Symbolic Execution of Dalvik Bytecode
EECS 450 Class Project
Midterm Presentation

Jedidiah McClurg Jonathan Friedman William Ng

Mentor: Vaibhav Rastogi

Northwestern University

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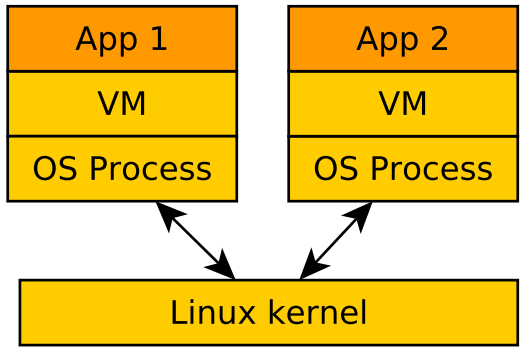
Background

- Android is a popular smartphone OS designed by Google
- Android is designed for security



  - Linux-based OS in which each application runs on a VM in its own process
  - Each application has unique user ID, preventing them from interacting maliciously
  - Explicit user permission is required for apps to access devices
- Android's virtual machine is called *Dalvik*
- Dalvik bytecode is similar to Java bytecode, with one major difference being its register-based (rather than stack-based) architecture

Problem Statement

- Android can still be vulnerable to several types of malware [3]
- Some attacks take advantage of user's haste or carelessness
- A specific attack of this form which we seek to address is the following:

Malware strategy

Obtain blanket permission to use SMS messaging, and then incur messaging fees or subscribe to "premium" services without the user's knowledge

- This type of attack can be detected using various program analyses [1]
  - Dynamic analysis – this is fast, but focuses on a limited number of program execution paths
  - Static analysis – this can cover all execution paths, but can be very slow as program complexity increases

Symbolic Execution

- A hybrid solution: symbolic execution
- Instead of running an application on the VM with *concrete* input/output, we can execute it using *symbolic* IO:

Concrete Execution

```
x = readint();
// wait for int, e.g. "5"
b = 10 + x;
b *= 2;
return b;
// result:  30
```

Symbolic Execution

```
x = readint();
// x is now symbol A
b = 10 + x;
b *= 2;
return b;
// result: 2*(10+A)
```

- This approach "executes" the program in a limited number of symbolic paths, so approximates the speed of dynamic analysis while covering more actual paths
- It focuses on collecting *constraints* rather than *values*, so it's faster than static analysis

Detecting Threats via Symbolic Execution

- Assuming we are trying to detect calls to unexpected SMS messaging, consider the following code:

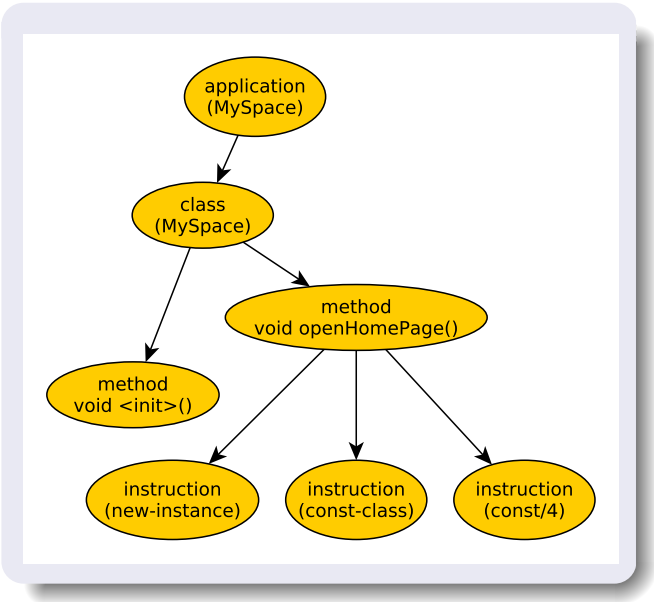
```
y = 5;
x = getchar();
if(2*x == y -1) {
   sendSMS(evilPhoneNumber, "subscribe");
   return 1;
}
return 0;
```

- Let's say in our concrete execution, we got the character 'z' from the keyboard... so, $x = 122$ meaning the body of the *if* statement will be skipped (overlooked threat!)
- Symbolic execution would find that the body is evaluated iff $2x = 5 - 1$, i.e. $x = 2$ (potential threat found!)

Assembly Code Parser

- Our symbolic execution system works at the Dalvik assembly code level
- Android applications are distributed as APK files, which can be decompiled using apk-tool/smali

```
.class public Lcom/myspace/android/MySpace;
.super Landroid/app/Activity;
.source "MySpace.java"

.method private openHomePage()V
    .locals 2

    .prologue
    new-instance v0, Landroid/content/Intent;

    const-class v1, Lcom/myspace/android/pages/HomePage;

    invoke-direct {v0, p0, v1},
      Landroid/content/Intent;-><init>(Landroid/content/Context;
                                       Ljava/lang/Class;)V

    .local v0, myIntent:Landroid/content/Intent;
    const/4 v1, 0x0
```



- The instructions (and structural directives provided by apk-tool/smali) are parsed into an abstract syntax tree (AST)

