Zero-Overhead Resilient Operation Under Pointer Integrity Attacks

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COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

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Security?


Security!

Inefficient security inconveniences the user

Most end users want security,
but do not want the inconvenience of having it.

Inefficient security inconveniences the user

Slow Performance
User want a snappy experience and security tends to detract from it.

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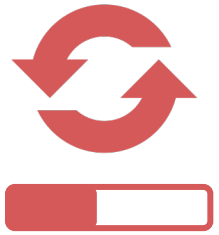

System Stability
Users can’t be bothered with updates and patches.

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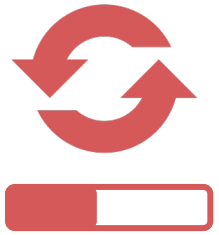

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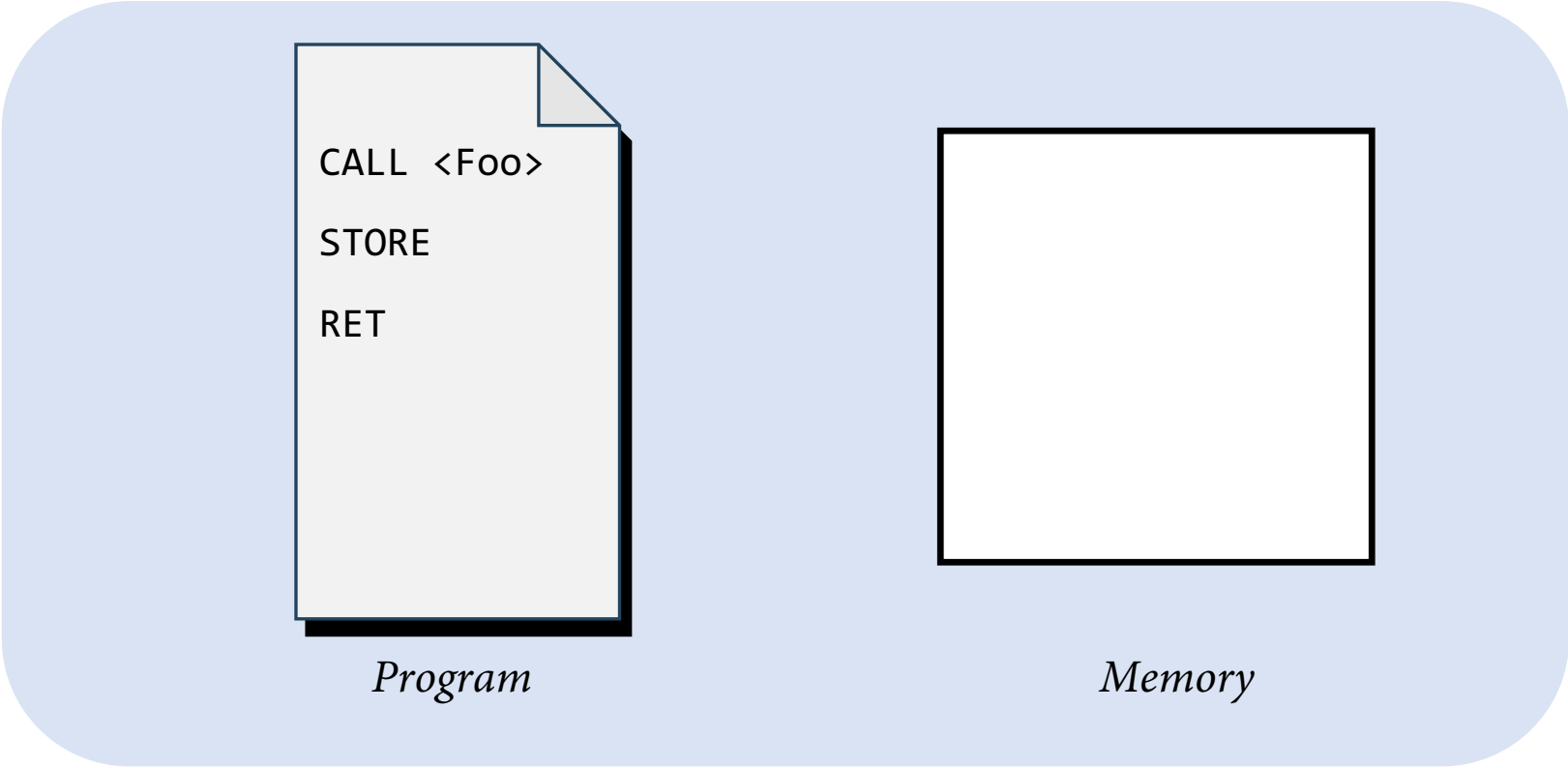
ZeRØ

Return Address Protection



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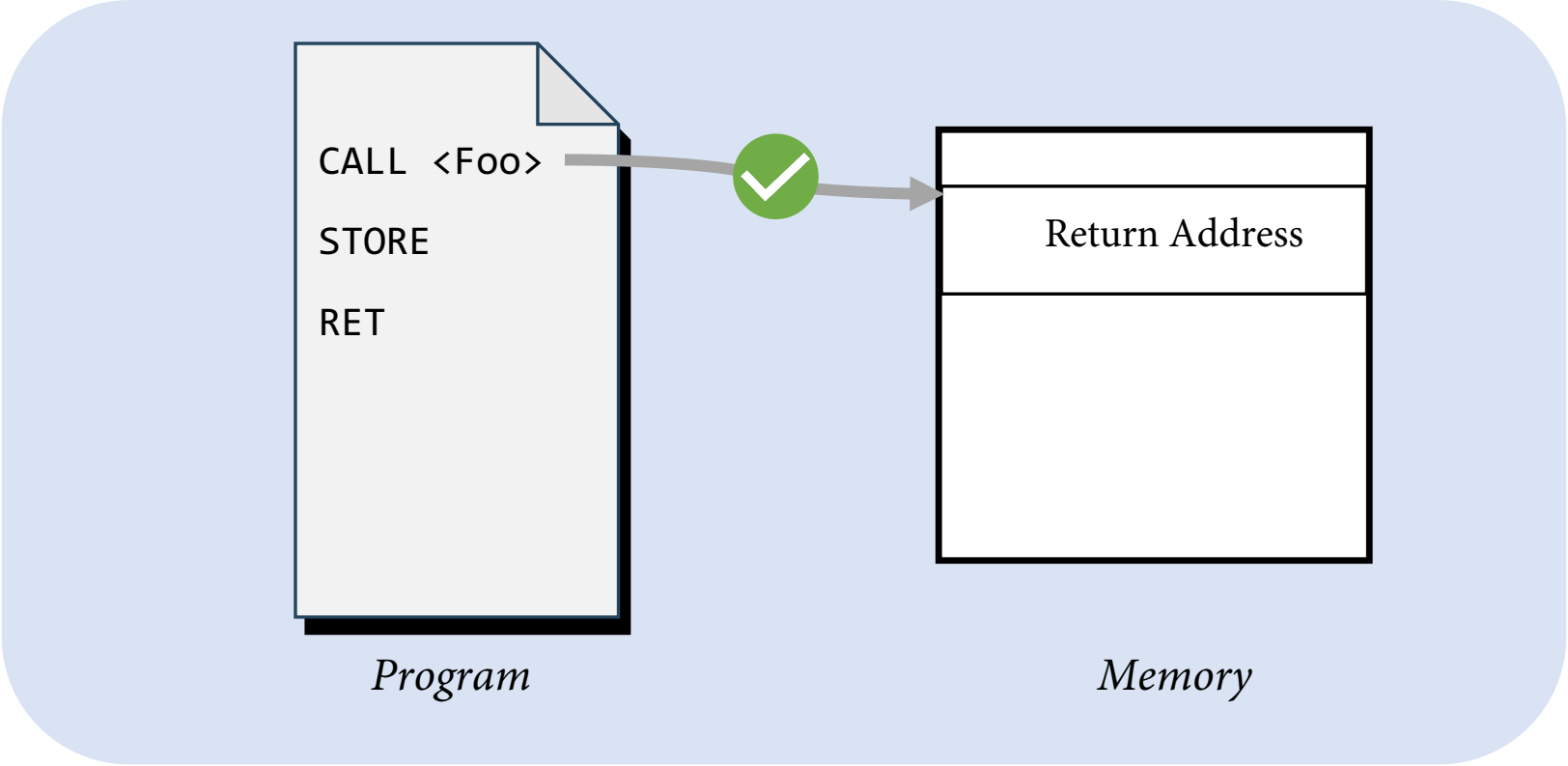

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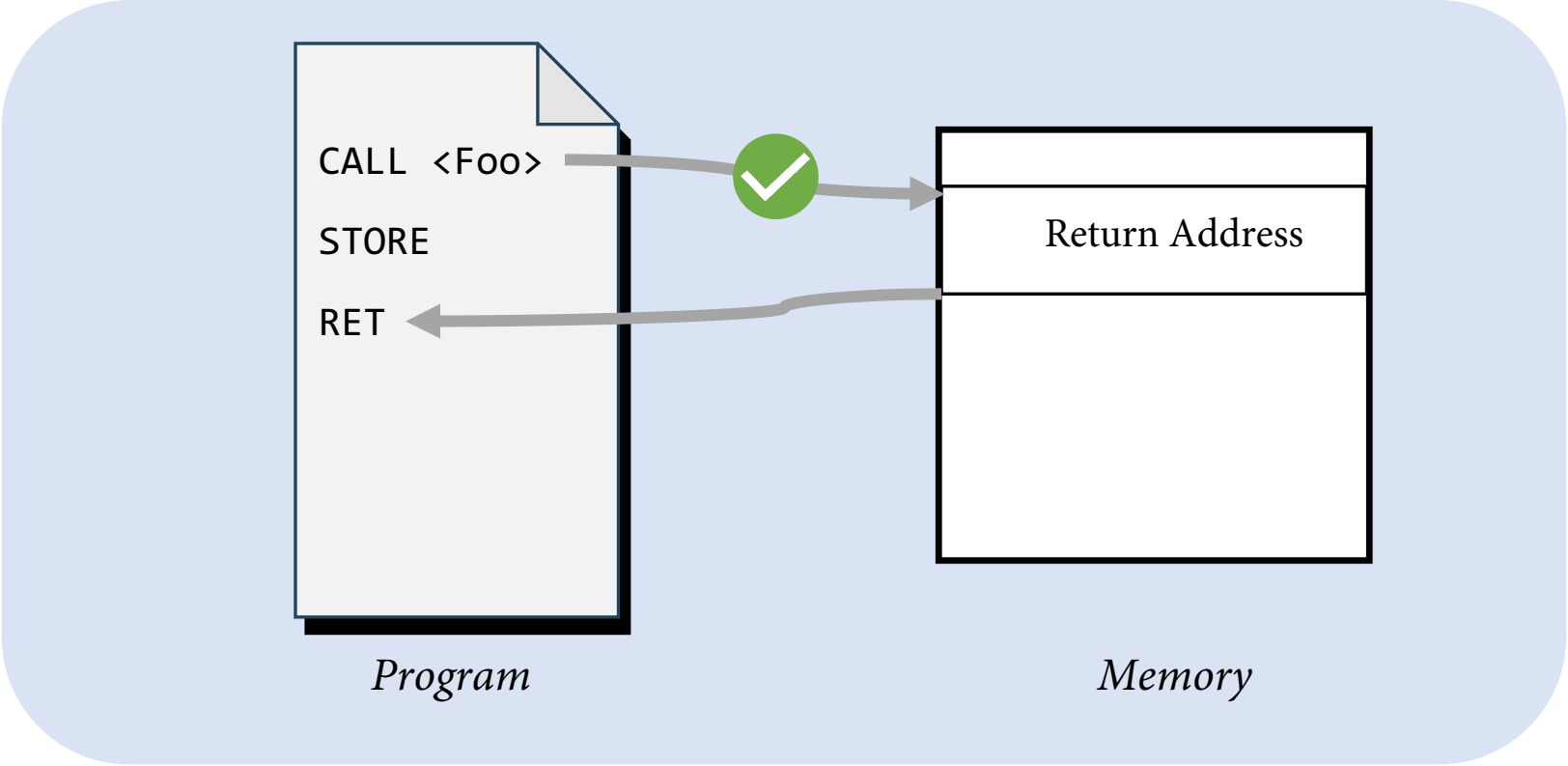

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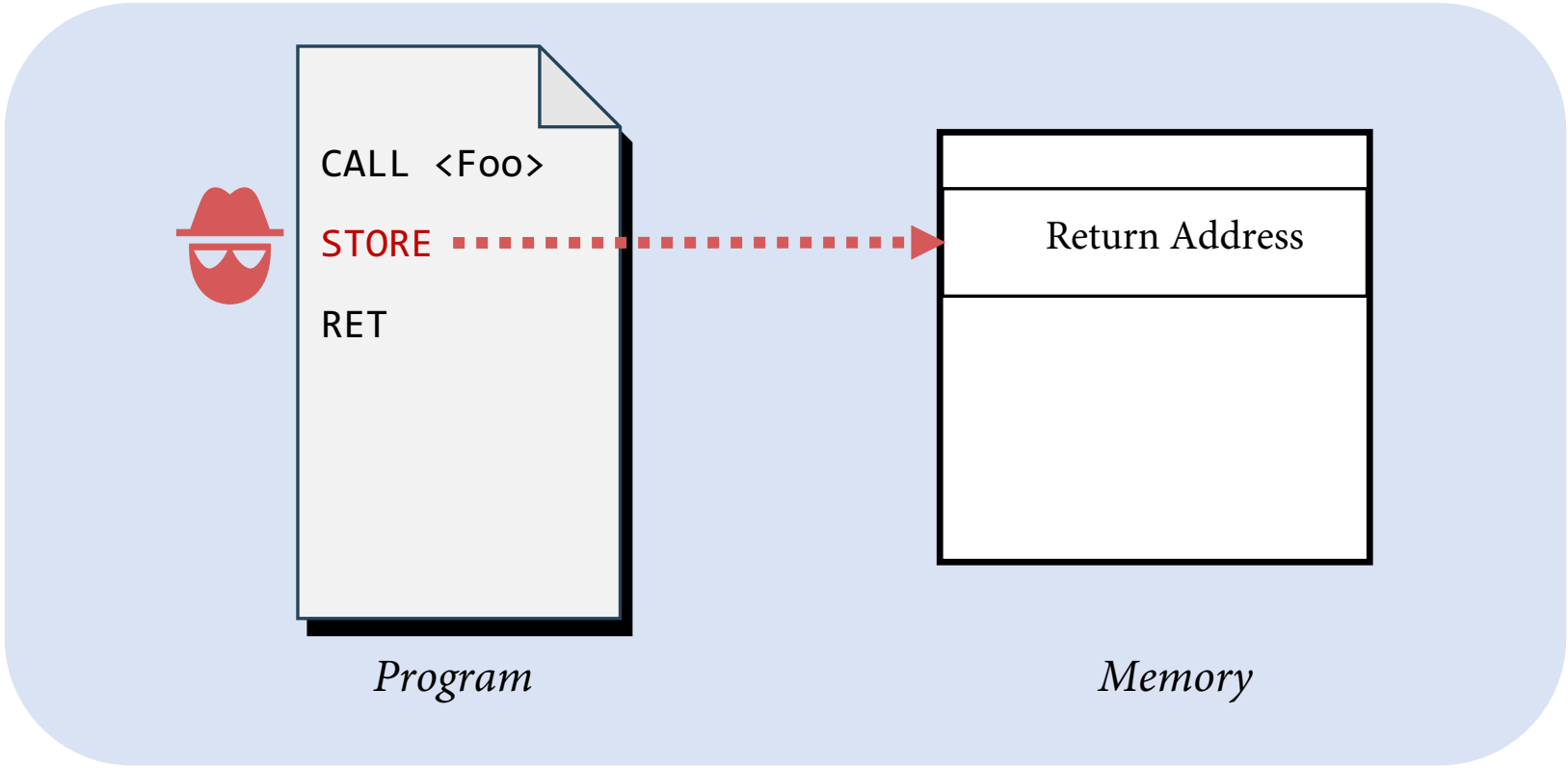

