Fantastic Timers and Where to Find Them: High-Resolution Microarchitectural Attacks in JavaScript

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Graz University of Technology

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Outline

- Building a covert channel from a virtual machine without network access to the browser
- Reviving cache attacks in the browser
- No high-resolution timers in JavaScript
- How can we build our own timers?
- How to get a higher resolution than the native timers?

Covert channel

What is a covert channel?

- Two programs would like to communicate

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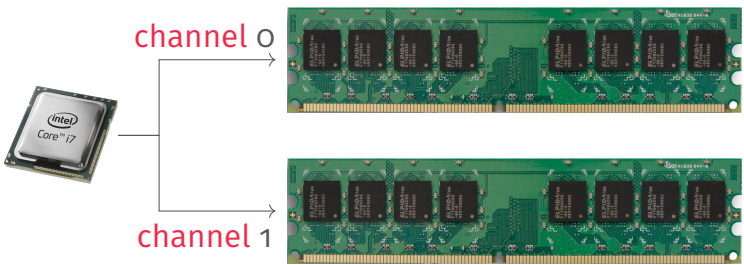
What is a covert channel?

- Two programs would like to communicate but are not allowed to do so
  - either because there is no communication channel...
  - ...or the channels are monitored and programs are stopped on communication attempts
- Use side channels to communicate

DRAM organization

DRAM organization



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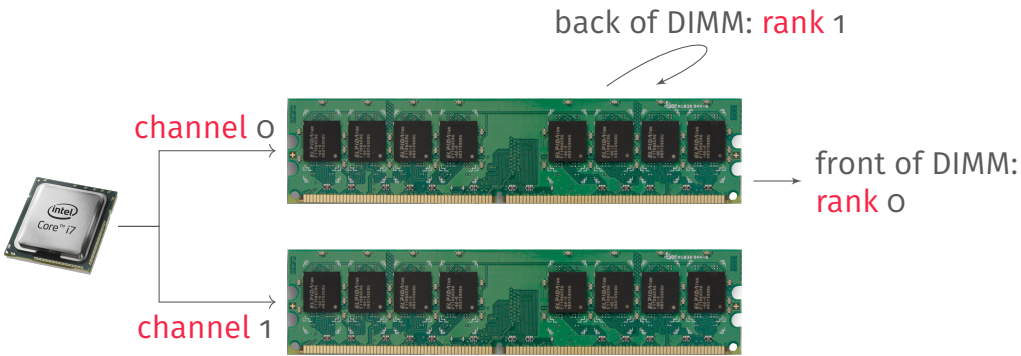

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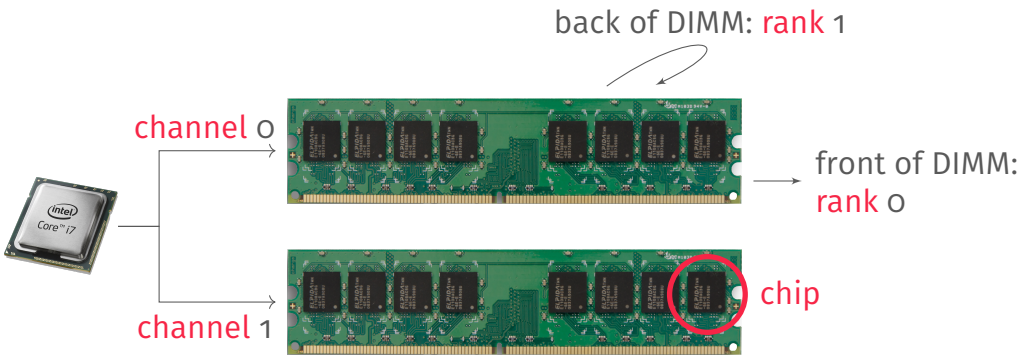
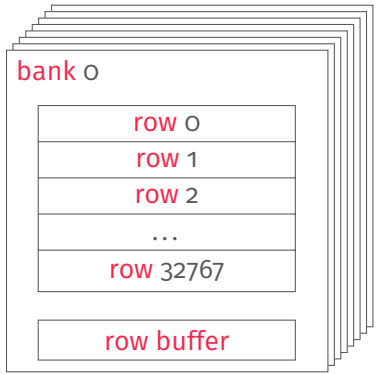


