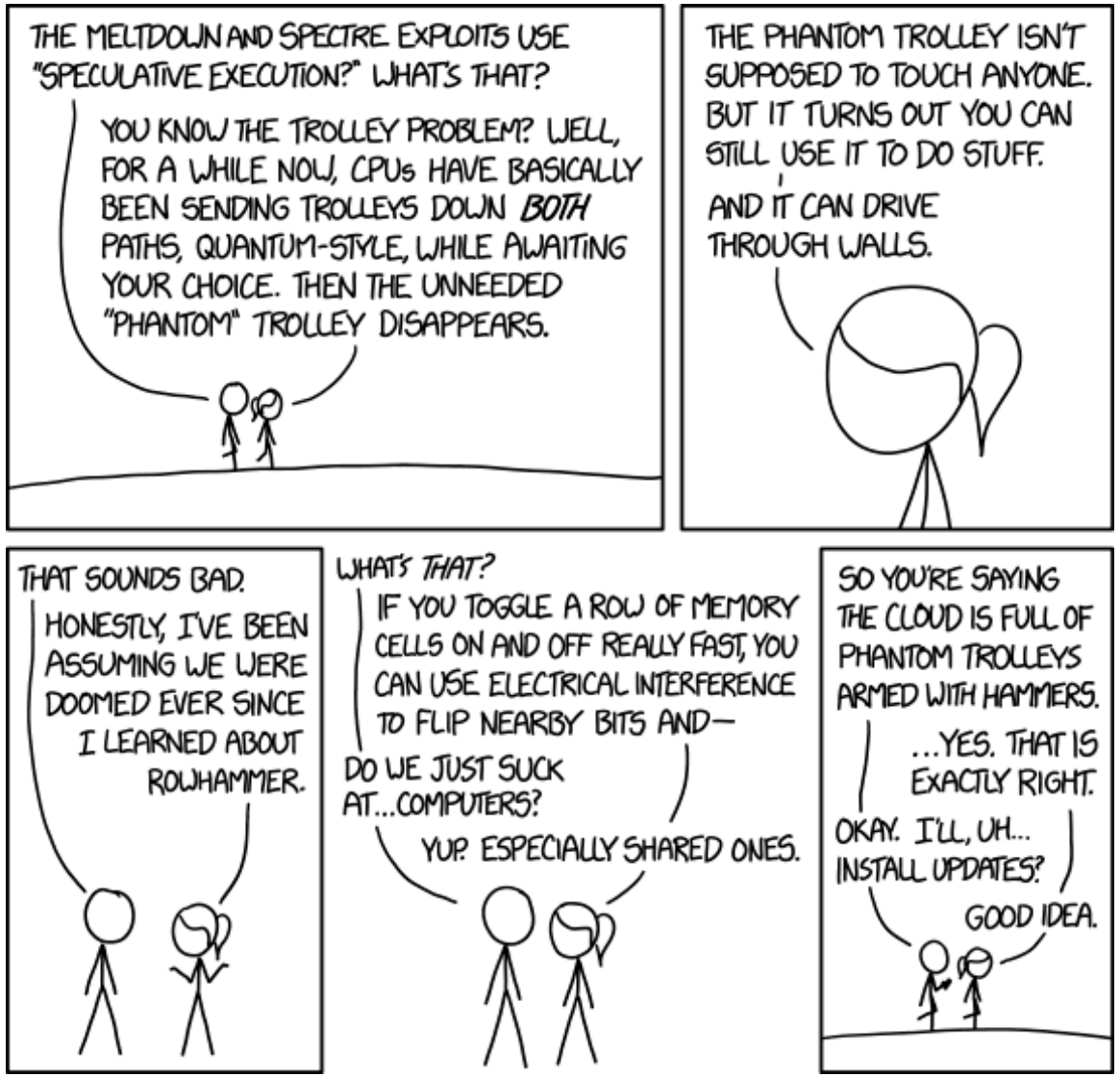

https://xkcd.com/1938/

Side Channels

System Security (CM0625, CM0631) 2022-23
Università Ca' Foscari Venezia

Matteo Busi
matteo.busi@unive.it
https://matteobusi.github.io/

An appetizer [Van Bulck et al., 2018]

https://youtu.be/8ZF6kX6z7pM

[Van Bulck et al., 2018] Van Bulck et al. "Foreshadow: Extracting the Keys to the Intel SGX Kingdom with Transient Out-of-Order Execution." *USENIX Security 2018*.

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What's all this jargon?

We'll spend the next 1.5 hours trying to decode the jargon

Computer Architecture 101

Remember how CPUs work?

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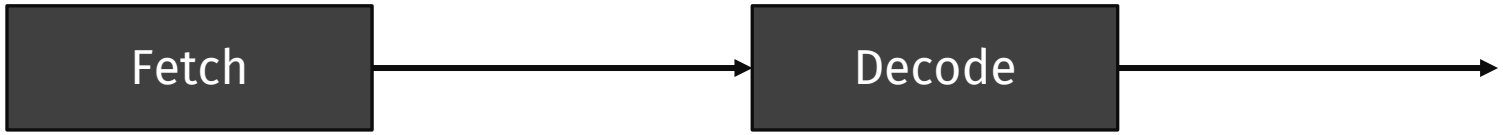

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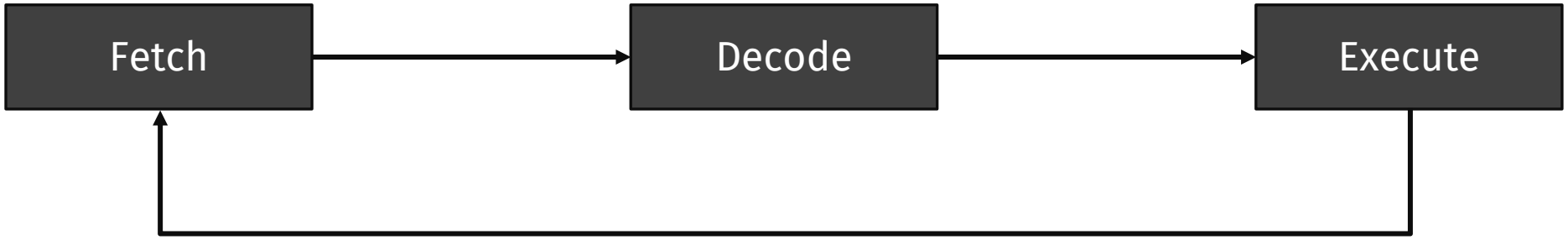

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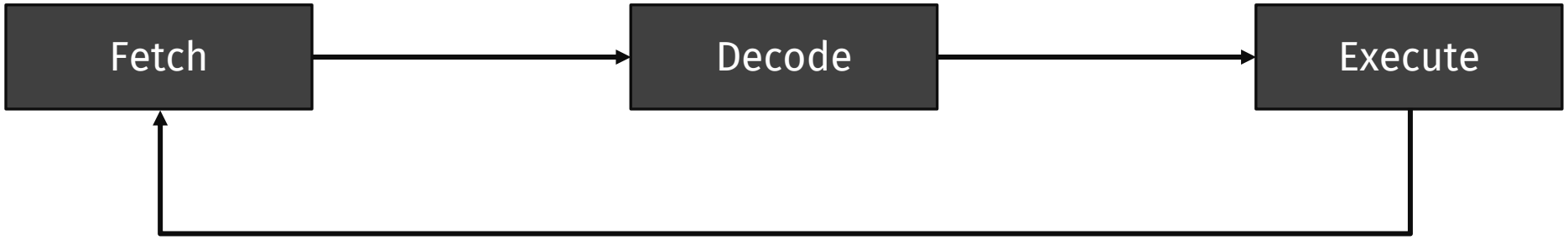

Problem: not very efficient (≥1 cycle per stage)

How to make processors faster?

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  - We can reach about 4 GHz
  - **Very good**, but ~2004 we reached the peak
  - Also: power-consumption issues, too much heat, …
- People started thinking about alternatives!
  - **Idea:** make the avg case faster
  - **Solutions:** caches, speculation, multi-core, multi-thread, …

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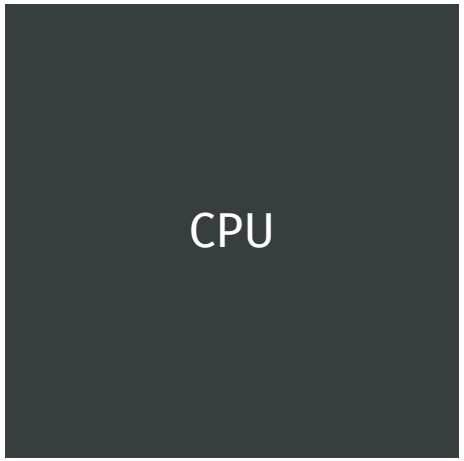

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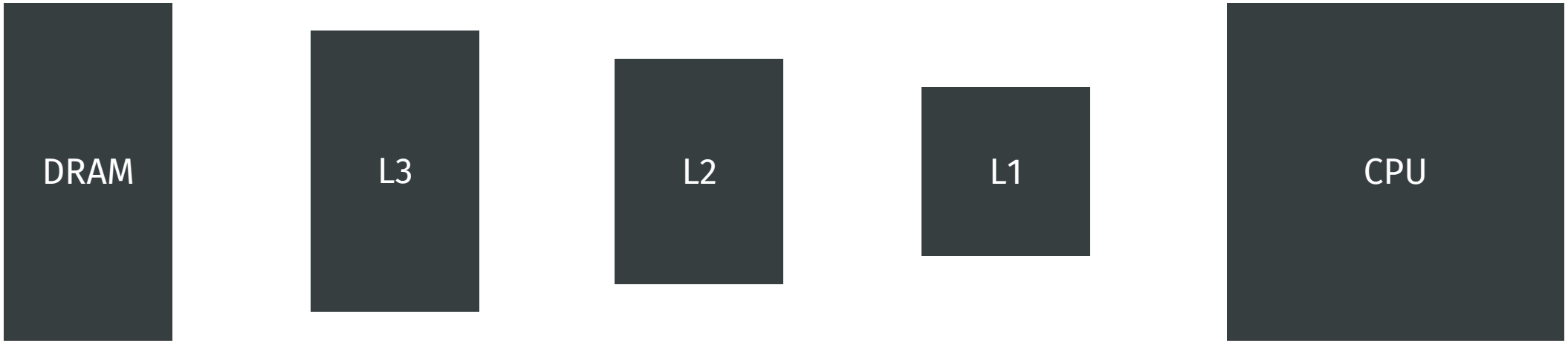

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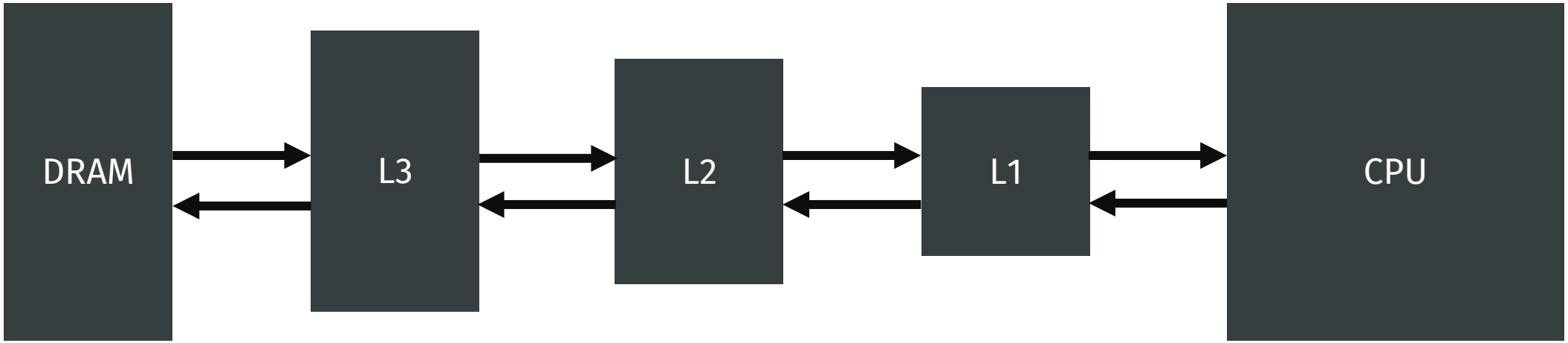

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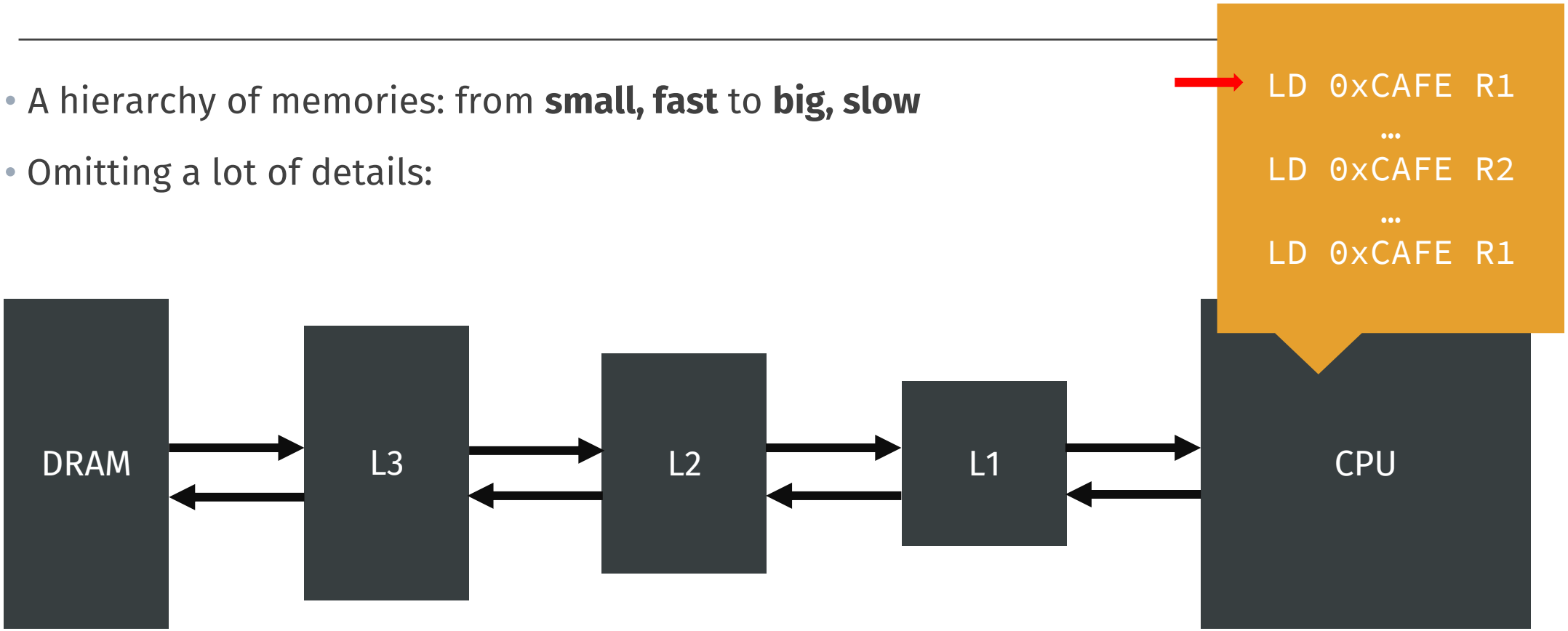

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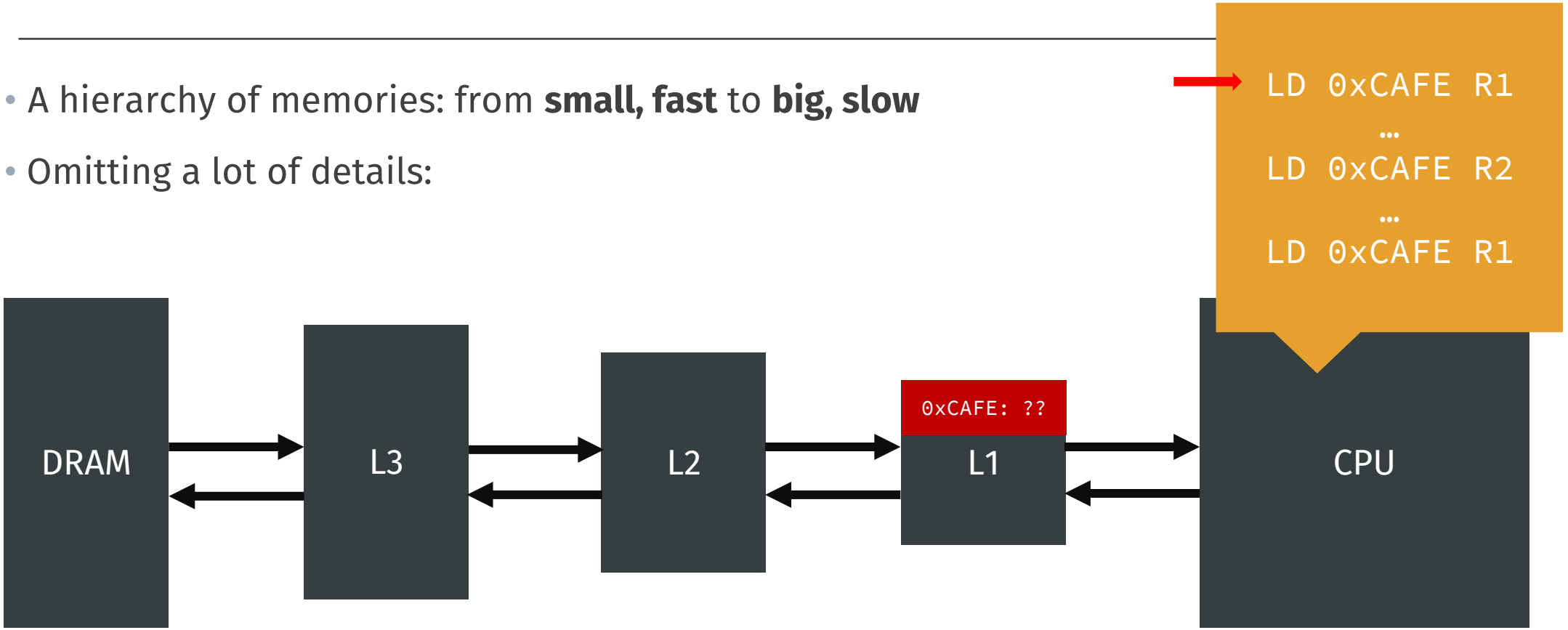

