NICTA

On the Effectiveness of Dynamic Taint Analysis for Protecting Against Private Information Leaks on Android-based Devices

Golam Sarwar, **Olivier Mehani**,
Roksana Boreli, Mohamed-Ali Kaafar

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- Mobile Privacy Threats
- TaintDroid
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- Conclusion

Mobile Privacy Threats

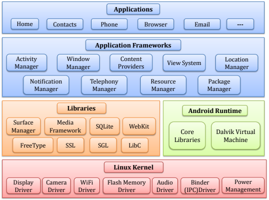
- Mobile devices
  - Always with the user
  - Always on
  - Always connected
- Trove of sensitive data
  - Private details → identity theft
  - Personal habits → profiling
- Third-party applications can access all this data
- Permissions systems easily side-stepped
  - User don't understand/care[1]
  - Developers ask too much (demo available)
  - Colluding applications[2]
- Need more effective systems

[1] A. P. Felt et al. (June 2012). "Android Permissions: User Attention, Comprehension, and Behavior". In: **SOUPS 2012**.

[2] C. Marforio et al. (Dec. 2012). "Analysis of the Communication Between Colluding Applications on Modern Smartphones". In: **ACSAC 2012**.

TaintDroid

- TaintDroid[3]
- Dynamic Taint Analysis system (see next slide)
- Taint data from sensitive sources (camera, contacts, . . .)
- Track it across **untrusted applications** (blue blocks)
- **Warns** when data reaches an untrusted sink
- Derivative protection systems (block the data)
    - AppFence[4]
    - MOSES[5]



Applications

Home | Contacts | Phone | Browser | Email | ---

Application Frameworks

Activity Manager | Window Manager | Content Providers | View System | Location Manager

Notification Manager | Telephony Manager | Resource Manager | Package Manager

Libraries

Surface Manager | Media Framework | SQLite | WebKit

FreeType | SSL | SGL | LibC

Android Runtime

Core Libraries | Dalvik Virtual Machine

Linux Kernel

Display Driver | Camera Driver | WiFi Driver | Flash Memory Driver | Audio Driver | Binder (IPC)Driver | Power Management

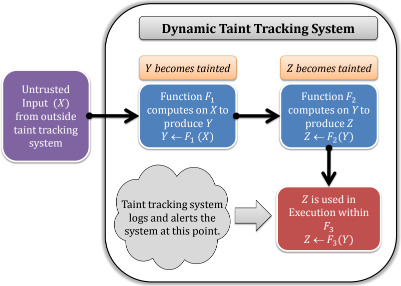
[3] W. Enck et al. (Oct. 2012). “TaintDroid: An Information-Flow Tracking System for Realtime Privacy Monitoring on Smartphones”. In: **OSDI 2010**.

[4] P. Hornyack et al. (Oct. 2011). ““These Aren’t the Droids You’re Looking For:” Retrofitting Android to Protect Data from Imperious Applications”. In: **CCS 2011**.

[5] G. Russello et al. (June 2012). “MOSES: Supporting Operation Modes on Smartphones”. In: **SACMAT 2012**.

TaintDroid

Taint Analysis Primer


Dynamic Taint Tracking System
Untrusted Input (X) from outside taint tracking system
Y becomes tainted
Function F_1 computes on X to produce Y $Y \leftarrow F_1(X)$
Z becomes tainted
Function F_2 computes on Y to produce Z $Z \leftarrow F_2(Y)$
Z is used in Execution within F_3 $Z \leftarrow F_3(Y)$
Taint tracking system logs and alerts the system at this point.

- Dynamic Taint Analysis
  - Mark variables with some information
  - Propagate marks across functions
  - Track data through execution paths
- **Help to the developer**
  - Avoid using unvalidated input or derivatives
  - Built in many languages (Perl, Ruby, . . .)
- Assumptions
  - **Code is trusted**
  - Data is not

TaintDroid

Limitations of the approach

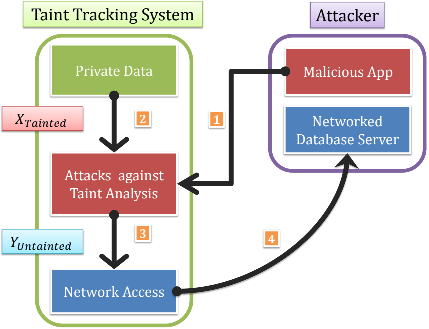
- Known limitations of Dynamic Taint Analysis[6]
  - Control dependence variable assignation
  - Subversion of benign code
  - Side channel attacks
- Assumptions no longer valid
  - Expected: Trusted code/untrusted data
  - Actual: Sensitive data/untrusted code

[6] L. Cavallaro et al. (July 2008). "On the Limits of Information Flow Techniques for Malware Analysis and Containment Detection of Intrusions and Malware, and Vulnerability Assessment". In: **DIMVA 2008**.

