Triceratops

Privacy-protecting Mobile Apps

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Motivation

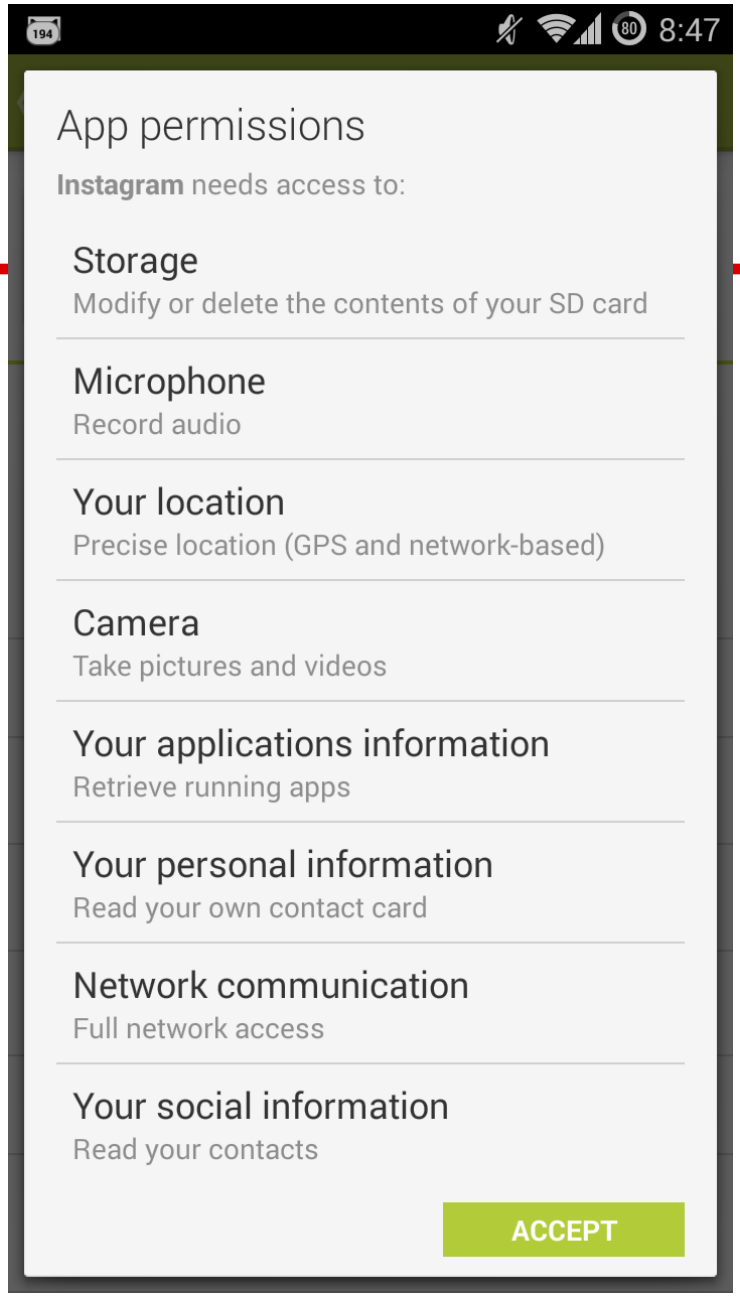
- Mobile security is becoming increasingly important
  - In 2013, there are over 1 billion smartphone users around the globe another billion users by 2015
  - F-Secure identified 275 new mobile threat families in Q1 2014, up from 149 last year
- Mobile privacy is a leading concern
  - Over 50% of the Android malware has some private information collection capabilities

Threat Model

- Mobile privacy: Leakage of personal or sensitive information
  - GPS coordinates
  - Audio recordings
  - Contacts list
  - SMS messages
- Not focusing on:
  - Attacks that tries to take over the device
  - Phishing, social engineering attacks
  - Denial of Service

Android Permission

- Coarse-grained permission system
  - Possible to hide malicious behavior
- Weak enforcement
  - All or nothing



Malware Example

Kittey Kittey

- A real Android malware, designed to evade detection tools

READ_FILESYSTEM **INTERNET_ACCESS**

Approach

An **enforcement tool** that allows users to enforce **fine-grained privacy policies** on a given mobile app

Design challenges:

- What is a easy-to-write and expressive syntax for privacy policies?
- How to build a tool that precisely and effectively enforce these policies?

Outline

- Privacy policy
- Enforcement tool
  - Survey of existing techniques
  - Static optimized dynamic enforcement
- Implementation
- Demo
- Preliminary Evaluations

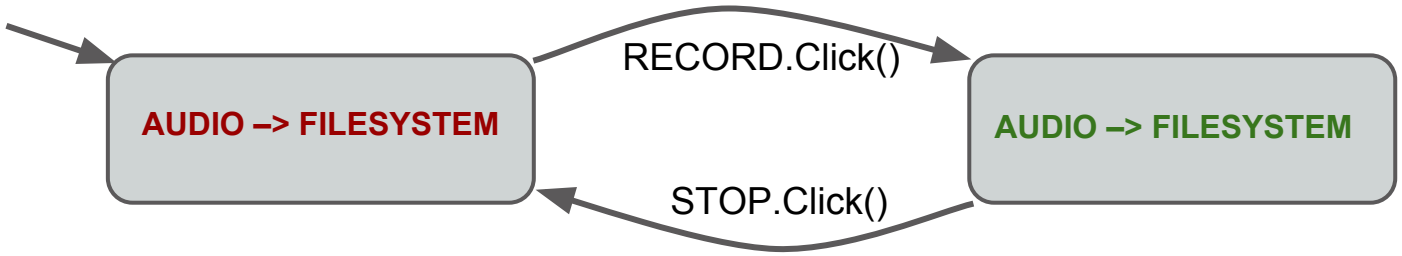
What is Privacy Policy

A specification determining how sensitive information is allowed or not allowed to be used within the app.

