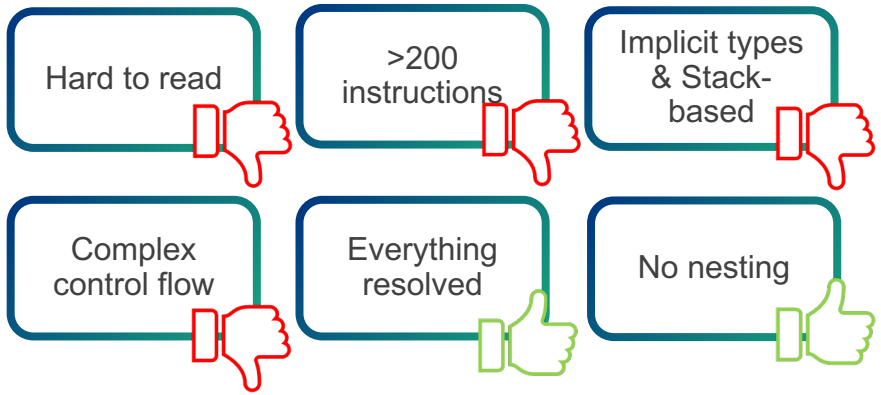
```java
public static void sampleMethod(int x) {
    if (x  % 2 == 0) {
        System.out.println("Even");
    } else {
        System.out.println("Odd");
    }
}
```

Java Source Code

```
1  public static sampleMethod(I)V
2    L0
3      ILOAD 0
4      ICONST_2
5      IREM
6      IFNE L1
7    L2
8      GETSTATIC java/lang/System.out : Ljava/io/PrintStream;
9      LDC "Even"
10     INVOKEVIRTUAL java/io/PrintStream.println (Ljava/lang/String;)V
11     GOTO L3
12   L1
13     FRAME SAME
14     GETSTATIC java/lang/System.out : Ljava/io/PrintStream;
15     LDC "Odd"
16     INVOKEVIRTUAL java/io/PrintStream.println (Ljava/lang/String;)V
17   L3
18     FRAME SAME
19     RETURN
20   L4
21     LOCALVARIABLE x I L0 L4 0
22     MAXSTACK = 2
23     MAXLOCALS = 1
24 }
```

Java Bytecode





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Source Code vs Bytecode vs Jimple

```java
public static void sampleMethod(int x) {
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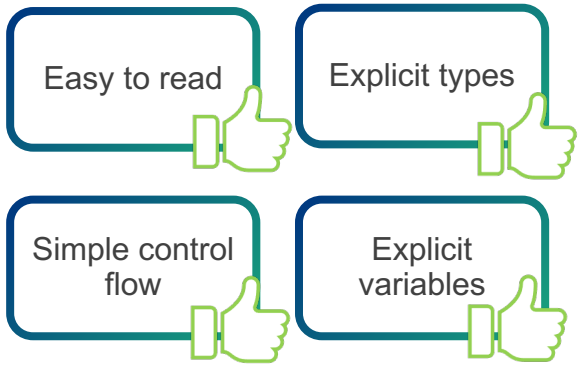
Java Source Code




```
1 public static void sampleMethod(int)
2 {
3   int x, $stack1;
4   java.io.PrintStream $stack2, $stack3;
5
6   x := @parameter0: int;
7
8   $stack1 = x % 2;
9   if $stack1 ≠ 0 goto label1;
10
11  $stack3 = <java.lang.System: java.io.PrintStream out>;
12  virtualinvoke $stack3.<java.io.PrintStream:
13    void println(java.lang.String)>("Even");
14  goto label2;
15
16  label1:
17    $stack2 = <java.lang.System: java.io.PrintStream out>;
18    virtualinvoke $stack2.<java.io.PrintStream:
19      void println(java.lang.String)>("Odd");
20
21  label2:
22    return;
23 }
```

Jimple

