Modelgen:
Mining Explicit Information Flow Specifications from Concrete Executions

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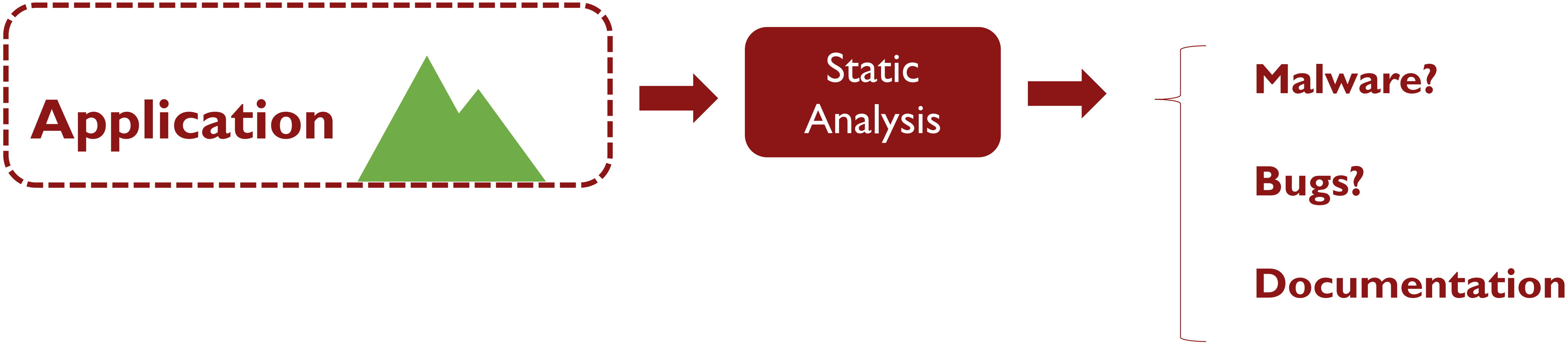
Why mine specifications?

Whole-program static analysis

Whole-program static analysis



Application

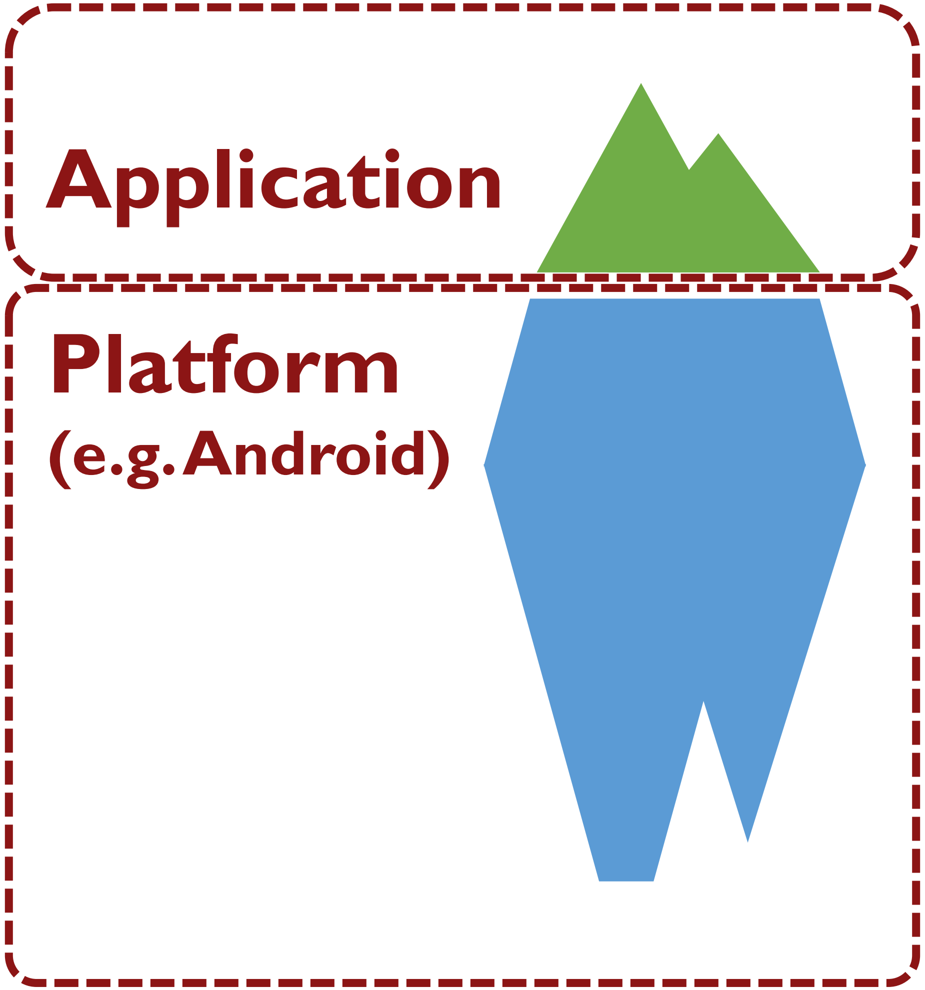
Static Analysis

Malware?

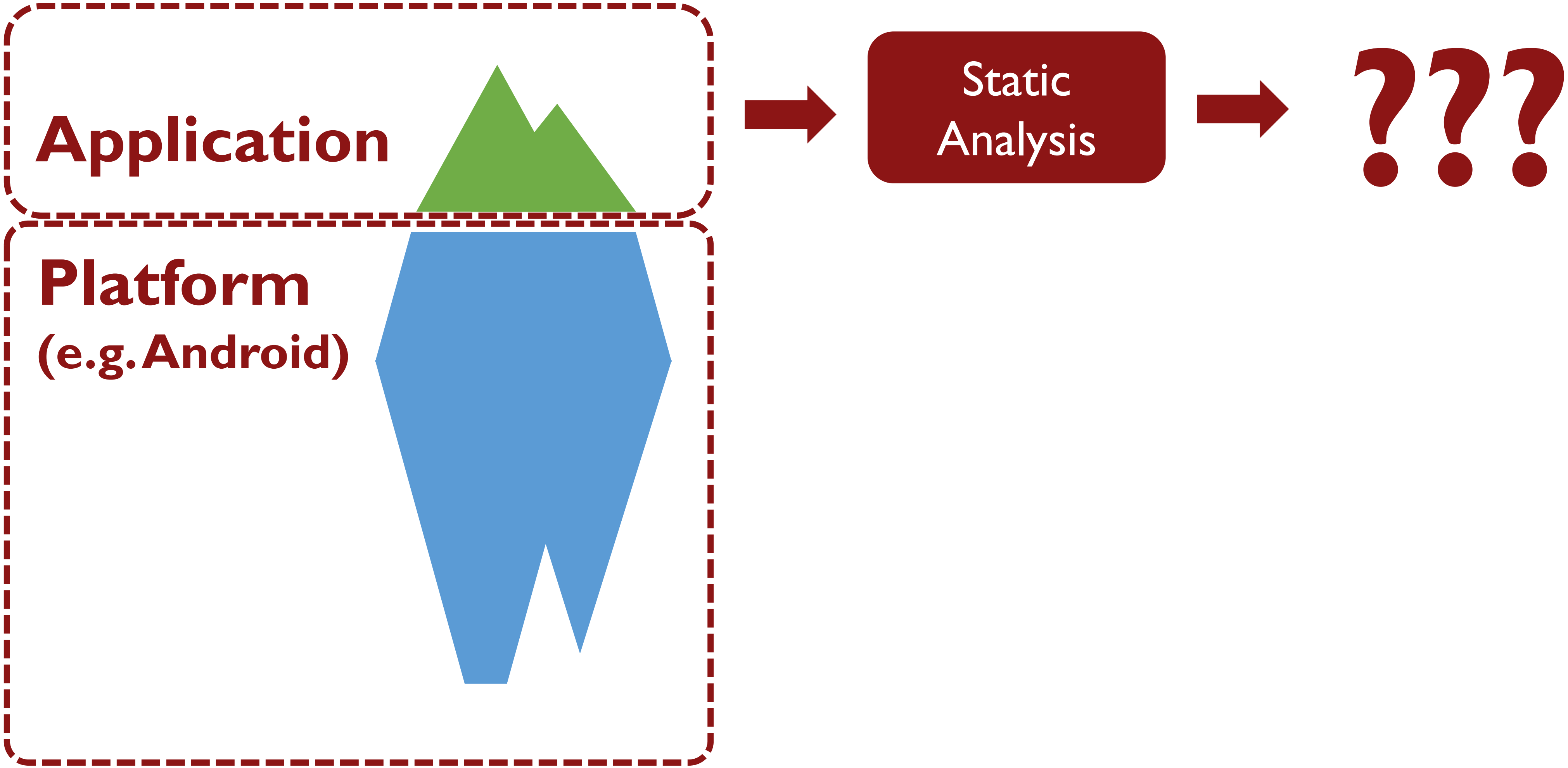
Bugs?

Documentation

Whole-program static analysis?



Whole-program static analysis?



Application

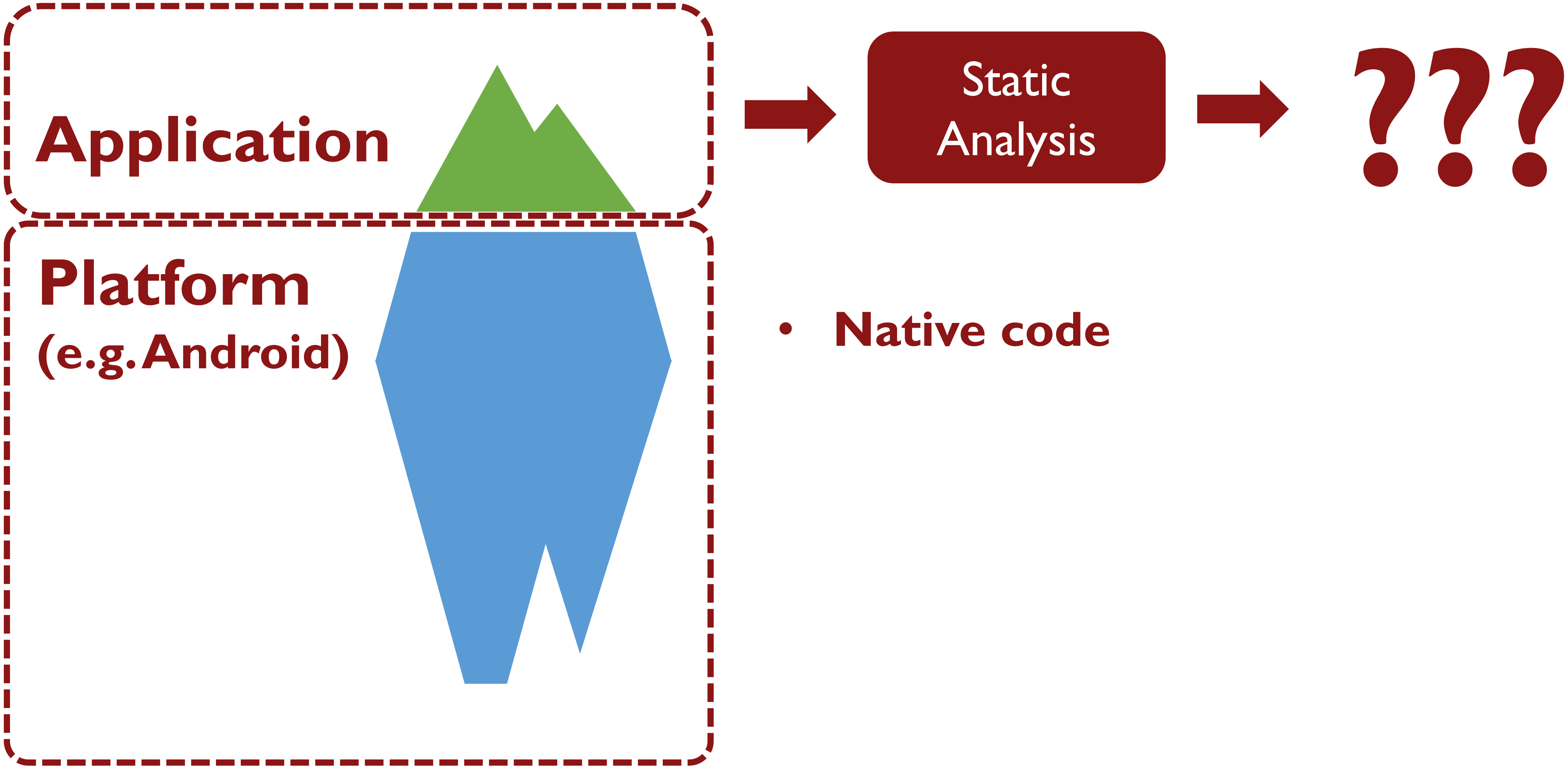
Platform

(e.g. Android)

Static Analysis

???

Whole-program static analysis?



Application

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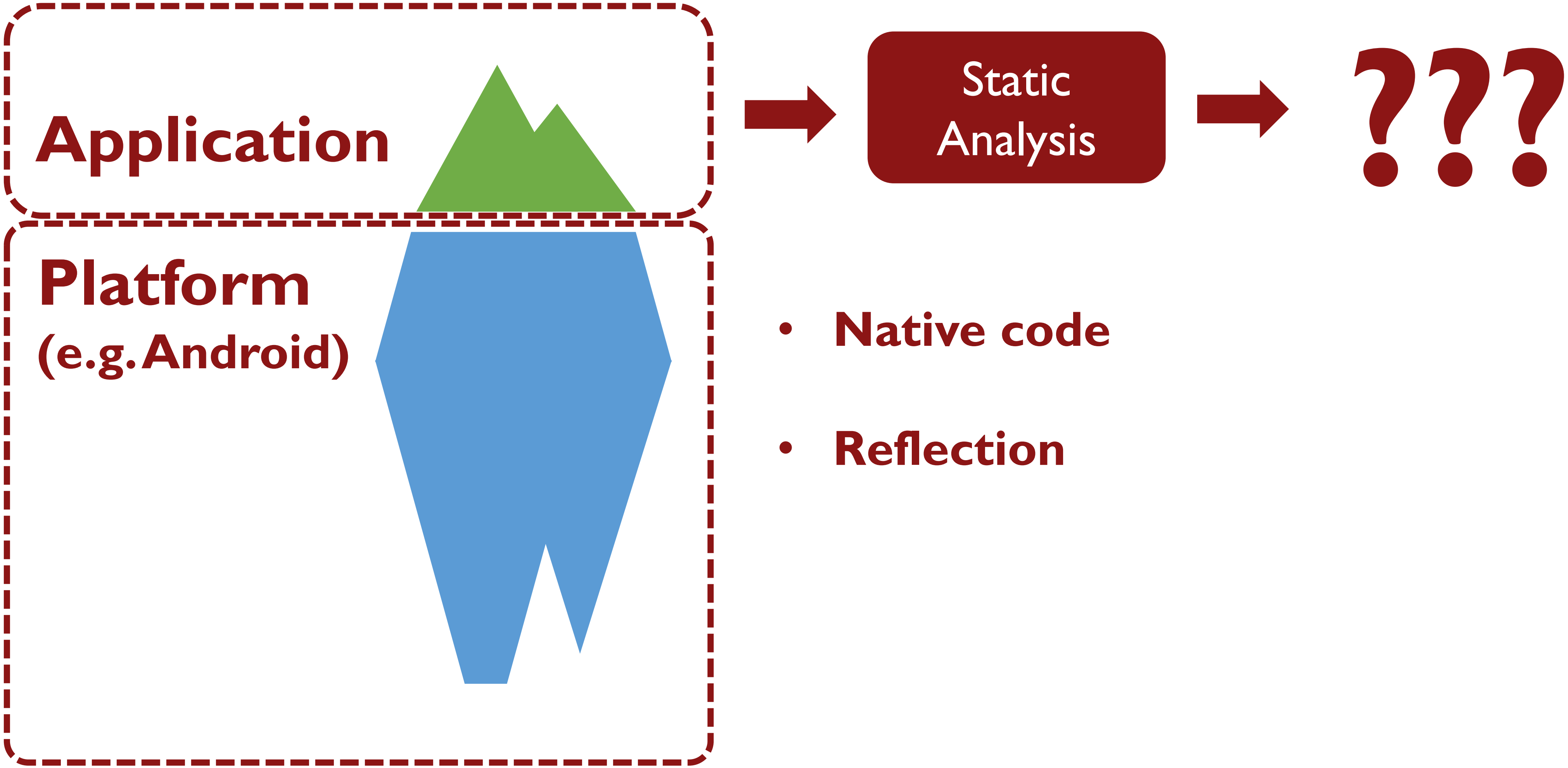
(e.g. Android)

Static Analysis

???