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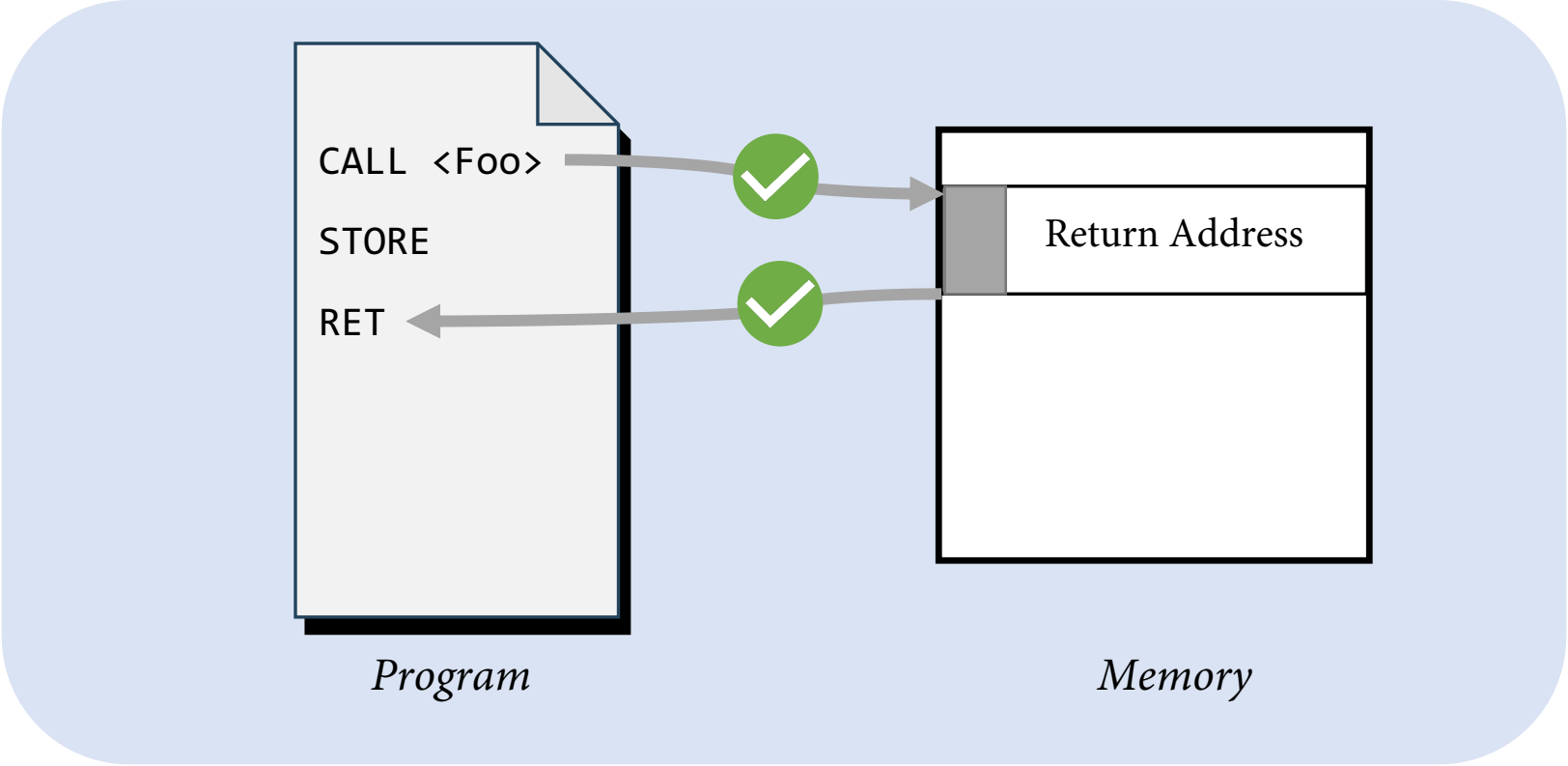

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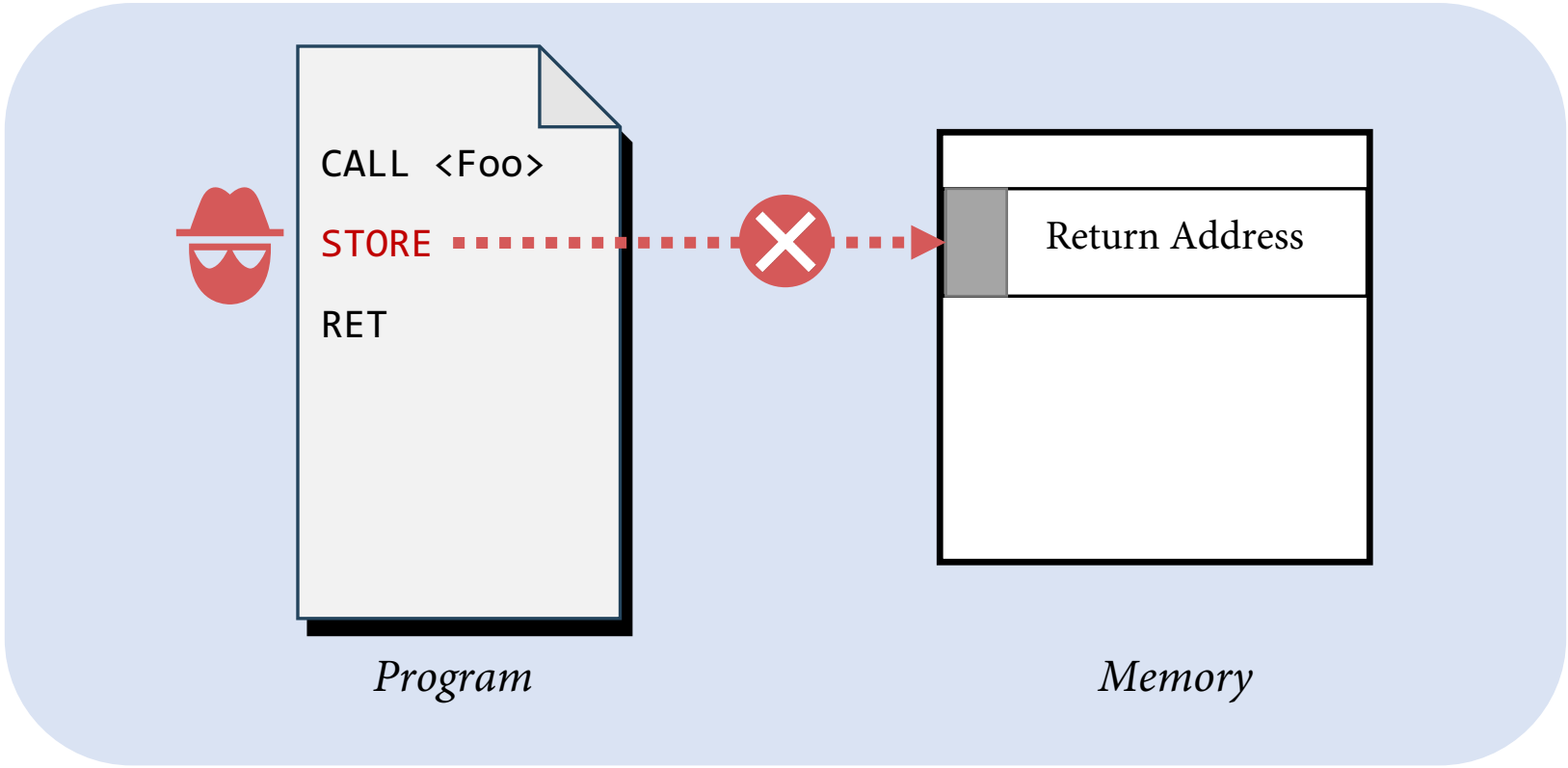

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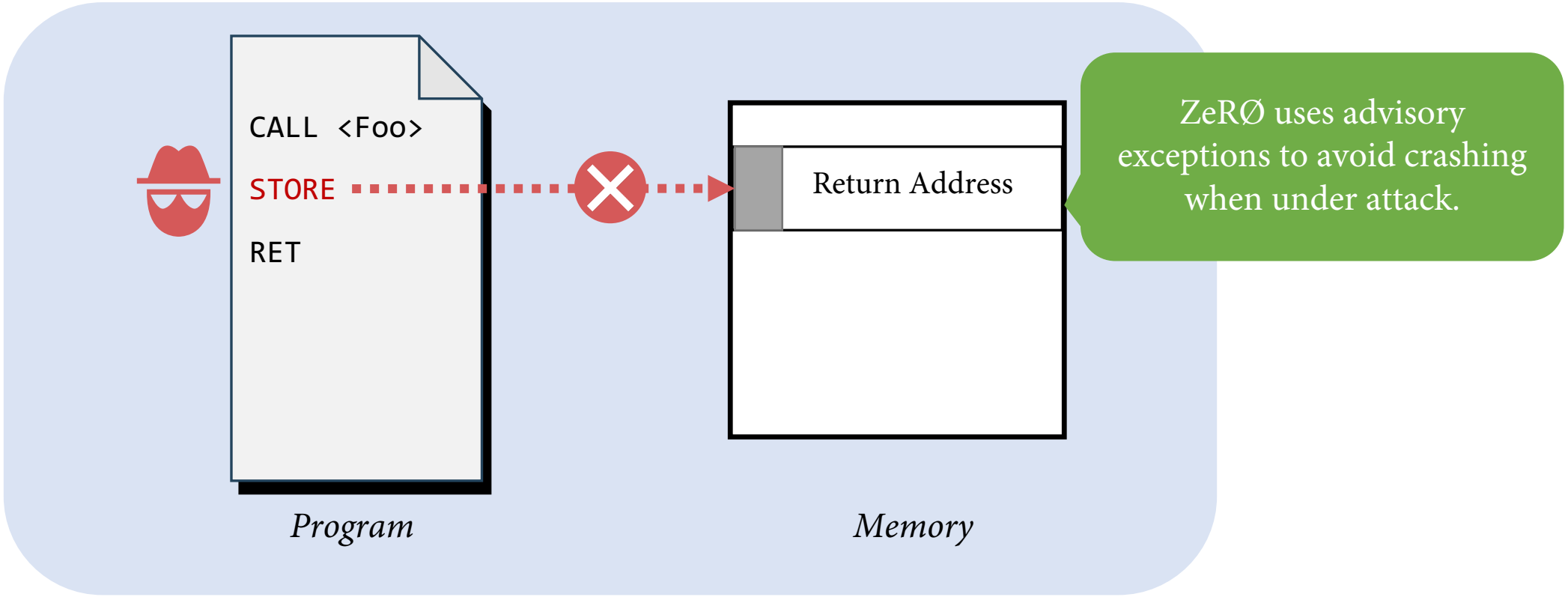
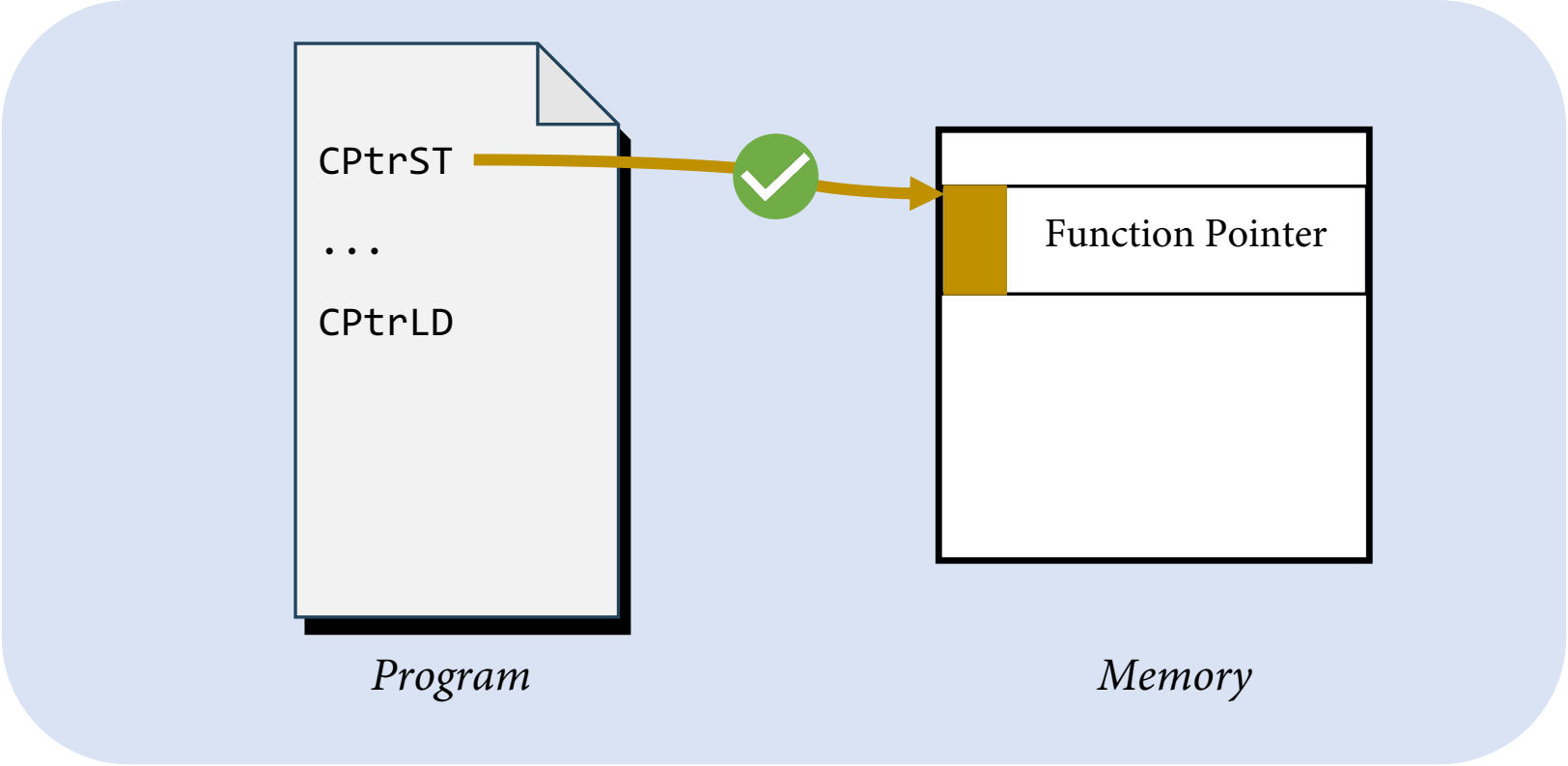