DRAM organization

chip



DRAM organization

chip

bank 0

row 0
row 1
row 2
…
row 32767

row buffer

64k cells
1 capacitor,
1 transitor each

The row buffer

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- Capacitors in cells discharge when reading them
- Bits are buffered when reading them from the cells
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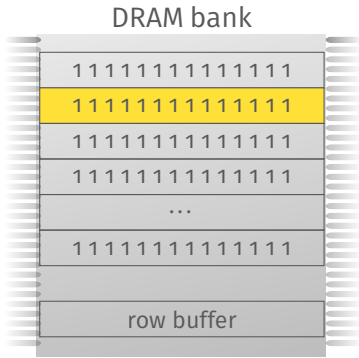
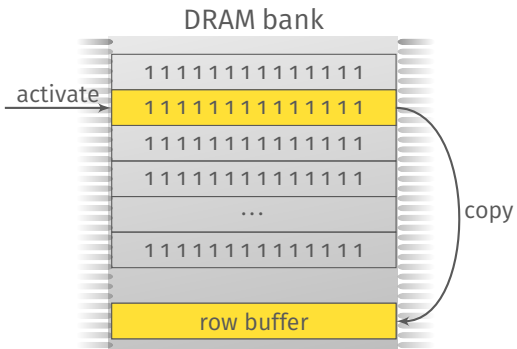
- $\rightarrow$ Row buffer

Reading from DRAM



CPU reads row 1, row buffer empty!

Reading from DRAM



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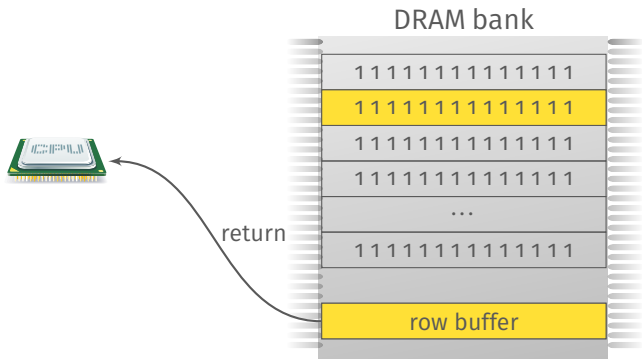

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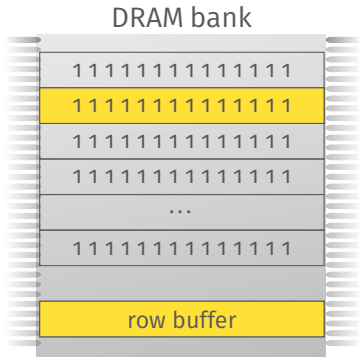
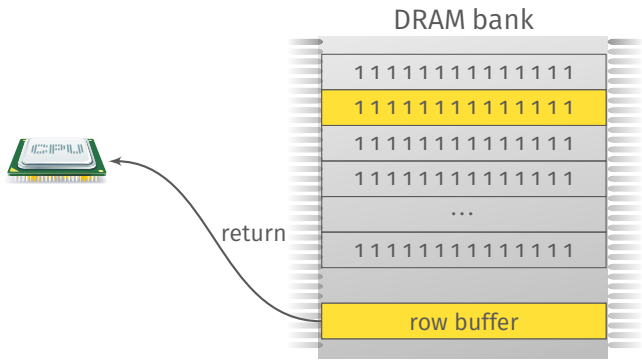


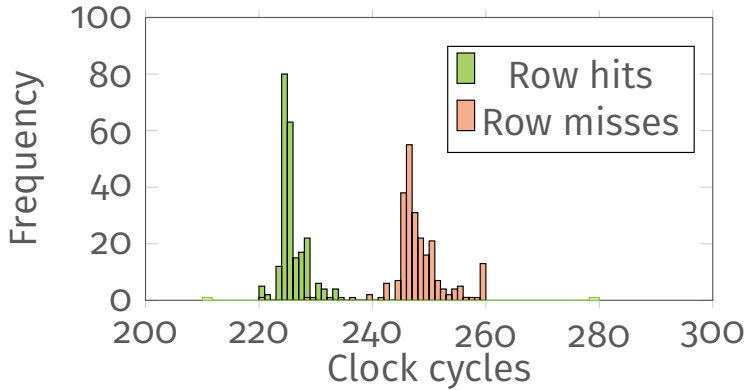
CPU reads row 1, row buffer now full!