Components:

- **Information Flow**: how sensitive data can be exfiltrated
  - Filesystem -> Internet
  - Call logs -> SMS
- **Control Flow:** specific code paths or preconditions
  - Not allowed to upload GPS coordinate till a button is pressed

Privacy Policy Example



Audio recording is only allowed after RECORD is clicked and before STOP is pressed

A FSM that describes both the information flow and the control flow specifications

- State: a list of allowed or disallowed information flows
- Edge: a specific program instruction that causes the state change

Who will write the privacy policy

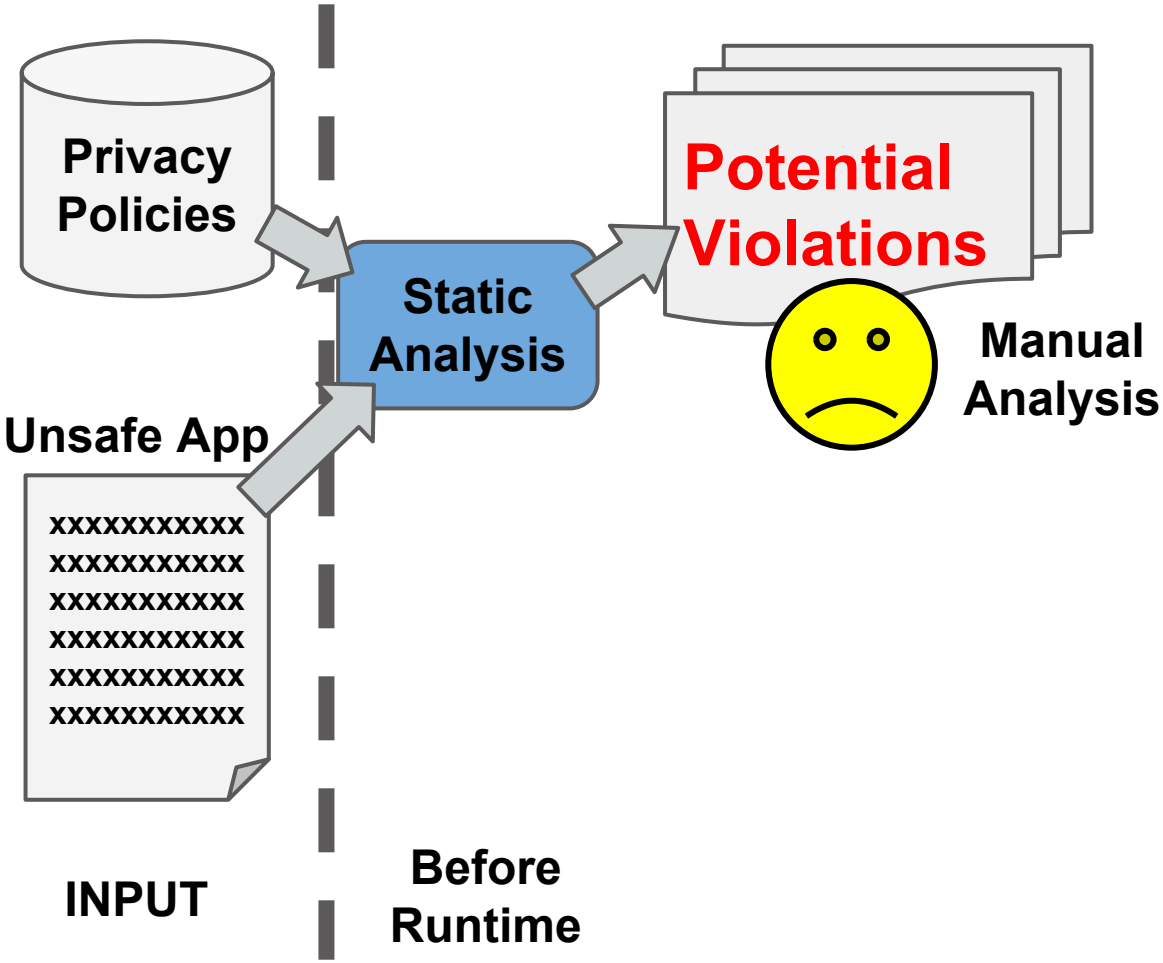
- App developer
  - Specifies how sensitive data are used in more detail
  - “Enhanced permission system”
- Sysadmins
  - Apply set of default “not-allowed” policies based on app’s permission
- User
  - All sensitive data flow is not-allowed by default
  - Ask user’s permission when a flow first occurs
  - Next time this specific flow occurs, it will be automatically allowed or blocked