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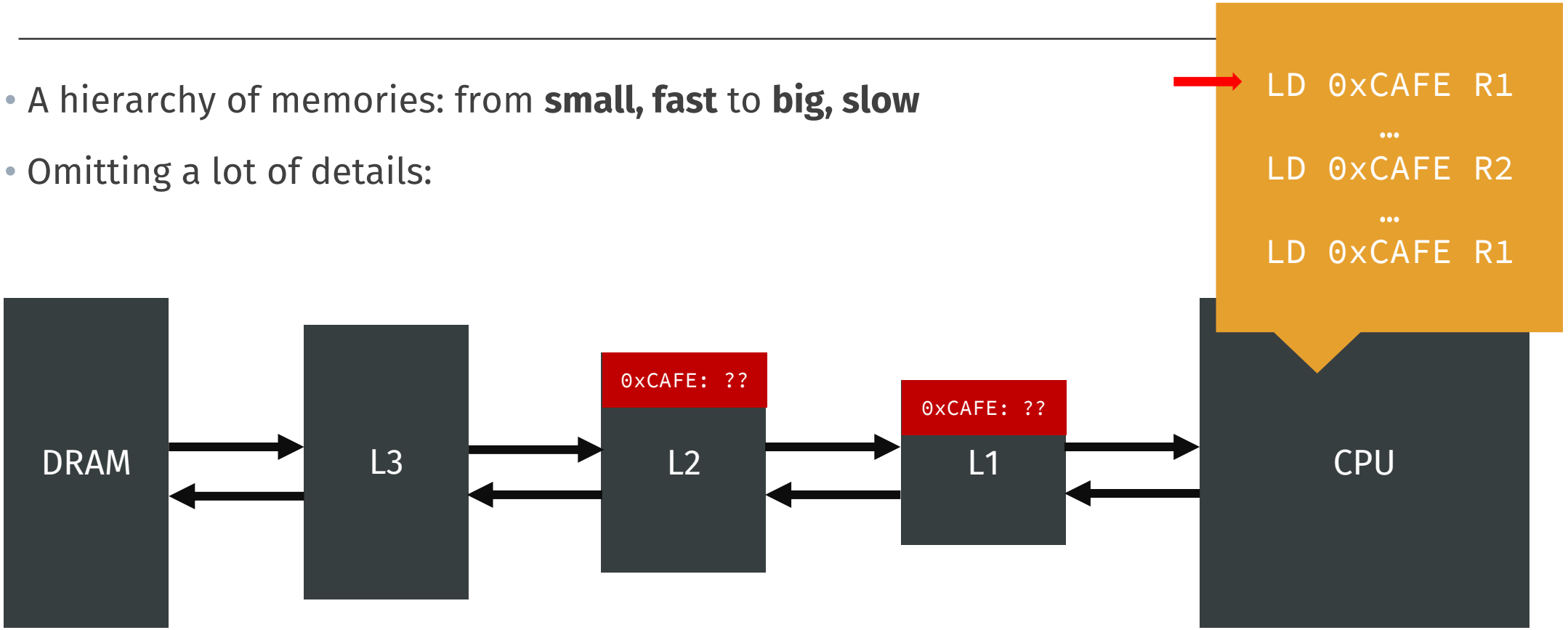

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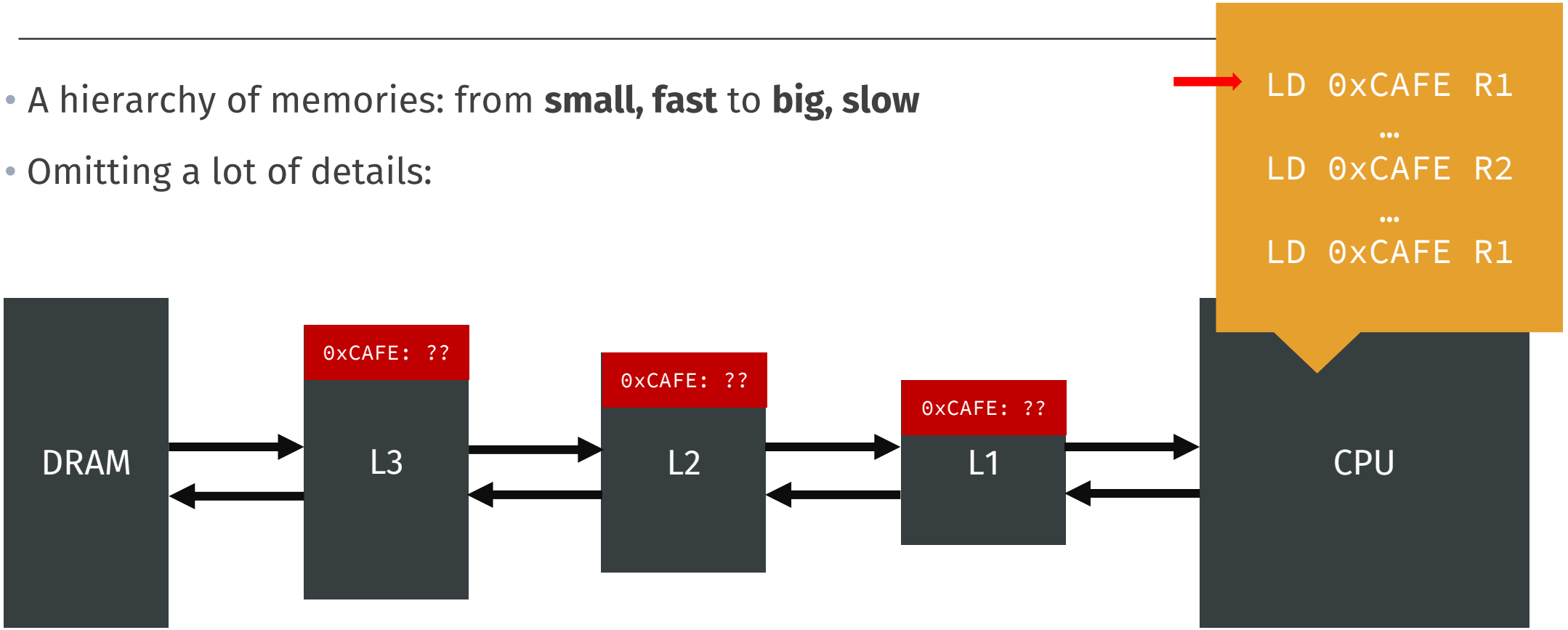

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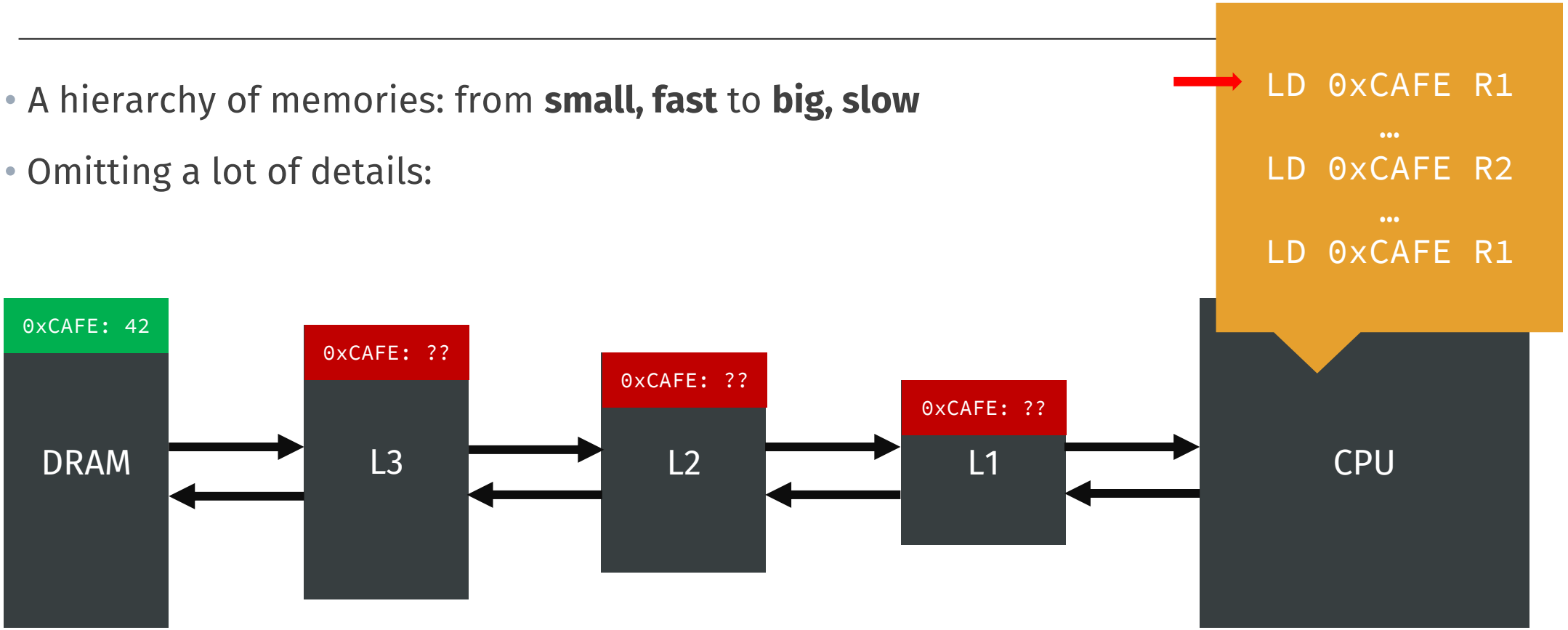

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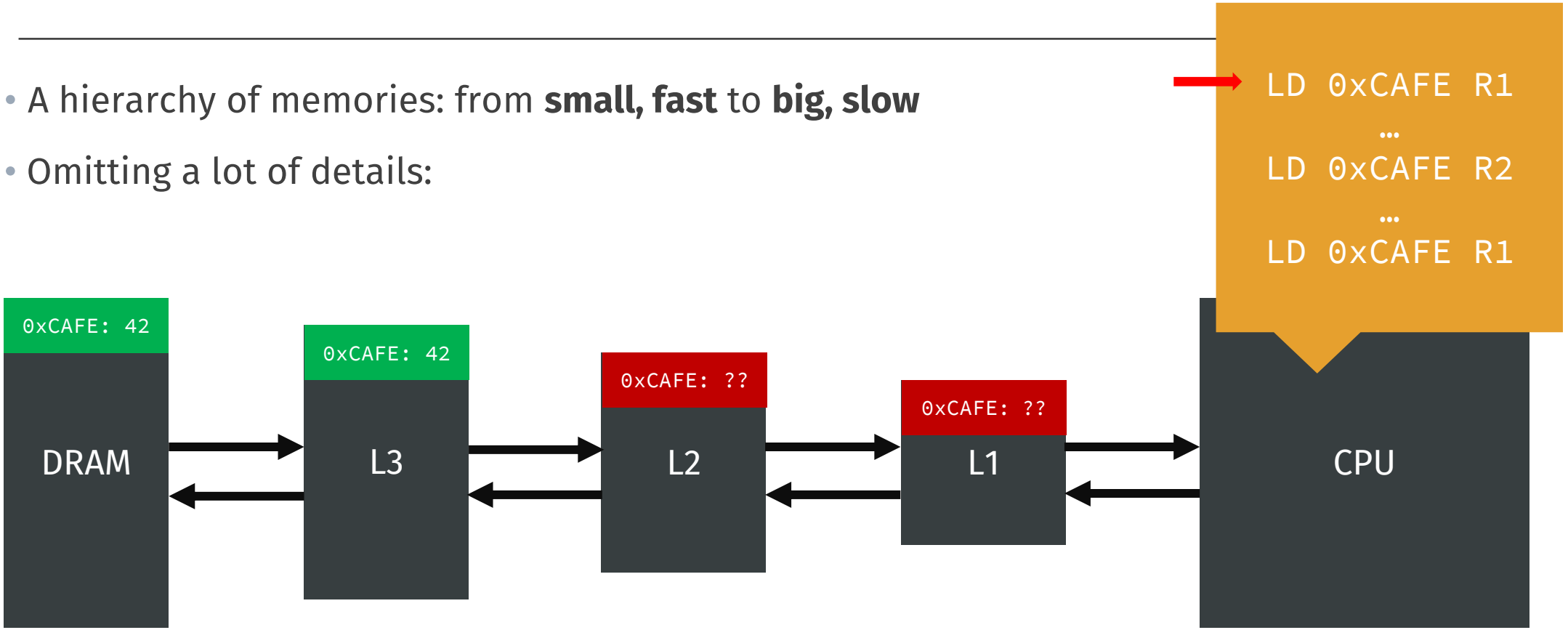

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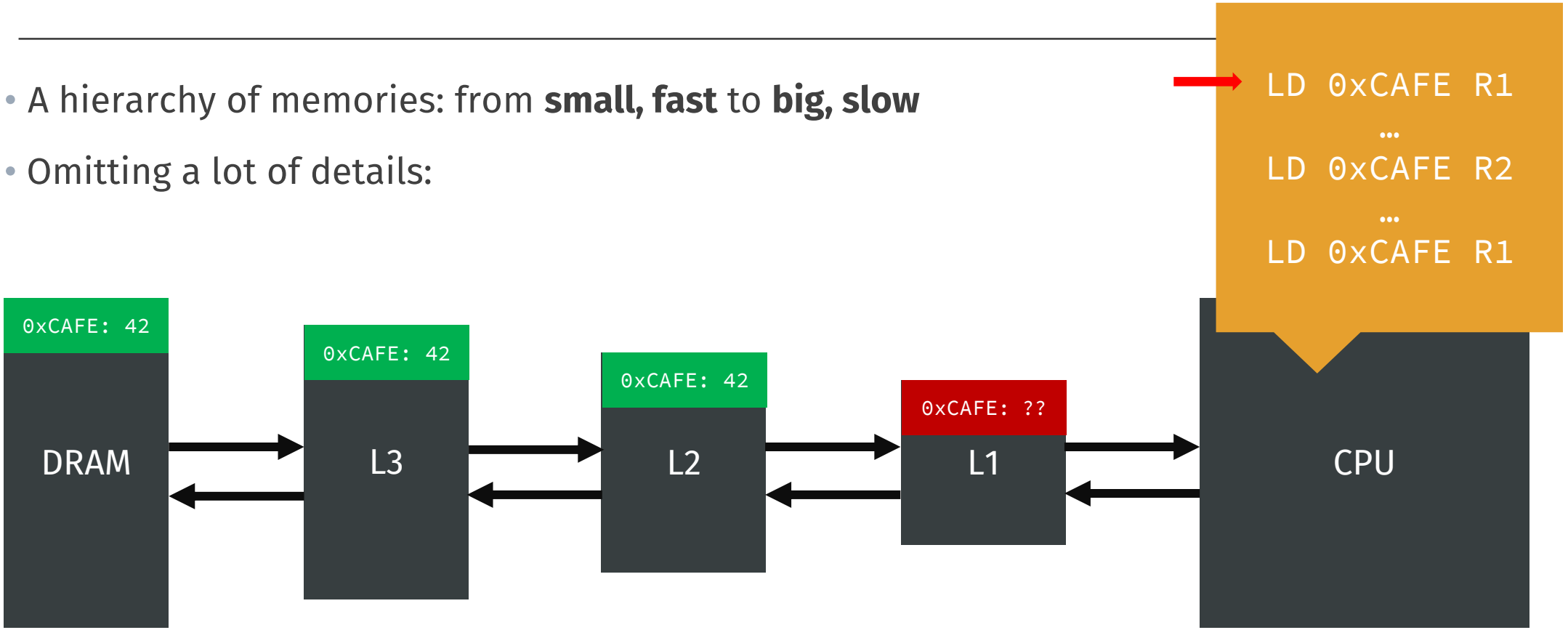

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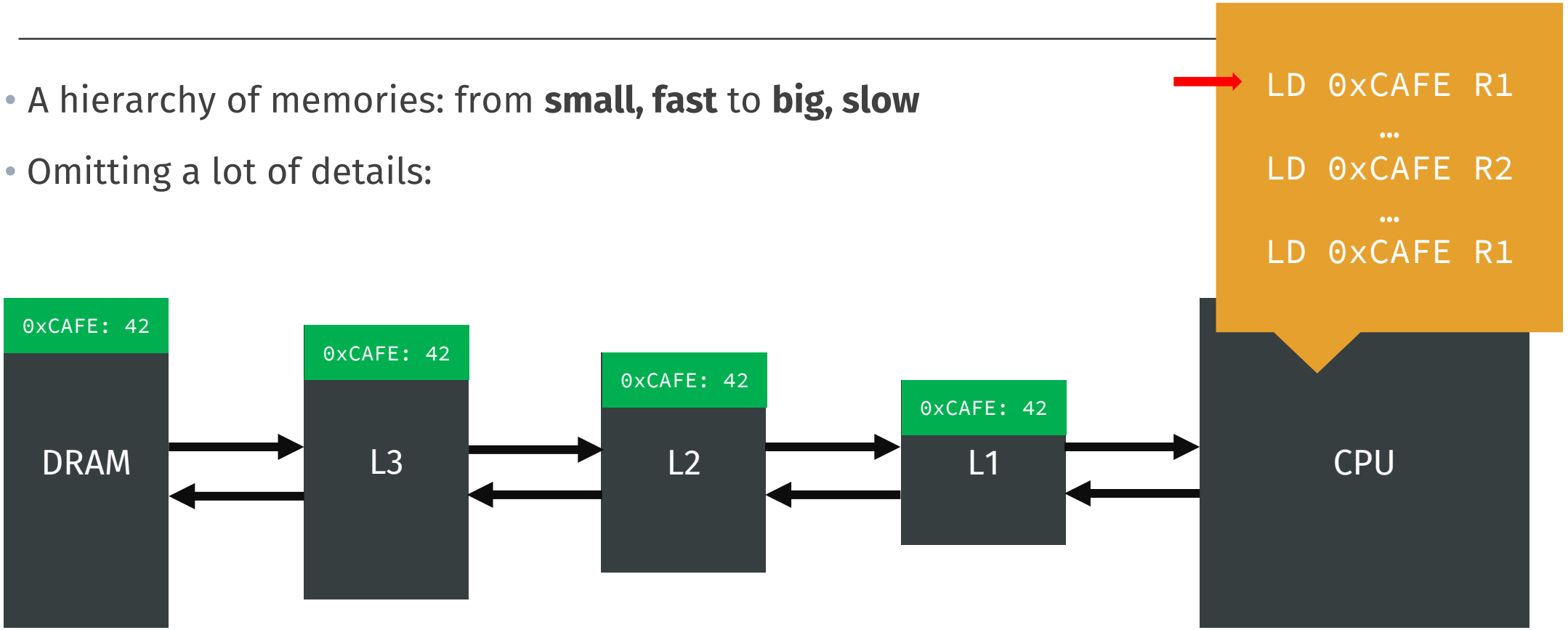

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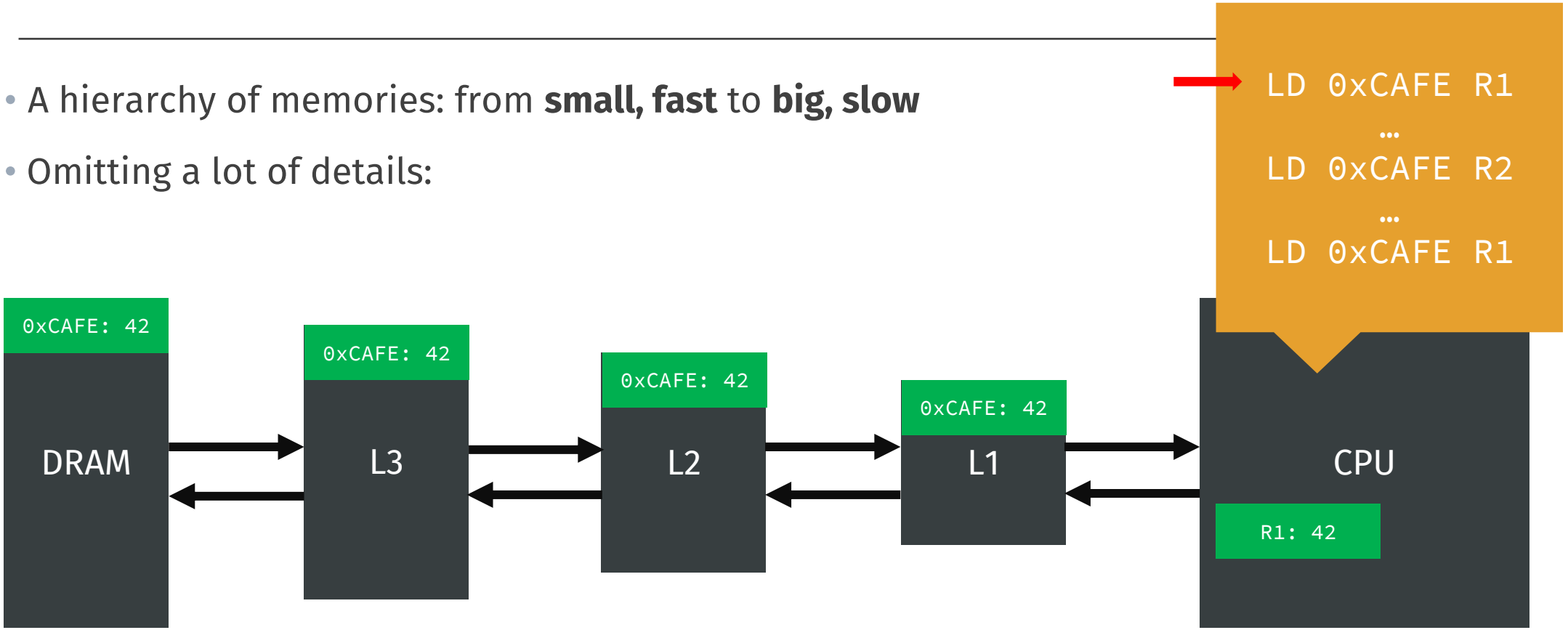

