Automated Synthesis of Semantic Malware Signatures using MaxSAT

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NDSS'17, San Diego

Newly Found Malware can steal bank details on Android phones

by **Ali Raza**
9 months ago

https://www.hackread.com/malware-can-steal-bank-details-android-phones/

Hundreds Of Operations Canceled After Malware Hacks Hospitals Systems

Thursday, November 03, 2016 Mohit Kumar

G+1 94 Like 3.3K Share 1187 Tweet 529 Share 279 share 2068

http://thehackernews.com/2016/11/hospital-cyber-attack-virus.html

Android Malware Used to Hack and Steal a Tesla Car

By Catalin Cimpanu   November 25, 2016   06:05 AM   2

http://www.bleepingcomputer.com/news/security/android-malware-used-to-hack-and-steal-a-tesla-car/

Statistics

https://www.symantec.com/content/dam/symantec/docs/reports/istr-21-2016-en.pdf

http://www.mcafee.com/us/resources/reports/rp-mobile-threat-report-2016.pdf

Statistics

37M

Total count of malware detected over 6 months

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Statistics

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Total count of malware detected over 6 months

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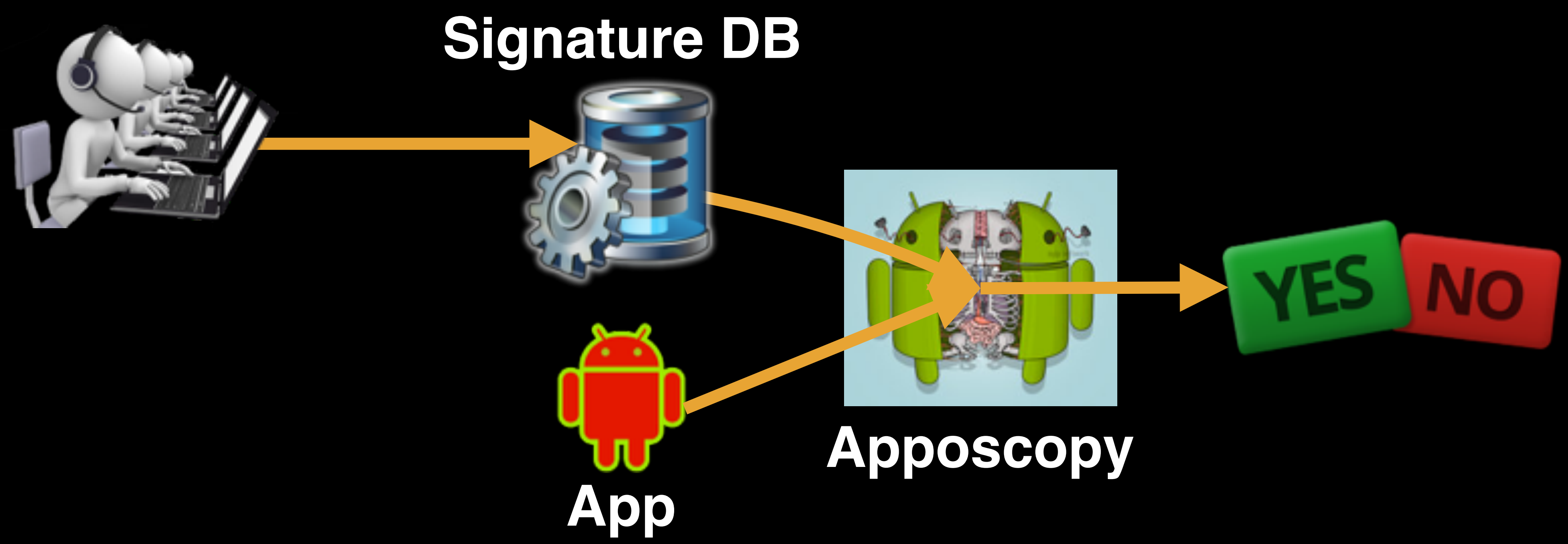
\# of Android malware families by 2016

Hundreds of signatures	≈	*Millions of samples*

https://www.symantec.com/content/dam/symantec/docs/reports/istr-21-2016-en.pdf

http://www.mcafee.com/us/resources/reports/rp-mobile-threat-report-2016.pdf

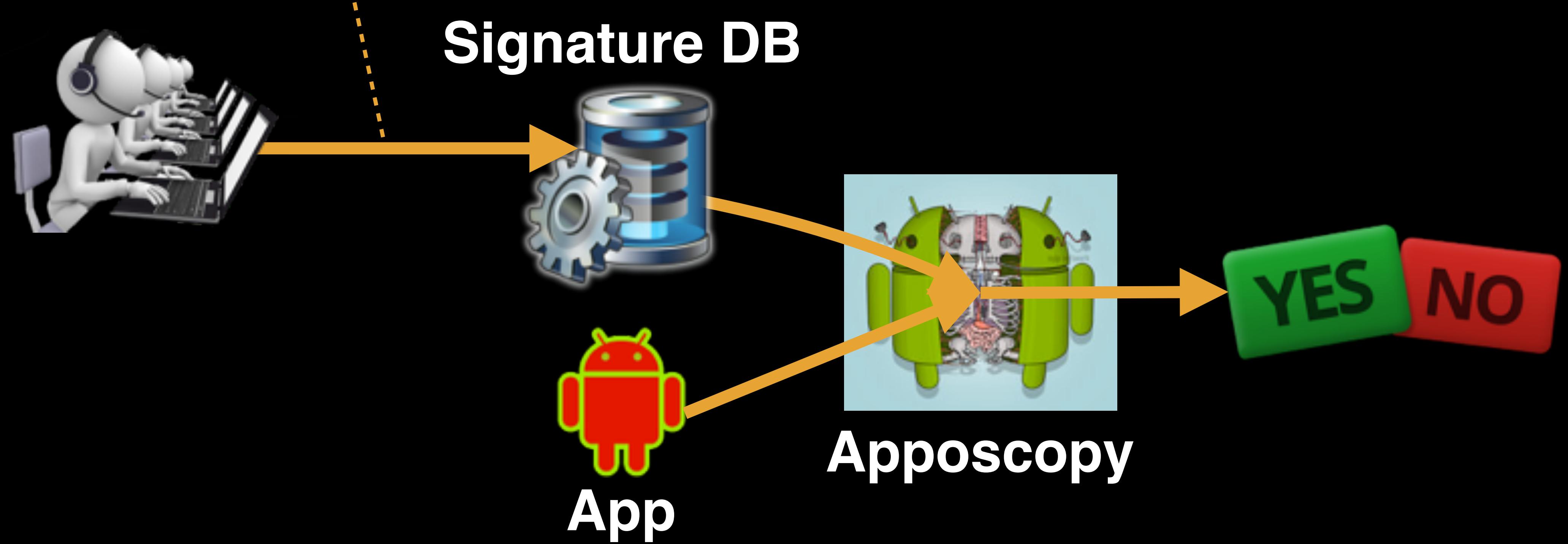
Apposcopy Overview



Feng, et al. FSE'14

Apposcopy Overview

A high-level language for describing semantic properties of malware

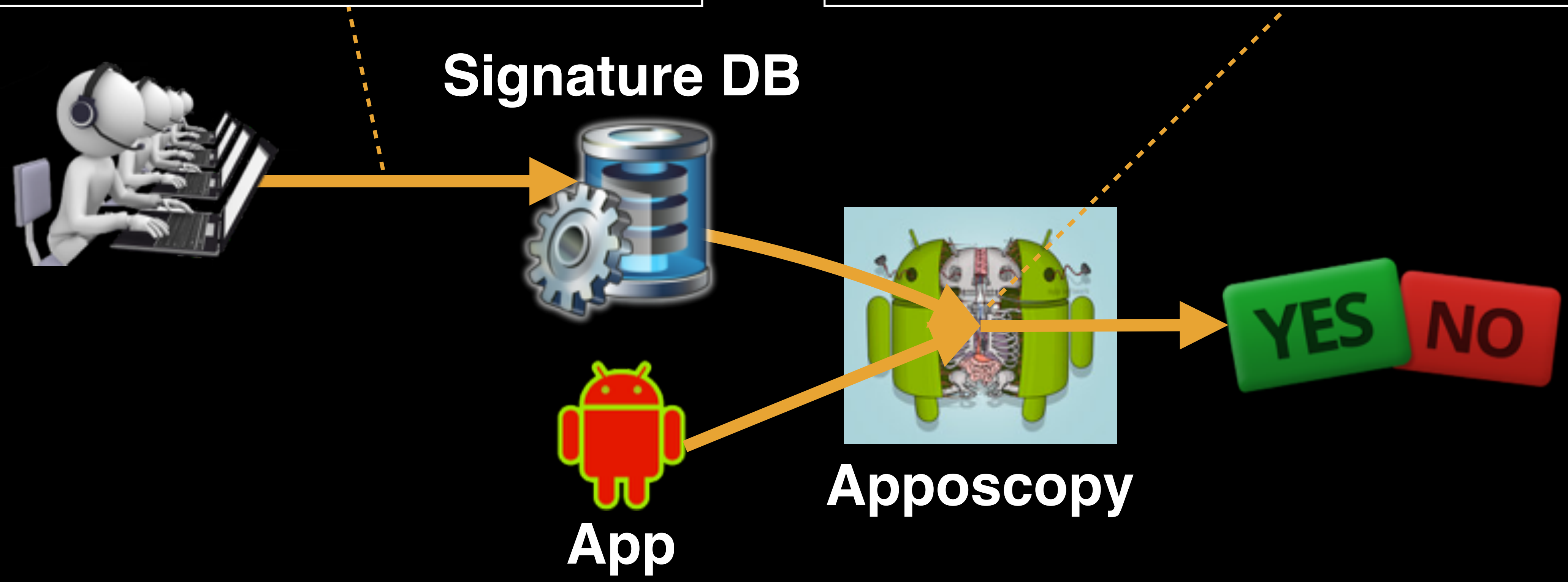


Feng, et al. FSE'14

Apposcopy Overview

A high-level language for describing semantic properties of malware

A novel static analysis for deciding if an app matches the signature of a family



Feng, et al. FSE'14

Caveats

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Writing signatures
is tedious

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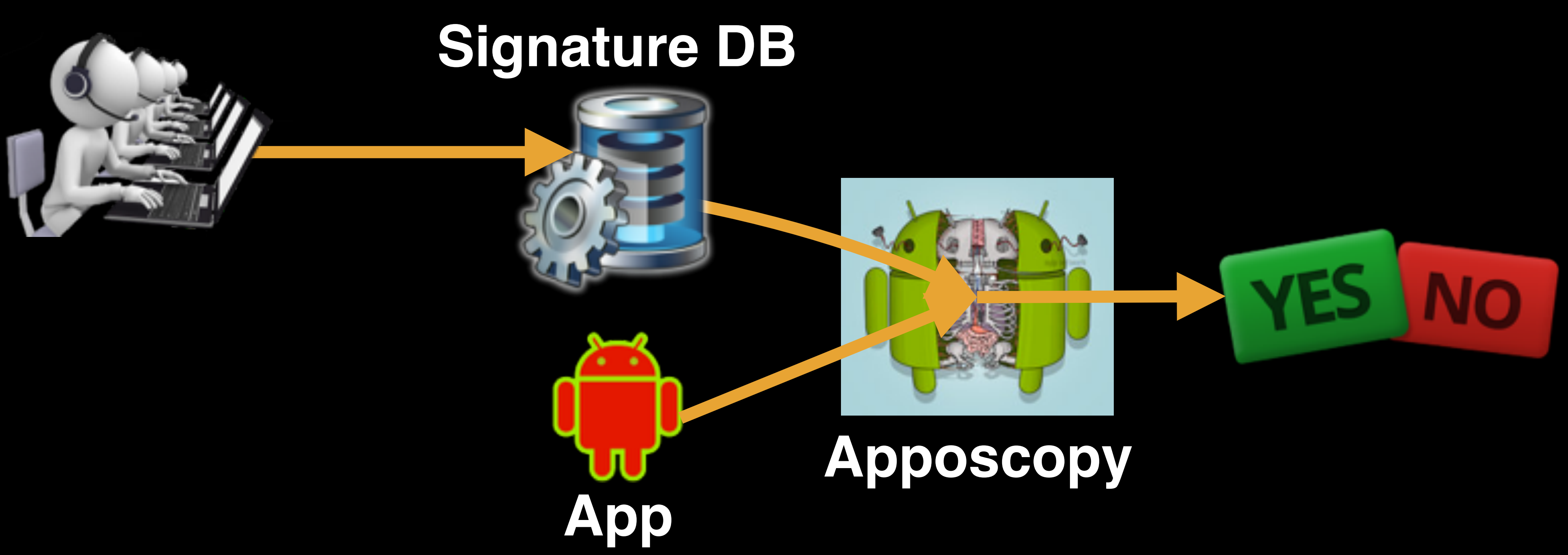
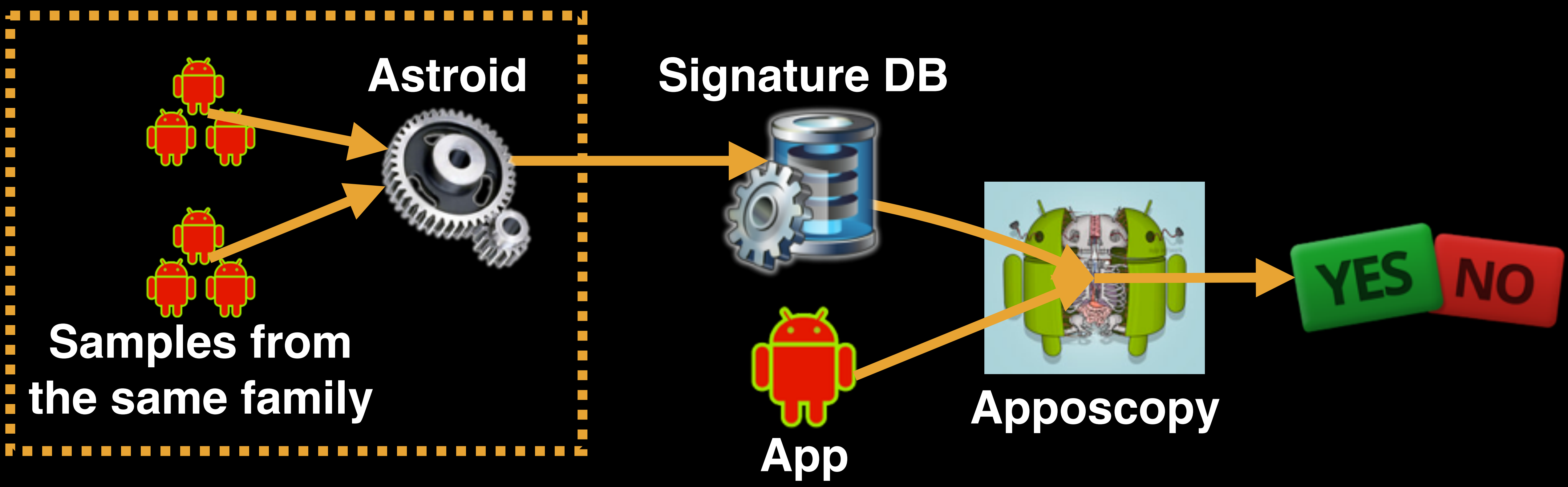
Vulnerable to
semantic obfuscation

Goal



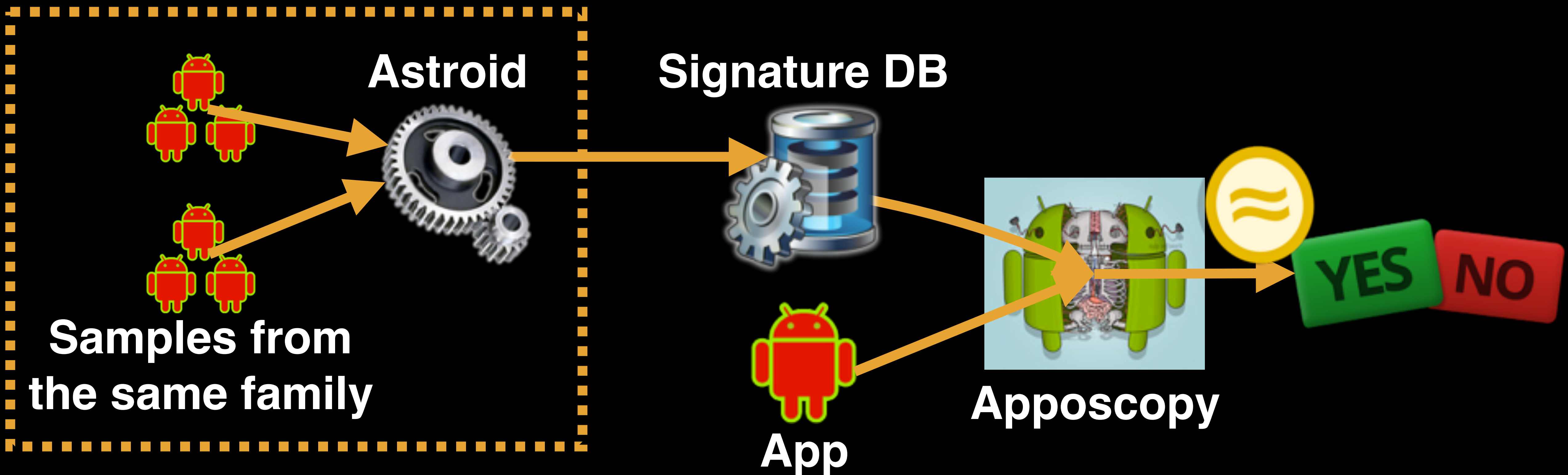
Goal

- Infer a signature from few samples of a malware family



Goal

- Infer a signature from few samples of a malware family
- Approximate matching algorithm that is resistant to semantic obfuscation