Code Pointer Integrity



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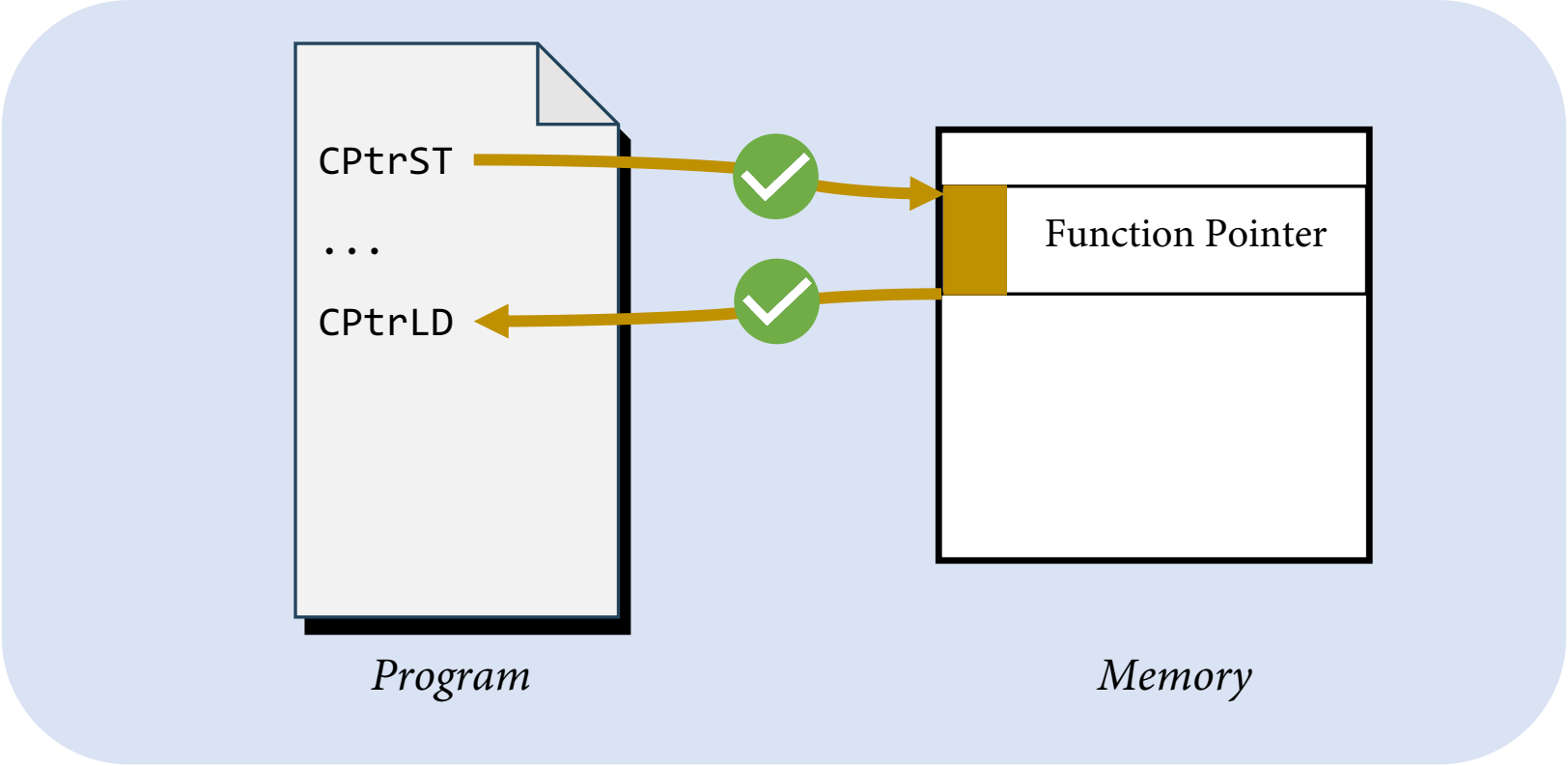

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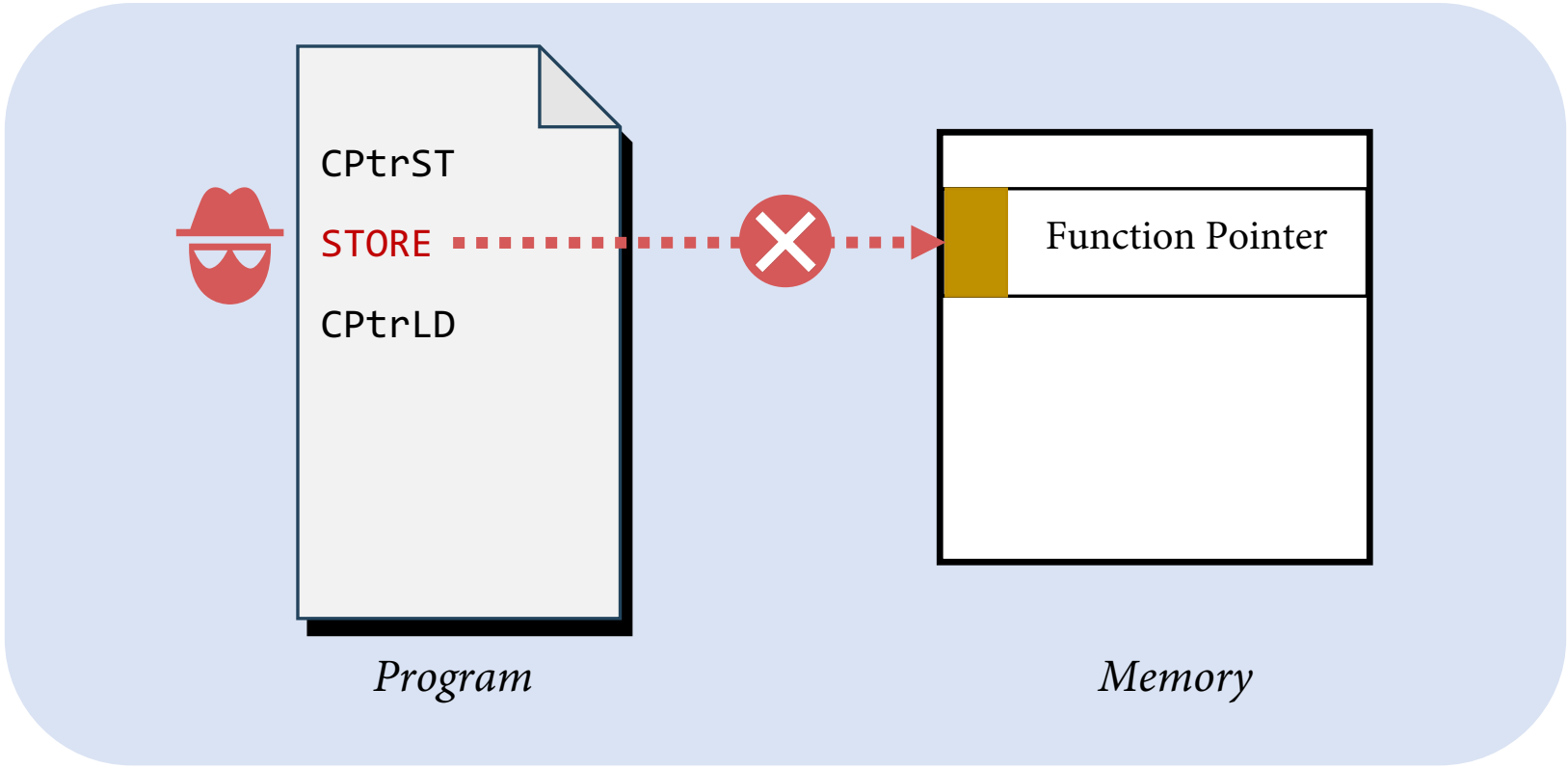
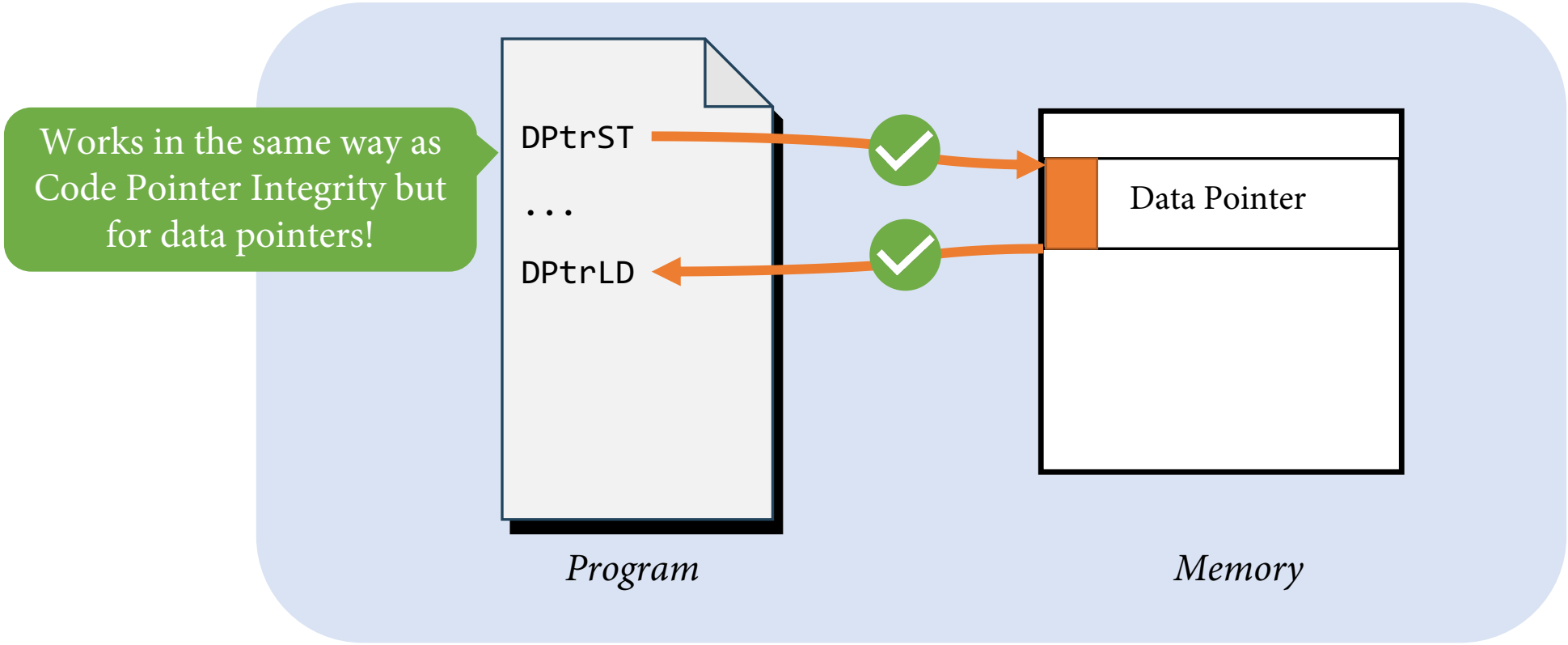


Data Pointer Integrity



ISA Extensions

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Same layout are regular load & stores!

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`ClearMeta Address, Mask`

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`ClearMeta Address, Mask` — Invoked on `free` or `delete`.

Cache Line Formats

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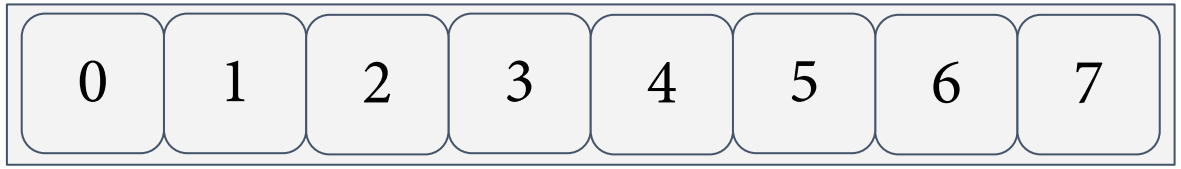

Normal

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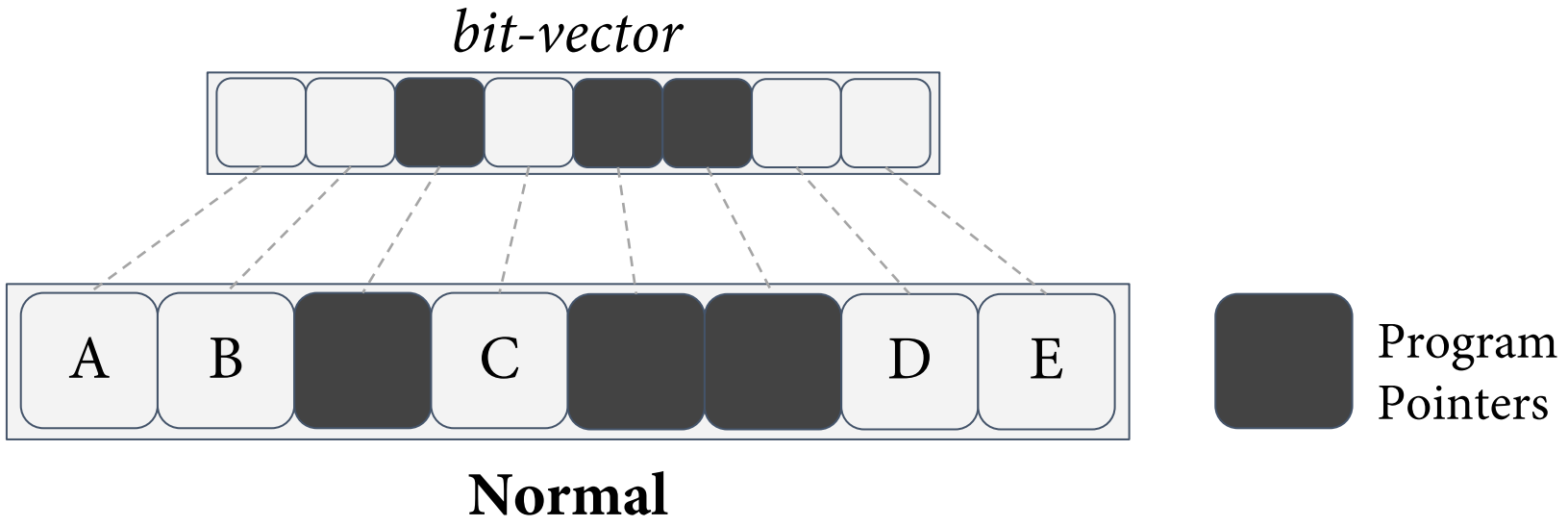
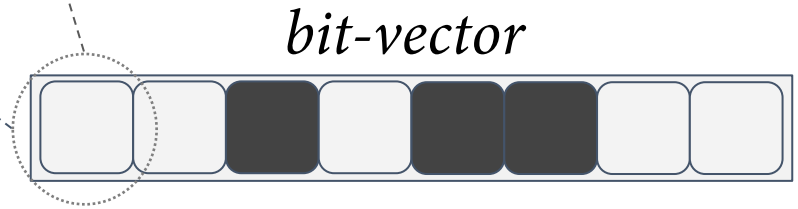
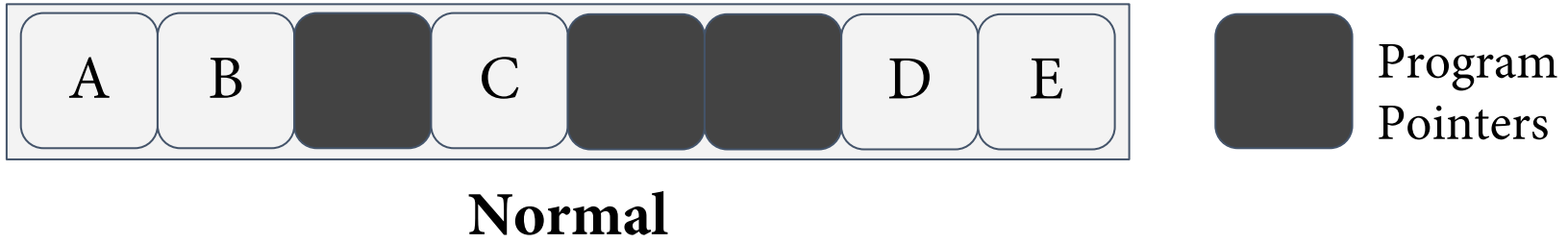