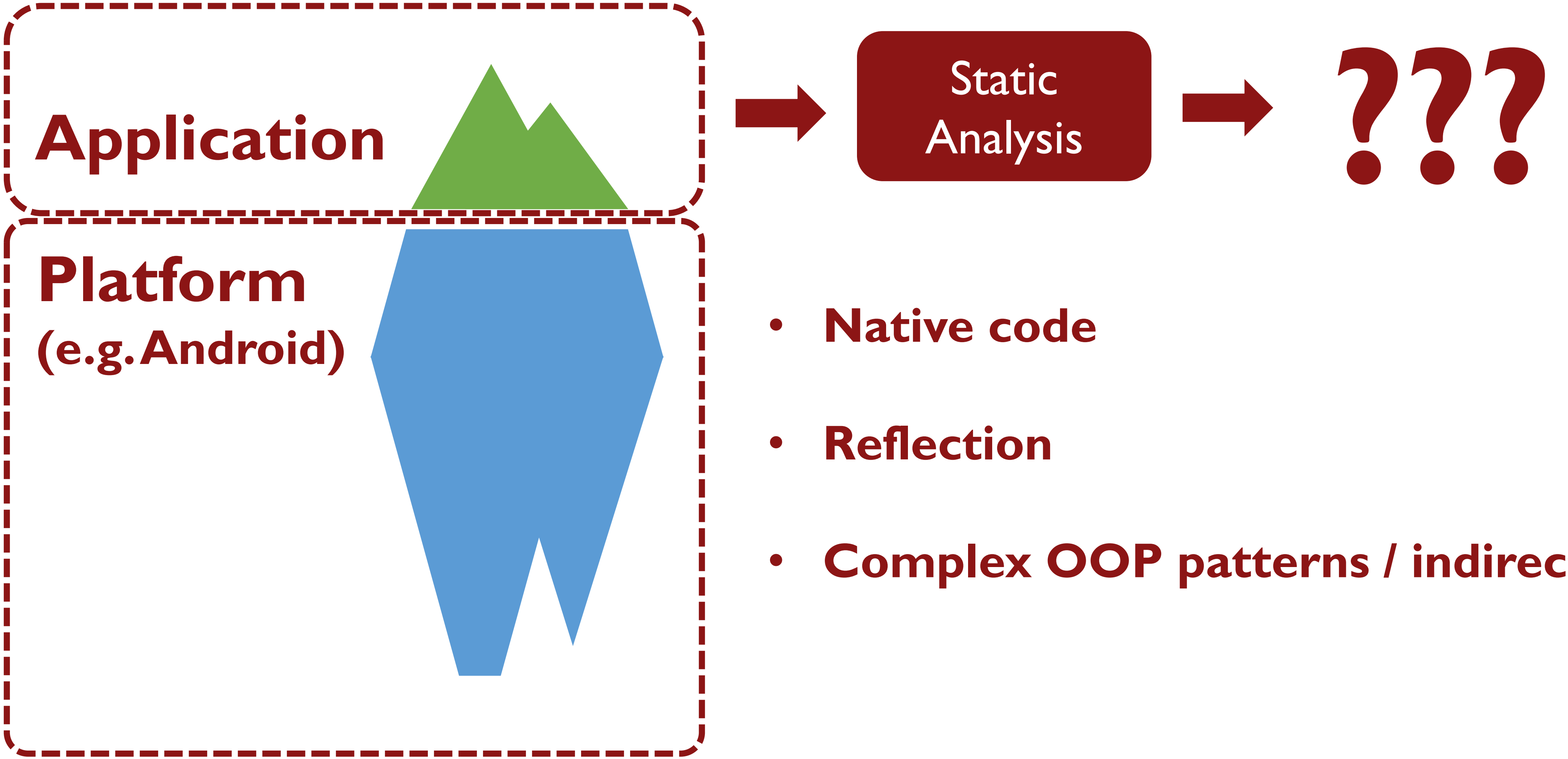
- **Native code**

Whole-program static analysis?



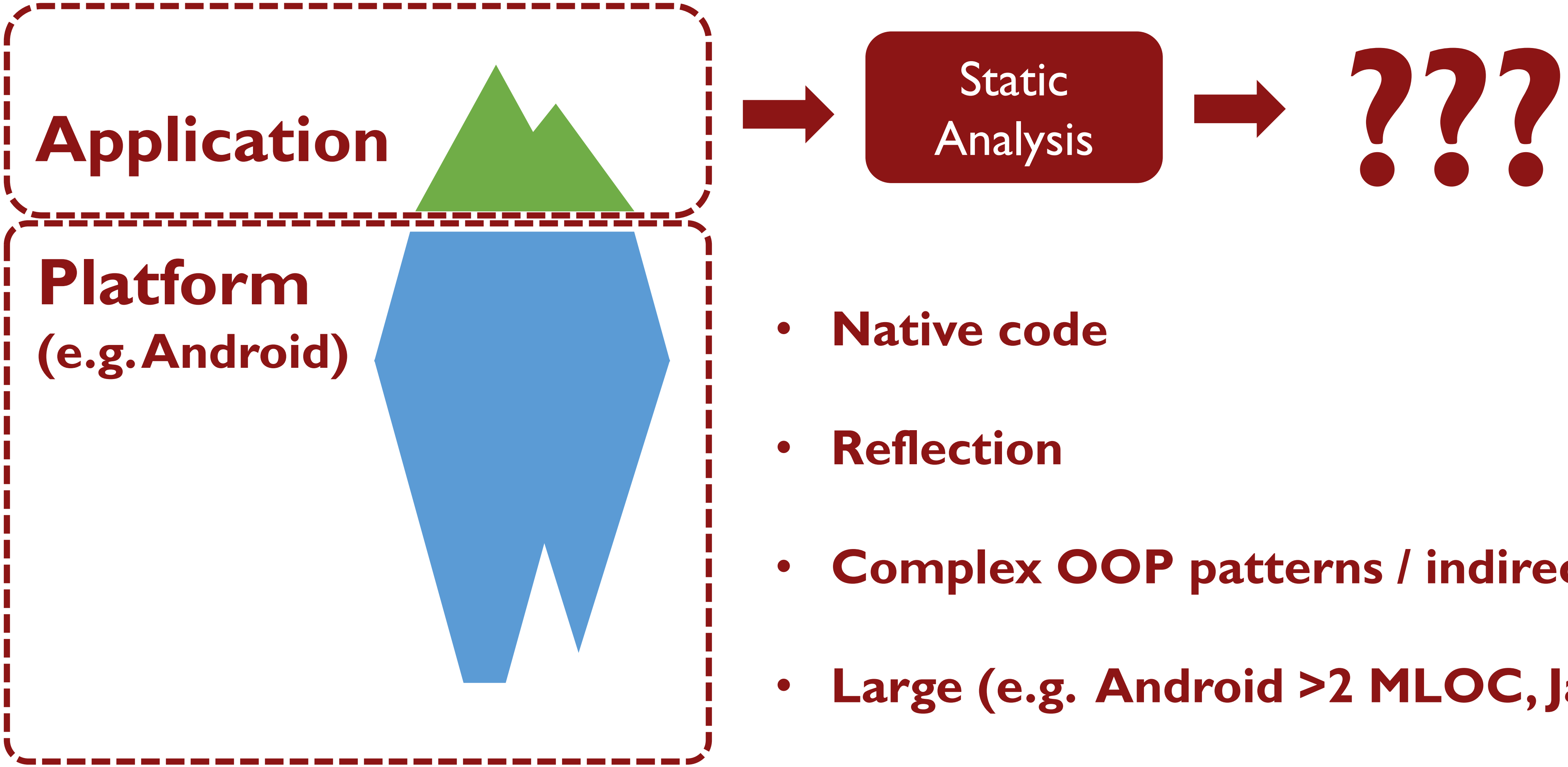
- **Native code**
- **Reflection**

Whole-program static analysis?



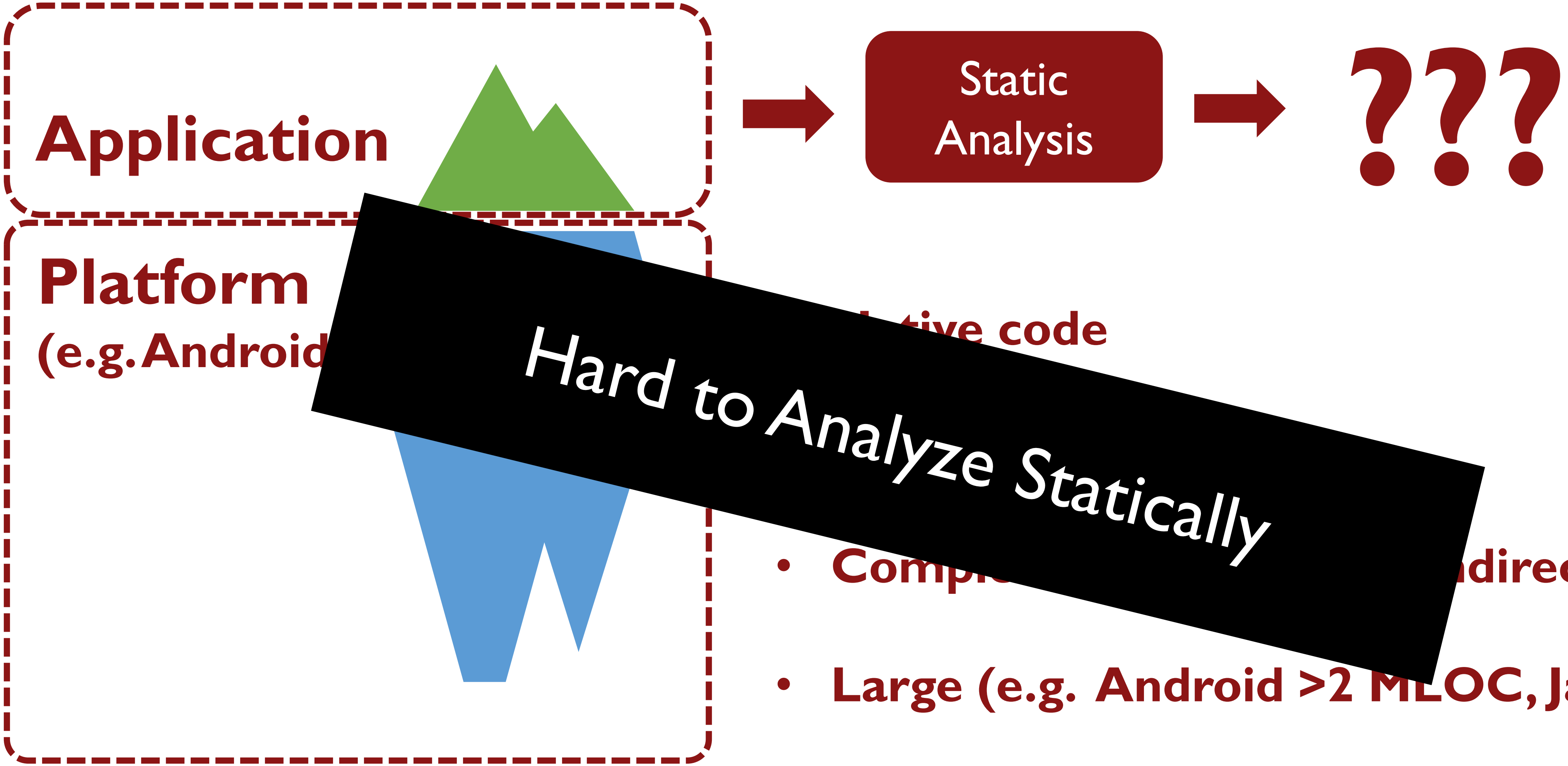
- **Native code**
- **Reflection**
- **Complex OOP patterns / indirection**

Whole-program static analysis?



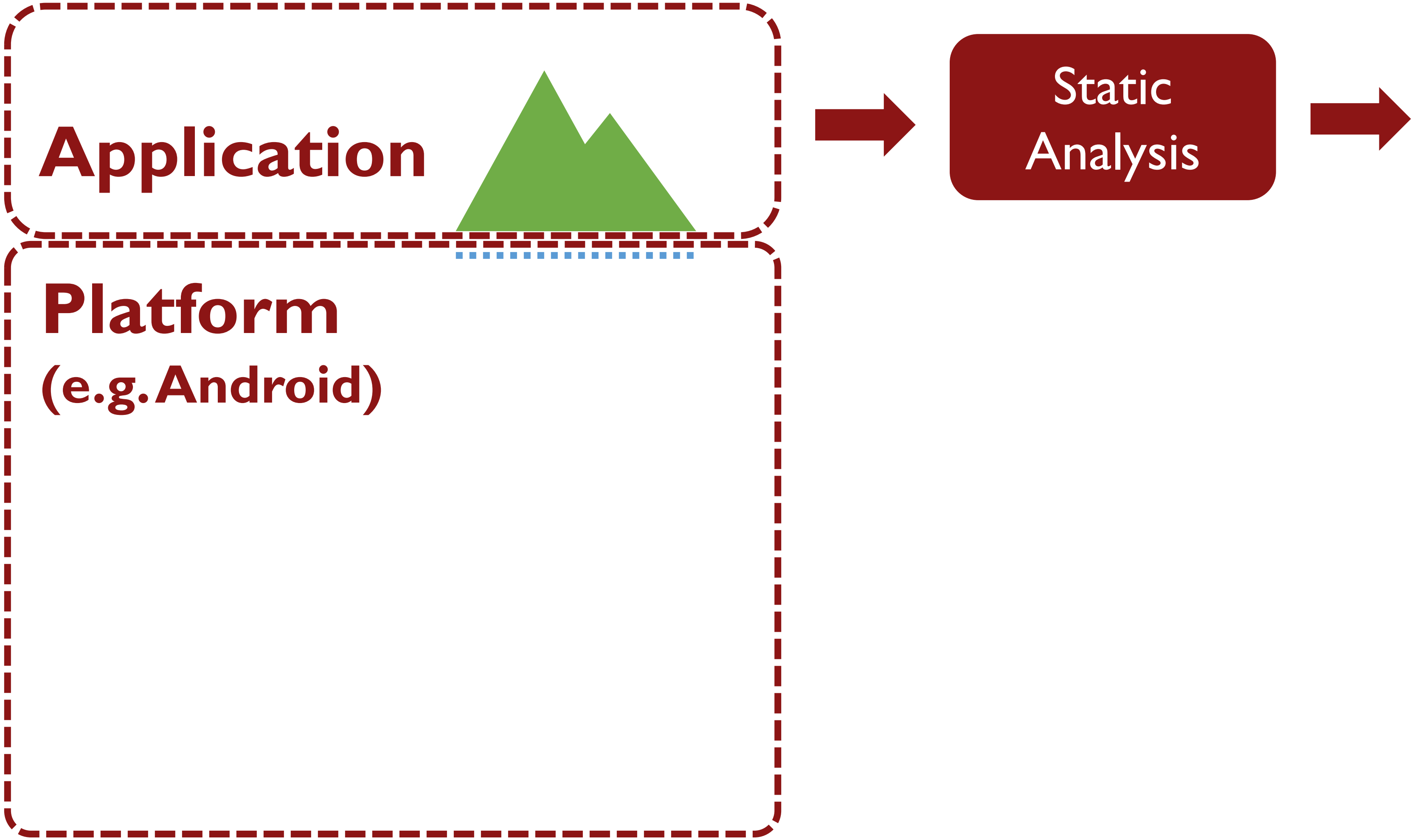
- Native code
- Reflection
- Complex OOP patterns / indirection
- Large (e.g. Android >2 MLOC, Java)

Whole-program static analysis?



- tive code
- Comp ndirection
- Large (e.g. Android >2 MLOC, Java)

Options: Best-case



Application

Platform

(e.g. Android)

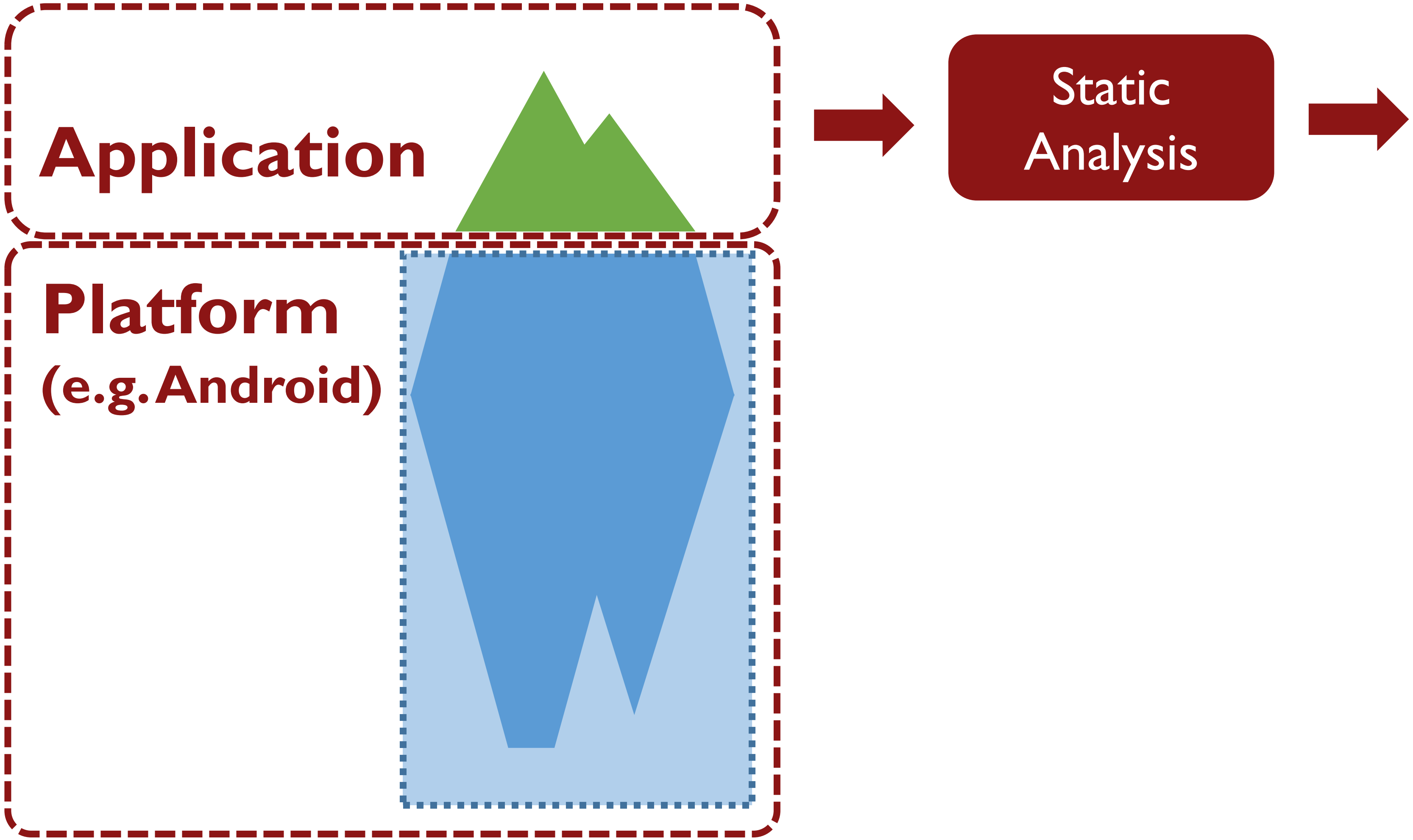
Static Analysis

Under-approximation

(Very) Unsound

False negatives

Options: Worst-case



Application

Platform (e.g. Android)

