# JavaScript Zero

## Real JavaScript and Zero Side-Channel Attacks

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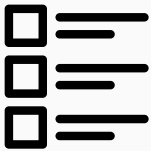
www.iaik.tugraz.at

# Outline



- Analysis of current microarchitectural and side-channel attacks
- Identifying building blocks for attacks
- Countermeasures for preventing attacks
- Implementation of countermeasures
- Evaluation of countermeasures

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  - Memory addresses
  - Accurate timing
  - Multithreading
  - Shared data
  - Sensor API

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- Analyse requirements for every attack
- Results in 5 categories
  - Memory addresses
  - Accurate timing
  - Multithreading
  - Shared data
  - Sensor API
- Every attack is in at least one category

# Memory Addresses

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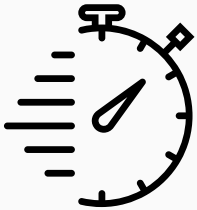
- Closest to virtual address: array indices
- Detect beginning of physical pages through high timing on page faults

# Accurate Timing



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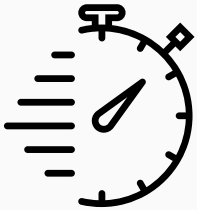

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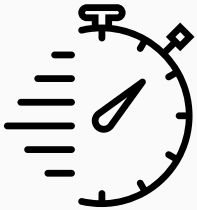

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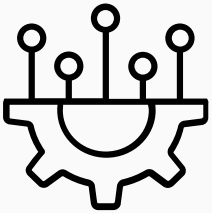
- No absolute timestamps required, only time differences
- Required accuracy varies between milliseconds and nanoseconds

# Multithreading



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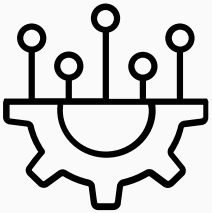

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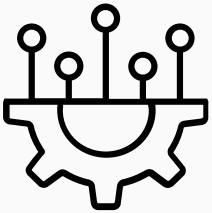

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- Enables new side-channel attacks

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- Every sensor is exploitable

# Defenses

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- Implementation is on the “microarchitectural” level of JavaScript
- If no category is usable for attacks anymore, future attacks are hard

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- Side effect: make exploits harder where addresses are required

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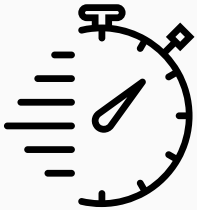

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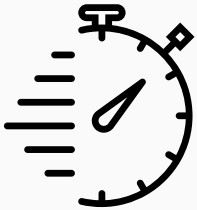

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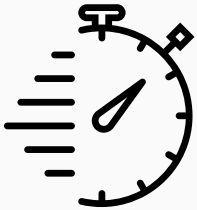

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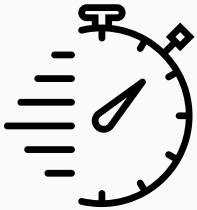

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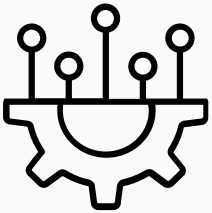
- Only rounding the timestamps is not sufficient
- Fuzzy time (Vattikonda et al.) adds random jitter
- Timestamps are still monotonic, but clock edges are randomized



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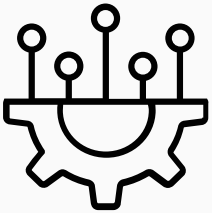

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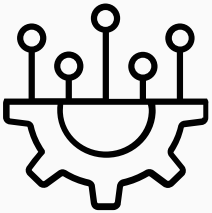

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- Prevents certain timing primitives and attacks on the event-queue latency

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- Degrades resolution of timing primitive to microseconds

- Reduce resolution and update frequency of sensors

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- To not break existing applications, sensors return constant value

