Practical Keystroke Timing Attacks in Sandboxed JavaScript

M. Lipp, D. Gruss, M. Schwarz, D. Bidner, C. Maurice, S. Mangard

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Graz University of Technology

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- First JavaScript-based keystroke timing attack
- Build classifiers to detect visited websites or to identify users and a covert channel
- Runs in the background and can monitor on other tabs and applications

Background

- Acquire accurate timestamps of keystrokes for input sequences

Keystroke Timing Attacks

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Keystroke Timing Attacks

- Acquire accurate timestamps of keystrokes for input sequences
- Depend on bigrams, syllables, words, keyboard layout and typing experience
- Exploit timing characteristics to learn information about the user or the input
  - Infer typed sentences
  - Recover passphrases

- Many ways to obtain keystroke timings have been presented:
  - SSH leaks inter-keystroke timings in interactive mode [Son+01]
  - Network latency with significant traffic [Hog+01]
  - Instruction and stack pointer, interrupt, network packet statistics [Zha+09]
  - CPU usage [Jan+12]
  - Wi-Fi Signals [Ali+15]
  - `/proc/interrupts` [Dia+16]
  - JavaScript Sensor API [Meh+16]

Interrupt-timing Attacks

- Idea: Continuously acquire a high-resolution timestamp and monitor differences between subsequent timestamps [Sch+17]

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- Requires unprivileged code execution and an accurate timing source (e.g., `rdtsc`)

Interrupt-timing Attacks

```
1  int now = rdtsc();
2  while (true) {
3    int last = now;
4    now = rdtsc();
5    if ((now - last) > threshold) {
6      reportEvent(now, now - last);
7    }
8  }
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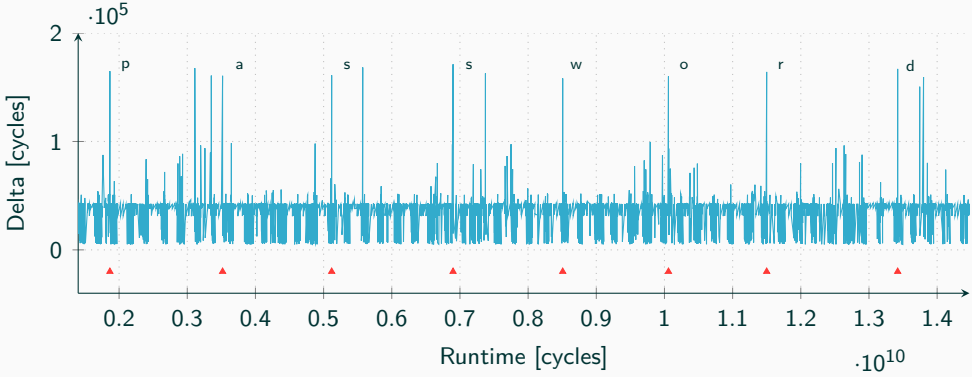
- Look at how much time has passed since the last measurement
  - Significant differences occur when the process is interrupted
  - More time the operating system consumes to handle the interrupt
    → higher timing difference


·10^5
2
1
0
Delta [cycles]
p
a
s
s
w
o
r
d
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
Runtime [cycles]
·10^10

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- W3C standard now recommends a resolution of 5 µs

Sandboxed Keystroke Timing Attacks without High-Resolution Timers

- Two phases:

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  - *Offline phase*: Post-processing and evaluation

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  - Constantly increment a value
  - Number of increments is proportional to the time the function is scheduled
    - Interrupt → lower increments

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  - `setTimeout`/`setInterval` enforce a minimum pause of 4 ms

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- Minimum timeout is reduced to 1000 ms if the user switches the tab
  - Utilize Web Worker API to execute code in background

Cooperative endless-loop slicing