```
1 public static sampleMethod(I)V
2   L0
3     ILOAD 0
4     ICONST_2
5     IREM
6     IFNE L1
7   L2
8     GETSTATIC java/lang/System.out : Ljava/io/PrintStream;
9     LDC "Even"
10    INVOKEVIRTUAL java/io/PrintStream.println (Ljava/lang/String;)V
11    GOTO L3
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17  L3
18    FRAME SAME
19    RETURN
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21    LOCALVARIABLE x I L0 L4 0
22    MAXSTACK = 2
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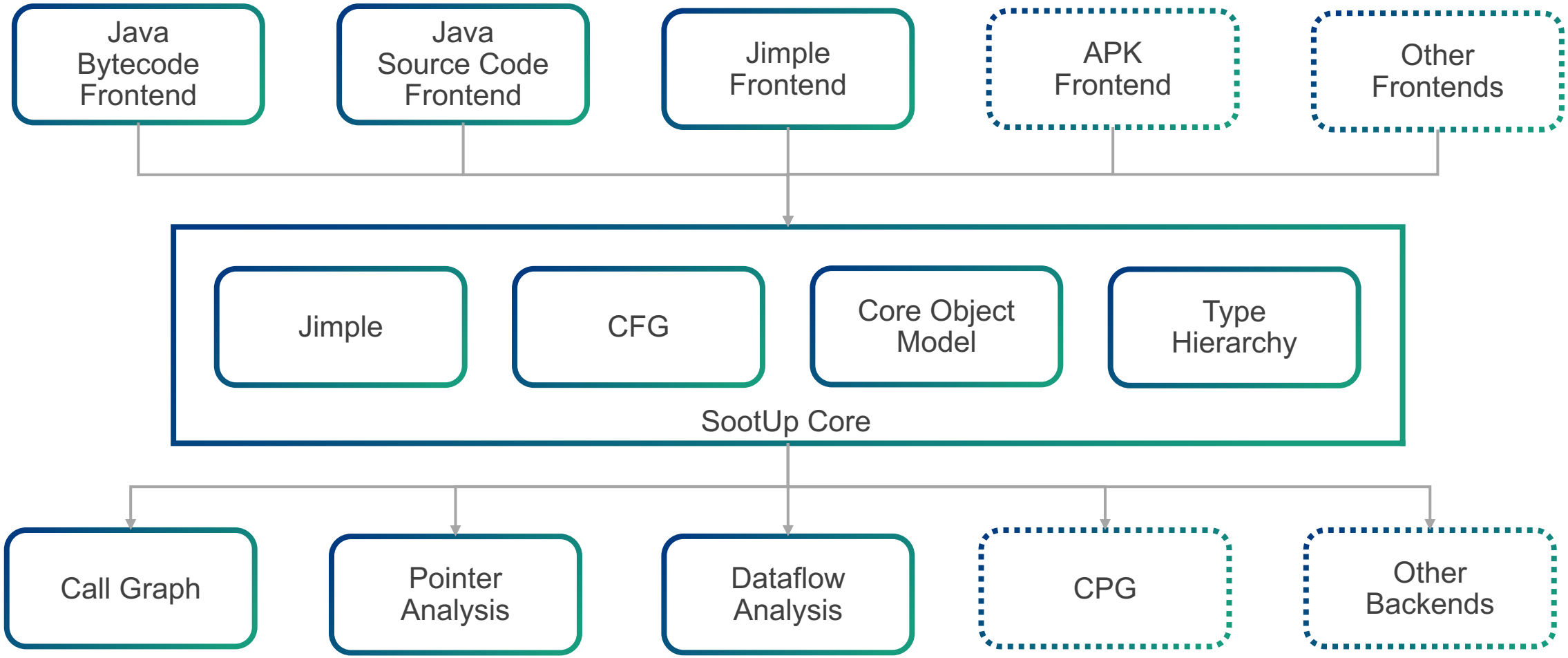
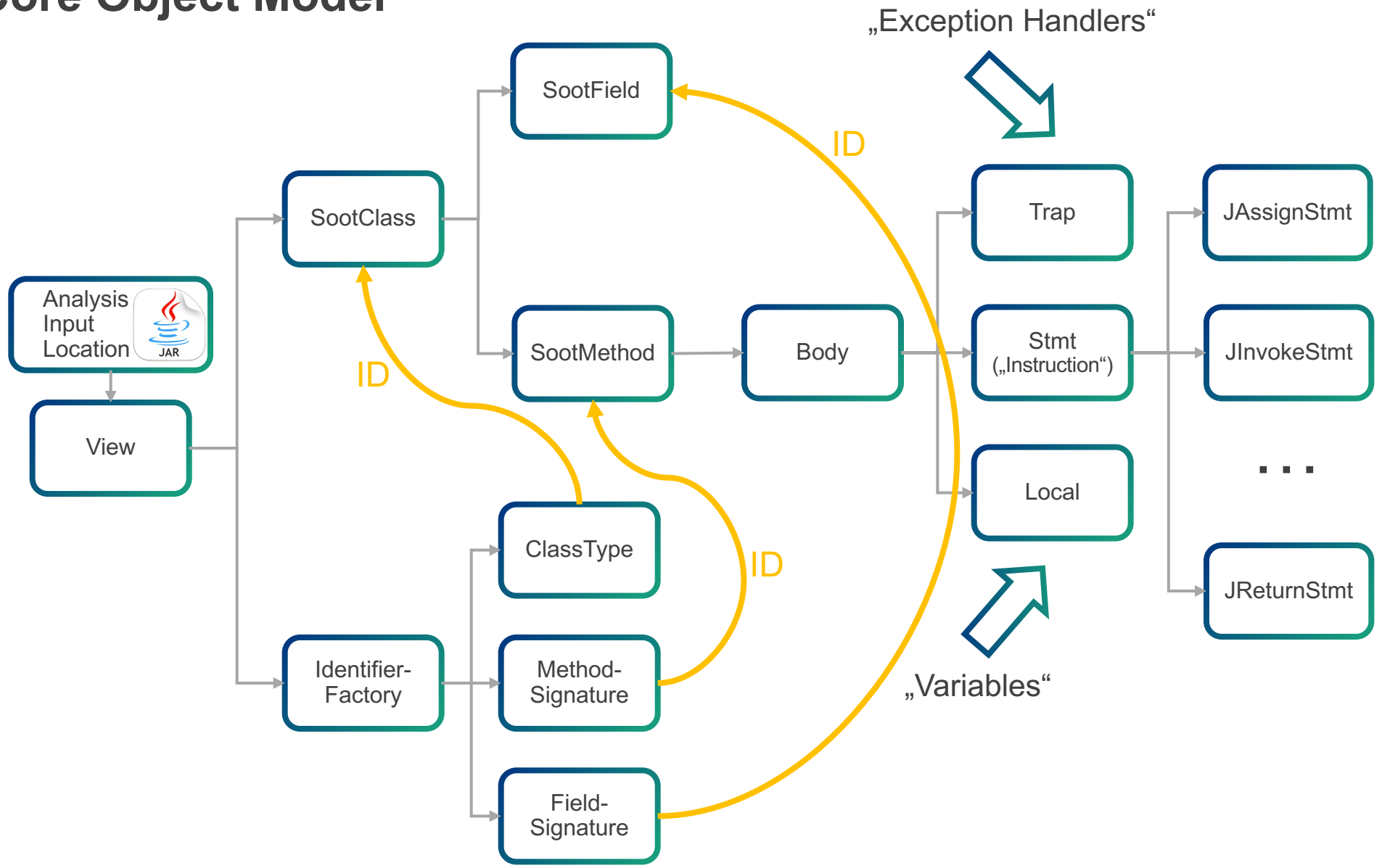
24 }
```

Java Bytecode

Architecture and Modules



Core Object Model

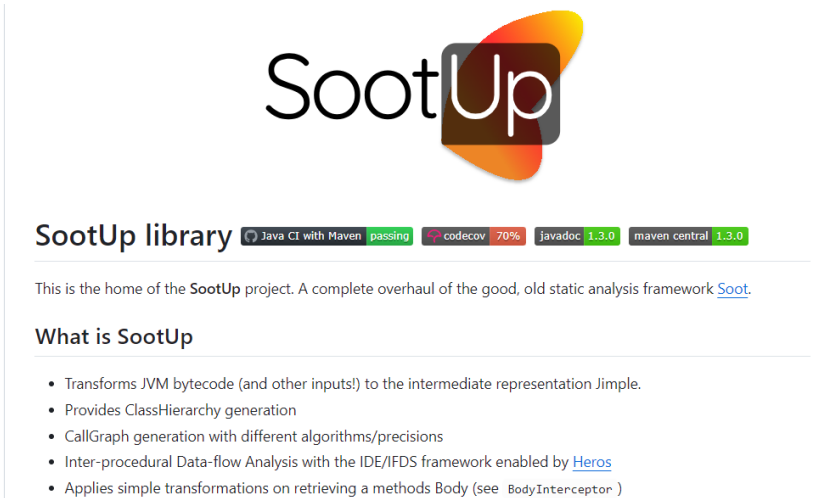


Basic API Usage

1.
2.
3.
4.

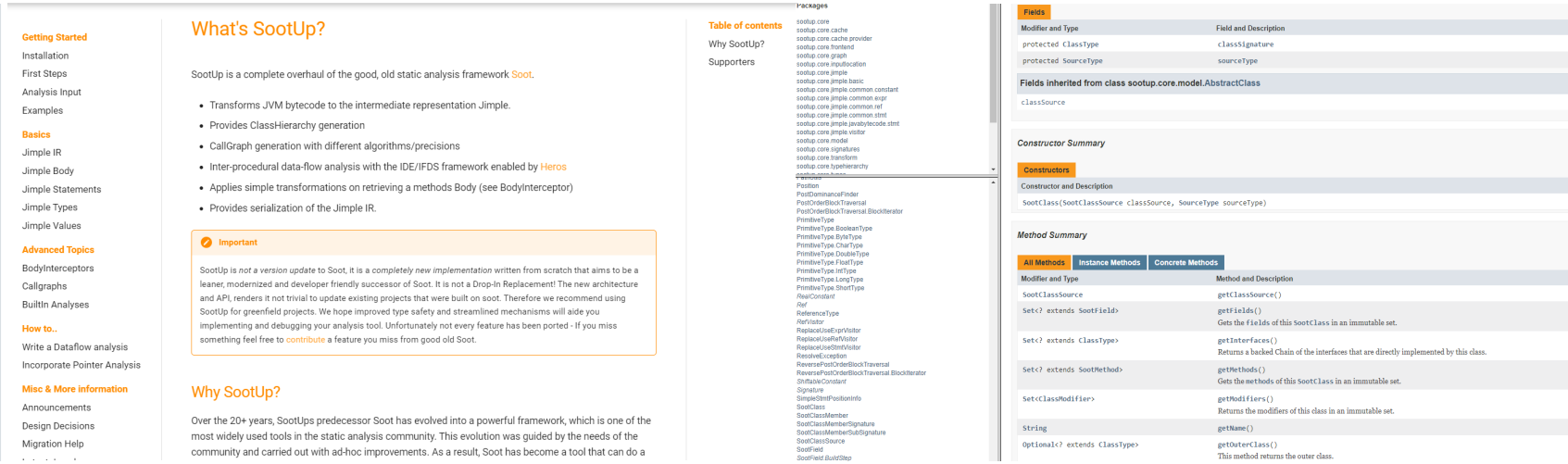
```
1  AnalysisInputLocation inputLocation =
2          new JavaClassPathAnalysisInputLocation("path2Binary");
3
4  JavaView view = new JavaView(inputLocation);
5
6  JavaClassType classType =
7          view.getIdentifierFactory().getClassType("example.HelloWorld");
8
9  Optional<JavaSootClass> sootClassOpt = view.getClass(classType);
10 JavaSootClass sootClass = sootClassOpt.get();
```

Helpful Resources



- Repository

https://github.com/soot-oss/SootUp



- Documentation

https://soot-oss.github.io/SootUp

- Javadoc

https://javadoc.io/doc/org.soot-oss/sootup.core

EXERCISE 1: GET TO KNOW THE API

Exercise 1: Get to know the API

- Task: Extract the following properties from the given Jar:
  1. Number of **classes**
  2. Number of **private methods**
  3. Number of **static fields**
  4. Number of **methods** where the **return type** is the same as its first **parameter type** (if exists)
  5. Number of **assignment statements** in method *„boolean test(java.lang.String)“* in class *„org.reflections.util.FilterBuilder“*

Steps to access the exercise:

1. git clone https://github.com/soot-oss/SootUp-Tutorial.git
2. git checkout 1_Exercise-1

OR

Download from: https://sootup-tutorial.surge.sh

Exercise 1: Helpful APIs

AnalysisInputLocation	
	new **JavaClassPathAnalysisInputLocation**(String path2jar)

JavaView	
	new **JavaView**(AnalysisInputLocation inputLocation)
IdentifierFactory	**getIdentifierFactory**()
Collection<JavaSootClass>	**getClasses**()
Optional<JavaSootMethod>	**getMethod**(MethodSignature sig)

IdentifierFactory	
ClassType	**getClassType**(String fullyQualifiedClassName)
MethodSignature	**getMethodSignature**(ClassType ct, String methodName, String returnType, List<String> parameterTypes)

JavaSootClass	
Optional<JavaSootMethod>	**getMethod**(String name, Iterable<Type> parameterTypes)
Set<JavaSootMethod>	**getMethods**()
Set<JavaSootField>	**getFields**()

JavaSootField	
boolean	**isStatic**()

JavaSootMethod	
boolean	**isPrivate**()
int	**getParameterCount**()
Type	**getReturnType**()
Type	**getParameterType**(int index)
boolean	**hasBody**()
Body	**getBody**()

Body	
List<Stmt>	**getStmts**()

Stmt
Subtypes: **JAssignStmt**, **JInvokeStmt**, **JReturnStmt**, **JIfStmt**, … (instanceof)

For more help check:

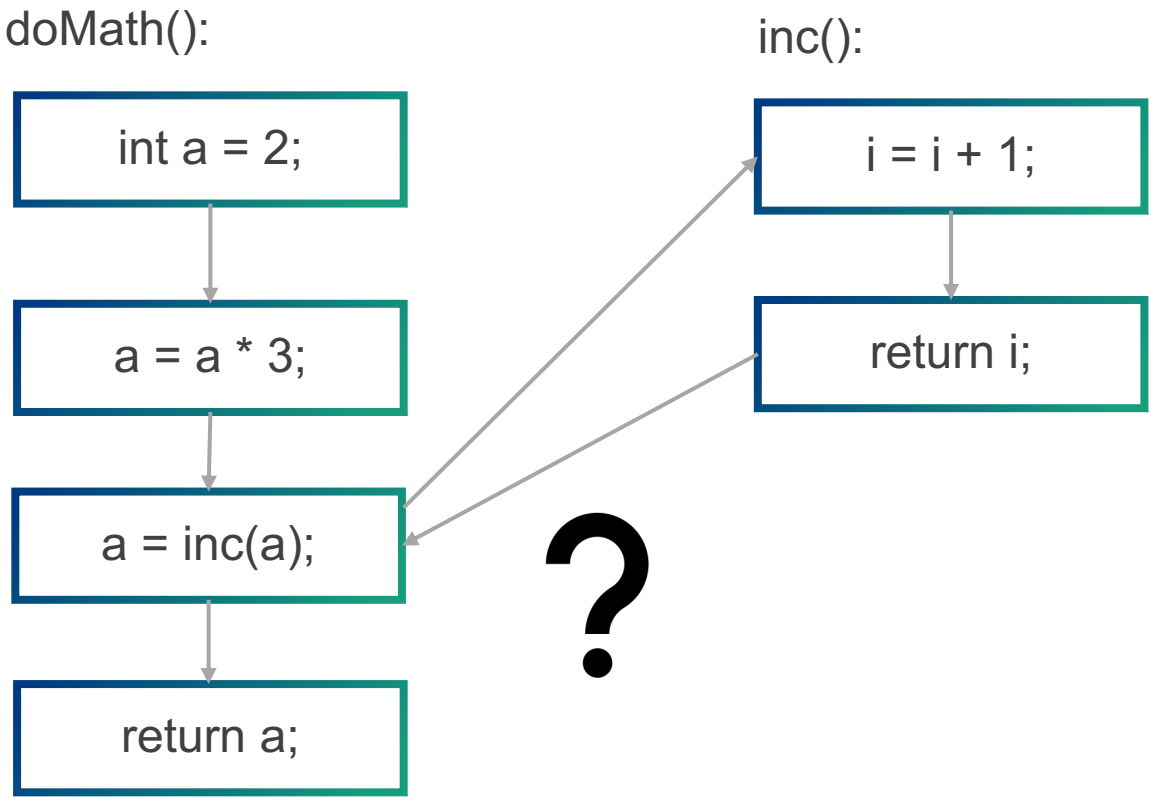
- Documentation: soot-oss.github.io/SootUp
- Javadoc: soot-oss.github.io/SootUp/apidocs

LIVE DEMO: CALL GRAPHS

Interprocedural Analysis