Survey of existing enforcement techniques

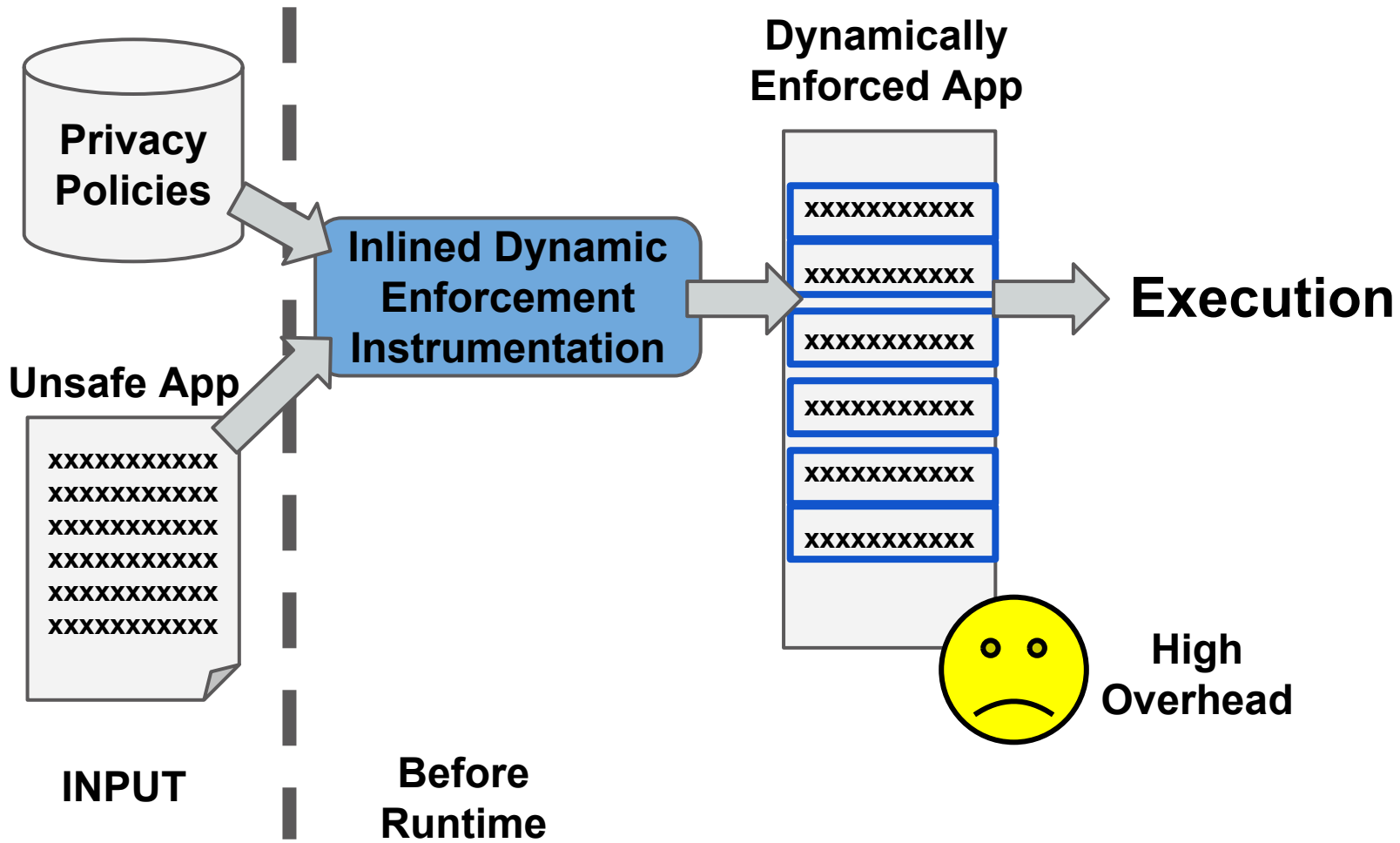
Metrics:

- Precision
  - No false positive
- Usability
  - Small runtime overhead
- Practicality
  - Automated
  - Does not require modification to the runtime system