Our Signature in a Nutshell

Inter-Component Call Graph

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Feng, et al. OOPSLA'15

Our Signature in a Nutshell

Activity1

Inter-Component
Call Graph

Android

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Our Signature in a Nutshell

Activity1

Activity2

Inter-Component Call Graph

Android

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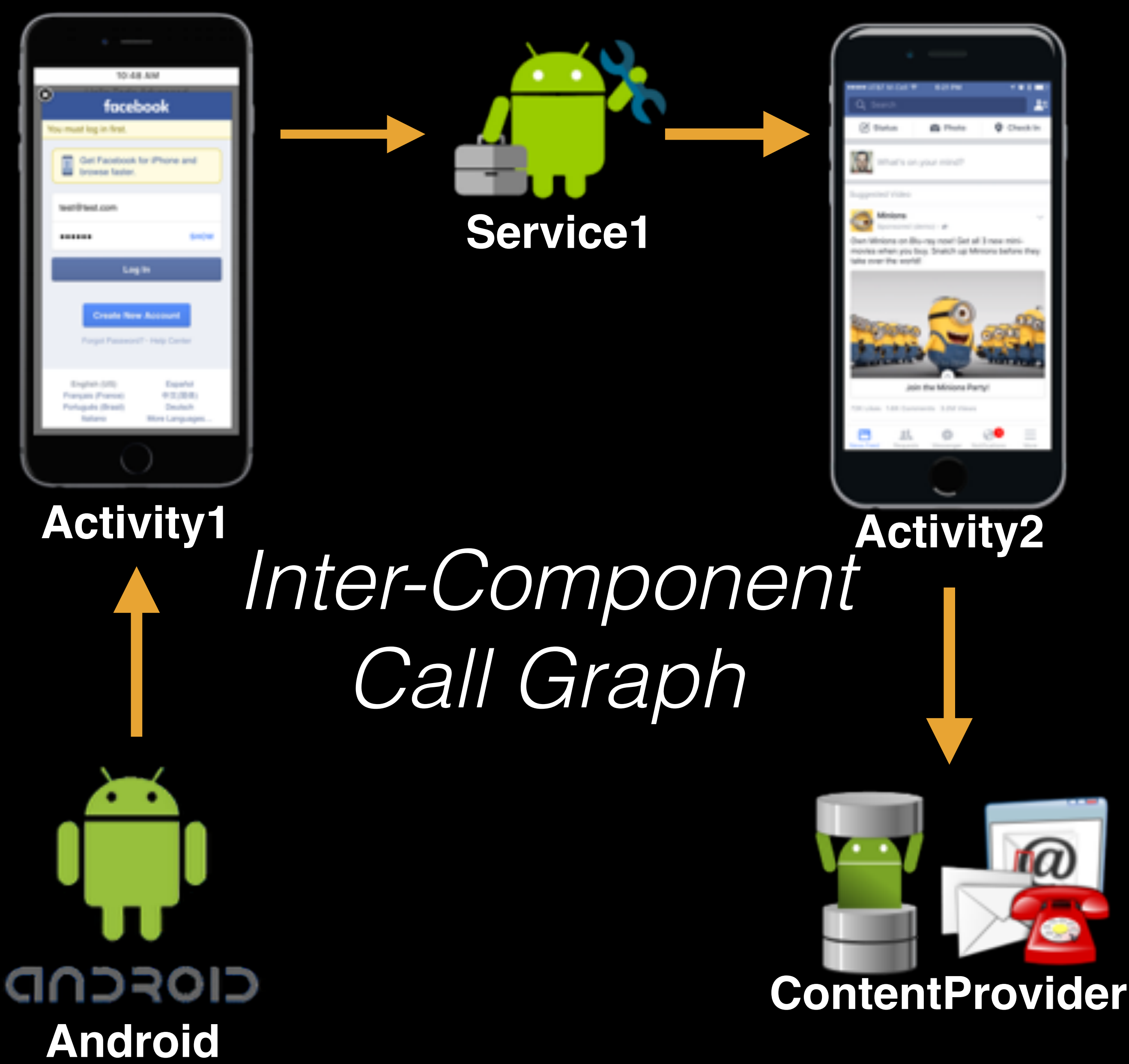

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Feng, et al. OOPSLA'15

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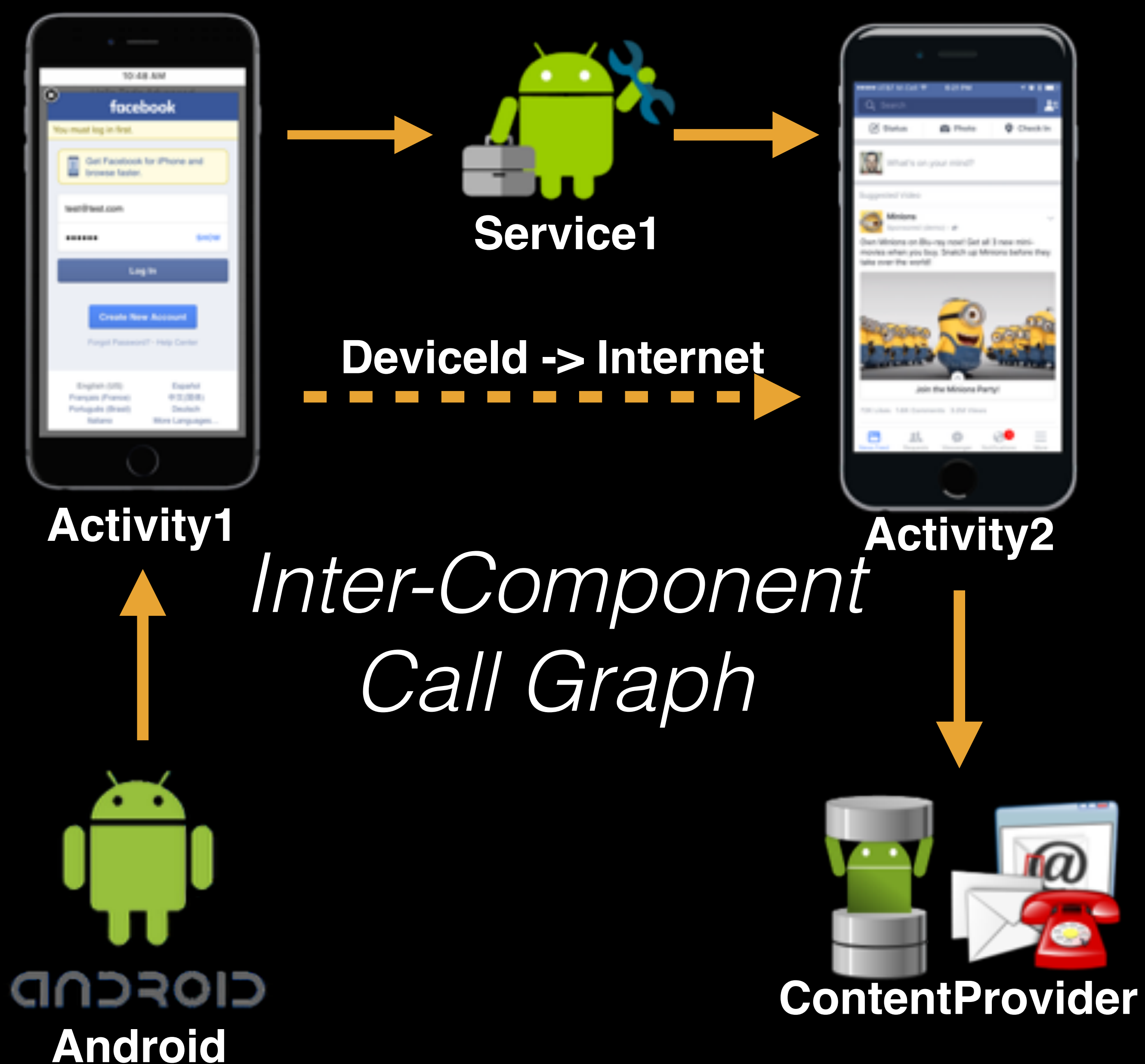

Feng, et al. FSE'14
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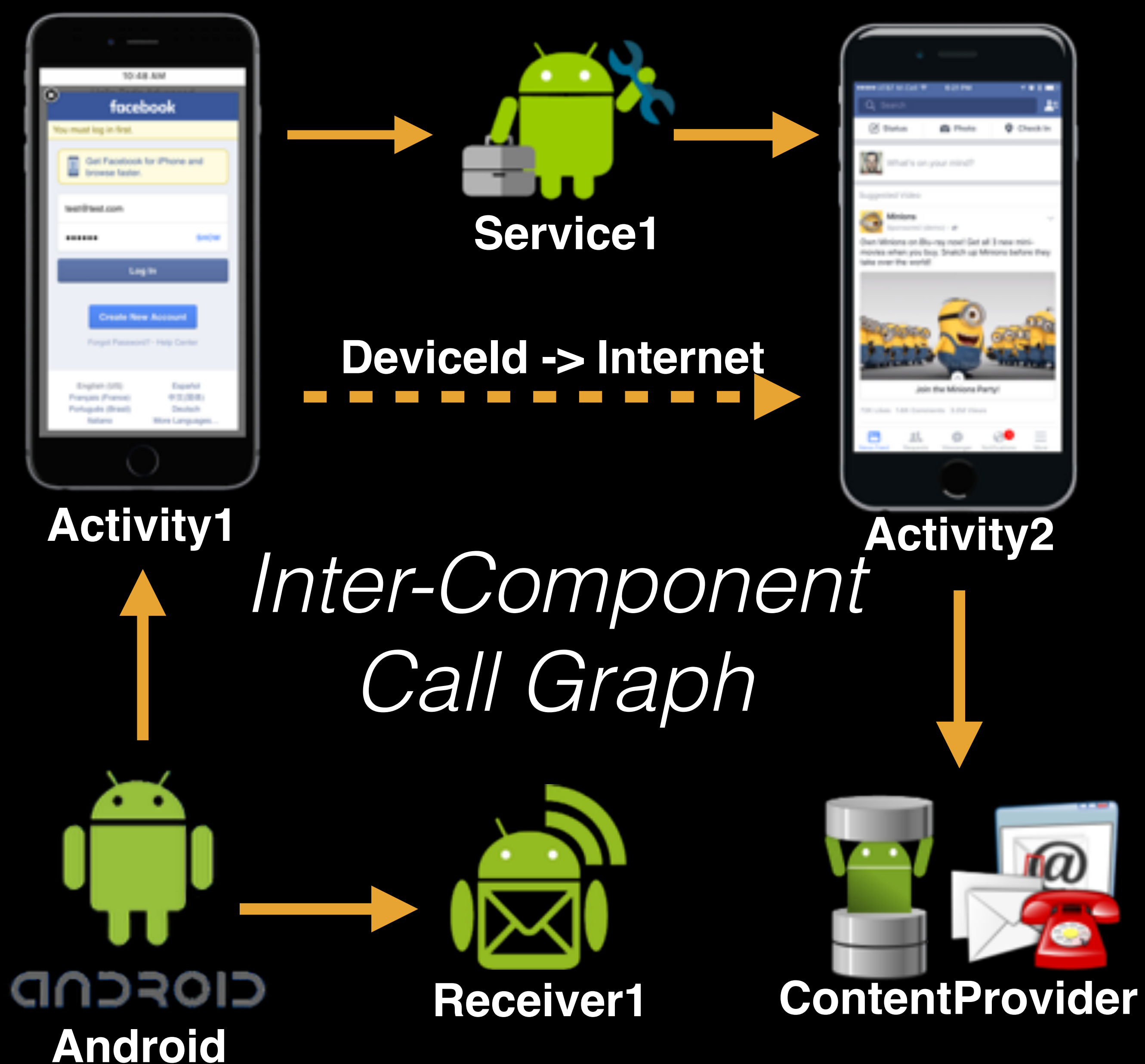

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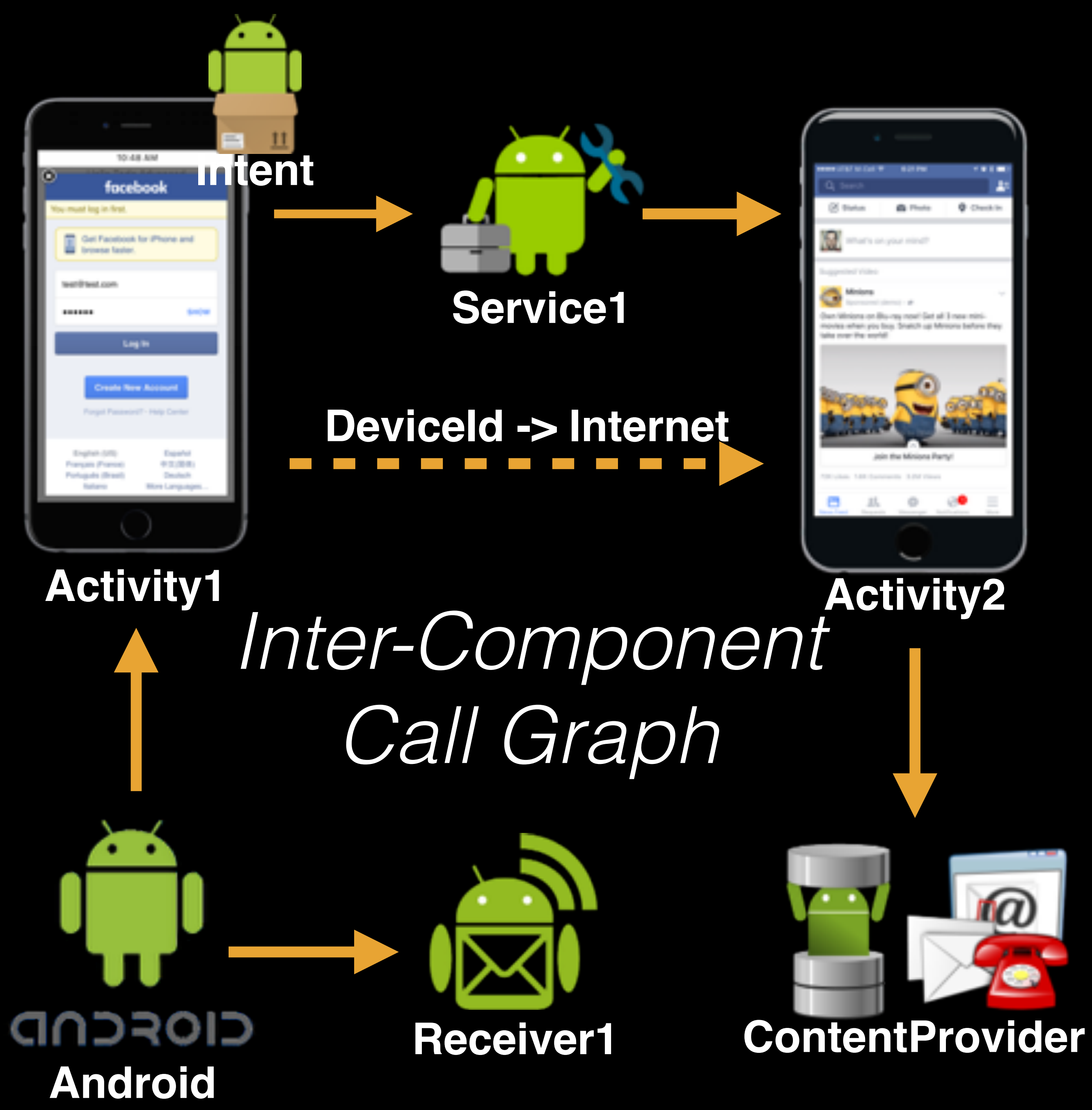

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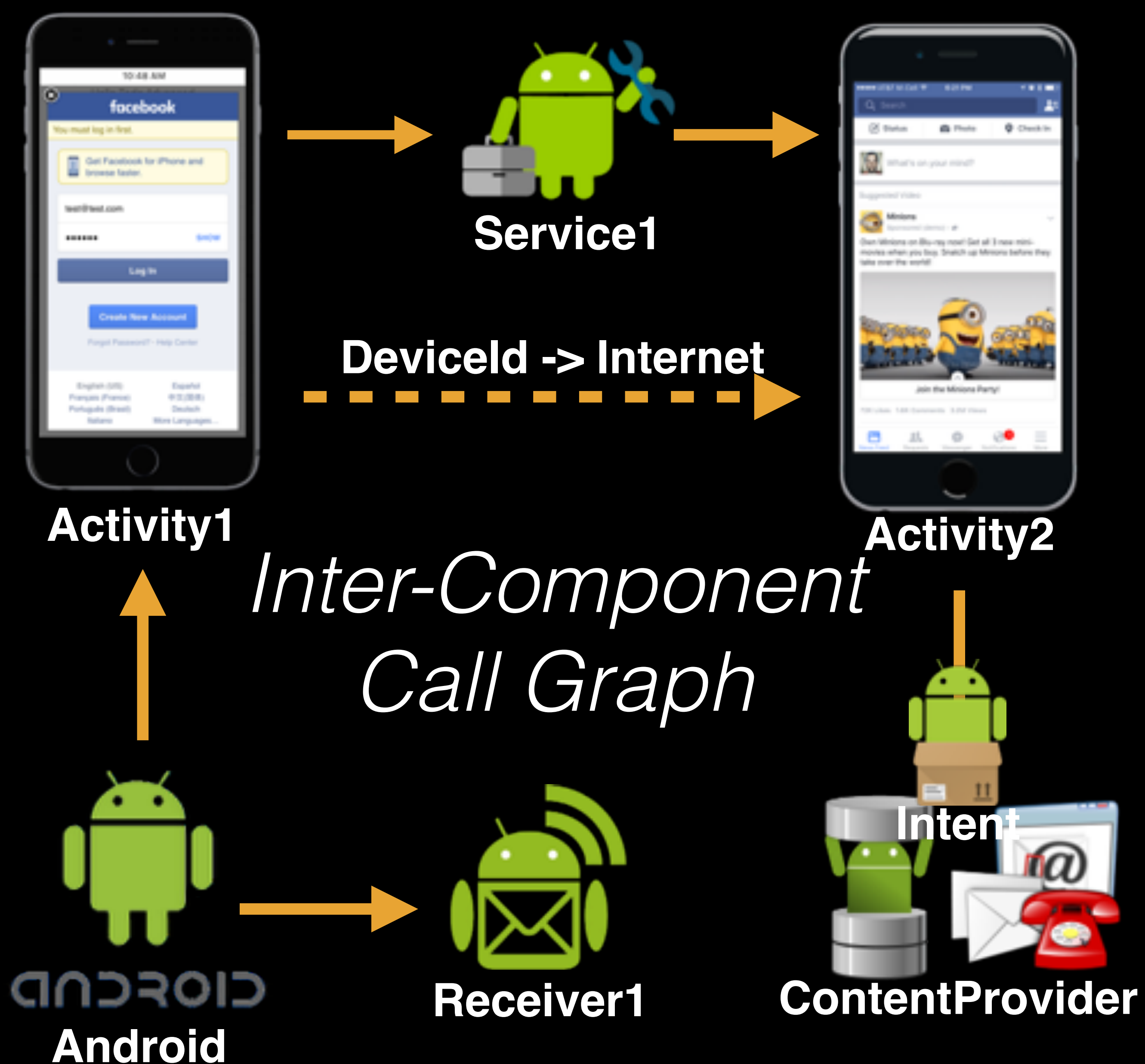

Solid line: control property
Dashed line: data property

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Feng, et al. OOPSLA'15

Our Signature in a Nutshell

GDEvent(SMS_RECEIEVED).
GDEvent(NEW_OUTGOING_CALL).
GoldDream :- **receiver(r)**,
icc(SYSTEM, r, e, _), GDEvent(e),
service(s), **icc*(r, s)**,
flow(s, DeviceId, s, Internet),
flow(s, SubscriberId, s, Internet).