```
public int doMath(){
  int a = 2;
  a= a*3
  a = inc(a);
  return a
}

public int inc(int i){
  return I + 1;
}
```

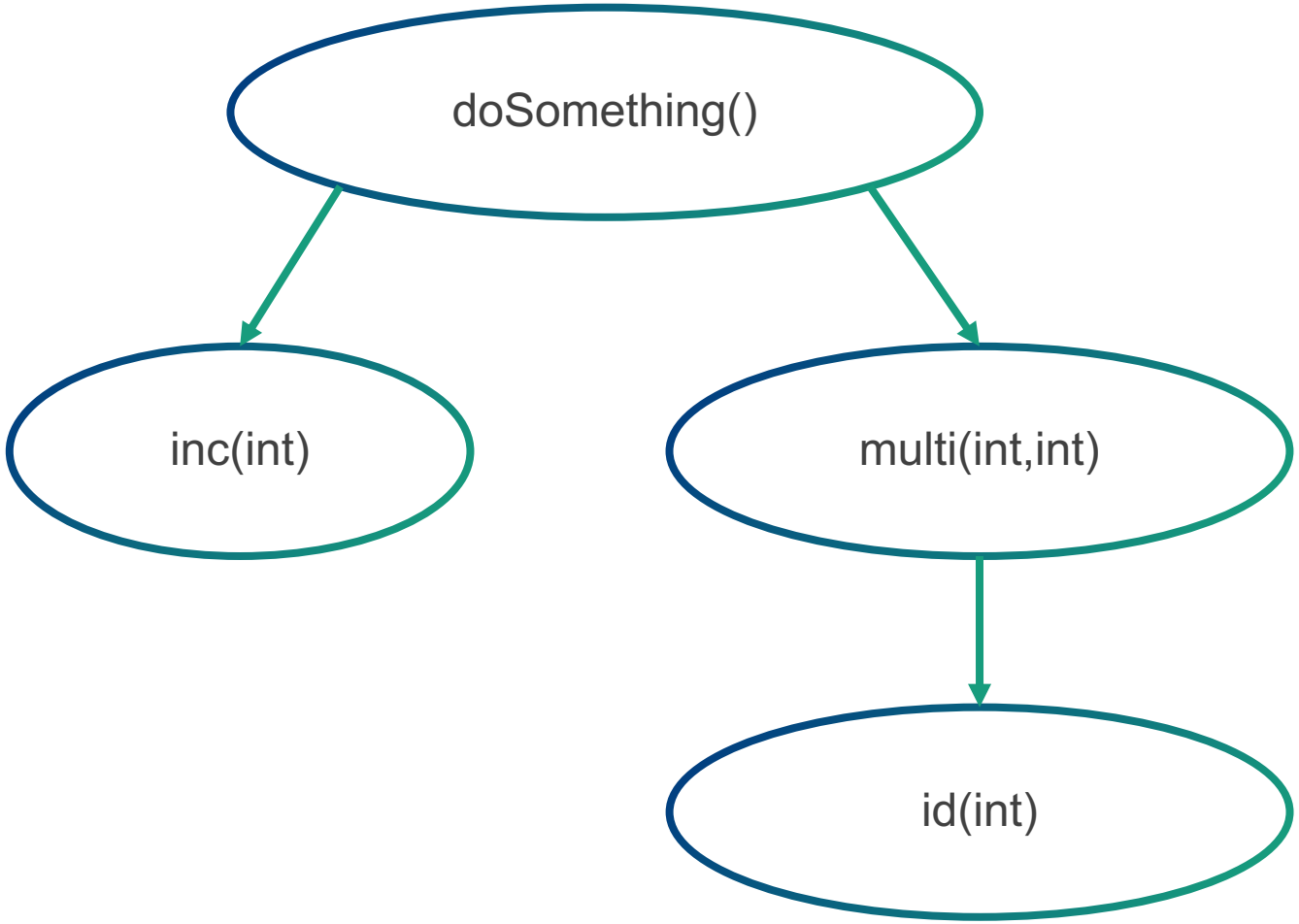


Call Graph

```
public int doSomething(){
  int a = 2;
  a = inc(a);
  a = inc(a);
  return multi(a,2);
}

public int inc(int i){
  return I + 1;
}

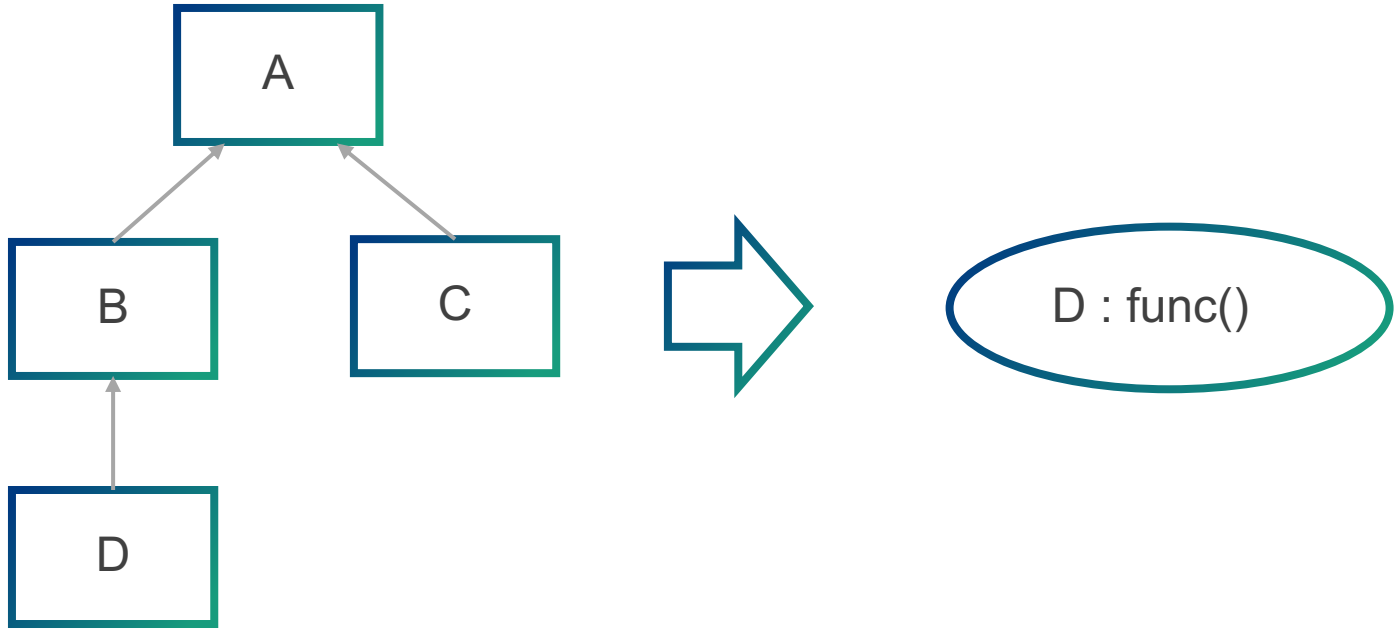
public int multi(int i, int d){
 return id(i) * d;
}
public int id(int i){
 return i;
}
```



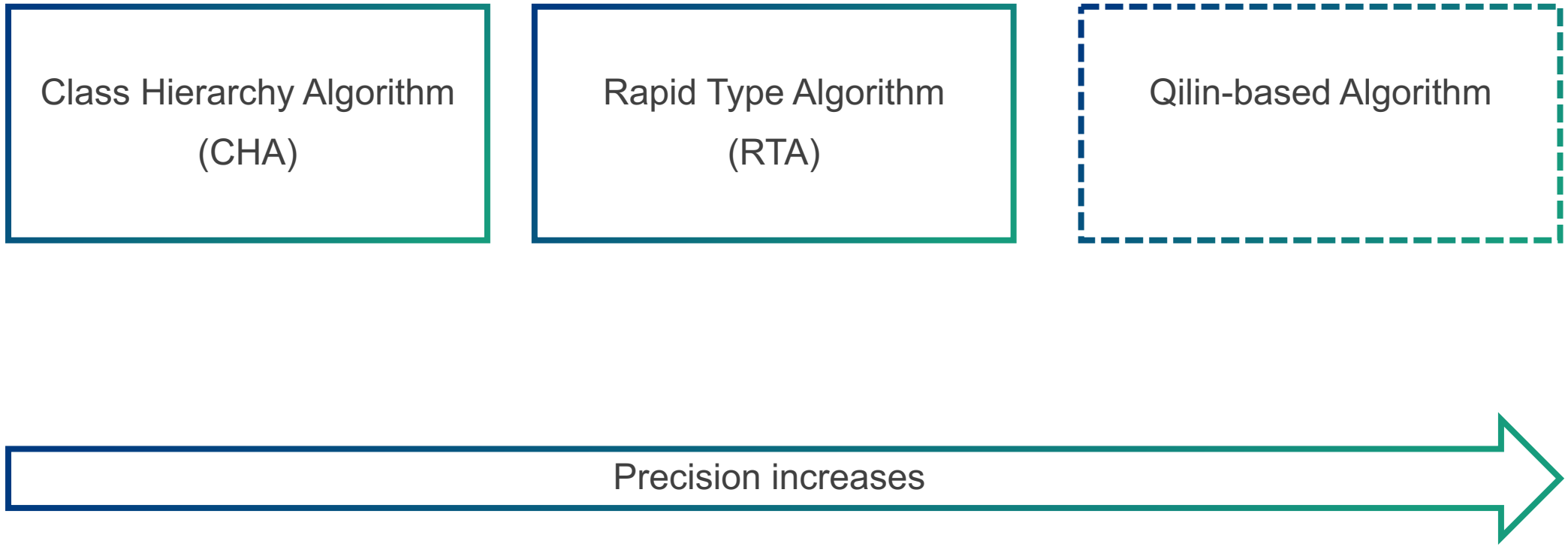
Polymorphism in Java

Virtual invokes