Reading from DRAM



Less work!
Is it faster?

Timing difference



Row hits ($\approx$ 225 cycles) and row conflicts ($\approx$ 247 cycles)

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performance.now()

[...] represent times as floating-point numbers with up to microsecond precision.

— Mozilla Developer Network

...up to microsecond precision?

Firefox ≤ 36	$1 \cdot 10^{-3}$

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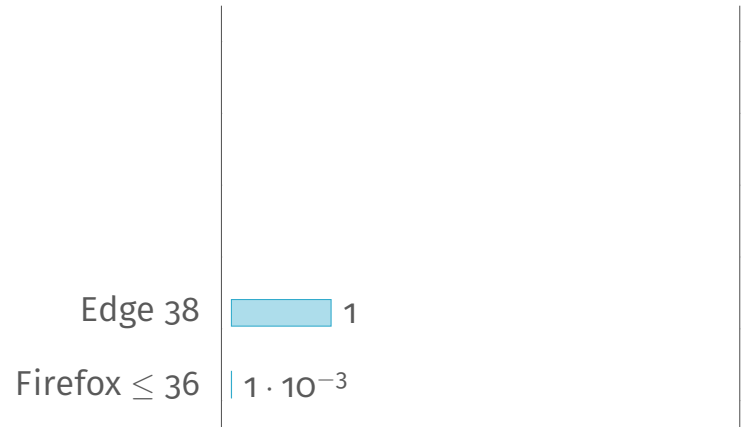

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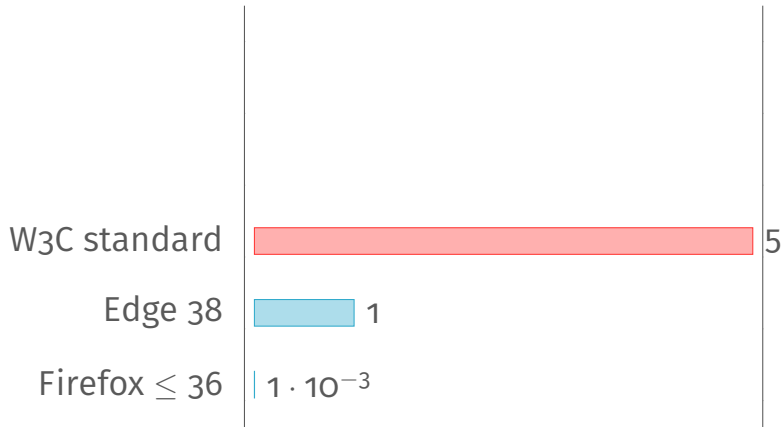

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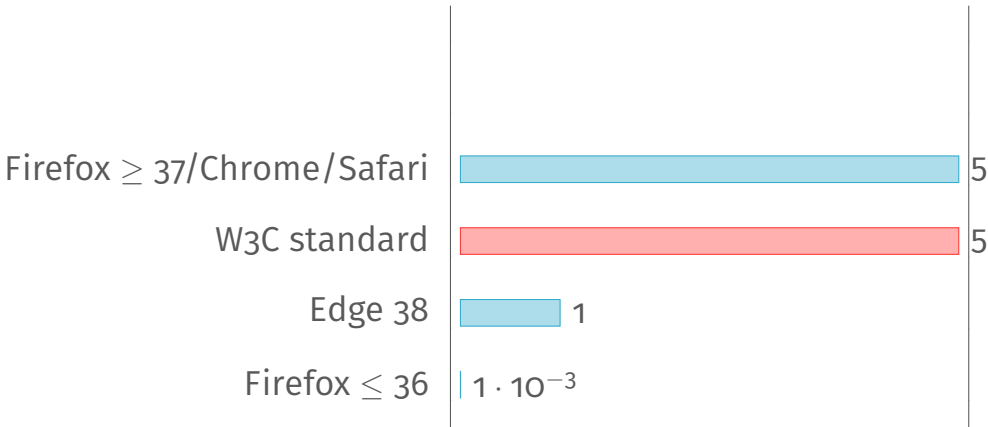