```
1  function measure_time(id) {
2    setTimeout(measure_time, 0, id + 1);
3    counter = 0;
4    begin = window.performance.now();
5    while ((window.performance.now() - begin) < 5) {
6      counter = counter + 1;
7    }
8    publish(id, counter);
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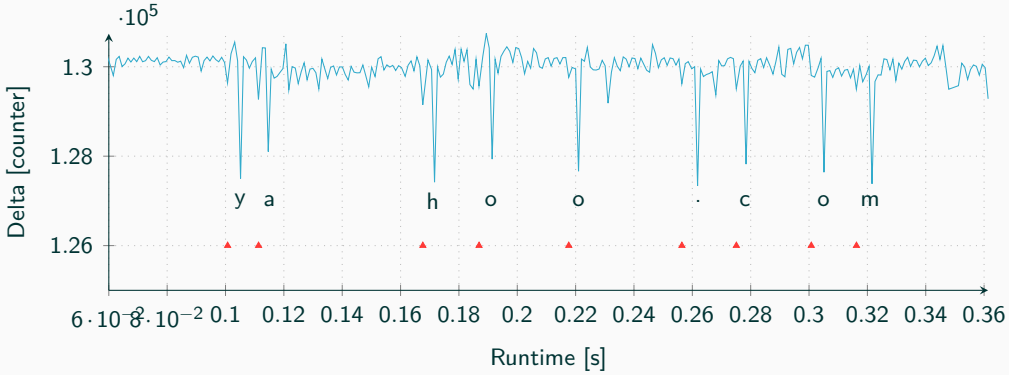
- Low impact on the system and browser performance
- Less than 256 bytes of code
- Can be hidden in modern JavaScript frameworks or online advertisements


$\cdot 10^5$
1.3
1.28
1.26
Delta [counter]
y a h o o · c o m
$6 \cdot 10^{-2}$
$8 \cdot 10^{-2}$
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
0.32
0.34
0.36
Runtime [s]

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  - Filter the measured trace to reduce noise
  - Detect threshold for keystroke events
- Features of recorded measurements are strong enough that simple techniques (k-nearest neighbours (KNN)) allow to build an efficient and accurate classifier

Practical Attacks and Evaluation

URL Classification

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  - Intel i7-6700K and Firefox 52.0
- Train a classifier with the input sequences of the top 10 most visited websites

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- Compute the correlation for different alignments
- Evaluate classifier using k-fold cross-validation

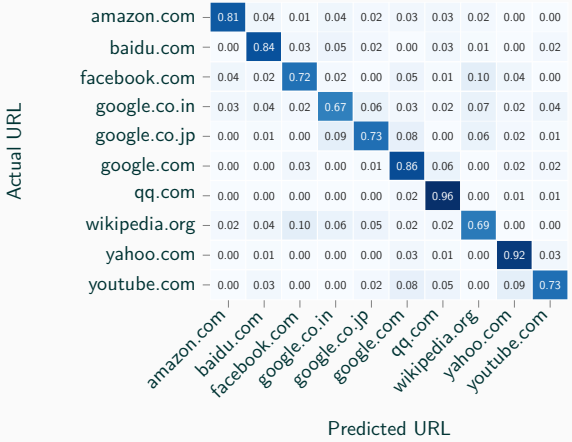

Figure 1: Confusion matrix for URL input.

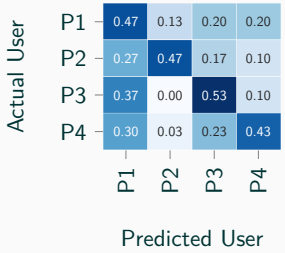

Figure 2: Confusion matrix for input by different users.