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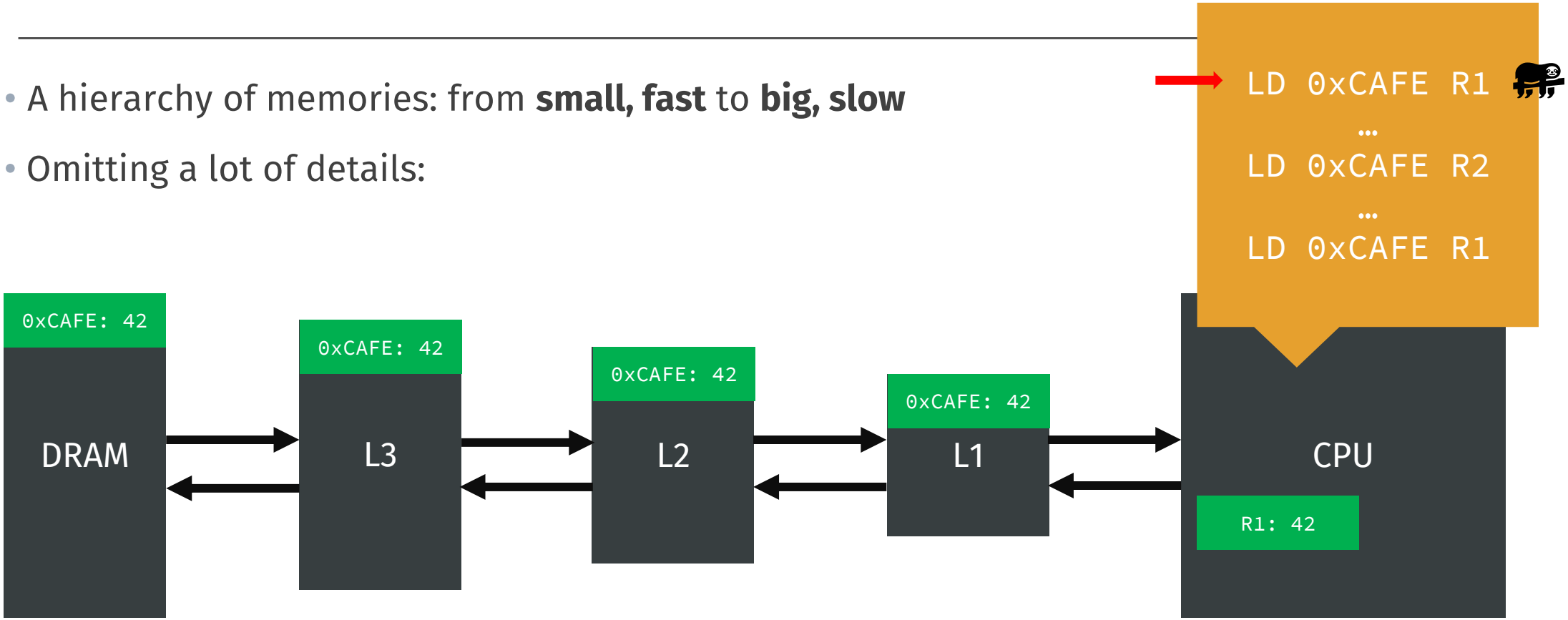

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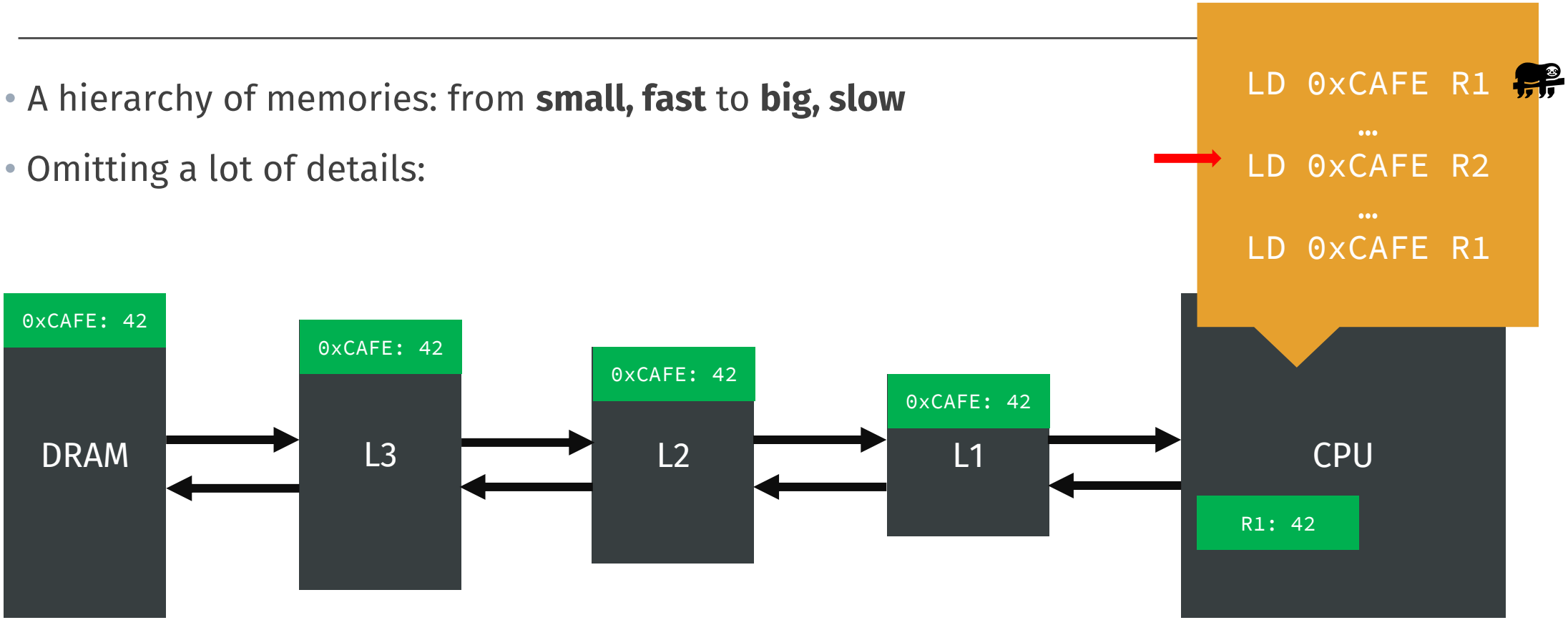

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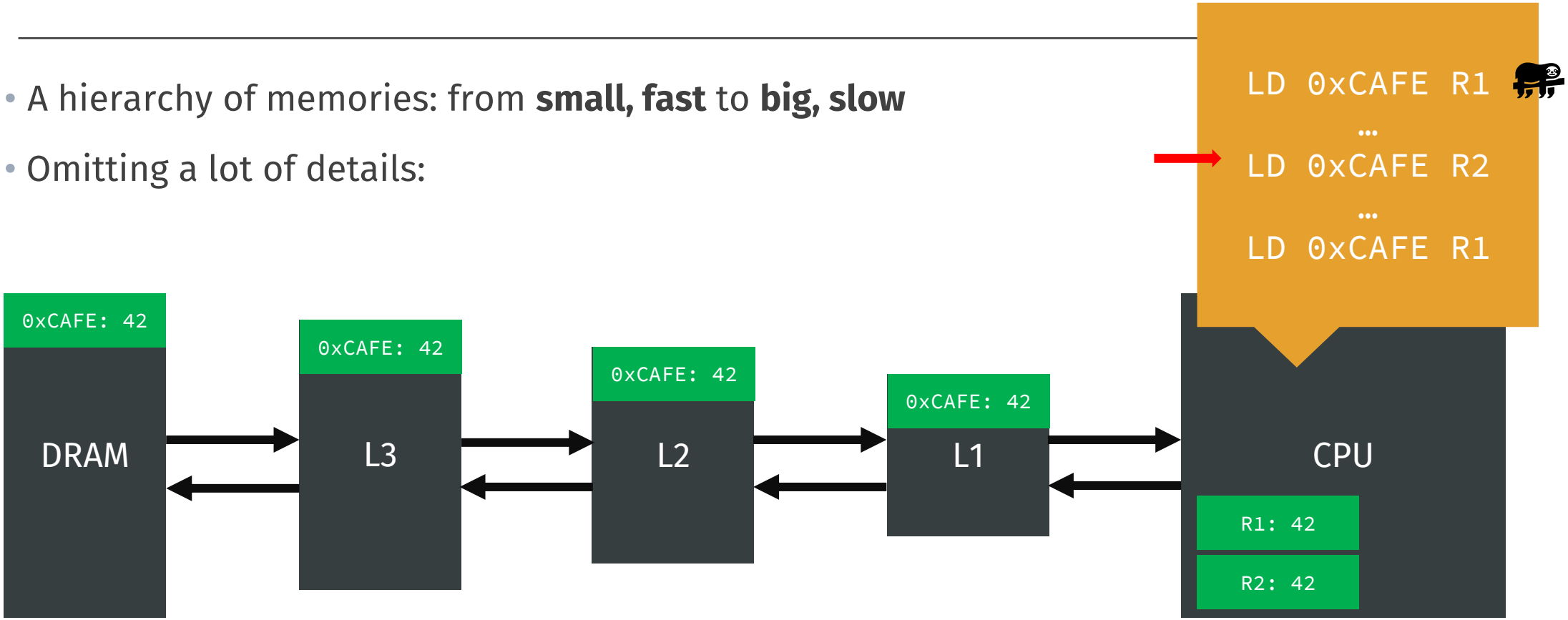

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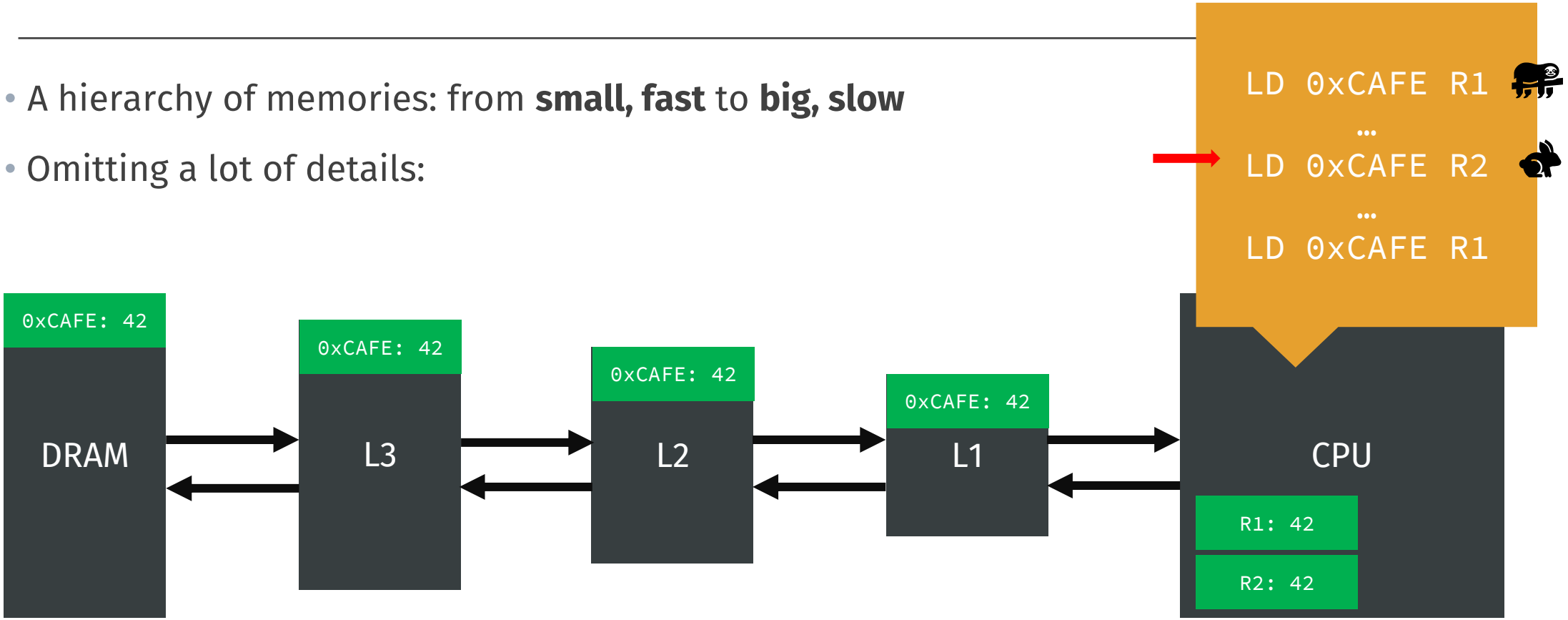

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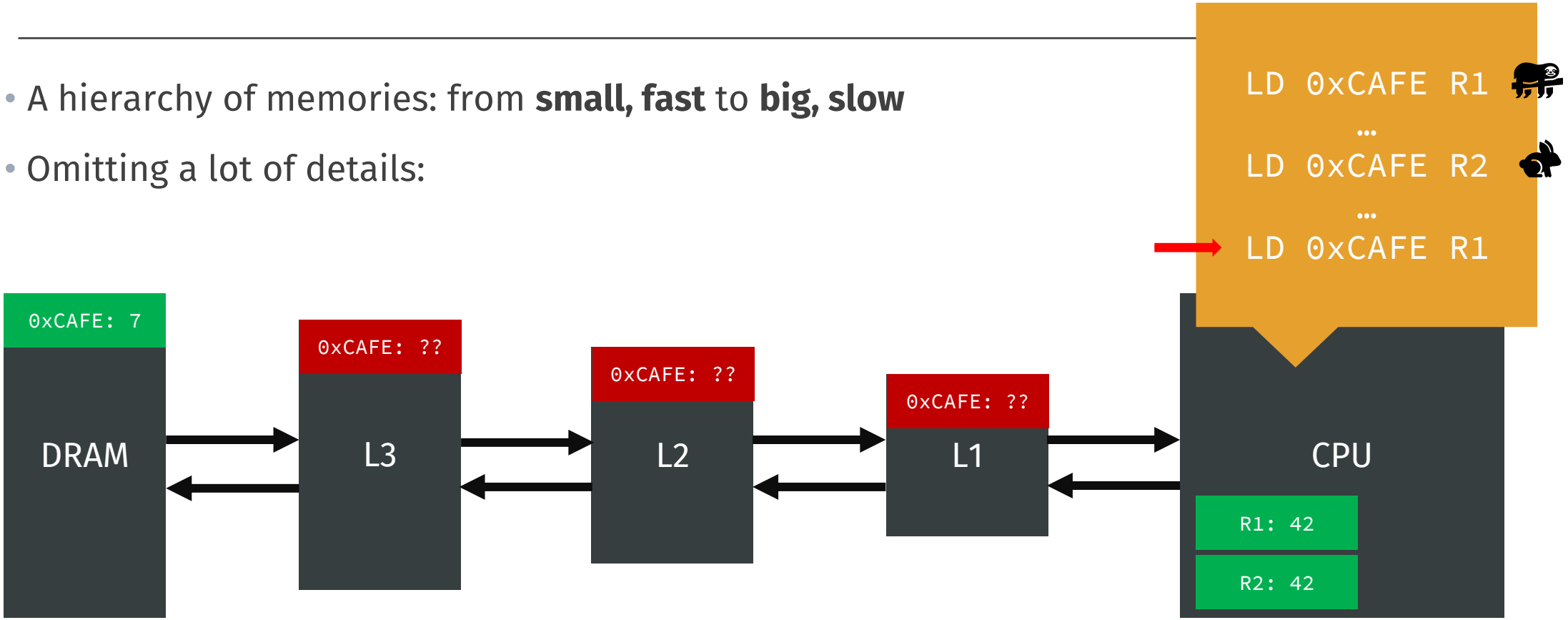

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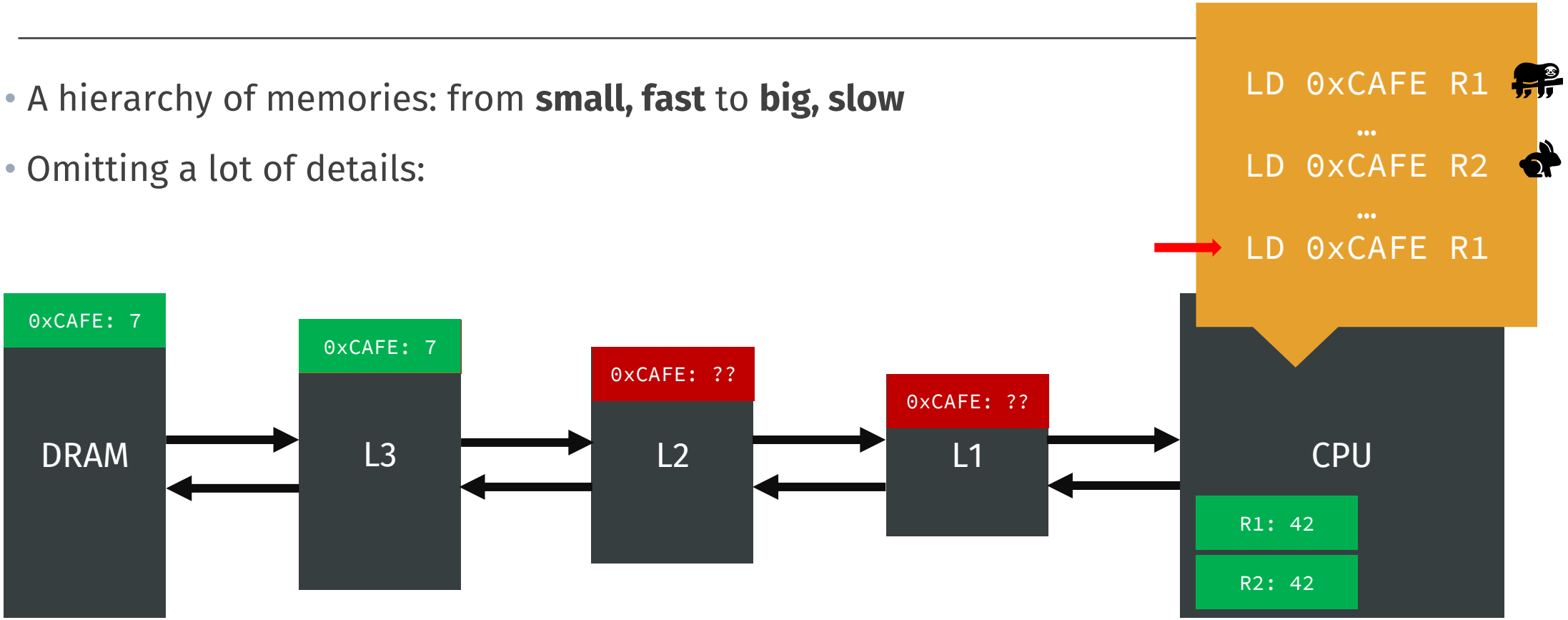

