TriggerScope: Towards Detecting Logic Bombs in Android Applications

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Introduction to logic bombs

Logic bombs

Logic bomb: malicious application logic that is triggered only under certain (narrow) conditions.

- *Malicious application logic*: violation of user's reasonable expectations
- Malware is designed to target **specific victims, under certain circumstances**

Example: take a navigation application, supposed to help a soldier in a war zone find the shortest route to a location.

- after a given (hardcoded) date, it gives to him longer, more dangerous routes

Another (real) example

RemoteLock: Android app that allows the user to remotely lock and unlock the device by using an user-defined keyword

- The app code also contains the following check:
  `(!= (#sms/#body equals "adfbdfgfsgyhytdfsw")) 0)`
  - The predicate is triggered when an incoming SMS contains that hardcoded string
- By sending a SMS containing that string, the device unlocks
- That's a backdoor implemented with a **logic bomb**!

Problems with traditional defenses

App Stores employ some defenses, but they are not sufficient.

- **Static analysis**: malicious application logic doesn't require additional privileges or make "strange" API calls
  - Malicious behavior is deeply hidden within the app logic
  - Example: the malicious navigation app... behaved like any navigation app!
- **Dynamic analysis**: likely won't execute code triggered only on a future date or in a certain location
  - Code coverage problems
  - Can be detected and evaded
  - Even if covered, how to discern malicious behavior from benign?
- **Manual audit**: if source code is not available, no guarantees
  - Code can be obfuscated

TriggerScope

Key observation

TriggerScope detects logic bombs by precisely analyzing and characterizing **the checks (conditionals, predicates) that guard a given behavior**.

- It gives less importance to the (malicious) behavior itself.

```
if(sms.getBody().equals("adfbdf...")) // Look here!
{
    myObject.doSomething(); // ...not there.
}
```

Trigger analysis

- **Predicate**: logic formula used in a conditional statement
  - `(&& (!= (#sms/#body contains "MPS:") 0) (!= (#sms/#body contains "gps") 0))`
  - **Suspicious predicate**: a predicate satisfied only under very specific, narrow conditions
- **Functionality**: a set of basic blocks in a program
  - **Sensitive functionality**: a functionality performing, directly or indirectly a sensitive operation
  - All calls to Android APIs protected by permissions, and operations involving the filesystem
- **Trigger**: suspicious predicate controlling the execution of a sensitive functionality

Analysis overview (1)

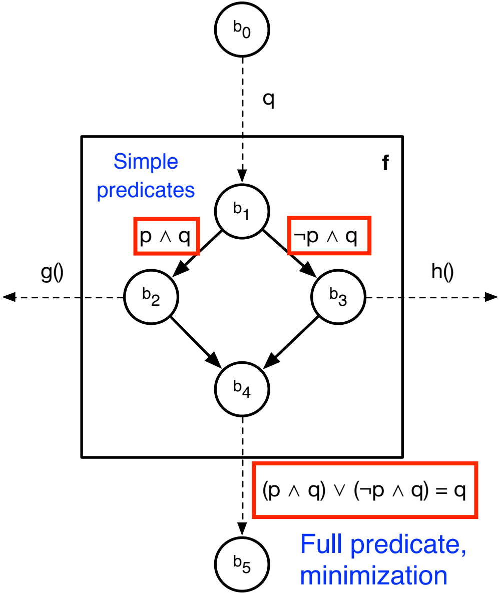
1. **Static analysis** of bytecode; building of Control Flow Graph
2. **Symbolic Values Modeling** for integer, string, time, location and SMS-based objects
3. **Expression Trees** are built and appended to each symbolic object referenced in a check
    - Reconstruction of the *semantics* of the check, often lost in bytecode

Figure 1: Example of expression tree.

Analysis overview (2)

4. **Block Predicate Extraction**: edges of Control Flow Graph are annotated with simple predicates
   - Simple predicate: P in `if P then X else Y`
5. **Path Predicate Recovery and Minimization**
   - Combine simple predicates to get the *full path predicate* that reaches each basic block
   - Minimization: elimination of redundant terms in predicates
     - important to reduce false dependencies

Path Predicate Recovery and Minimization



Analysis overview (3)

6. **Predicate Classification**: a check is **suspicious** if it's equivalent to:
    - Comparison between current *time* value and constant
    - Bounds check on GPS *location*
    - Hard-coded patterns on body or sender of *SMS*
7. **Control-Dependency Analysis**: control dependency between *suspicious predicates* and *sensitive functionalities*.
    - sensitive = privileged Android APIs + fileystem ops
    - **Suspiciousness propagates** with data flows and callbacks
    - Problem: data flows through files
        - When in doubt: suspicious!
8. **Post-processing**: whitelisting for some edge cases