Cache Line Formats

Format Encoding Table

Type	Bits
Return address	01



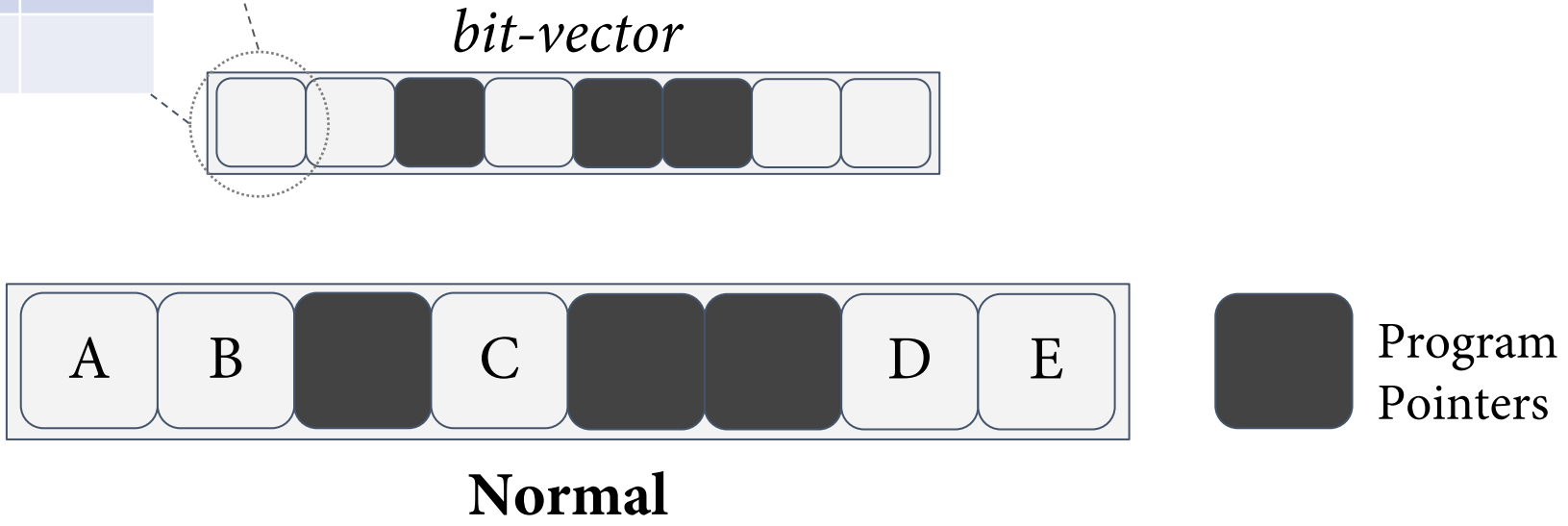


Normal

Cache Line Formats

Format Encoding Table

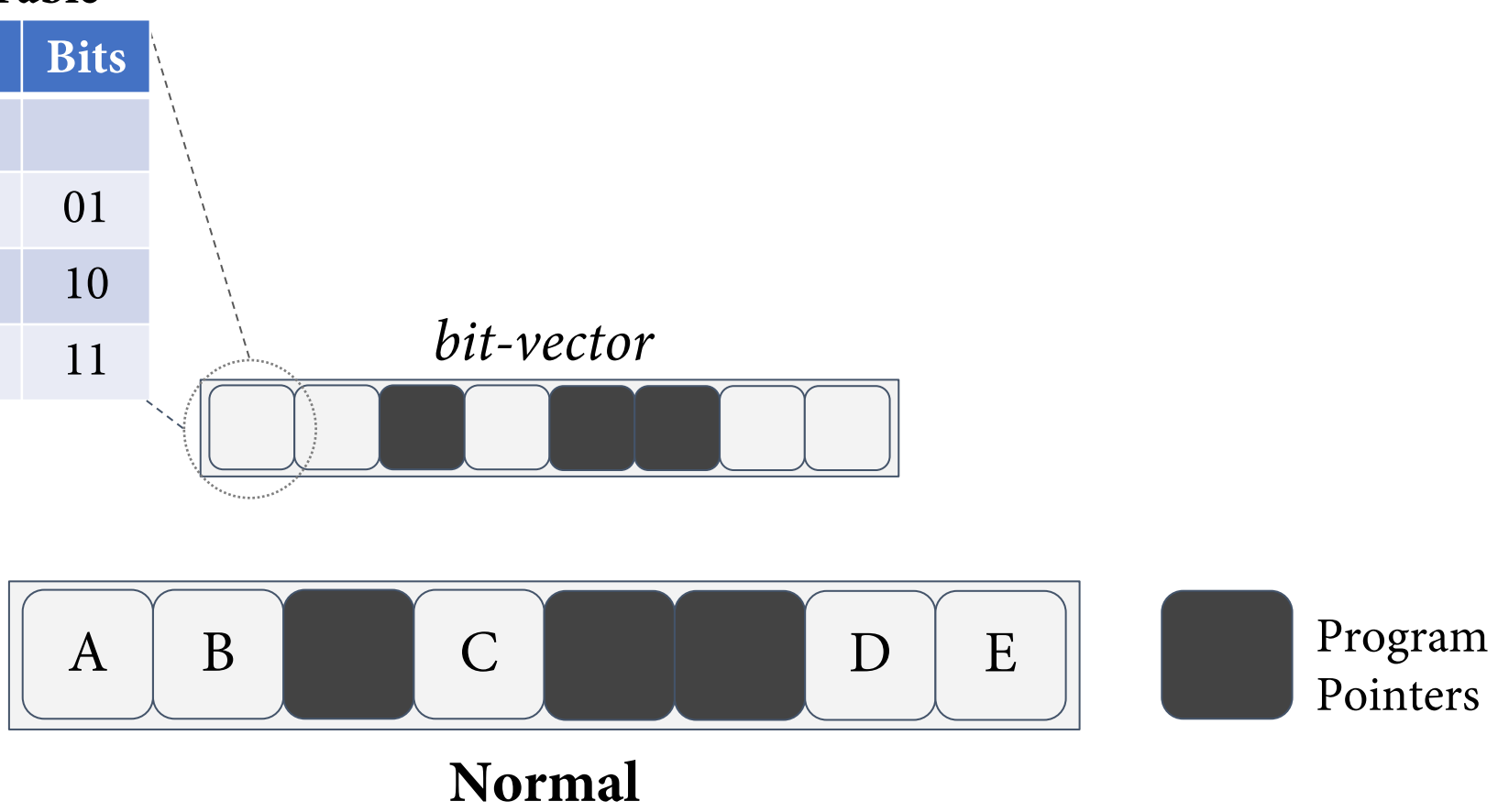
Type	Bits
Return address	01
Function pointer	10



Cache Line Formats

Format Encoding Table

Type	Bits
Return address	01
Function pointer	10
Data pointer	11



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Regular data	00
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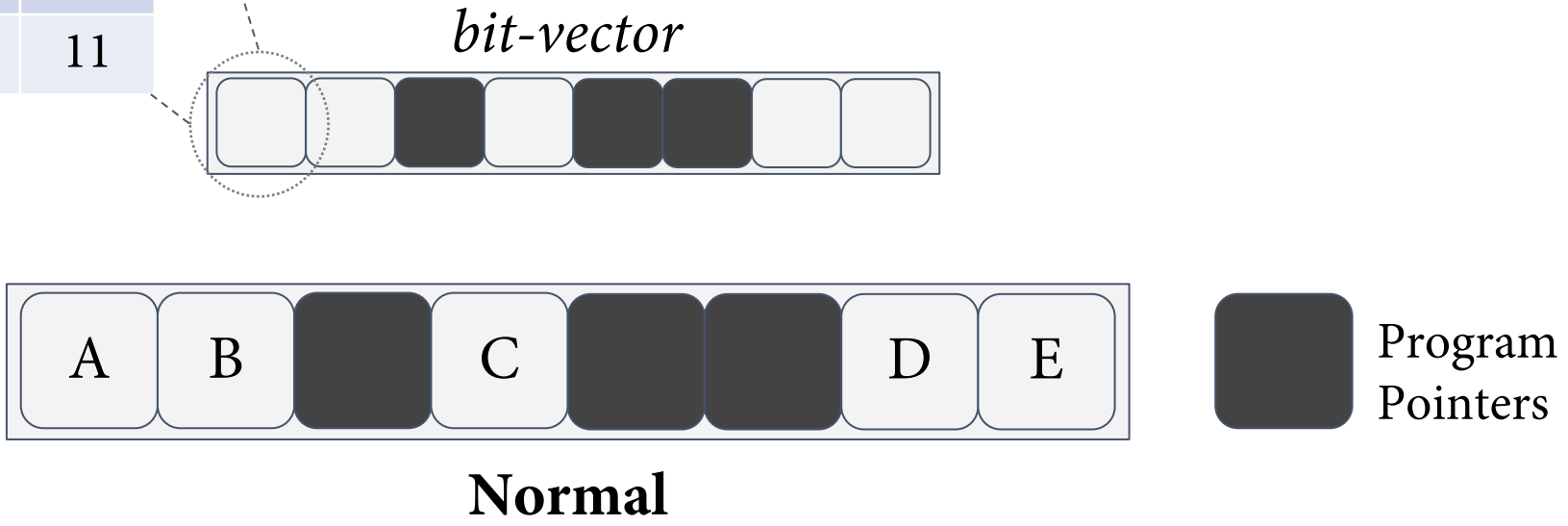

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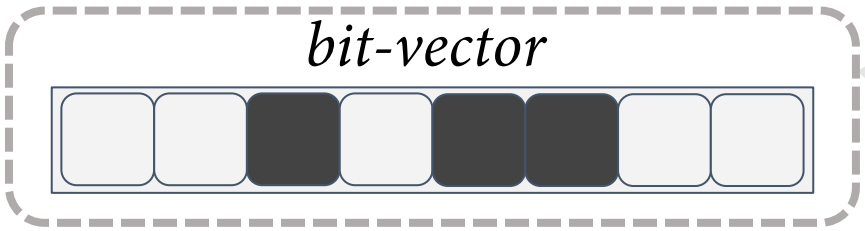


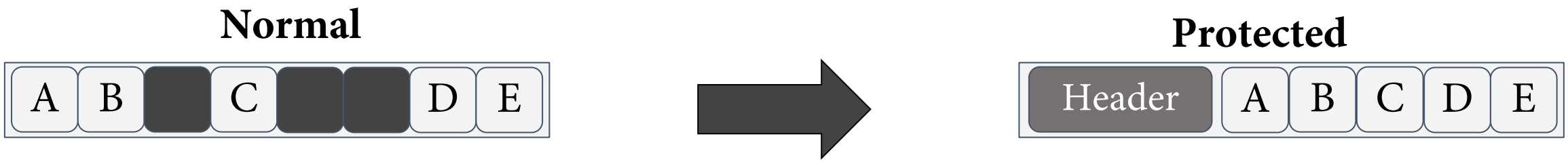
This introduces a 3.125% area overhead.

Normal

Cache Line Formats

Our Metadata: Encoded within unused pointer bits.