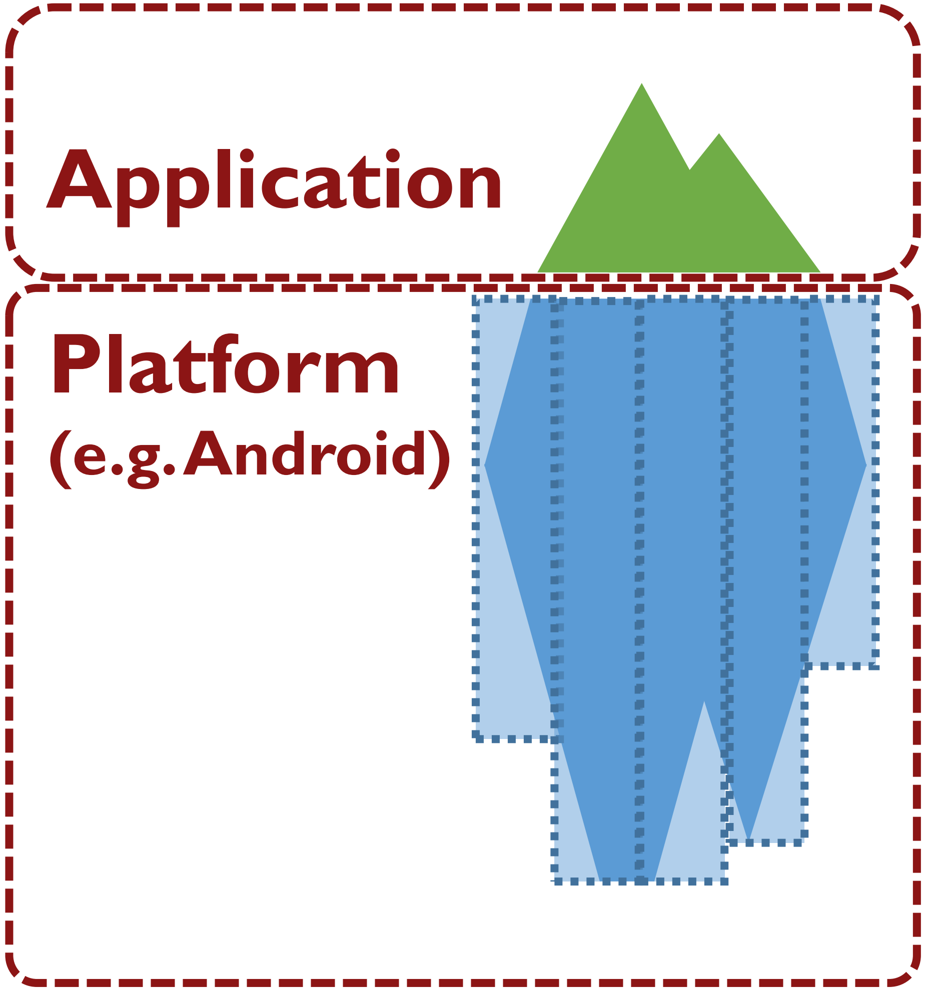
Static Analysis

Over-approximation

(Very) Imprecise

False positives

Options: Specifications



Application

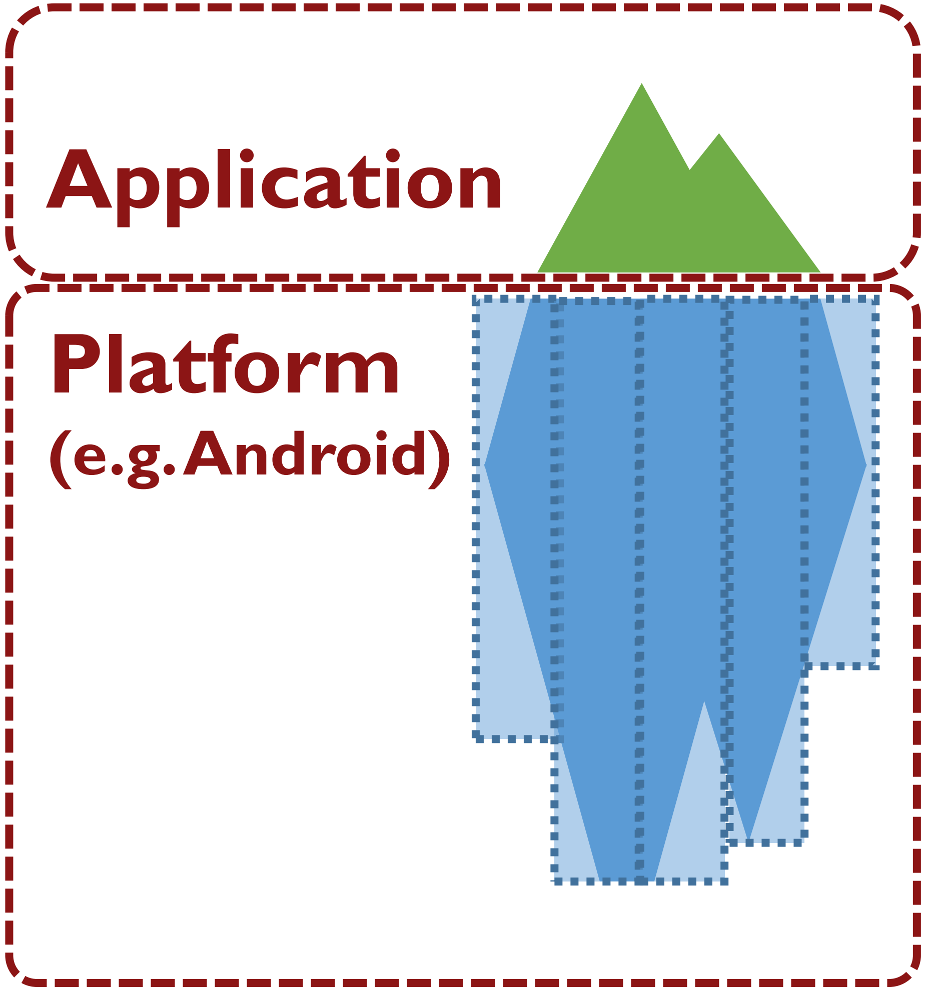
Platform

(e.g. Android)

- **Slight over-approximation**
- **Manually written**
- **Effort intensive***

* Our system (STAMP):
Models for 1,116 methods, written over 2 years

Mining Specifications



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(e.g. Android)

- Slight over-approximation
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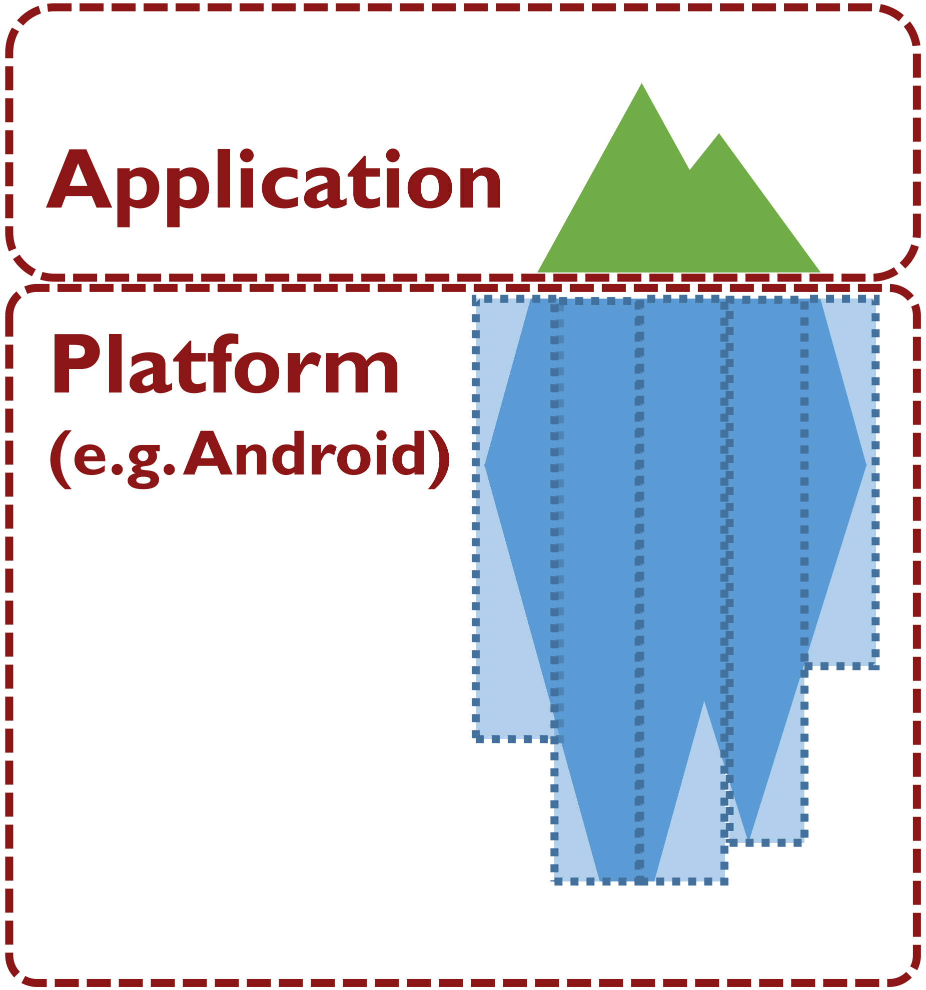
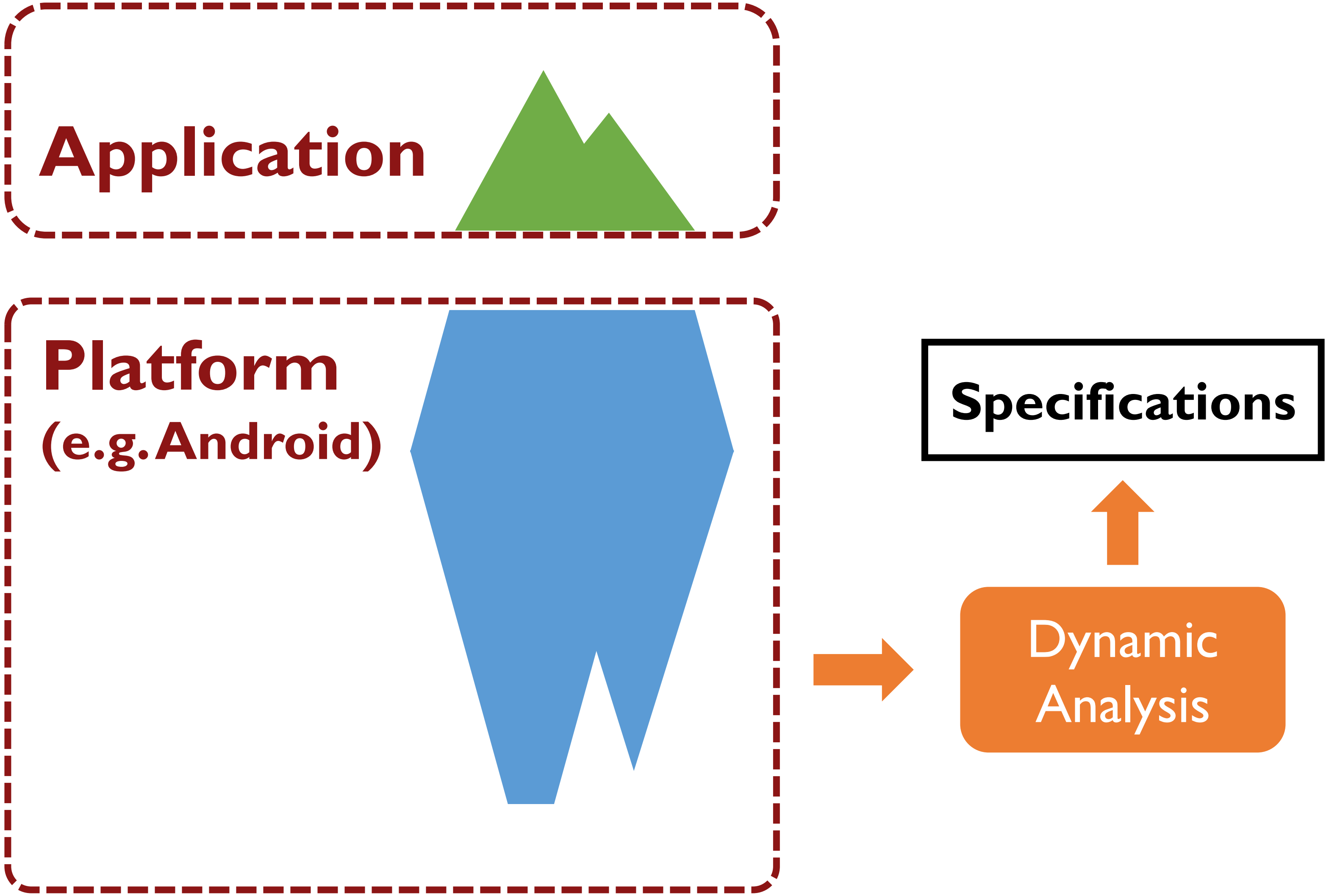


- **Slight over-approximation**
- **Mined automatically using dynamic analysis**

Mining Specifications



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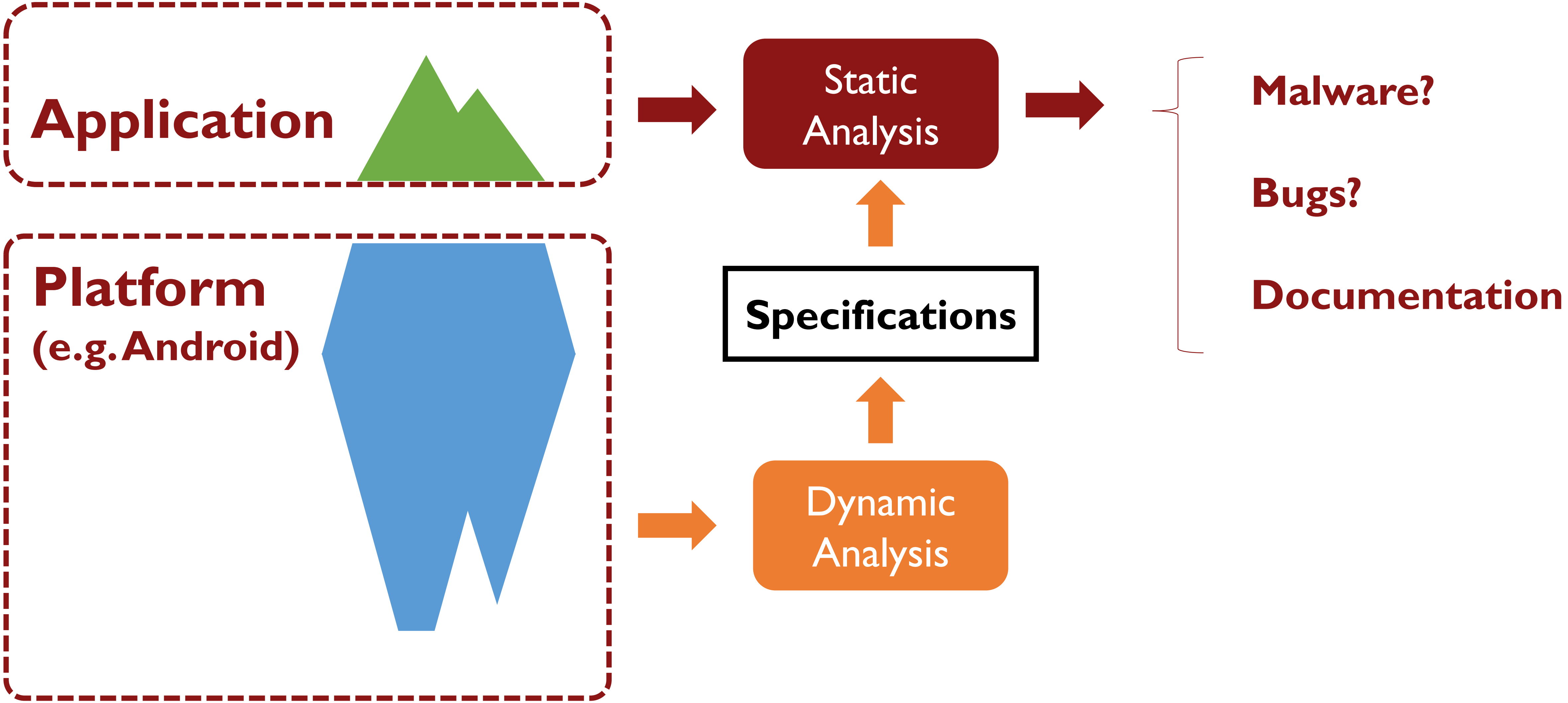
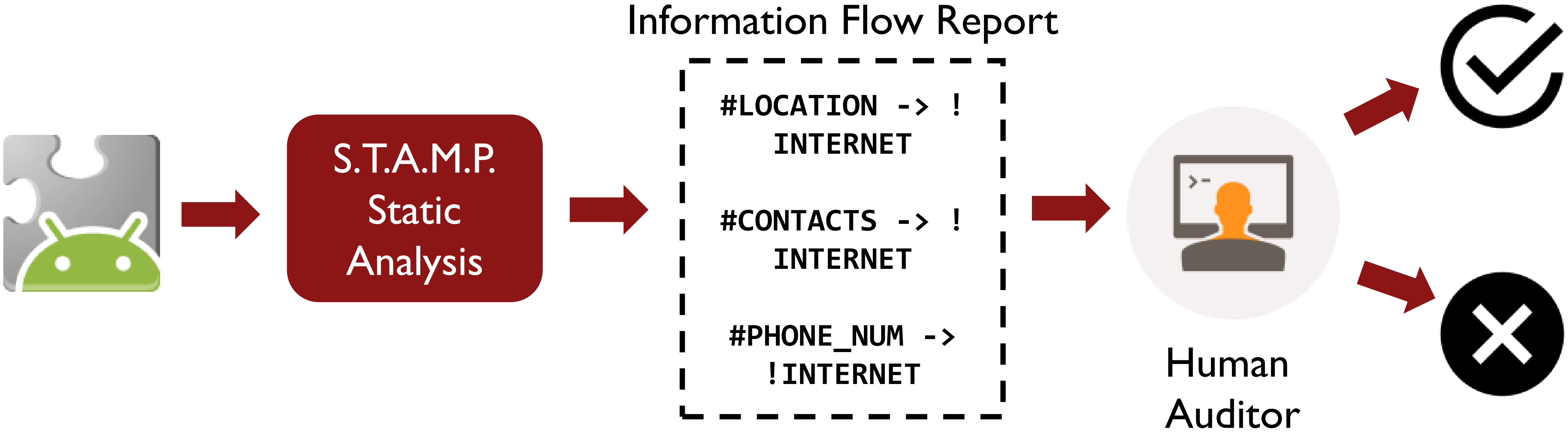