# Implementation

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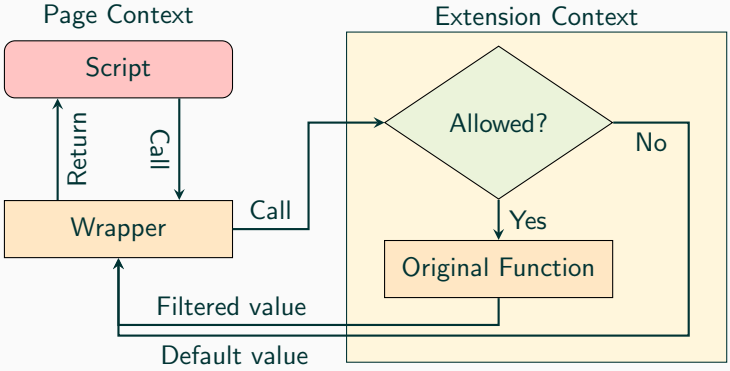
- Implementation in JavaScript → Virtual machine layering
- Proof-of-concept is implemented as browser extension

- Functions and properties are replaced by wrappers



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- Properties can be replaced by accessor properties

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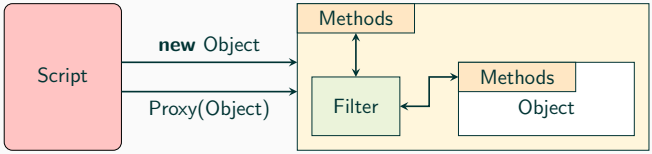

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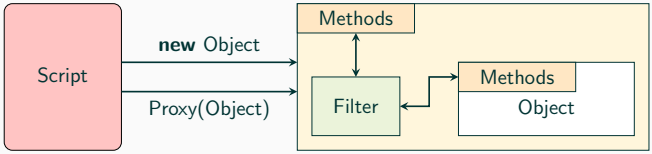


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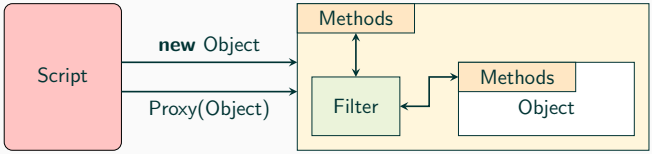


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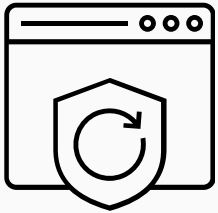
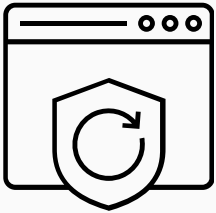
- Functions and properties can be overwritten in the proxy object

- Attacker tries to circumvent JavaScript Zero



# Self Protection



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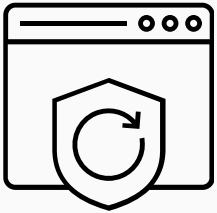

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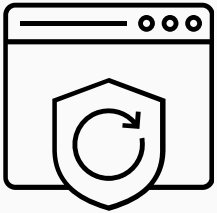

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- Prevent objects from being modified: `Object.freeze`

# Evaluation

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- Page border raise pagefault, taking significantly longer to access