```
public void start (){
   C c = new C();
   A a = new D();
   a.func();
}
```



Supported Call Graph Algorithm



Supported Call Graph Algorithm

```
public void start (){
   C c = new C();
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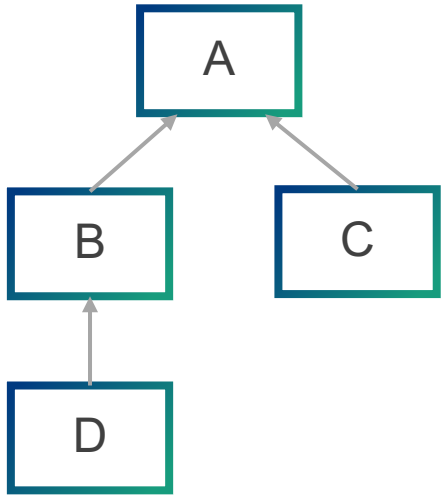
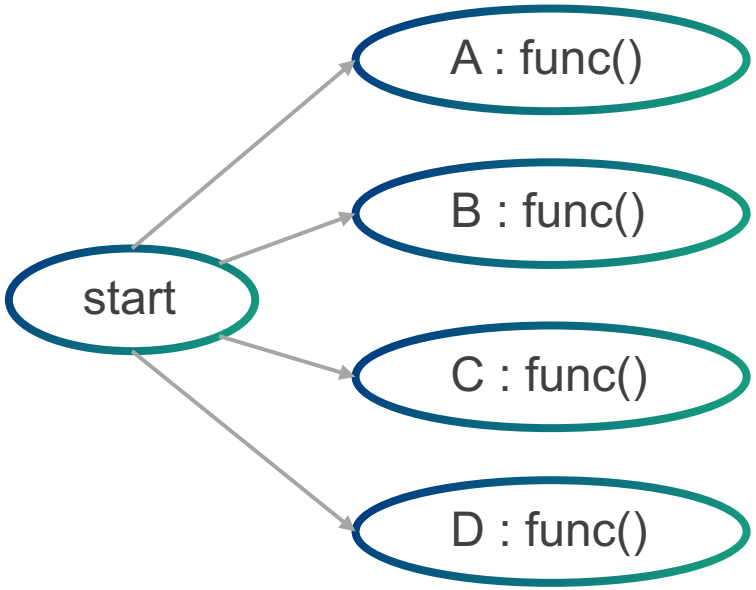
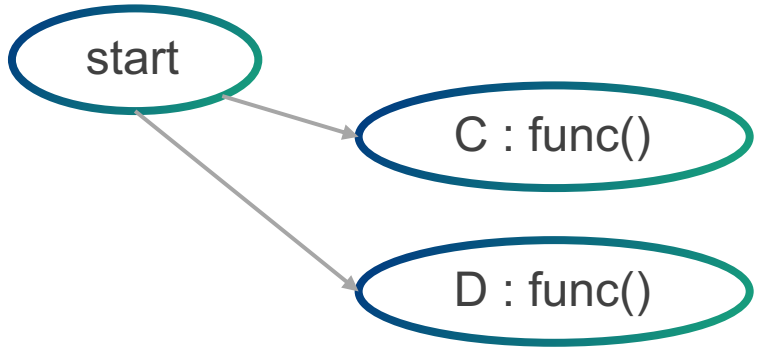
   a.func();
}
```

Class Hierarchy Algorithm (CHA)

Rapid Type Algorithm (RTA)