II

Information flow specifications

Static taint analysis



S.T.A.M.P.
Static
Analysis

Information Flow Report

```
#LOCATION -> !
  INTERNET

#CONTACTS -> !
  INTERNET

 #PHONE_NUM ->
  !INTERNET
```

Human
Auditor

Information flow specifications

```
// Set-up
SocketChannel socket = ...;
CharBuffer buffer = ...;
CharsetEncoder encoder =  ...;
TelephonyManager tMgr = ...;

// Leak phone number
// ( #PHONE_NUM -> !INTERNET )
String mPhoneNumber = tMgr.getLine1Number();
CharBuffer b1 = buffer.put(mPhoneNumber,0,10);
ByteBuffer bytebuffer = encoder.encode(b1);
socket.write(bytebuffer);
```

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```

#PHONE_NUM ->

Information flow specifications

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```

#PHONE_NUM -> ... -> ... -> ... *-> !INTERNET*

Information flow specifications

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```
TelephonyManager.getLine1Number()
#PHONE_NUM -> return
```

#PHONE_NUM -> mPhoneNumber

Information flow specifications

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SocketChannel socket = ...;
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ByteBuffer bytebuffer = encoder.encode(b1);
socket.write(bytebuffer);
```

```
TelephonyManager.getLine1Number()
          #PHONE_NUM -> return
```

```
CharBuffer.put(String,int,int)
          arg#1 -> this
          arg#1 -> return
          this -> return
```

#PHONE_NUM -> mPhoneNumber -> b1

Information flow specifications

```
// Set-up
SocketChannel socket = ...;
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TelephonyManager.getLine1Number()
        #PHONE_NUM -> return
```

```
CharBuffer.put(String,int,int)
        arg#1 -> this
        arg#1 -> return
        this -> return
```

```
CharsetEncoder.encode(CharBuffer)
        arg#1 -> return
```

#PHONE_NUM -> mPhoneNumber -> b1 -> bytebuffer

Information flow specifications

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SocketChannel socket = ...;
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TelephonyManager.getLine1Number()
          #PHONE_NUM -> return
```

```
CharBuffer.put(String,int,int)
          arg#1 -> this
          arg#1 -> return
          this -> return
```

```
CharsetEncoder.encode(CharBuffer)
          arg#1 -> return
```

```
SocketChannel.write(ByteBuffer)
          arg#1 -> !INTERNET
```

#PHONE_NUM -> mPhoneNumber -> b1 -> bytebuffer -> !INTERNET

III

Technique

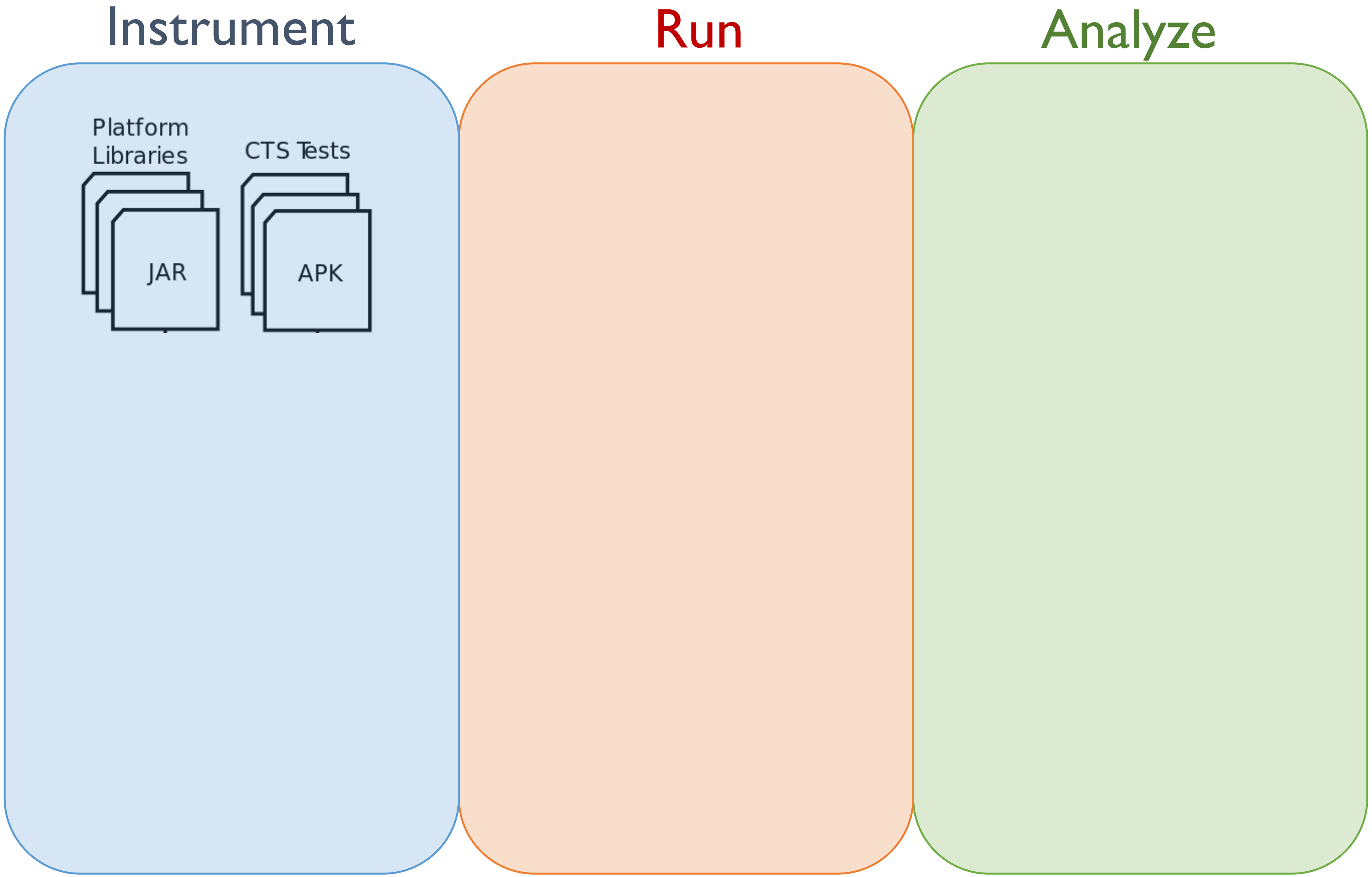
Instrument, run, analyze

Instrument

Run

Analyze

Instrument, run, analyze



Instrument

Run

Analyze

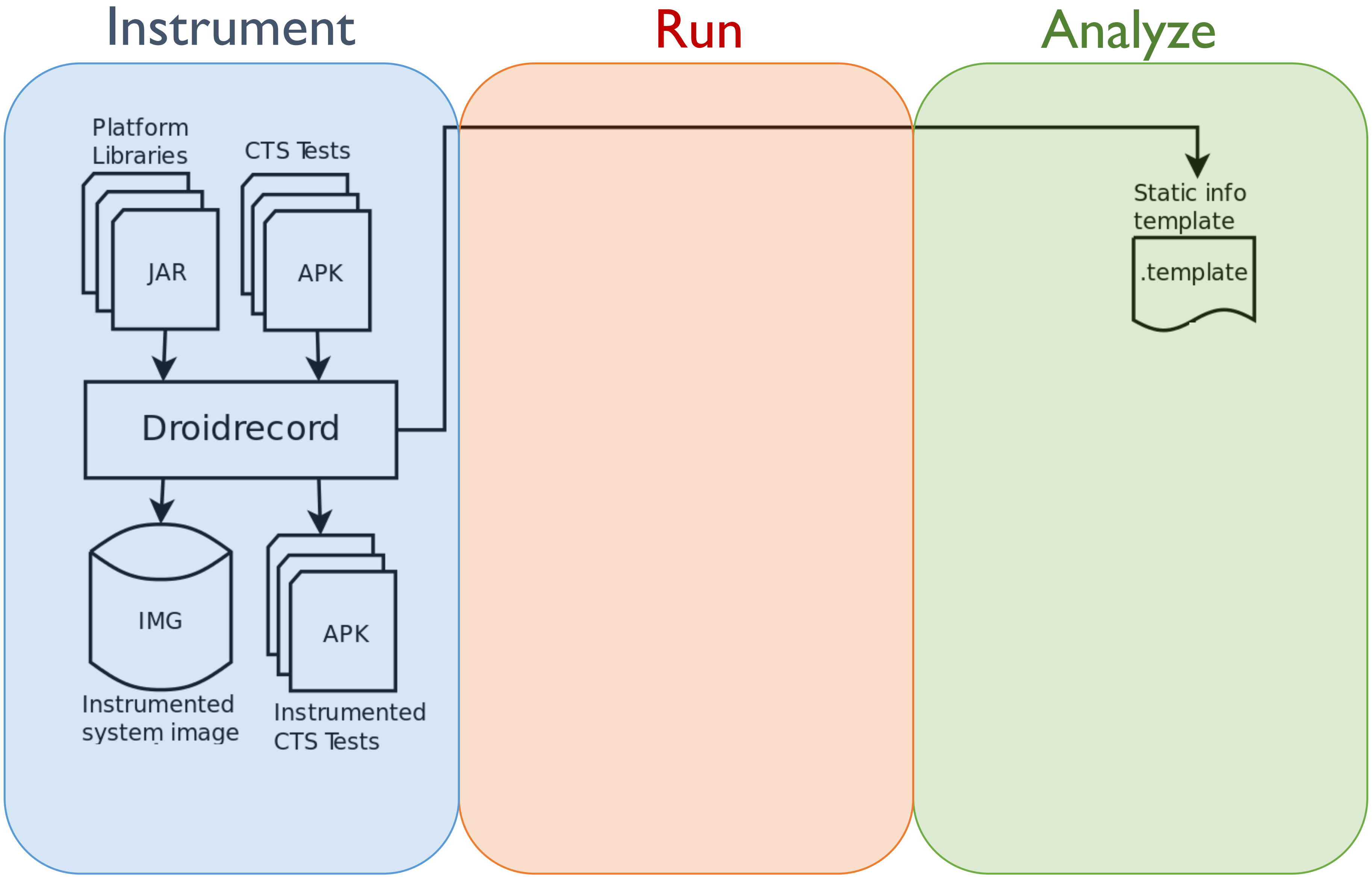
Platform Libraries

CTS Tests

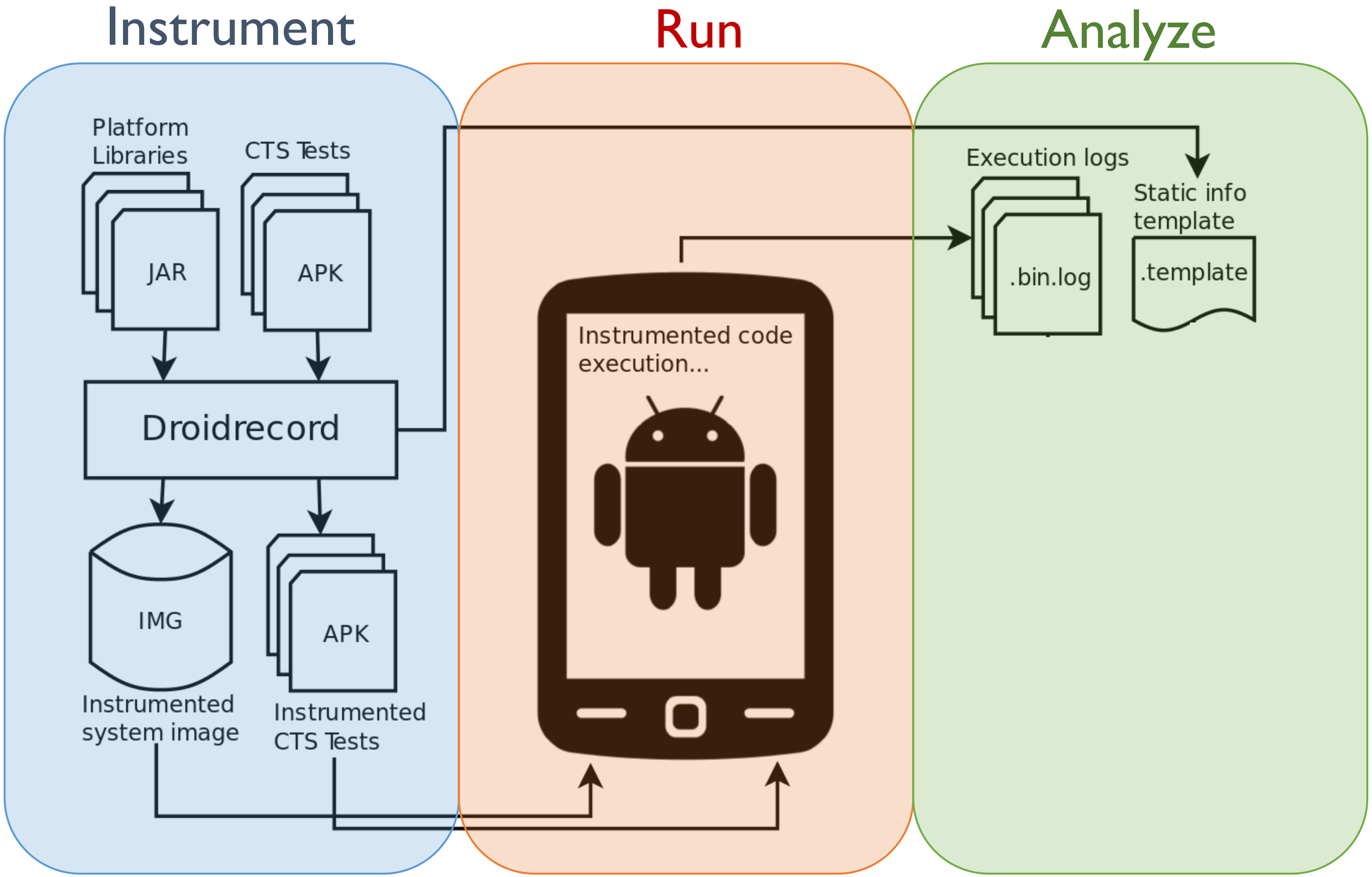
JAR

APK

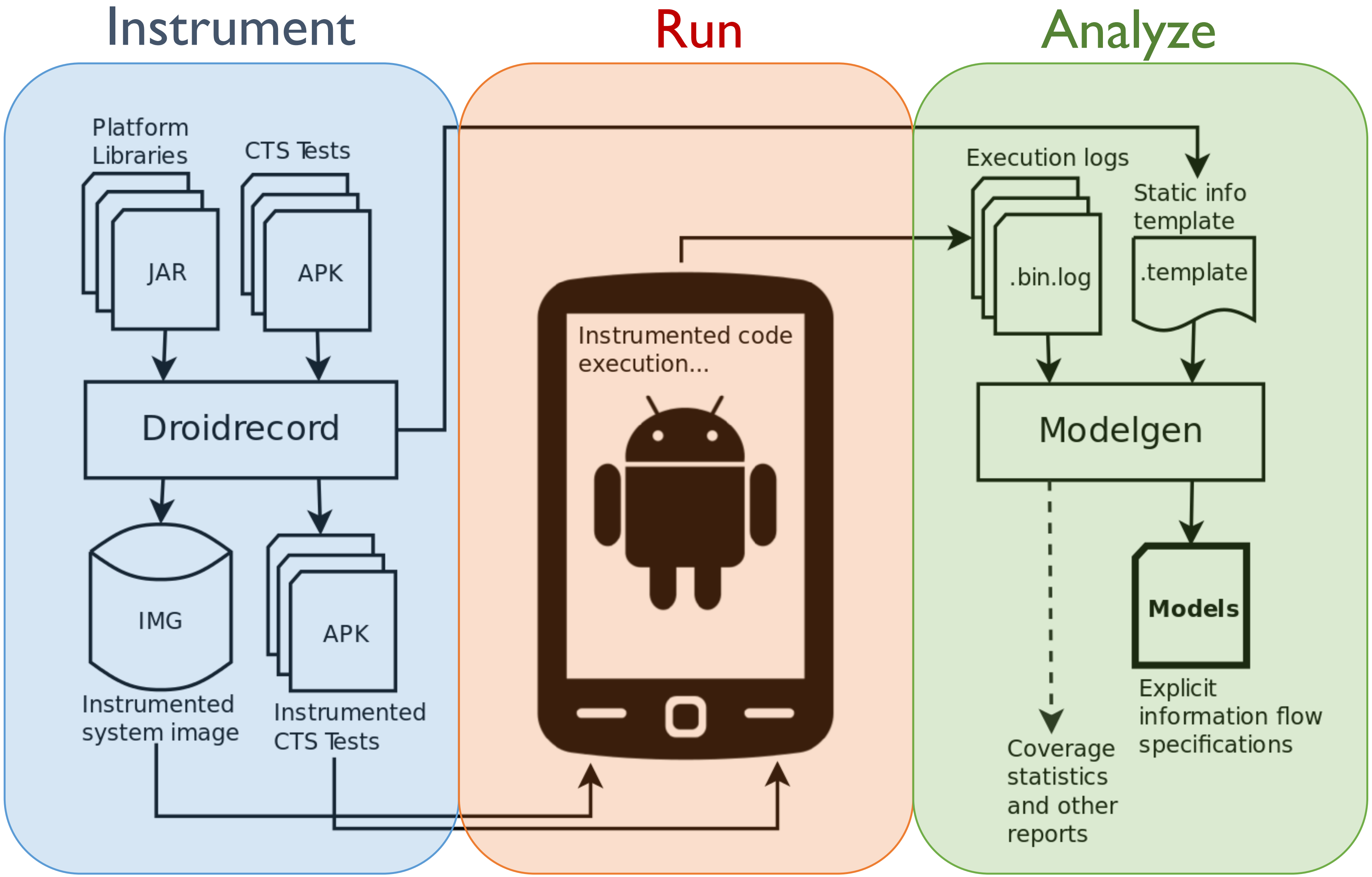
Instrument, run, analyze



Instrument, run, analyze



Instrument, run, analyze



Method trace

Definition:

Method trace

Definition:

- **Sequence of recorded operations between method entry and return.**

Method trace

Definition:

- **Sequence of recorded operations between method entry and return.**
- **Including calls to other methods.**

Example