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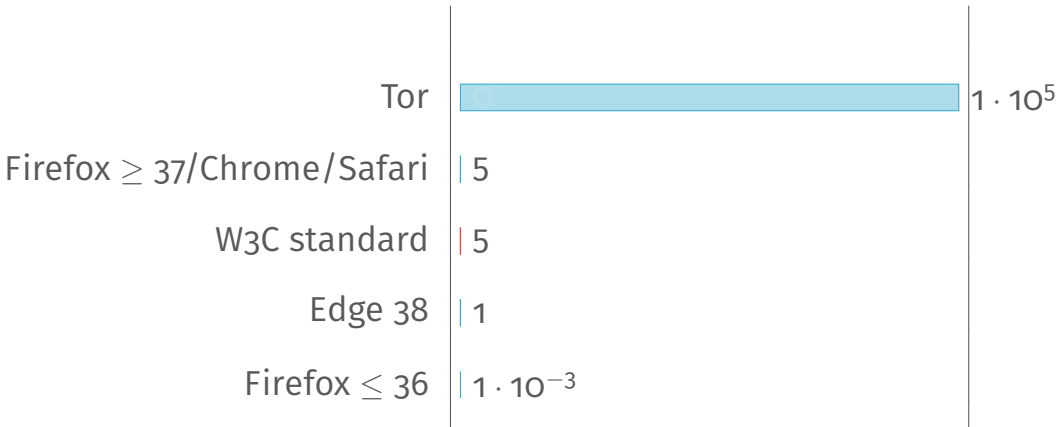

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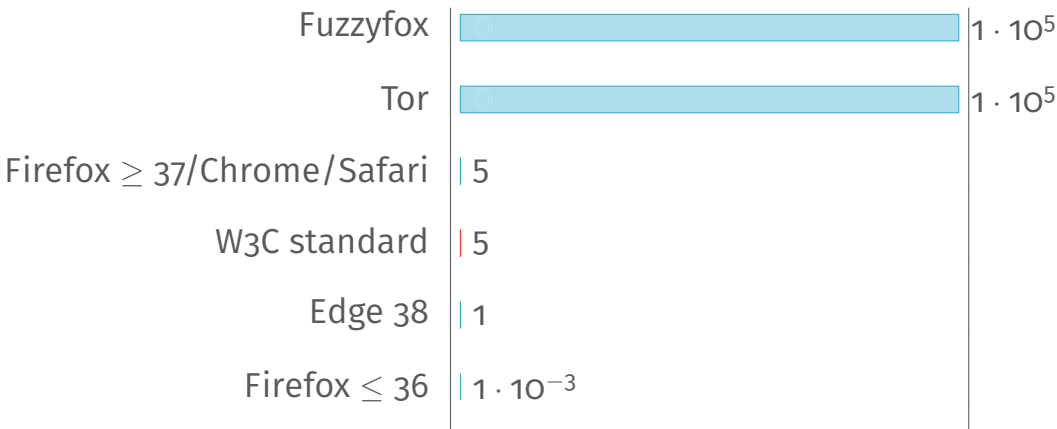

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- Build our own high-resolution timer

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- To measure with high resolution:
  - Start measurement at clock edge
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- Highly accurate: 500 ns (Firefox/Chrome), 15 µs (Tor)

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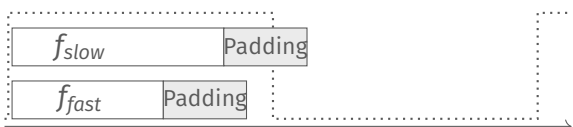

- Edge thresholding: apply padding such that the slow function crosses one more clock edge than the fast function.

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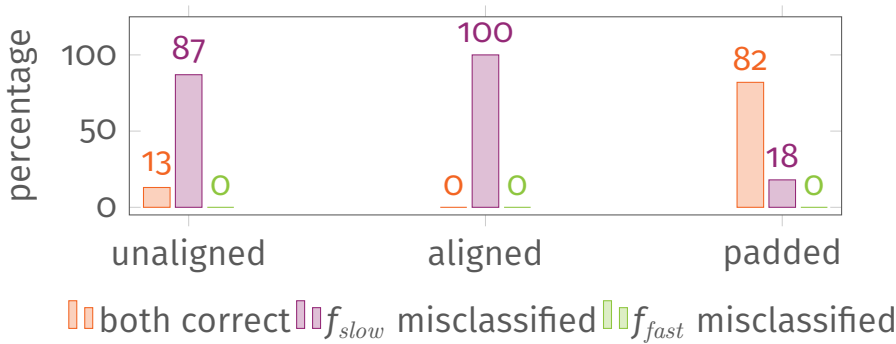