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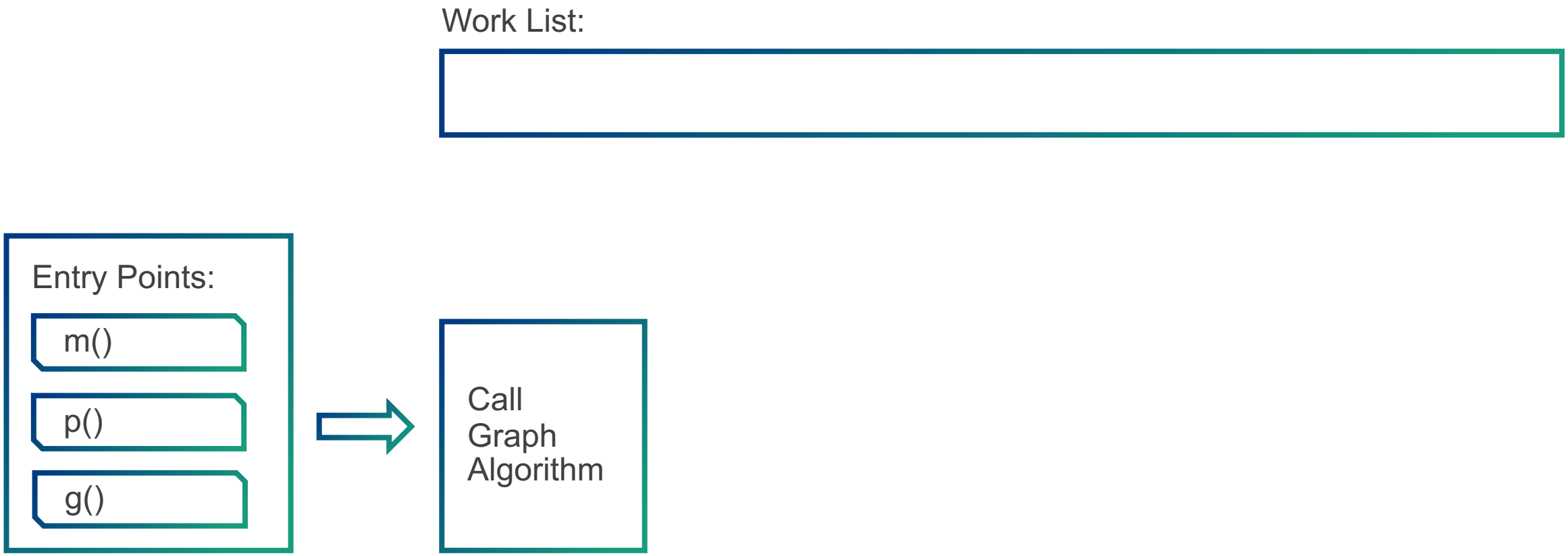
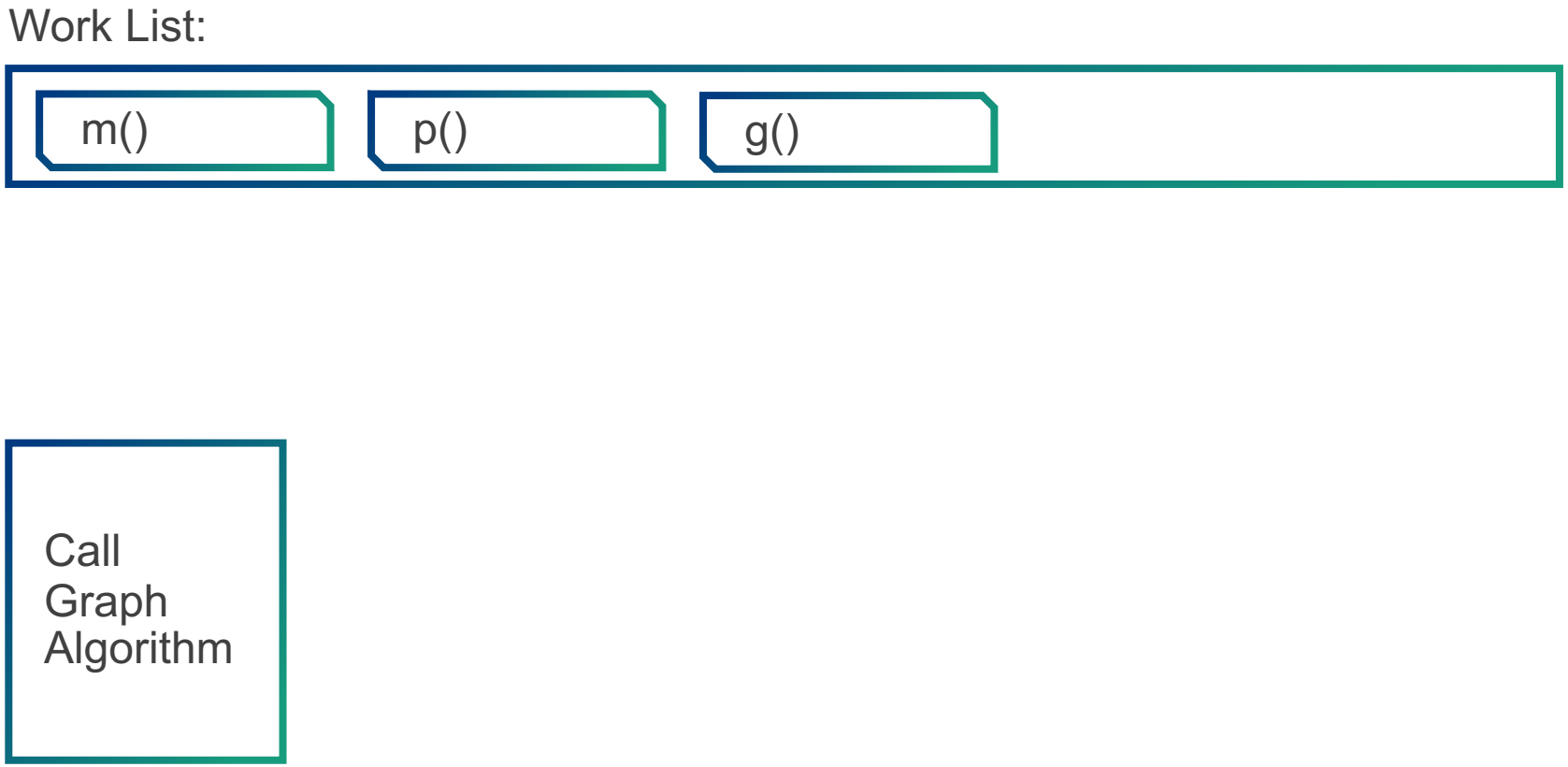
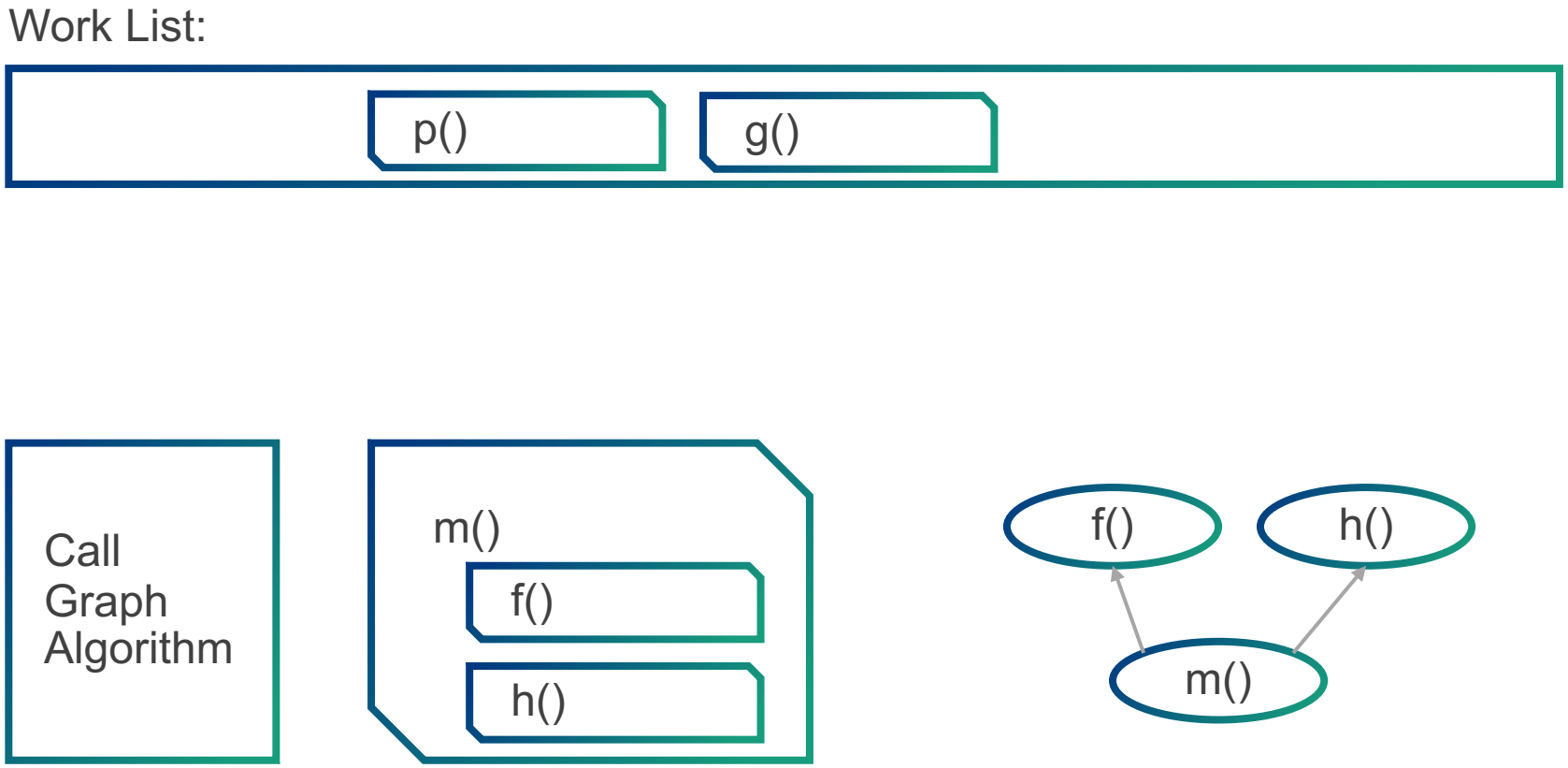
How to Create a Call Grap



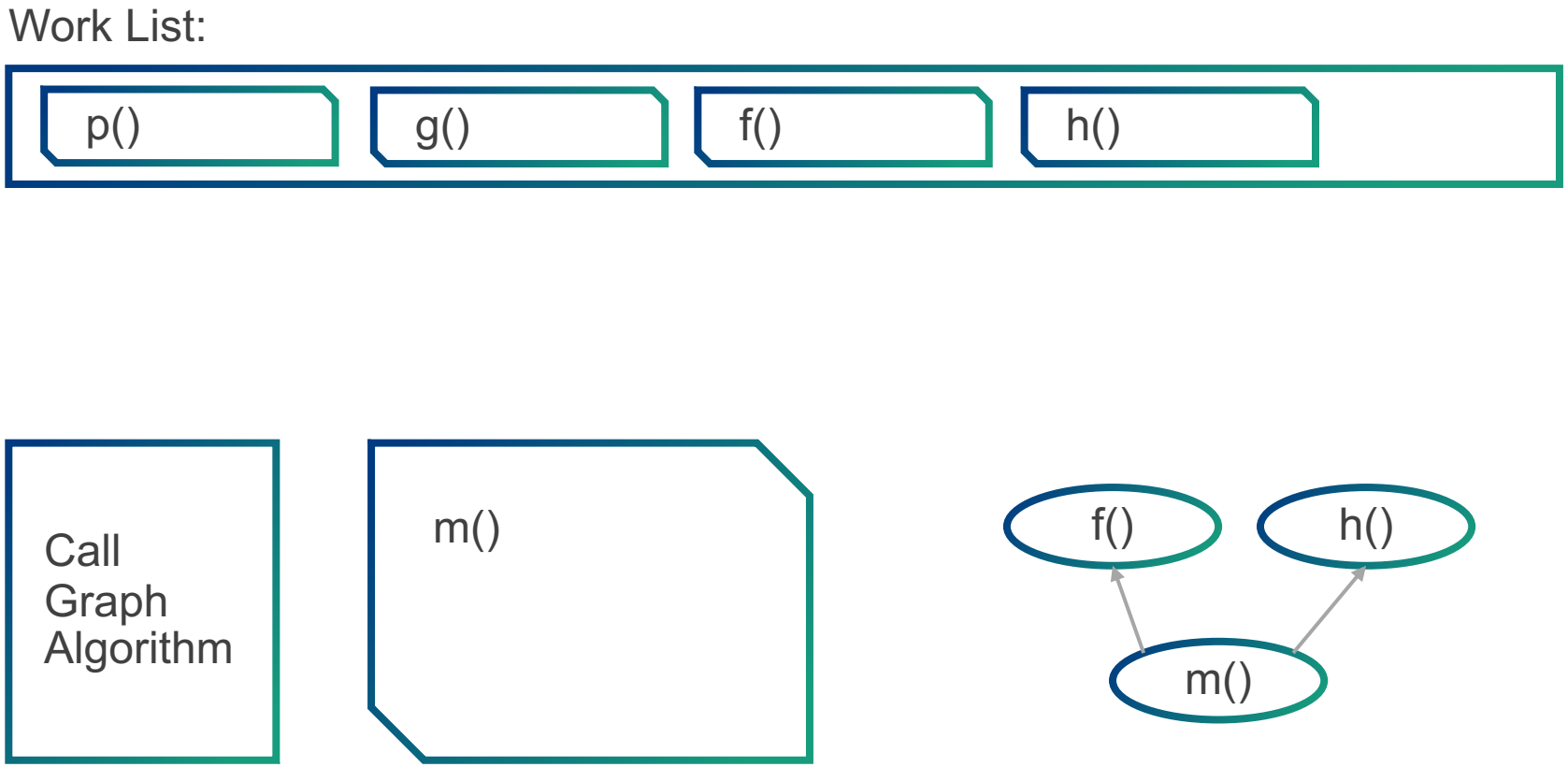
How to Create a Call Graph



How to Create a Call Graph



How to Create a Call Graph



Implicit Calls

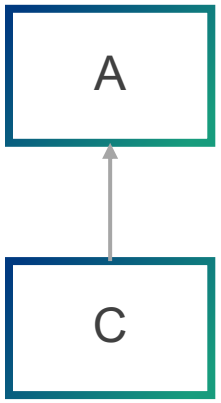
Static Initializer

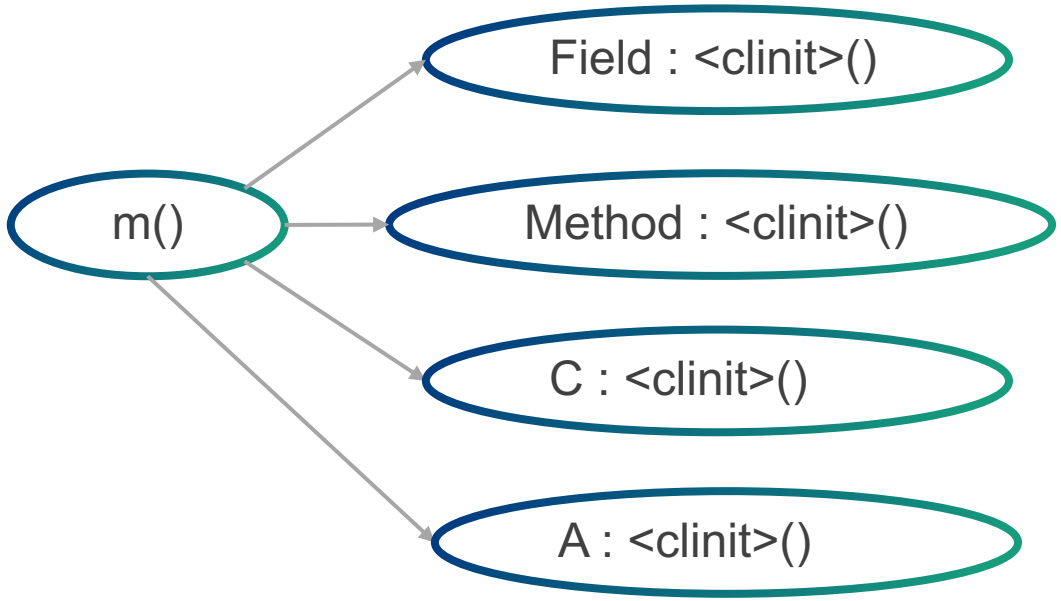
```
public class Field{
static int f = doMath();
}
```