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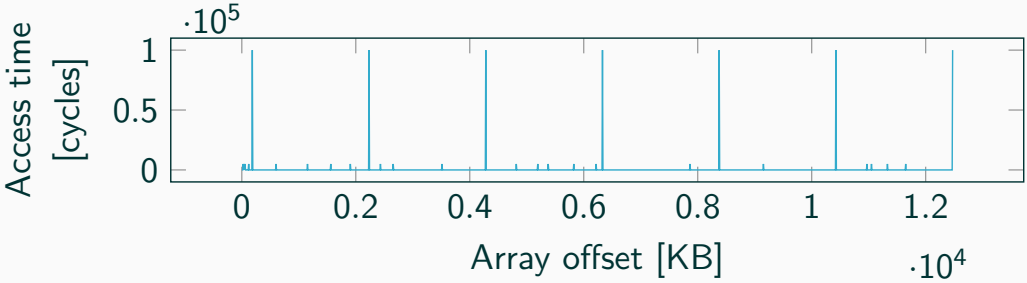
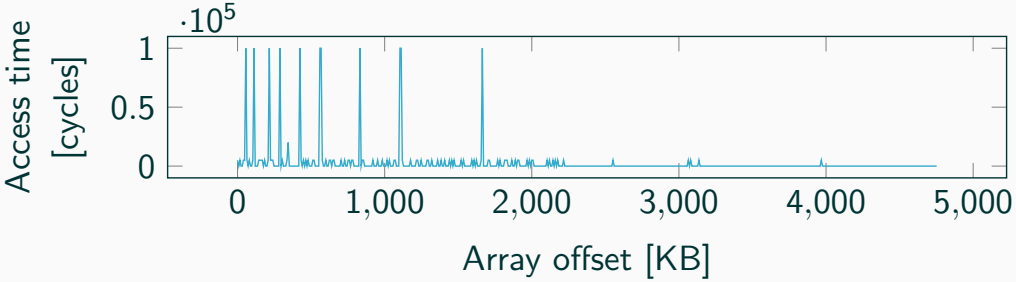
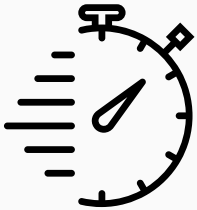


# Page Border Detection with Random Access





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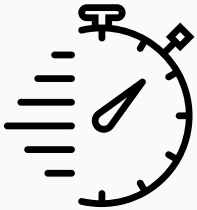

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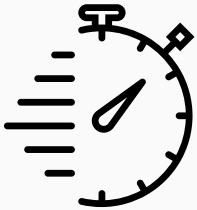

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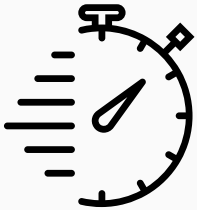

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- Endless loop which counts number of increments in time window
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- Fuzzy time prevents deterministic equally-sized time window

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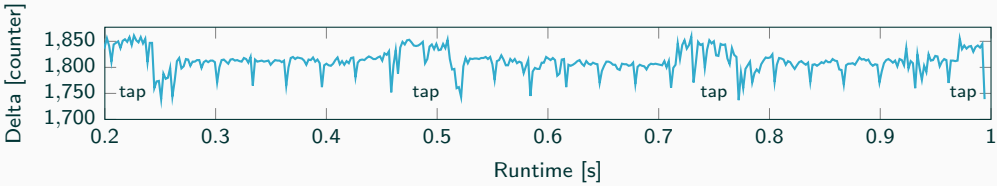
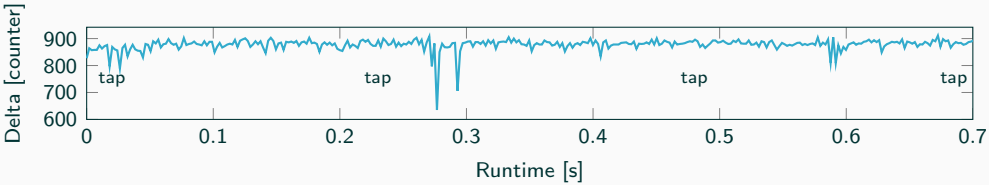
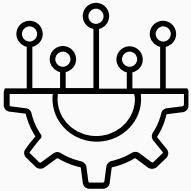


# Interrupt Detection with Fuzzy Time





- Messages between web workers are handled in the event queue

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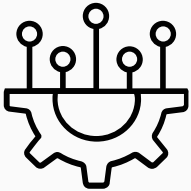

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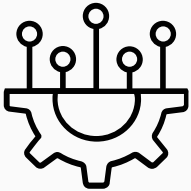

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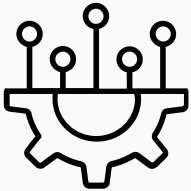

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- Latency indicates user input