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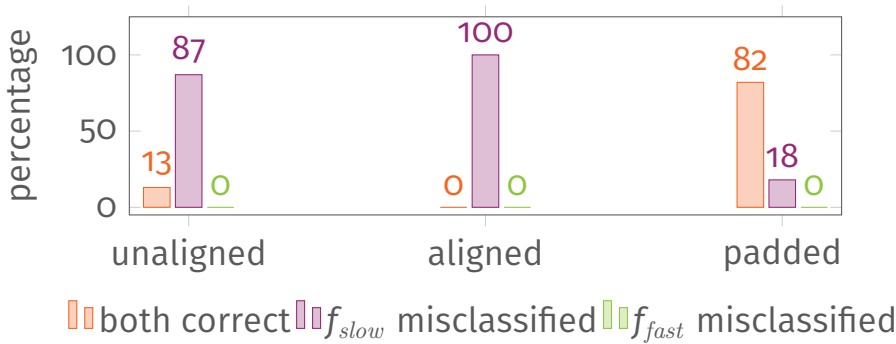

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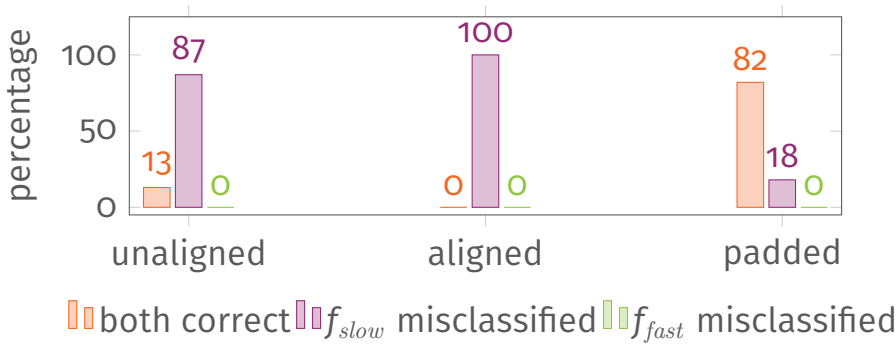

- Yields nanosecond resolution
- Firefox/Tor (2 ns), Edge (10 ns), Chrome (15 ns)

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- However, animation is limited to 60 fps $\rightarrow$ 16 ms

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- Multiple possibilities: `postMessage`, `MessageChannel` or `BroadcastChannel`
- Yields microsecond resolution (even on Tor and Fuzzyfox)

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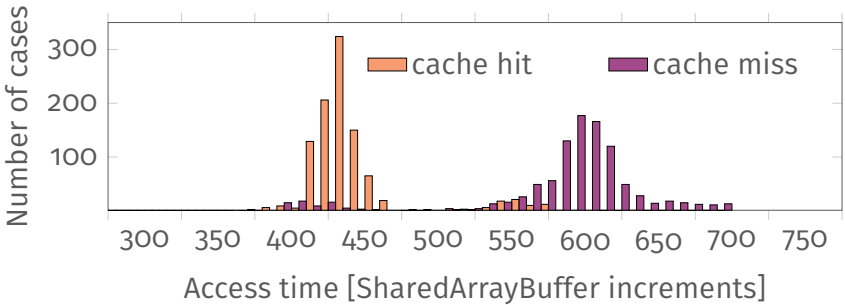
- Experimental feature to share data: `SharedArrayBuffer`
- Web worker can simultaneously read/write data
- No message passing overhead
- One dedicated worker for incrementing the shared variable
- Firefox/Fuzzyfox: 2 ns, Chrome: 15 ns
- Sufficient for microarchitectural attacks

Measuring cache timing



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- Both (native) sender inside VM and JavaScript on host select a different row inside this bank
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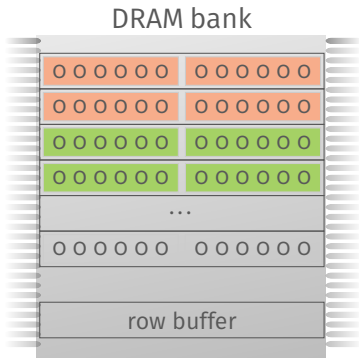
- Sender can transmit 0 by doing nothing and 1 by causing row conflict
- If measured timing was “fast” sender transmitted 0.