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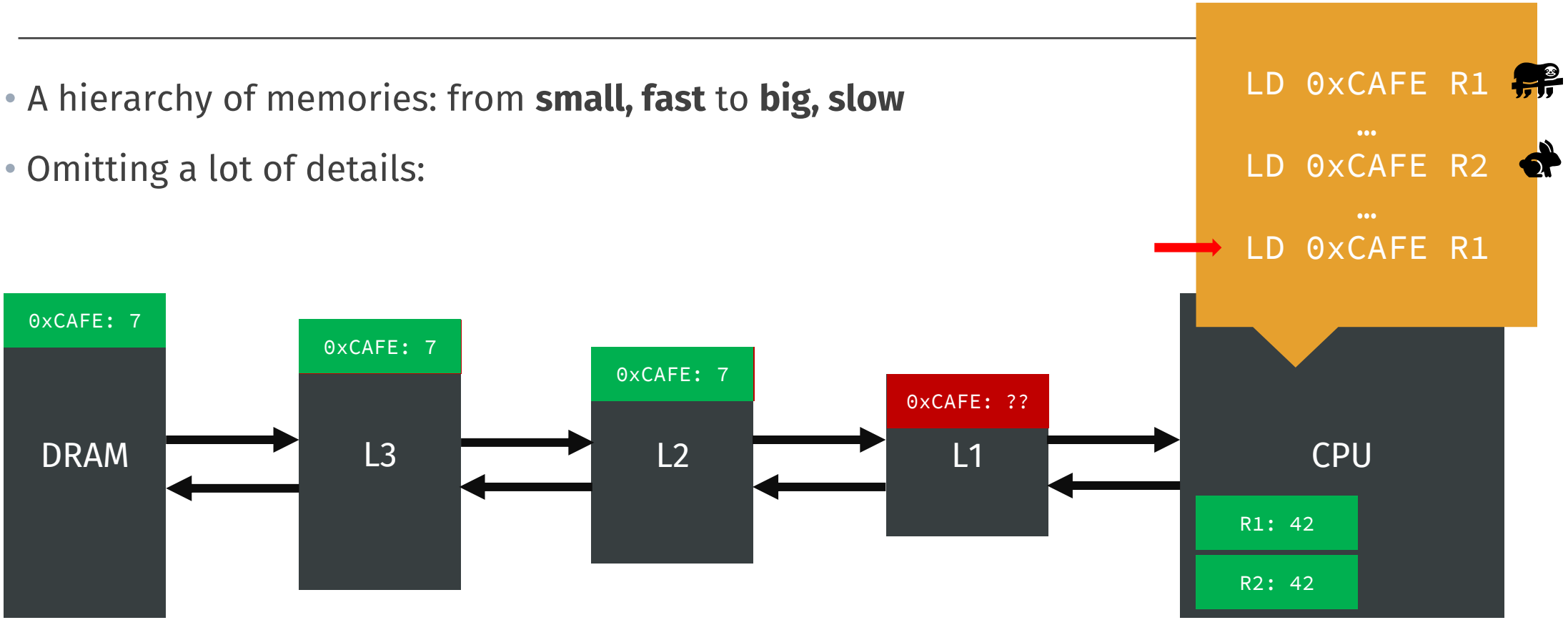

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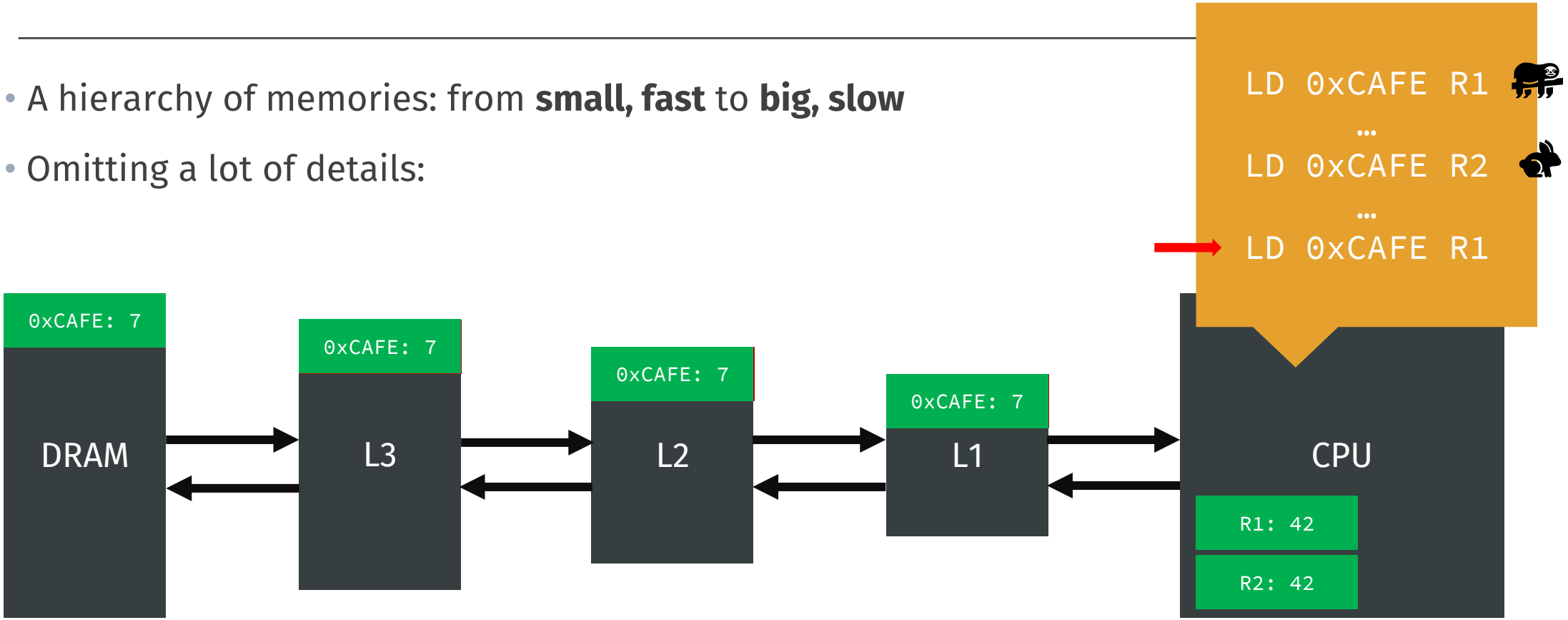

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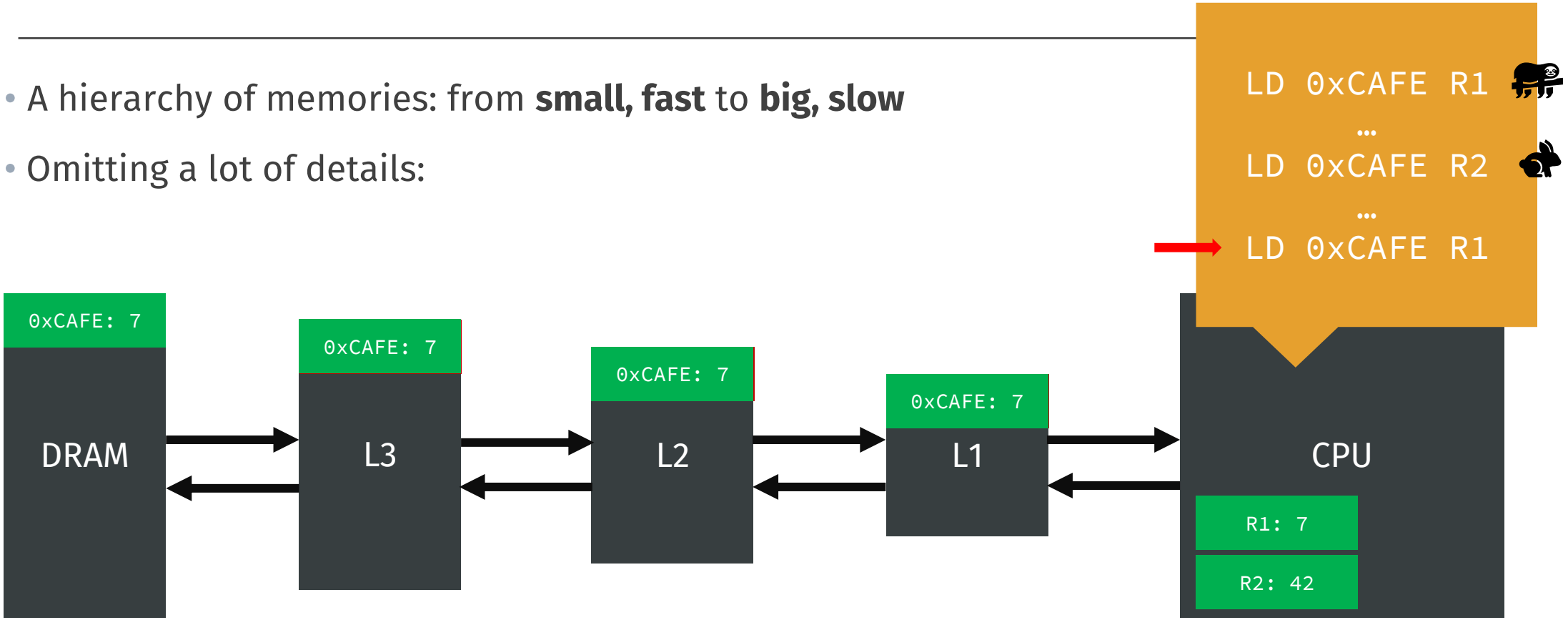

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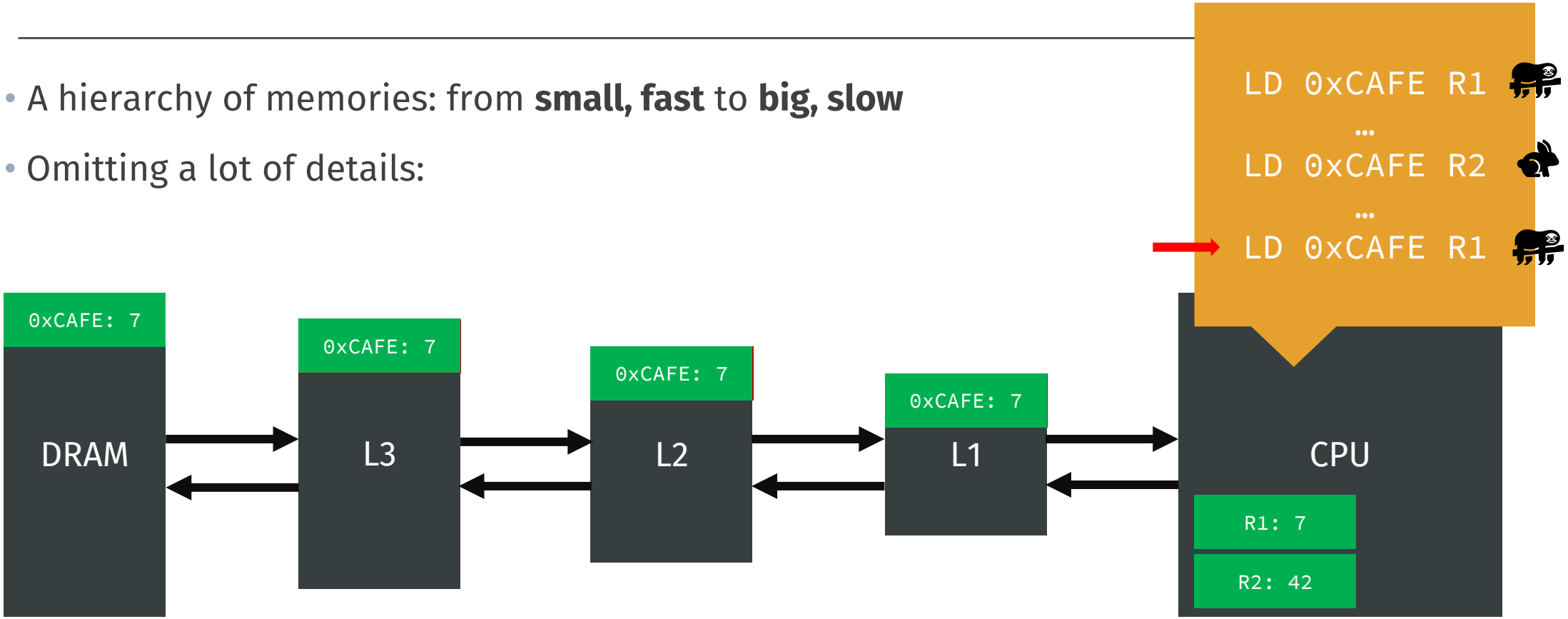

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  - The CPU **trains** its branch predictor by **observing** what happened before
  - Modern branch predictors are complex
    - but **for our purposes just one bit telling if we should take the branch**!

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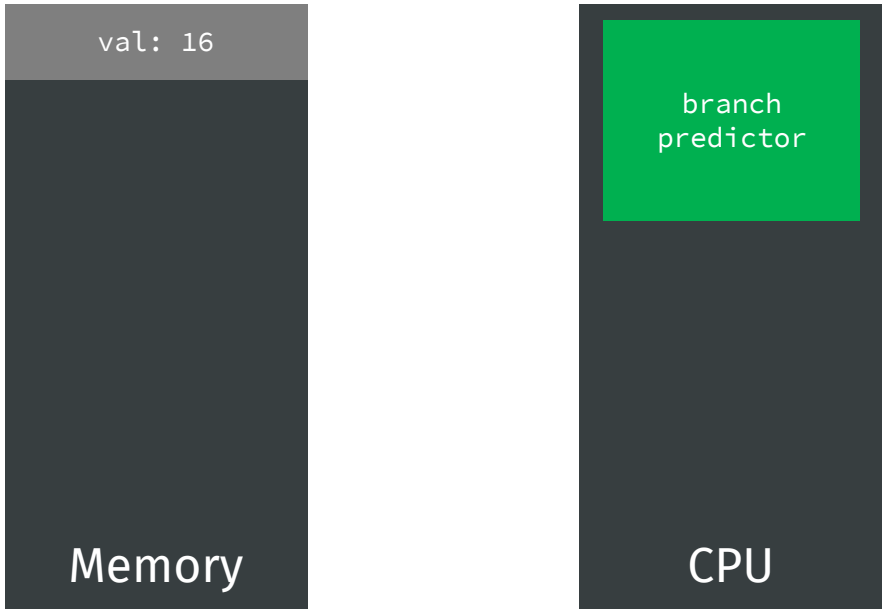

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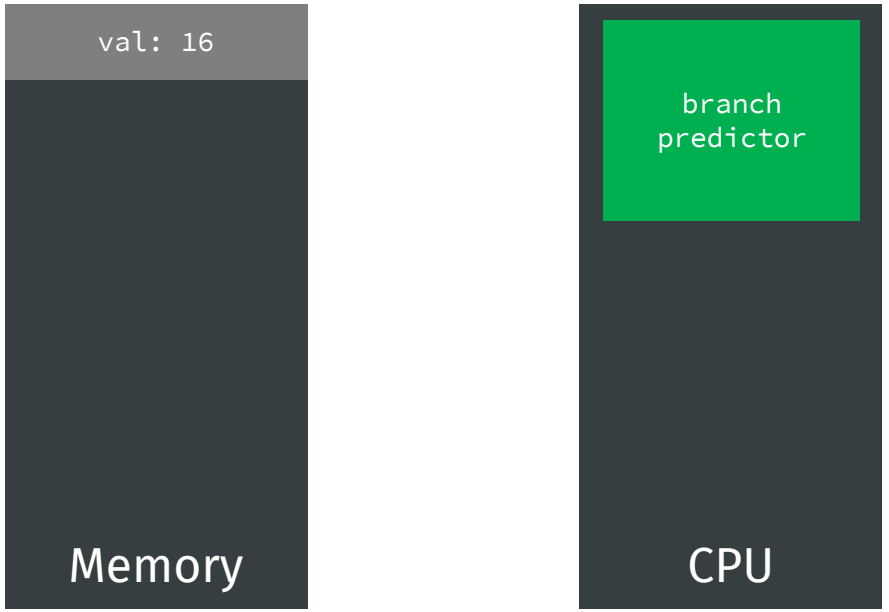

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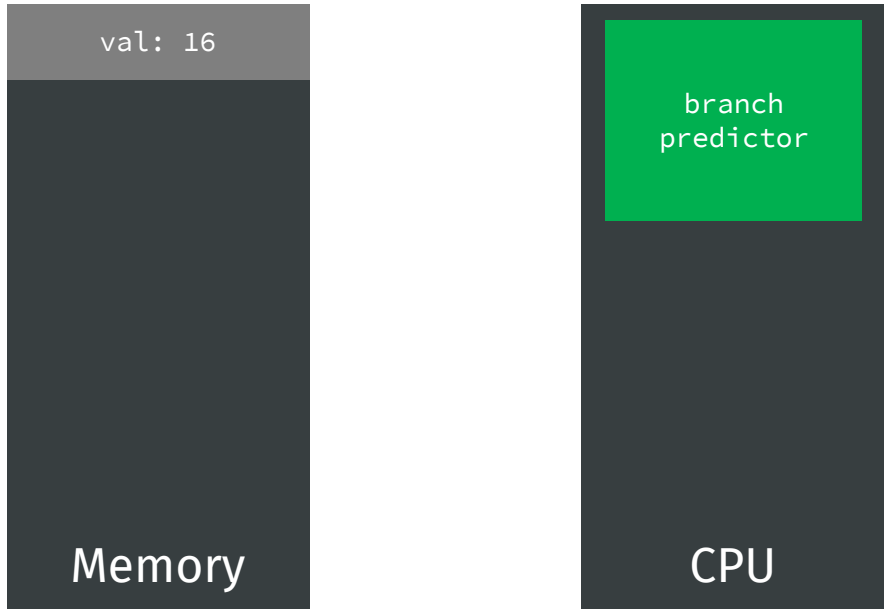

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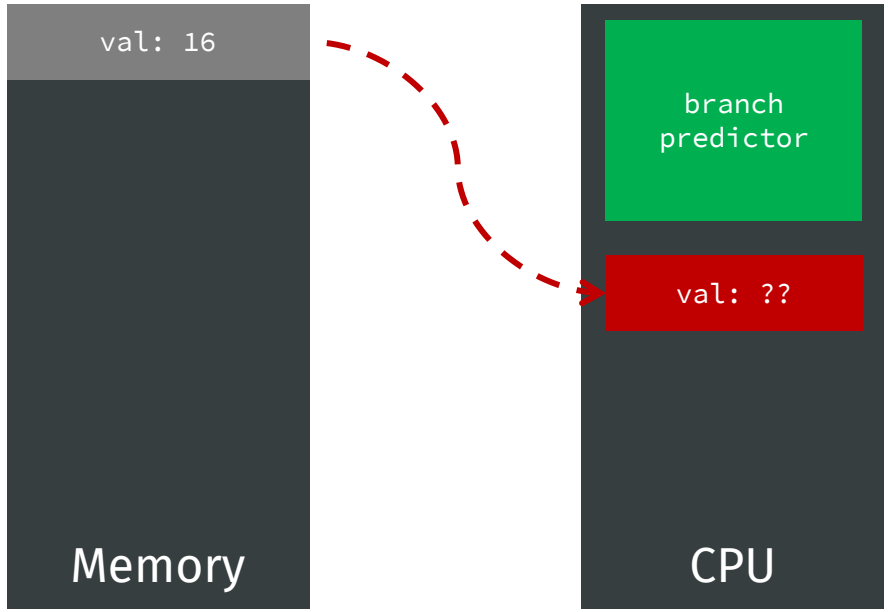