GoldDream Signature

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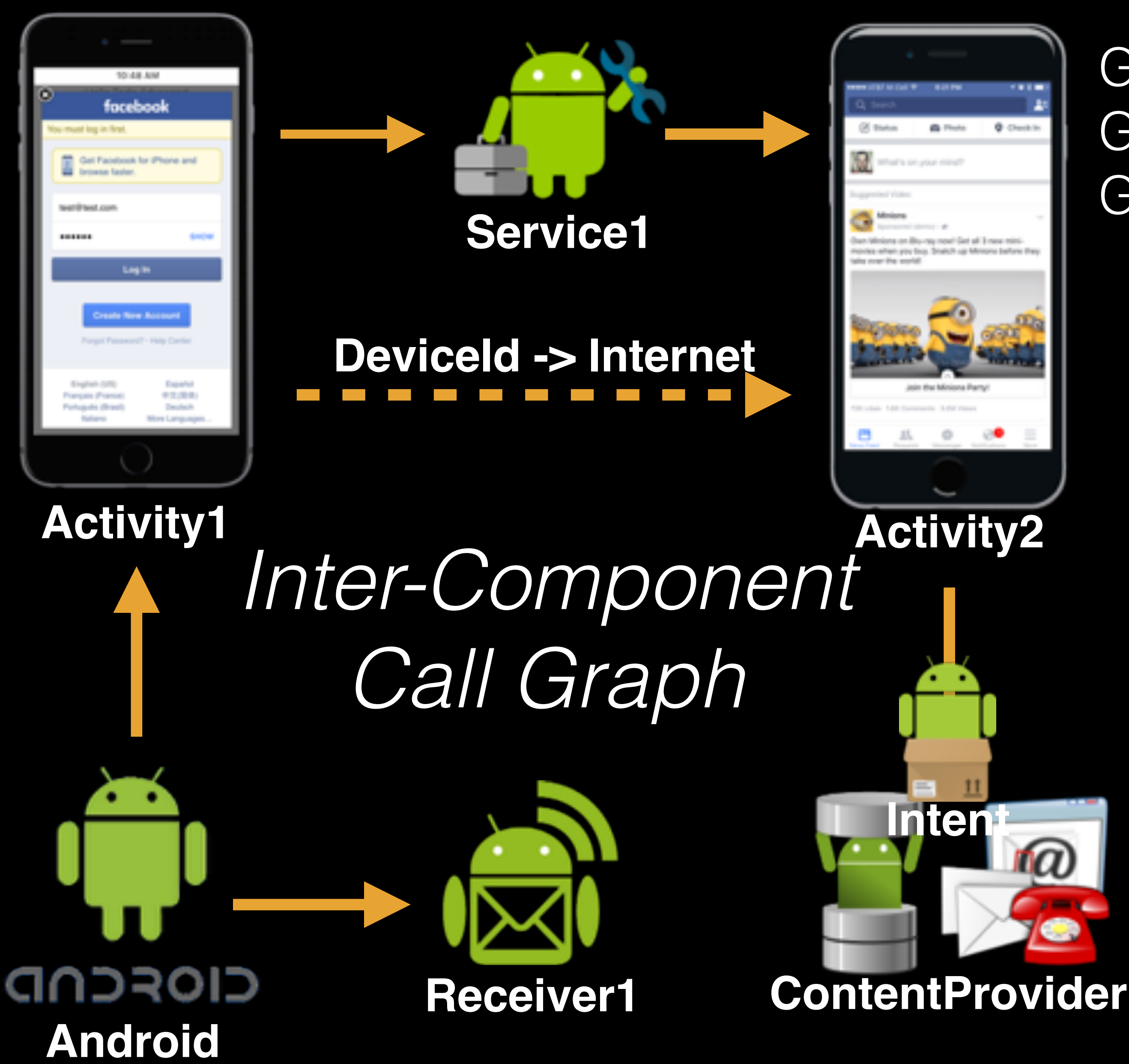

Component Predicate

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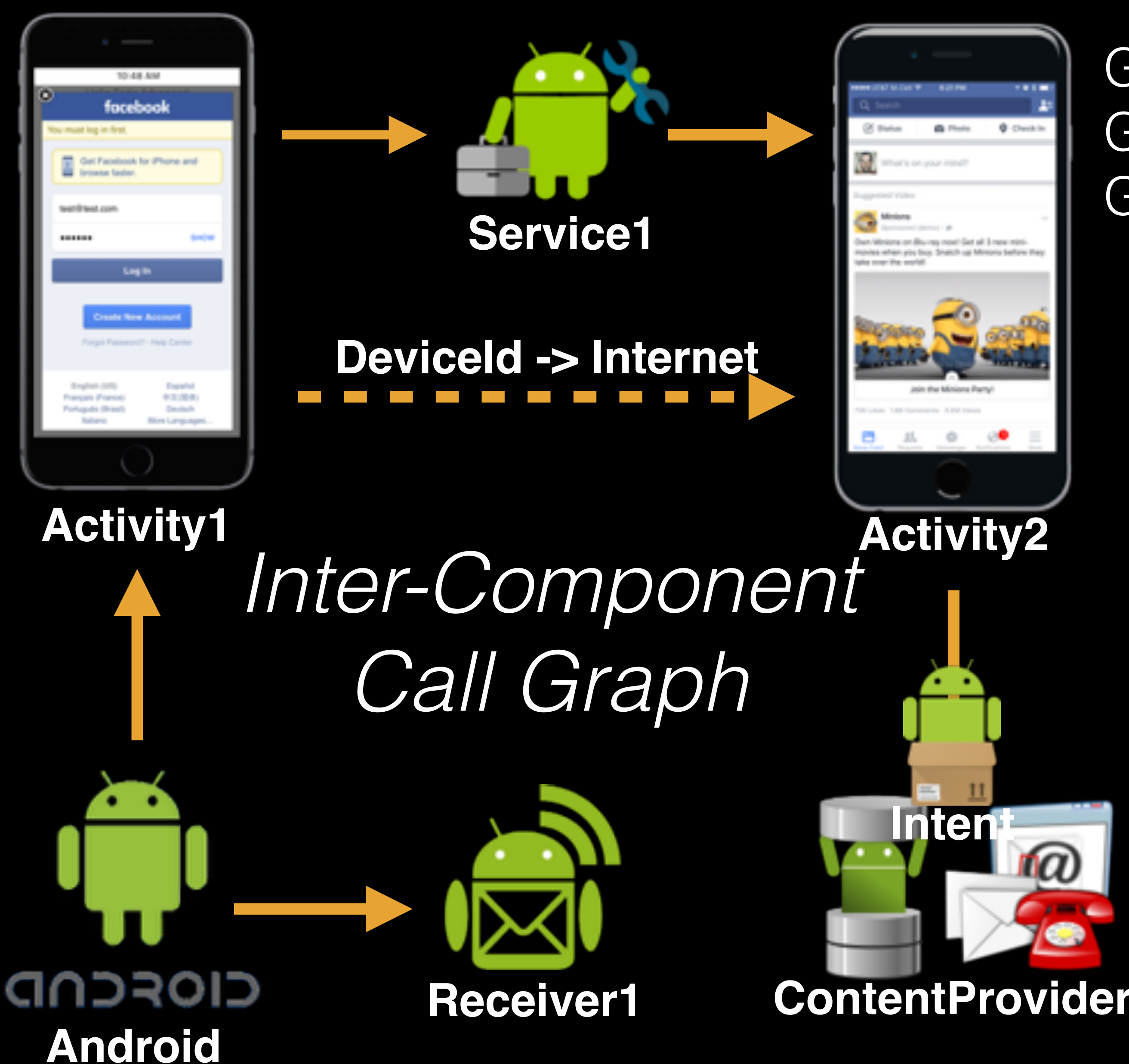

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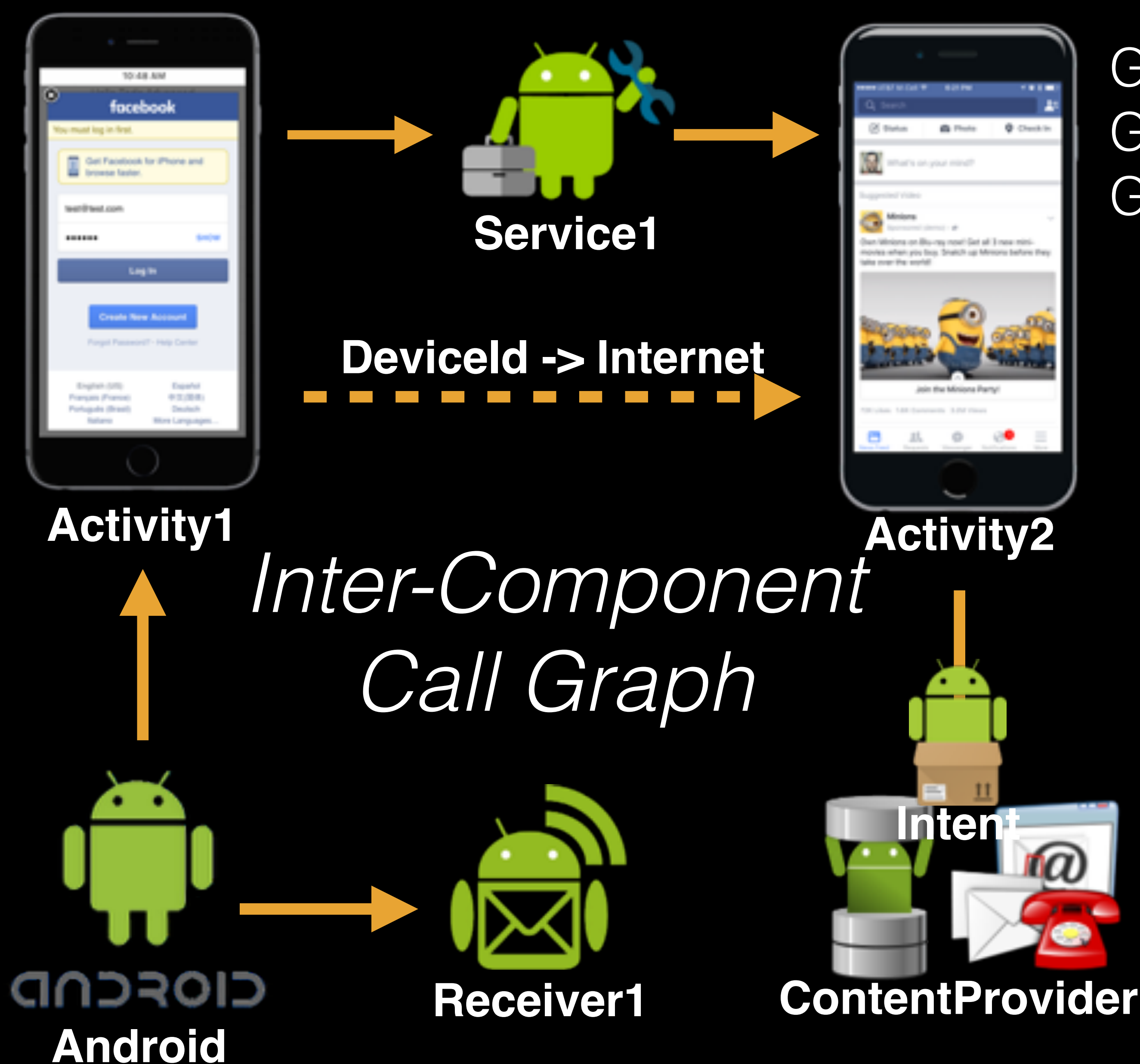

Inter-Component Call Graph

Component Predicate

Control Predicate

Flow Predicate

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GoldDream Signature

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Signature Inference

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Given ***n*** malware samples from family ***F***, compute its signature ***S***

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Any signature that matches n samples

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Given ***n*** malware samples from family ***F***, compute its signature ***S***

Any signature that matches n samples

Empty signature could also be a solution!

Insight

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Given ***n*** malware samples from family ***F***, compute its signature ***S***

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  - Maximally suspicious to minimize <u>false positives</u>

Insight

Given ***n*** malware samples from family ***F***, compute its signature ***S***

- Our candidate ***S*** should be
    - A common subgraph to minimize <u>false negatives</u>
    - Maximally suspicious to minimize <u>false positives</u>

Infer signatures by finding a <u>Maximally Suspicious Common Subgraph</u> of n malware samples

Example

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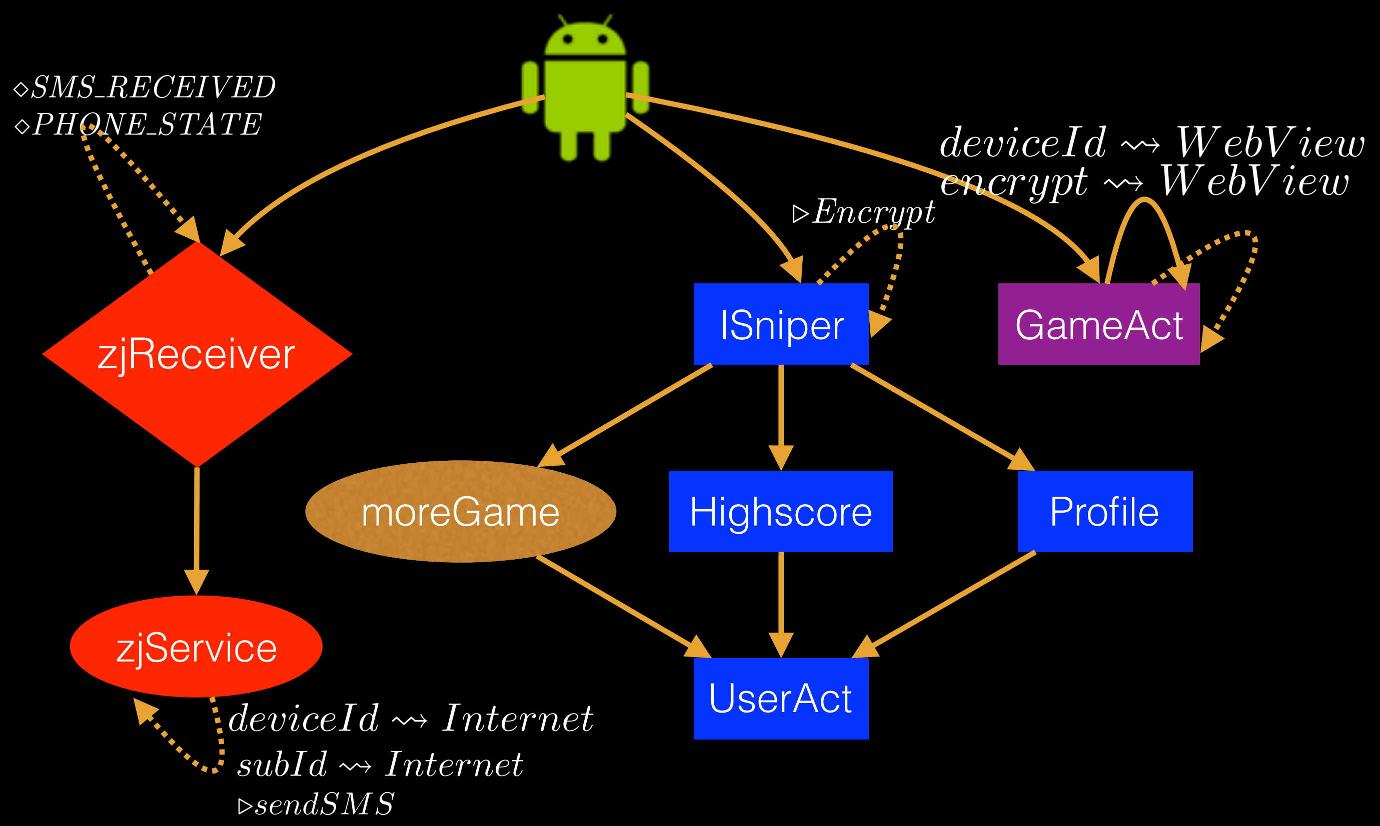
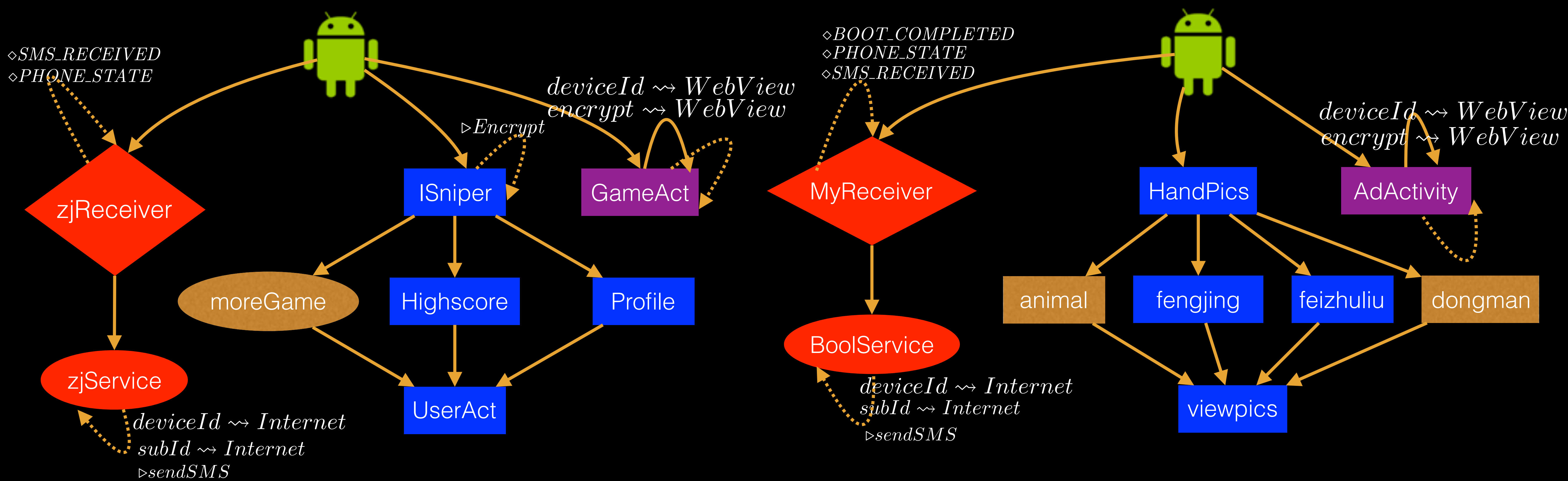

◇SMS_RECEIVED
◇PHONE_STATE
zjReceiver
zjService
deviceId ⇝ Internet
subId ⇝ Internet
▷sendSMS
▷Encrypt
ISniper
deviceId ⇝ WebView
encrypt ⇝ WebView
GameAct
moreGame
Highscore
Profile
UserAct