Transmitting data



Sender and receiver decide on one bank

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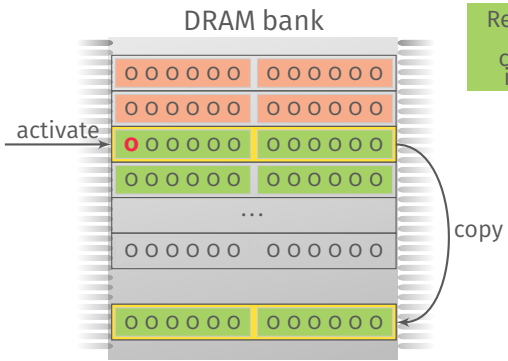

Receiver measures access time to its address

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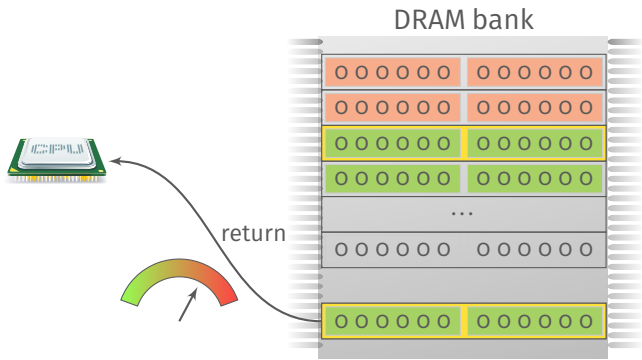

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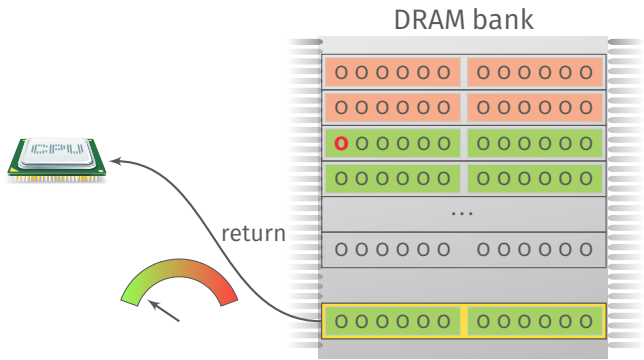

Repeated access always has low access times

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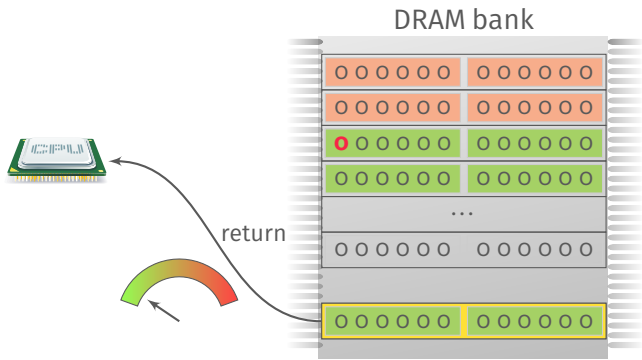

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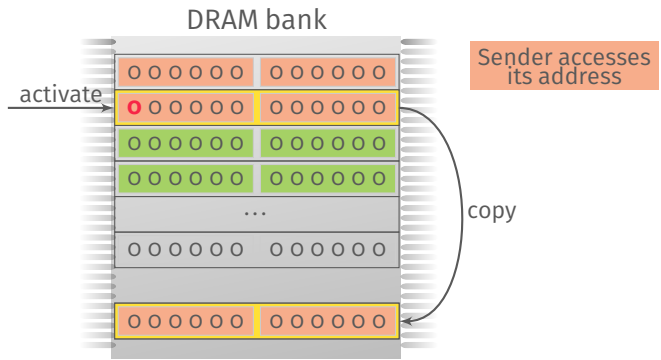