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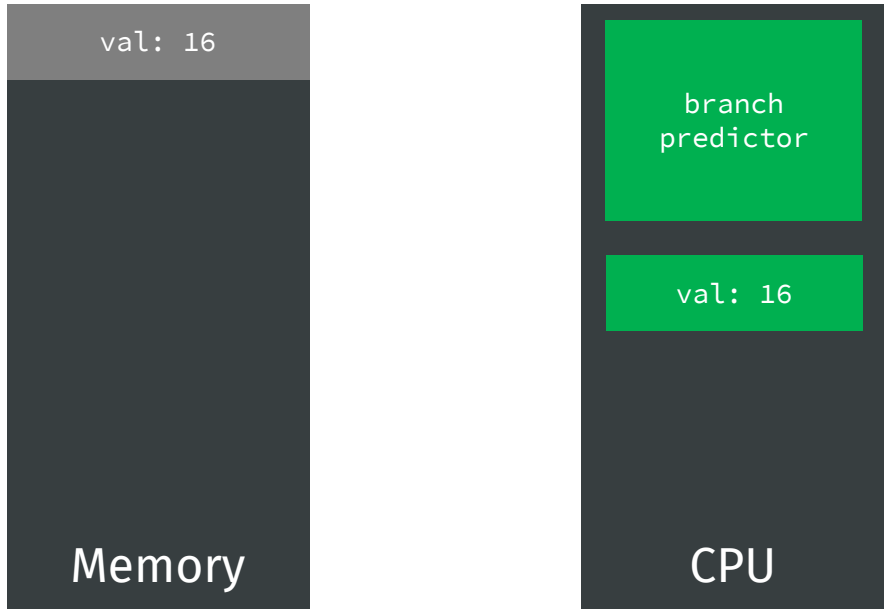

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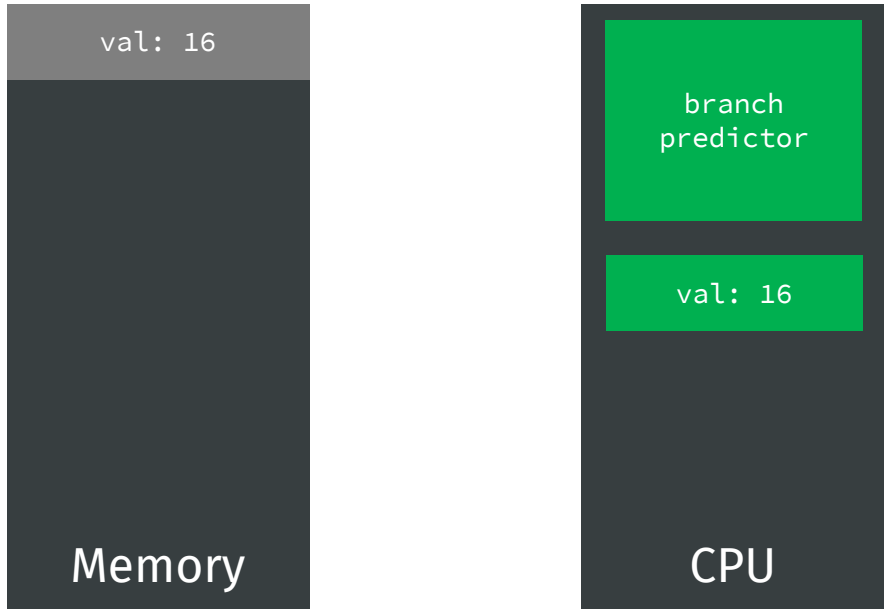

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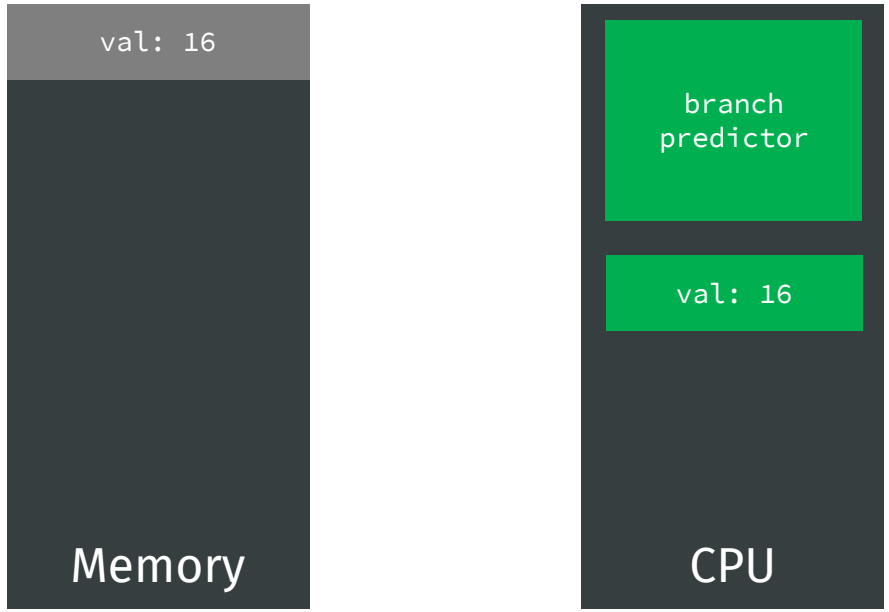

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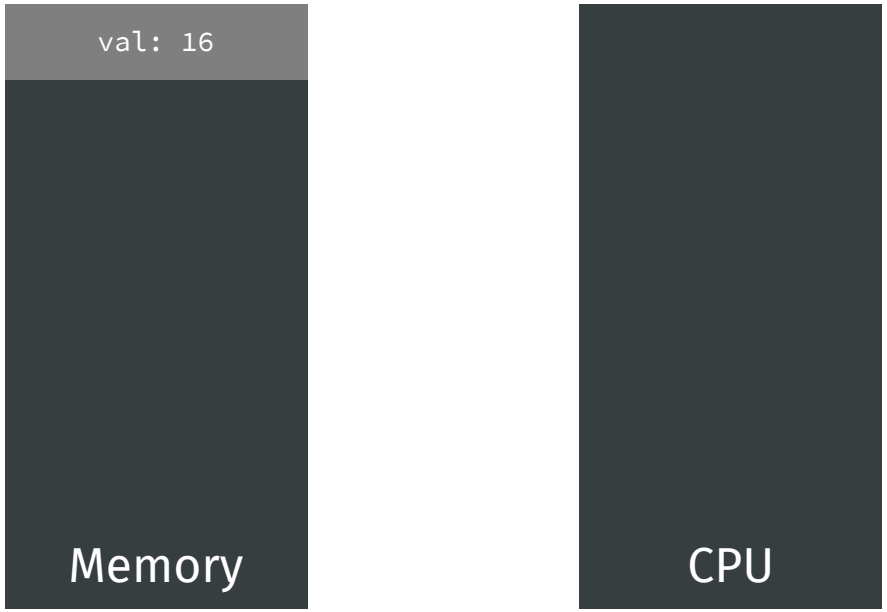

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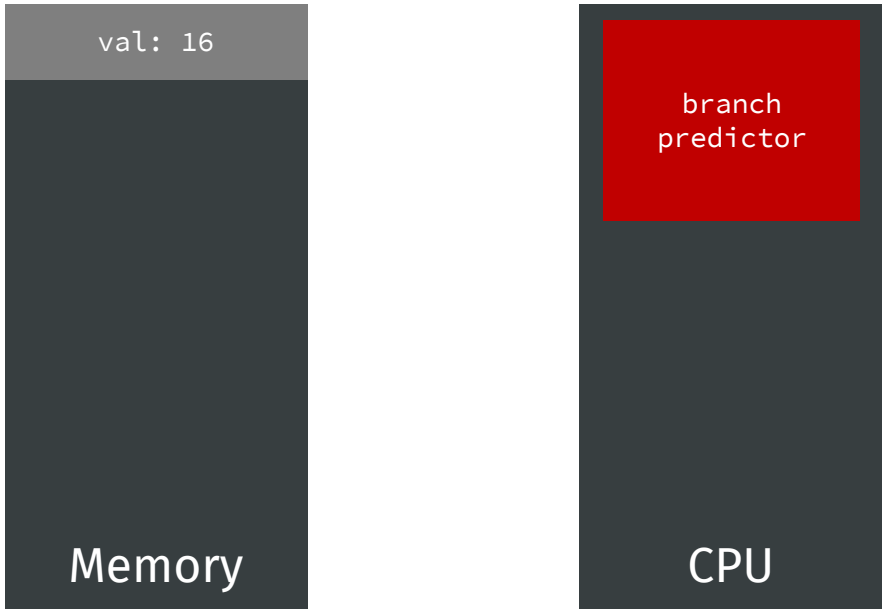

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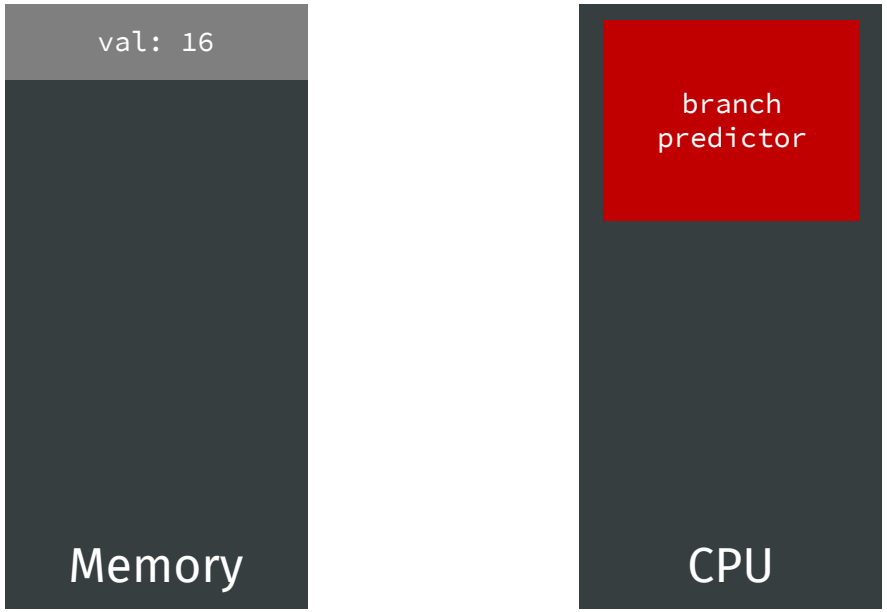

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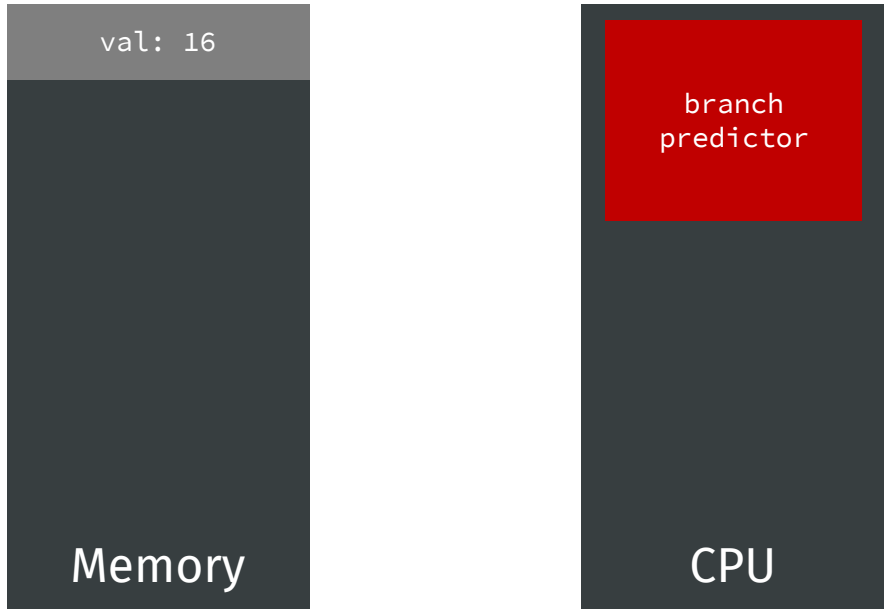

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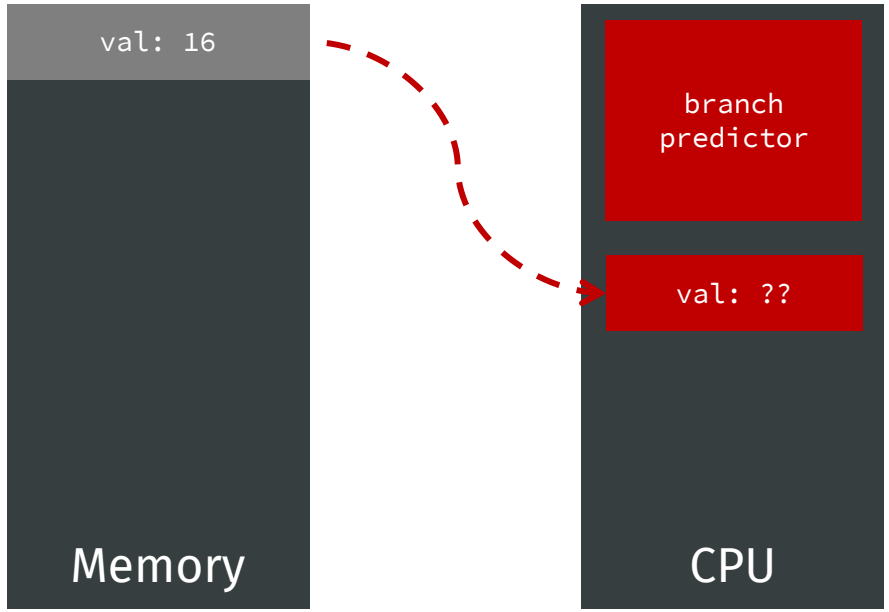

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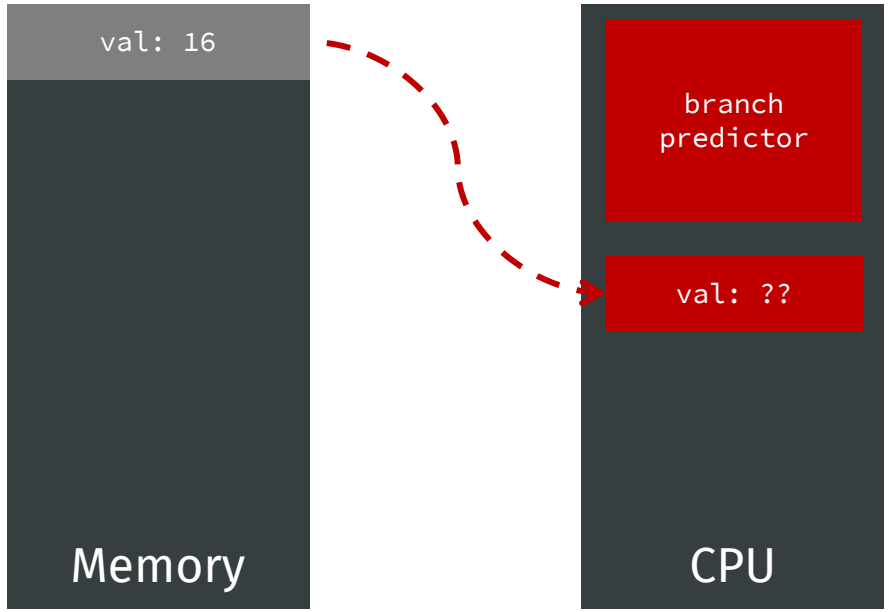

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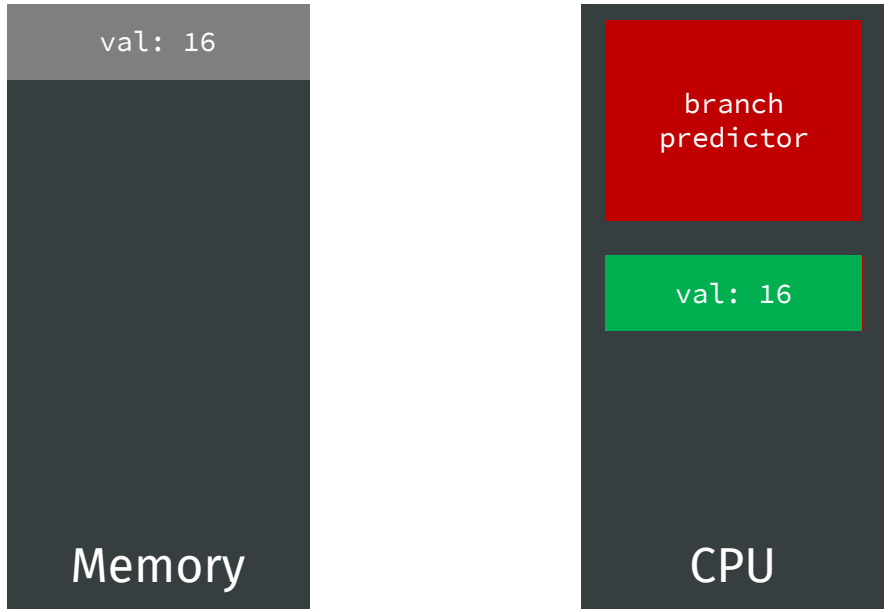

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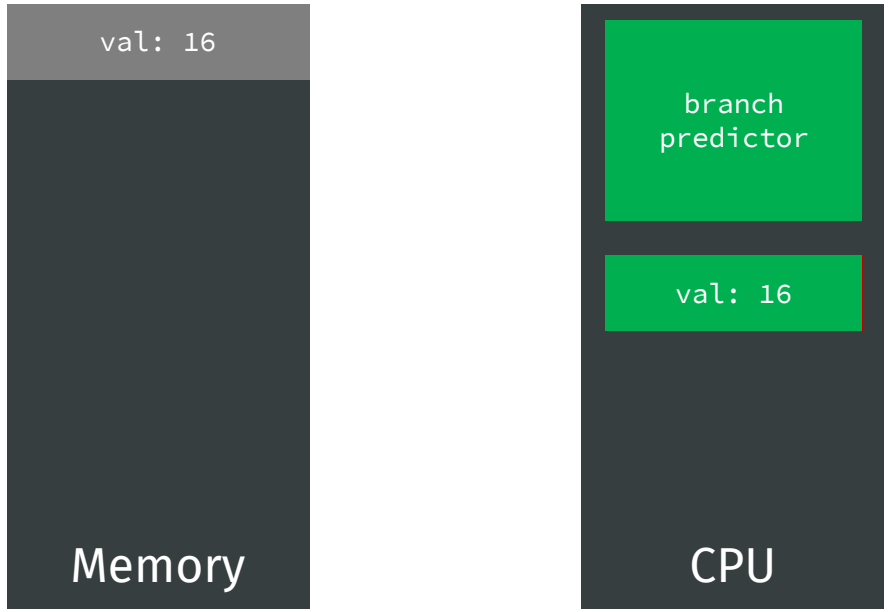