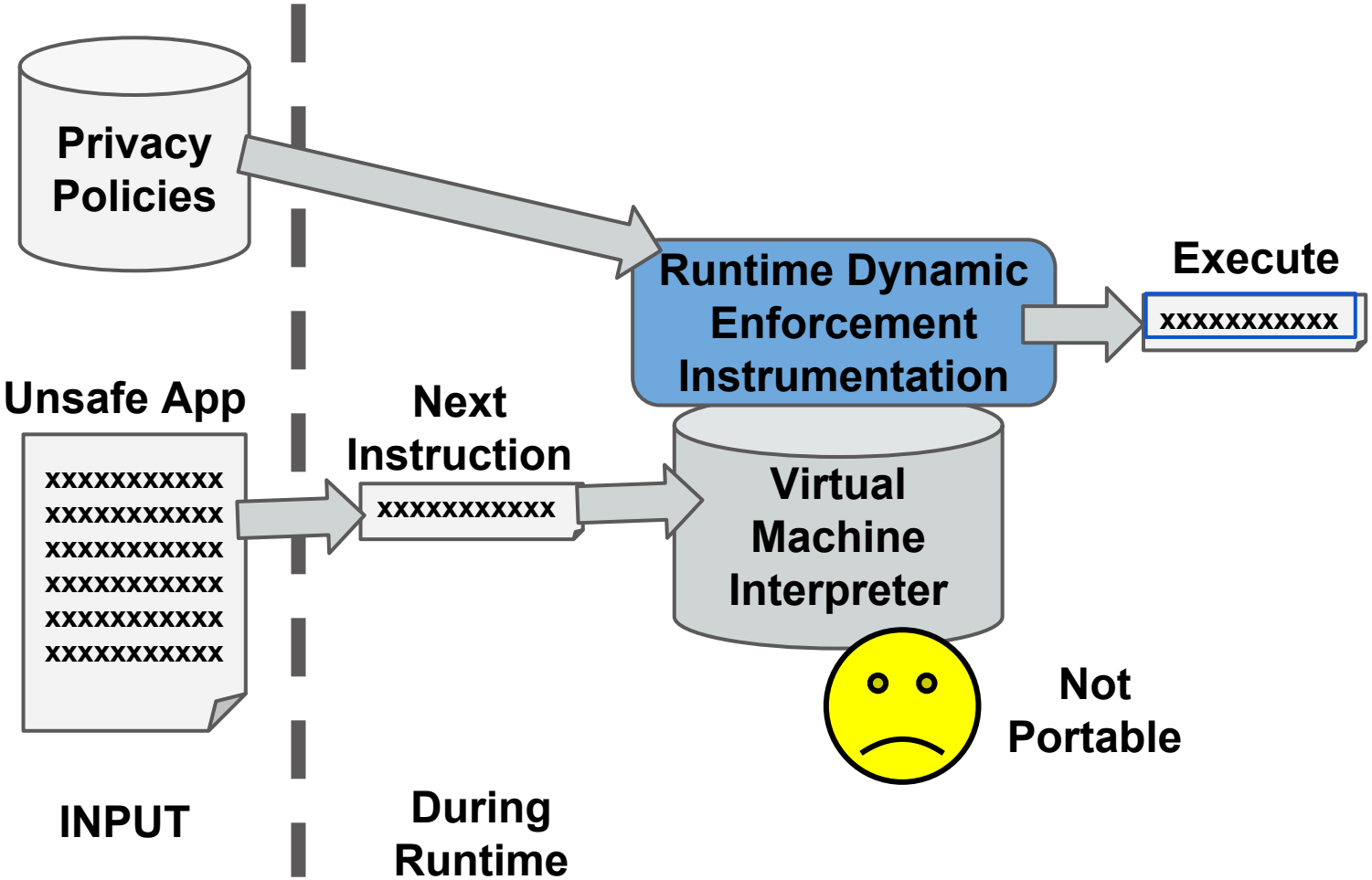
Static Analysis



Inlined Dynamic Enforcement



Runtime Dynamic Enforcement

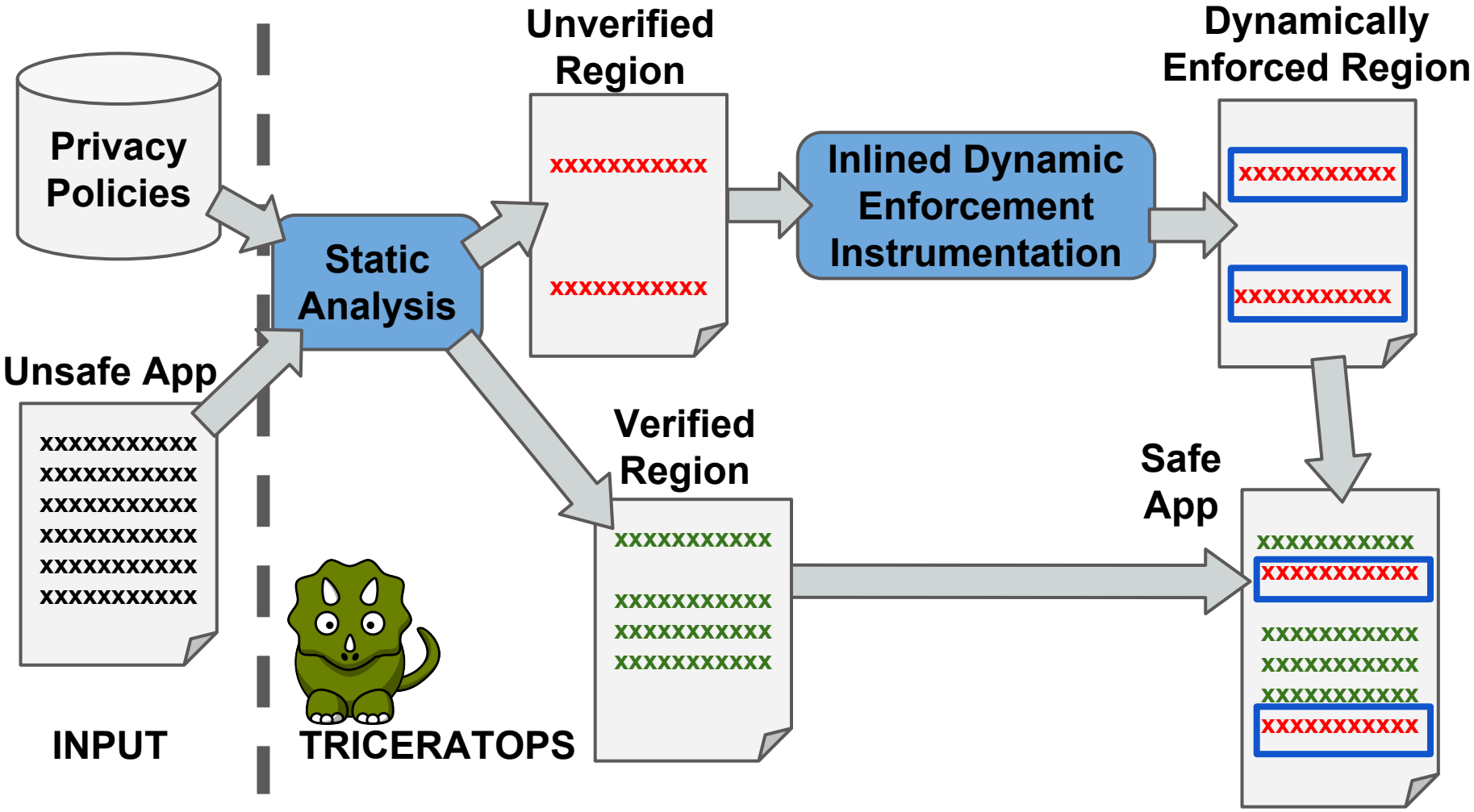


Comparison

Techniques	Runtime Overhead	Portable	False Positives
Static Analysis (Conservative)	N/A	N/A	YES
Runtime Dynamic Enforcement	Low	NO	NO
Inlined Dynamic Enforcement	High	YES	NO
Triceratops	Low	YES	NO

Key idea: Combine static analysis and inlined dynamic enforcement

Intuition


Privacy Policies
Unsafe App
xxxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxx
INPUT
Static Analysis
TRICERATOPS
Unverified Region
xxxxxxxxxxx
xxxxxxxxxxx
Verified Region
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xxxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxx
Inlined Dynamic Enforcement Instrumentation
