ZeRØ: Zero-Overhead Resilient Operation Under Pointer Integrity Attacks

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COLUMBIA | ENGINEERING

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About Me

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Memory Safety is a serious problem!

Computing Sep 6

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The tech giant gave a rare statement that bristled at Google's analysis of the novel hacking operation.

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It’s easy to make mistakes

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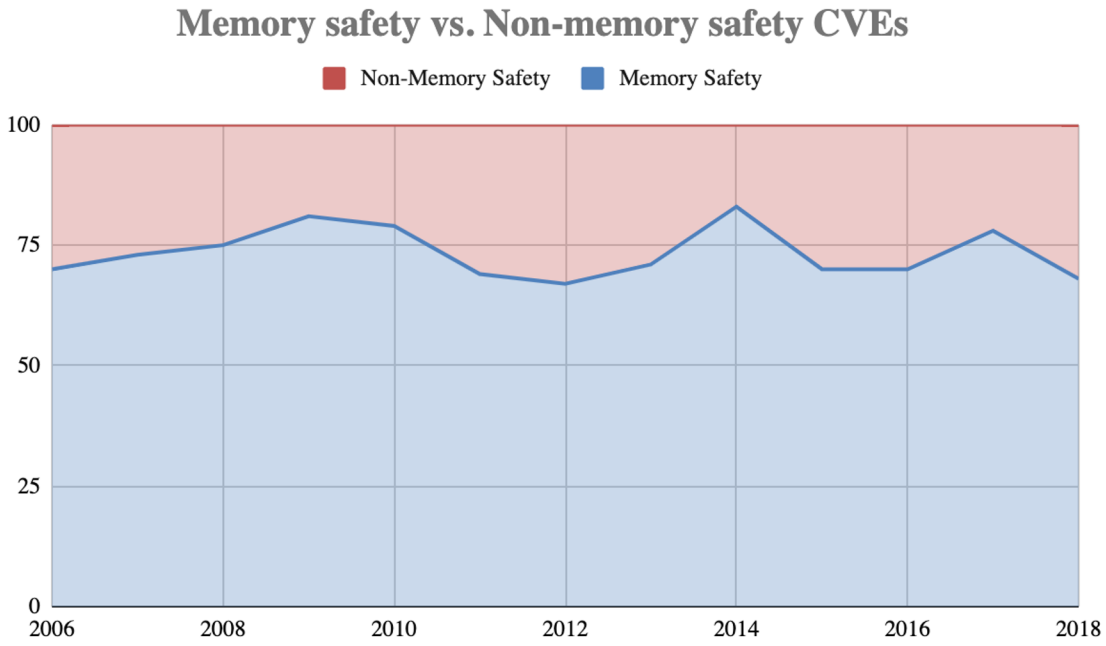
SEGFAULT!

Prevalence of Memory Safety Vulns



Microsoft Product CVEs

Source: *Matt Miller, Microsoft Security Response Center (MSRC) - BlueHat 2019*

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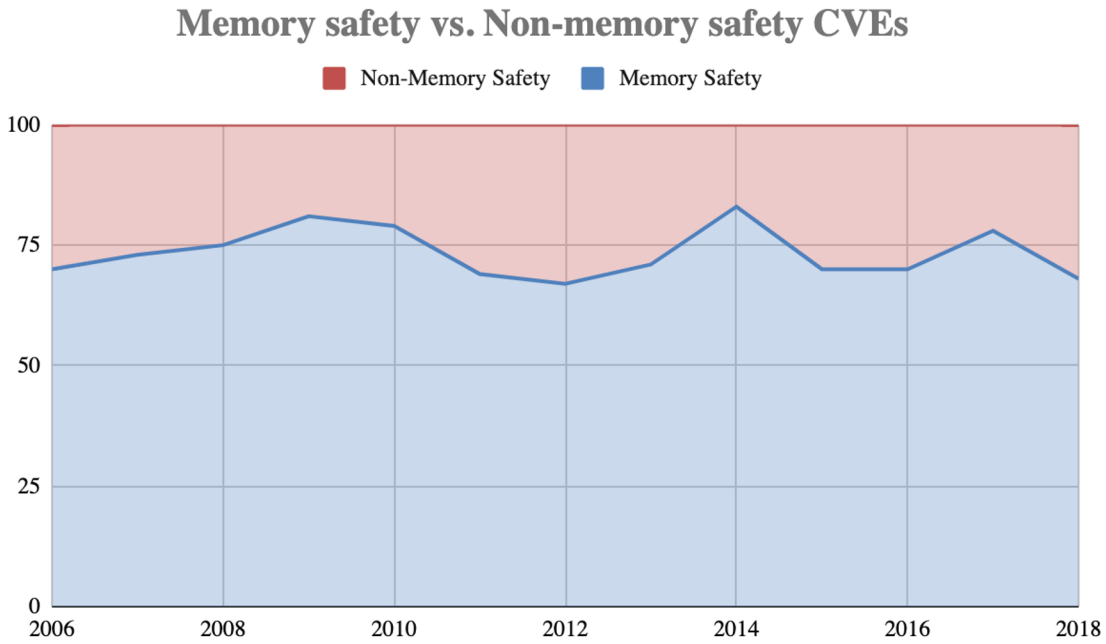

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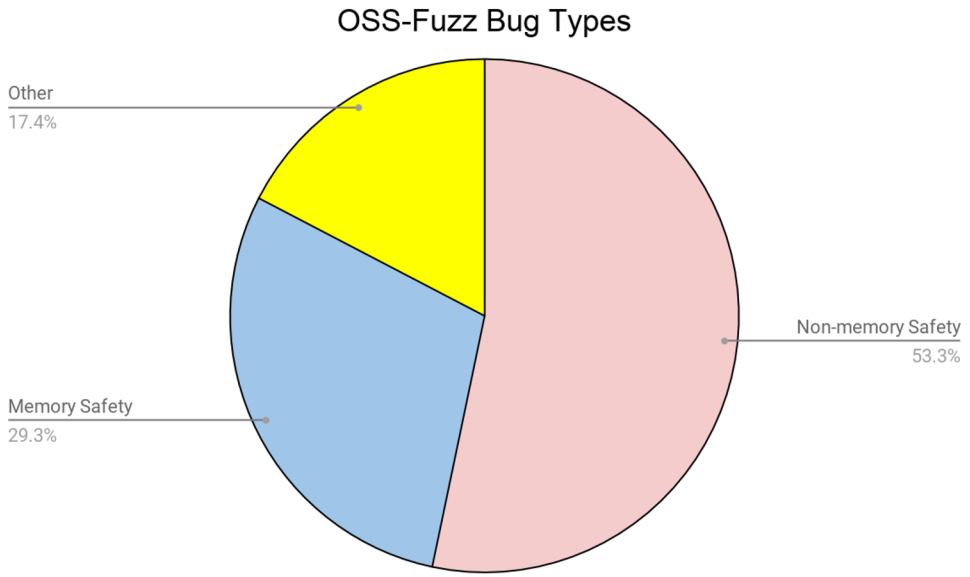


Google OSS-Fuzz bugs from 2016-2018.

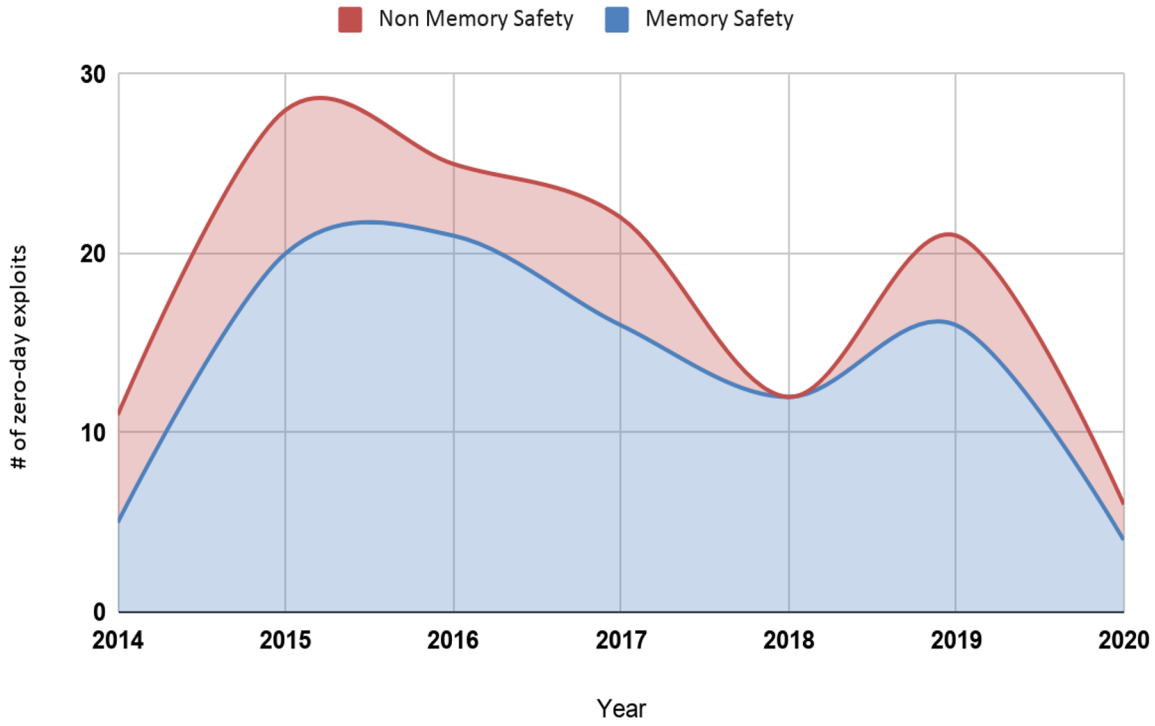
Source: *Matt Miller, Microsoft Security Response Center (MSRC) - BlueHat 2019*

Source: *https://security.googleblog.com/2018/11/a-new-chapter-for-oss-fuzz.html*

ATTACKERS

MEMORY SAFETY

Attackers Prefer Memory Safety Vulns



Zero-day “in the wild” exploits
from 2014-2020

Source: *Google Project Zero, 0day "In the Wild" spreadsheet. Last updated: April 2020*

How To Fix Memory (Un)Safety?

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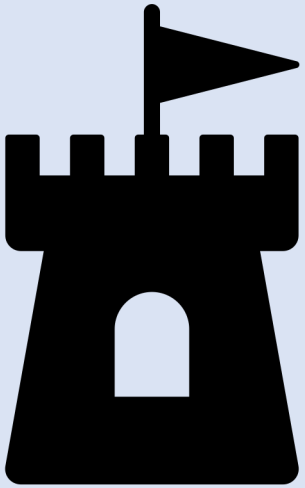
Memory Safe Languages



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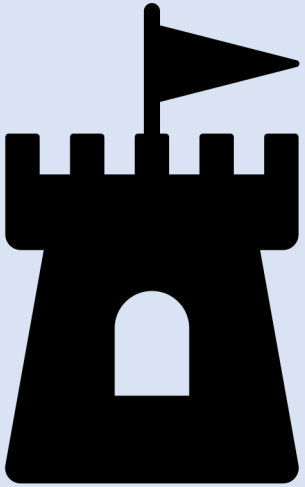

- Performance?
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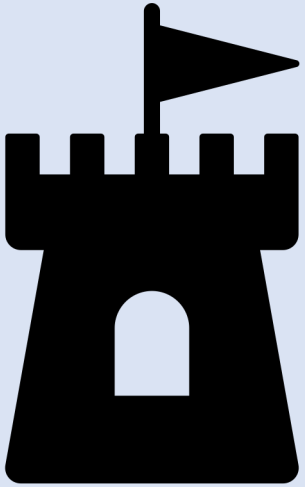

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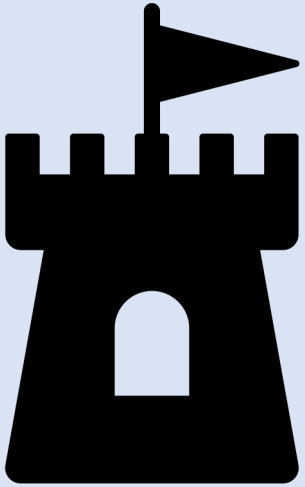

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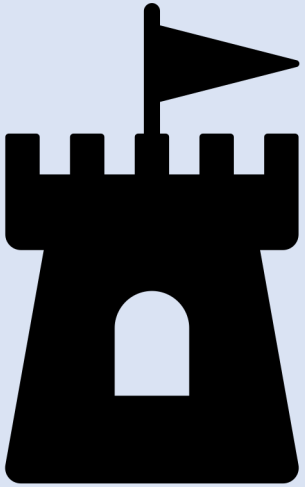