Attacks Against TaintDroid

Attack model

- ScrubDroid[7]
  - Android application (1)
  - Server receiving the data
- Implement attacks from vulnerable classes
  - Obtain X_{Tainted} from sensitive sink (2)
  - Untaint the variable ($Y_{\text{Untainted}}$) (3)
  - Leaks the information without warning (4)



[7] http://nicta.info/scrubdroid

Attacks Against TaintDroid

Control dependence

- Use conditional execution paths not directly using the tainted variable
- Implemented in ScrubDroid

Simple encoding Choose $Y_{\mathrm{Untainted}}$ from an array so it matches X_{Tainted}

Count-to-X Increment $Y_{\mathrm{Untainted}}$ until it is equal to X_{Tainted}

Deliberate exception Trigger X_{Tainted} exceptions for which the rescue path increments $Y_{\mathrm{Untainted}}$

Attacks Against TaintDroid

Code subversion

- Use otherwise benign code/tools to create a malevolent chain
- Implemented in ScrubDroid

System command
: Pass X_{Tainted} to system command (*e.g.*, `echo`) which outputs it verbatim, to be captured as $Y_{\text{Untainted}}$

System-file hybrid
: Use unprotected system command to write X_{Tainted} in a file, to be read as $Y_{\text{Untainted}}$

Attacks Against TaintDroid

Side channels

- Use unmonitored channel to pass information
- Implemented in ScrubDroid

Timing Set a timer to expire X_{Tainted} amount of time ahead, compute the time difference as $Y_{\text{Untainted}}$

File length Write X_{Tainted} random bytes in a file, read its lenght metadata as $Y_{\text{Untainted}}$

Bitmap cache Render X_{Tainted} on the screen, OCR $Y_{\text{Untainted}}$ out of the cache

Text scaling Change a widget's property to X_{Tainted}, retrieve it as $Y_{\text{Untainted}}$

Direct buffer Write X_{Tainted} into a memory buffer, read $Y_{\text{Untainted}}$ out

Attacks Against TaintDroid

Evaluation: Success Rates

- Process for each attack
  1. Leak untainted variable $Y_{\text{Untainted}}$
  2. Leak tainted variable X_{Tainted}
  3. Leak untainted variable $Y'_{\text{Untainted}}$
- **All false negatives**
- Direct buffer attack fix (2012-10-06..17d49f89) **leads to false positives**

Technique	$Y_{\text{Untainted}}$	X_{Tainted}	$Y'_{\text{Untainted}}$
Tainted Variable	–	✓	–
File R/W (ovrwr.)	–	✓	–
File R/W (app.)	–	✓	✓ (FP)
Simple Encoding	–	– (FN)	–
Count-to-X	–	– (FN)	–
Exception-Error	–	– (FN)	–
Shell Command	–	– (FN)	–
File-Shell Hybrid	–	– (FN)	–
Timekeeper	–	– (FN)	–
File Length	–	– (FN)	–
Clipboard Length	–	– (FN)	–
Bitmap Cache	–	– (FN)	–
Bitmap Pixel	–	– (FN)	–
Text Scaling	–	– (FN)	–
Direct Buf. (Rel.)	–	– (FN)	–
Direct Buf. (Git)	–	✓	✓ (FP)
Remote Control	–	– (FN)	–

Attacks Against TaintDroid

Evaluation: Timing

- Two types of data
  - IMEI (15 B)
  - 5 s sound recording from microphone (11 kB)
- Not practical **but doable**

Technique	IMEI		5 s audio	
	avg. [ms]	σ	**avg. [ms]**	σ
Tainted Variable	3.48	4.07	364.97	67.31
File R/W	47.62	19.56	386.01	49.85
Simple Encoding	9.55	4.55	795.72	49.12
Count-to-X	10.14	5.41	8278.64	84.20
Exception-Error	53.22	22.09	—	
Shell Command	72.22	12.69	—	
File-Shell Hybrid	78.10	25.80	—	
Timekeeper	1037.66	82.60	—	
File Length	72.37	21.78	—	
Clipboard Length	84.89	18.61	—	
Bitmap Cache	312.27	24.45	—	
Bitmap Pixel	35.95	12.35	2899.80	172.56
Text Scaling	12.92	5.91	3022.58	84.12
Direct Buffer	4.00	3.67	2988.70	87.69
Remote Control	2583.10	976.82	—	

Attacks Against TaintDroid

Mitigation

- Overmark
  - Increase false positives (*e.g.*, Direct Buffer attack)
  - Impractical in case of blocking systems
- Manual marking
  - Requires cooperative developer
- Include comparisons to propagation rules
  - Most control dependence attacks use them for checks

Conclusion

- **Taint analysis** works as a help for the developer
  - identify use of untrusted data in trusted code
- but **is limited** when used against them
  - **untrusted code can be written** to misuse and leak sensitive data
- Future work
  - Study static analysis in this context
- ScrubDroid is Open Source[8]
  - Main author: `<golam.sarwar@nicta.com.au>`
  - Longer technical report available at `http://www.nicta.com.au/pub?id=7091`

[8] `http://nicta.info/scrubdroid`

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  - Demonstration available!

Thanks — `<olivier.mehani@nicta.com.au>`

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