Program Pointers



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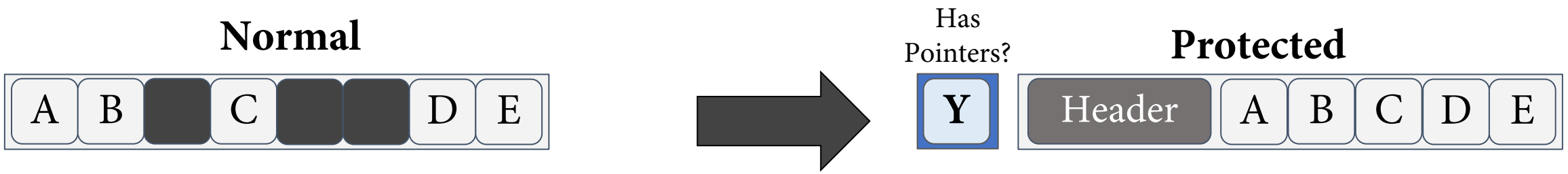

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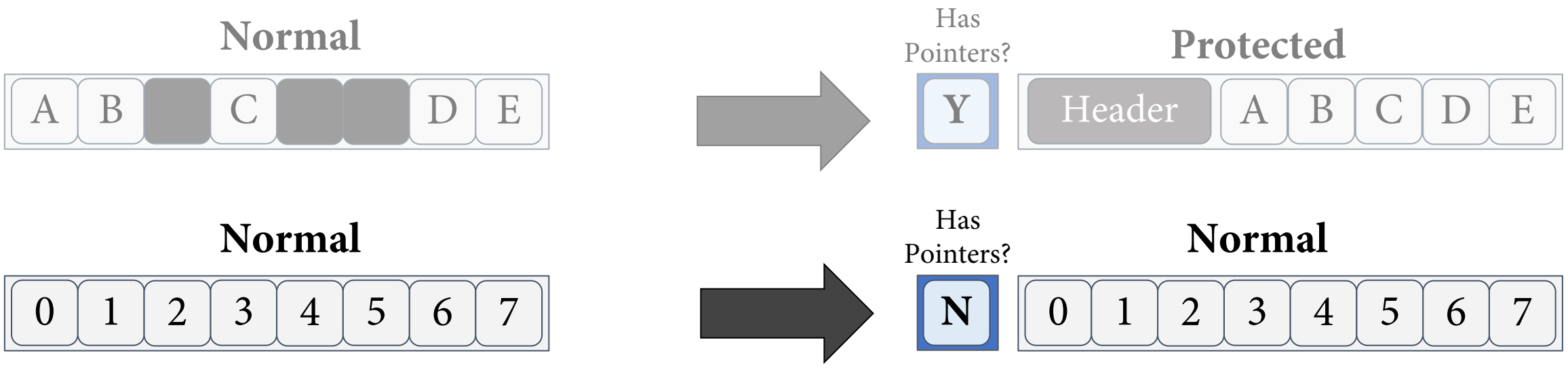

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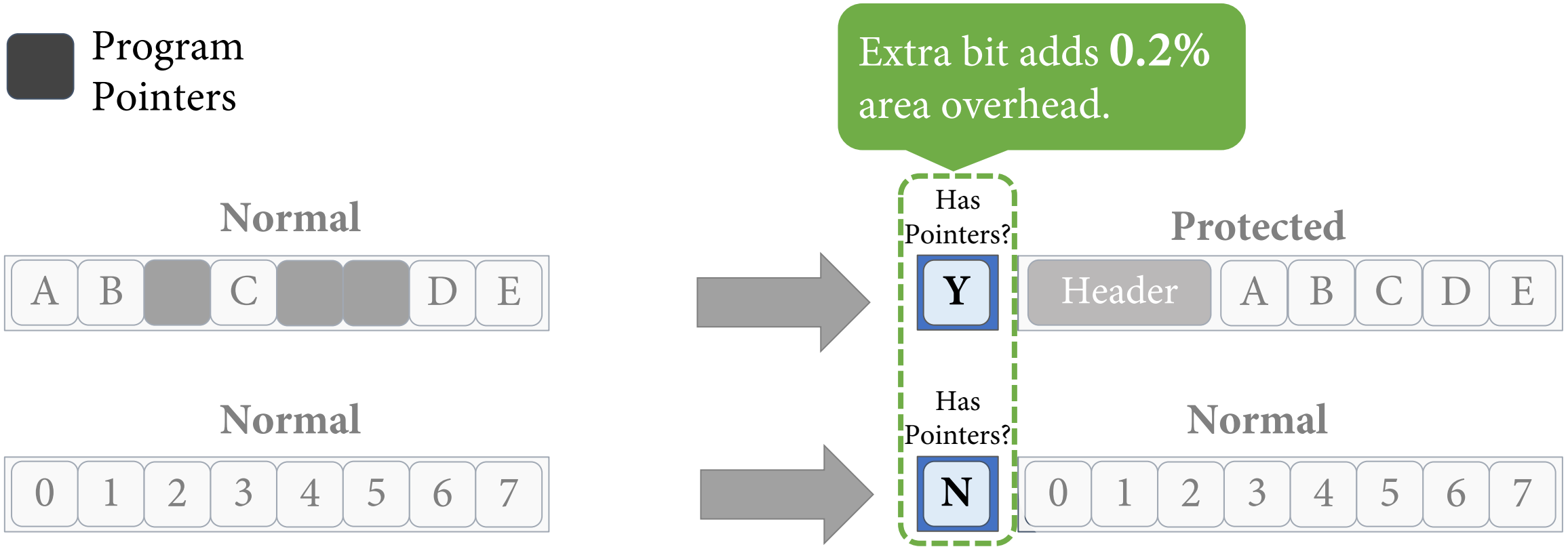

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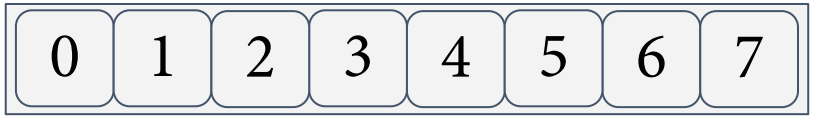

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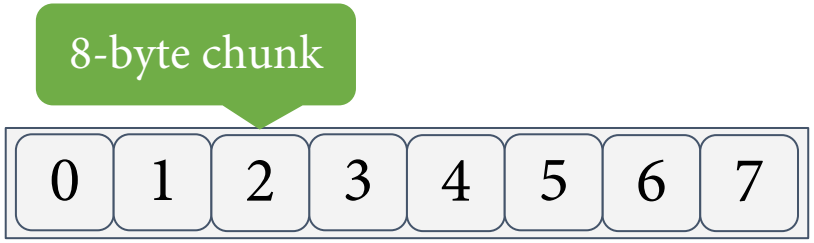

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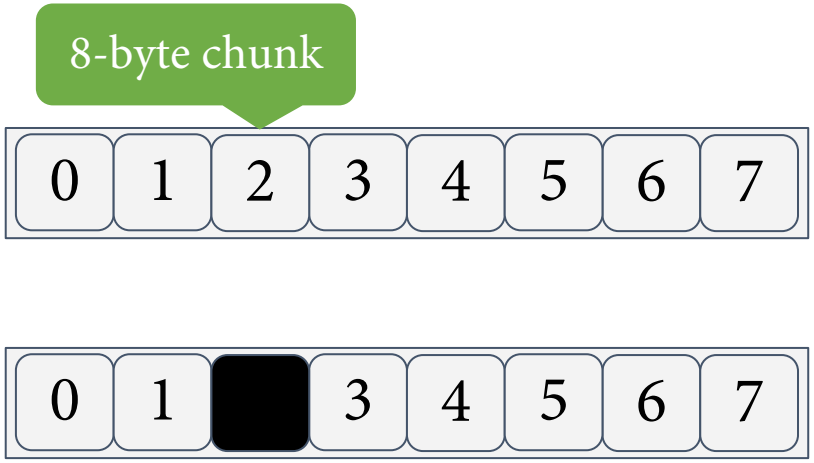

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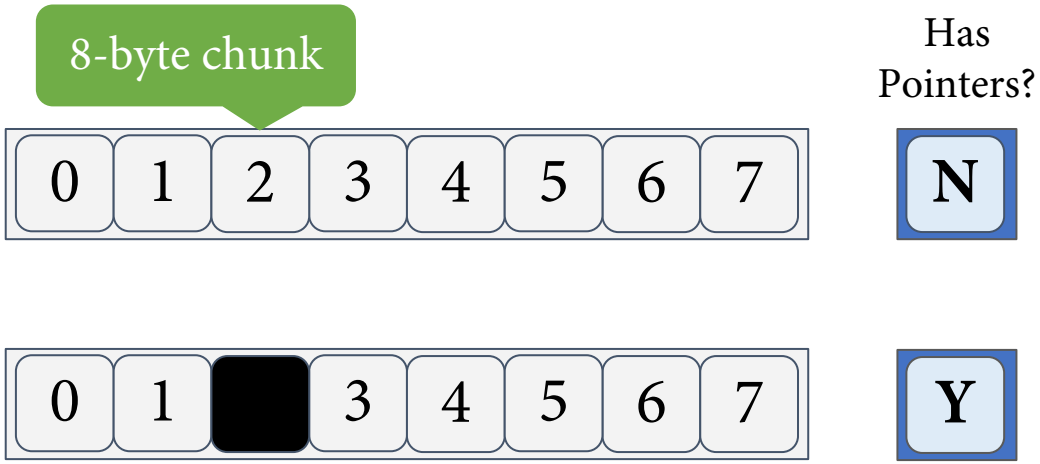

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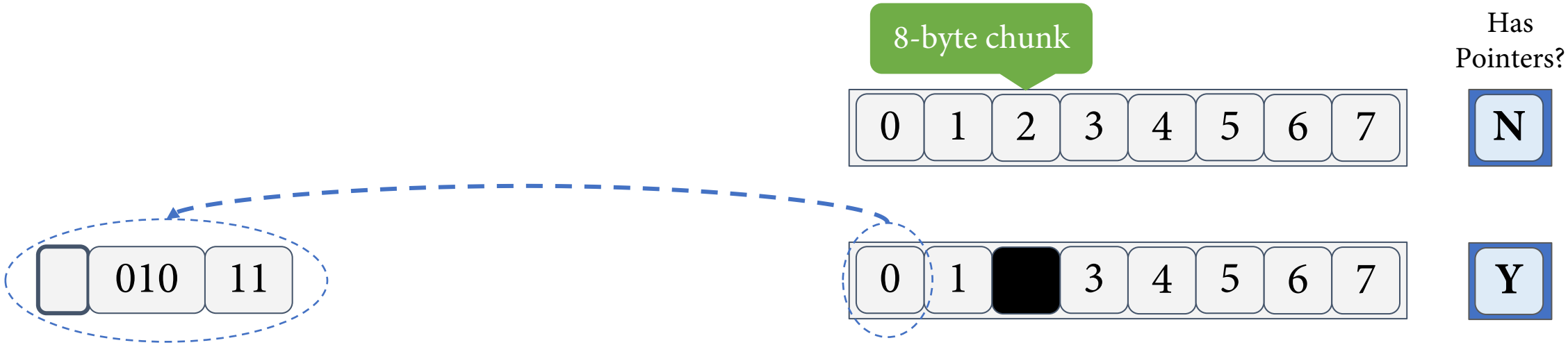

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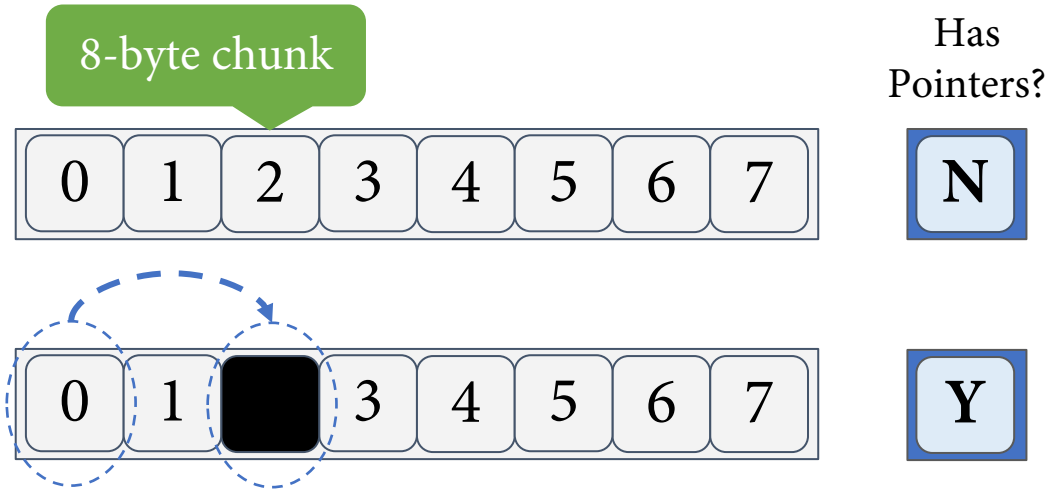

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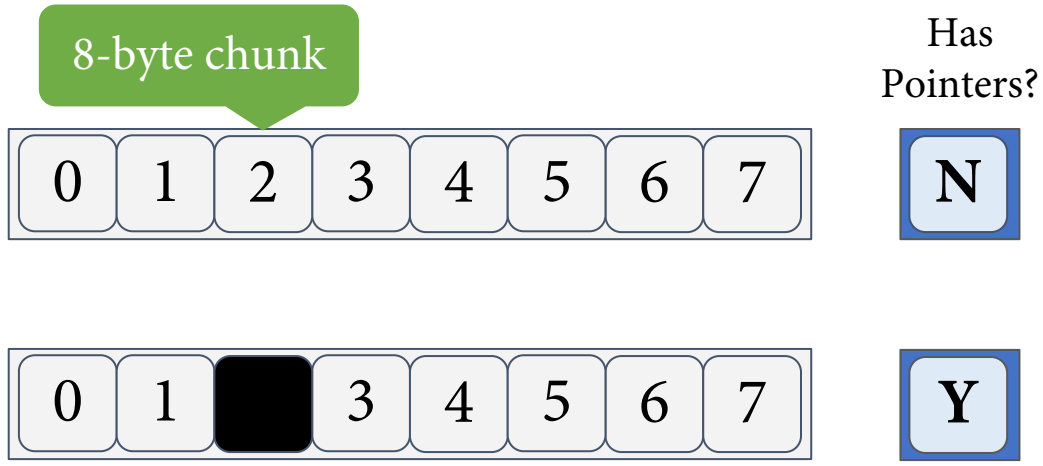


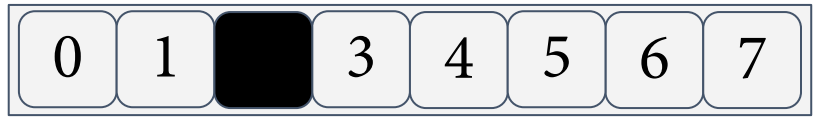
Cache Line Formats

Header Size?

8-byte chunk

Has Pointers?