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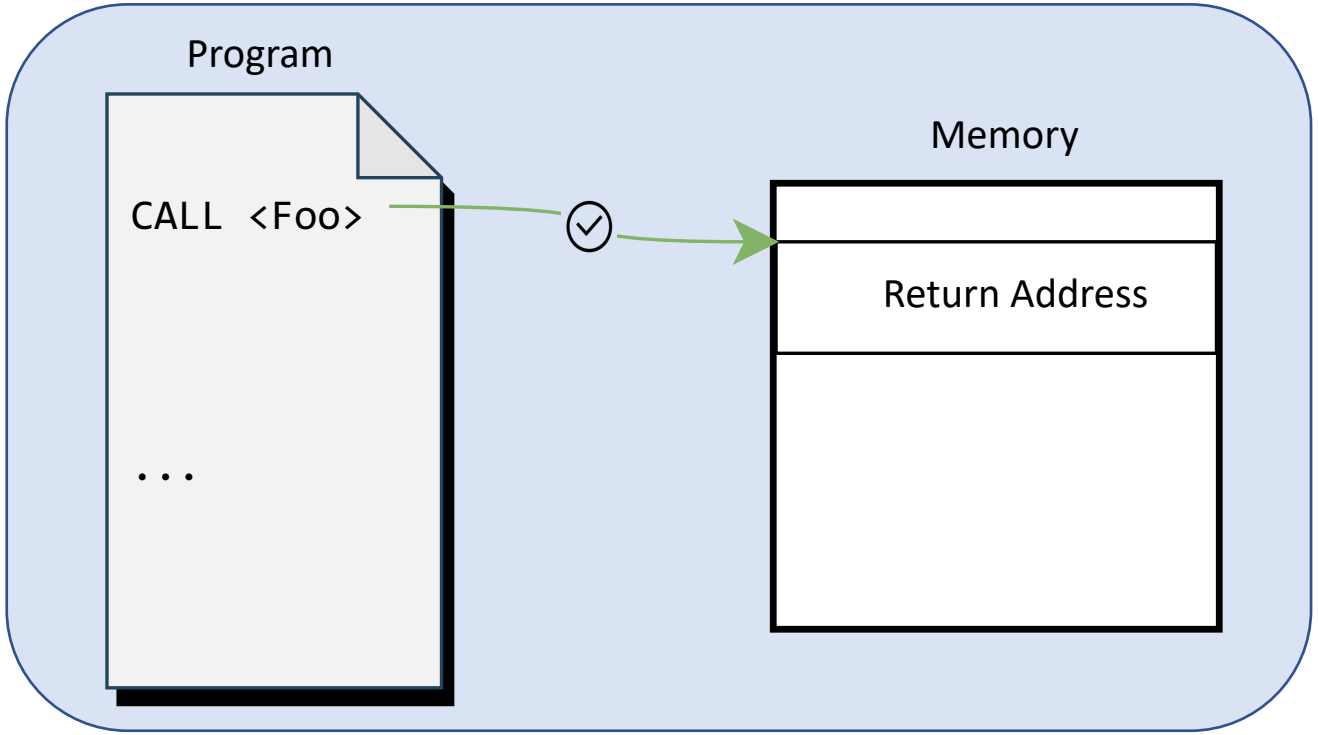
Post-deployment Mitigations


ZeRØ

Overview

ZeRØ: Overview



Return Address Protection

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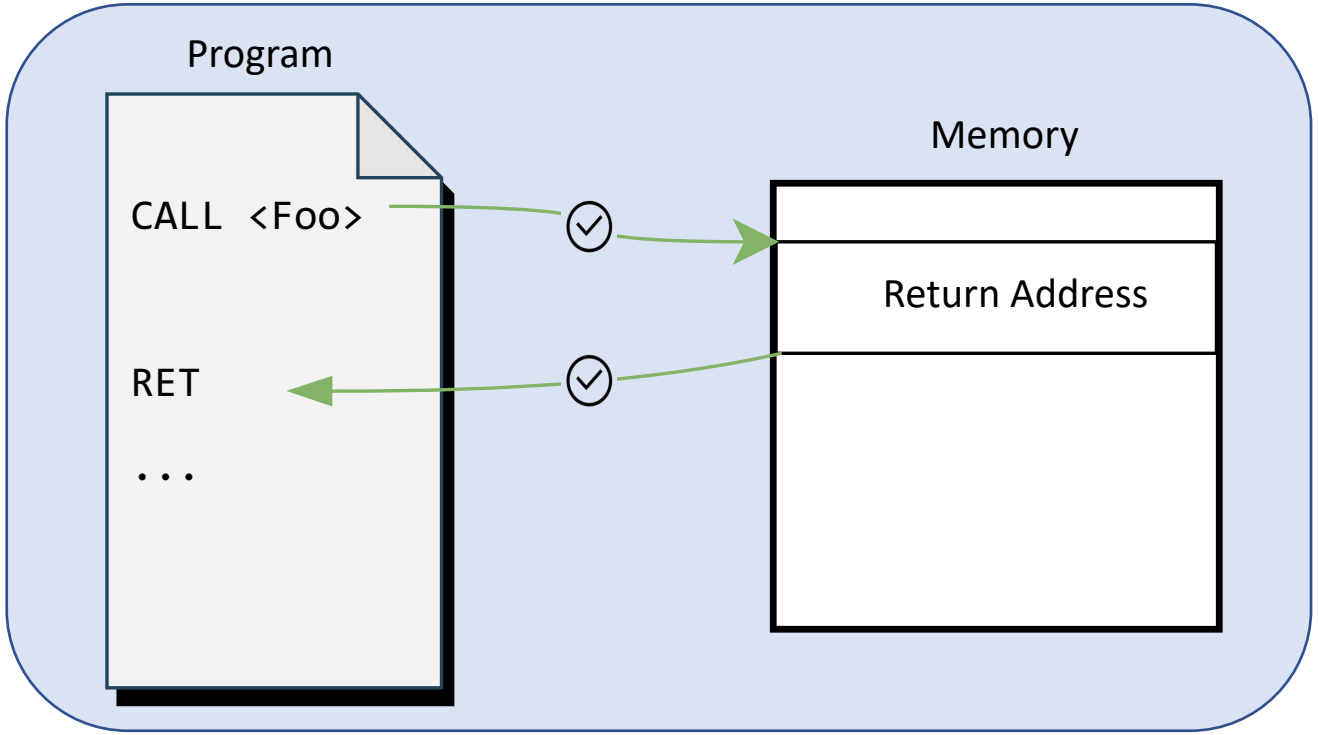

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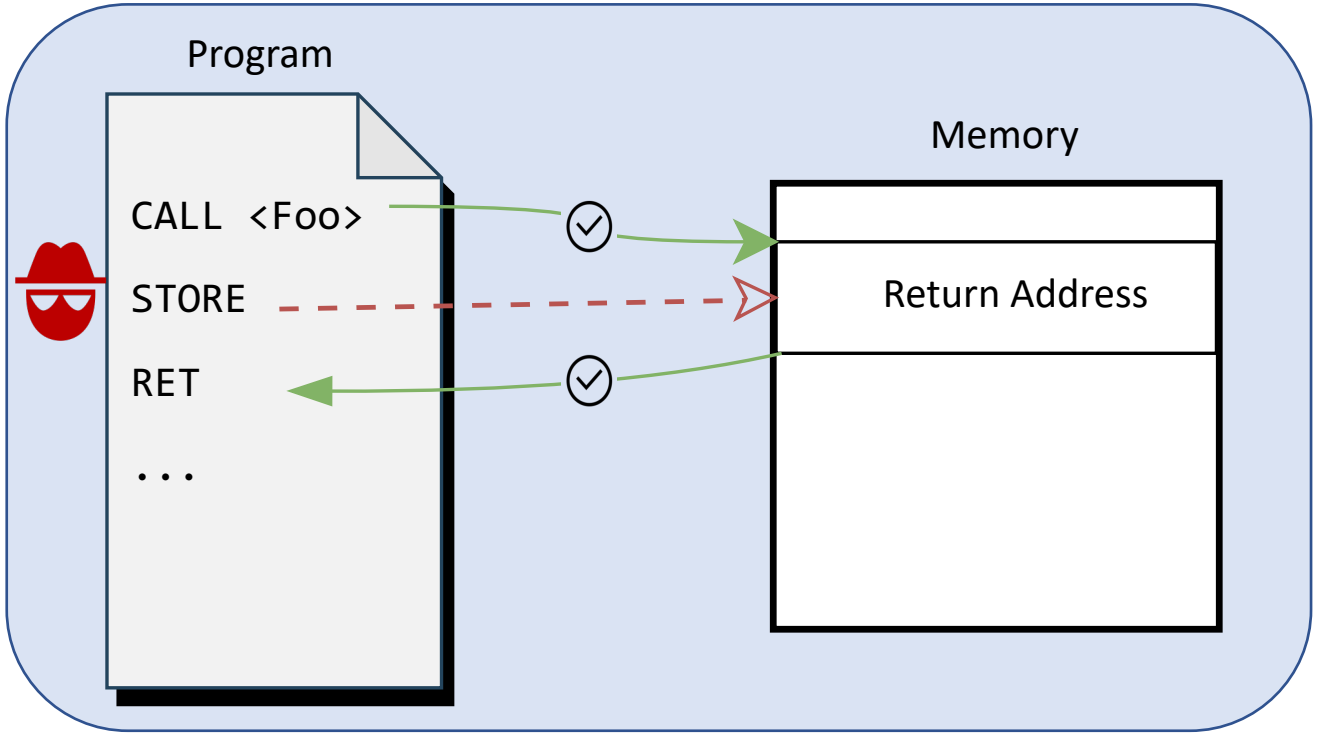

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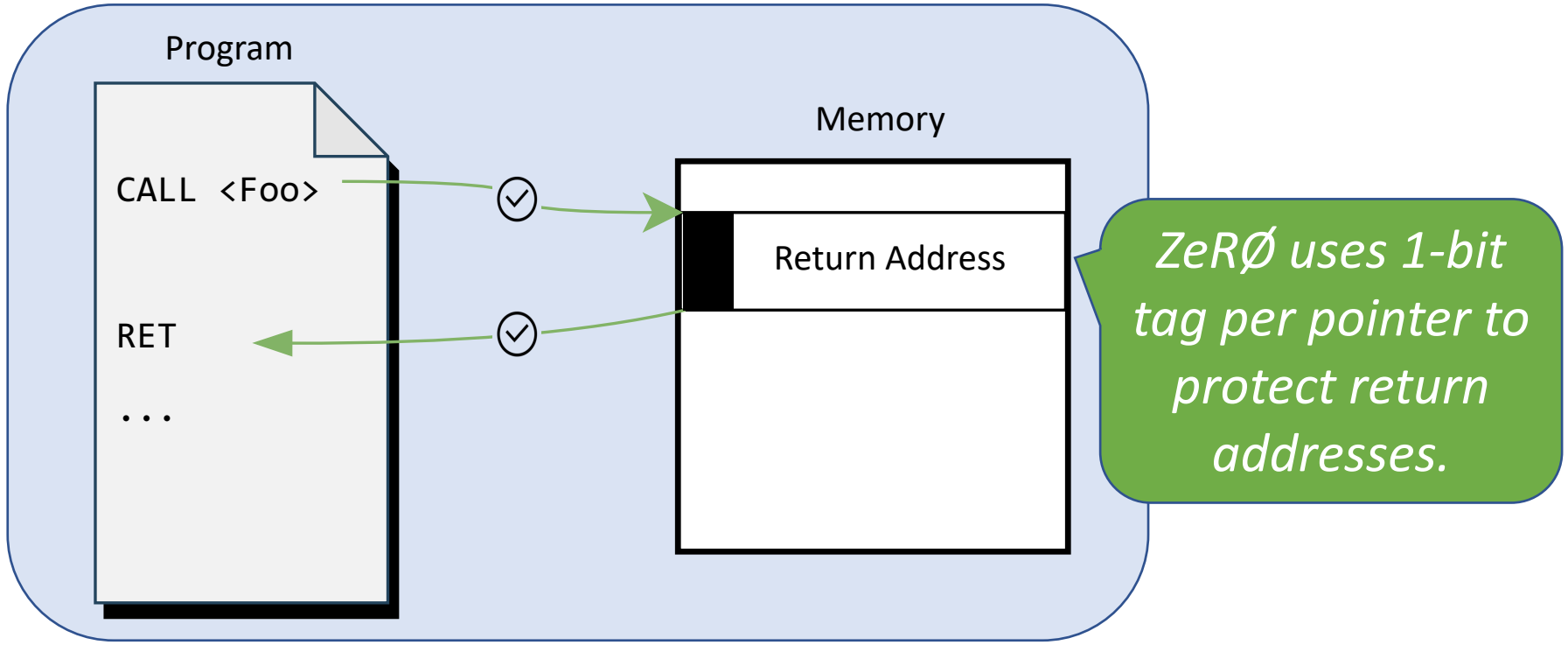

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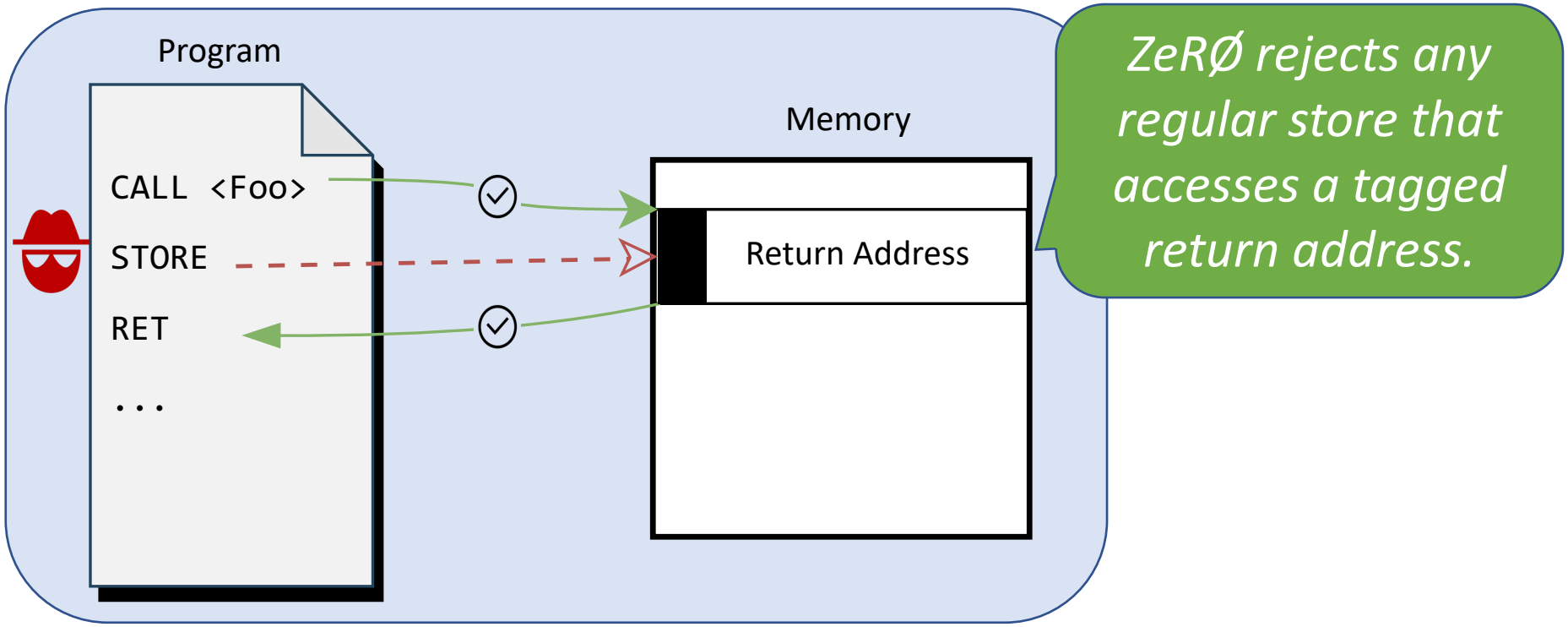