Example



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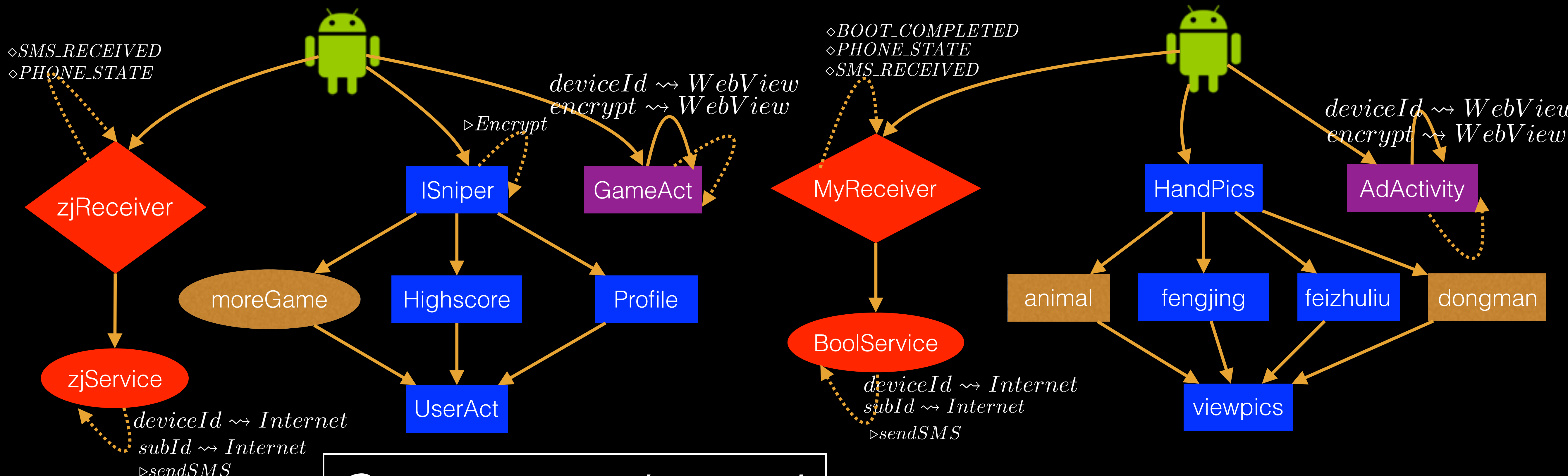
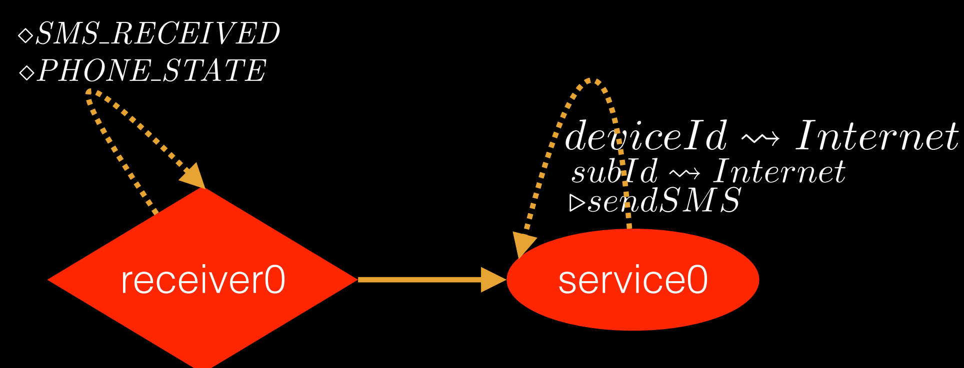


Common subgraph



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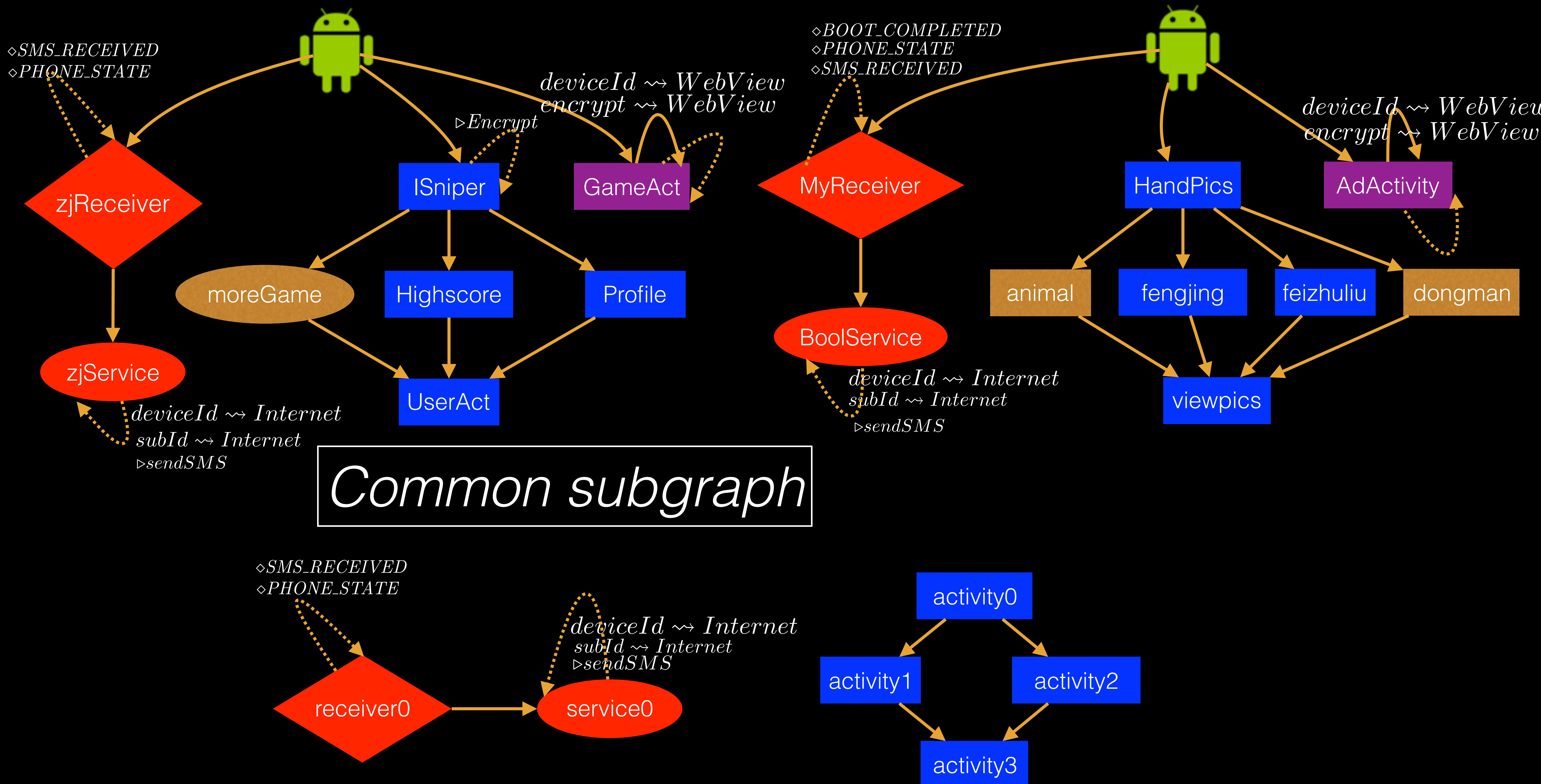
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activity2
activity3

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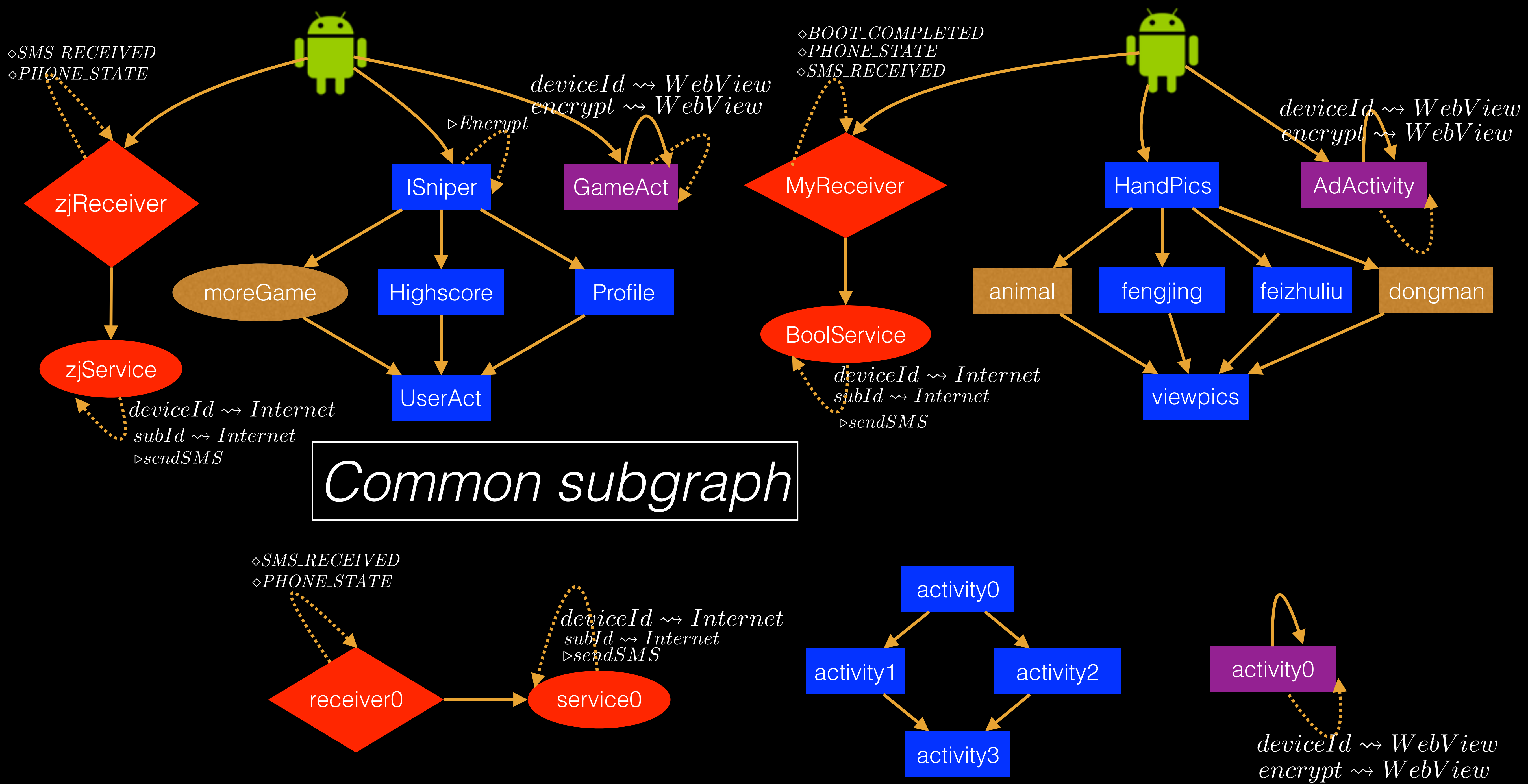
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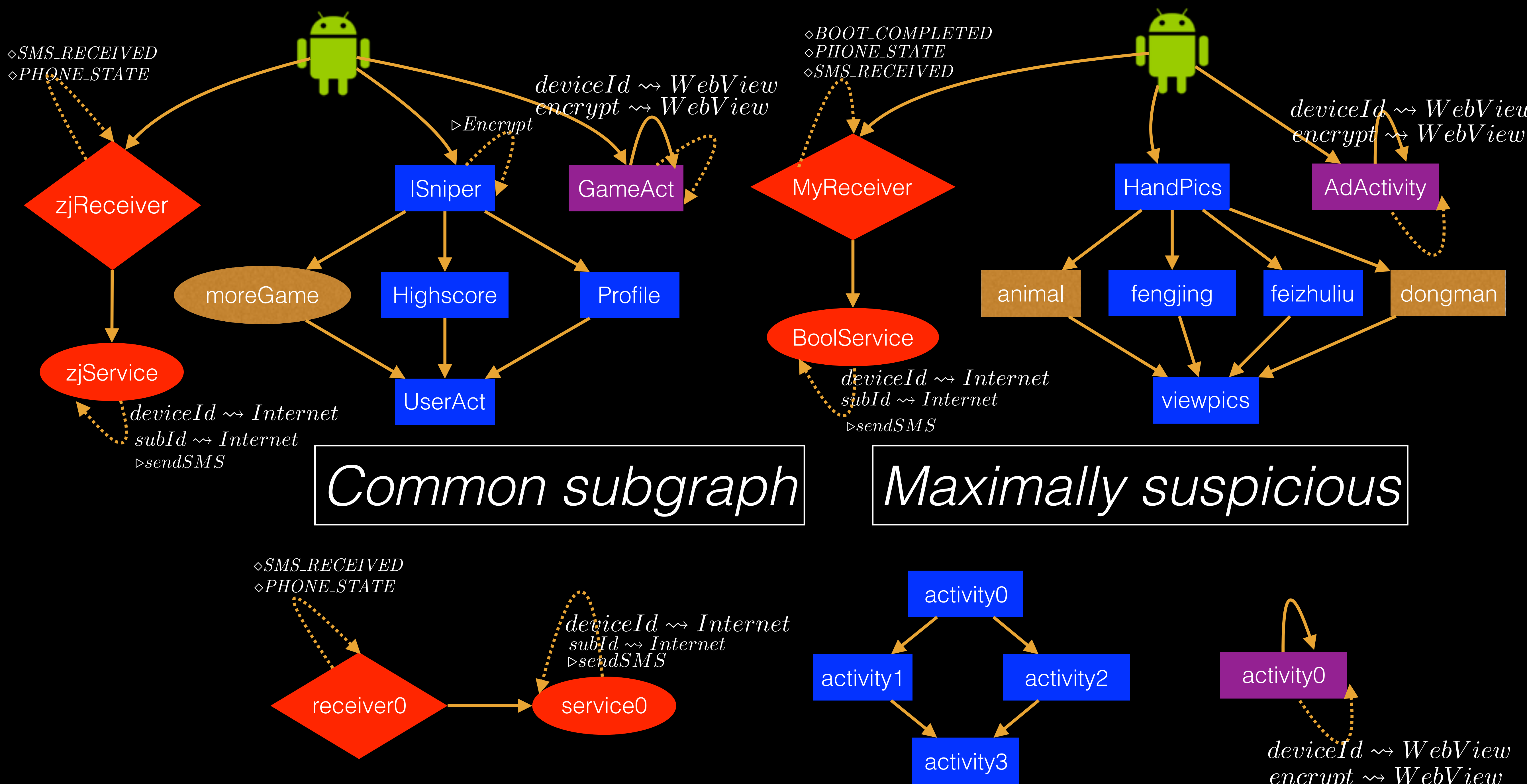
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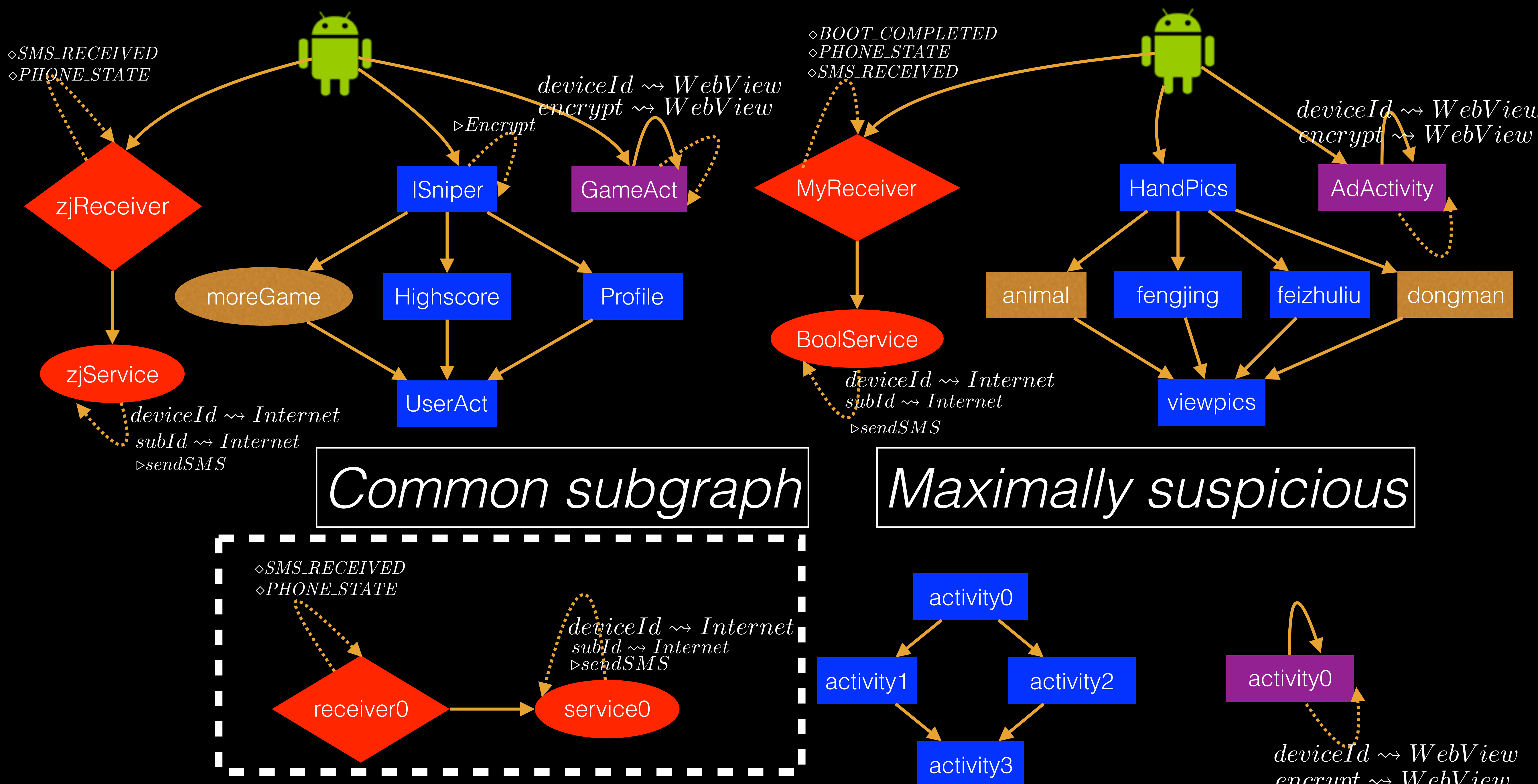

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How to infer the signature

Infer signatures by finding a Maximally Suspicious Common Subgraph of n malware samples

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Signature Inference

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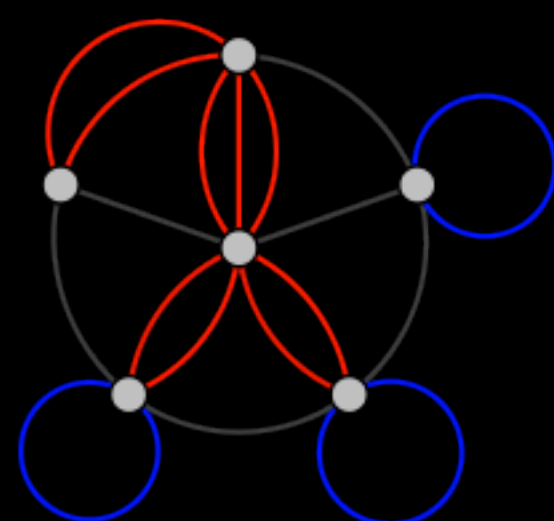
Signature Inference



MSCS

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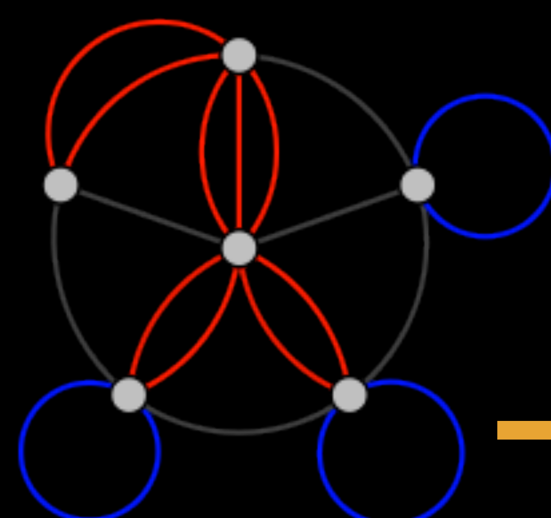

MSCS

MaxSat

MaxSat in a nutshell

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MaxSat: Given a UNSAT boolean formula in CNF, determine the maximum number of satisfied clauses

$$(x_0 \lor x_1) \land (\neg x_0 \lor x_1) \land (x_0 \lor \neg x_1) \land (\neg x_0 \lor \neg x_1)$$

MaxSat in a nutshell

MaxSat: Given a UNSAT boolean formula in CNF, determine the maximum number of satisfied clauses

$$(x_0 \vee x_1) \wedge (\neg x_0 \vee x_1) \wedge (x_0 \vee \neg x_1) \wedge (\neg x_0 \vee \neg x_1)$$

Hard Clause: has to be satisfied

MaxSat in a nutshell

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Soft Clause: preferable to be satisfied but could be UNSAT. Each has different weight since some are more important than the others

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Hard Clause: has to be satisfied

Soft Clause: preferable to be satisfied but could be UNSAT. Each has different weight since some are more important than the others

Find an assignment s.t. the total weight of satisfied clauses is maximized

$$\{x_0 \mapsto 0, x_1 \mapsto 0\}$$

Synthesis using MaxSat

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- Hard Clause: common subgraph (control-flow property)

Synthesis using MaxSat

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- Soft Clause: maximally suspiciousness (data-flow property)

Synthesis using MaxSat

- Hard Clause: common subgraph (control-flow property)
- Soft Clause: maximally suspiciousness (data-flow property)
- Weight for each clause
  - Inverse frequency from benign samples
  - Higher weight to features that are commonly found in malware

$$\mathcal{O} = \underbrace{\sum_{v,v' \in V} x_0(v,v')}_{\textit{Hard}} + \underbrace{\sum_{v,v' \in V} \sum_{d \in \mathcal{D}} w_{(v,v',d)} y_0(v,v',d)}_{\textit{Soft}}.$$

Example, cont.

$$\mathcal{O} = \underbrace{\sum_{v,v' \in V} x_0(v,v')}_{\textit{Hard}} + \underbrace{\sum_{v,v' \in V} \sum_{d \in \mathcal{D}} w_{(v,v',d)} y_0(v,v',d)}_{\textit{Soft}}.$$

Example, cont.