```
o . m ( arg1 , arg2 ) :
    t = arg1 ⊗ arg2
    o1 = o.f
    o2 = o1.g
    o3 = o.g
    o2.f = t
    return o
```

Example

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o . m ( arg1 , arg2 ) :
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Spec:

arg1->this

arg2->this

Example

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this->return

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```

Spec:

arg1->this

arg2->this

this->return

arg1->return

arg2-> return

Example: Initialization

```
o . m ( arg1 , arg2 ) :
        t = arg1 ⊗ arg2
        o1 = o.f
        o2 = o1.g
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        return o
```

ret = o . m (arg1 , arg2)

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Example: Taint propagation

```
o . m ( arg1 , arg2 ) :
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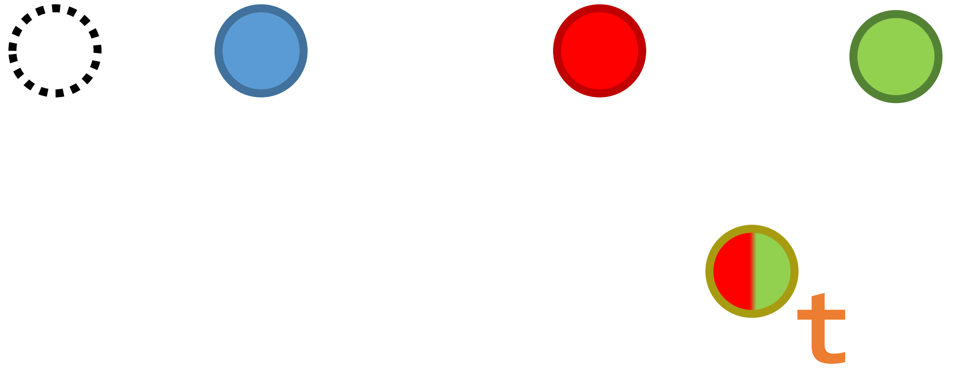

Example: Loads

o . m (arg1 , arg2) :

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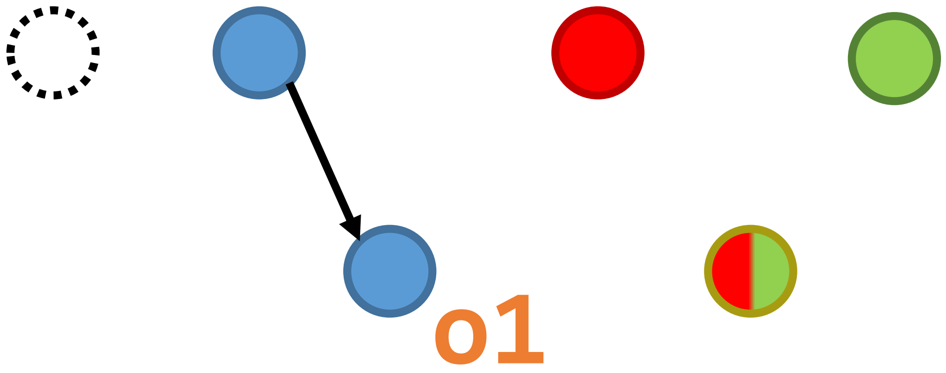

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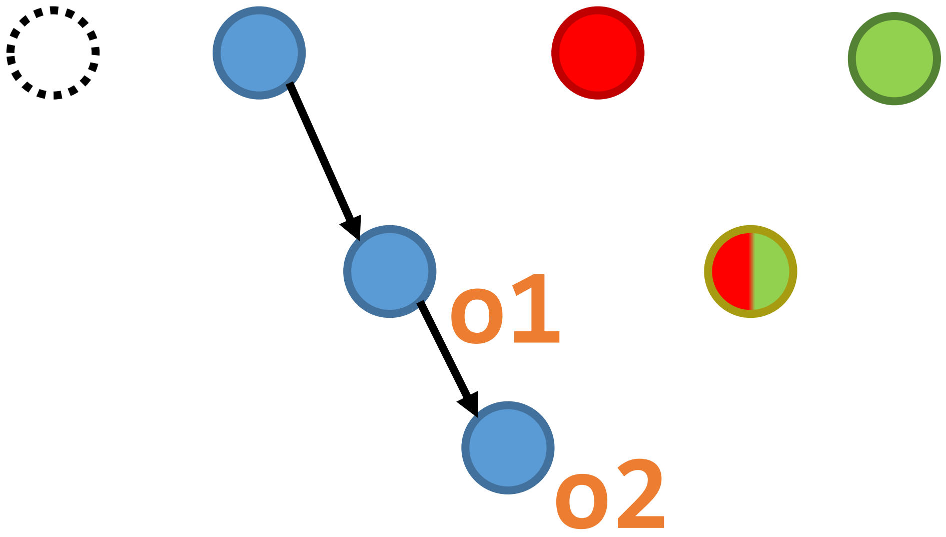

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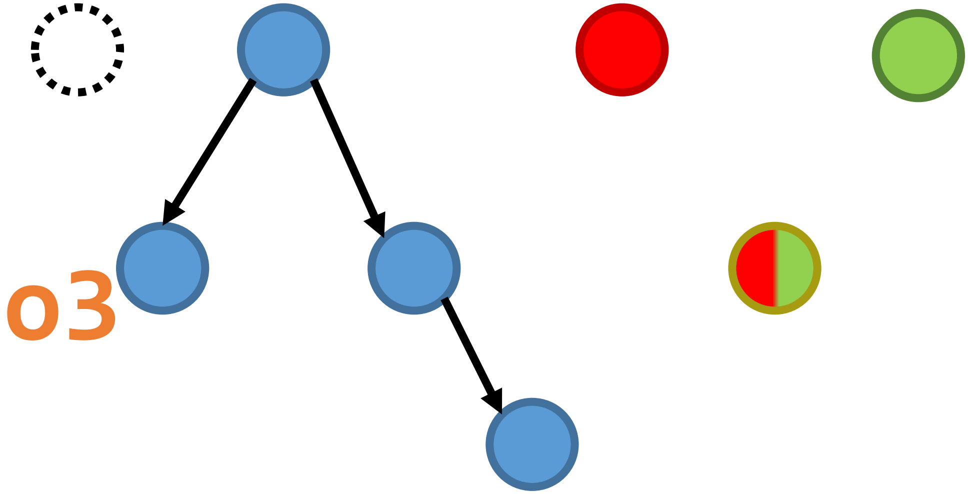

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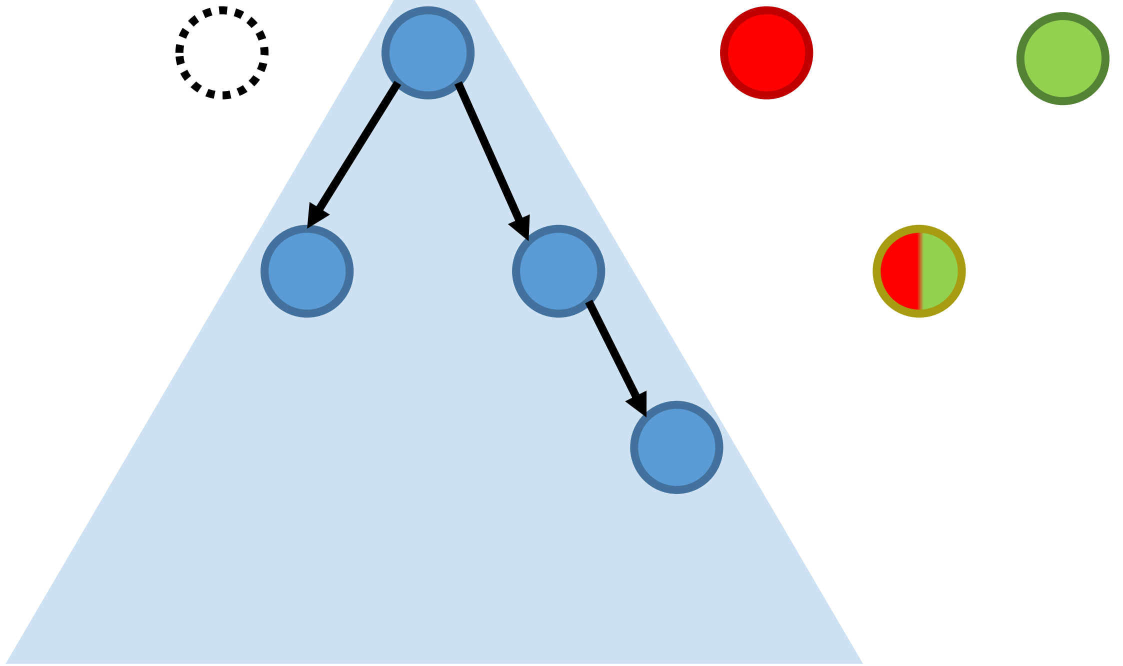

Example: Store

o . m (arg1 , arg2) :

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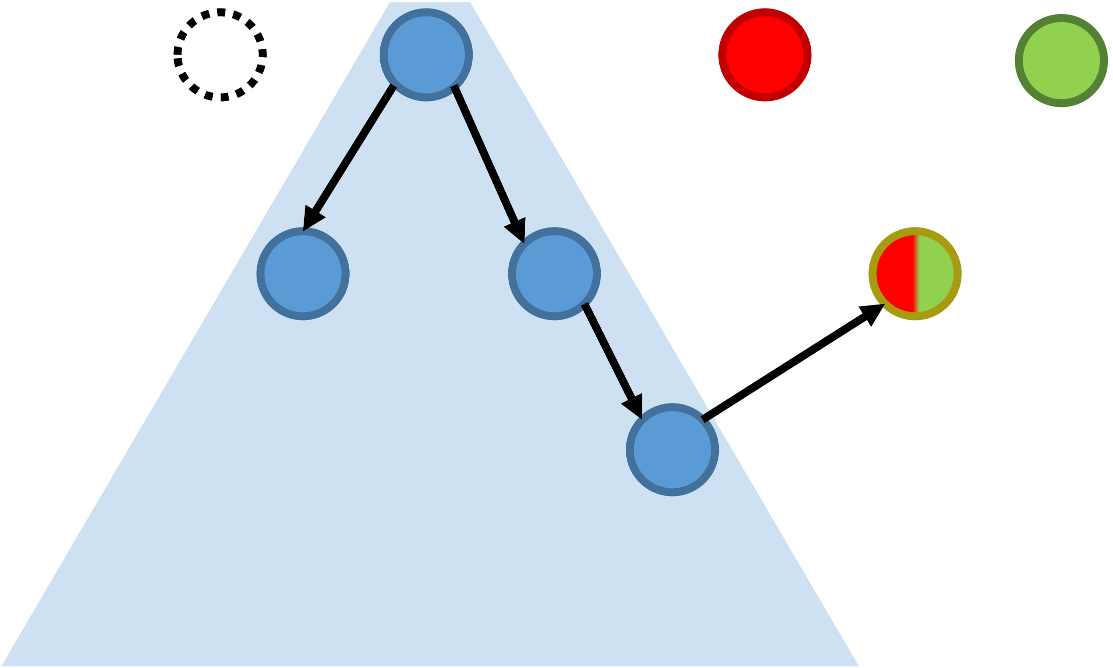

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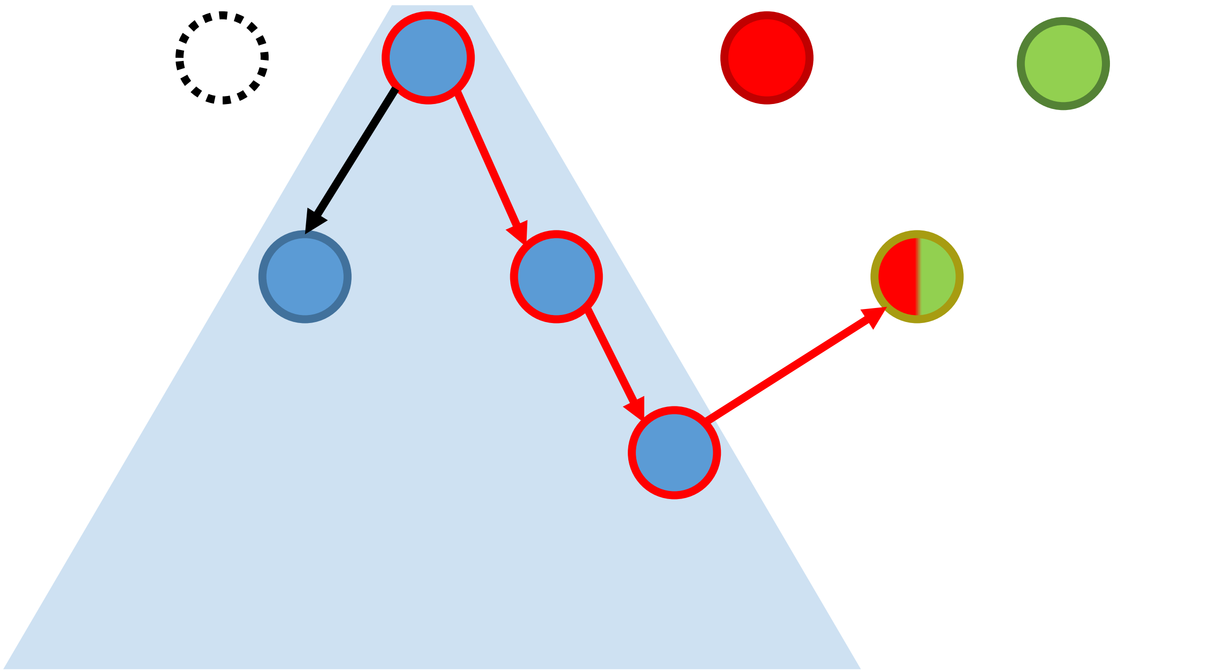