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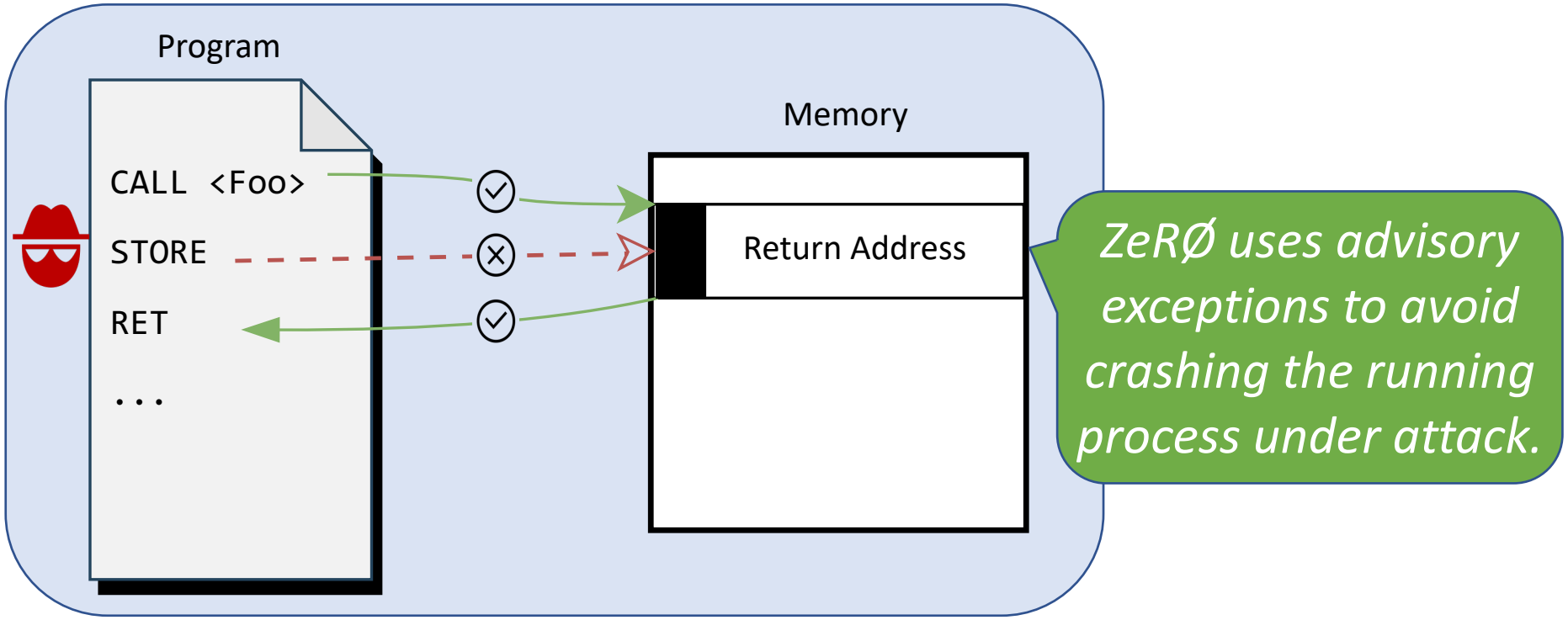

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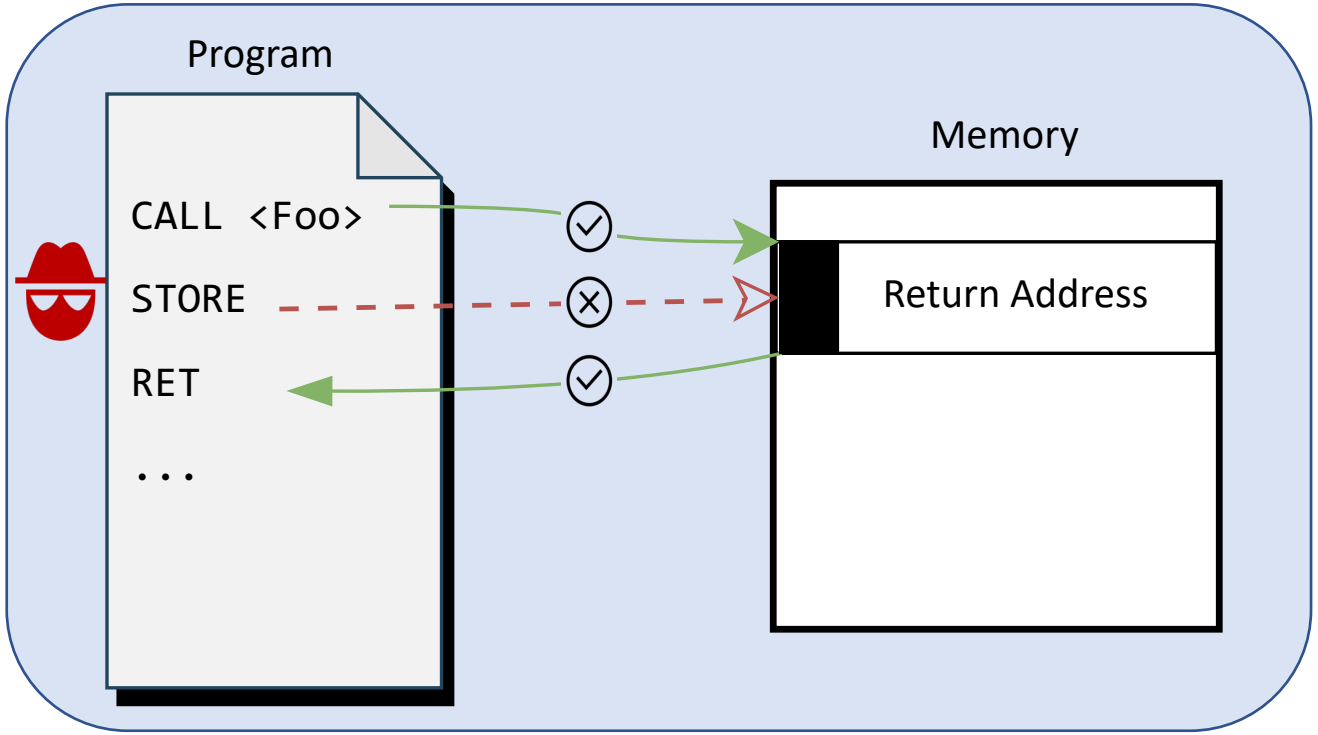

ZeRØ protects return addresses, code pointers, and data pointers.

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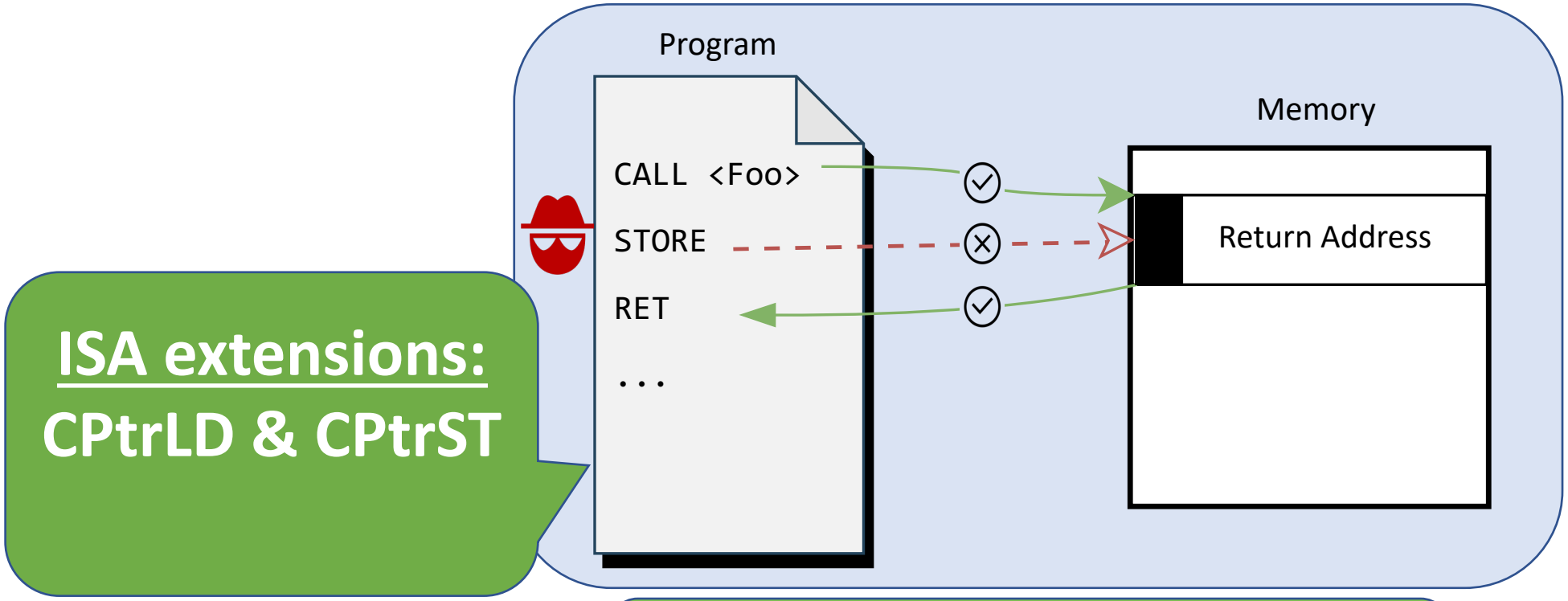

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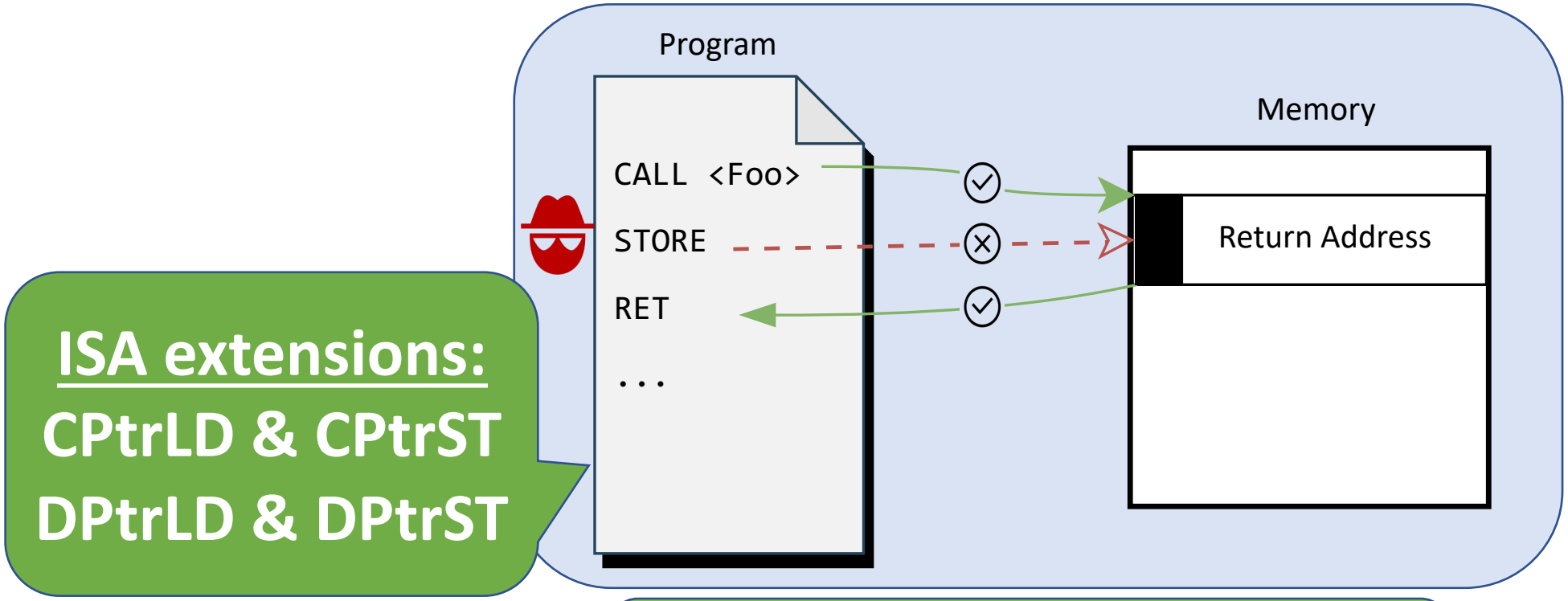