6 bits



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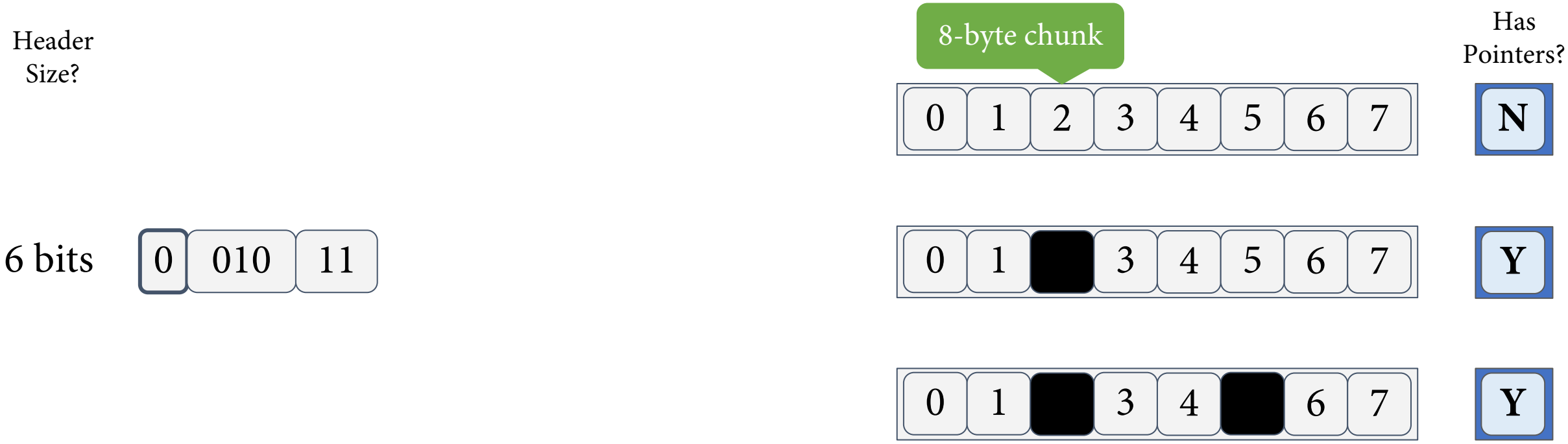

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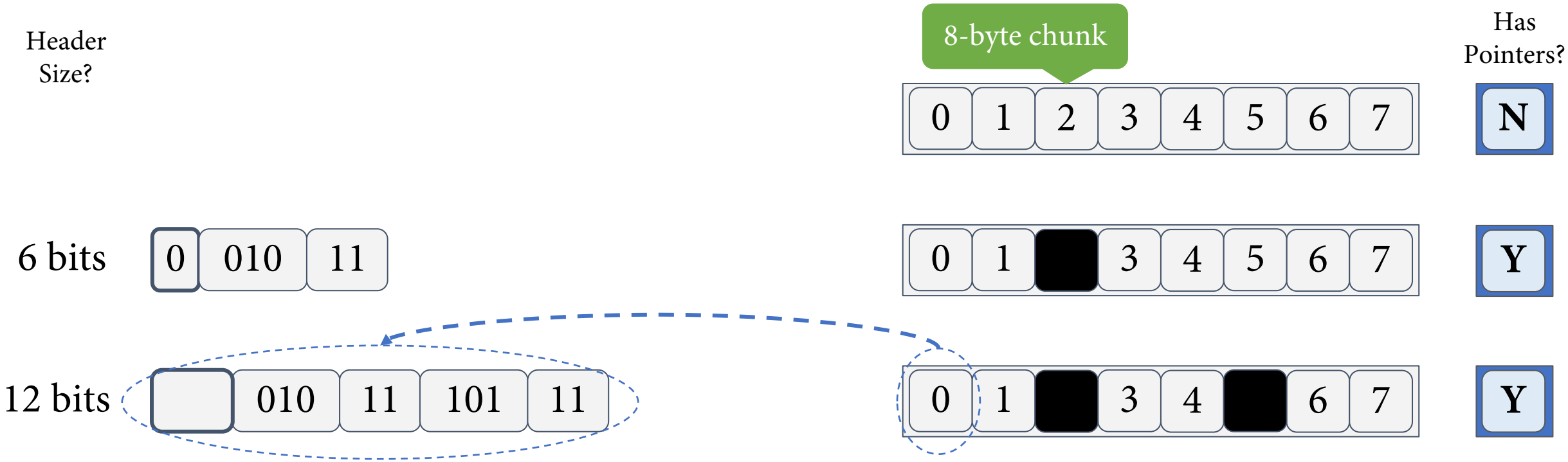

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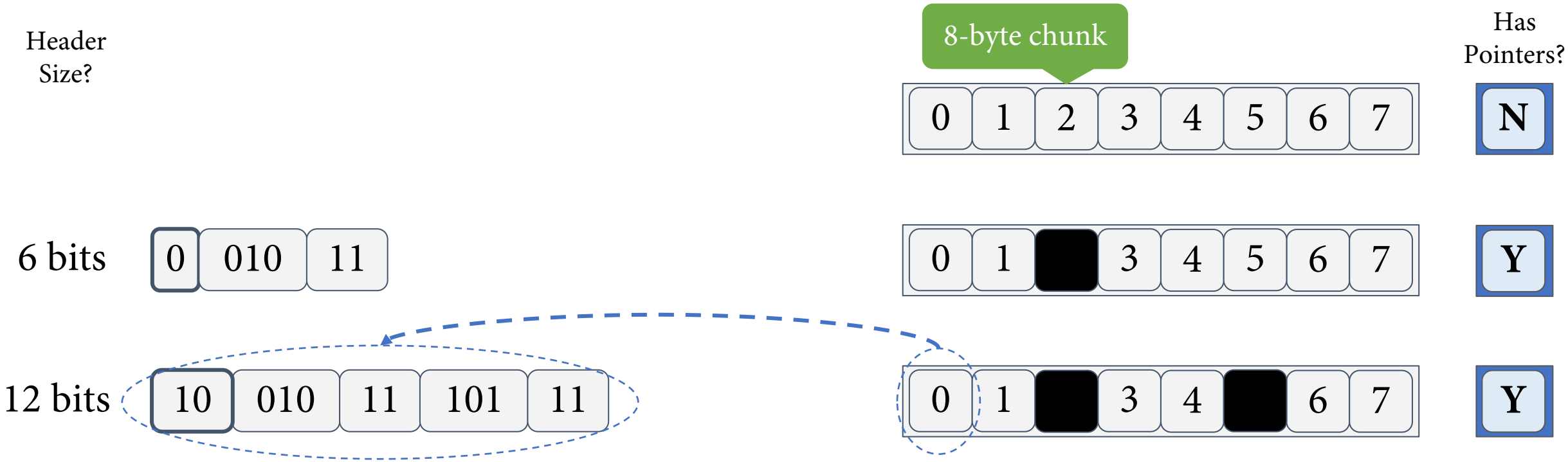

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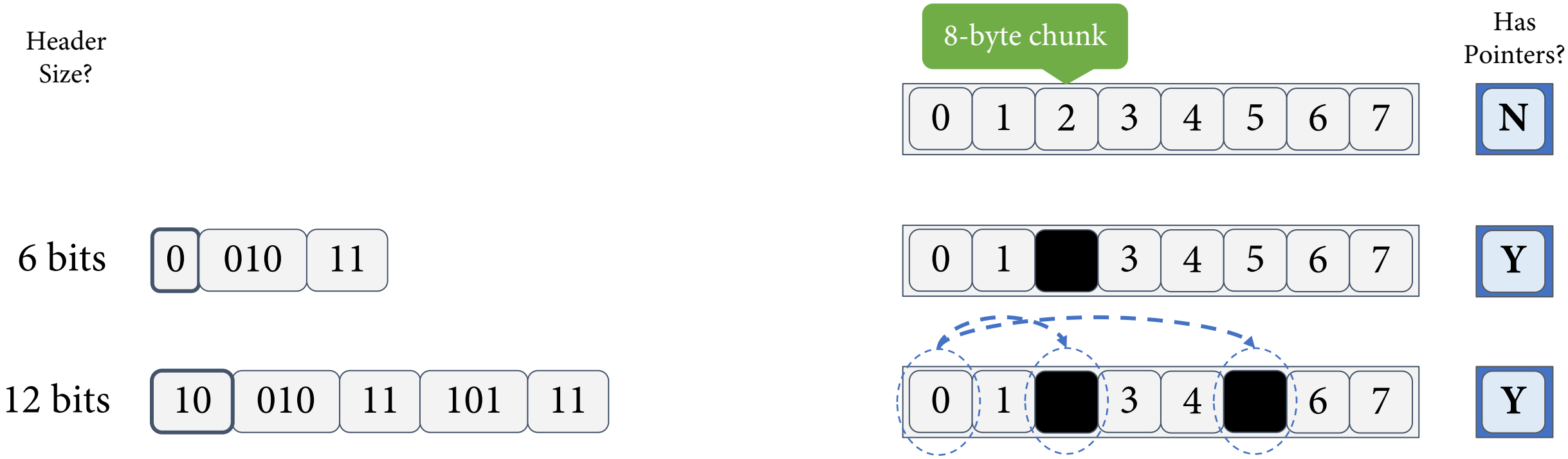

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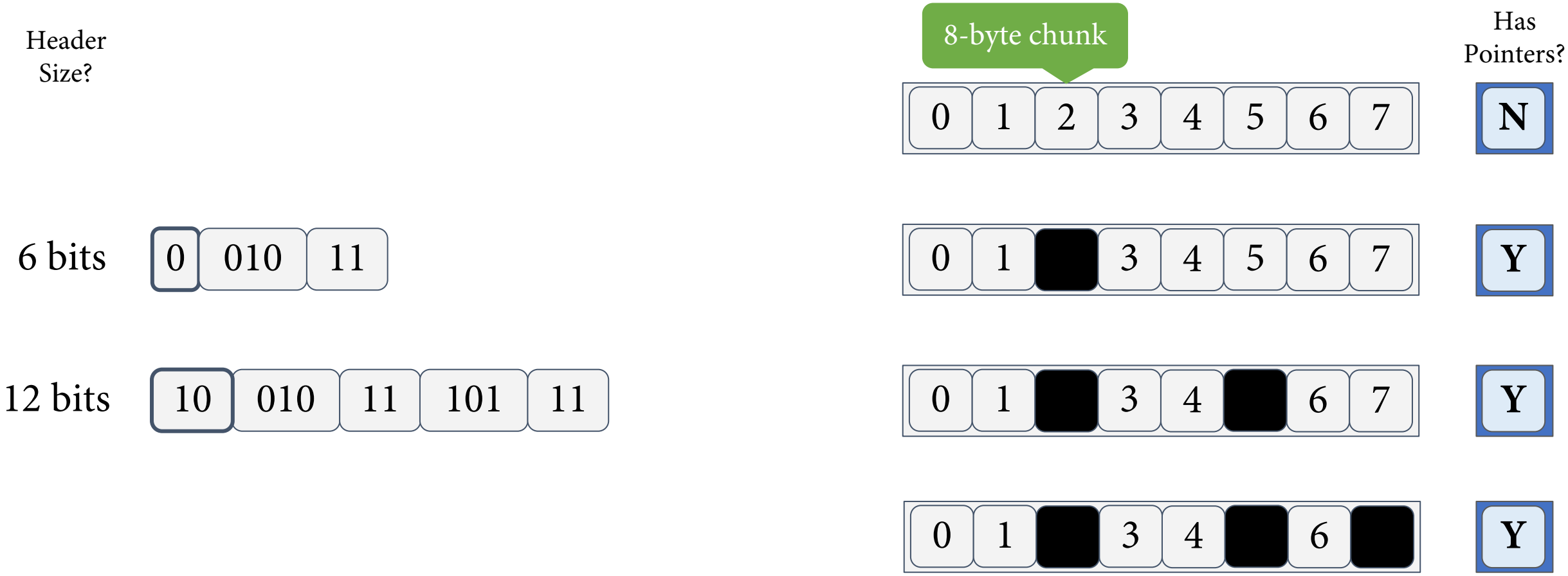

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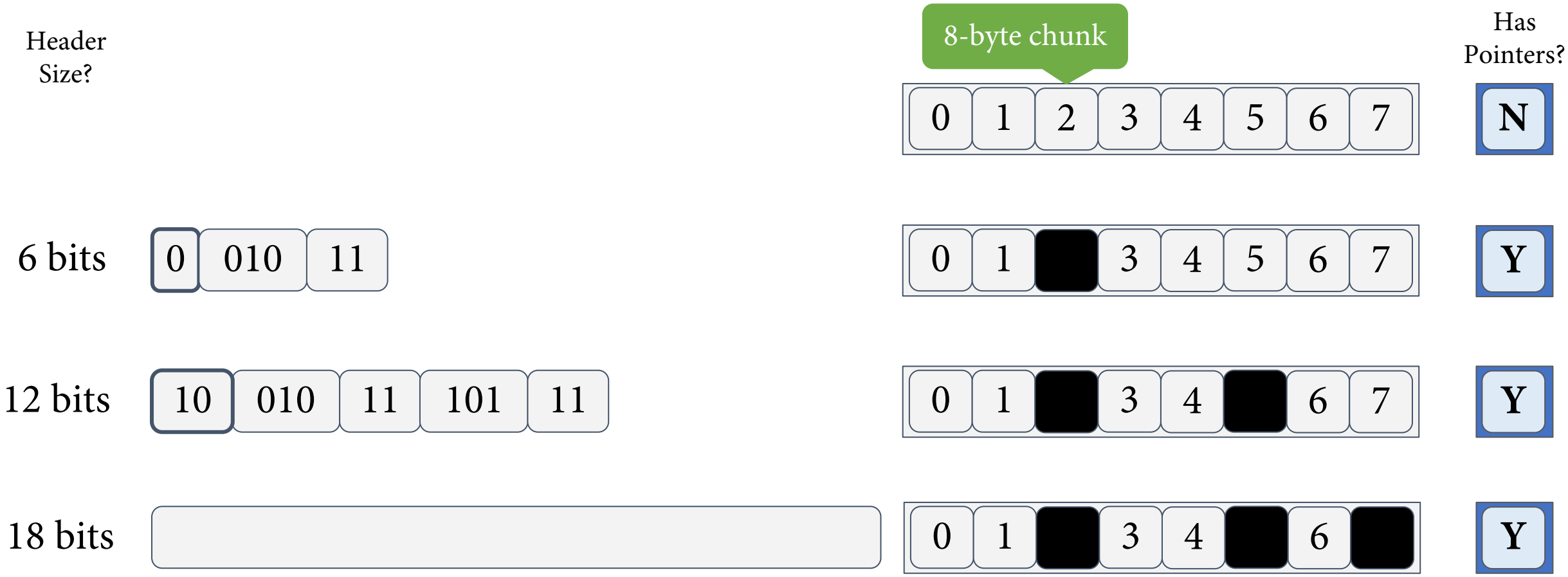

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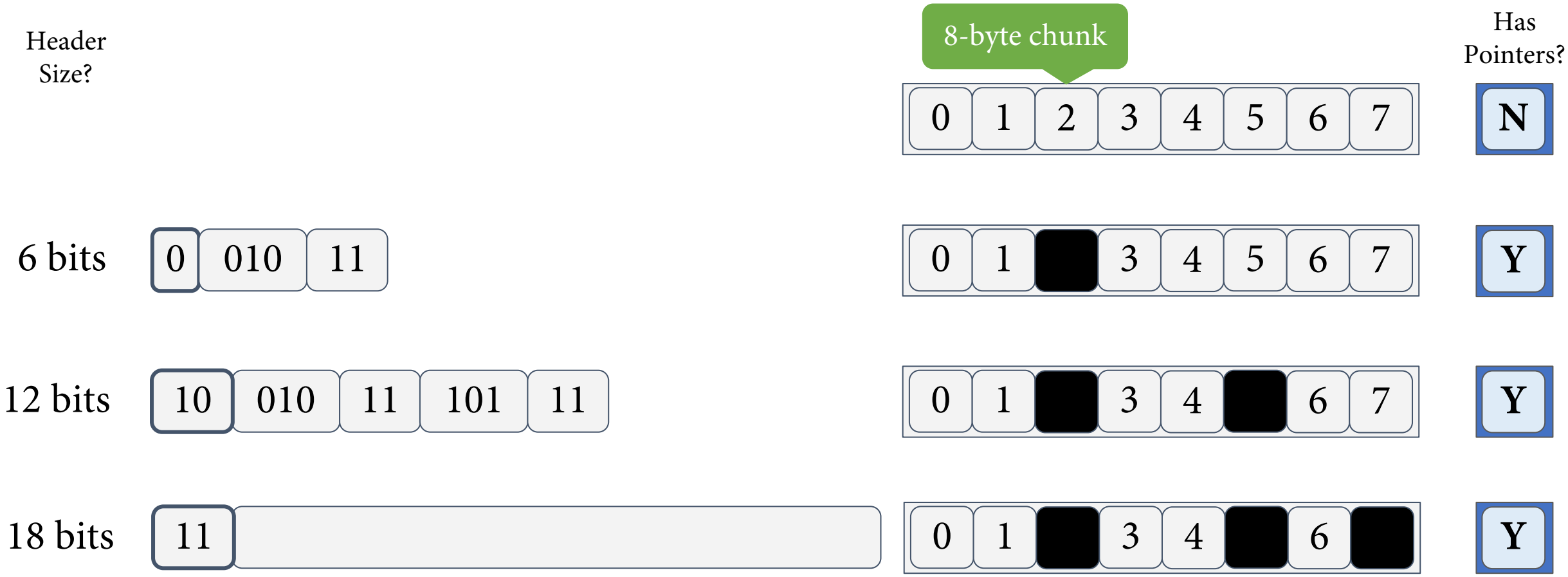