Dynamically Enforced Region
xxxxxxxxxxx
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Safe App
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Static Optimized Dynamic Enforcement

- Minimizes the instrumentation needed to enforce a set of policies by using static analysis to:
  - Apply API summaries
  - Identify unsafe code regions
  - Optimize enforcement code

API Summary

- Allows static analysis to reason about API's effect without executing the app
- Remove the need to instrument API bodys

```
File f=sensitiveFile
String x= Long.toString(f.lastModified())  ⇨  String x= f
uploadToInternet(x)
```

```
Long.toString(long)
File.lastModified()
```

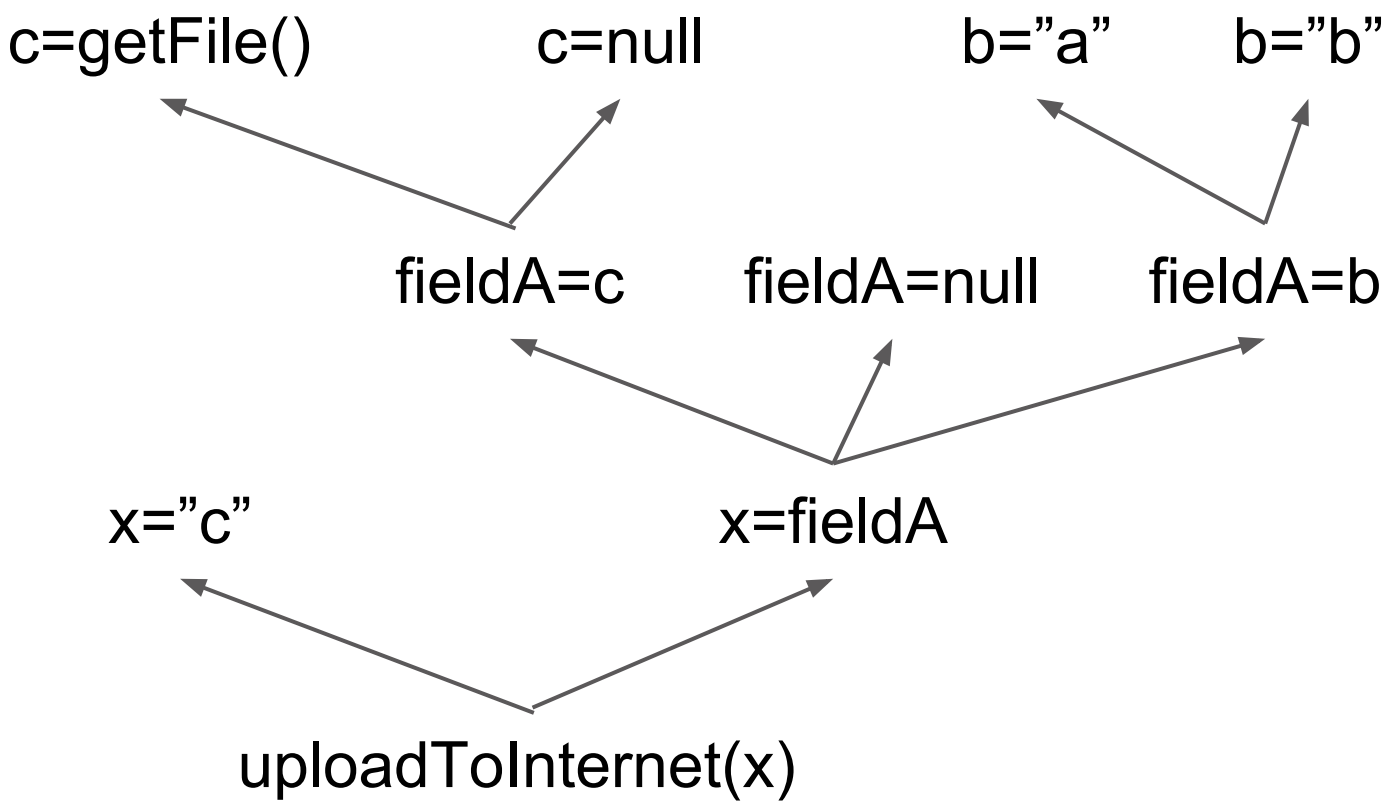
```
if (parameter.isSensitive)
    return Sensitive
else
    return NotSensitive
```