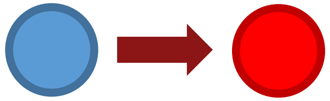

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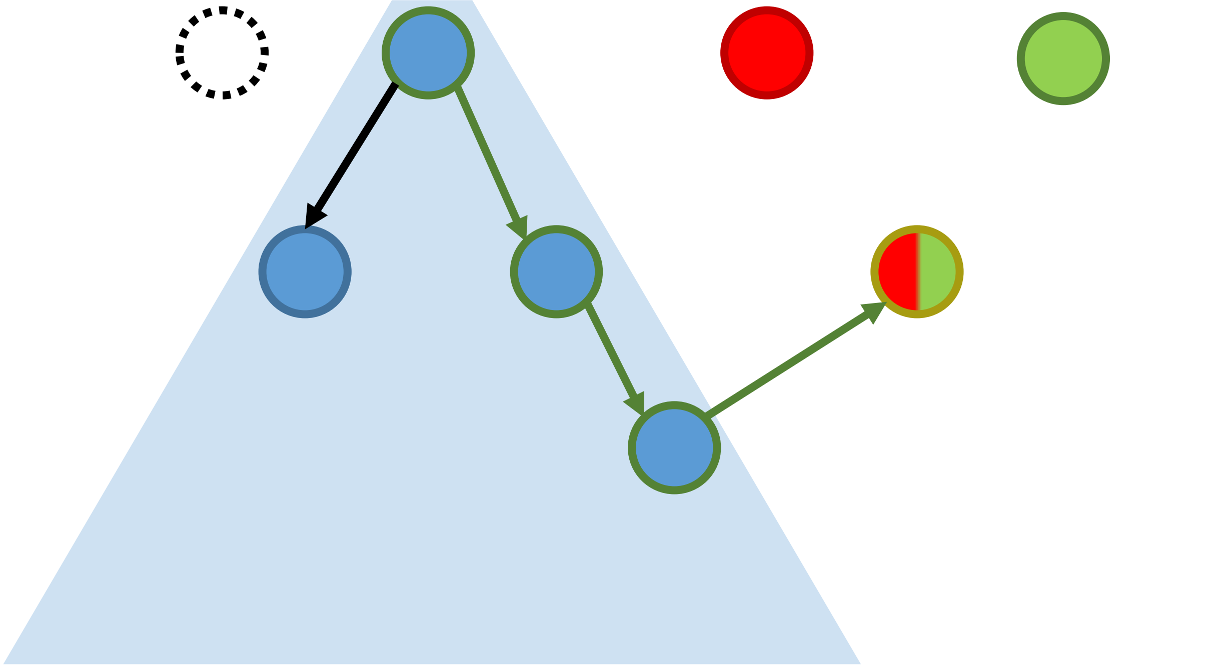

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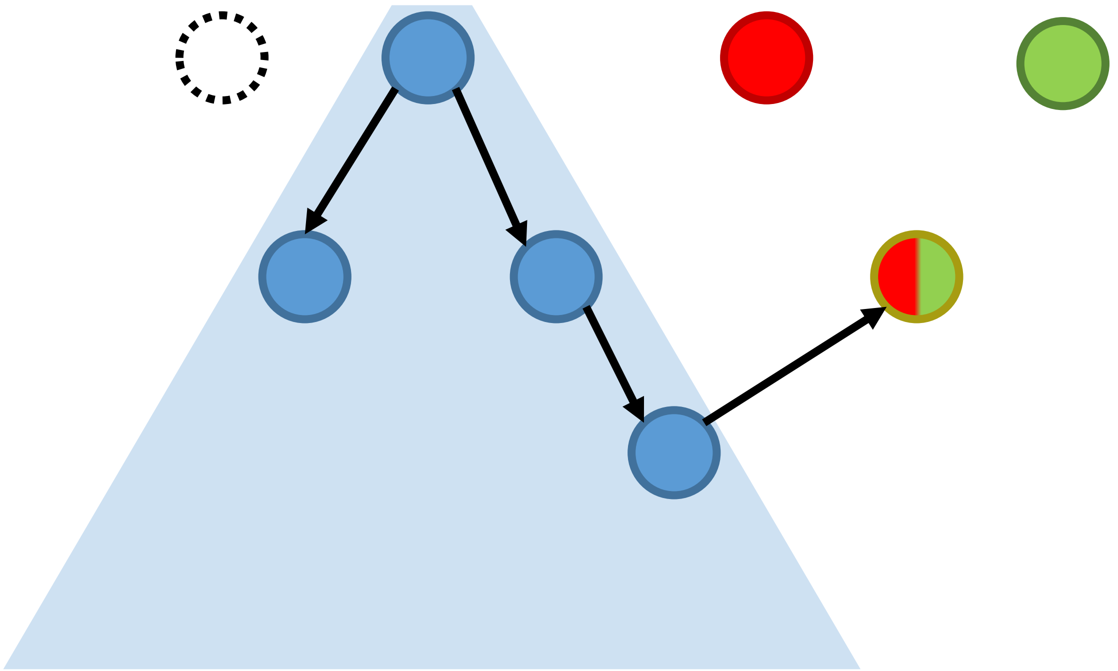
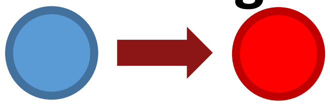
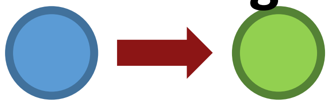


this <- arg1



this <- arg2



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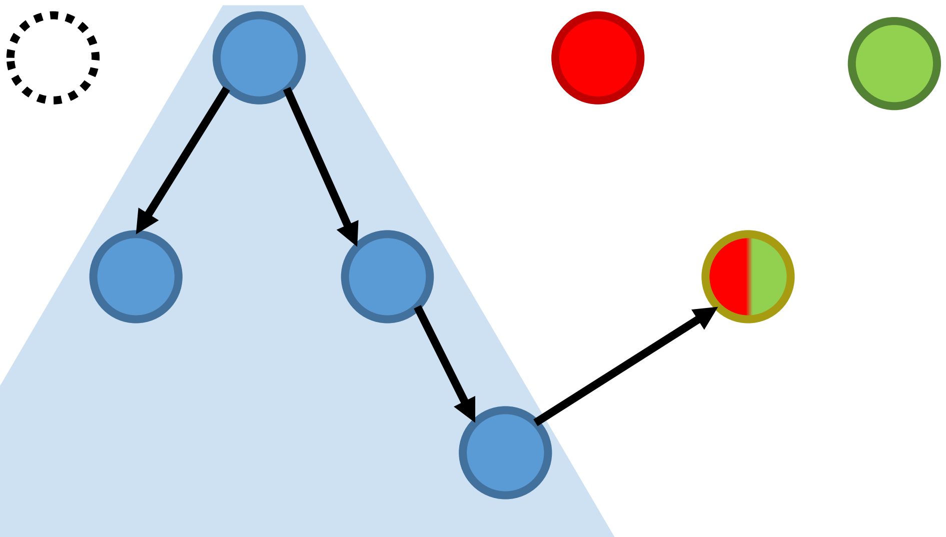
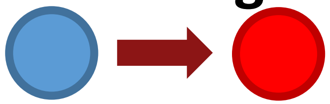
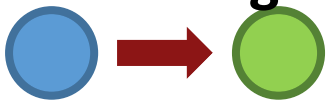


! : Information flow
goes in the opposite direction
of reachability

this <- arg1



this <- arg2



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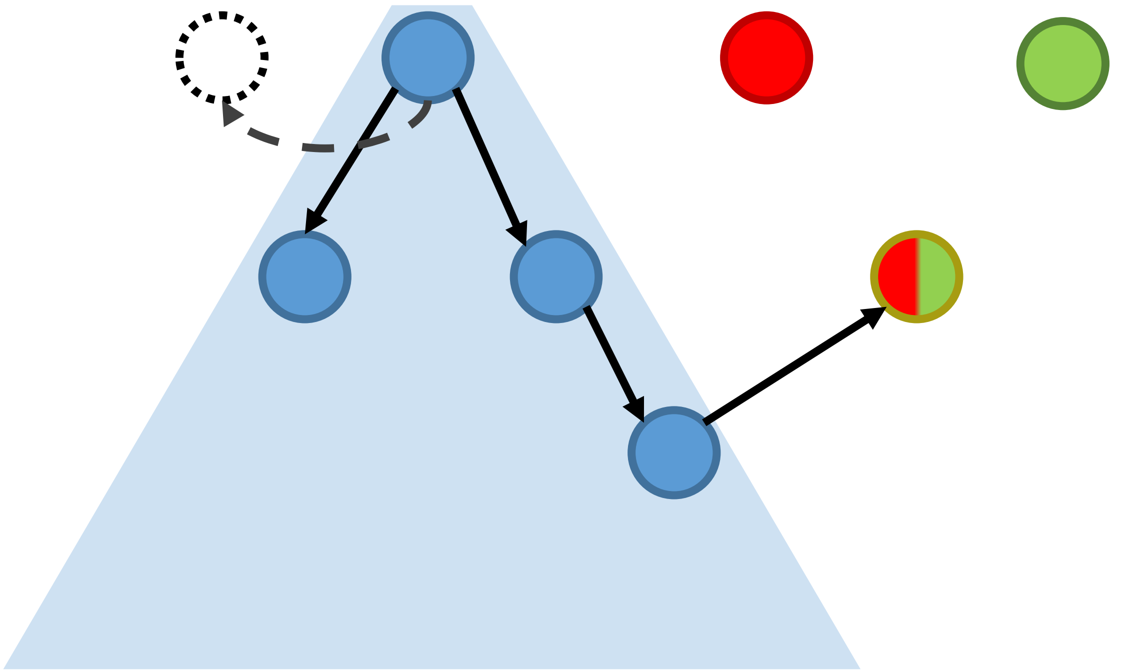

this <- arg1

this <- arg2

Example: Store

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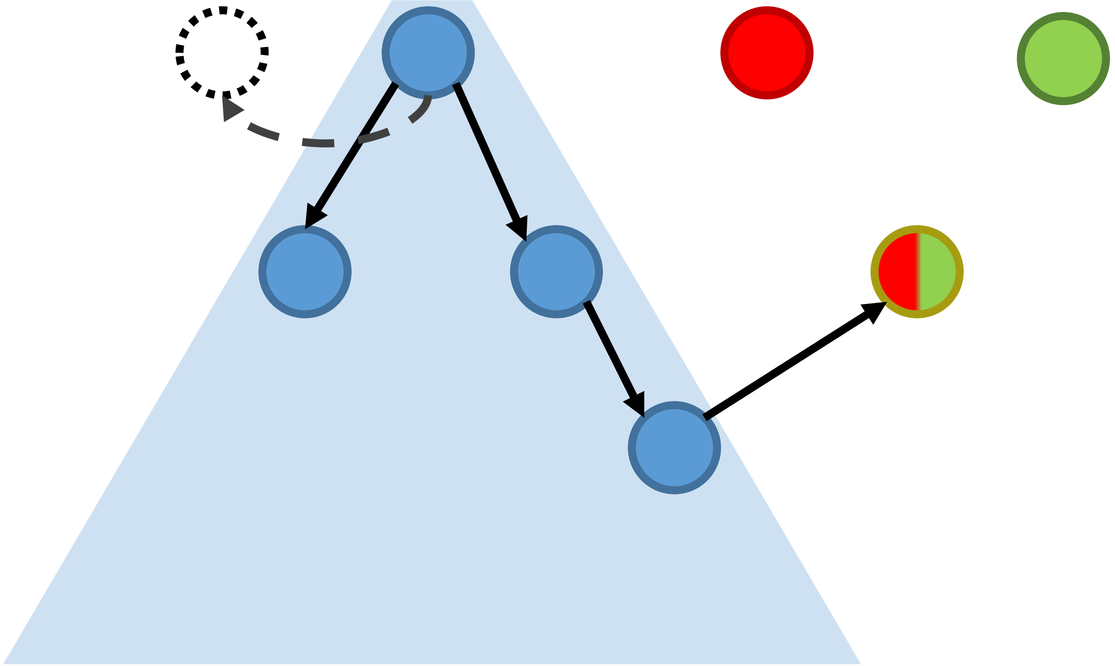

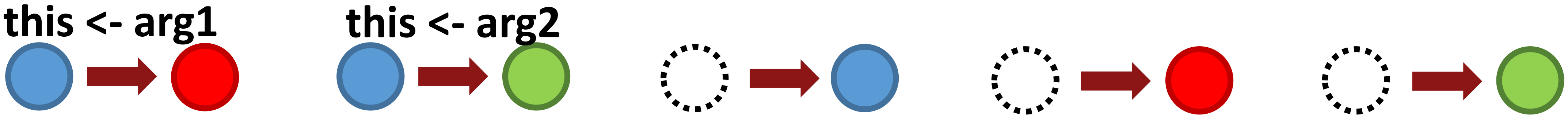

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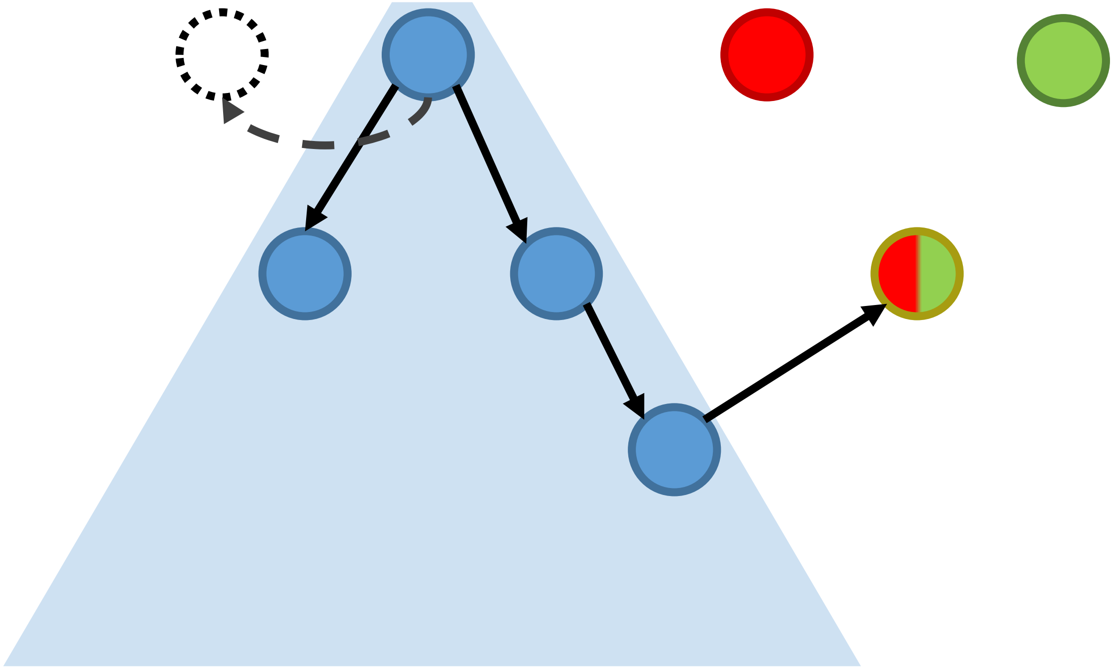
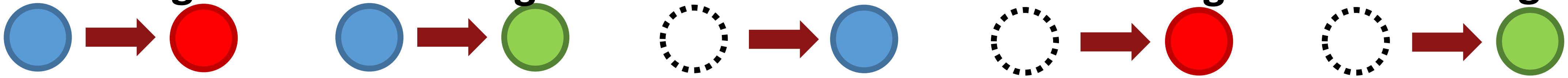
```

ret = o . m (arg1 , arg2)



this <- arg1 **this <- arg2** **return <- this** **return <- arg1** **return <- arg2**



Example: Store

Spec:

arg1->this

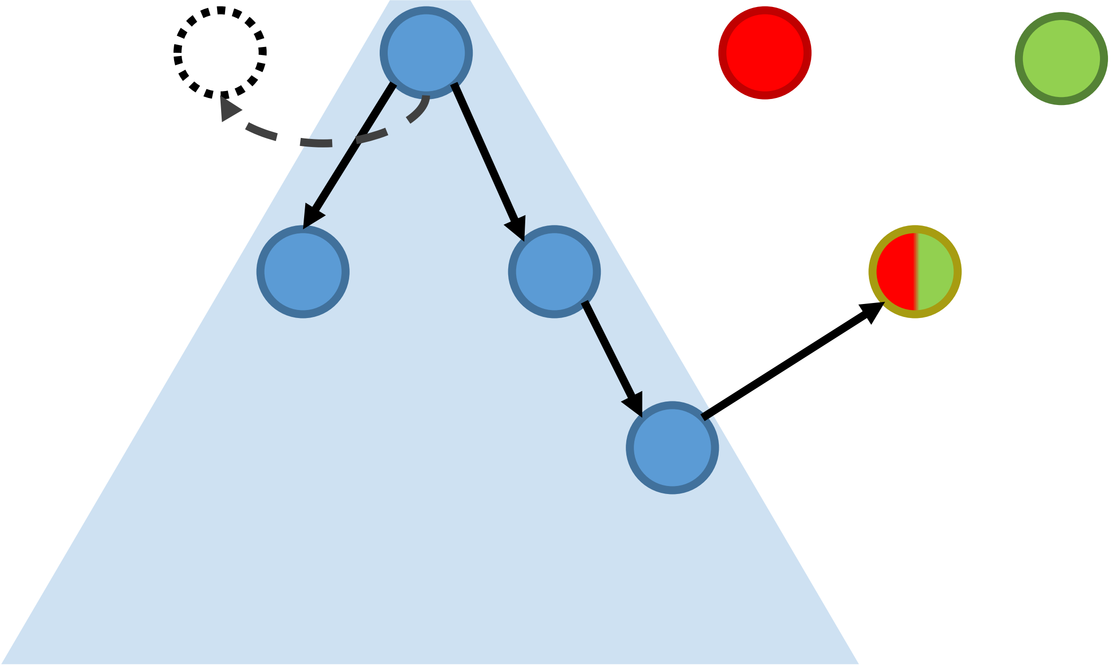
arg2->this

this->return

arg1->return

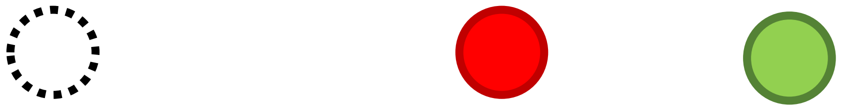
arg2-> return

ret = o . m (arg1 , arg2)



Merging specifications