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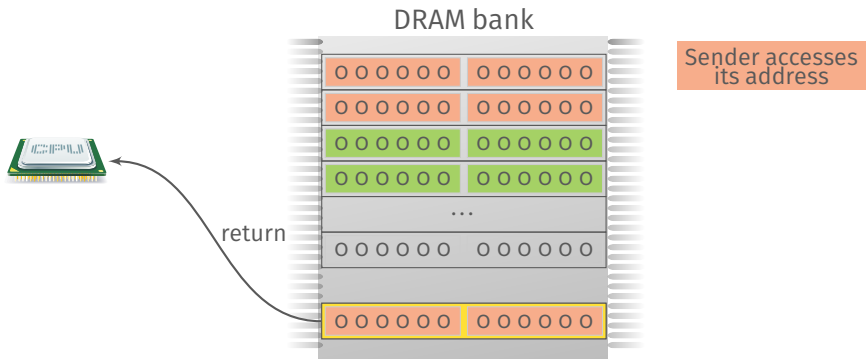

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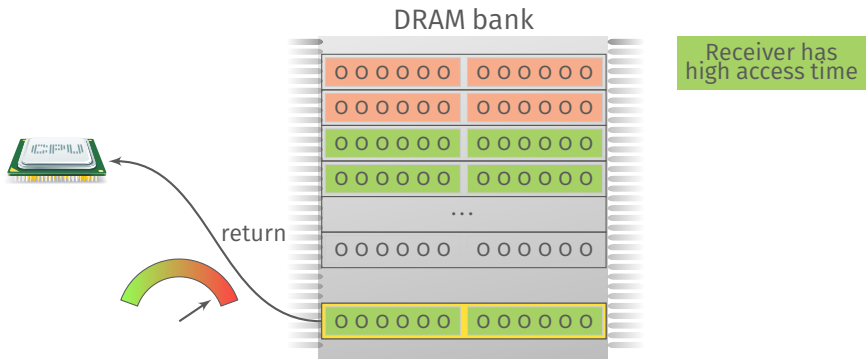
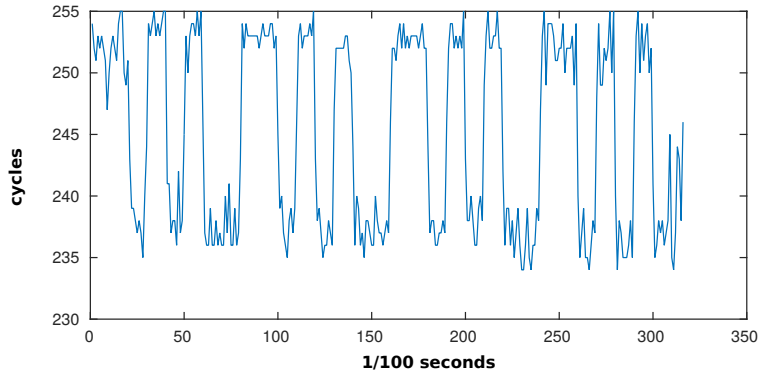


Measurement



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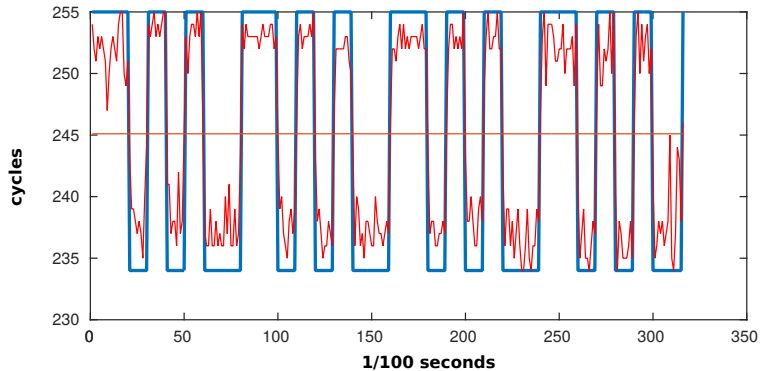

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- Data integrity is checked by an error-detection code (EDC)
- Sequence bit indicates whether it is a re-transmission or a new packet

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  - What is possible in native code? 596 kbit/s cross CPU and cross VM

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- Tor → Working on fuzzy time

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- Shared data comes with great risks
- It allows to build timers with nanosecond resolution
- Microarchitectural attacks in the browser are possible again

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FANTASTIC TIMERS AND WHERE TO FIND THEM

HIGH-RESOLUTION MICROARCHITECTURAL ATTACKS IN JAVASCRIPT