Control properties

$$\mathcal{O} = \underbrace{\sum_{v,v' \in V} x_0(v,v')}_{\textit{Hard}} + \underbrace{\sum_{v,v' \in V} \sum_{d \in \mathcal{D}} w_{(v,v',d)} y_0(v,v',d).}_{\textit{Soft}}$$

Example, cont.

Control properties

Data properties

$$\mathcal{O} = \sum_{v,v' \in V} x_0(v,v') + \sum_{v,v' \in V} \sum_{d \in \mathcal{D}} w_{(v,v',d)} y_0(v,v',d).$$

Hard

Soft

Example, cont.

Control properties **Data properties**

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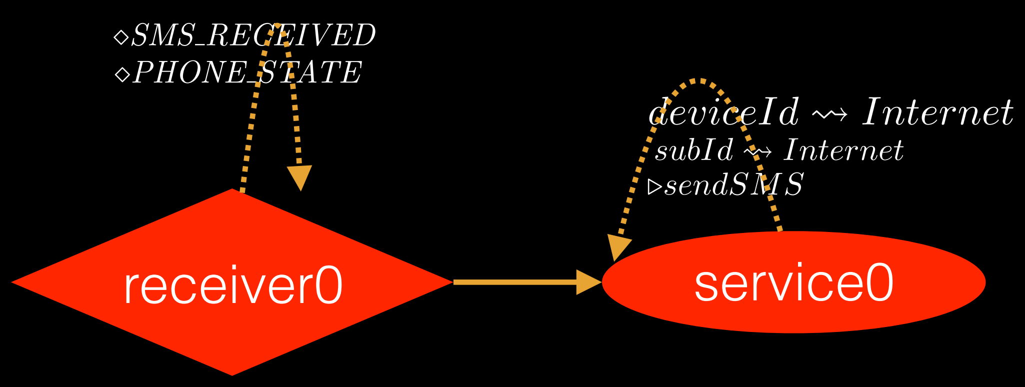
Hard *Soft*



$$\mathcal{O}_1 = 6$$

Example, cont.

Control properties

Data properties

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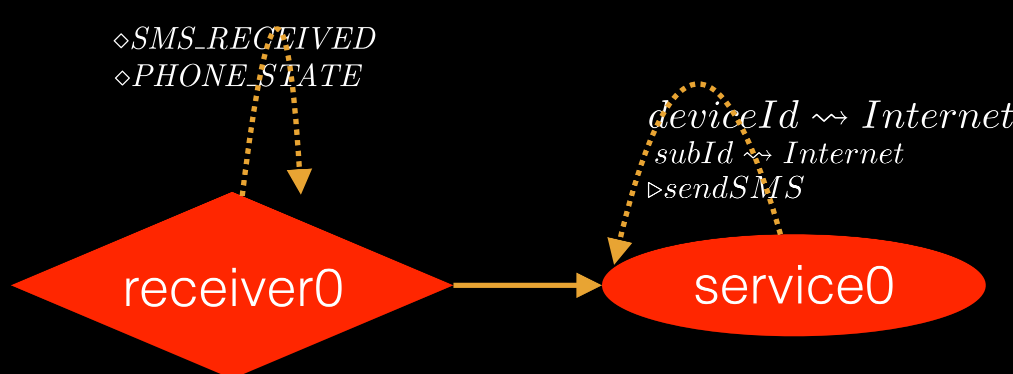
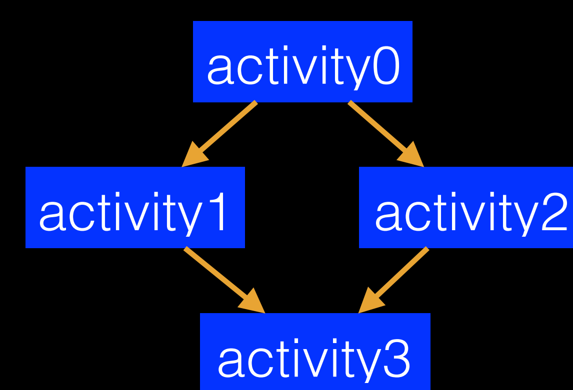
Hard

Soft



$\mathcal{O}_1 = 6$



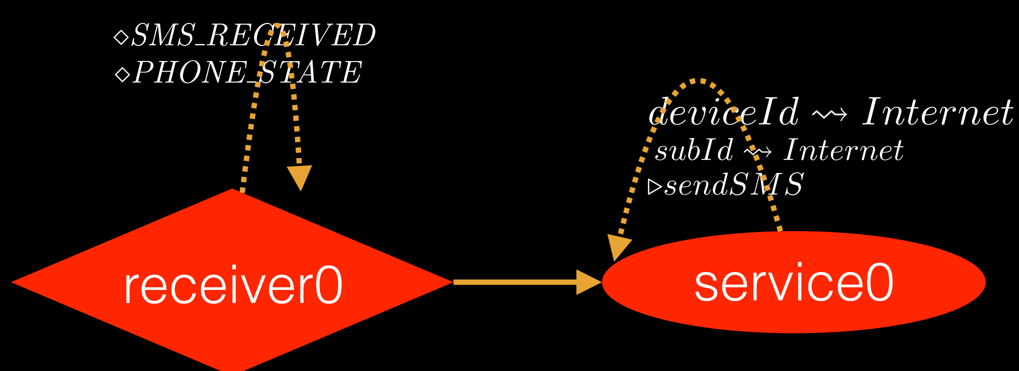
$\mathcal{O}_2 = 4$

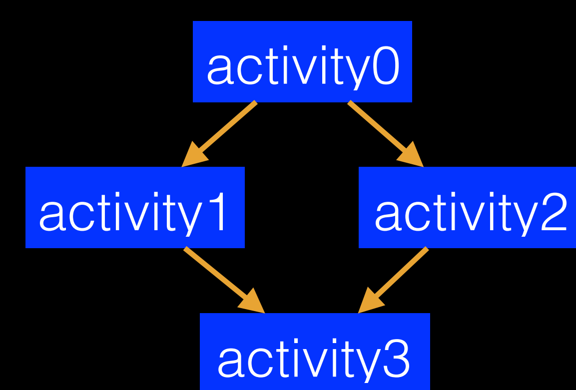
Example, cont.

Control properties

Data properties

$$\mathcal{O} = \underset{\text{Hard}}{\sum_{v,v'\in V} x_0(v,v')} + \underset{\text{Soft}}{\sum_{v,v'\in V}\sum_{d\in\mathcal{D}} w_{(v,v',d)}\, y_0(v,v',d)}.$$





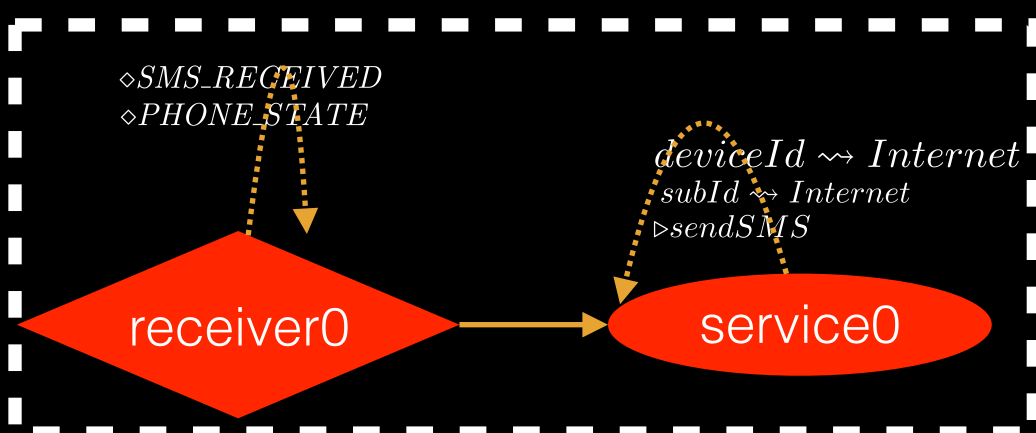
$\mathcal{O}_1 = 6$ $\mathcal{O}_2 = 4$ $\mathcal{O}_3 = 3$

Example, cont.

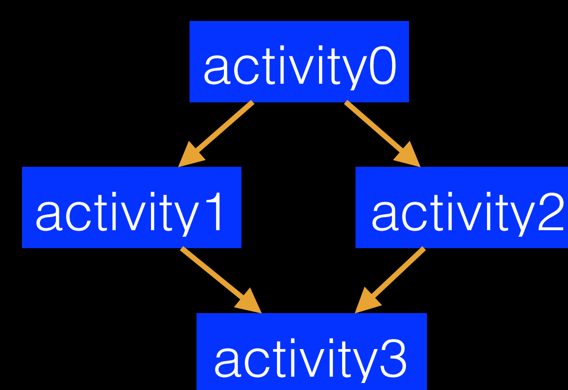
Control properties **Data properties**

$$\mathcal{O} = \sum_{v,v' \in V} x_0(v,v') + \sum_{v,v' \in V} \sum_{d \in \mathcal{D}} w_{(v,v',d)} y_0(v,v',d).$$

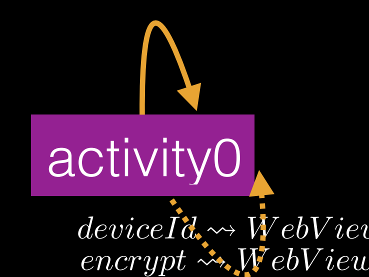
Hard *Soft*



$\mathcal{O}_1 = 6$



$\mathcal{O}_2 = 4$



$\mathcal{O}_3 = 3$

Approximate matching

Now that we have the signature…

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Utilize existing signature inference algorithm to decide if a sample A belongs to a family F:

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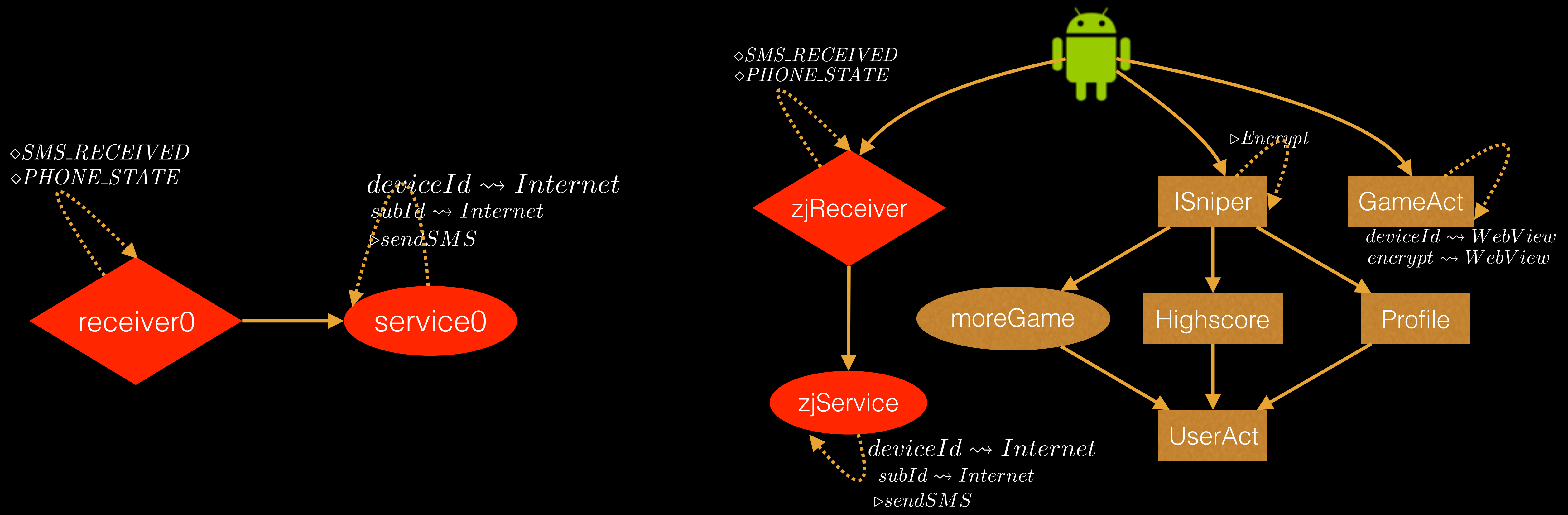
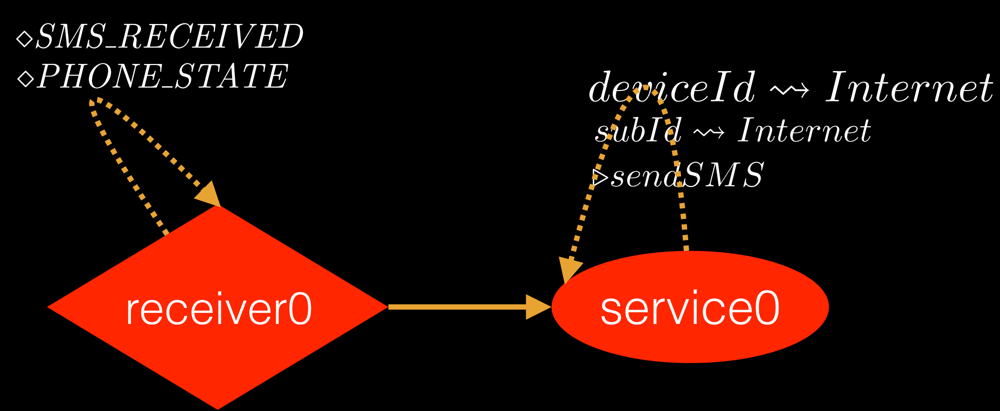
$$\delta(\mathcal{A}, \mathcal{F}) = \frac{f(\textsc{InferSignature}(\mathcal{A}, \mathcal{S}_{\mathcal{F}}))}{f(\mathcal{S}_{\mathcal{F}})}$$

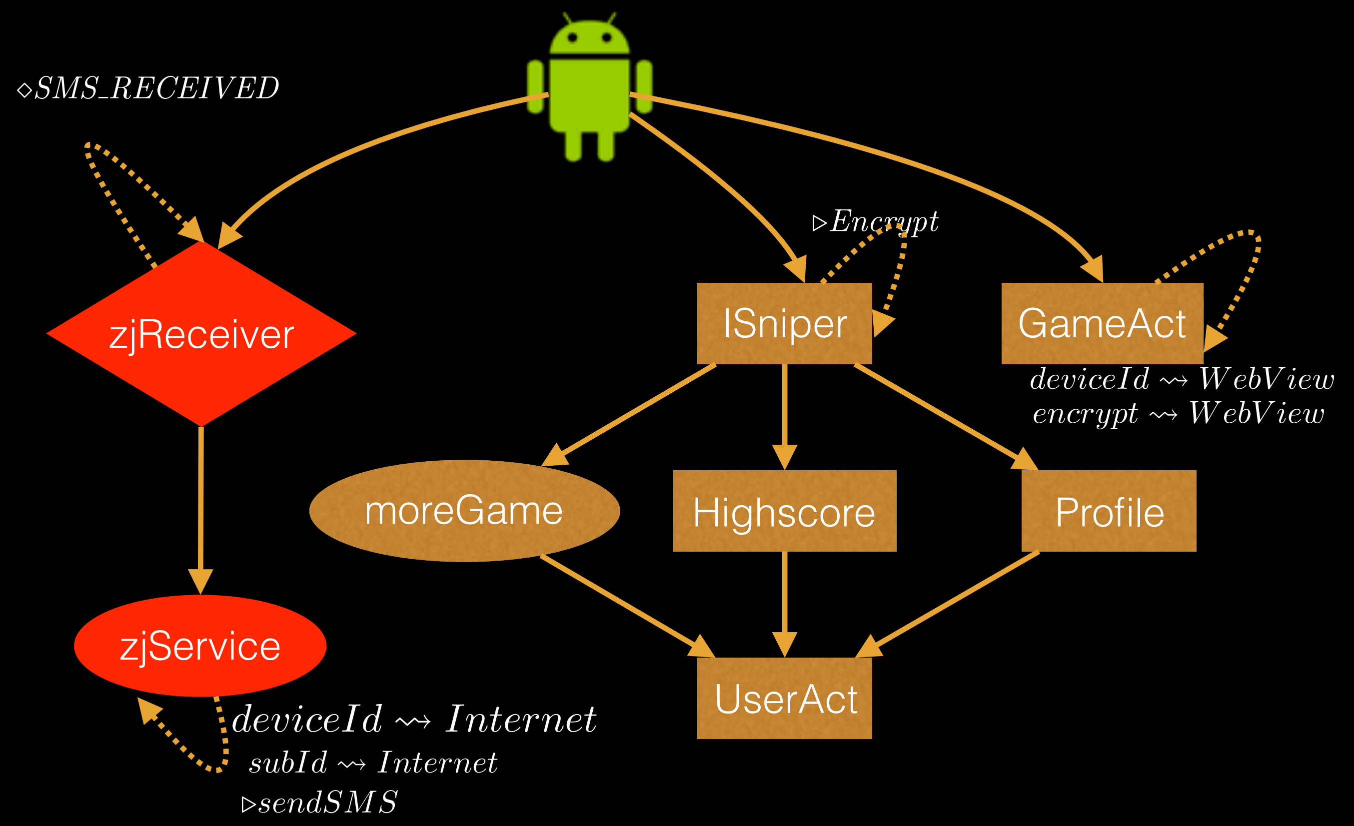
f(S): Weighted sum of the number of nodes and edges in S

Example, cont.