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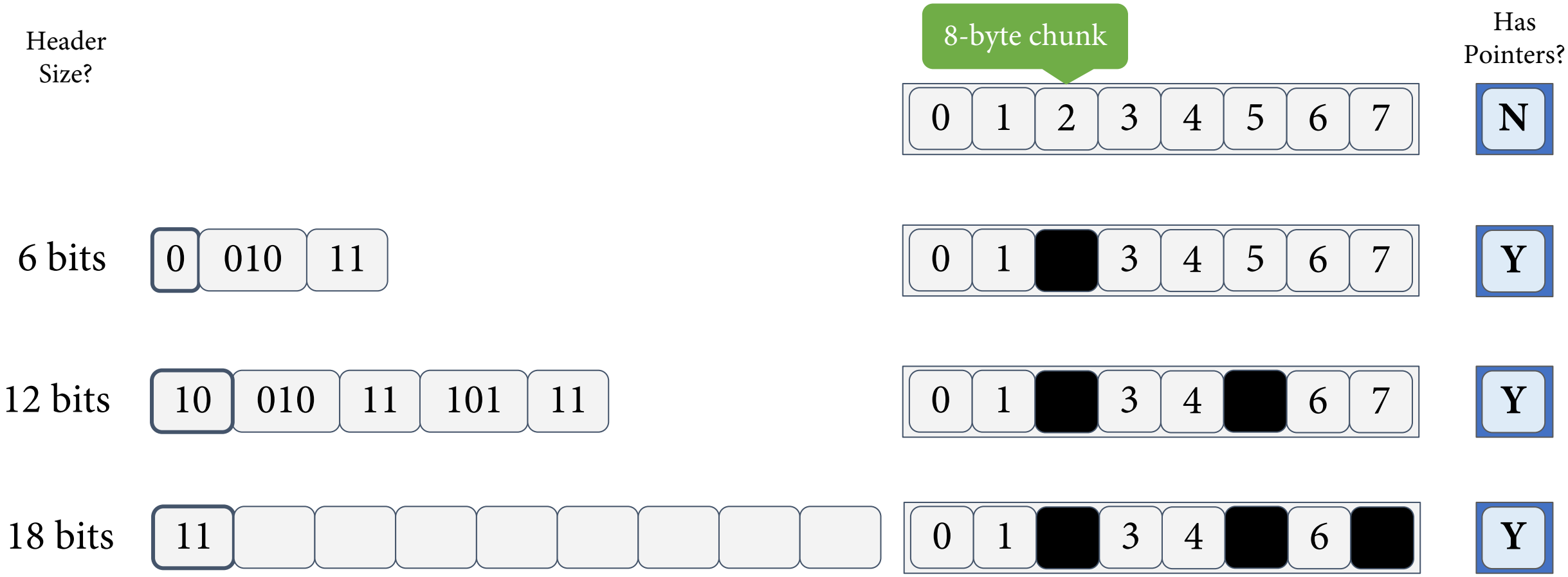

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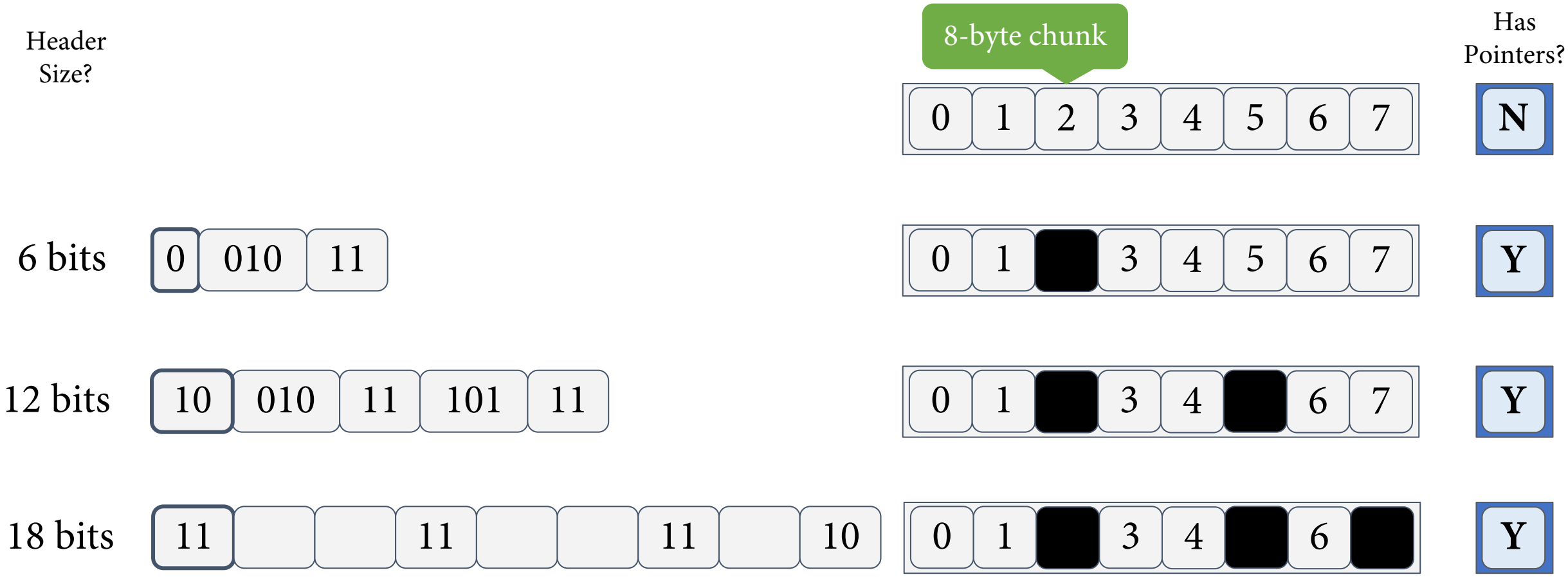

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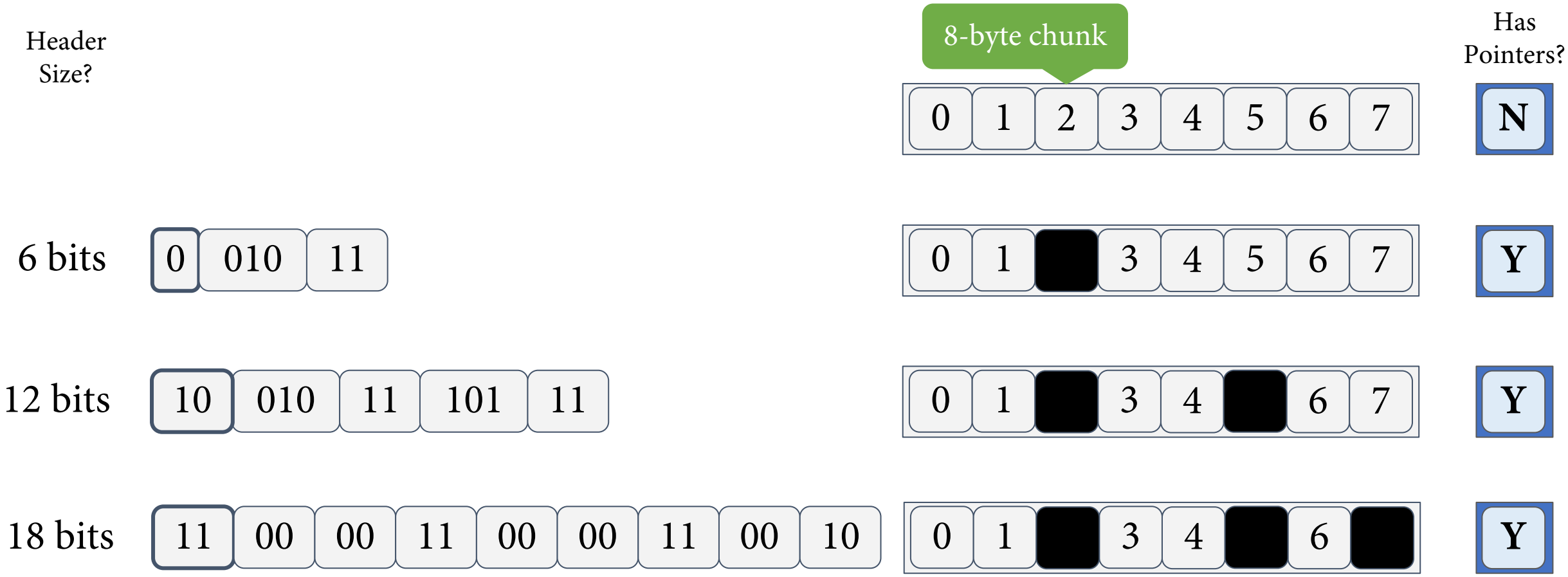

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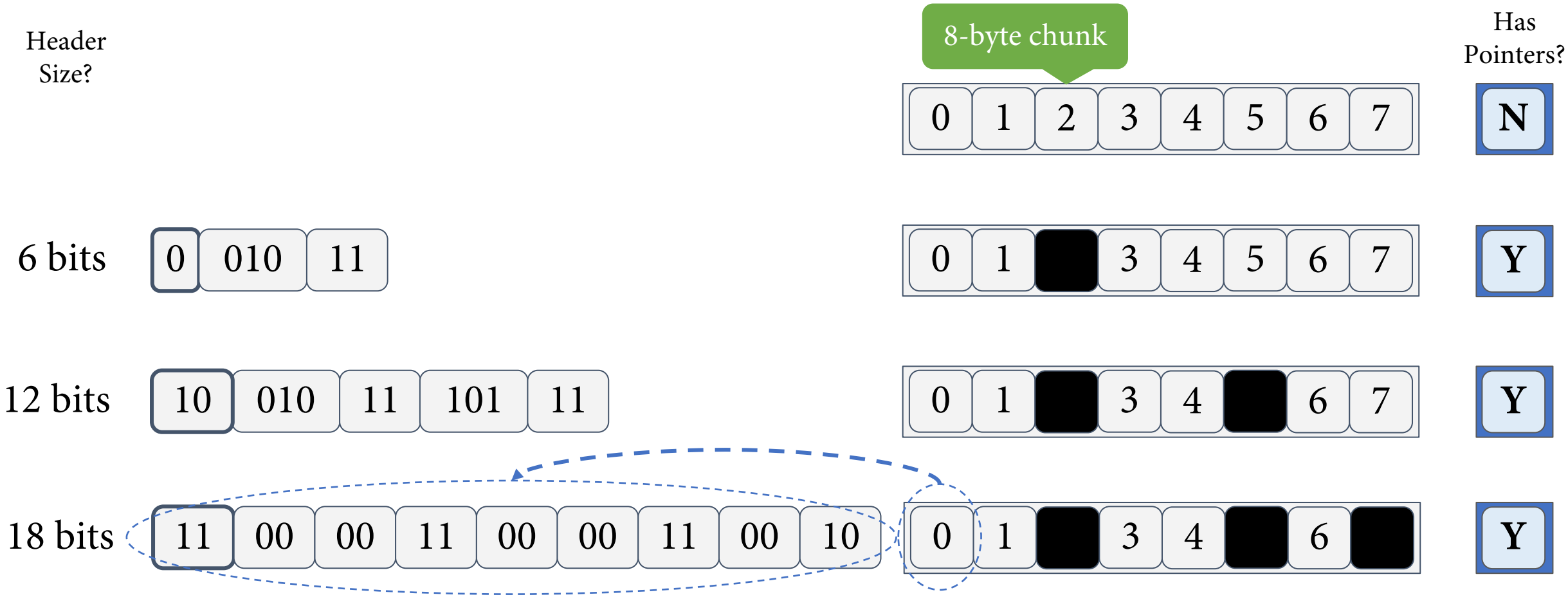

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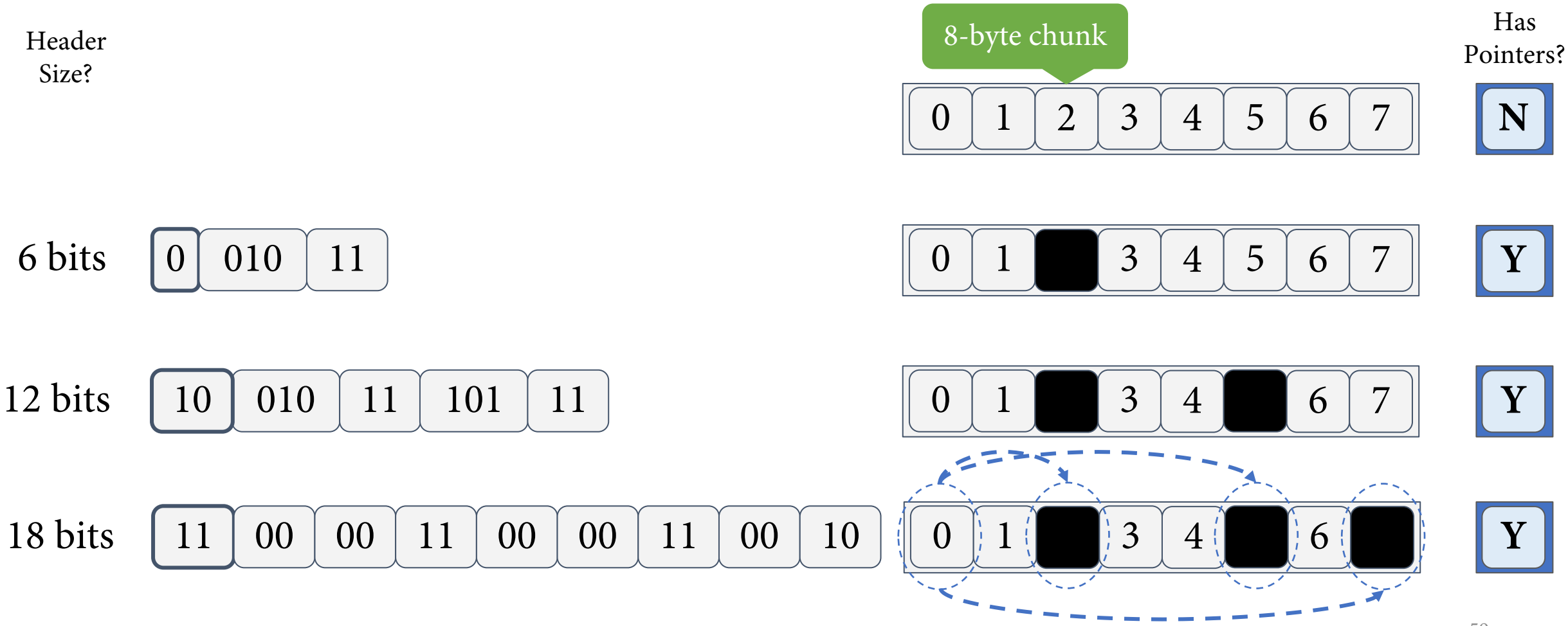