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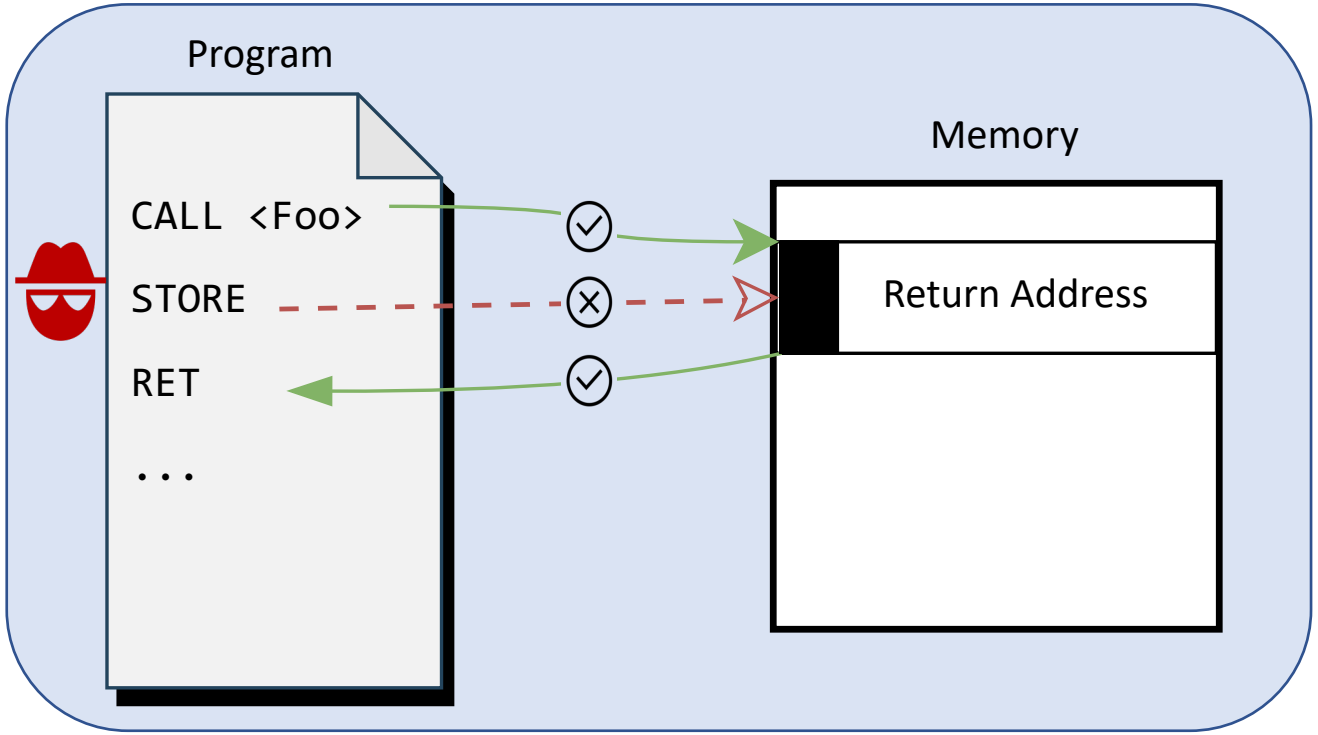
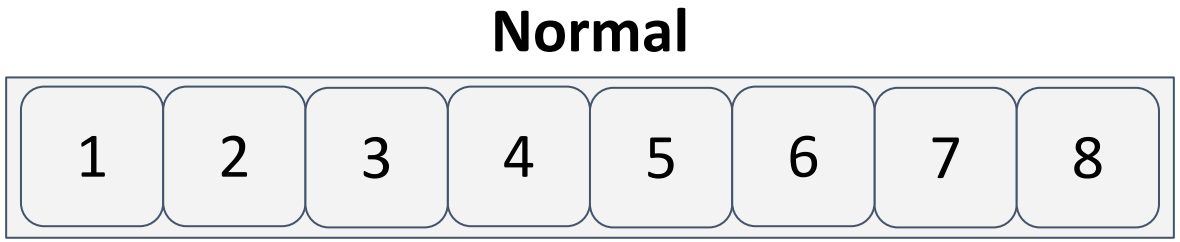


How can ZeRØ efficiently identify if a memory word is a return address, code pointer, data pointer, or regular data?

Cache Line Formats

ZeRØ: Cache Line Formats



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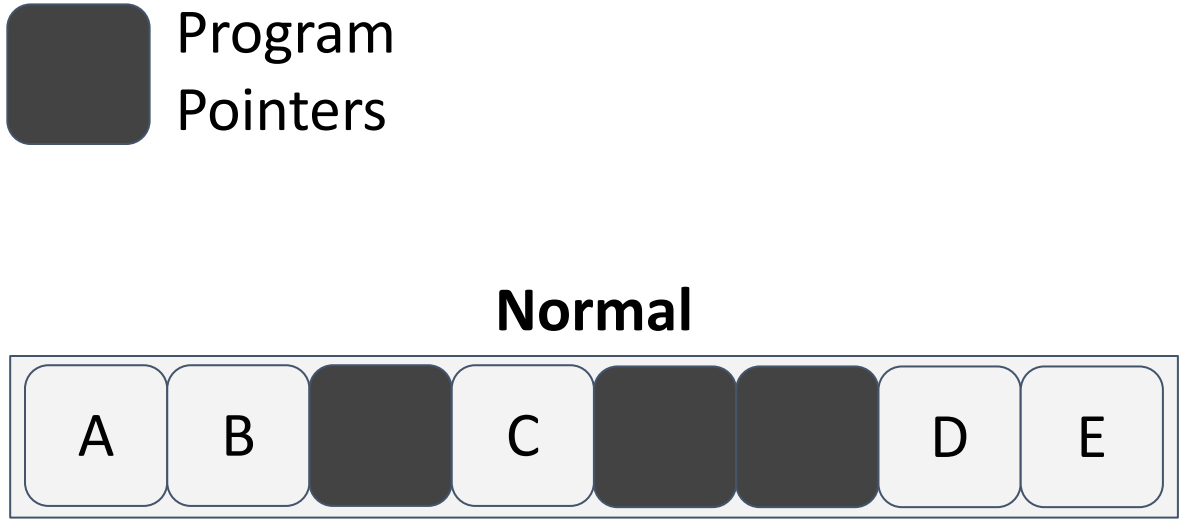

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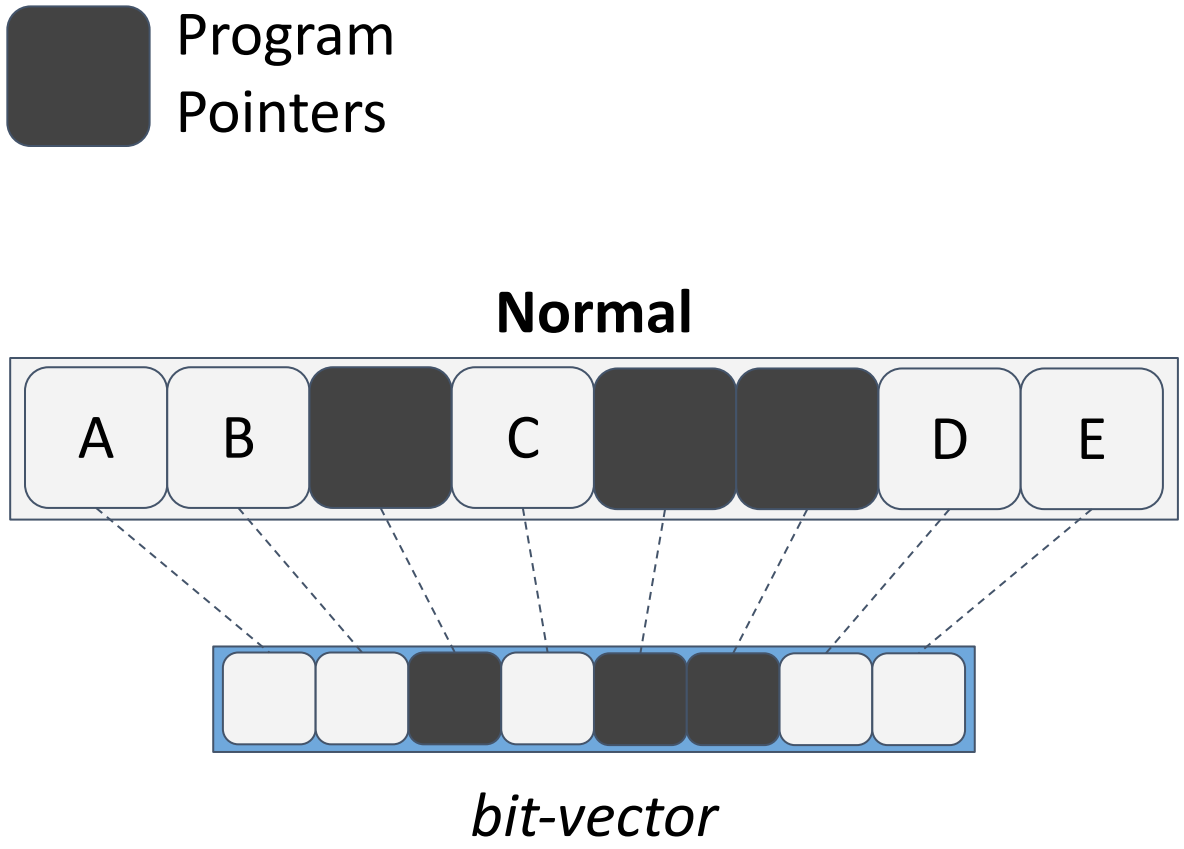
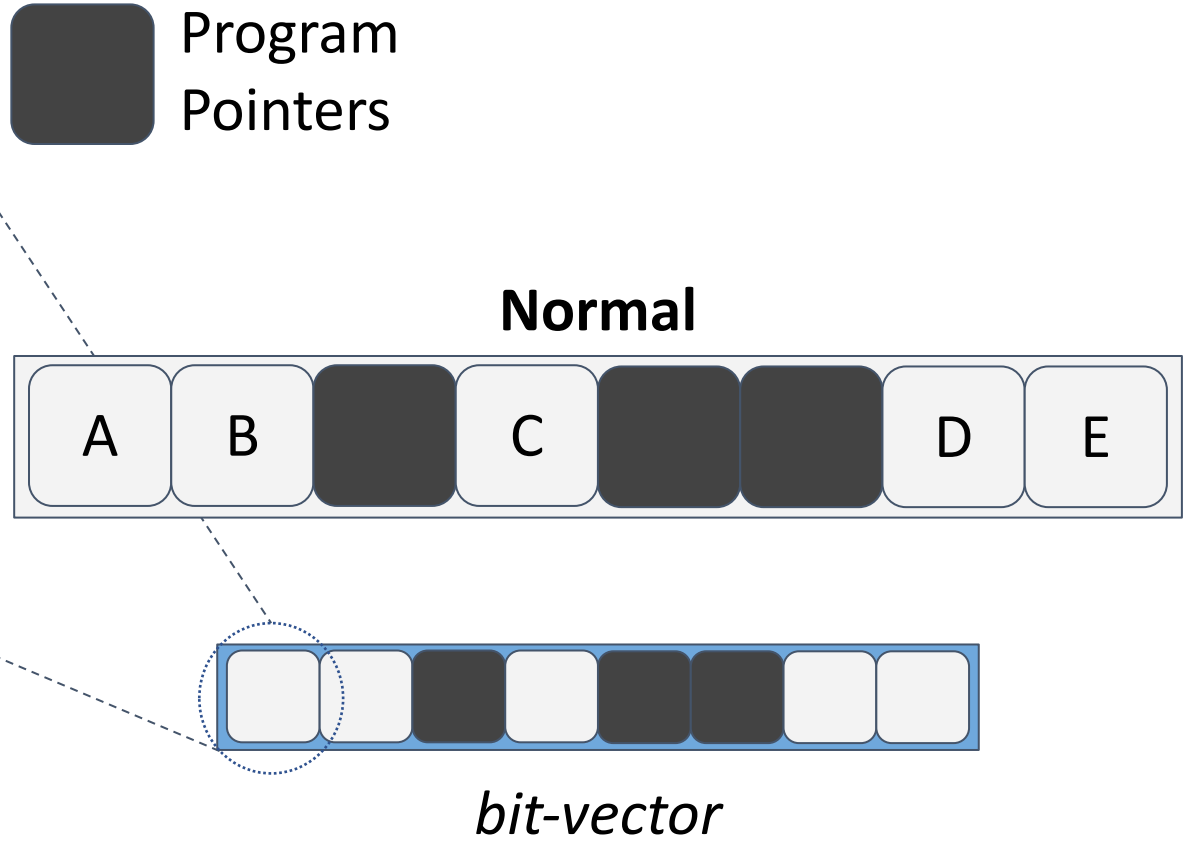