Experiment

Data sets

- **Benign applications**: 9582 apps from Google Play Store
  - They all use time-, location- or SMS-related APIs
  - Actually, TriggerScope identified backdoors in two “benign” apps, confirmed by manual inspection!
- **Malicious applications**: 14 apps from several sources
  - Stealthy malware developed for previous researches
  - Real-world malware samples
  - HackingTeam RCSAndroid

Results of analysis

Analysis step	TP	FP	TN	FN	FPR	FNR
Predicate detection	14	1386	7927	0	14.88%	0%
Suspicious Predicate A.	14	462	8851	0	4.96%	0%
Control-Dependency A.	14	117	9196	0	1.26%	0%
TriggerScope (all)	14	35	9278	0	0.38%	0%

Table 1: Results of analysis after each step. Note how each step is useful to refine the analysis.
$FPR = \frac{FP}{FP+TN}$, $FNR = \frac{FN}{FN+TP}$

False Positives decreasing step after step

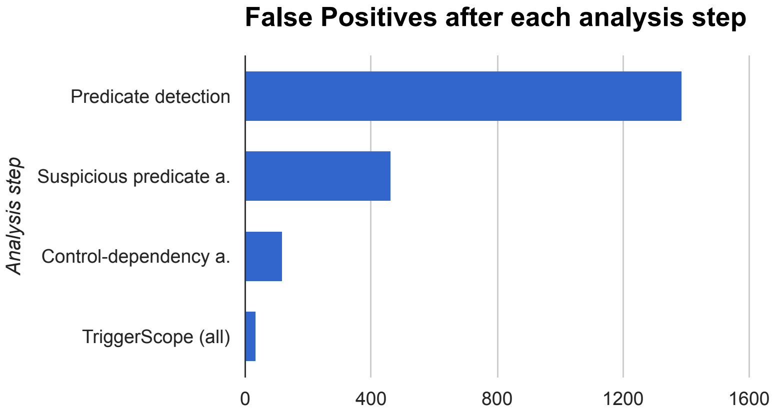


Figure 3: Each analysis stage is useful, because it reduces False Positives.

Critique

Strengths

- TriggerScope provides **rich semantics** on predicates that help manual analysis
  - Great help for manual analysis
  - This makes the tool extensible, open for future research
- Novel approach: **focus on checks**, not malicious behaviors
- **Fewer FPs, FNs** than other tools

Issues: limits of analysis

- Definition of **suspicious predicate** is too narrow
  - Only checks against hardcoded values are considered
- Authors claim **0% FNs**, but the evaluation isn't conclusive
  - *we manually inspected a random subset of 20 applications for which our analysis did not identify any suspicious check. We spent about 10 minutes per application, and we did not find any false negatives.*
  - Difficult to assess FNs if no tool finds anything and source code is unavailable
- This analysis is still **blacklisting**
  - We're competing against attackers' creativity

Issues: evasion techniques

- *Reflection*, *dynamic code loading*, *polymorphism* and *conditional code obfuscation* [Sharif, 2008] can defeat static analysis.
  - Authors say that these techniques are themselves suspicious, but they also have legitimate uses
- Predicate minimization is **NP-complete**
  - Is it possible to design "pathological" code to slow down and defeat analysis?
  - Or result in very complex, meaningless predicates?
- **Exceptions** were not cited as a control flow subversion method
  - *Statically reasoning in the presence of exceptions and about the effects of exceptions is challenging* [Liang, 2014]
  - Unclear how the static analysis engine handles exceptions
  - Unchecked exceptions (e.g. division by zero) could be exploited as stealthy triggers

Related and future work

Related work: AppContext

AppContext [Yang, 2015]: supervised machine learning method to classify malicious behavior statically

1. Starts identifying suspicious actions
2. Context: which category of input controls the execution of those actions?

Similar idea: just looking at the action isn't enough. Differences:

- AppContext only **classifies** triggers as suspicious or not; TriggerScope also provides **semantics** about the predicates, helping manual inspection
- AppContext does not consider the typology of the predicate, only the type of its inputs
- **Higher FP rate** than TriggerScope

Future evolutions

- **Extend trigger analysis** not only to time, location, SMSs
  - The trigger could come e.g. from the network
  - The framework is easily extensible to other types of triggers with more work to model other symbolic values
  - Is there **a more general approach**?
- **Quantitative analysis** of predicate "suspiciousness"
  - Currently, it's defined in a qualitative, ad-hoc way
  - Could be combined with classification methods

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