- Evaluate attack on mobile devices

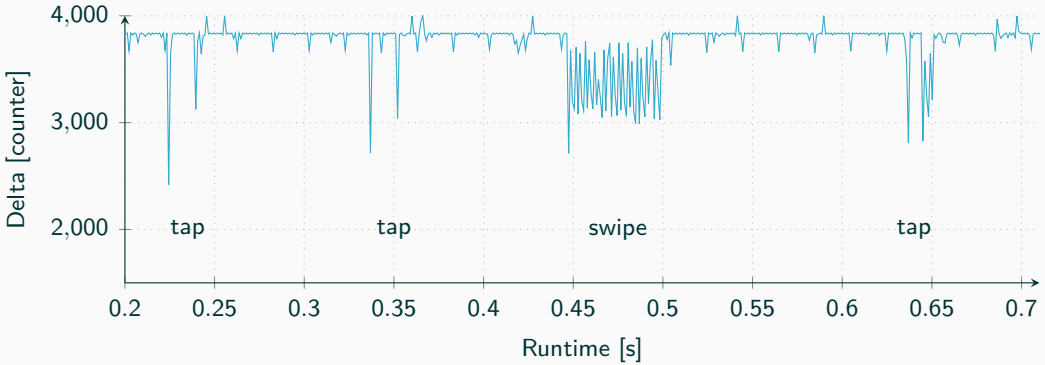

Figure 3: Keystroke timing attack running in a native app on the Google Nexus 5.

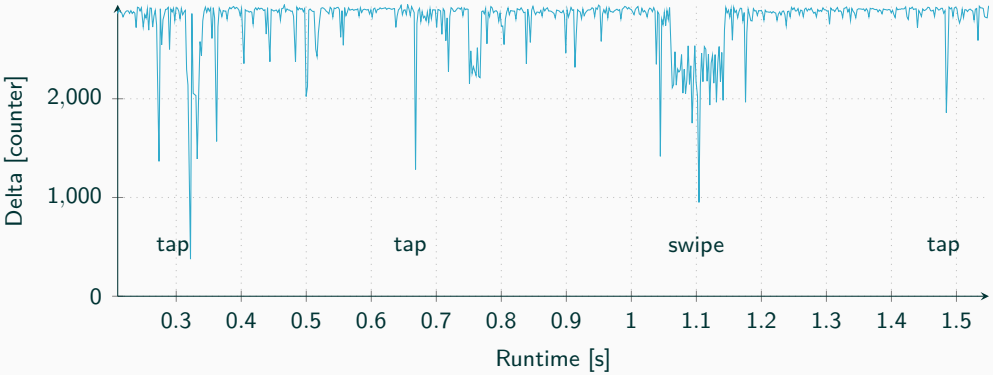

Figure 4: Keystroke timing attack running in JavaScript on the Google Nexus 5.

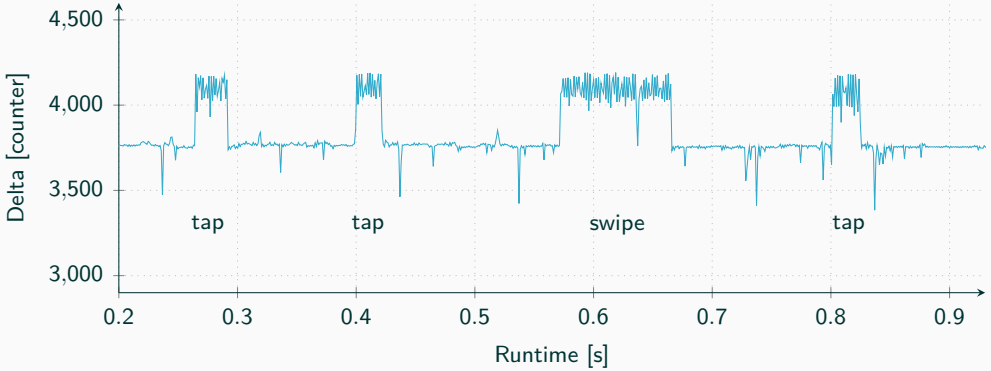

Figure 5: Keystroke timing attack running in JavaScript on the Xiaomi Redmi Note 3.