Operational Semantics

- In order to generate the symbolic constraints as we process the assembly code, we need to have a formal semantics for Dalvik bytecode
- Dalvik instructions are fairly low-level, so it is relatively straightforward to develop a formal semantics for Dalvik bytecode [2]
- Using a similar approach, we are building a structural operational (i.e. *compositional*) semantics

$$\frac{}{\langle \textbf{nop}, (H, R, pc)\rangle \longrightarrow (H, R, pc+1)}$$

$$\frac{a : \text{int} \qquad b : \text{int} \qquad c : \text{int}}{\langle \textbf{add-int}\ a\ b\ c, (H, R, pc)\rangle \longrightarrow (H, R[a \mapsto [\![b]\!] + [\![c]\!]], pc+1)}$$

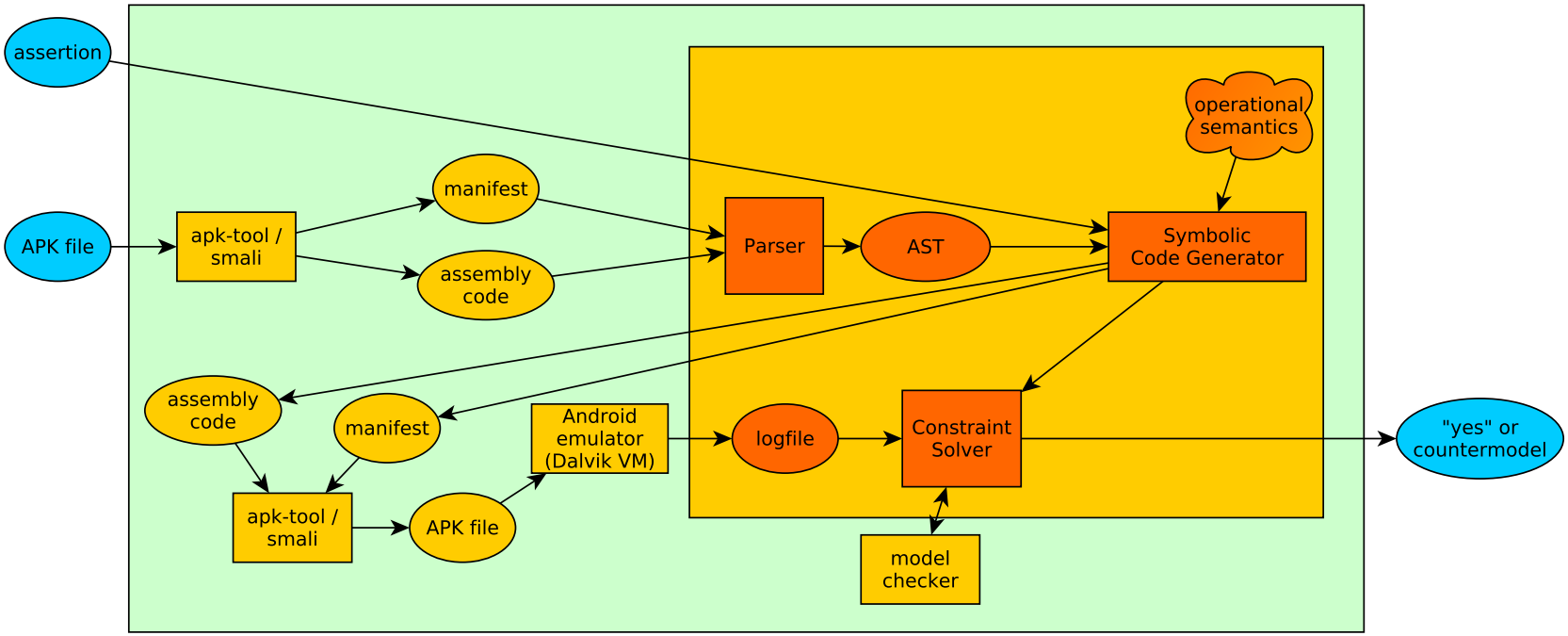
$$\frac{\langle S_1, (H, R, pc)\rangle \longrightarrow (H', R', pc')}{\langle S_1 S_2, (H, R, pc)\rangle \longrightarrow \langle S_2, (H', R', pc')\rangle}$$

Symbolic Code Generation, Simulation, and Checking

- The parser and semantics are almost finished, and then we can implement the symbolic execution engine
- This module will load the AST representation of the application and symbolically execute it with respect to the operational semantics
- To make this more manageable, we will *instrument* the bytecode (i.e. AST) with symbolic functionality, instead of building an interpreter from scratch
- The Dalvik VM (possibly via the Android emulator) will then be used to perform the symbolic simulation by simply running the recompiled APK file and generating a logfile with symbolic constraints for each instruction of interest
- Finally, we will implement a checker by sending the constraints and the properly-structured assertion to a model checker

Overall System Architecture

The box on the right is the "core" of the symbolic simulator:



- The **Parser** loads the Dalvik code into a data structure
- The **Symbolic Code Generator** instruments the parsed code using the symbolic constraint propagation rules
- The **Constraint Solver** checks the property with respect to constraints generated by running the instrumented application

Conclusion

- Security issues can arise in Android due to unexpected use of user information
- These types of information leaks can be detected by program analysis
- We seek to detect a simple set of events efficiently by symbolic simulation of Dalvik bytecode
- This type of functionality could be integrated quite smoothly into the Dalvik VM itself, offering a higher level of security

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