Identify Unsafe Code Regions

- Because the tool knows exactly what data flow it needs to track
- Conservatively identify code regions that help compute or propagate data from the source

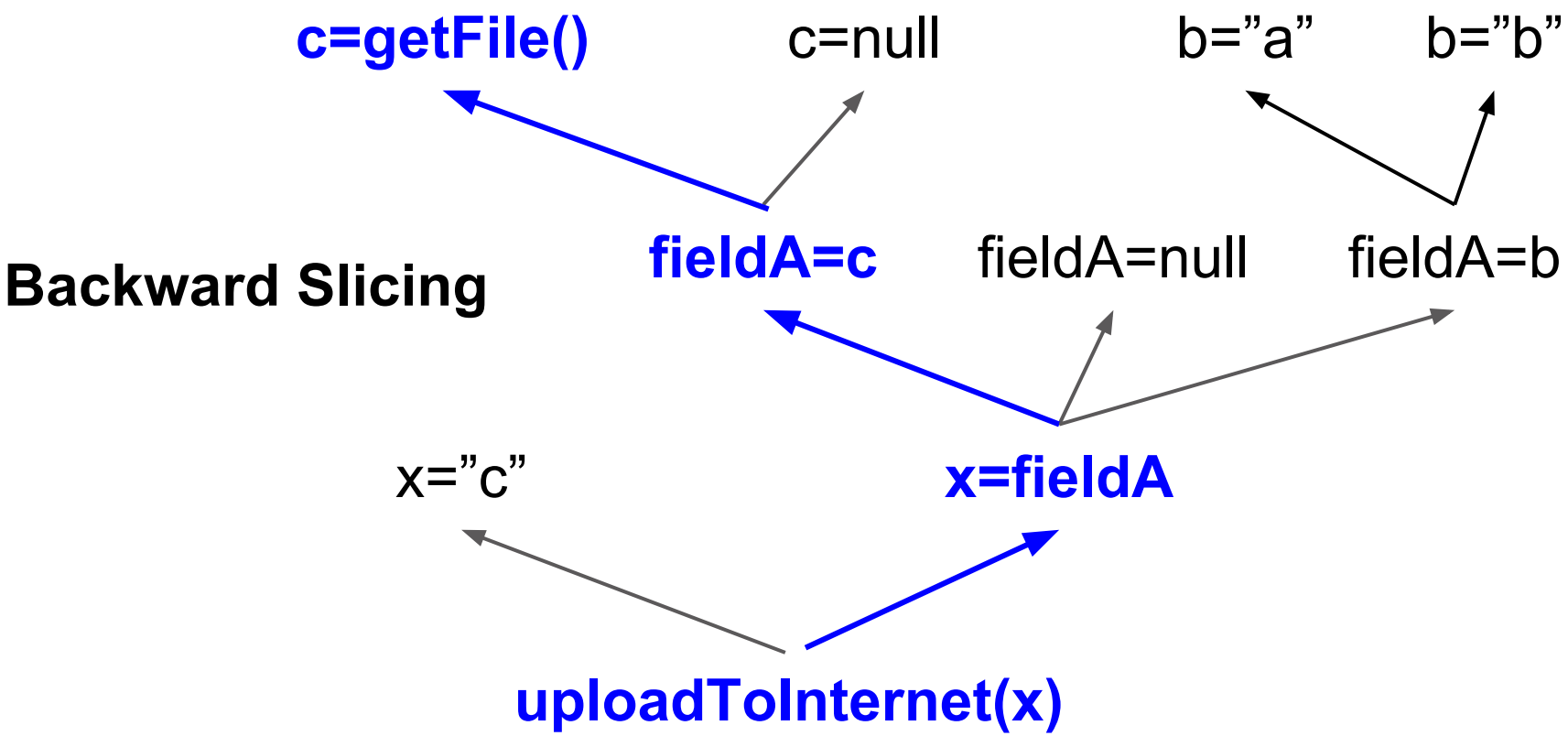