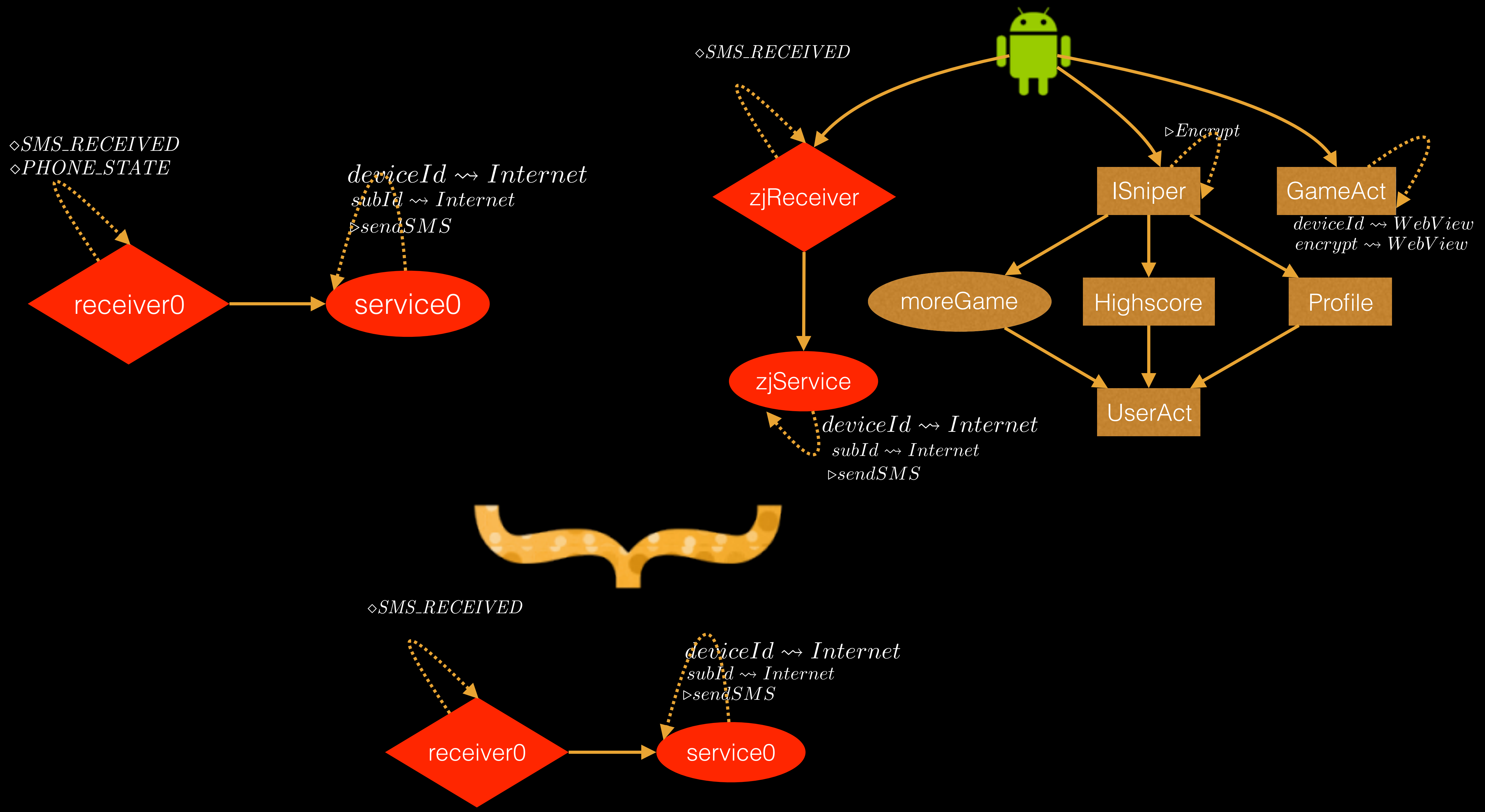


Example, cont.





Example, cont.



Example, cont.

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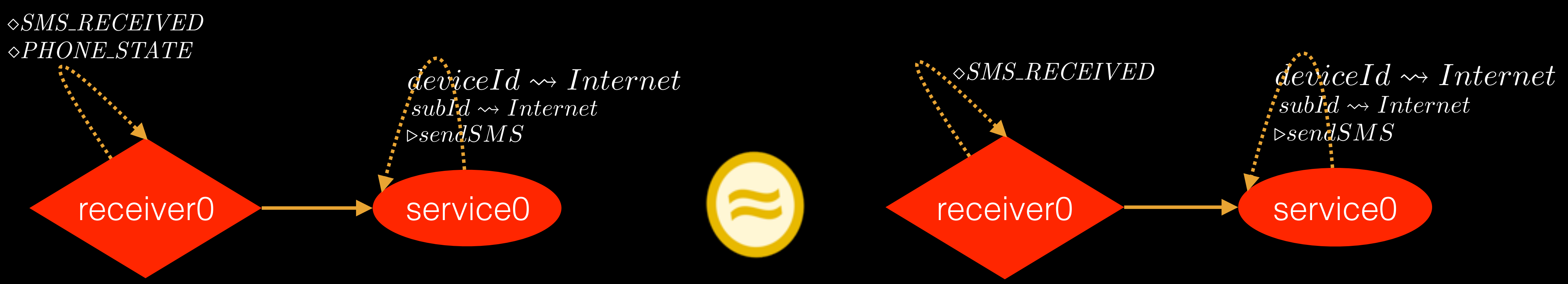
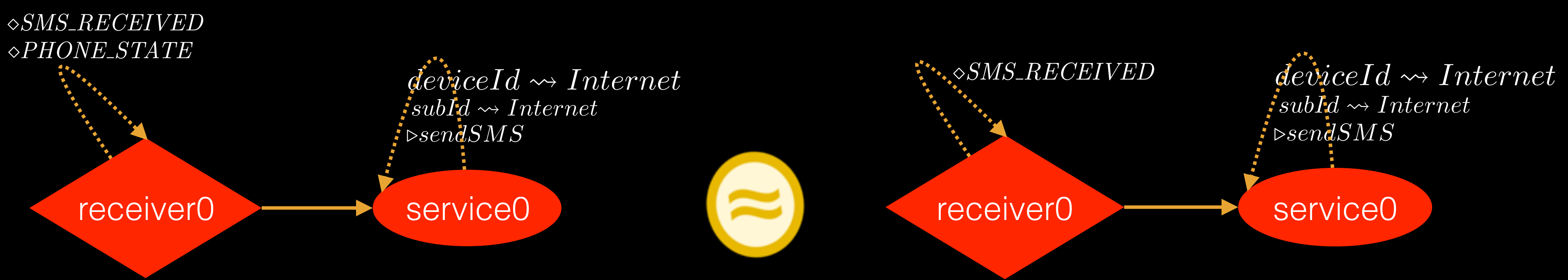


Example, cont.



Resistant to semantic obfuscation!

Evaluation

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- RQ3: How does Astroid compare against state-of-the-art malware detectors?

Manual v.s. Automated

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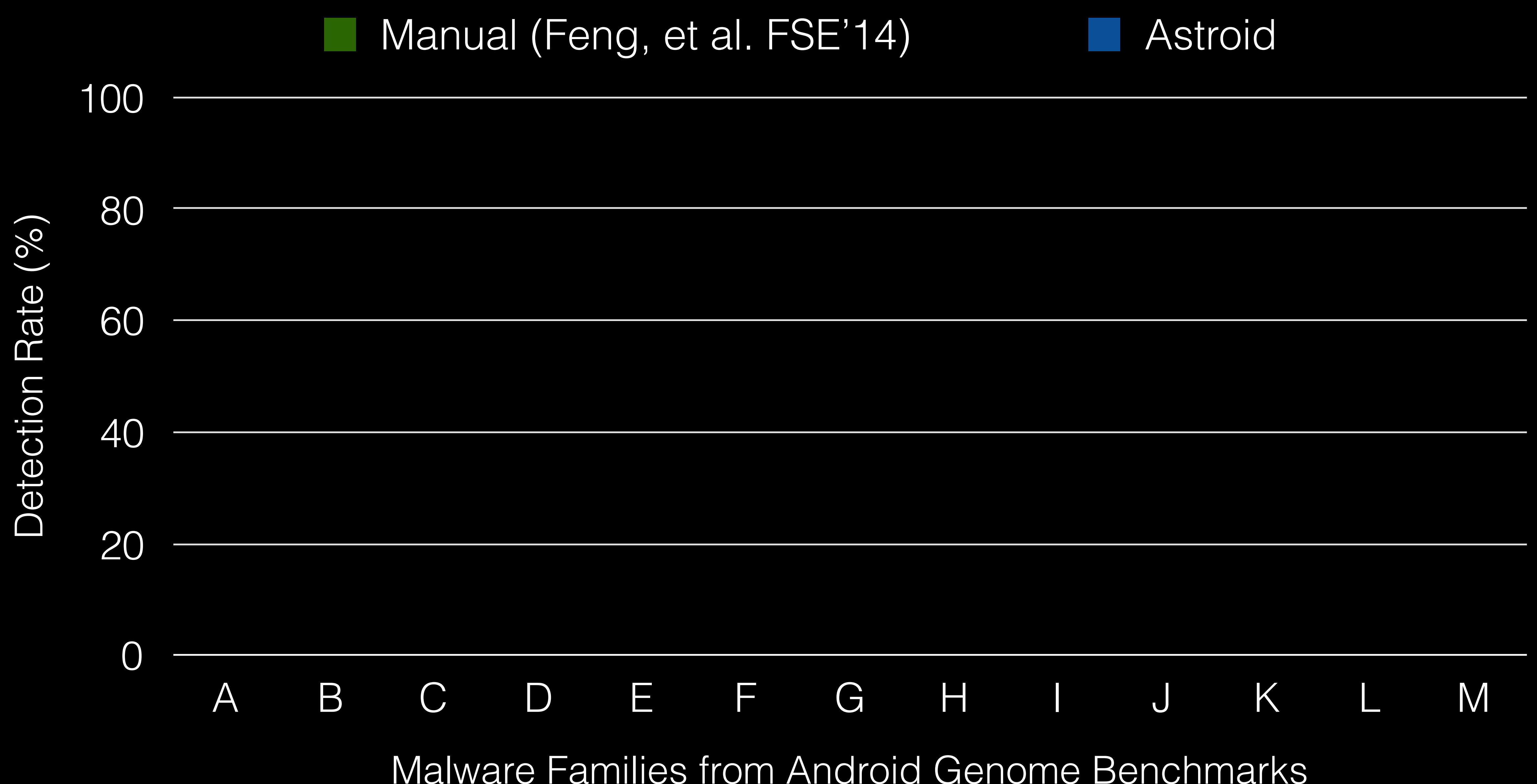

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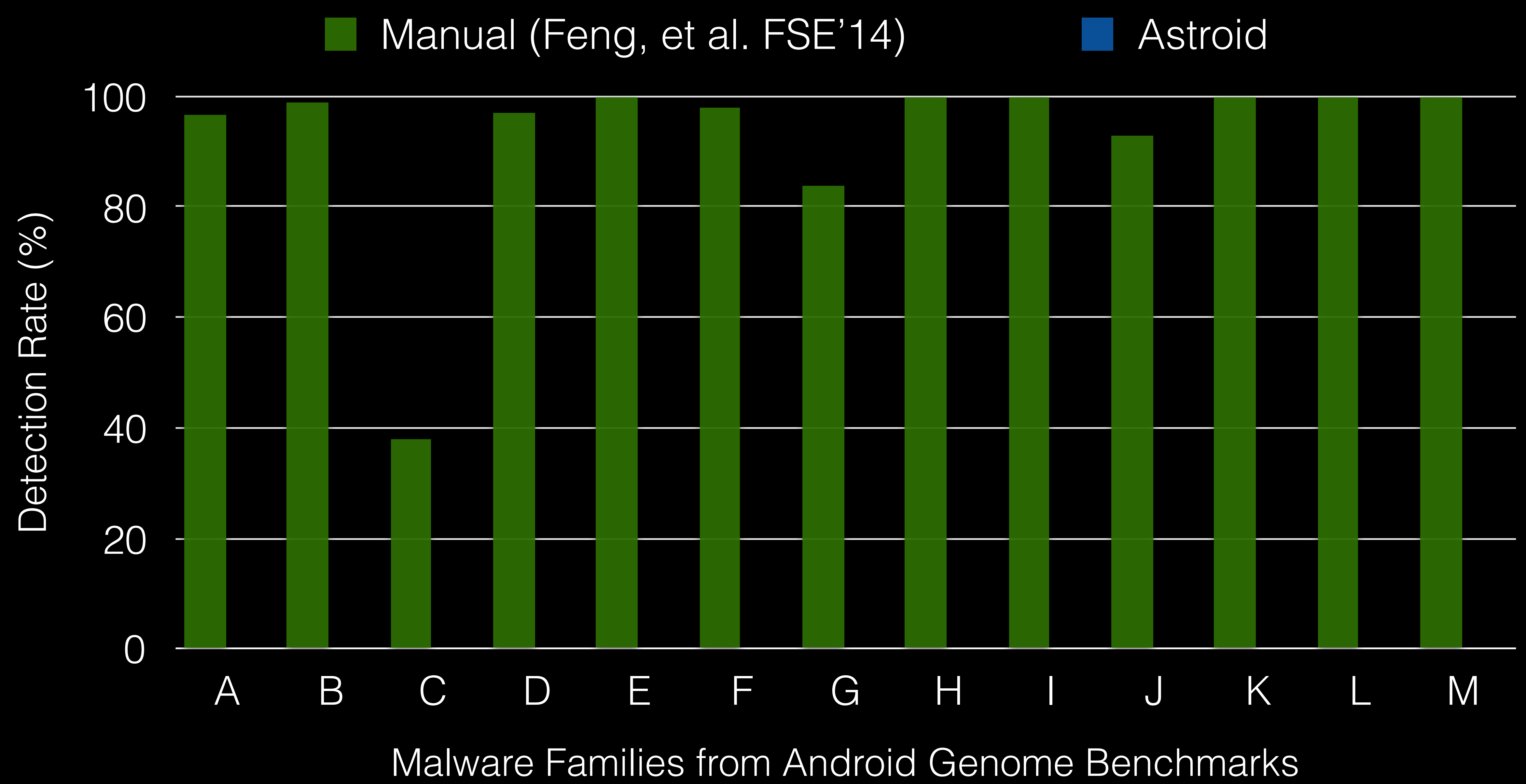

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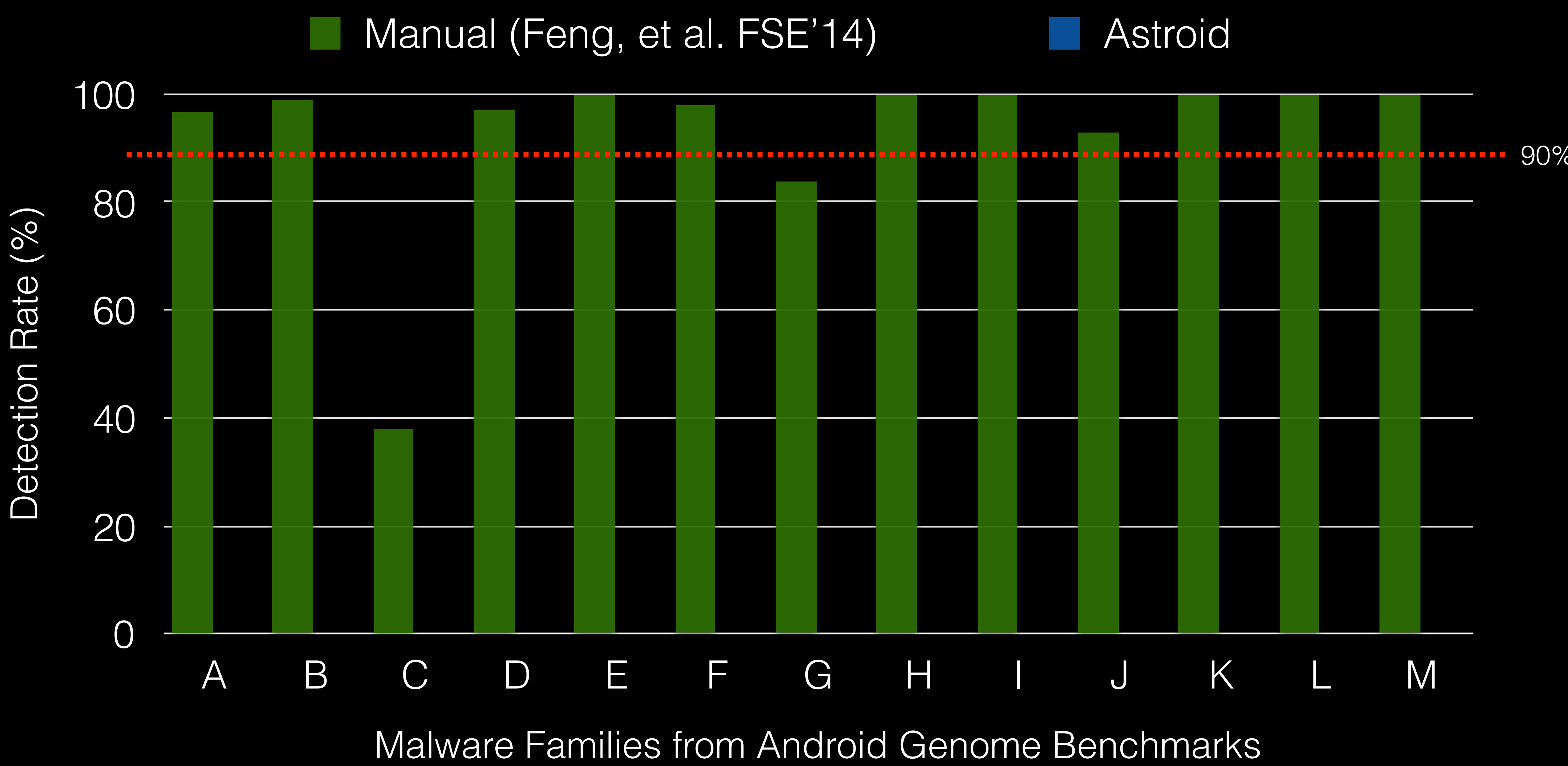