```
r = max (arg1 , arg2 )
```



Merging specifications

r = max (5 , 3)

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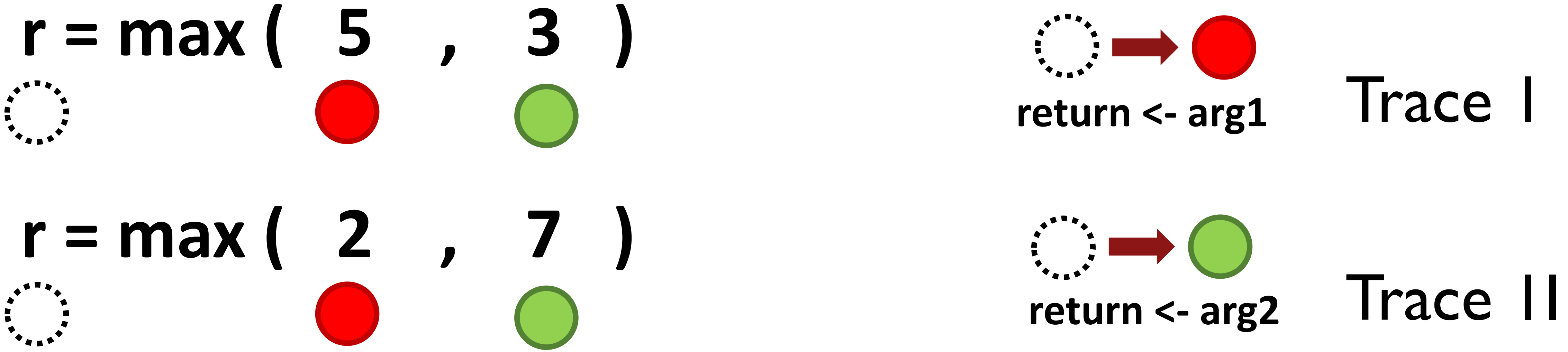
return <- arg1

Trace 1

Merging specifications



r = max (5 , 3)

r = max (2 , 7)

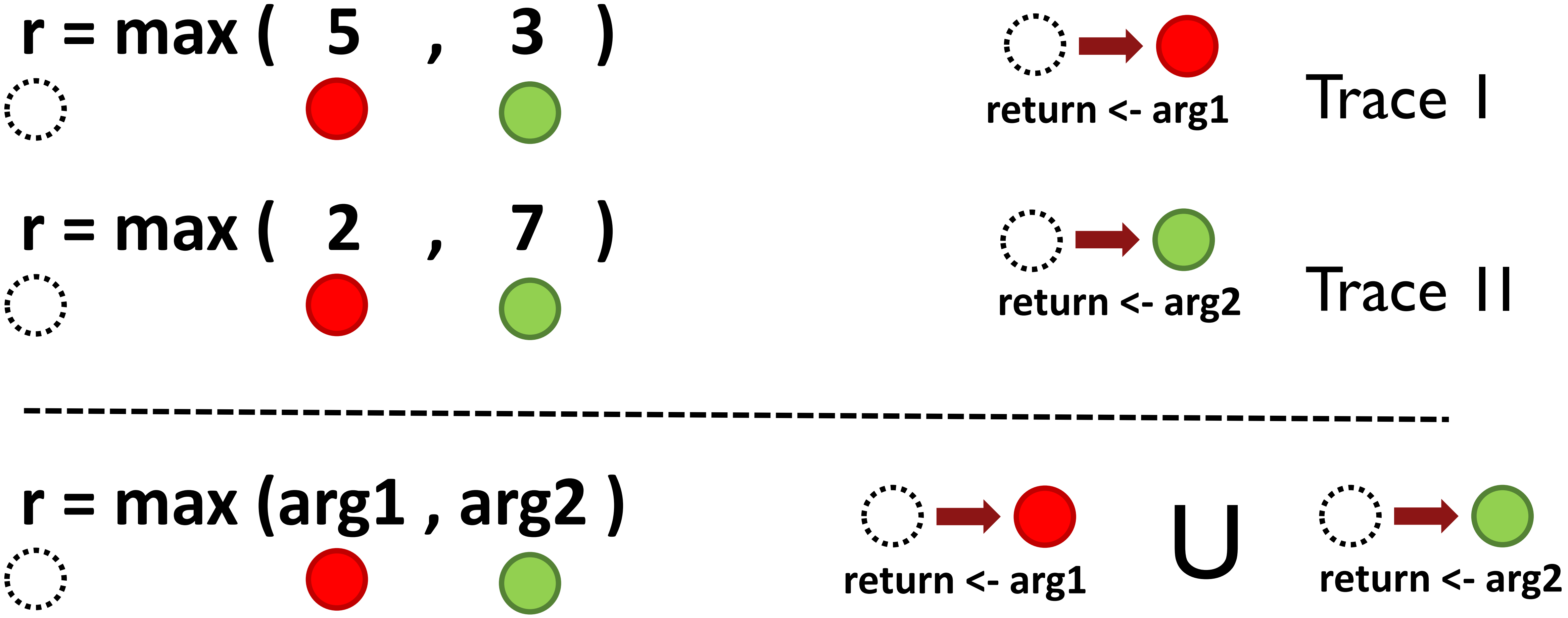
return <- arg1

Trace I

return <- arg2

Trace II

Merging specifications



r = max (5 , 3)

return <- arg1

Trace I

r = max (2 , 7)

return <- arg2

Trace II

r = max (arg1 , arg2)

return <- arg1 U return <- arg2

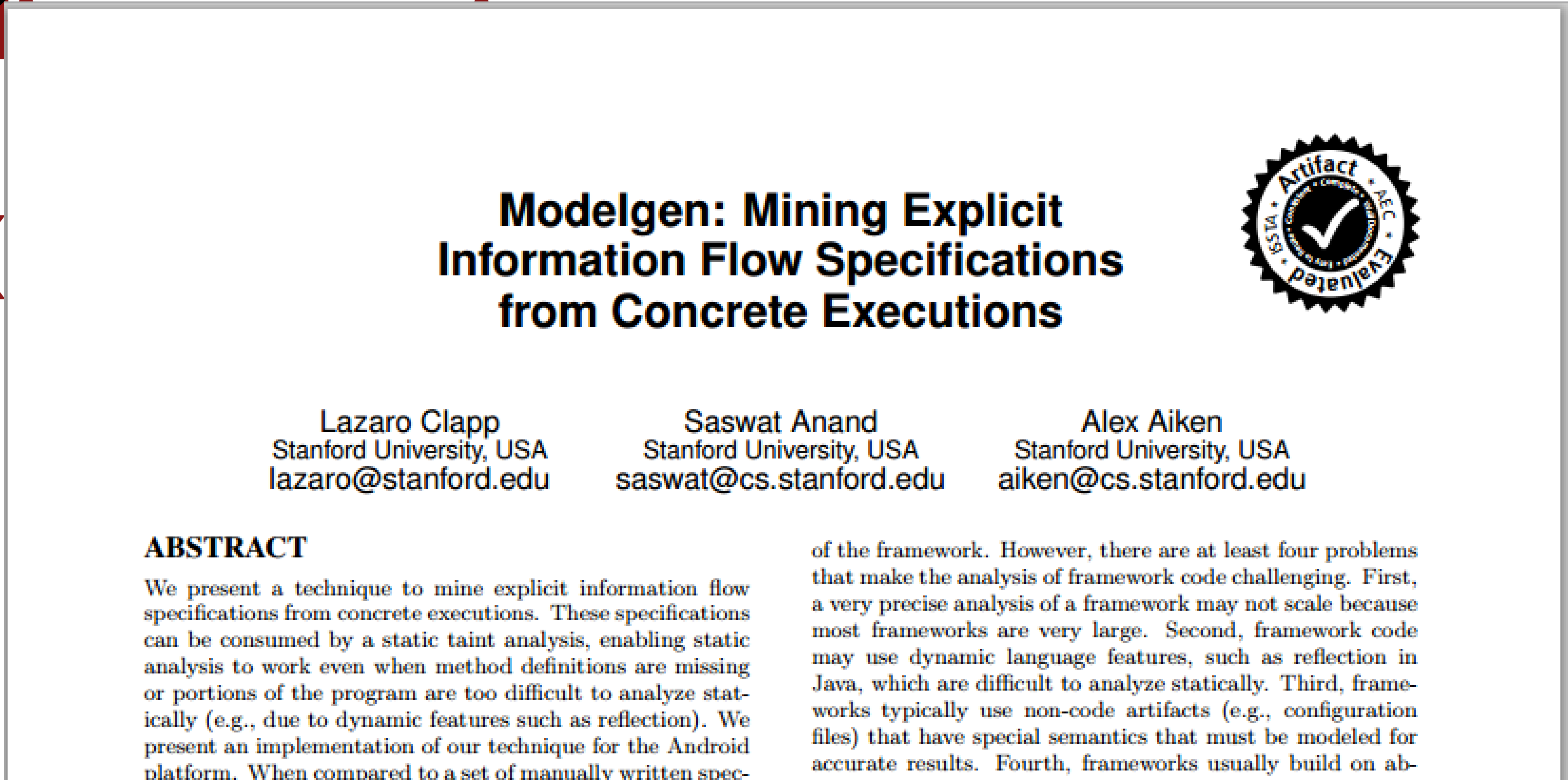
Notes and gotchas

- **Native code / instrumentation holes**
- **Arrays, threading, exceptions**
- **Method calls (and recursion)**
- **Etc.**

Notes and gotchas

- Native co trumentation holes
- Arr d
- calls (
- Etc.

See paper



Modelgen: Mining Explicit Information Flow Specifications from Concrete Executions

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ABSTRACT

We present a technique to mine explicit information flow specifications from concrete executions. These specifications can be consumed by a static taint analysis, enabling static analysis to work even when method definitions are missing or portions of the program are too difficult to analyze statically (e.g., due to dynamic features such as reflection). We present an implementation of our technique for the Android platform. When compared to a set of manually written spec-

of the framework. However, there are at least four problems that make the analysis of framework code challenging. First, a very precise analysis of a framework may not scale because most frameworks are very large. Second, framework code may use dynamic language features, such as reflection in Java, which are difficult to analyze statically. Third, frameworks typically use non-code artifacts (e.g., configuration files) that have special semantics that must be modeled for accurate results. Fourth, frameworks usually build on ab-

IV

Experiments and results

Experiment I: Man vs Machine

309 methods, 51 classes

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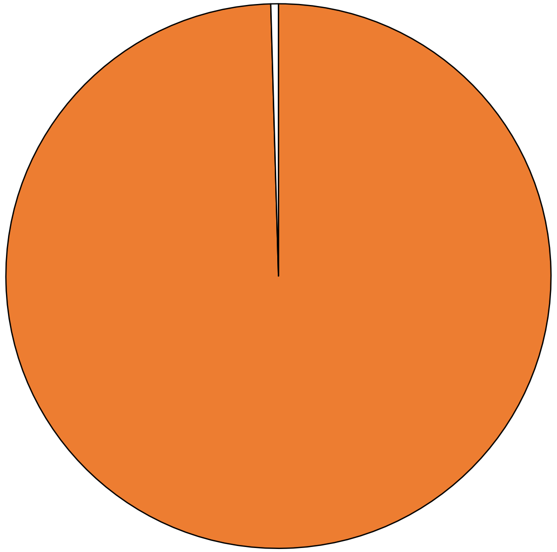
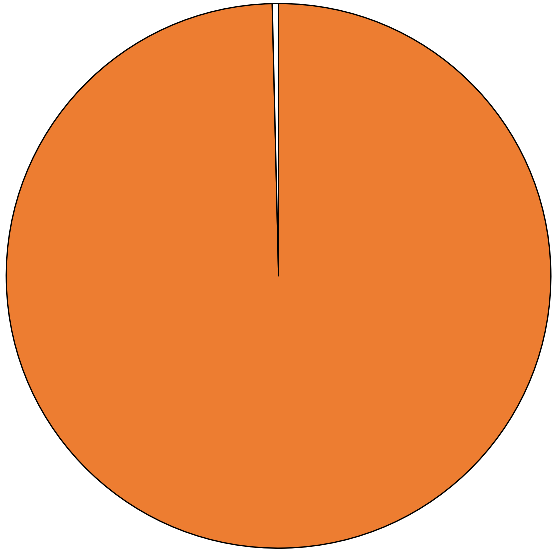
309 methods, 51 classes

99.55% Precision



440 TP / 2 FP

99.63% Precision

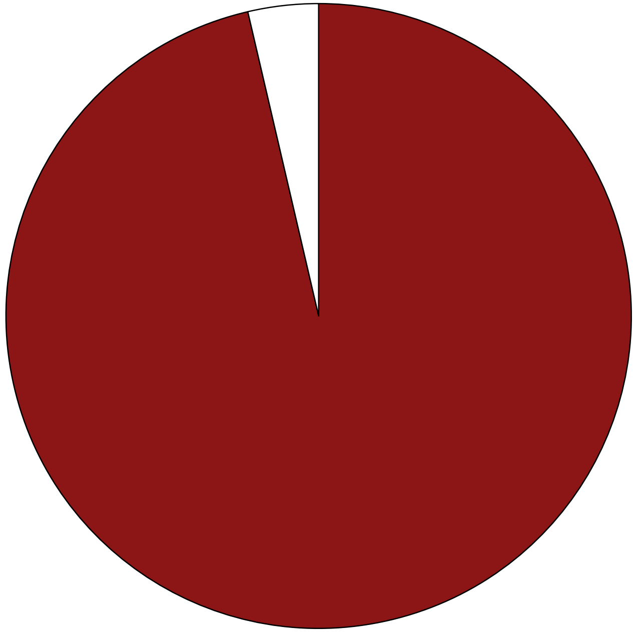


540 TP / 2 FP

Experiment I: Man vs Machine

309 methods, 51 classes

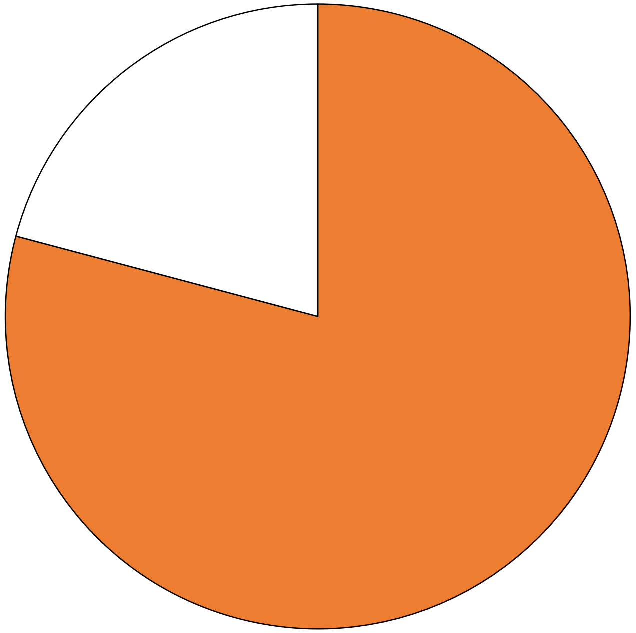
96.36% Recall vs Manual



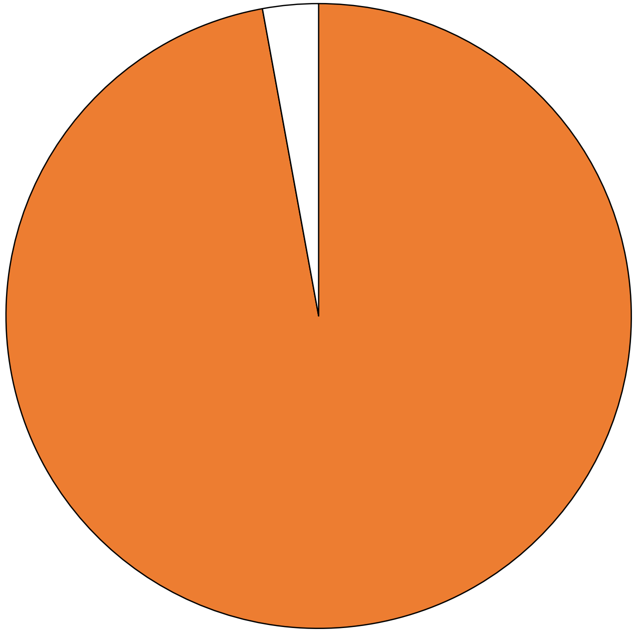
Experiment 1: Man vs Machine

309 methods, 51 classes

79.14% Recall vs Total (TP)



97.12% Recall vs Total (TP)



Experiment II: STAMP

Experiment II: STAMP

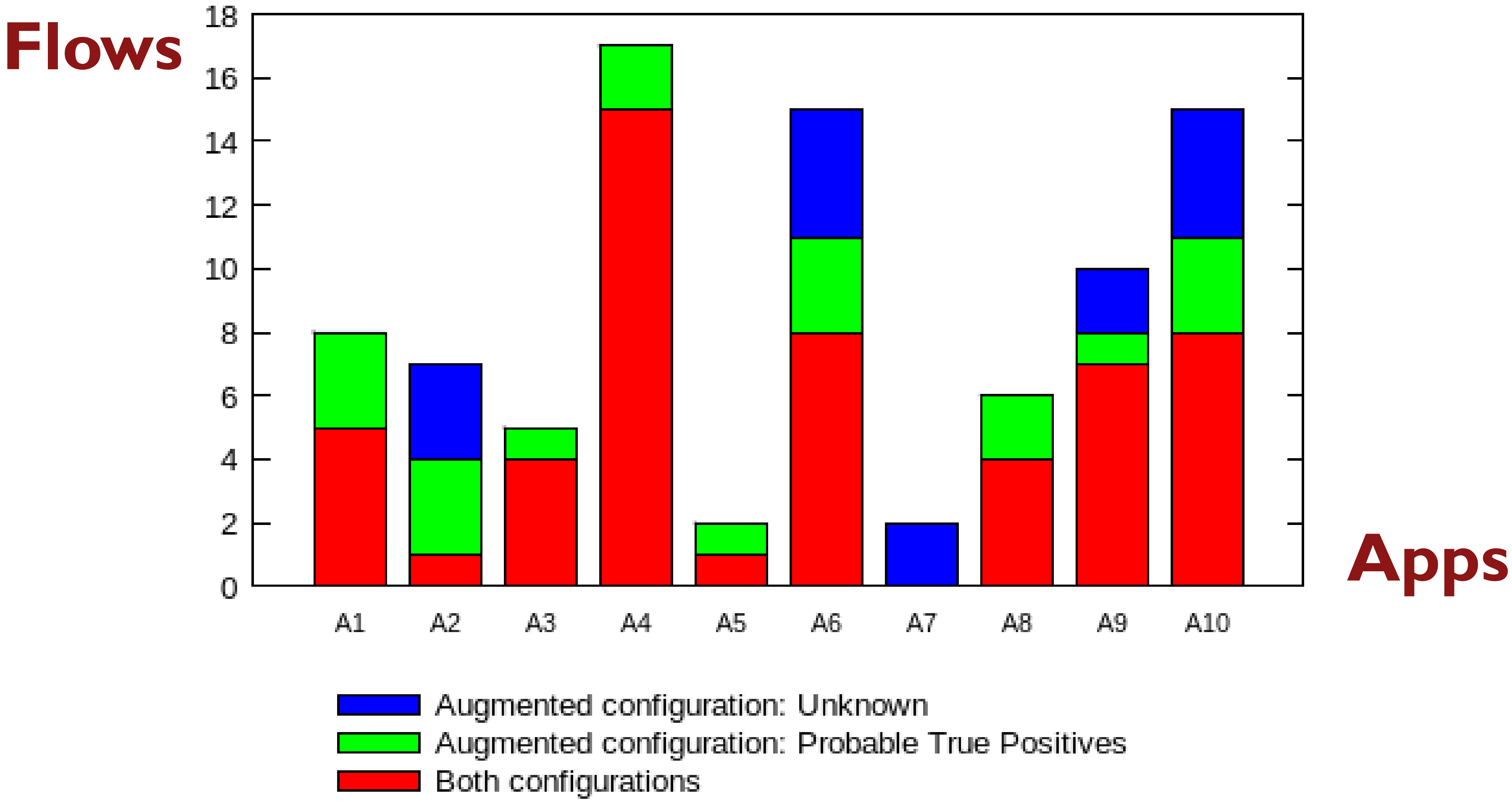