Example

Filesystem -> Internet



Example

Filesystem -> Internet

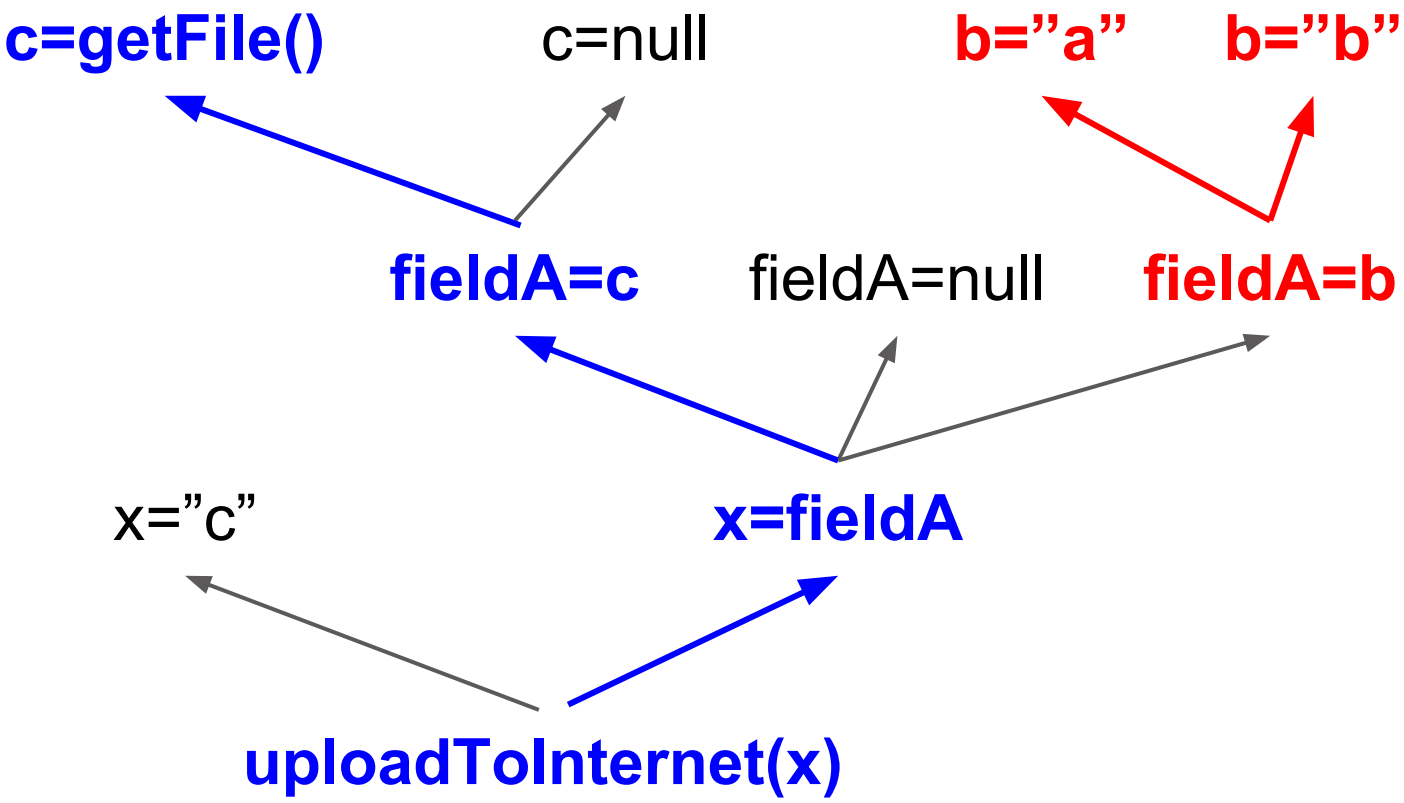


Enforcement Code Optimization

- Static taint propagation
- Constant folding
- Copy propagation
- Dead code elimination