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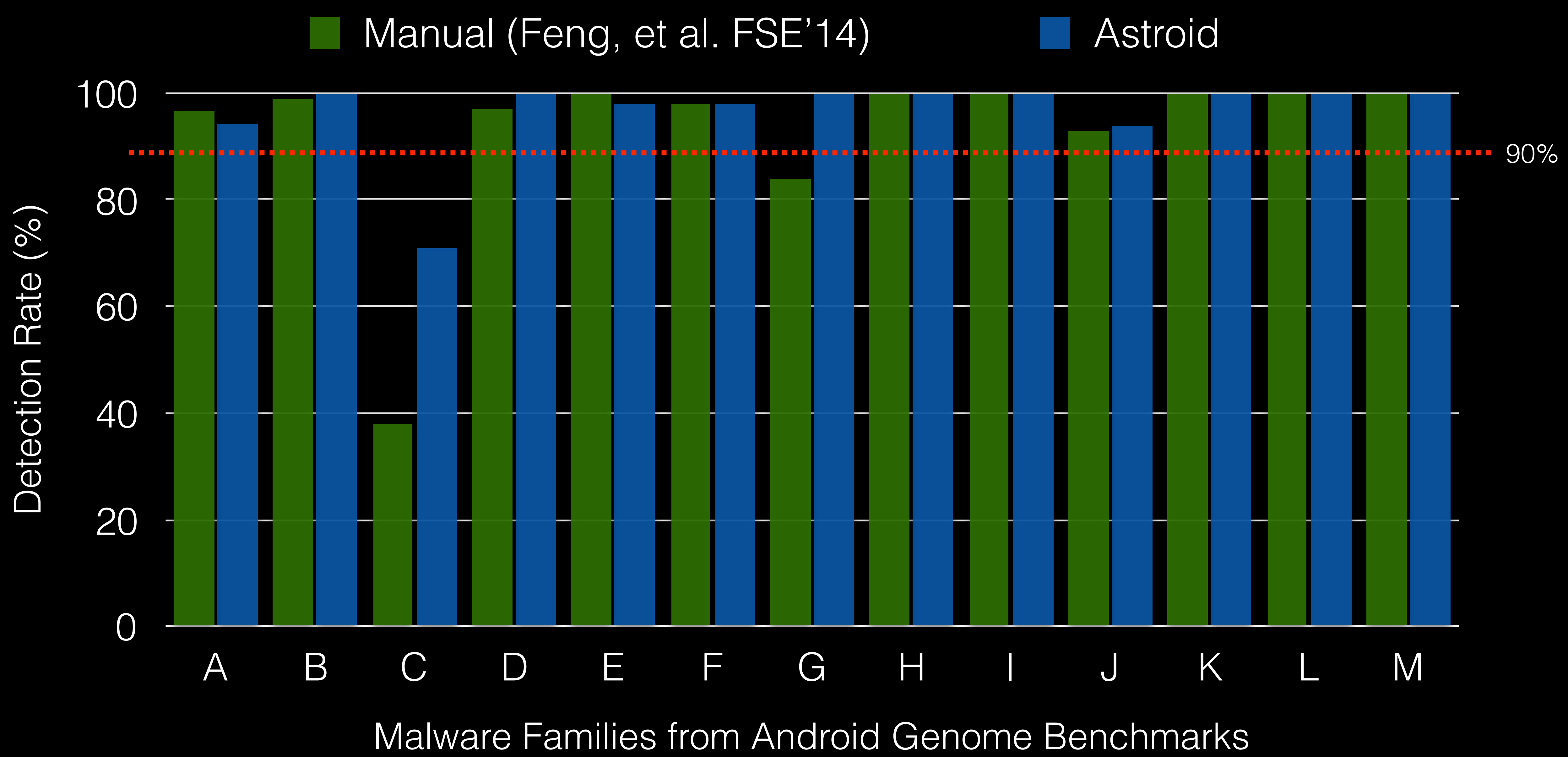

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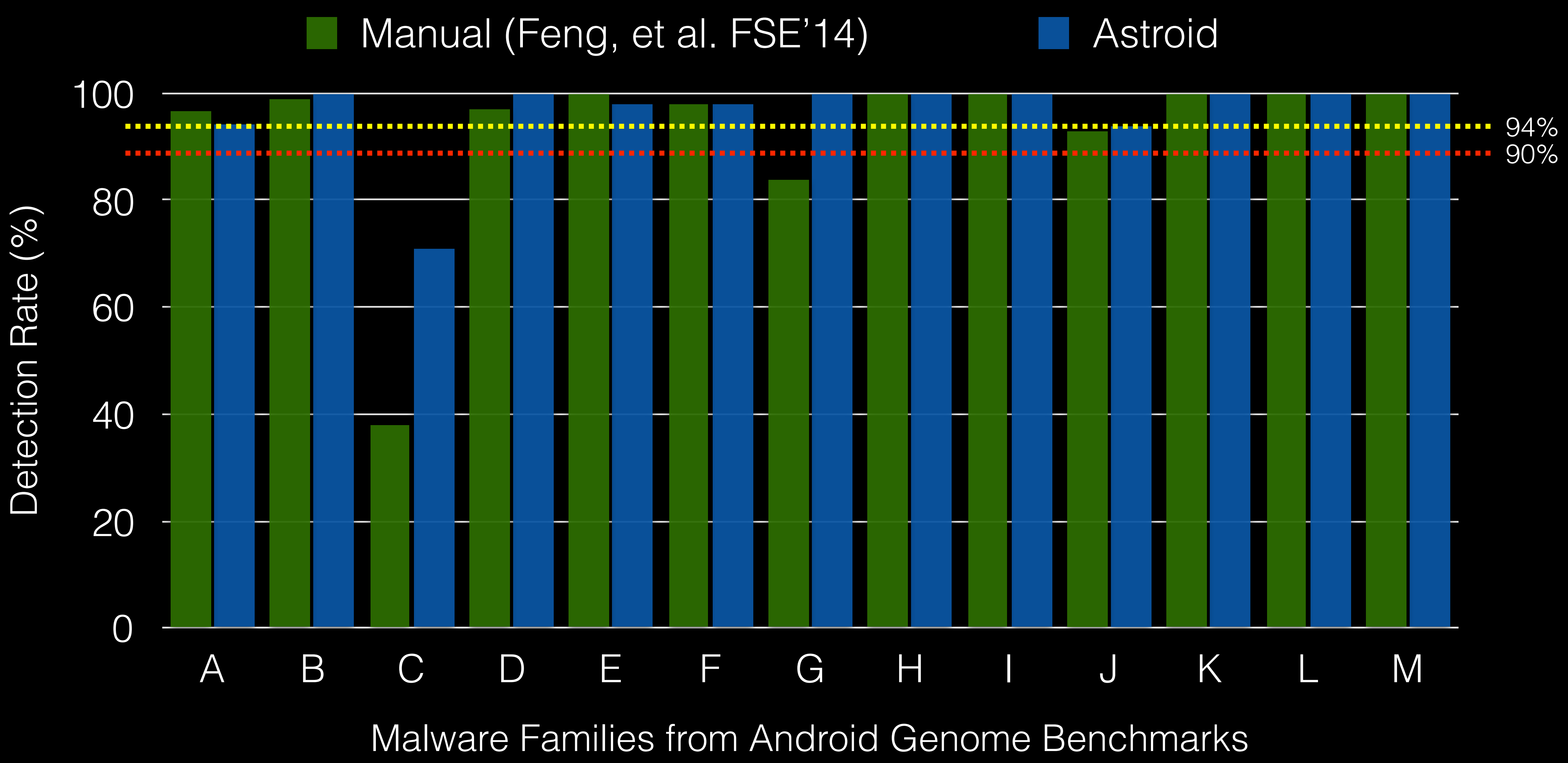
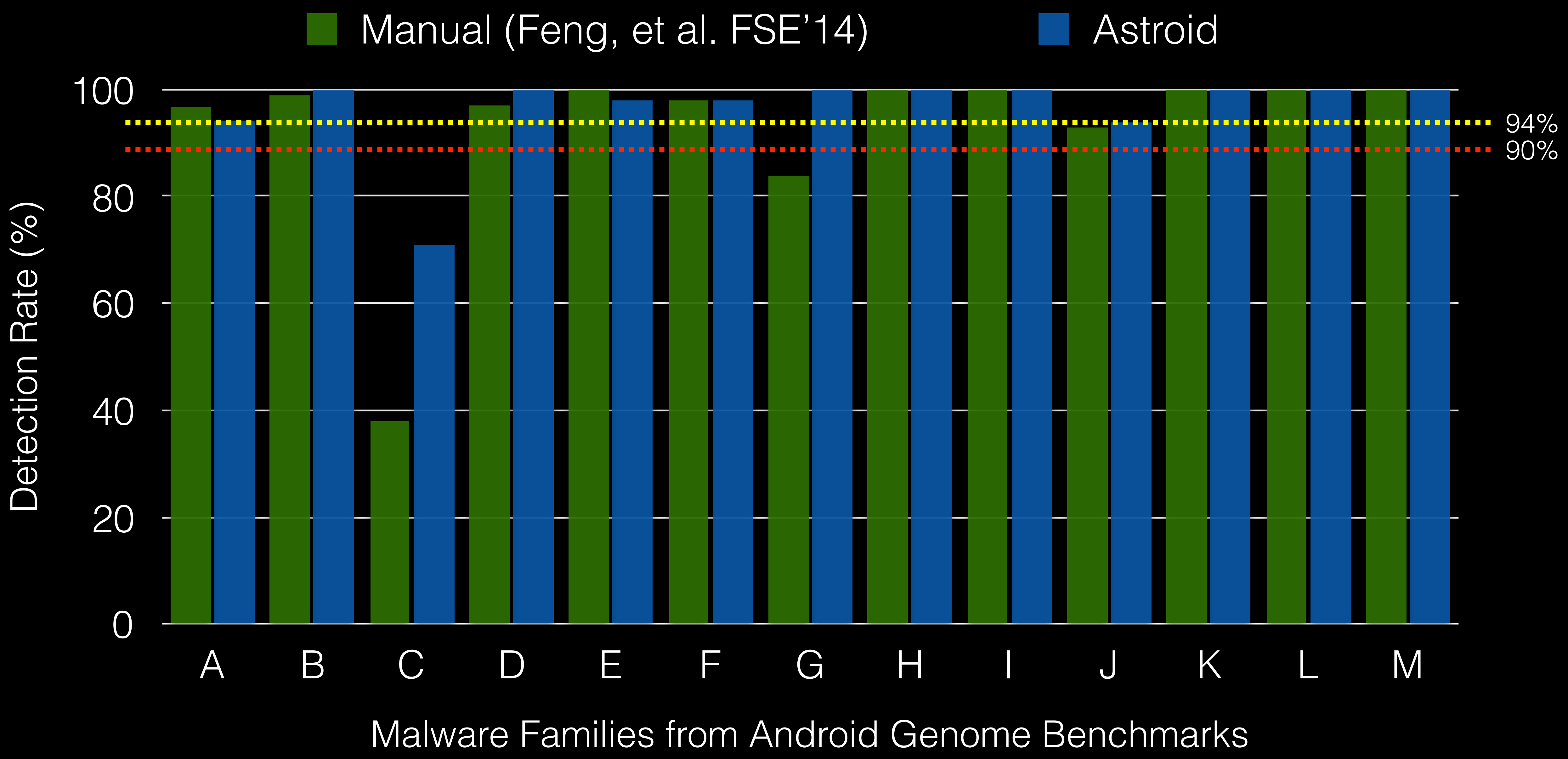


Manual v.s. Automated

Outperform manual version!



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Our approximate matching is effective!

Comparison with other tools

False positive rate: Drebin(NDSS'14): 1%, MassVet (Security'15): 175/503, Astroid: 0.04%

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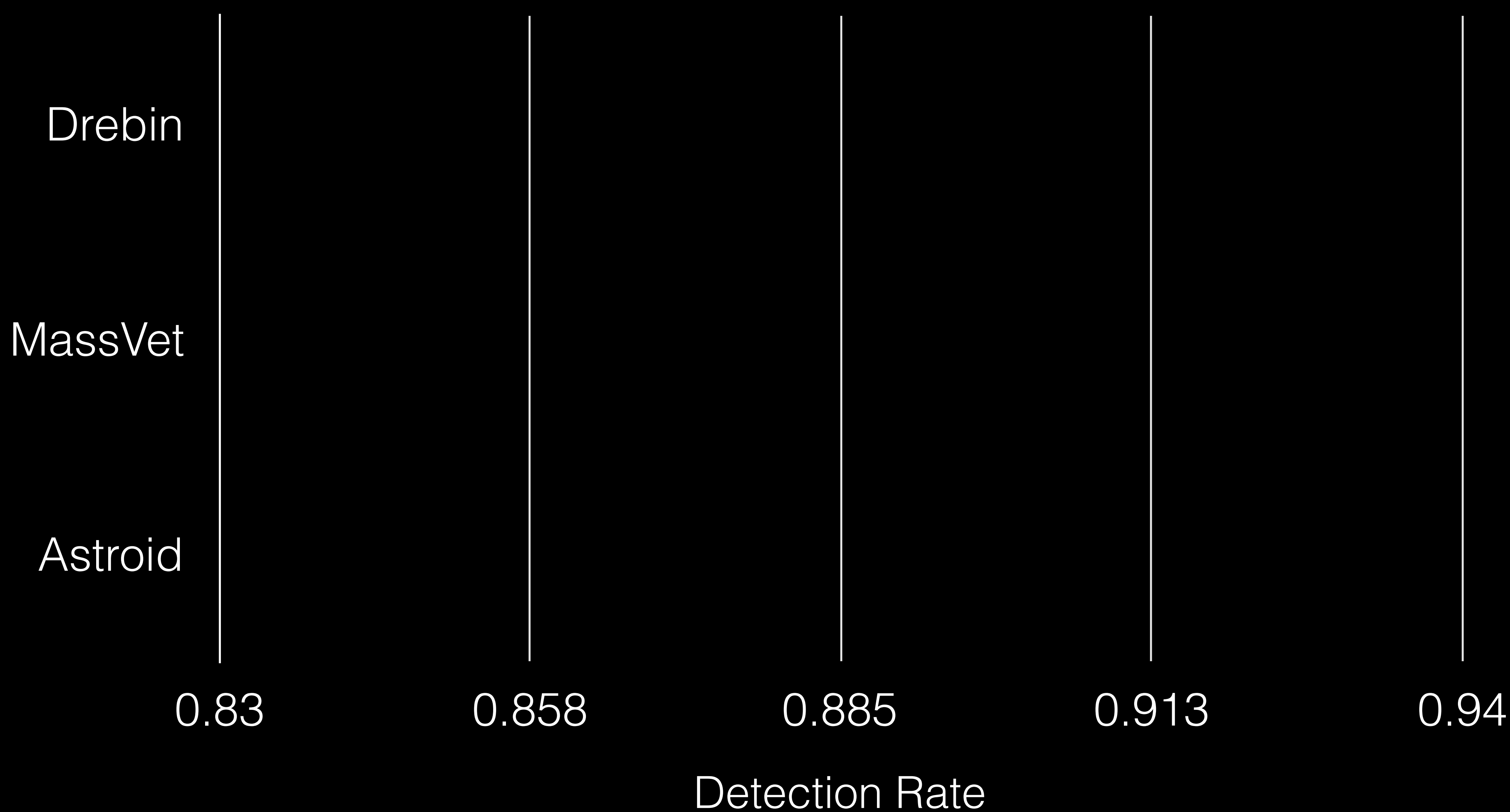

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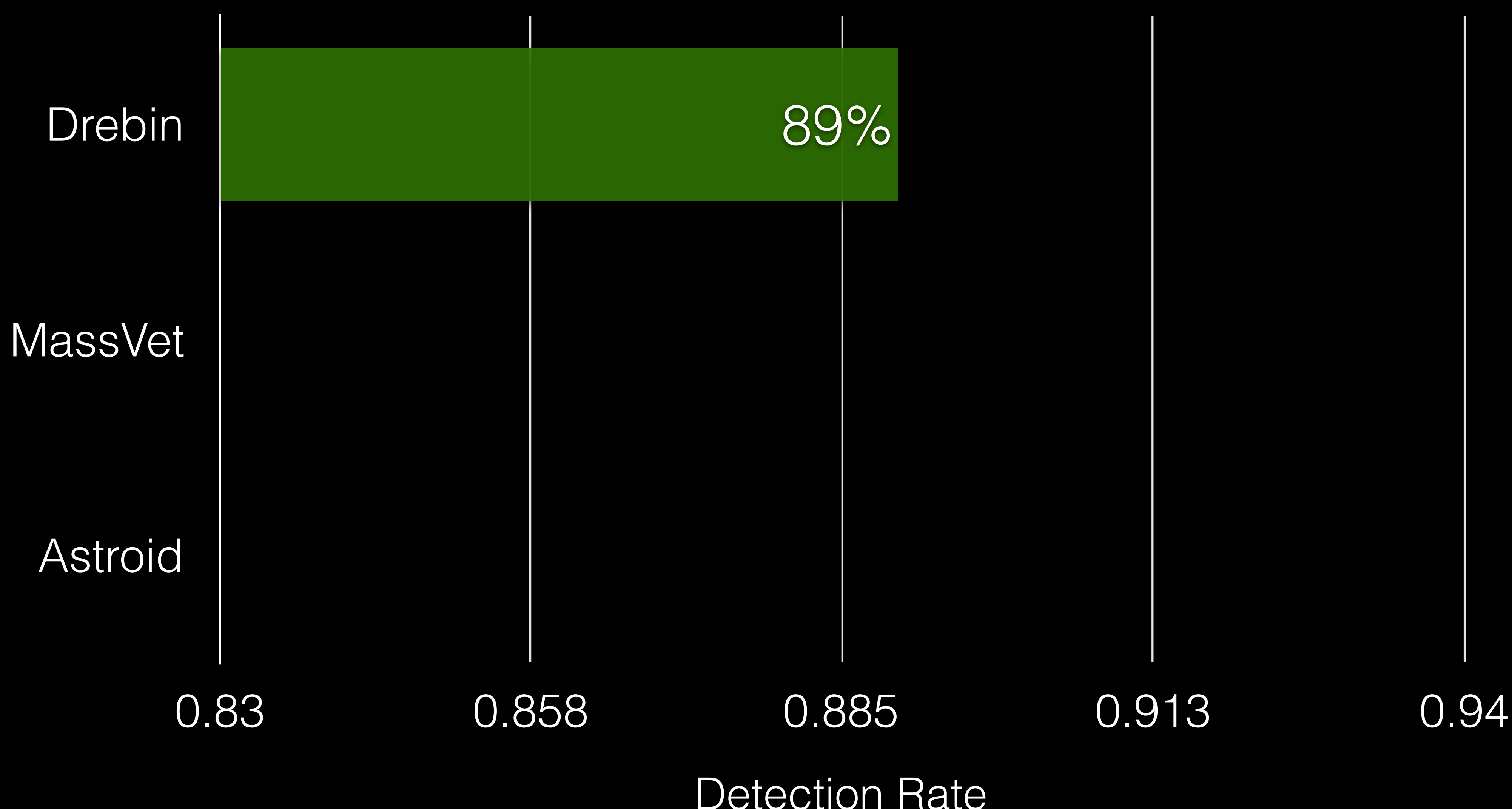