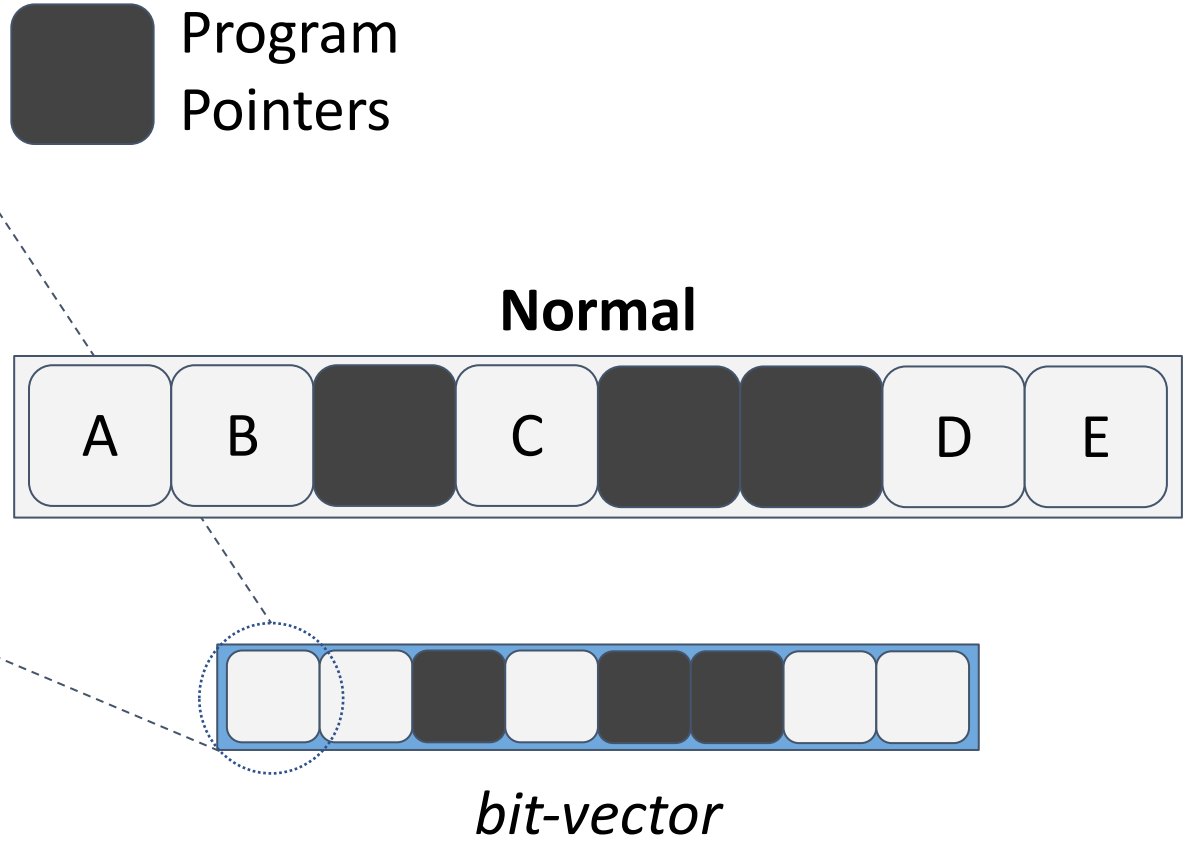
ZeRØ: Cache Line Formats

Type	Bits
Return address	01



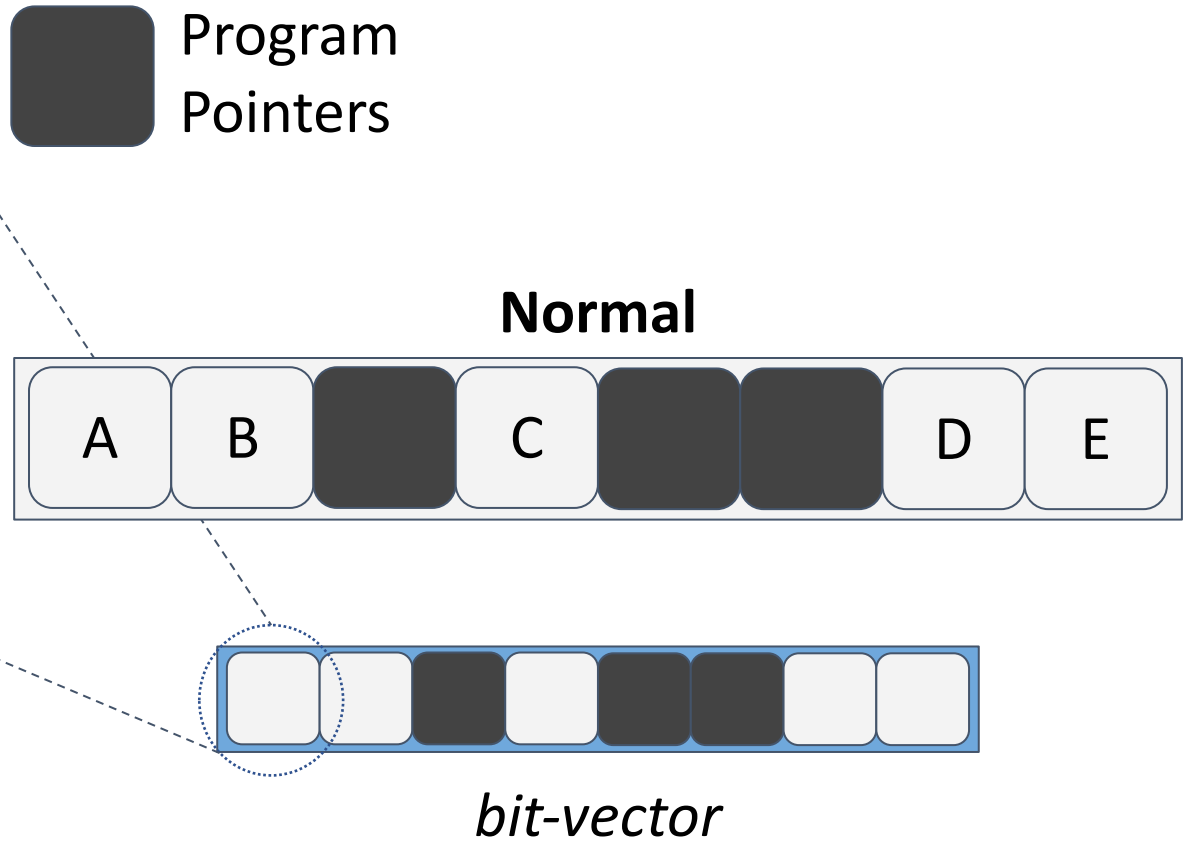
ZeRØ: Cache Line Formats

Type	Bits
Return address	01
Function pointer	10



ZeRØ: Cache Line Formats

Type	Bits
Return address	01
Function pointer	10
Data pointer	11



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Regular data	00
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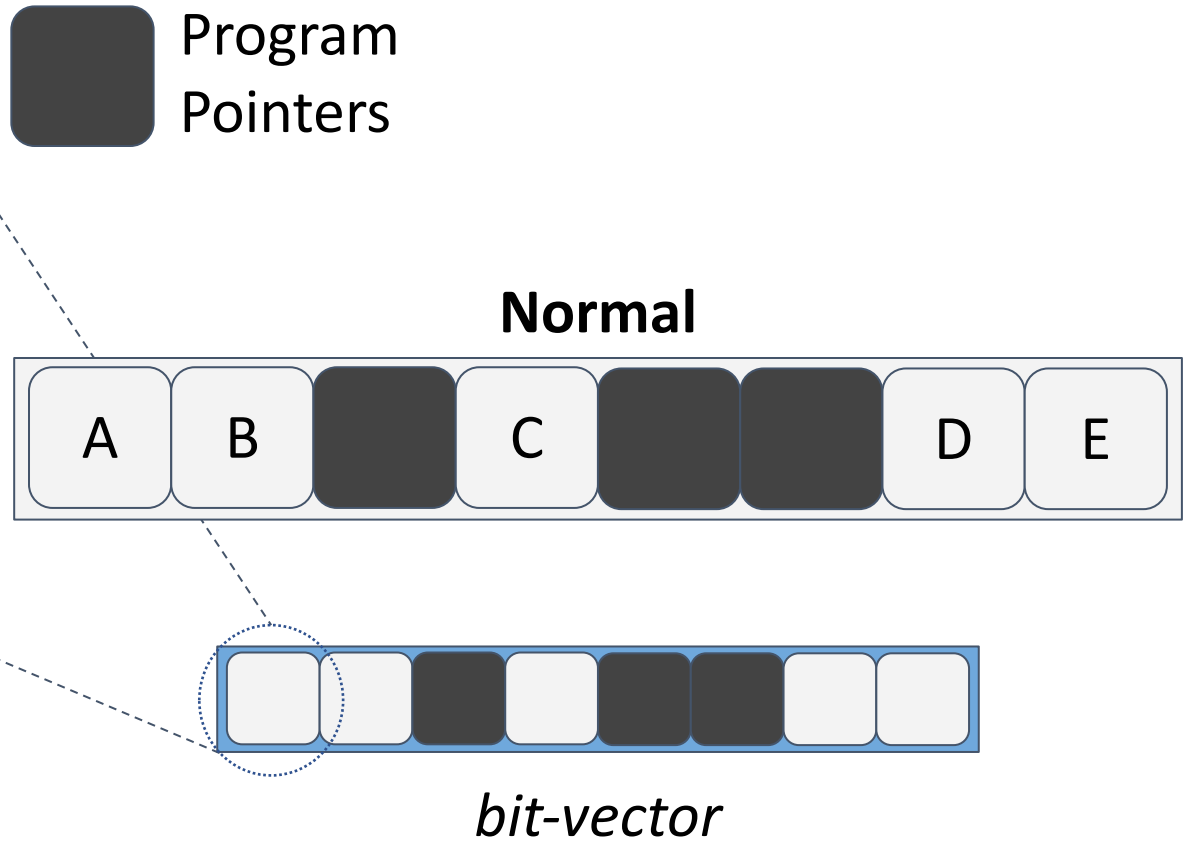

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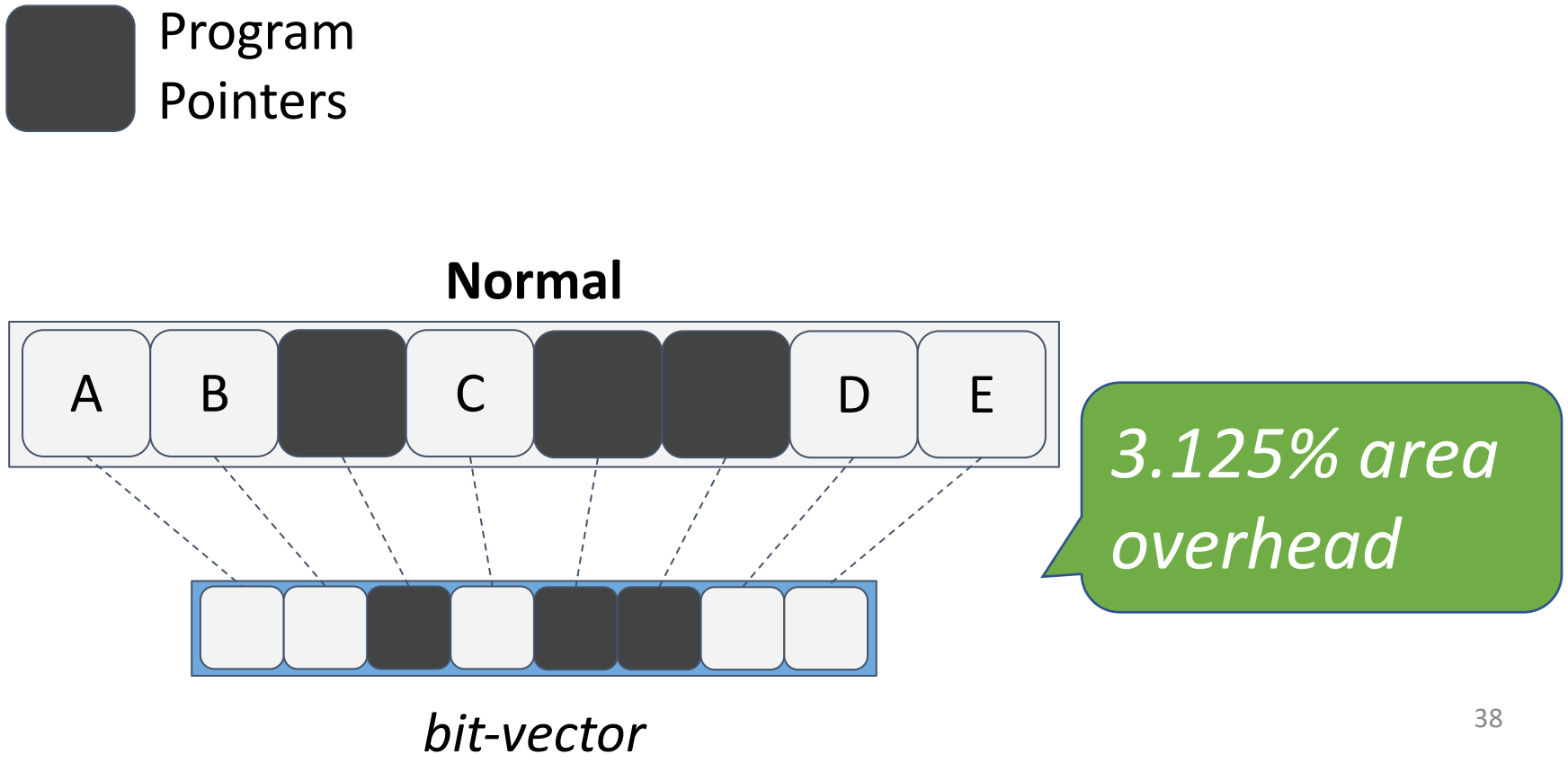

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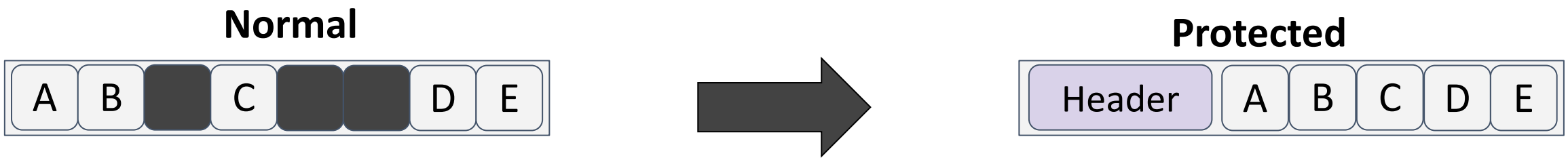
Our Metadata: Encoded within unused pointer bits.