Speculation: when the CPU is wrong

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for (…)
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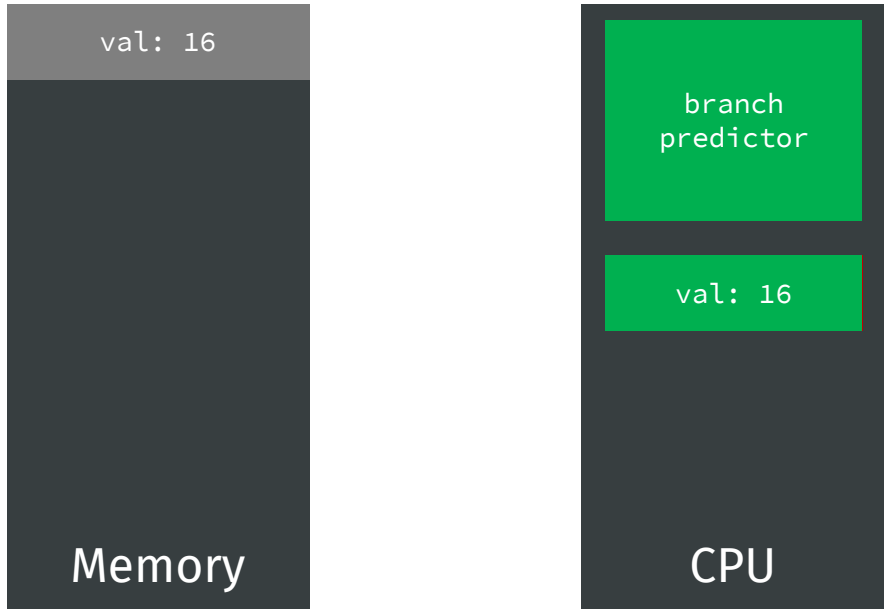

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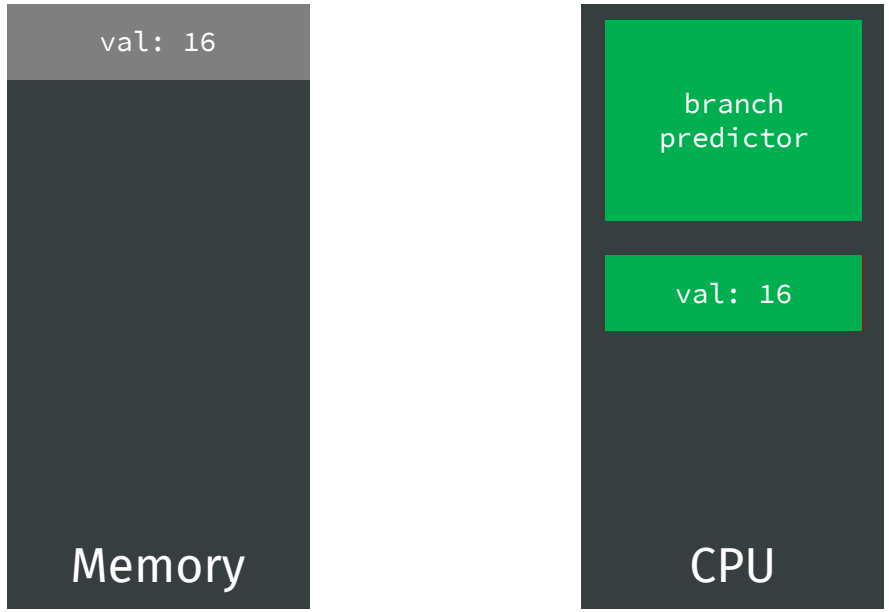

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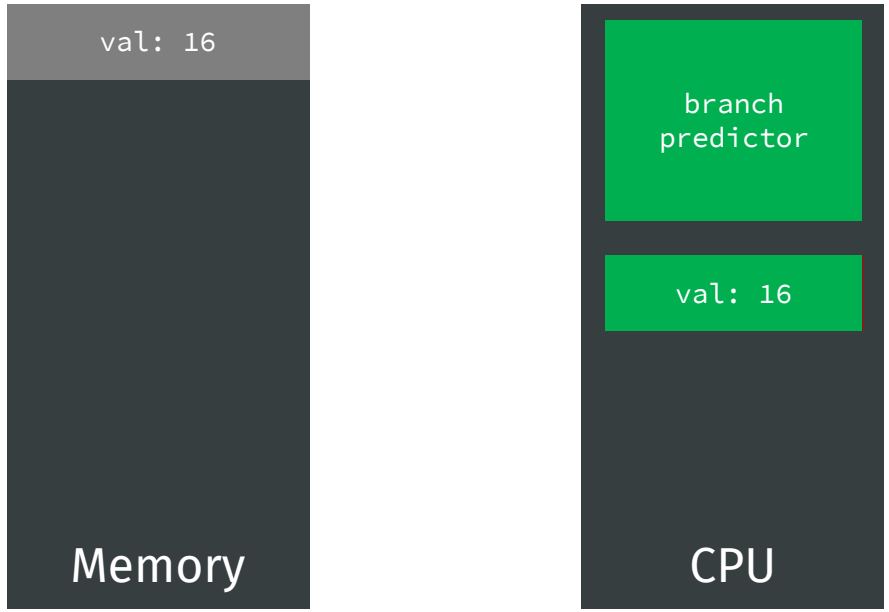

Side channels...

Designers are trying to optimize the avg case!

- In the **worst** case the execution will be **slow**
- In the **best** case the execution will be **very fast**

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- If it can learn some information from its observation, then there is a side channel!
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More precisely:

"A **side channel** is any observable side effect of computation that an attacker could measure and possibly influence." [Lawson, 2009]

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Your first side-channel attack

FLUSH+RELOAD [Yarom&Falkner, 2014]

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- **Flush+Reload** exploits **caches** to **leak secrets**
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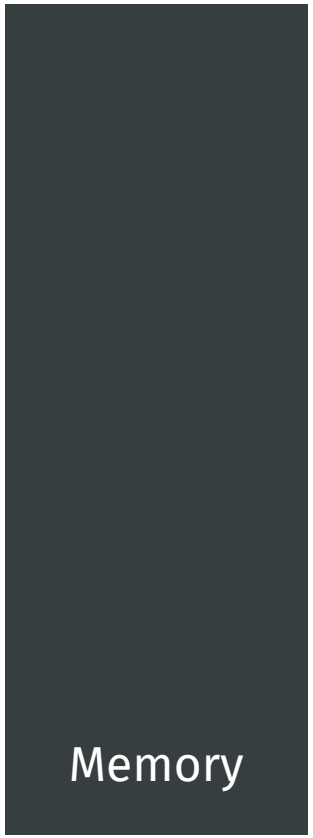

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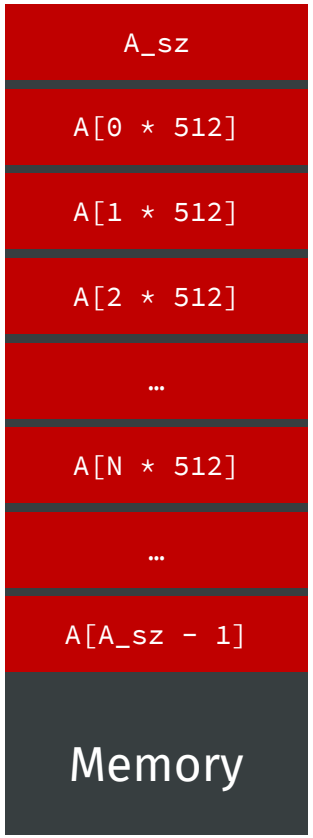


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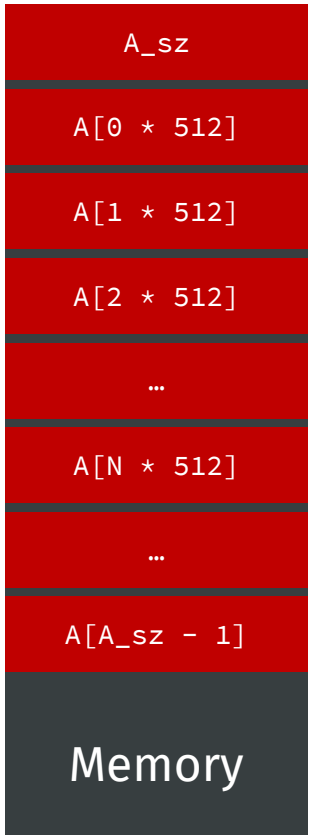


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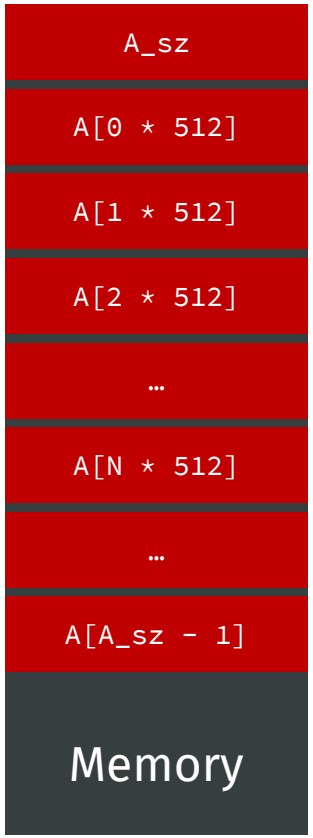

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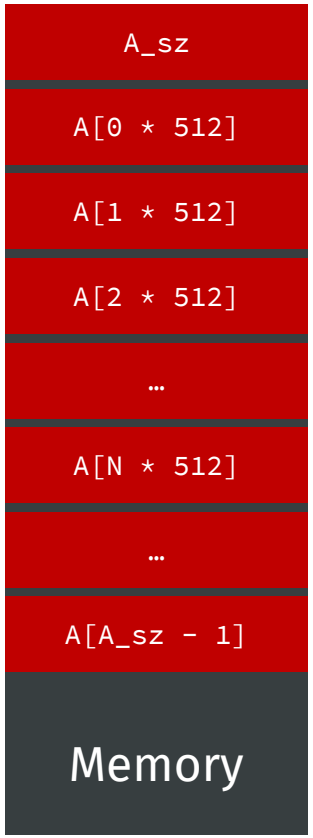


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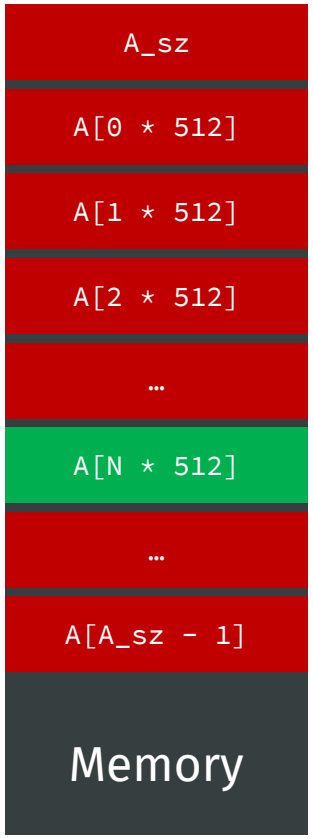


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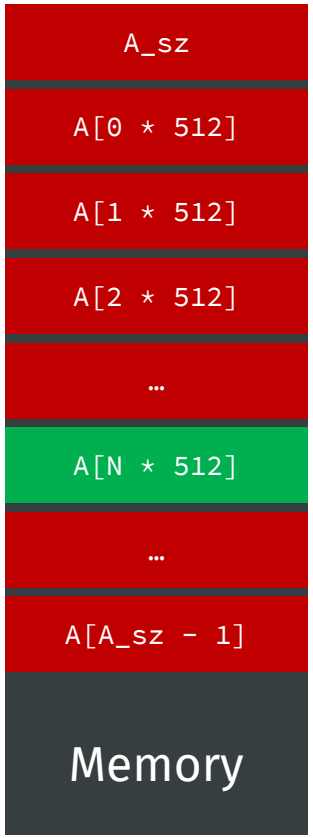

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      - for `i = N` the access will be fast, the **secret is leaked**!

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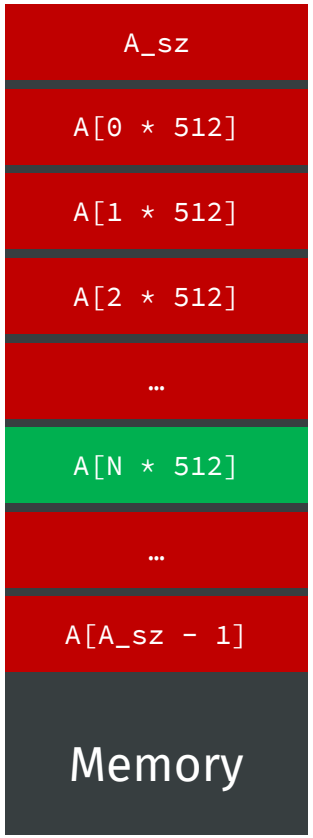

Mitigating FLUSH+RELOAD

- Detecting **FLUSH+RELOAD**: Anomalous cache hit/misses patterns using HW performance counters
- Mitigating **FLUSH+RELOAD**:
  - **Software-based:** fix victims avoiding secret-dependent memory accesses; disable page sharing/de-duplication; limit access to high-resolution timers
  - **Hardware-based:** limit `clflush` access; make caches non-inclusive

What about speculation?

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The **Spectre** attack!

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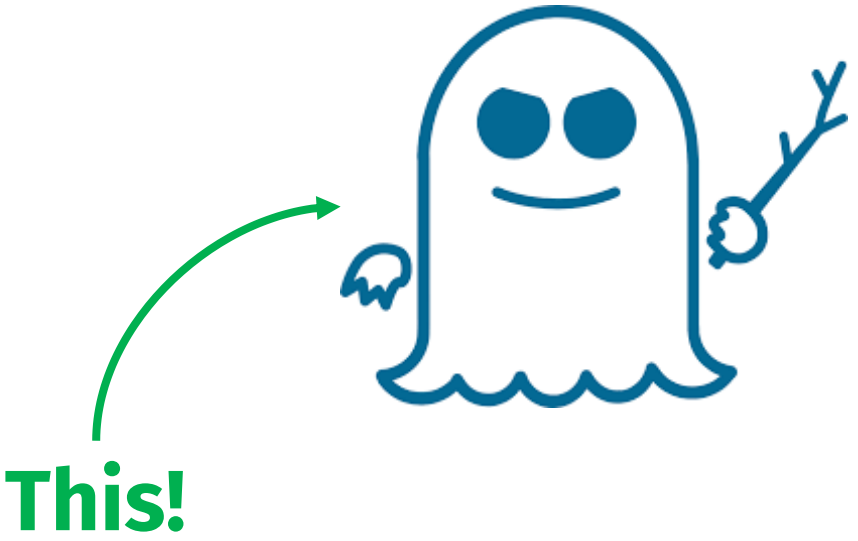


What about speculation?

The **Spectre** attack!

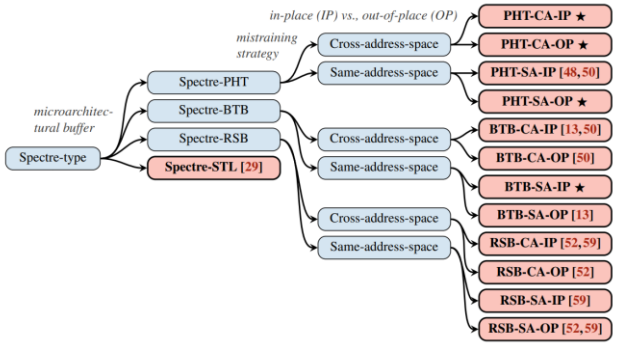
Not this!

This!

Spectre [Kocher et al., 2019]

Spectre is an attack exploiting **speculative execution** to **leak secrets**

- It is part of a recent wave of **micro-architectural attacks**, i.e., attacks using side-channels induced by the micro-architecture of a processor (e.g., cache, timers, virtual memory, …)
- "**Spectre** […] **transiently** bypasses software-defined security policies (e.g., bounds checking, function call/return abstractions, memory stores) to leak secrets out of the program's intended code/data paths." [Canella et al., 2019] (← bit outdated, but a good survey on Spectre!)
- Many variants, here an updated version https://transient.fail/



[Kocher et al., 2019] P. Kocher et al. "Spectre attacks: Exploiting speculative execution." IEEE S&P 2019.

[Canella et al., 2019] C. Canella et al. "A systematic evaluation of transient execution attacks and defenses." *USENIX Security* 2019. URL: https://arxiv.org/abs/1811.05441v3

Spectre v1/v1.1 (special-cases of PHT)

We focus on Spectre v1 and v1.1

- Also called **Spectre-PHT**: the attacker **mistrains** the branch predictor by poisoning the **P**attern **H**istory **T**able
- How? **For example**
  - The attacker**:**
    1. Looks for a piece of “vulnerable code” (**code gadget**) including a condition (next slide)
    2. Runs that code multiple times with an input s.t. the condition always holds (so training the branch predictor to take the “true” branch)
    3. Then, runs the code with a specially-crafted input making the condition false: now the CPU mis-speculates and executes the “true” branch with wrong data (!!!)
    4. Finally, it looks for information left behind after the CPU discovered it mis-speculated and rolled-back the computation (e.g., contents of caches)

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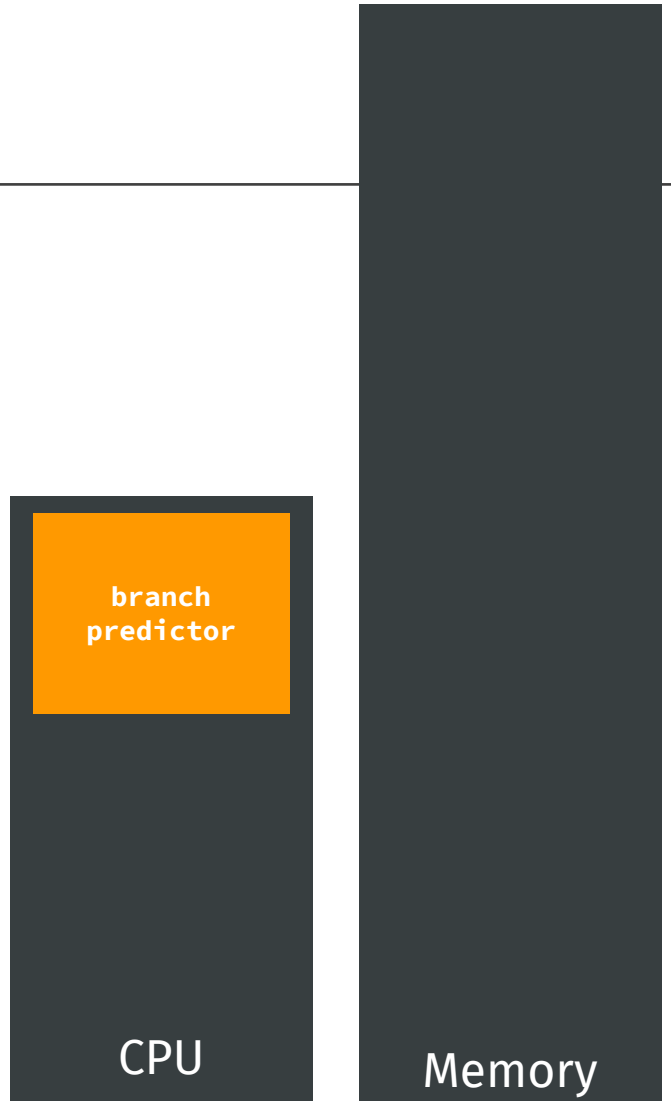