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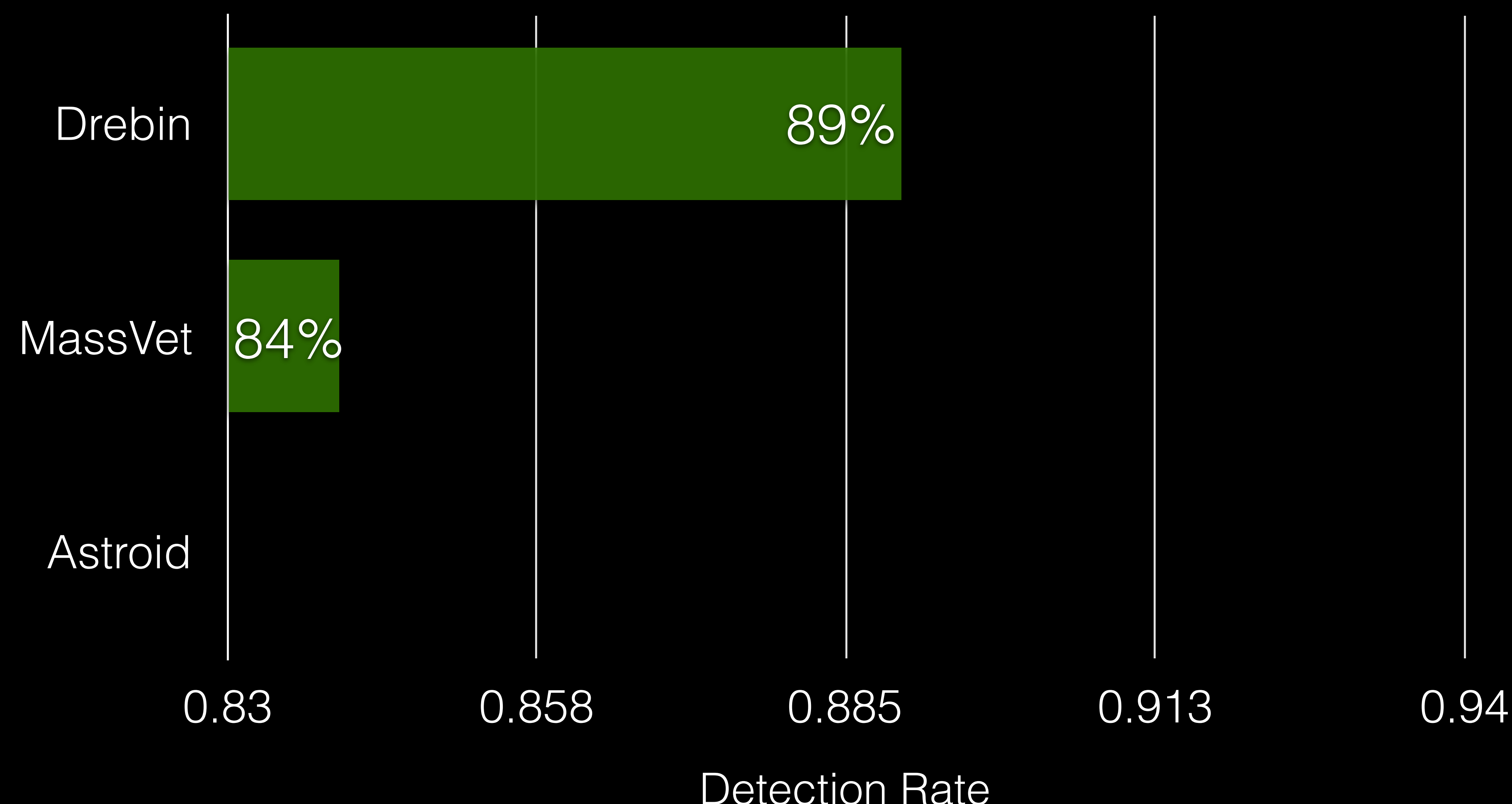

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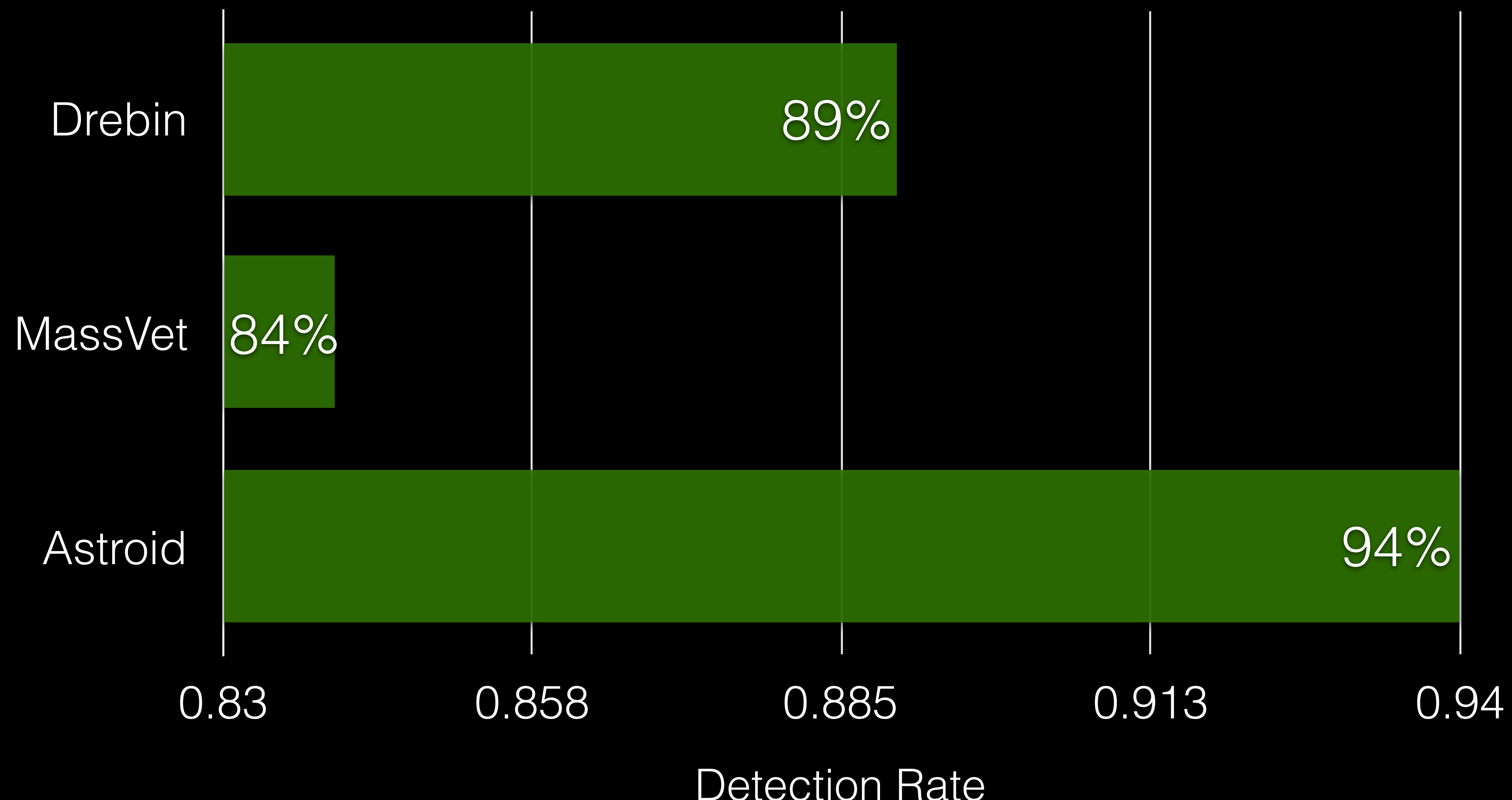

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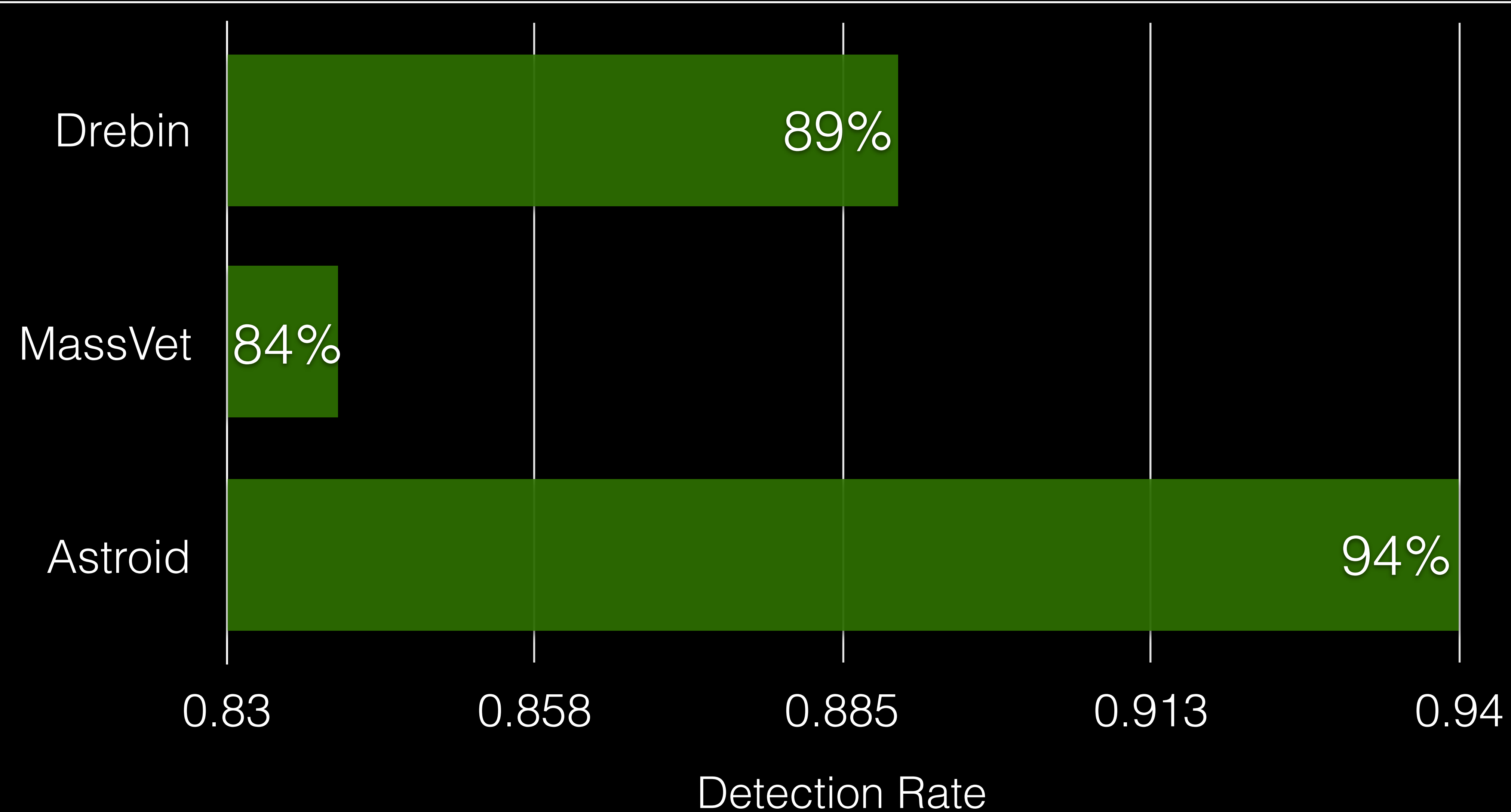
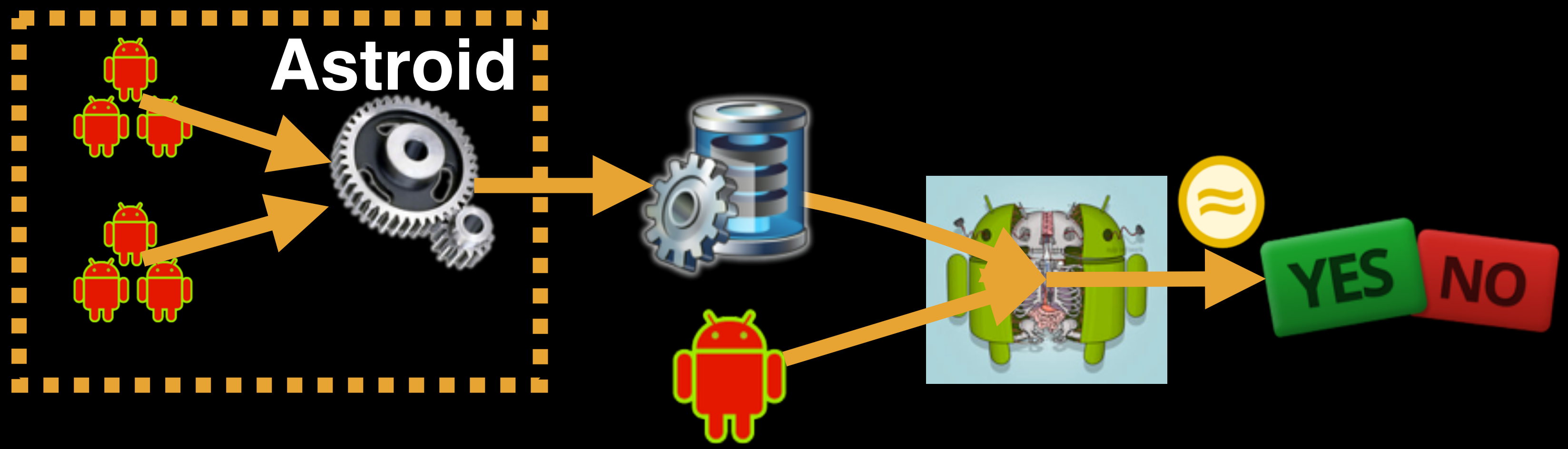
Astroid achieves high detection rate with low FP!

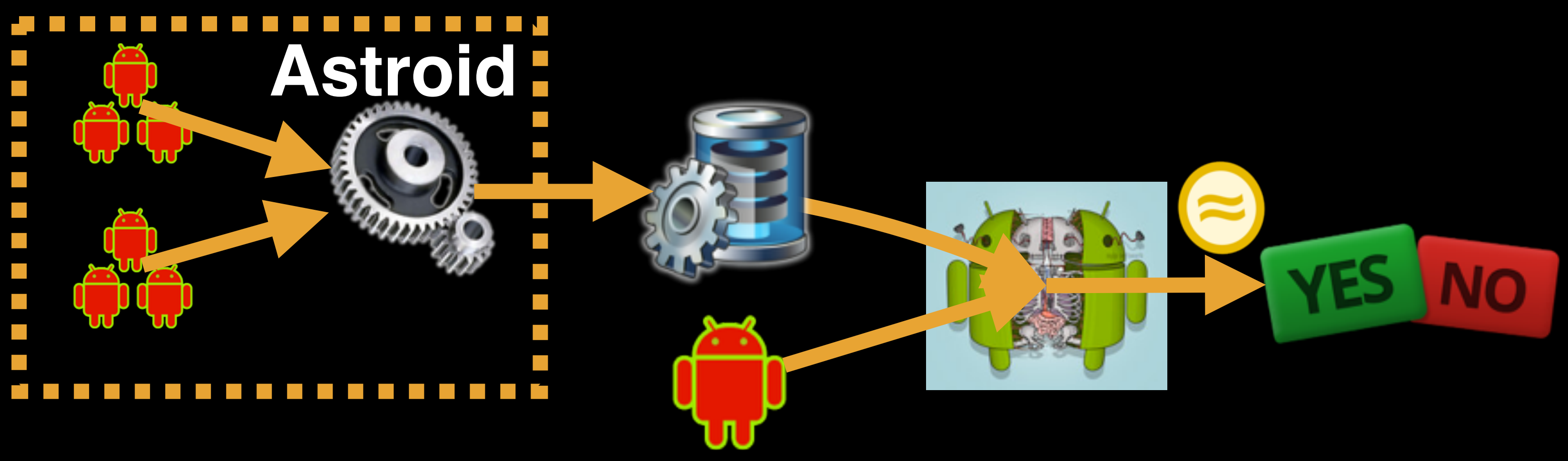


Conclusion



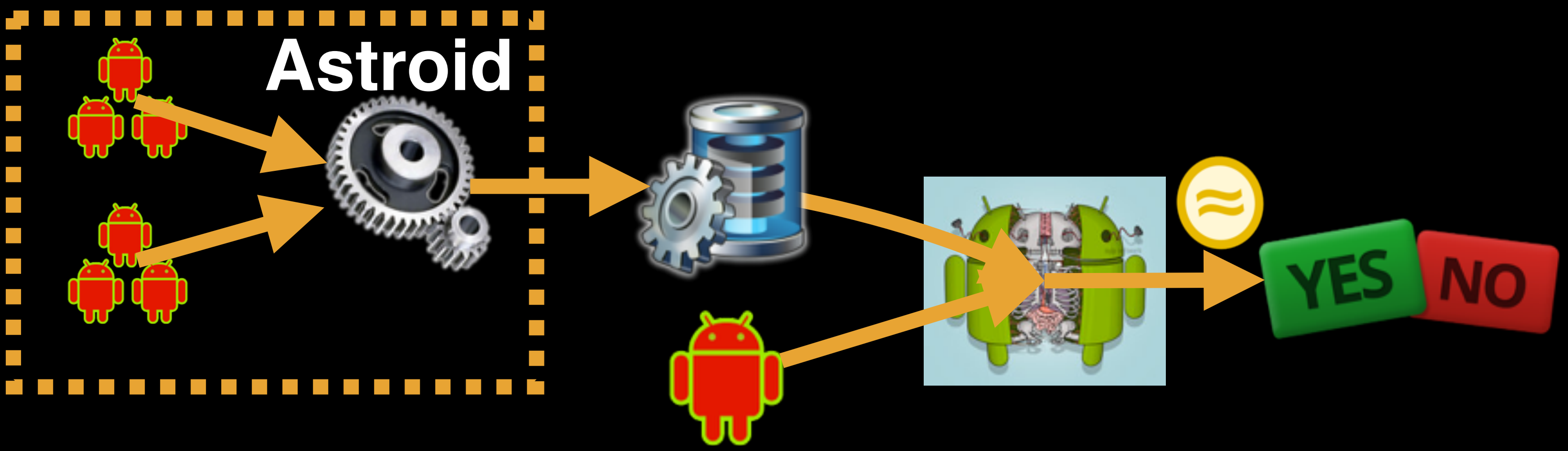
Conclusion

- Automatically infer semantic malware signature from very few samples



Conclusion

- Automatically infer semantic malware signature from very few samples
- Our approximate matching is resilient to semantic obfuscations



Thank you!

Automated Synthesis of Semantic Malware Signatures using Maximum Satisfiability.
Yu Feng, Osbert Bastani, Ruben Martins, Isil Dillig, Saswat Anand. NDSS 2017.

EXPLORER: Query- and Demand-Driven Exploration of Interprocedural Control Flow Properties. *Yu Feng, Xinyu Wang, Isil Dillig, Calvin Lin. OOPSLA 2015.*

Apposcopy: Semantics-Based Detection of Android Malware through Static Analysis.
Yu Feng, Saswat Anand, Isil Dillig, Alex Aiken. FSE 2014.