Program Pointers



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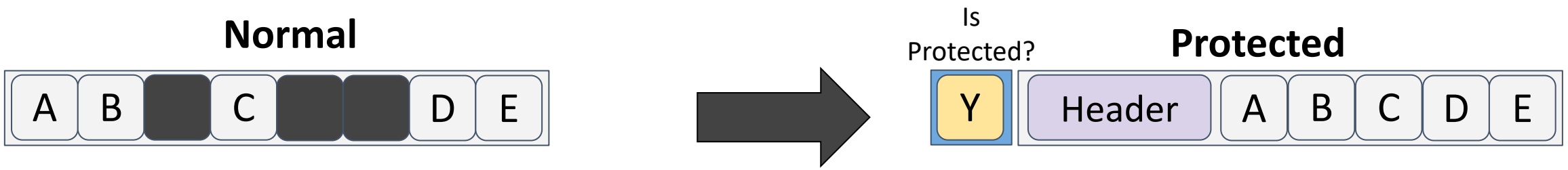

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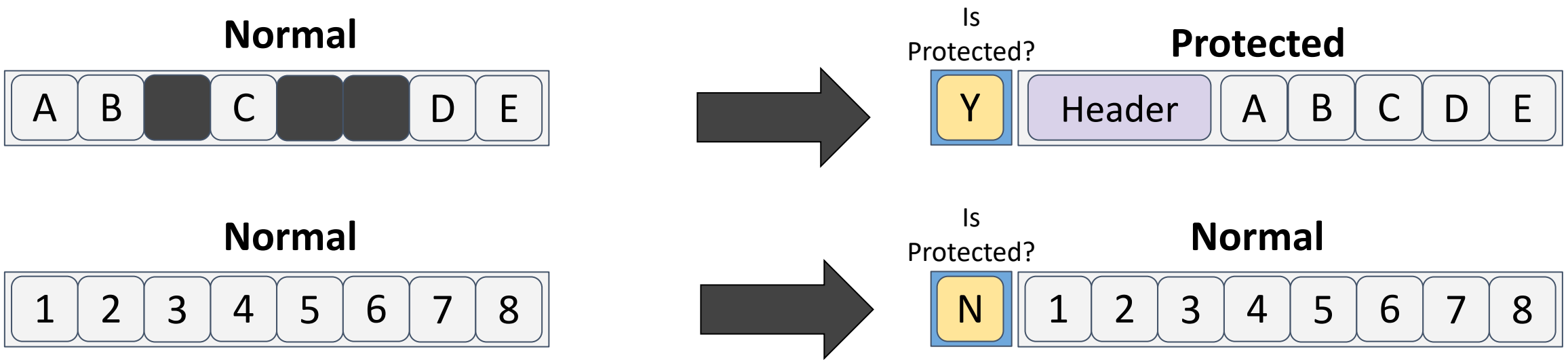

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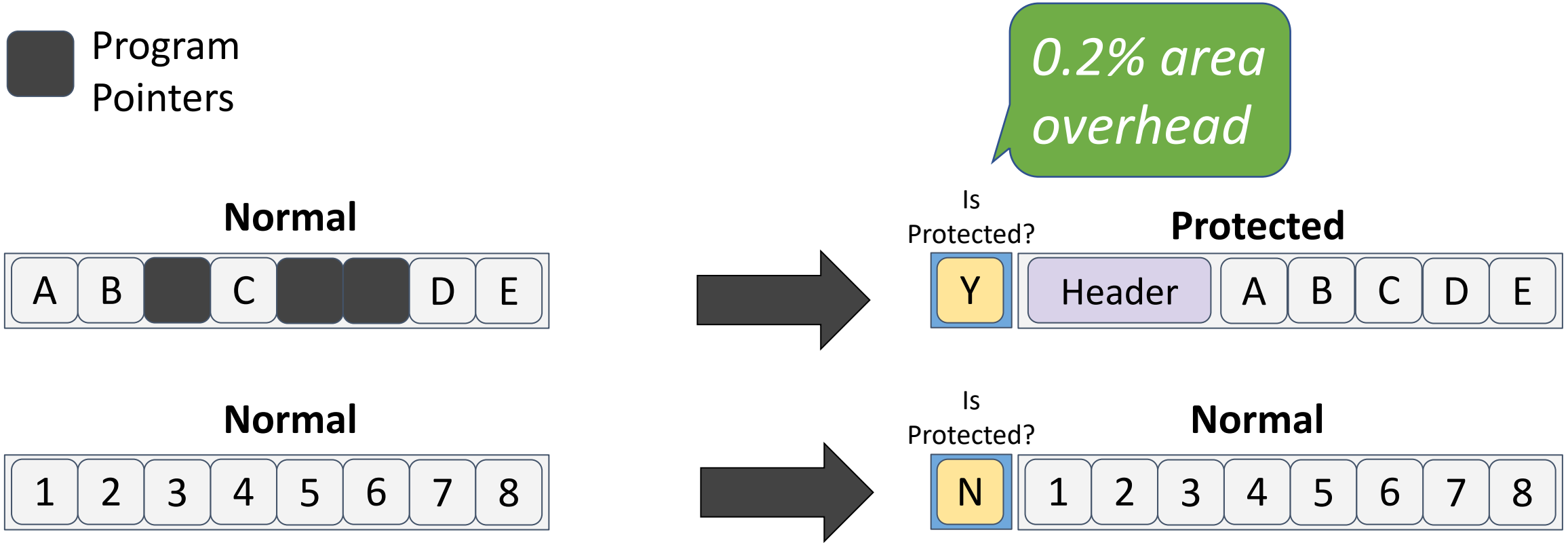

Microarchitectural Overview

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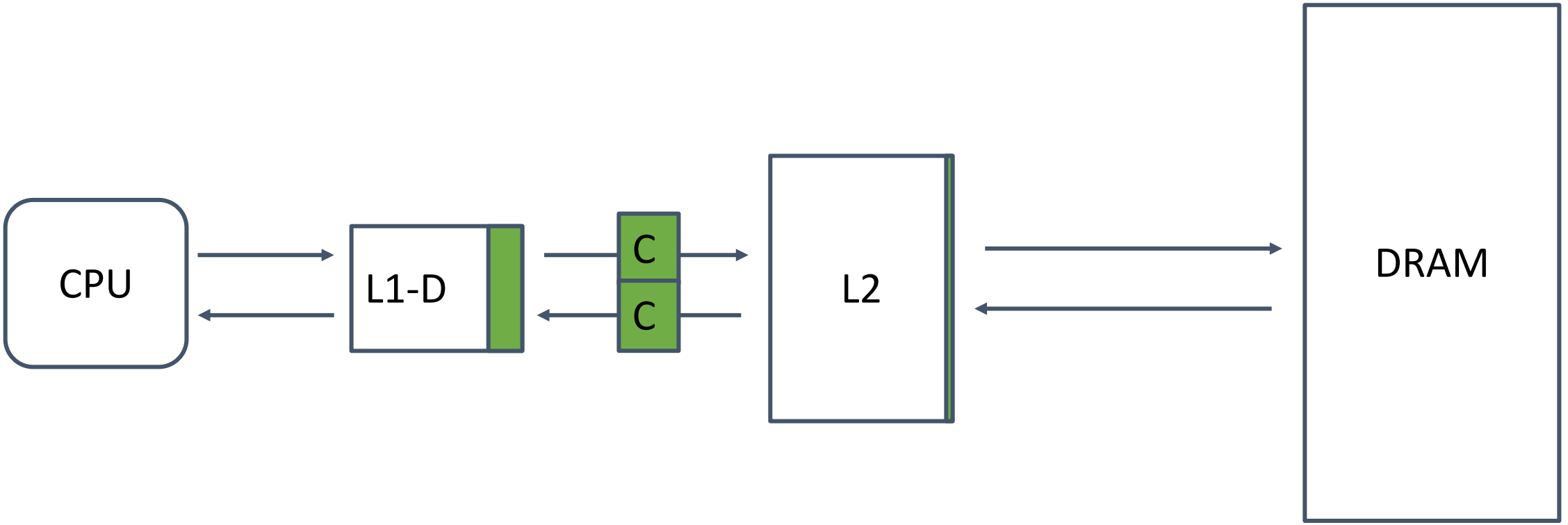

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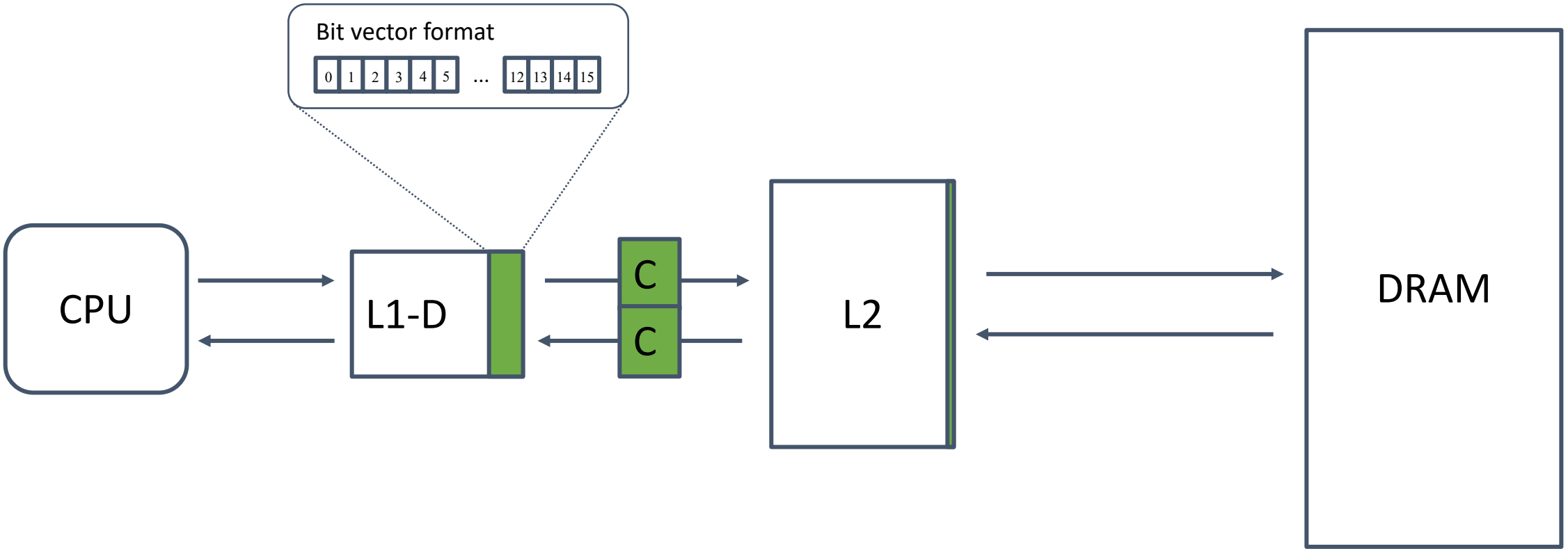

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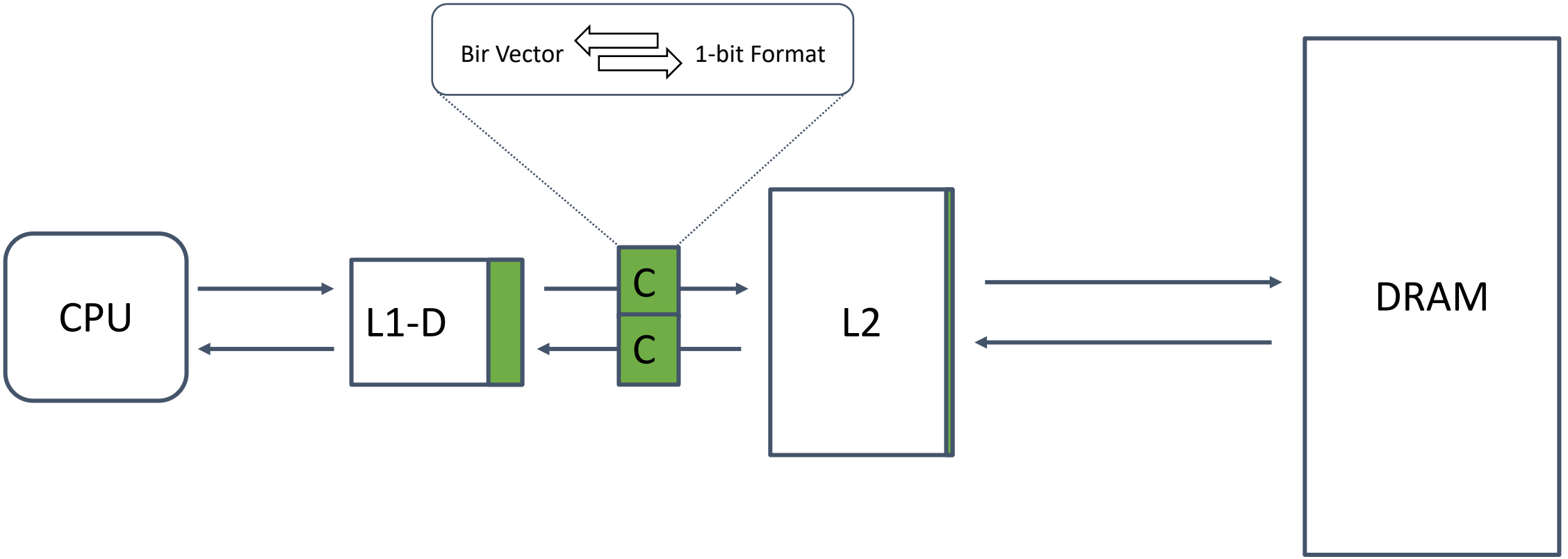