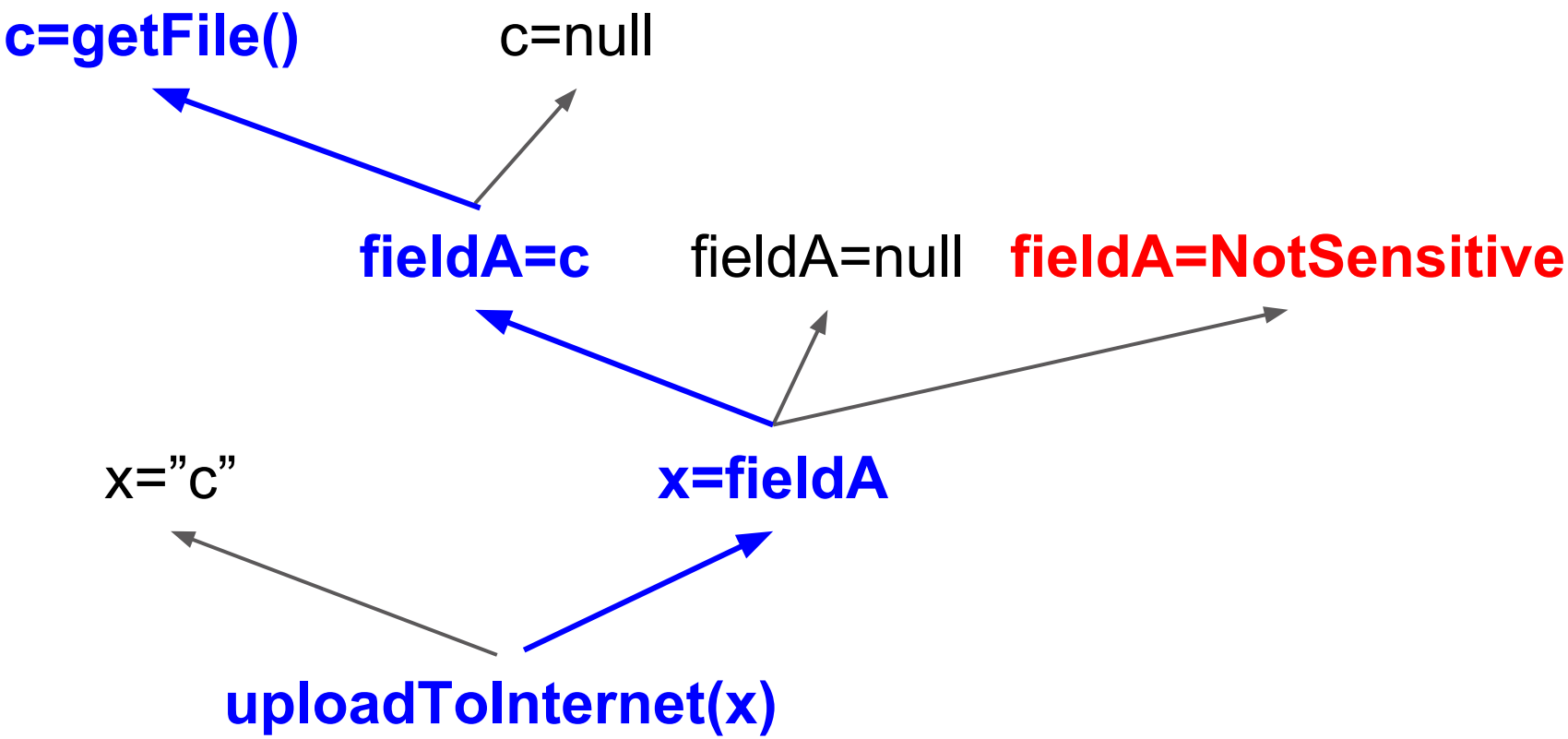
Static Taint Propagation Example

Filesystem -> Internet



Static Taint Propagation Example

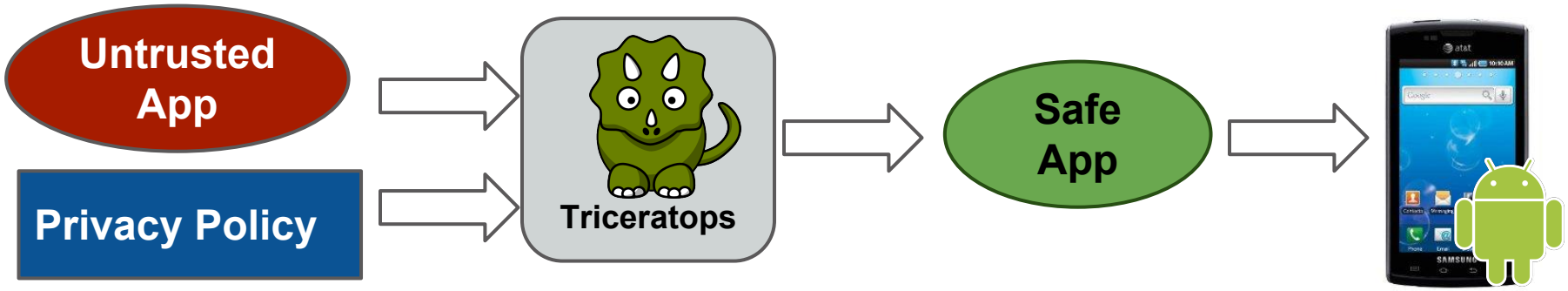
Filesystem -> Internet



Implementation

- Mainly built on top of Wala analysis framework
- Directly perform analysis on Dalvik bytecode (no need for source code)
- Use smali assembler and disassembler toolchain for instrumentation
- Existing API summary from SPARTA project

Triceratops Demo



Preliminary Evaluations

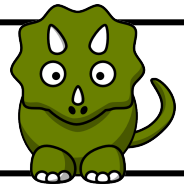
- Kittey Kittey
  - No Filesystem -> Internet
- SMS replicator
  - No SMS -> SMS before a button is clicked

Enforcement Overhead (# of additional instructions)

App	No Optimization	API Summary Relevant Code	Full Optimization
Kittey Kittey	2757	75/61	6/4
SMS replicator	886	20/13	4/3

Very low runtime overhead!

Preliminary Evaluations

Tools	Kittey Kittey	SMS Replicator	Root Cause
Android Permission System	✗	✗	No IF, CF
Pegasus [Chen'13]	☹	☹	Multiple code path to potential violation
TaintDroid [Enck'10]	☺	☹	No CF
Aurasium [Xu'12]	✗	☹	No IF
Triceratops 	☺	☺	Finer-grained privacy policy IF+CF

Supports more types of malware

Limitations

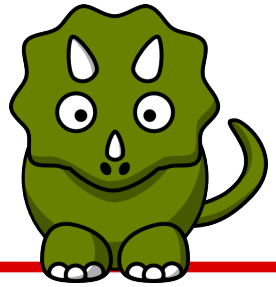
- Classical Java static analysis challenges
  - Reflection
  - Precision of points-to analysis
- Static modeling of Android runtime behavior
  - Dynamically register a callback function to a button
- Completeness of the API summary
- Native code

- Can be addressed by other research

Future Work

- Implicit Flow
  - Static analysis assisted dynamic analysis can be used to track implicit flow while achieving high precision
- Data tracking mechanisms for persistent storage mediums and side channels
  - Databases and file systems
  - Displaying sensitive information on screen, then take a screenshot

Conclusion



A powerful **enforcement tool** that allows users to enforce **fine-grained privacy policies** on a given mobile app

- Finer-grained privacy policy (IF+CF)
  - Defend against more types of malicious apps
- Static optimized dynamic enforcement
  - Portable, low runtime overhead, and no false positives