```
public void m (){
int a = Field.f;
Method.m();
A a = new C();
}
```

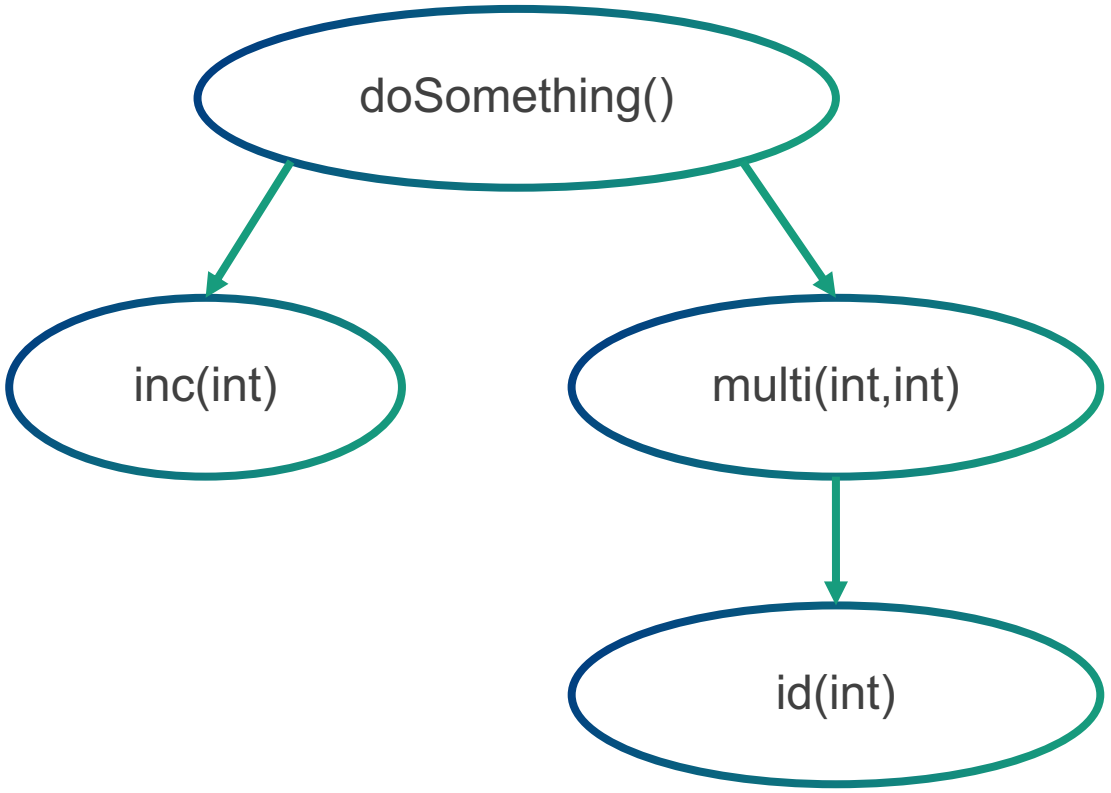
Bytecode:

```
public class Field{
  static int f;
  public void <clinit> (){
    f = doMath();
  }
}
```

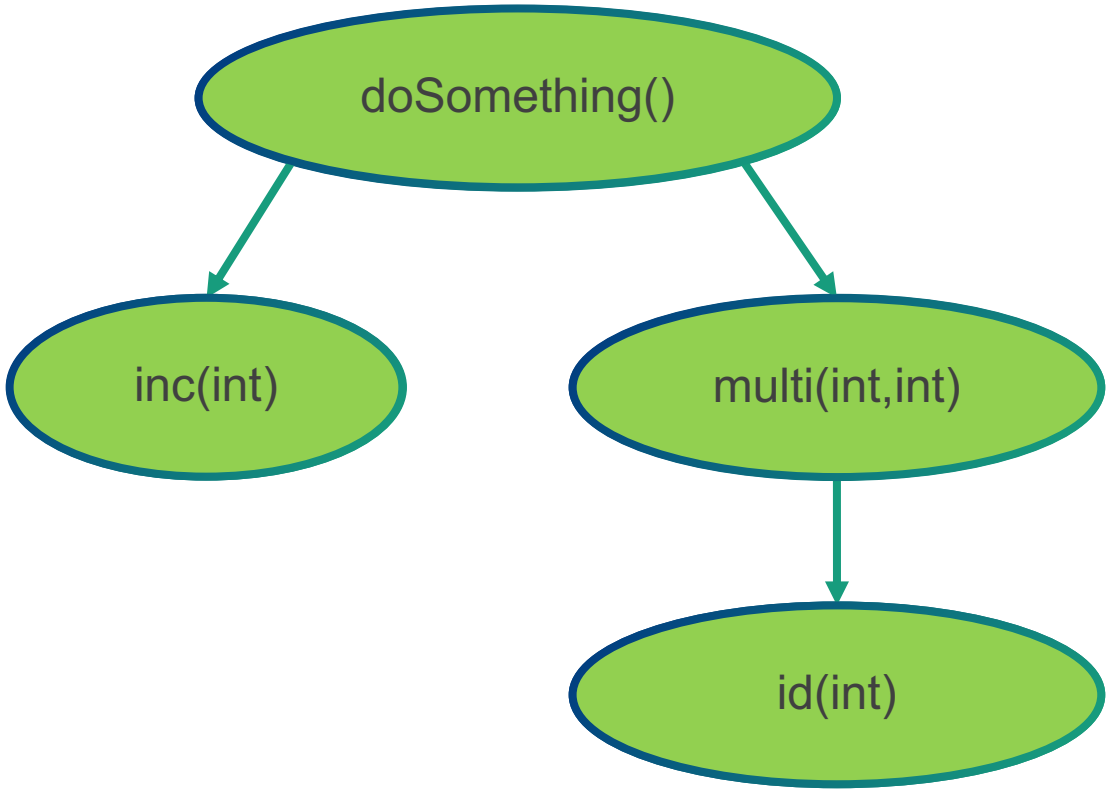




Call Graph API

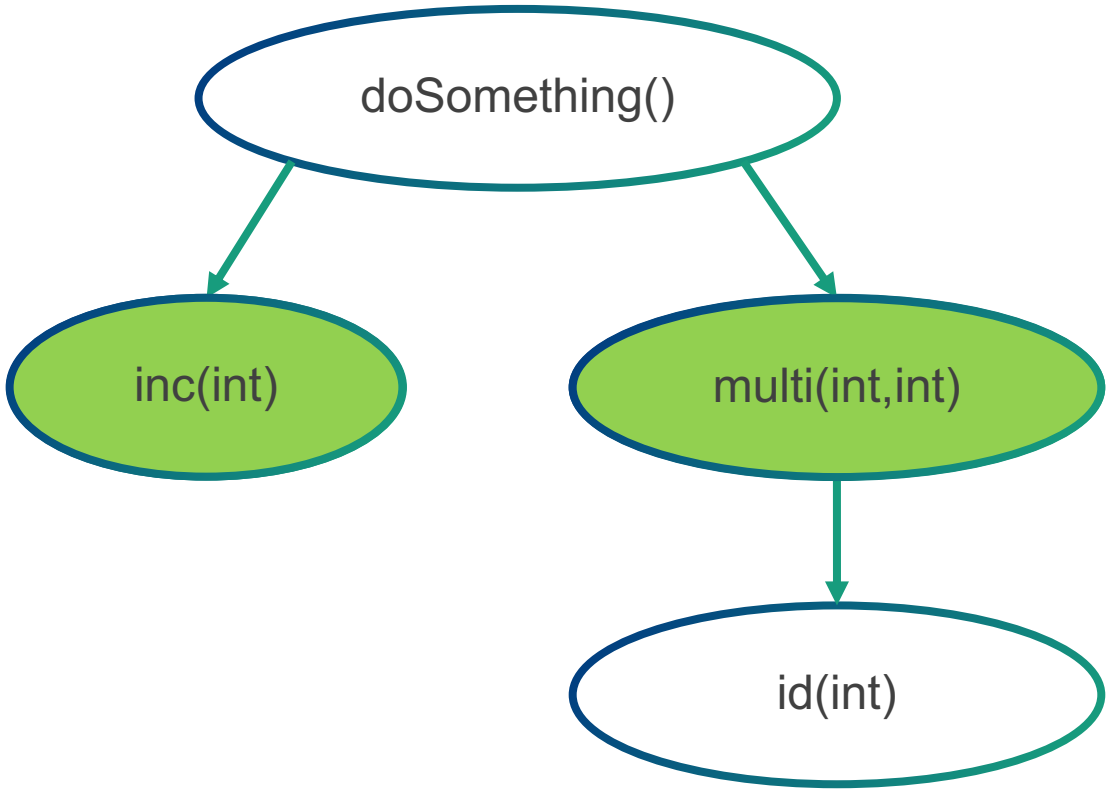


Call Graph API



getMethodSignatures() :

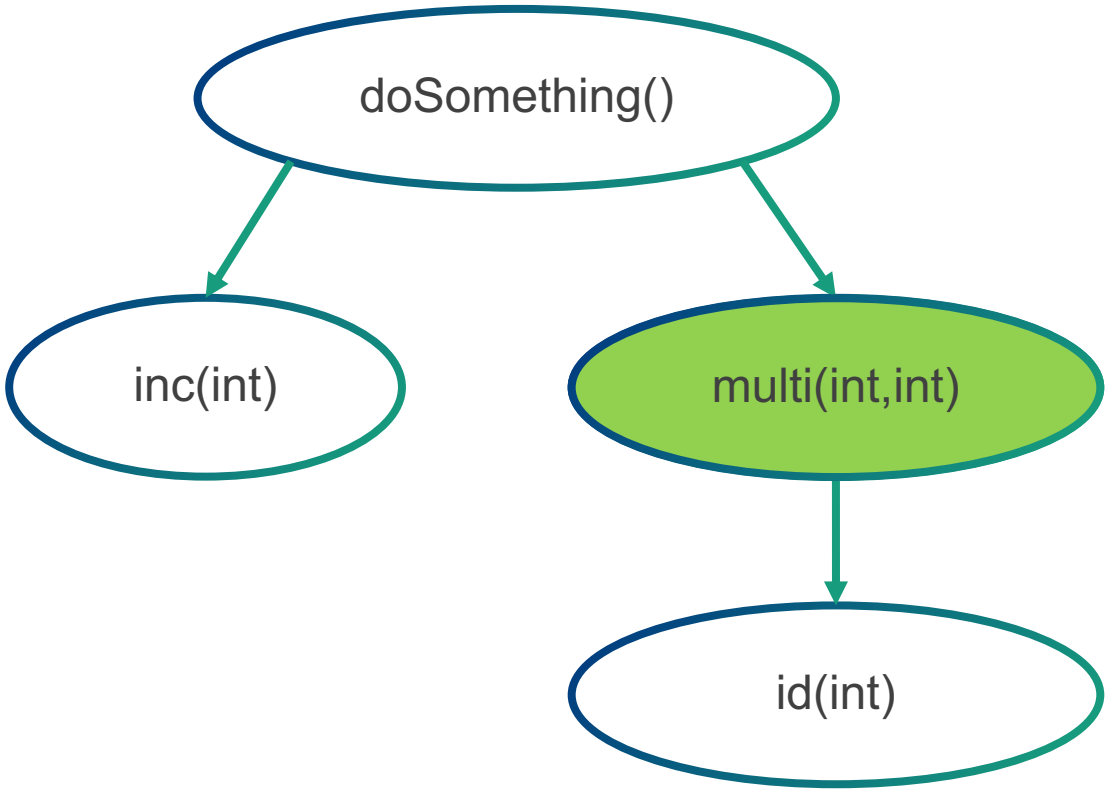
Call Graph API



getMethodSignatures() :

callsFrom(„doSomething()“)

Call Graph API

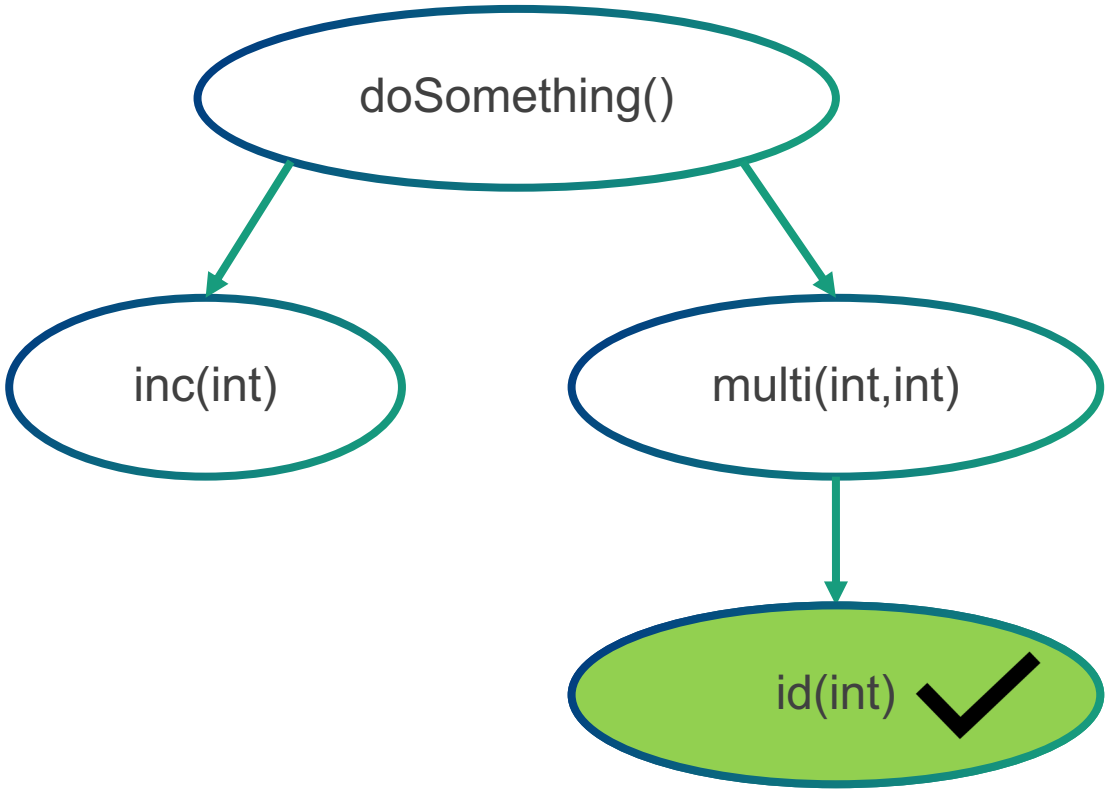


getMethodSignatures() :

callsFrom(„doSomething()“)

callsTo(„id(int)“)

Call Graph API



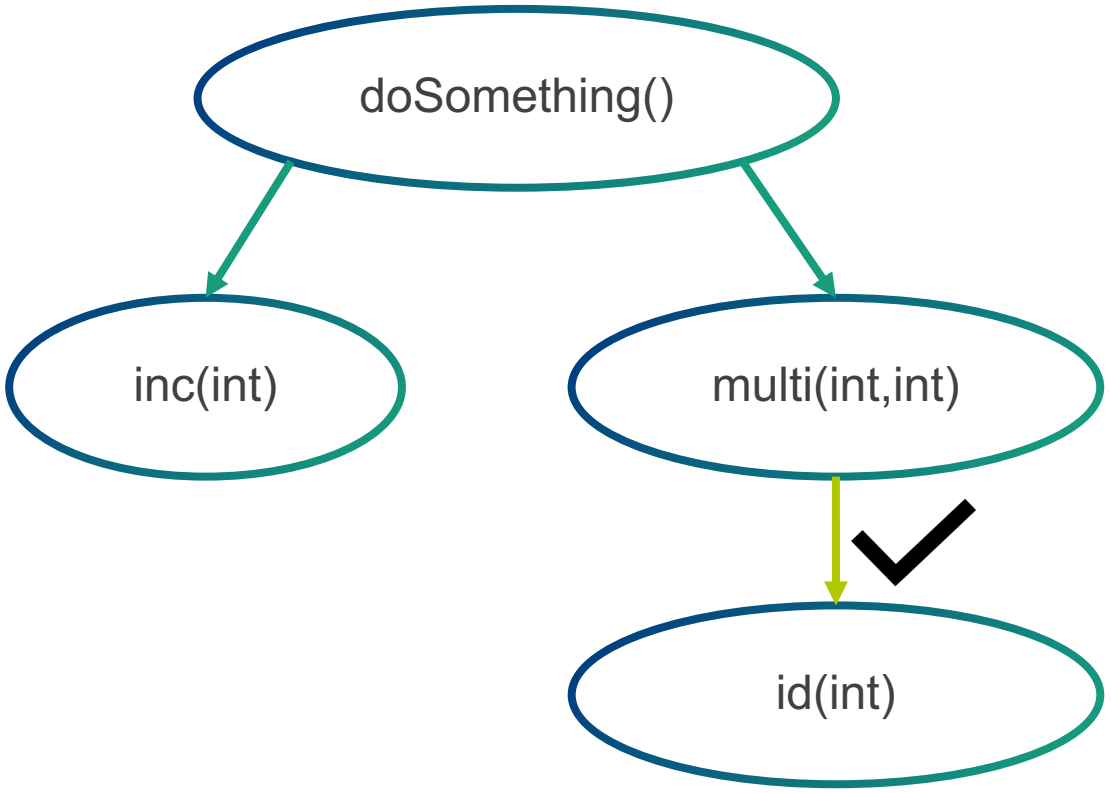
getMethodSignatures() :

callsFrom(„doSomething()“)

callsTo(„id(int)“)

containsMethod(„id(int)“)

Call Graph API



getMethodSignatures() :

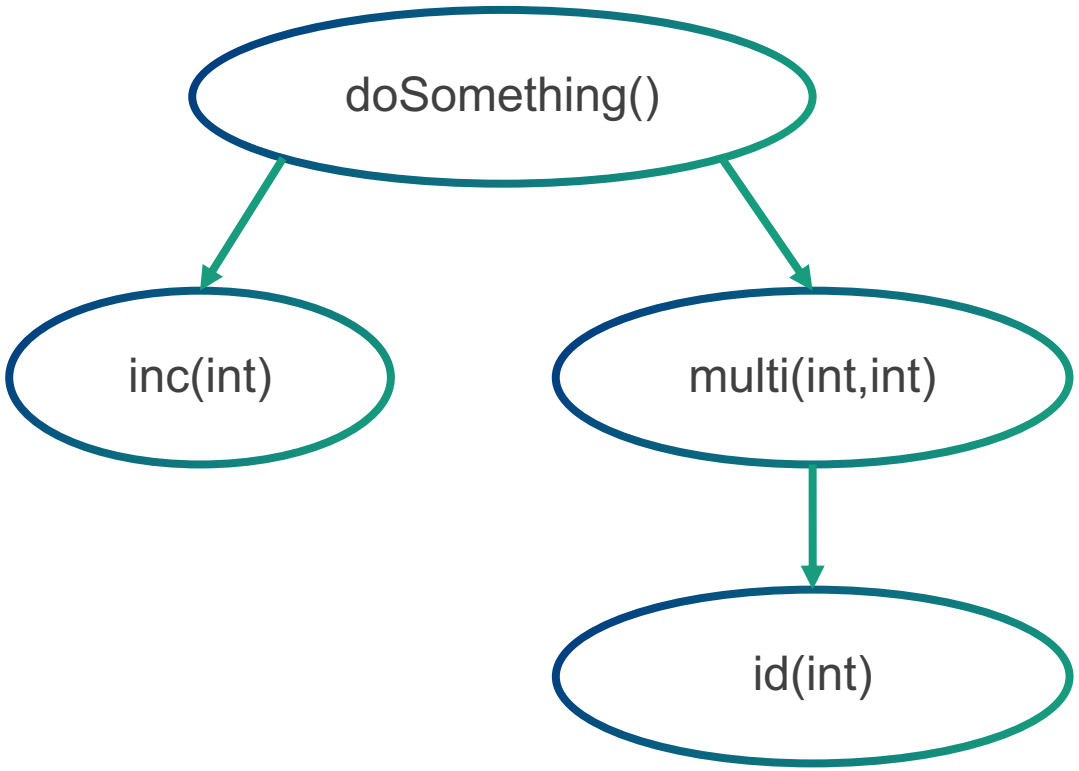
callsFrom(„doSomething()“)

callsTo(„id(int)“)

containsMethod(„id(int)“)

containsCall(„multi(int,int)“,„id(int)“)

Dot Exporter