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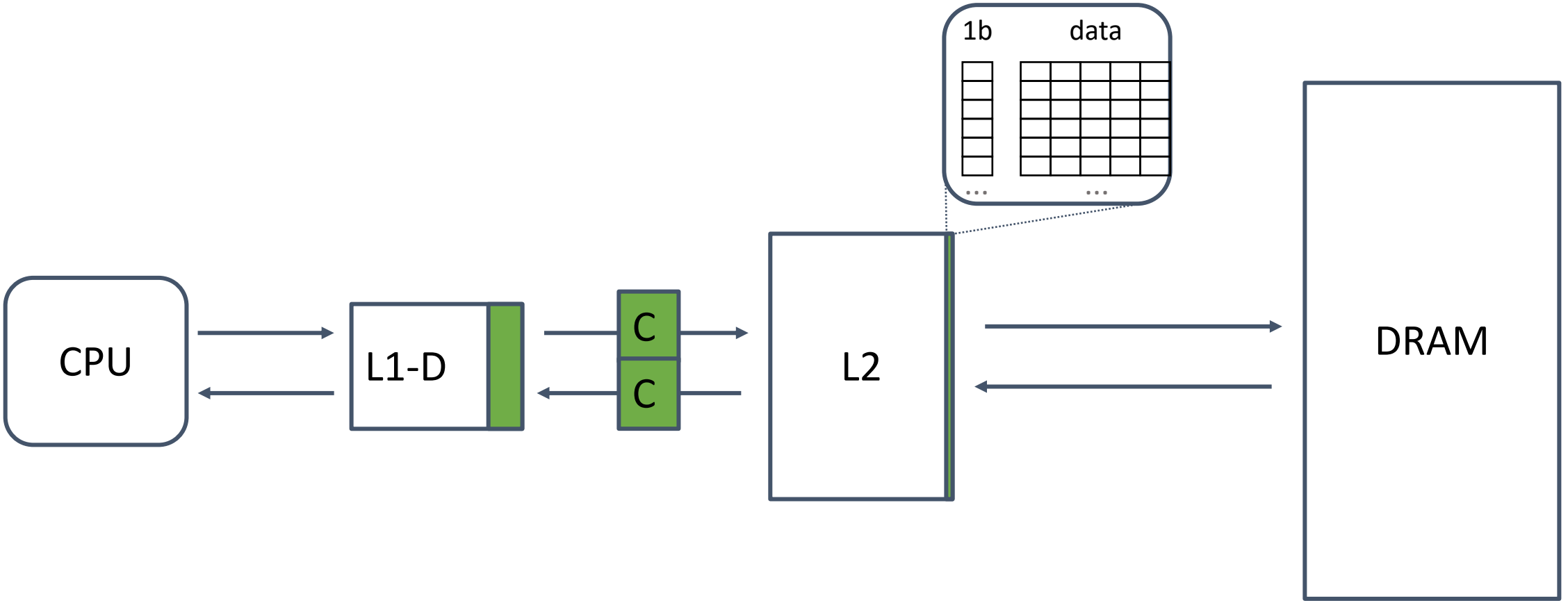

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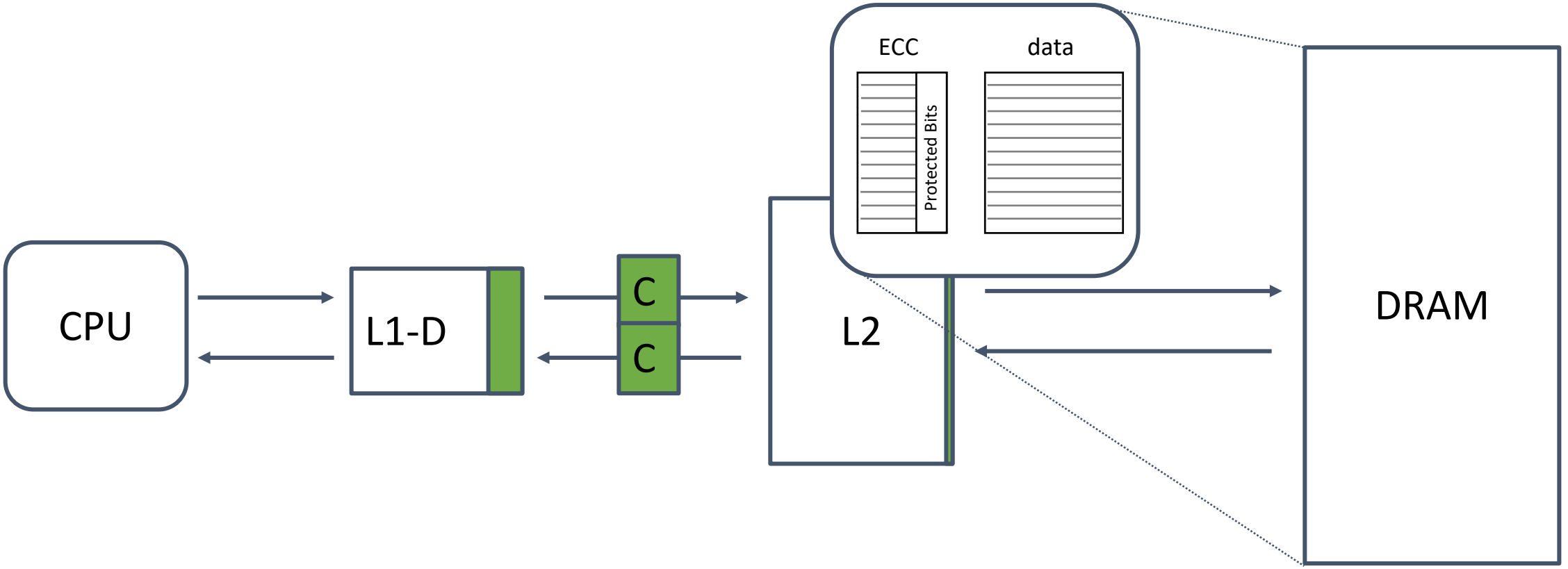

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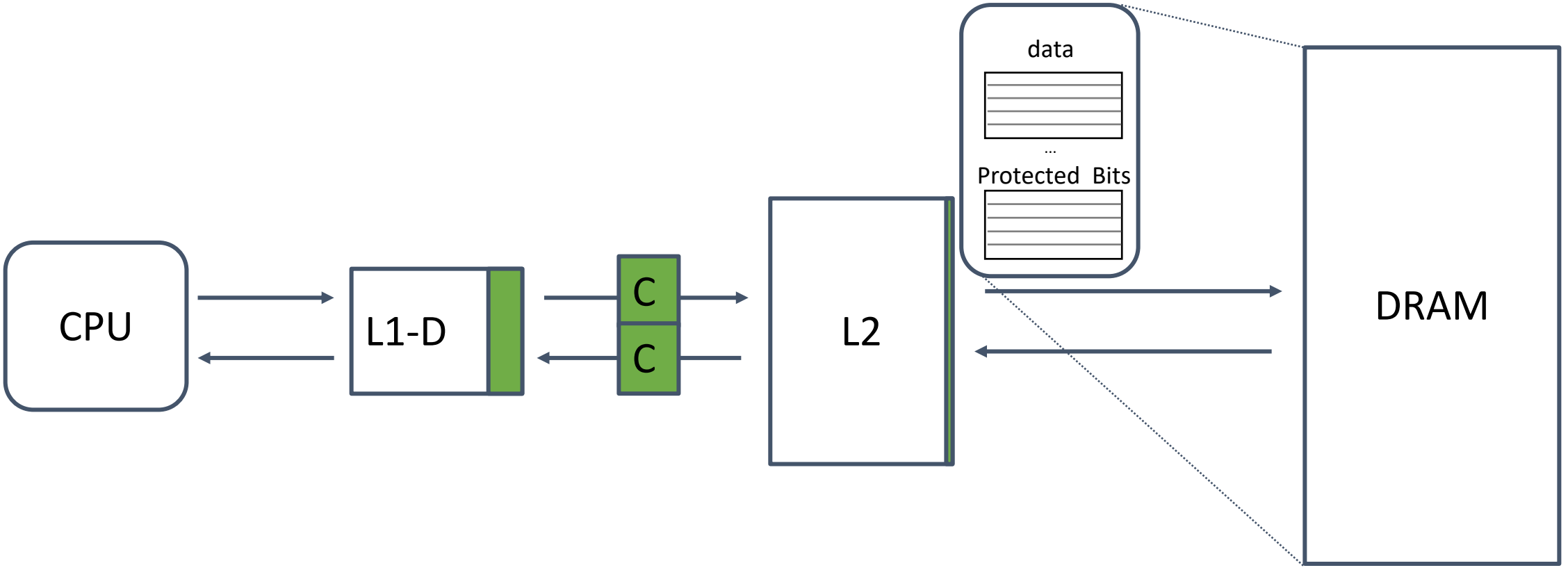

ISA Extensions

ZeRØ: ISA Extensions

```
CPtrST/CPtrLD Address, Value
```

```
DPtrST/DPtrLD Address, Value
```

ZeRØ: ISA Extensions

`CPtrST/CPtrLD Address, Value`

`DPtrST/DPtrLD Address, Value`

Same Layout as regular Loads/Stores

ZeRØ: ISA Extensions

```
CPtrST/CPtrLD Address, Value
```

```
DPtrST/DPtrLD Address, Value
```

```
ClearMeta Address, Mask
```

Only invoked upon free() or delete()

Performance

ZeRØ: Performance Overheads

- Hardware Overheads.

- Software Overheads.

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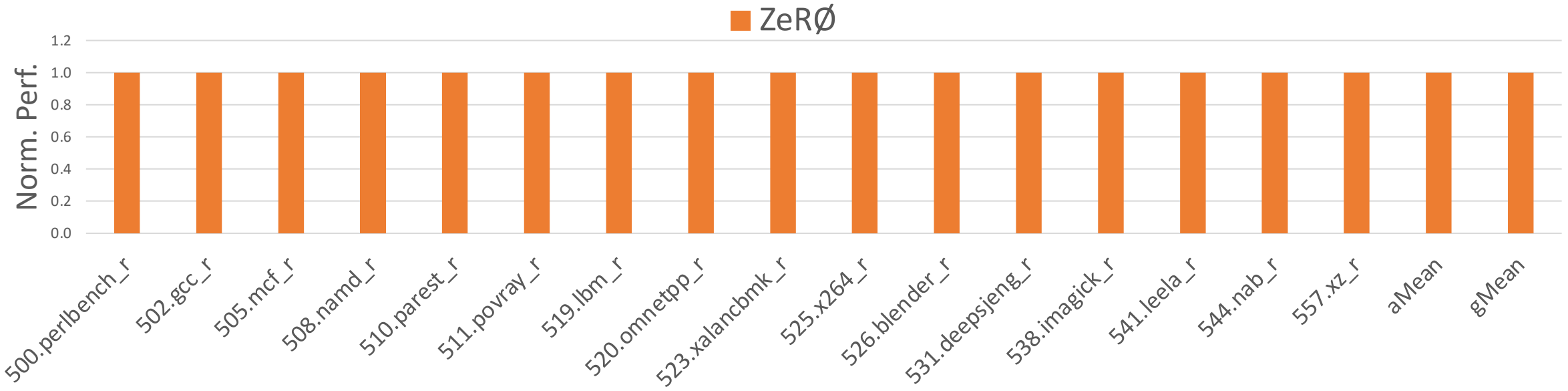
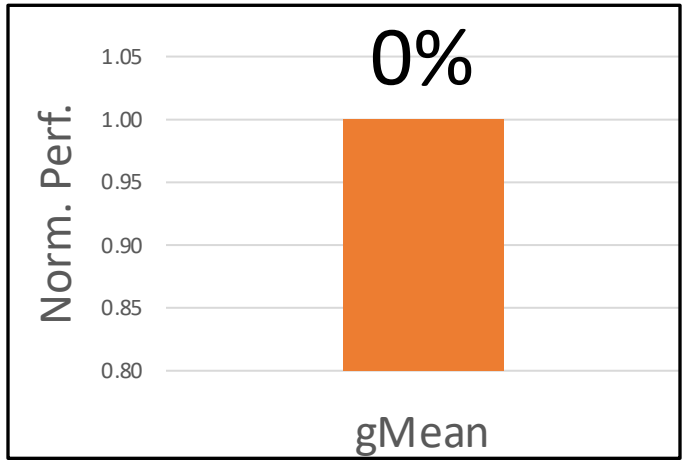
The ClearMeta instructions are emulated on x86_64 using dummy stores

ZeRØ: Performance Results on x86_64





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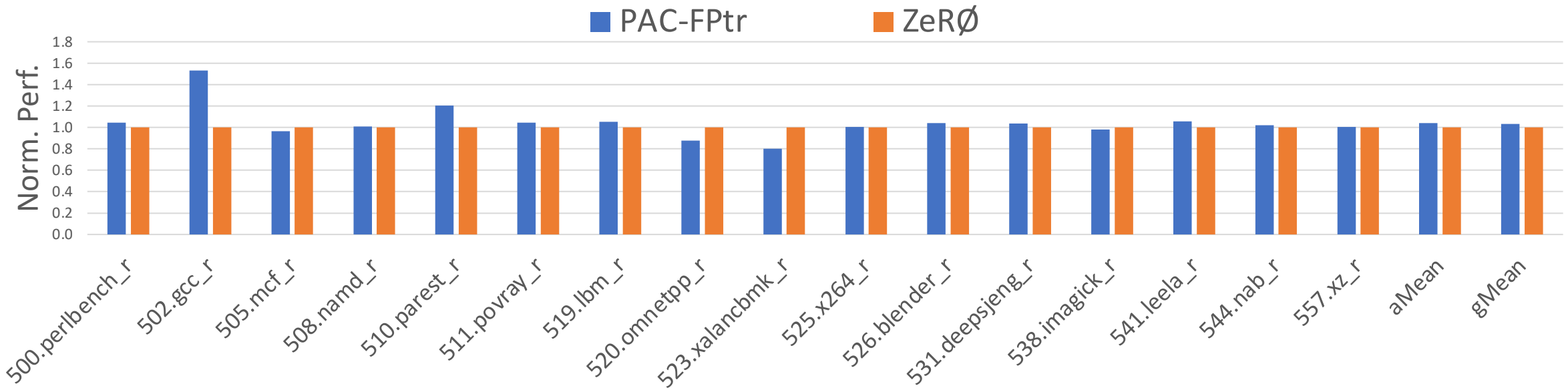