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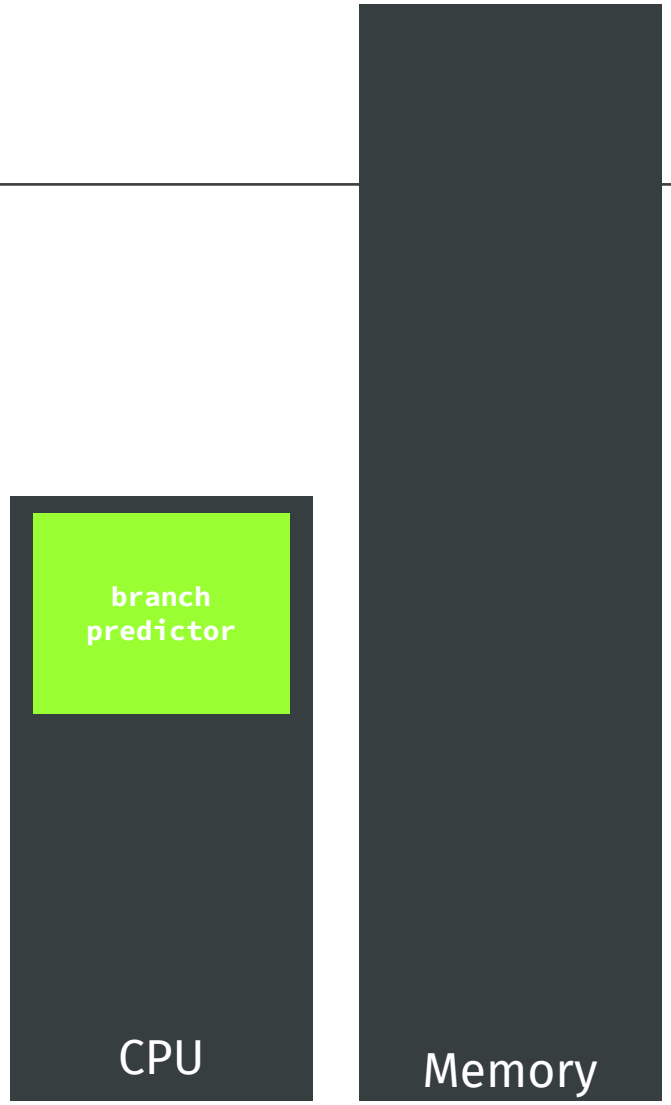

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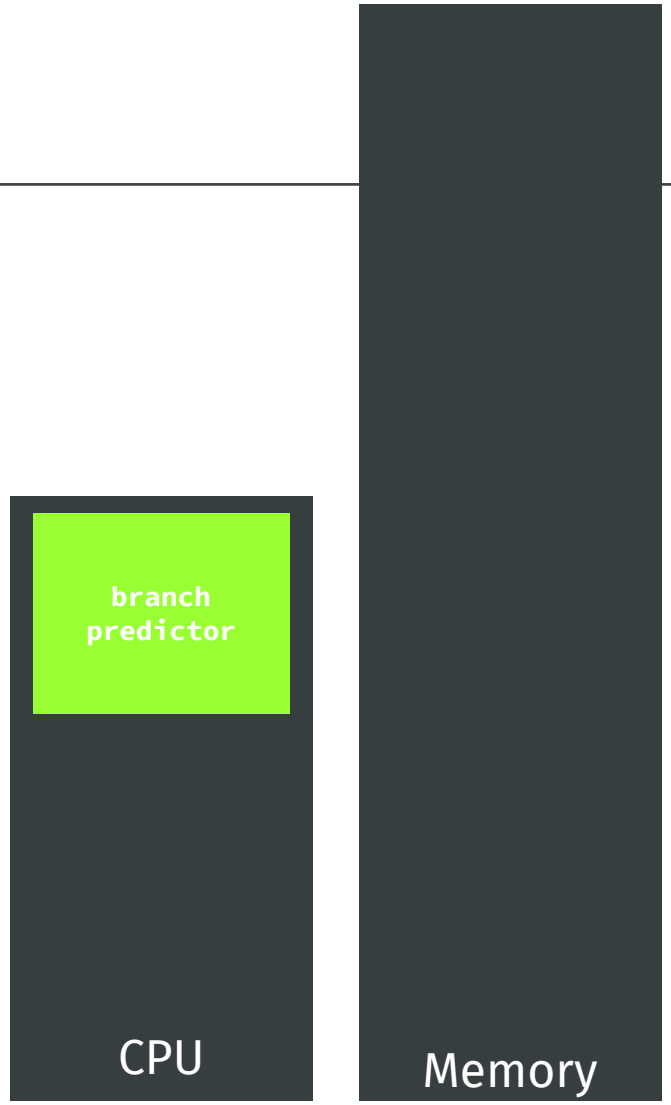

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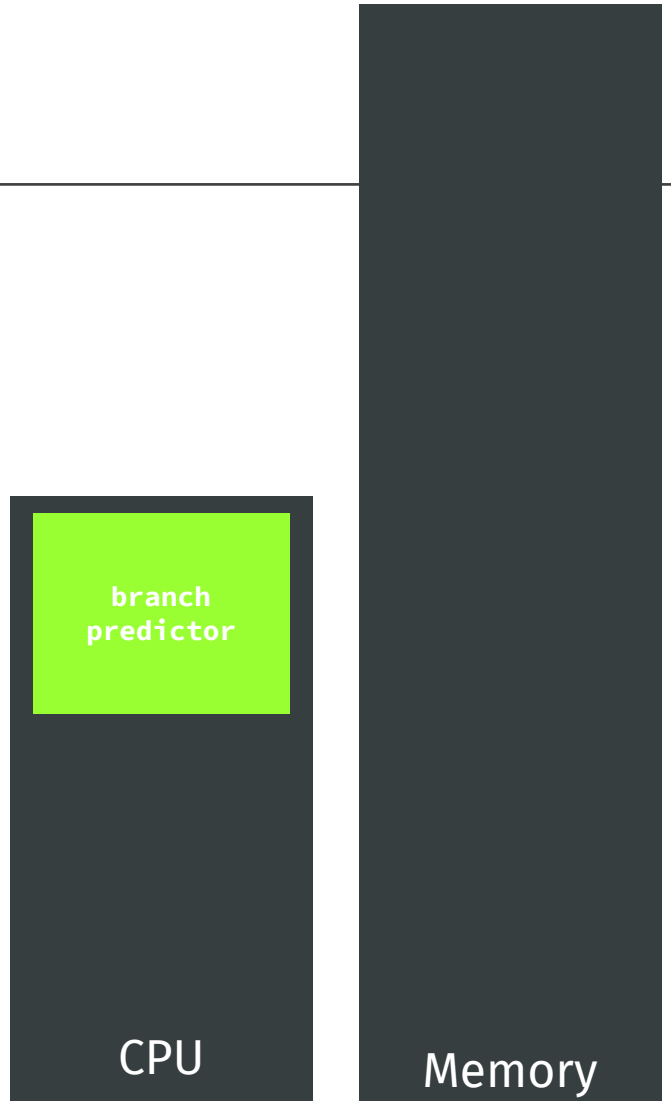

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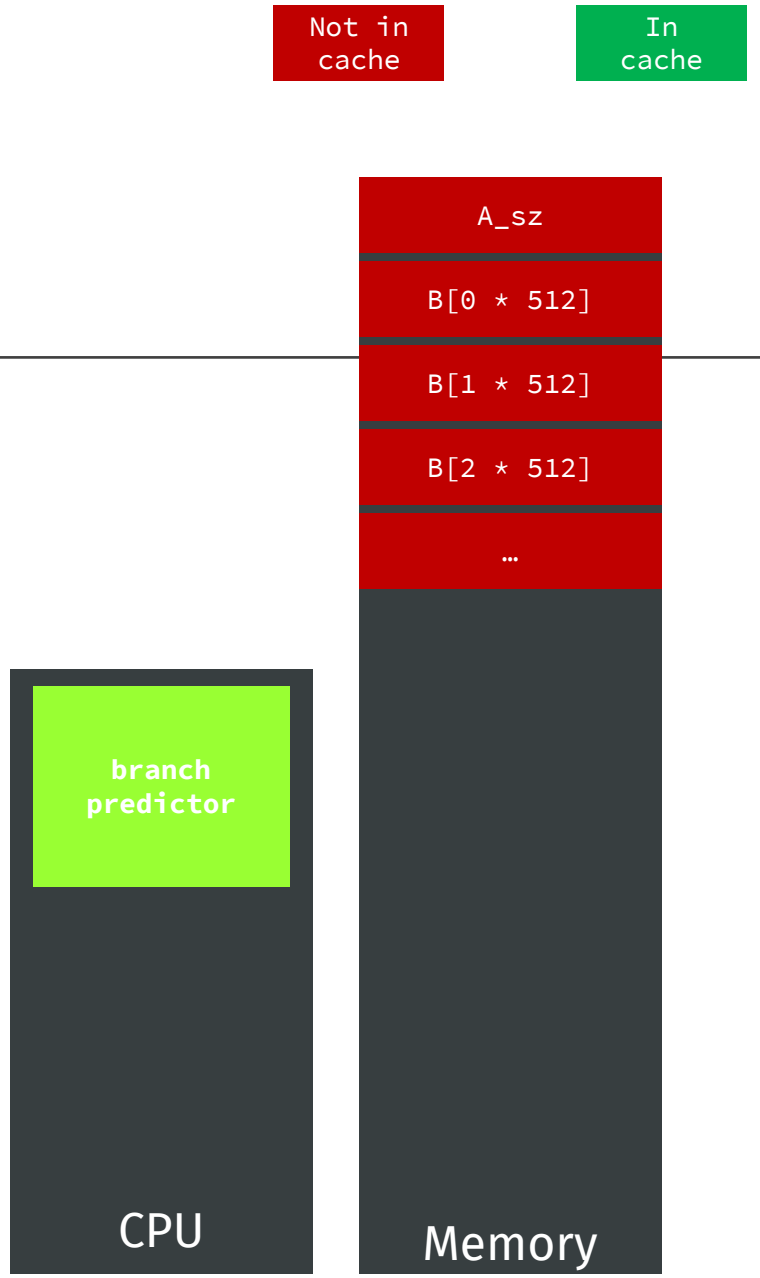

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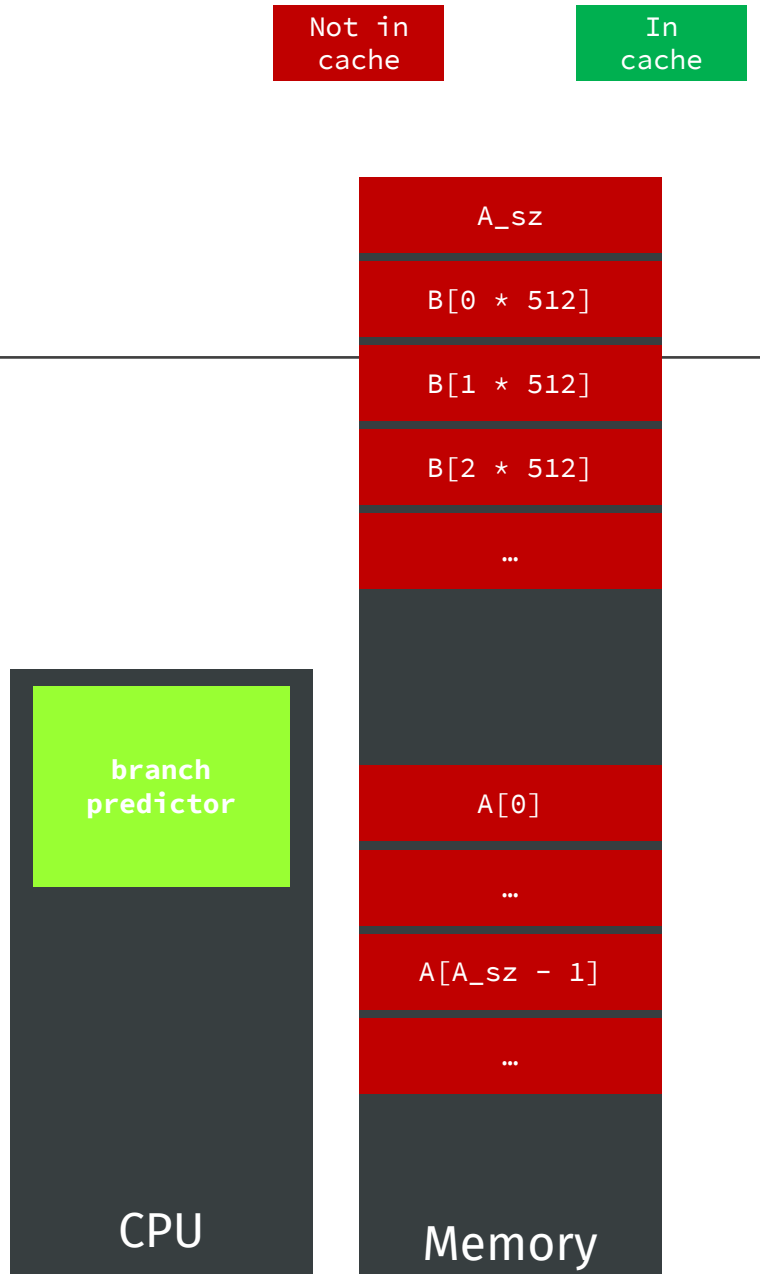

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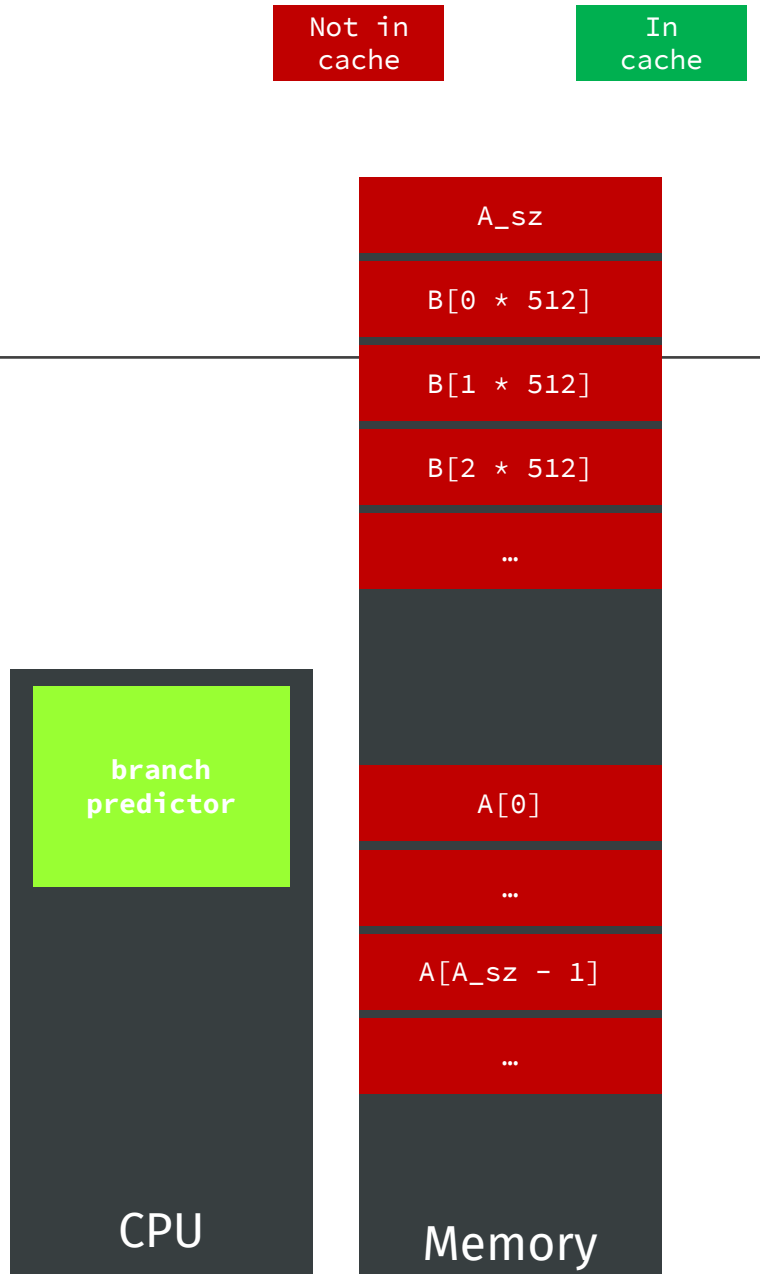

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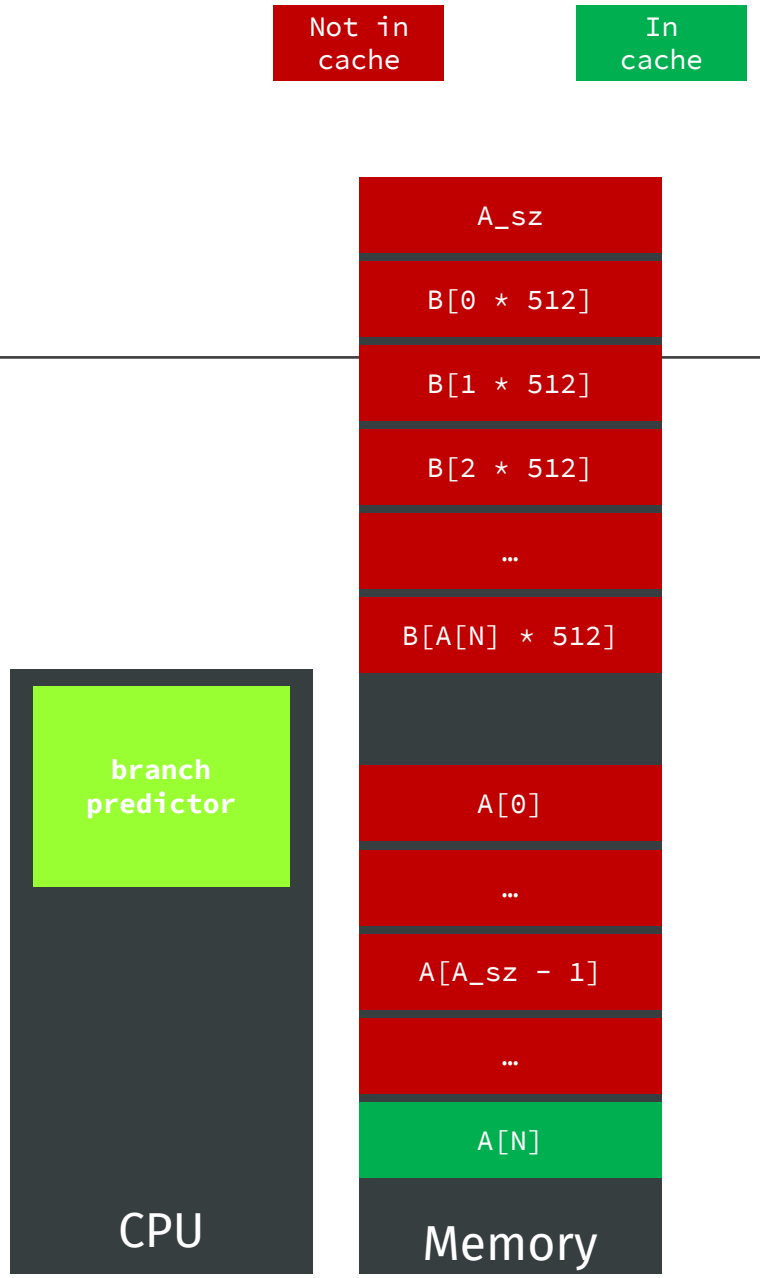