Spying on other applications and PIN unlock

- Attack allows monitoring of every other event triggering interrupts

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- Attack allows monitoring of every other event triggering interrupts
- Allows to monitor keystrokes in different tabs and other applications

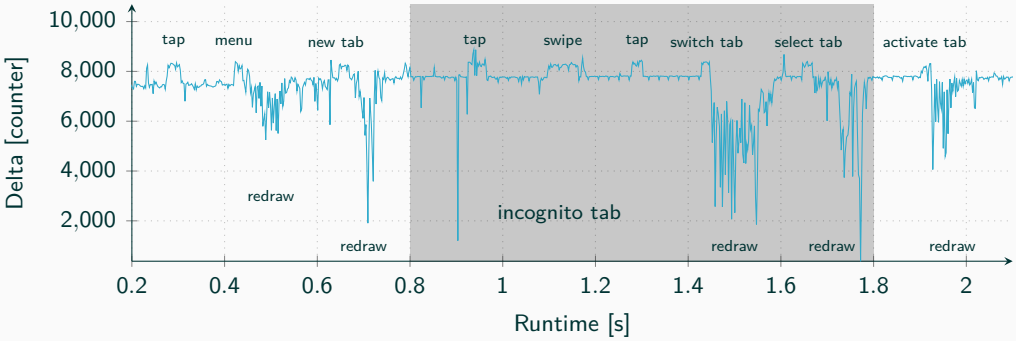

Figure 6: Keystroke timing attack running while switching to a different tab in the Chrome browser on the Xiaomi Redmi Note 3.

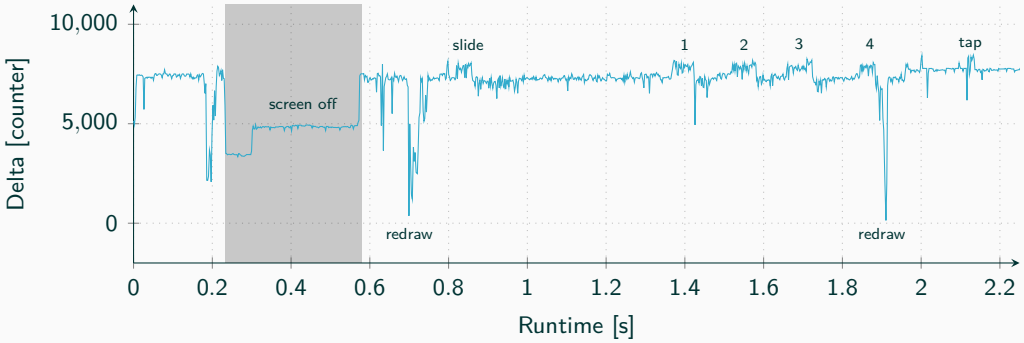

Figure 7: Keystroke timing attack running in the Firefox browser on the Xiaomi Redmi Note 3. While the user locked the screen, the application still detects keystrokes as long as it is executed on the last used tab.

Device	SoC	Keystrokes	Screen lock
Google Nexus 5	Qualcomm MSM8974 Snapdragon 800	✓	-
Xiaomi Redmi Note 3	Mediatek MT6795 Helio X10	✓	✓
Homtom HT3	MediaTek MTK6580	✓	✓
Samsung Galaxy S6	Samsung Exynos 7420	-	✓
OnePlus One	Qualcomm MSM8974AC Snapdragon 801	✓	✓
OnePlus 3T	Qualcomm MSM8996 Snapdragon 821	-	-

Table 1: Mobile test devices.

- Establish a unidirectional covert channel

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- Establish a unidirectional covert channel
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- Utilize `XMLHttpRequest` to fetch a network resource from an invalid URL to implicitly issue an interrupt

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- Transmission rate
  - Raw transmission rate of 25 bps using a sample interval of 40 ms

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- Fine-grained Permission Model for JavaScript
  - Per-page level access control to APIs, e.g., web workers

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  - independent of browser and operating system
- Infer accurate timestamps of keystrokes as well as taps and swipes
- Built classifiers to detect visited websites and identify users and a covert channel
- Highly practical, as it runs in background to spy on other tabs and applications

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