- **242 apps (Google Play)**
- **Base: 3.08 flows (x app)**
- **Modelgen: 4.07 flows (x app)**

Experiment II: STAMP

- **242 apps (Google Pl**
- **Base: ws (x app)**
- **Modelg 4.07 flows (x app)**

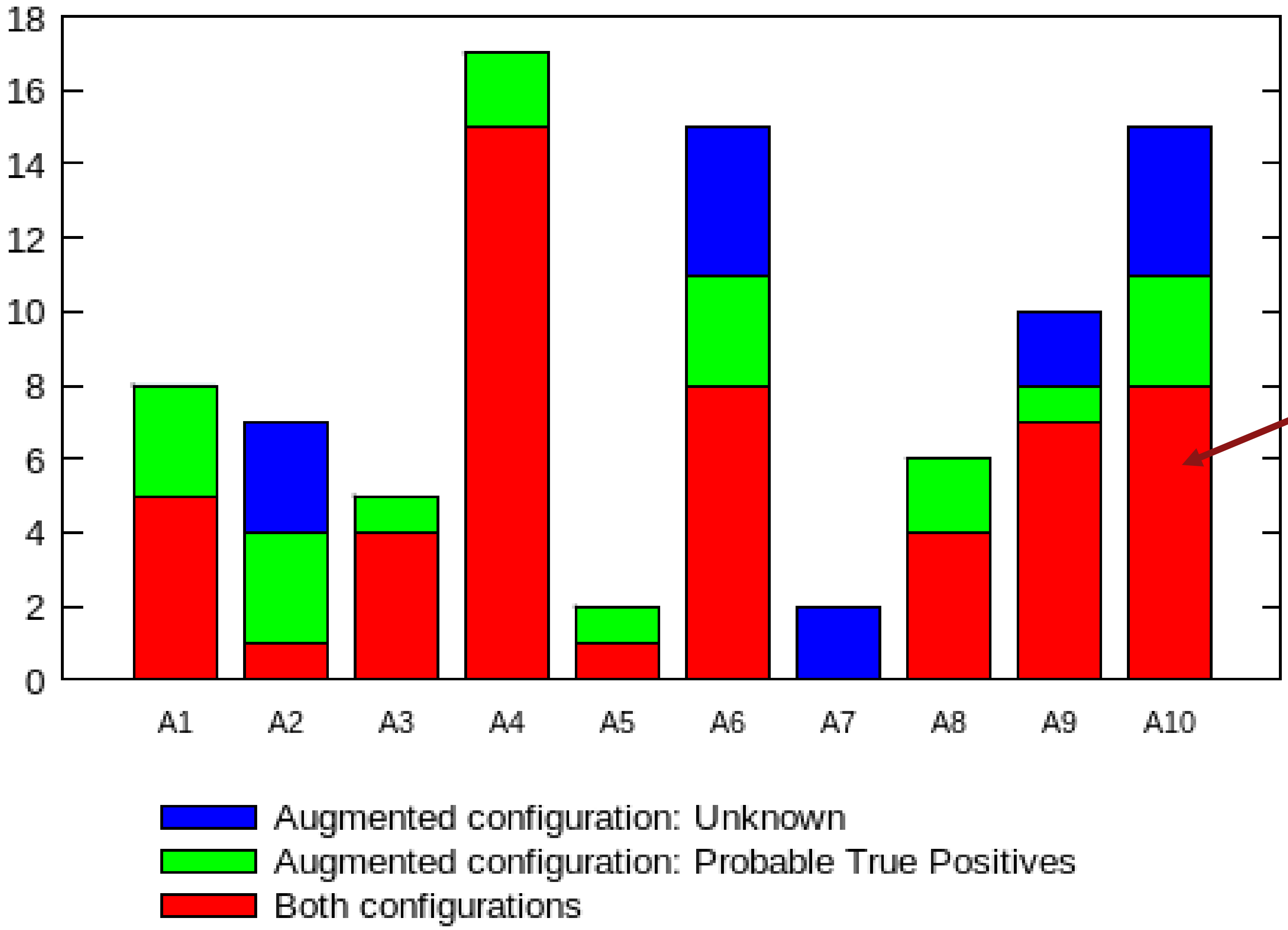
But, are this… true positives?

Experiment II: STAMP



Experiment II: STAMP

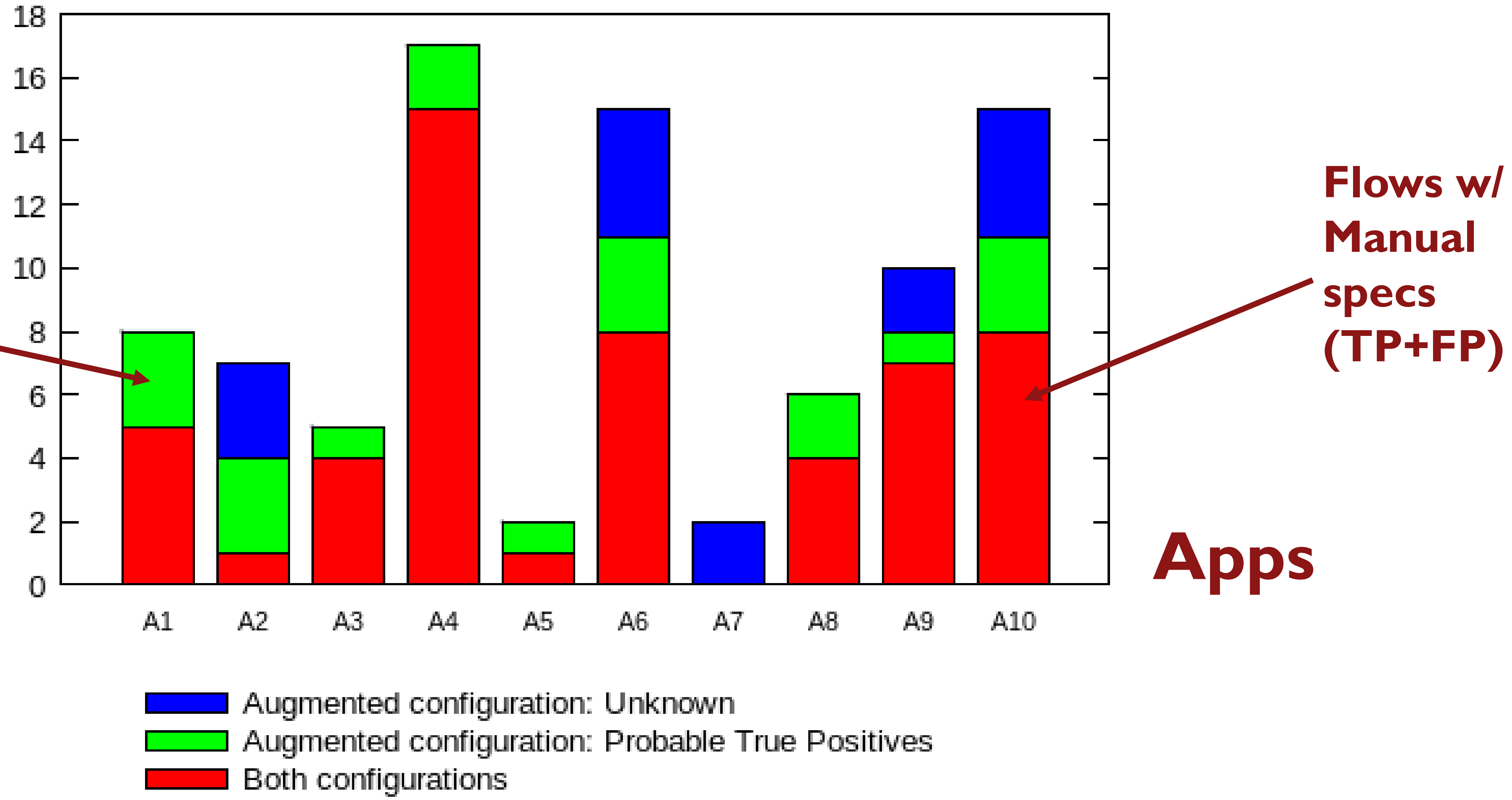
Flows



Flows w/ Manual specs (TP+FP)

Apps

Experiment II: STAMP

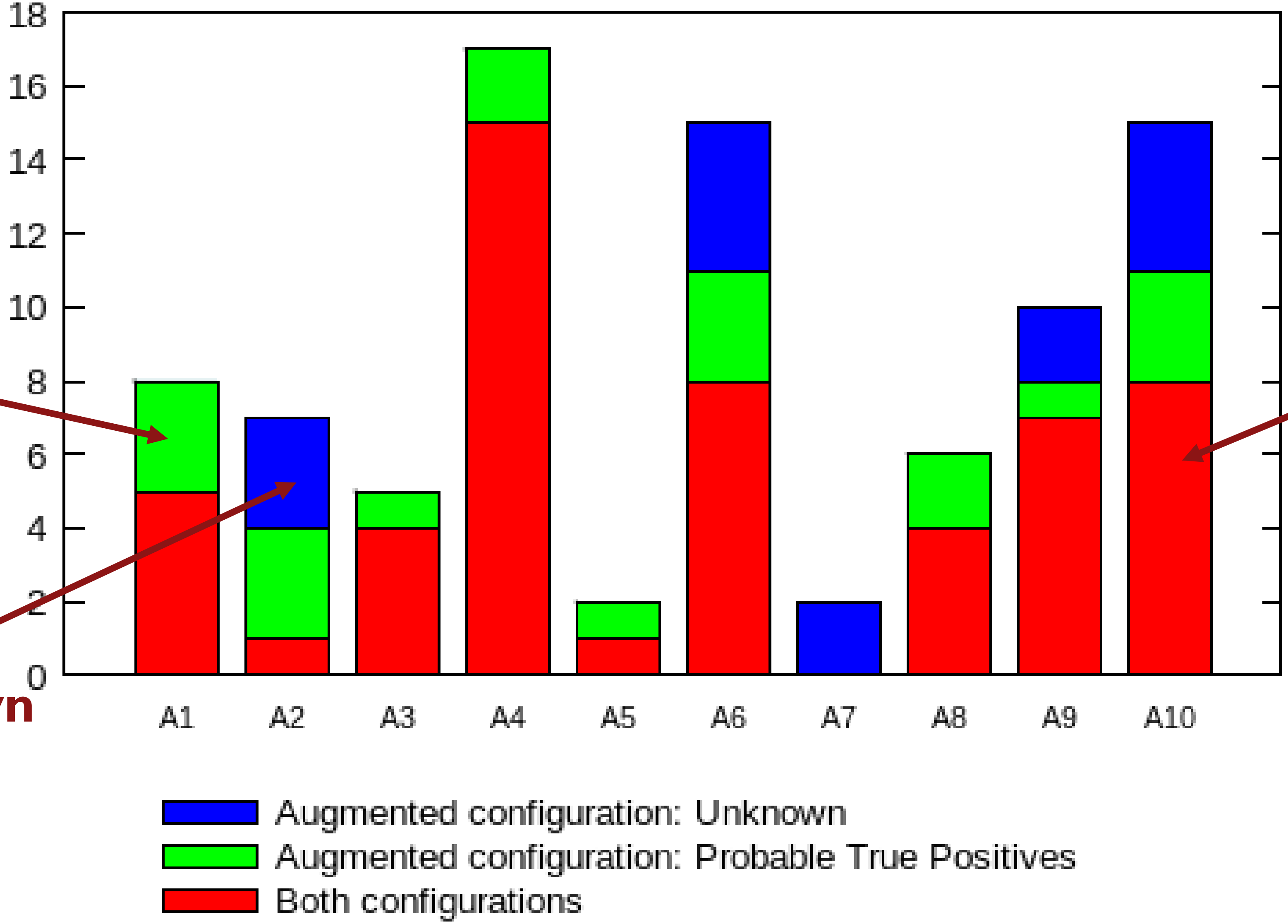


New TP

Flows w/ Manual specs (TP+FP)

Experiment II: STAMP

Flows



New TP

New Unknown

Apps

Flows w/ Manual specs (TP+FP)

V

Conclusions and related work

Key points

- **Platform code specifications**

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- **Platform code specifications**
- **Dynamic analysis > manual effort (sometimes)**

Key points

- **Platform code specifications**
- **Dynamic analysis > manual effort (sometimes)**
- **For IF Specs: > 97% precision and recall**

(Some) Related work

Dynamic techniques for generating API specifications

- V. K. Palepu, G. H. Xu, and J. A. Jones. Improving efficiency of dynamic analysis with dynamic dependence summaries. ASE 2013
- A. W. Biermann and J. A. Feldman. On the synthesis of finite-state machines from samples of their behavior. IEEE ToC, 1972.
- G. Ammons, R. Bodık, and J. R. Larus. Mining specifications. POPL 2002.
- T. Xie, E. Martin, and H. Yuan. Automatic extraction of abstract-object-state machines from unit-test executions. ICSE 2006
- D. Lorenzoli, L. Mariani, and M. Pezze. Automatic generation of software behavioral models. ICSE 2008
- J. W. Nimmer and M. D. Ernst. Automatic generation of program specifications. ISSTA 2002

Dynamic / Static taint analysis

- J. A. Clause, W. Li, and A. Orso. Dytan: A generic dynamic taint analysis framework. ISSTA 2007
- W. Enck, P. Gilbert, B. gon Chun, L. P. Cox, J. Jung, P. McDaniel, and A. Sheth. Taintdroid: An information-flow tracking system for realtime privacy monitoring on smartphones. OSDI 2010
- S. Arzt, S. Rasthofer, C. Fritz, E. Bodden, A. Bartel, J. Klein, Y. L. Traon, D. Octeau, and P. McDaniel. Flowdroid: Precise context, flow, field, object-sensitive and lifecycle-aware taint analysis for Android apps. PLDI 2014
- M. Sridharan, S. Artzi, M. Pistoia, S. Guarnieri, O. Tripp, and R. Berg. F4F: Taint analysis of framework-based web applications. OOPSLA 2011
- O. Bastani, S. Anand, and A. Aiken. Specification inference using context-free language reachability. POPL 2015

Code and models available

https://bitbucket.org/lazaro_clapp/droidrecord

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Bitbucket

Questions?