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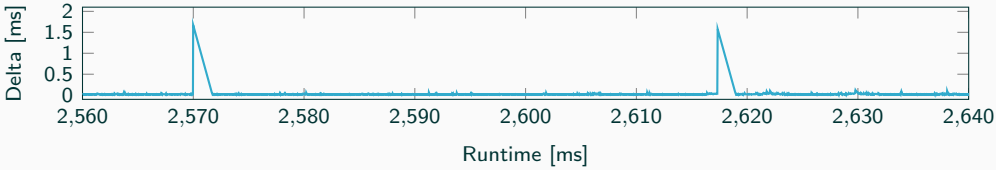
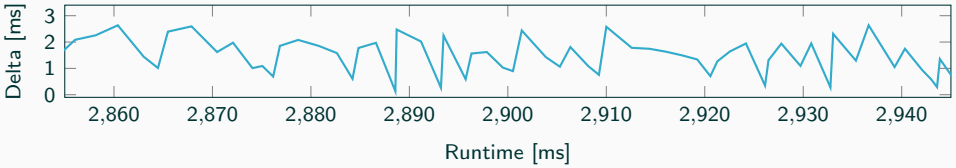


# Event Queue Spying with Message Delay



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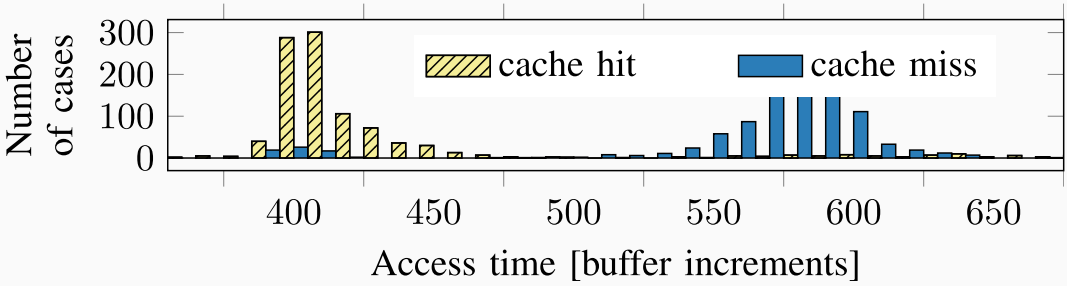
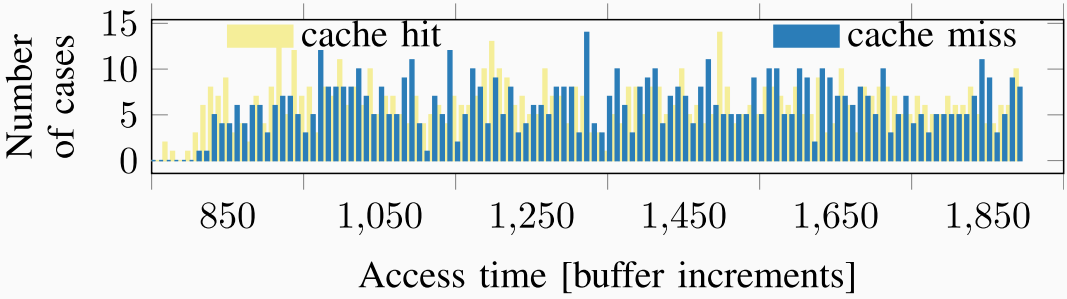
- One web worker continuously increments variable in the shared array
- Other worker uses this as a timestamp
- Adding random delay to access degrades resolution