```
digraph : {
        doSomething() -> inc(int)
        doSomething() -> multi(int,int)
        multi(int,int) -> id(int)
}
```

EXERCISE 2: TAINT ANALYSIS WITH SOOTUP AND HEROS

Taint Analysis

- A taint is a sensitive information that we want to track throughout the application run.
  - Hardcoded credentials that might leak
  - Untrusted input that might reach critical methods

- Terminology
  - Source:
    - x = „SECRET“
  - Sink:
    - sink(x)

```
void entryPoint() {
    String a = "SECRET";

    String b = a;

    String c = id(b);

    SinkClass sc = new SinkClass();

    sc.sink(c);
}
```

Taint Analysis with SootUp and Heros

- Heros is an IFDS solver
- IFDS framework let‘s us define data-flow analysis problems:
  - Interprocedural
    - Across method boundaries
  - Flow- and context-sensitive
    - Maintaining order statements
    - Precisely tracking effects in all method contexts
  - Flow Functions to define effects of each statement

Taint Analysis with SootUp and Heros

Flow Functions

```
void entryPoint() {
    String a = "SECRET";

    String b = a;

    String c = id(b);

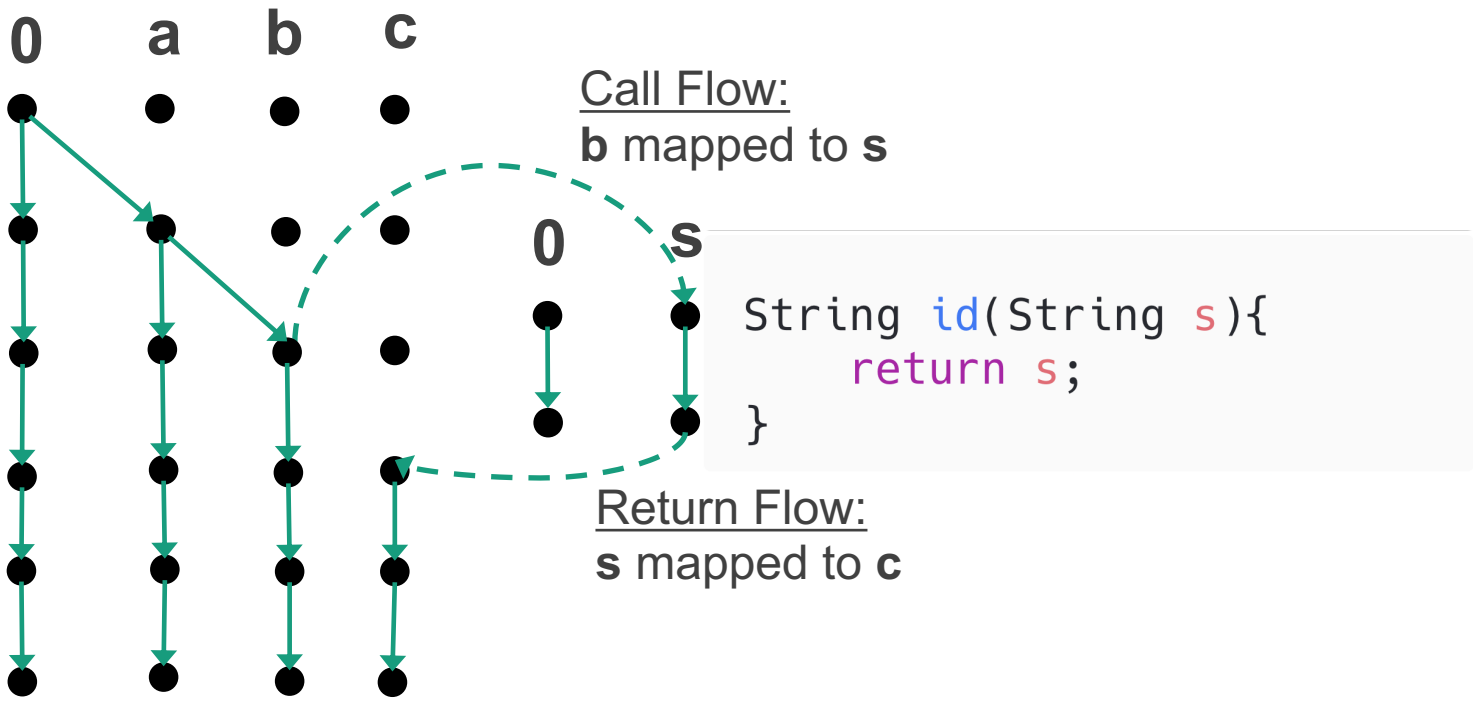
    SinkClass sc = new SinkClass();

    sc.sink(c);
}
```

Normal Flow:
Generate **a**

Propagate **a** to **b**

Call-to-Return Flow



Exercise 2: Implement a Taint Analysis Problem

- Task: Implement the Flow Functions in TaintAnalysisProblem.java
  1. **getNormalFlow**()
     1. Generating a Taint: only for this specific assignment, x = "SECRET"
     2. Propagating (Transferring) a Taint between different variables
  2. **getCallFlow**()
     1. Mapping call arguments to local parameters, foo(x)
  3. **getReturnFlow**()
     1. Mapping returned variable to assigned variable, y = foo(x)

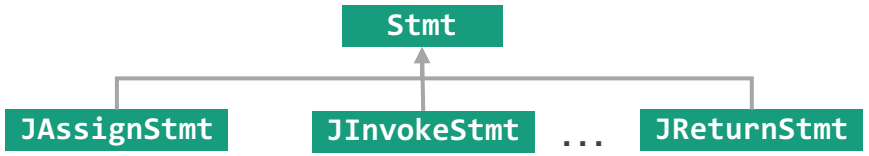
Steps to access the exercise:

1. git clone https://github.com/soot-oss/SootUp-Tutorial.git
2. git checkout 3_Exercise-2

OR

Download from: https://sootup-tutorial.surge.sh

Exercise 2: Helpful APIs



StringConstant	
String	**getValue**()

JAssignStmt	
Value	**getLeftOp**()
Value	**getRightOp**()

JReturnStmt	
Value	**getOp**()

Gen<D>	
	Gen(D genValue, D zeroValue)

Transfer<D>	
	Transfer(D toValue, D fromValue)

Identity<D>	
Identity<D>	**v**()

KillAll<D>	
KillAll<D>	**v**()

For more help check:

- Documentation: soot-oss.github.io/SootUp
- Javadoc: soot-oss.github.io/SootUp/apidocs
- Heros: javadoc.io/doc/de.upb.cs.swt/heros/latest/index.html

CLOSING

Future Work

In Progress

- Android frontend

FlowDroid

- Scalable demand-driven pointer analysis

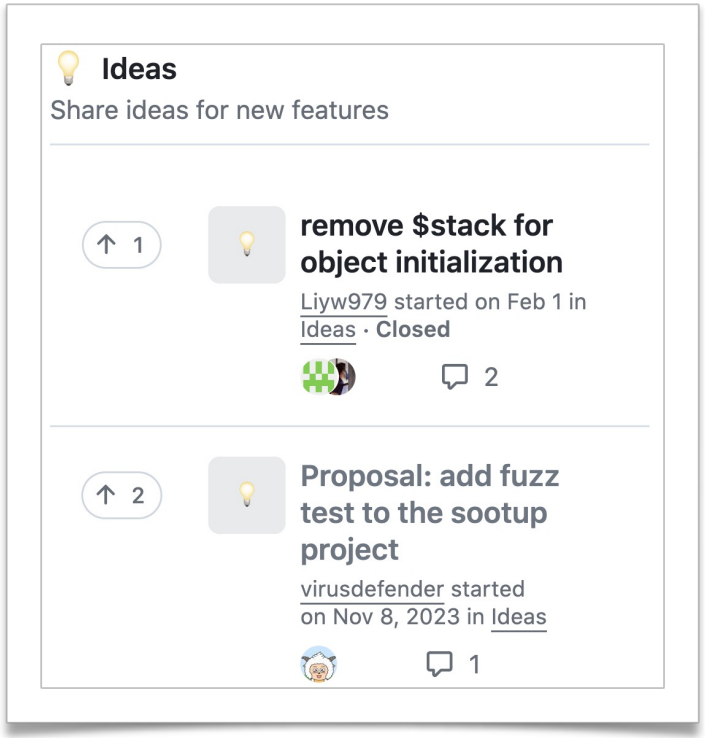
SparseBoomerang

In Near Future

- Frontends for other languages: e.g. Python, Javascript
- Partial code analysis

We are always open to suggestions!

Feel free to propose your ideas in discussions:



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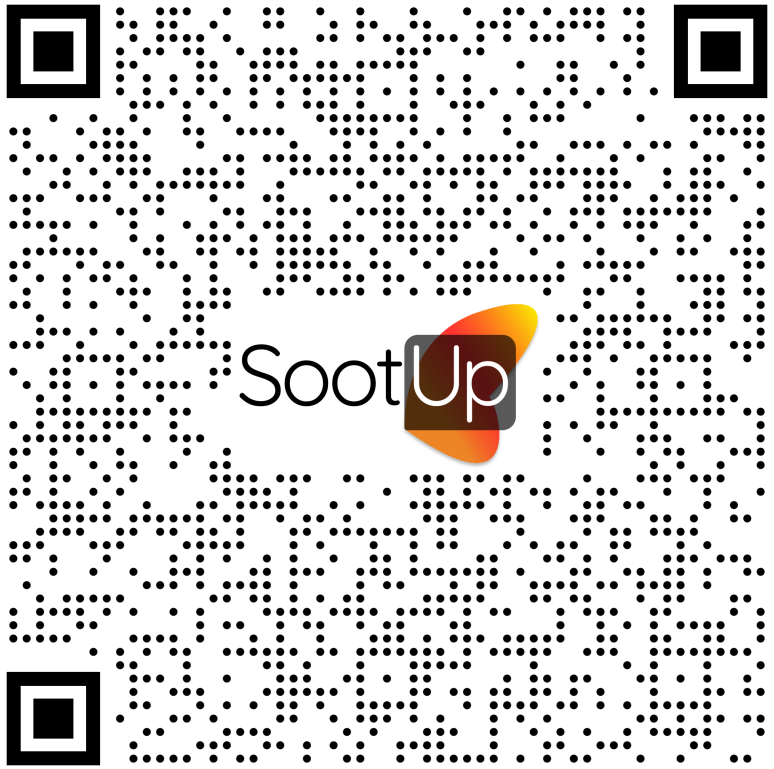
SUS Questionnaire



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aws

We are looking forward to see you be part of the SootUp community!

SootUp

https://github.com/soot-oss/SootUp