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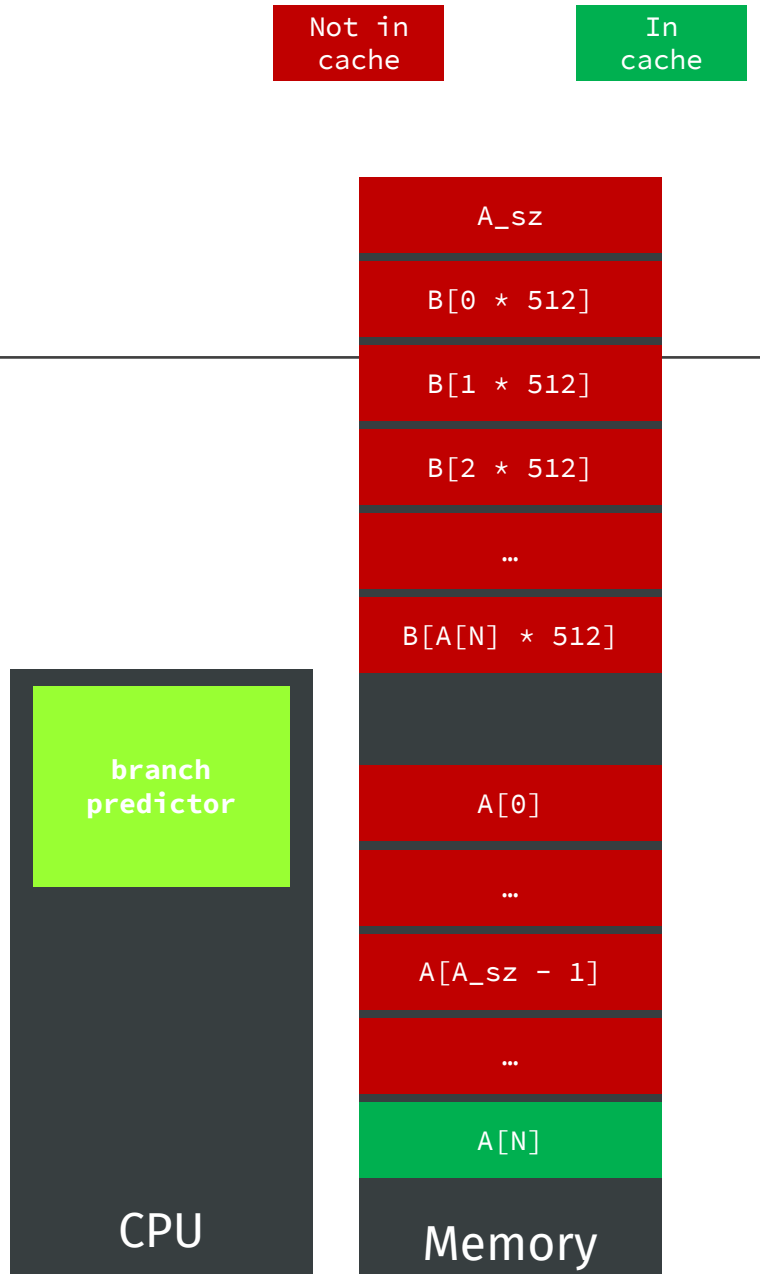

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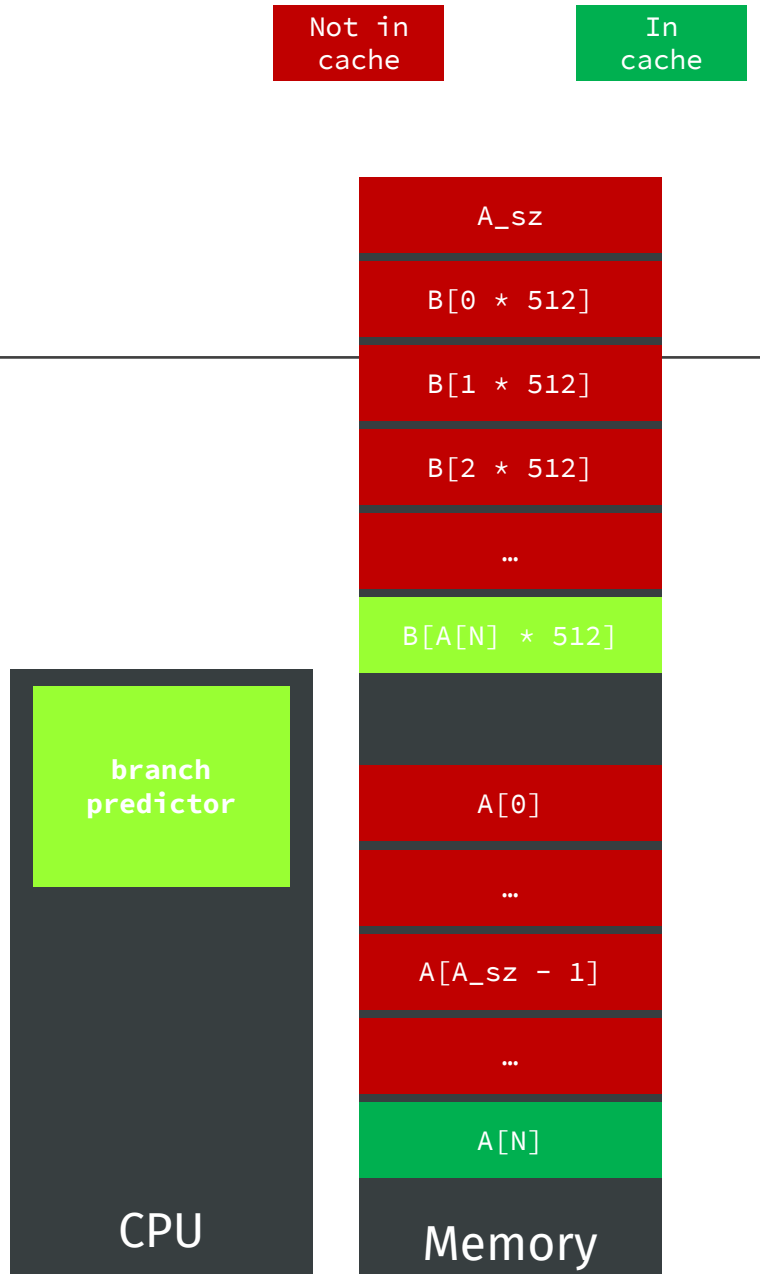

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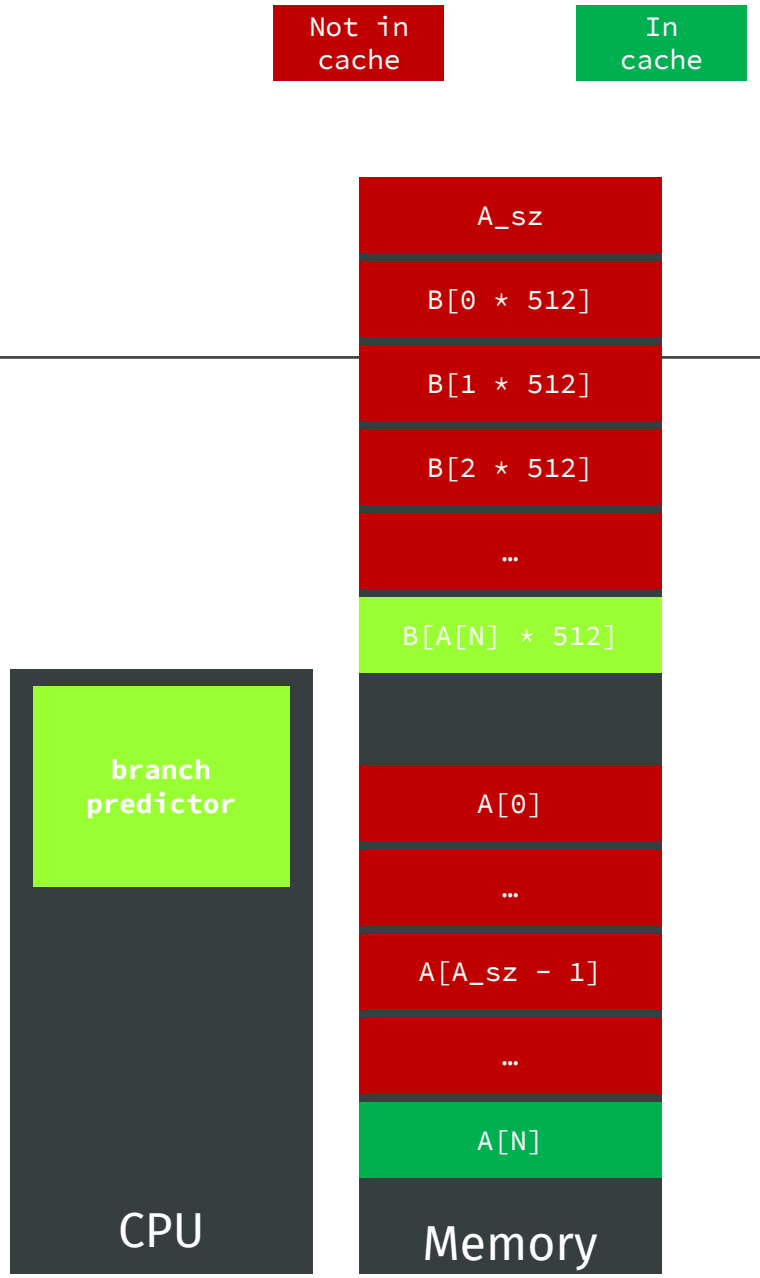

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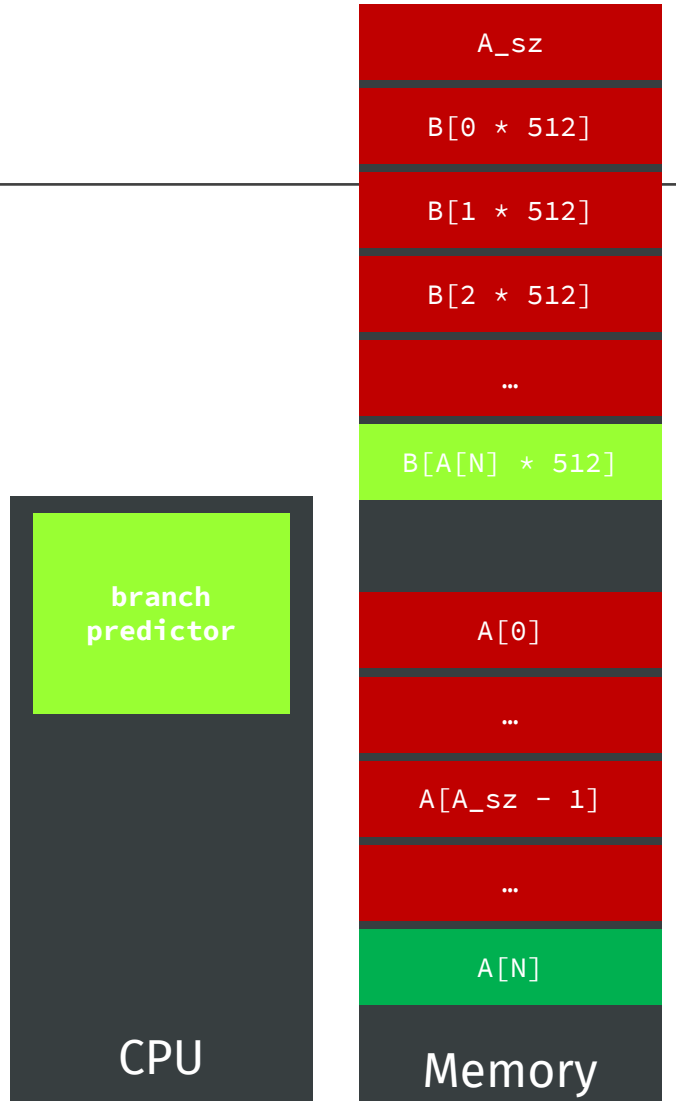

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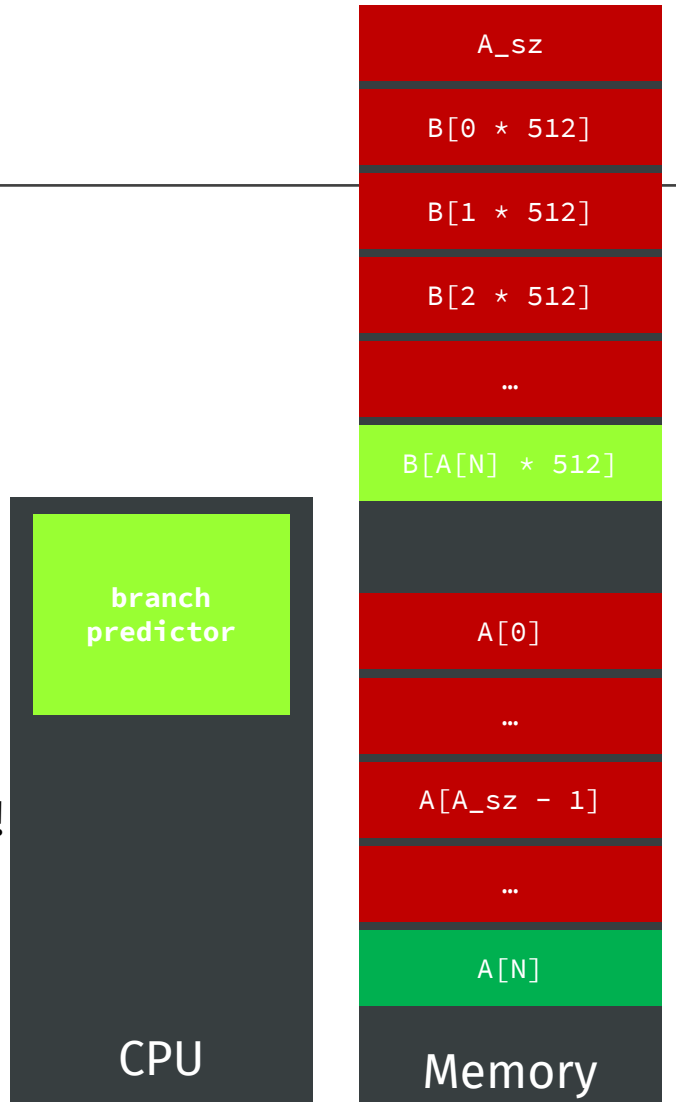

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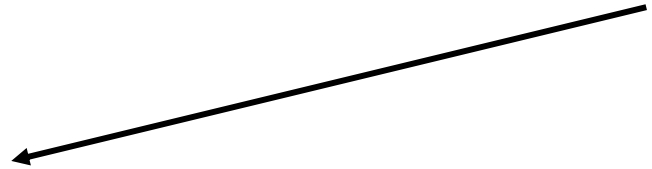

Fences

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- In pseudo-C:

```
if (x < A_sz) {
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- To make this a bit better one could use static analysis to decide where fences should go
  - E.g., **Microsoft MSVC** does that by detecting known problematic patterns or **Blade tool**

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- Speculative Load Hardening (SLH) is a bit more sophisticated than fences
- **Idea:**
  - It may be more efficient to introduce an **artificial** data dependency between the condition of a jump and the pointer
  - Simplifying, for Spectre v1 (assuming "_ ? _ : _" to be implemented w/o branching, e.g., using a `cmov`)

```
uint mask = ALL_ONES;
if (cond) {
  mask = !cond ? ALL_ZEROES : mask;
  // …
  y = B[(A[x] * 512) & mask];
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  - No need of static analysis code (but still could help)
- The **Bad:**
  - Still slow (`mask` must be known when accessing to `B`, also when speculating!)
  - Must be carefully implemented
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Mitigating Spectre: other ideas

Other possible fixes:

- Make secrets non reachable:
  - Just like **Chrome** and **Firefox**: isolate secrets in different processes
- Reduce the bandwidth of side-channels:
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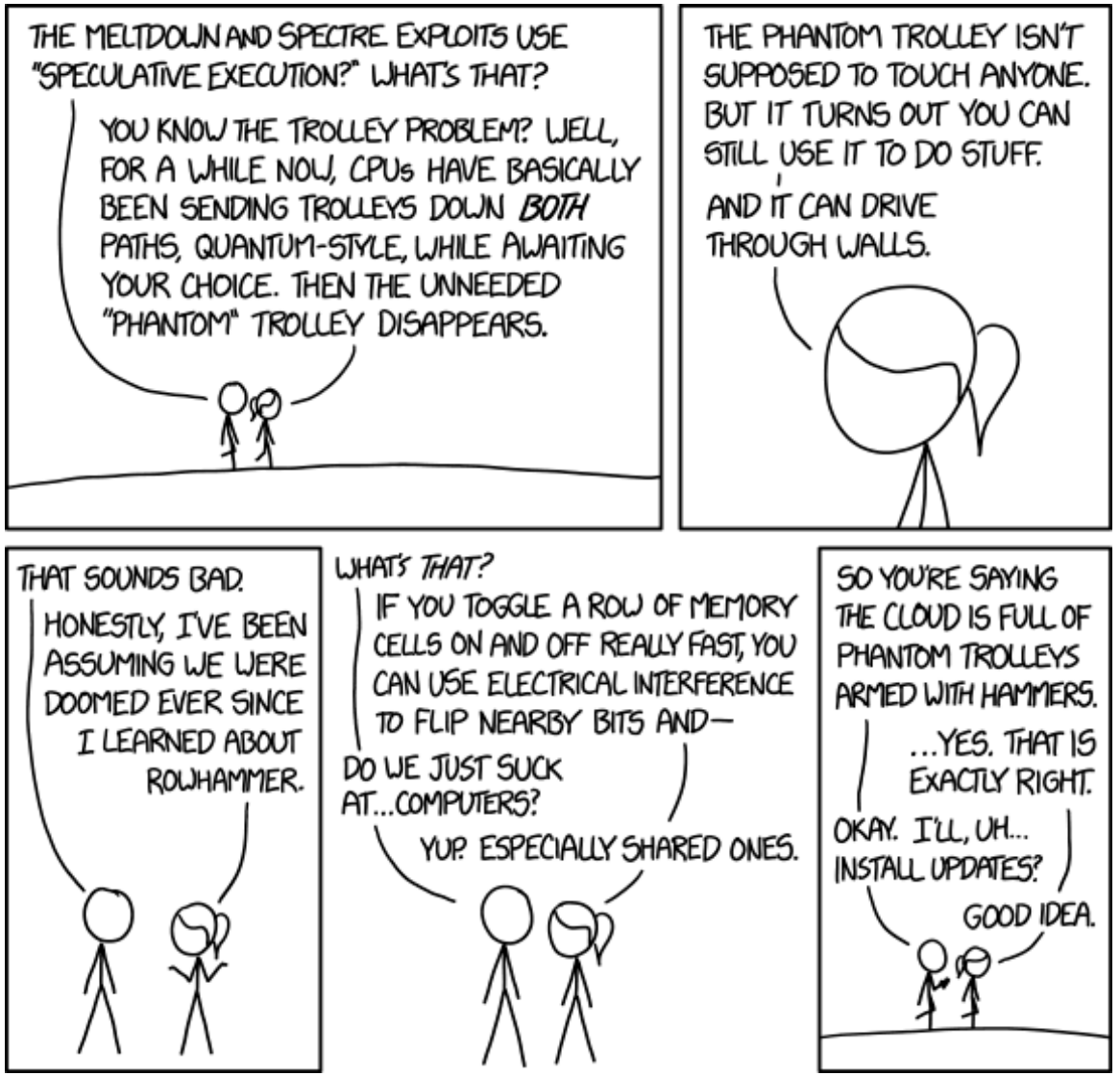
Is Spectre fixed?

Only if you are willing to re-compile/re-design your system and make it slow 😗

The End



https://xkcd.com/1938/