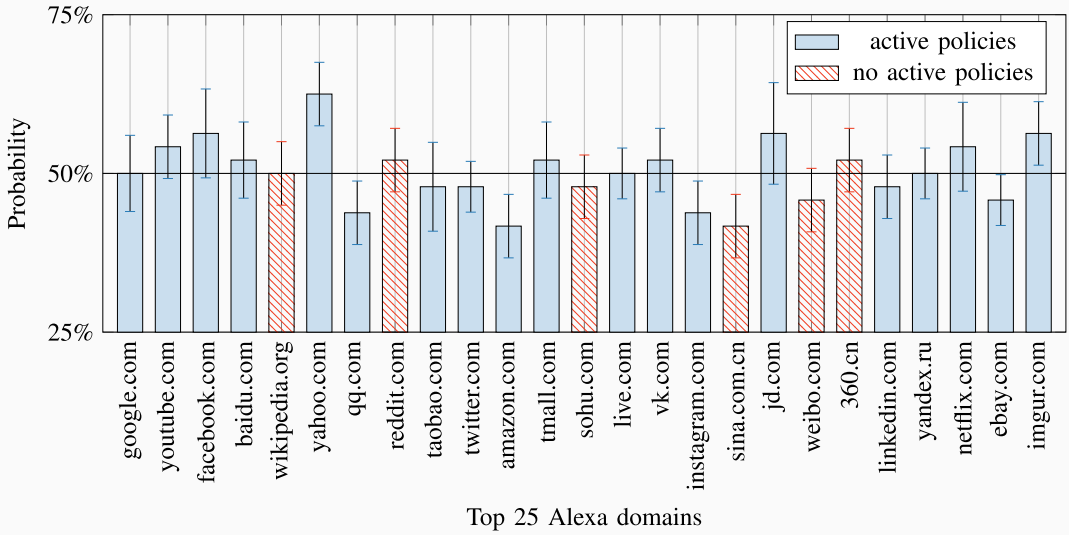

Number of cases
300
200
100
0
cache hit
cache miss
400
450
500
550
600
650
Access time [buffer increments]


Number of cases
15
10
5
0
cache hit
cache miss
850
1,050
1,250
1,450
1,650
1,850
Access time [buffer increments]

| Defense \ Prevents | Rowham-mer.js | Page Dedu-plication | DRAM Covert Channel | Anti-ASLR | Cache Eviction | Keystroke Timing | Browser |
|---|---|---|---|---|---|---|---|
| Buffer ASLR | ○ | ◐ | ○ | ● | ● | ○ | ○ |
| Array preloading | ● | ○ | ● | ○ | ○ | ○ | ○ |
| Non-deterministic array | ● | ◐ | ◐ | ● | ● | ○ | ○ |
| Array index randomization | ○ | ● | ○ | ● | ○ | ○ | ○ |
| Low-resolution timestamp | ○ | ◐ | ○ | ○ | ○ | ◐ | ◐ |
| Fuzzy time | ○ | ◐* | ○ | ○* | ○ | ●* | ●* |
| `WebWorker` polyfill | ○ | ○ | ● | ● | ● | ● | ○ |
| Message delay | ○ | ○ | ○ | ○ | ○ | ◐ | ◐ |
| Slow `SharedArrayBuffer` | ○ | ○ | ● | ◐ | ● | ○ | ○ |
| No `SharedArrayBuffer` | ○ | ○* | ● | ●* | ● | ○* | ○* |
| **Summary** | ● | ● | ● | ● | ● | ● | ● |

Symbols indicate whether a policy fully prevents an attack, (●), partly prevents and attack by making it more difficult (◐), or does not prevent an attack (○).

A star (*) indicates that all policies marked with a star must be combined to prevent an attack.


75%
50%
25%
Probability
active policies
no active policies
google.com
youtube.com
facebook.com
baidu.com
wikipedia.org
yahoo.com
qq.com
reddit.com
taobao.com
twitter.com
amazon.com
tmall.com
sohu.com
live.com
vk.com
instagram.com
sina.com.cn
jd.com
weibo.com
360.cn
linkedin.com
yandex.ru
netflix.com
ebay.com
imgur.com
Top 25 Alexa domains

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- Just rounding timers is not sufficient
- Multithreading and shared data allow to build new timers
- Microarchitectural attacks in the browser are possible at the moment
- Efficient countermeasures can be implemented in browsers
- More microarchitectural attacks in JavaScript will appear

# JavaScript zero

## REAL JavaScript AND ZERO SIDE-CHANNEL ATTACKS

Michael Schwarz, Moritz Lipp, Daniel Gruss