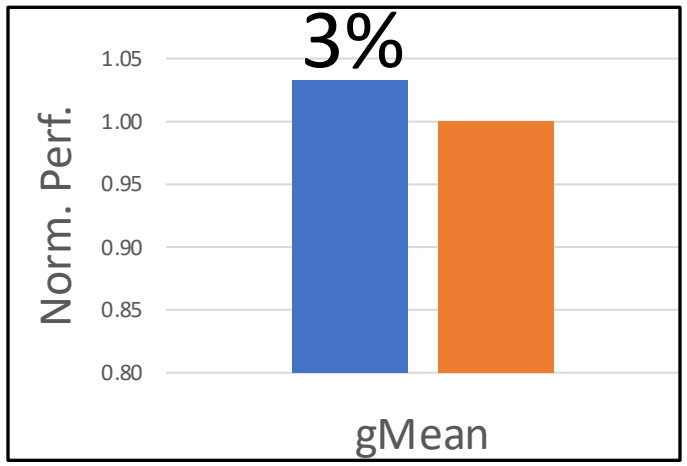

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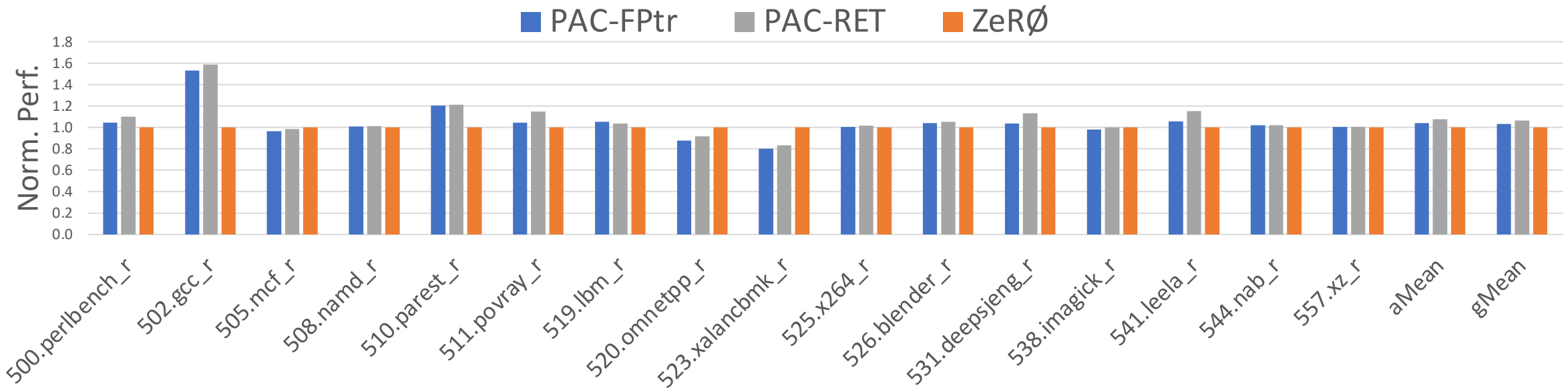

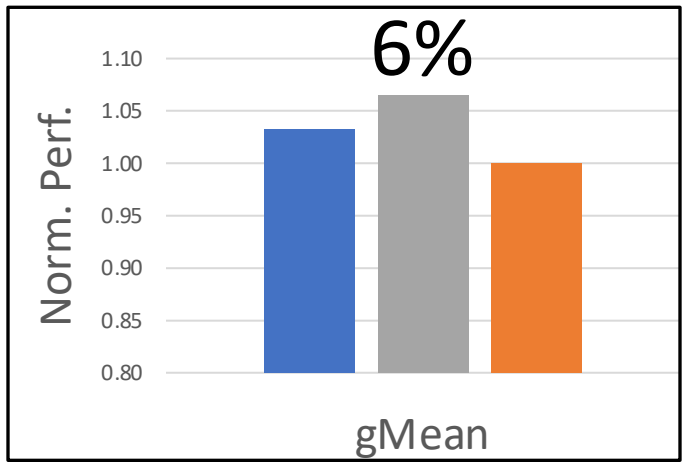

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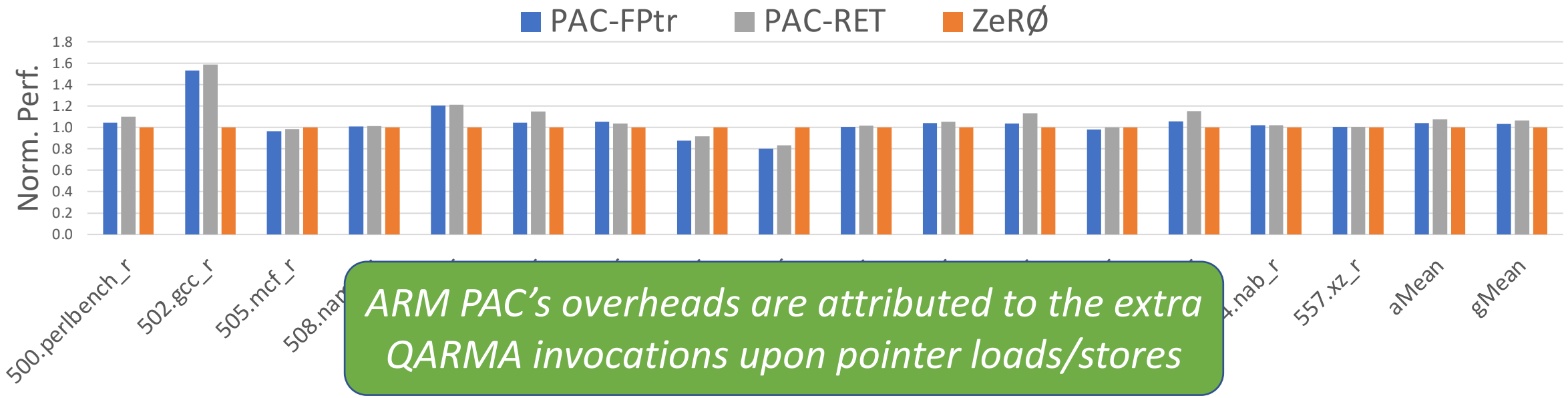
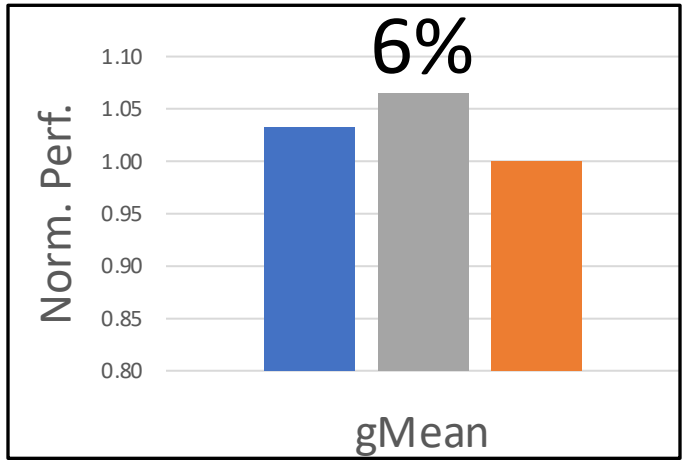


ARM PAC's overheads are attributed to the extra QARMA invocations upon pointer loads/stores



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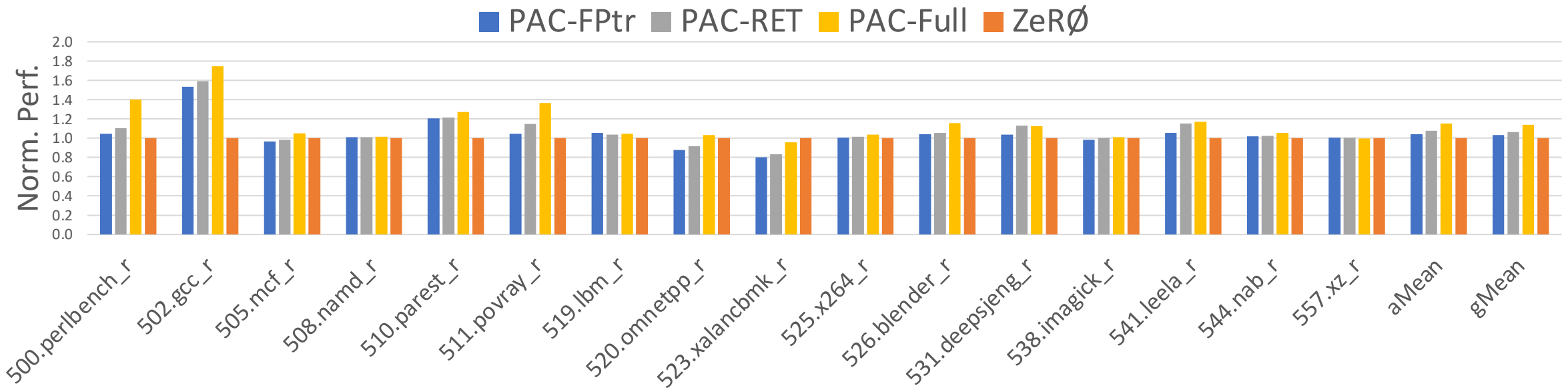
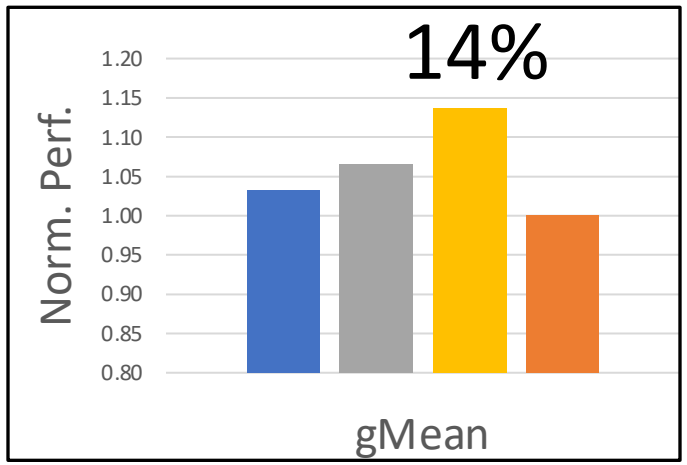
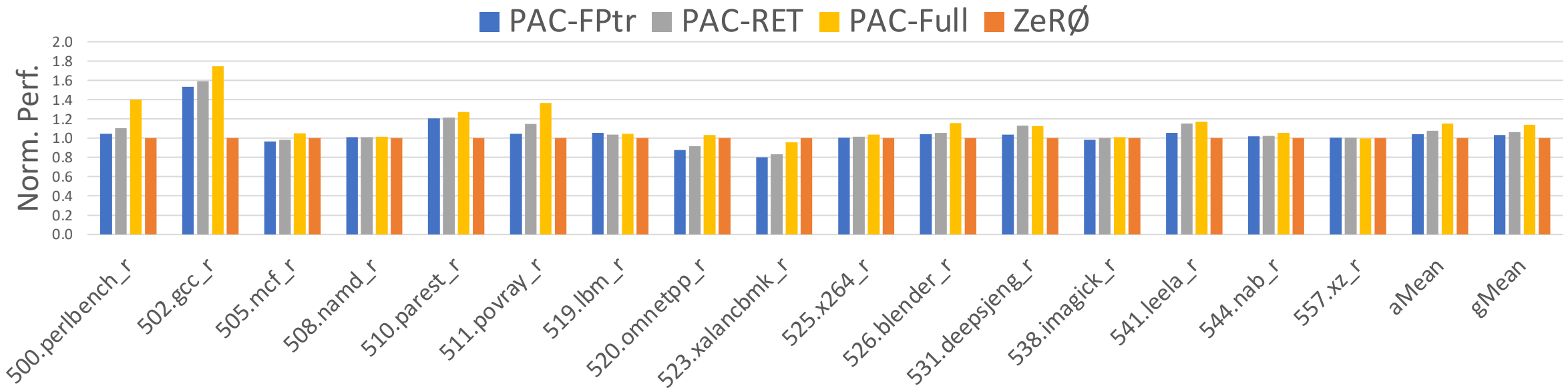
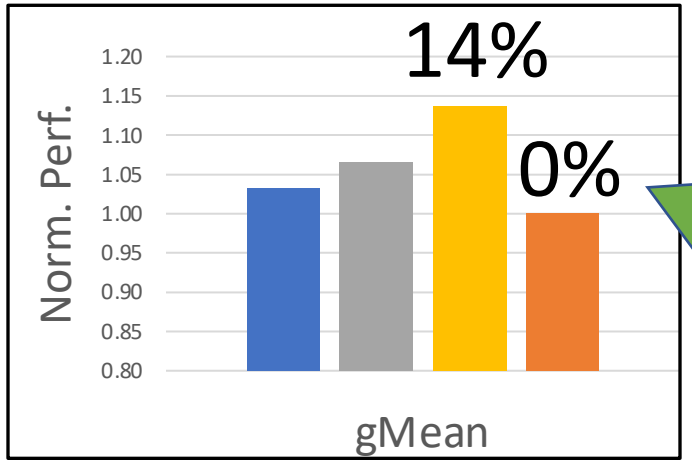




ZeRØ: Performance Results on x86_64





ZeRØ reduces the average runtime overheads of pointer integrity from 14% to 0%

Limitations

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- Third-party code.
  - Clear the metadata bits before passing pointers to shared libraries.

Conclusion

- ZeRØ provides an efficient pointer integrity mechanism:
  - Is **easy to implement**.
  - Has **no runtime overheads**.
  - Offers **robust security**.

- ZeRØ can be applied to a wide variety of systems:
  - Ranging from servers to mobile devices.