Microarchitectural Overview

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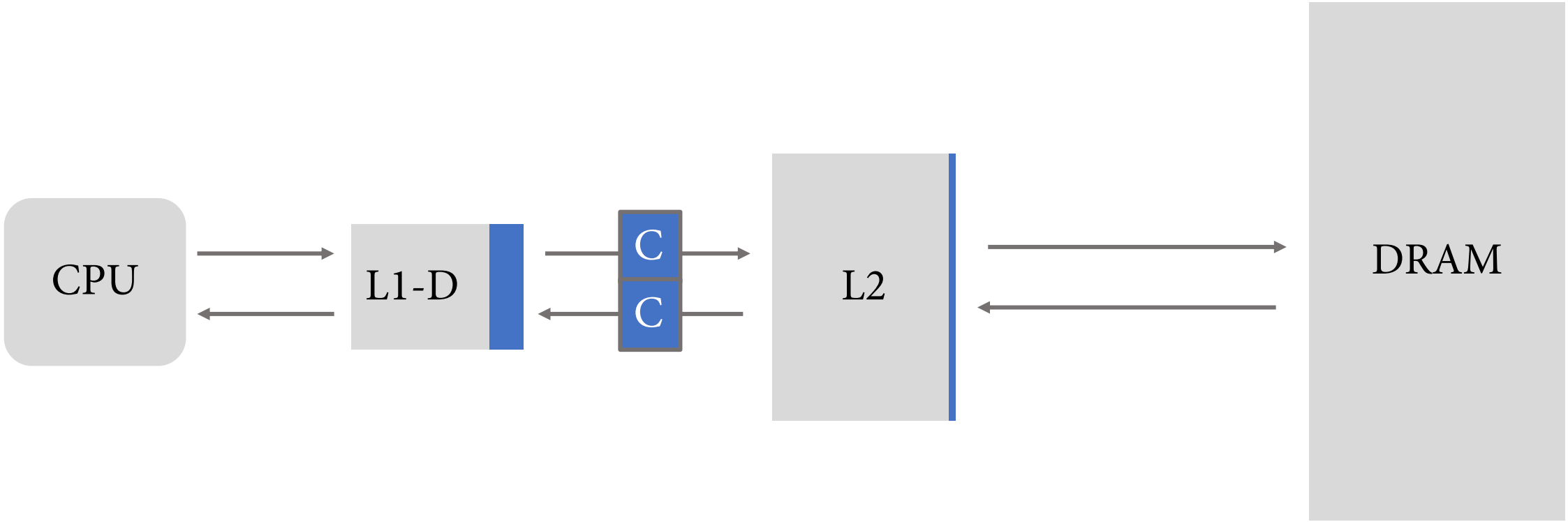

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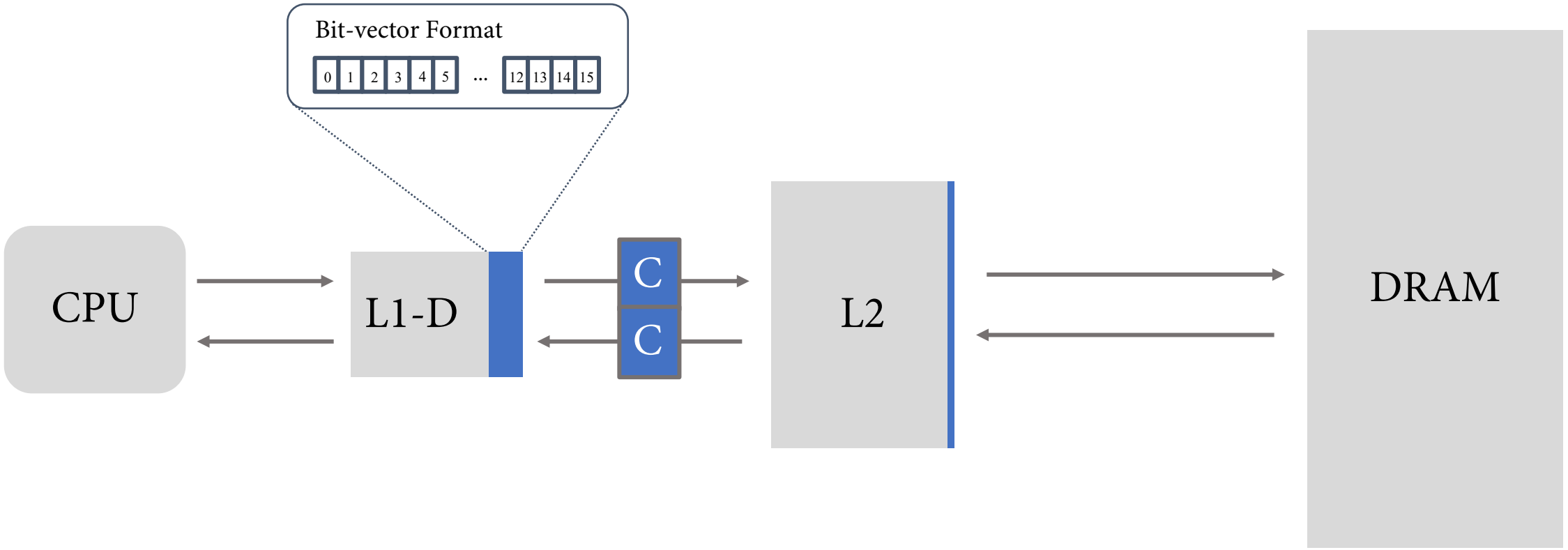

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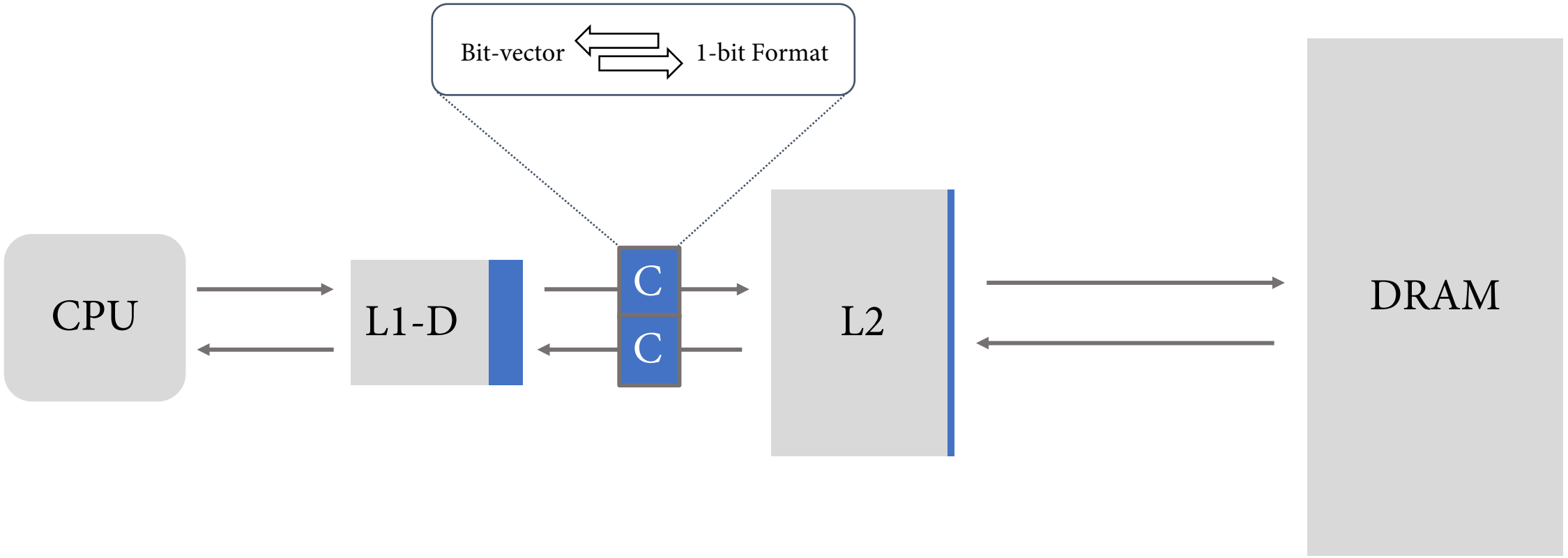

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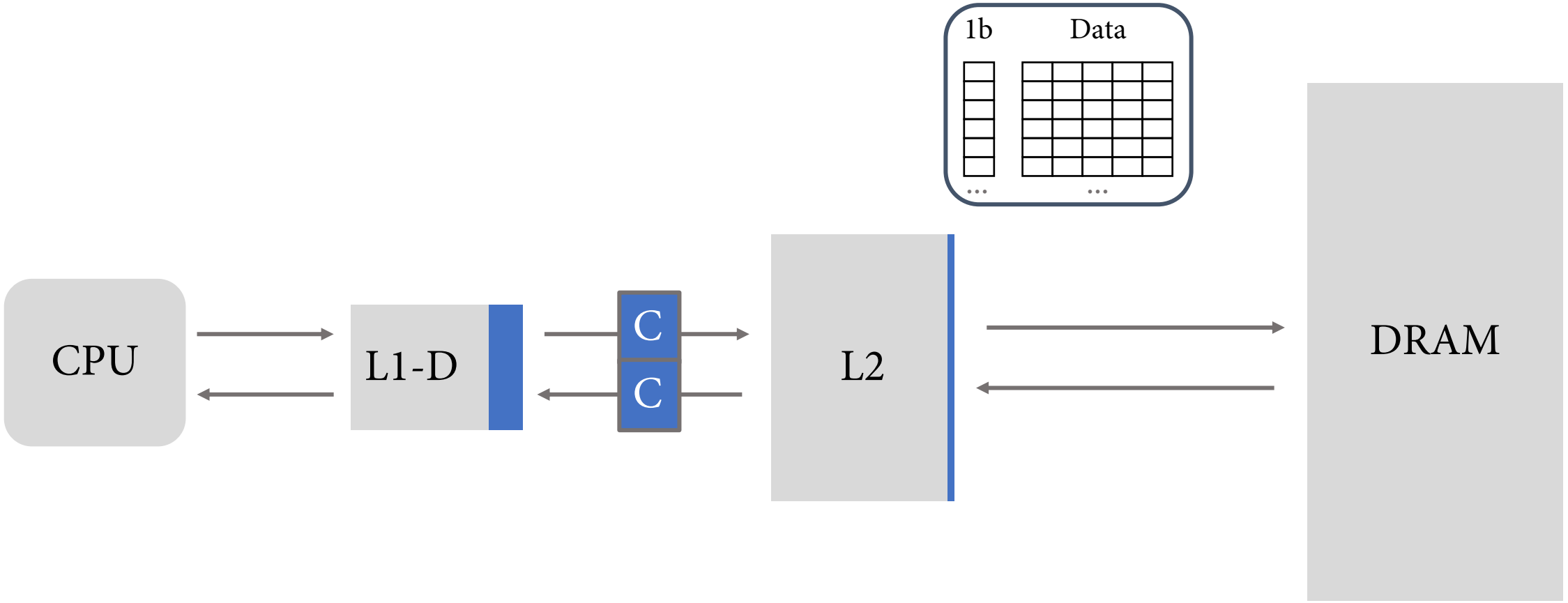

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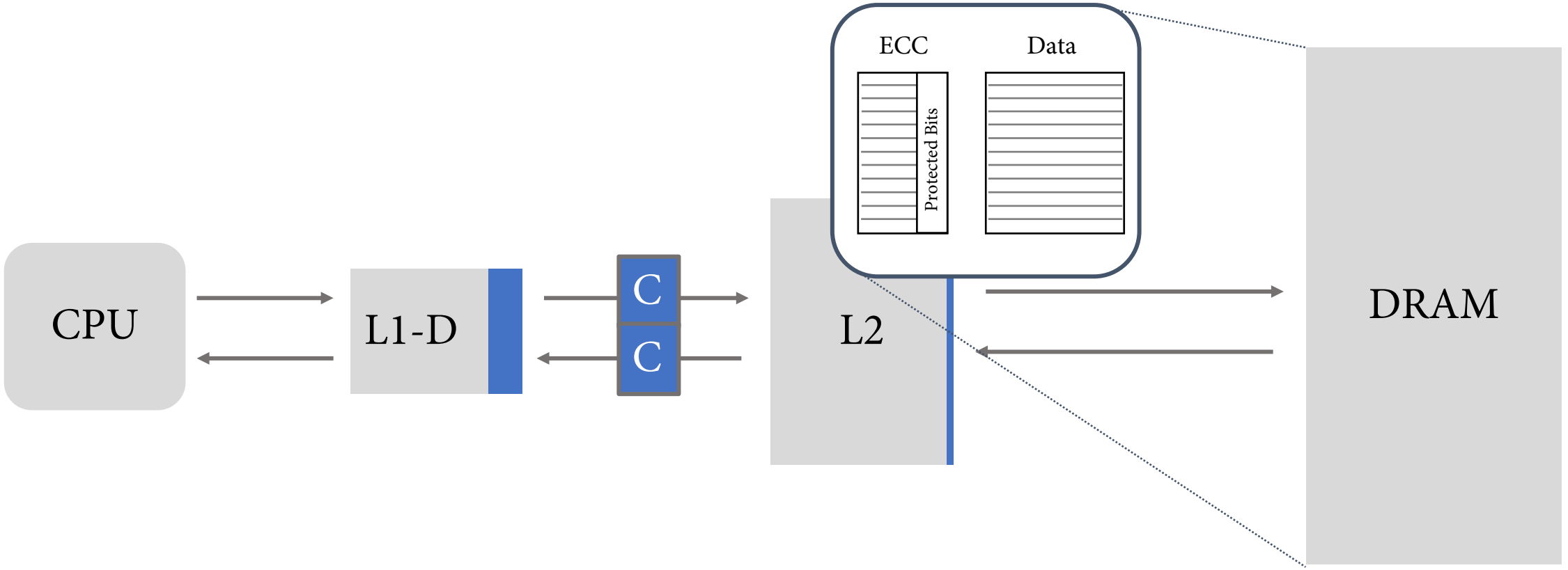

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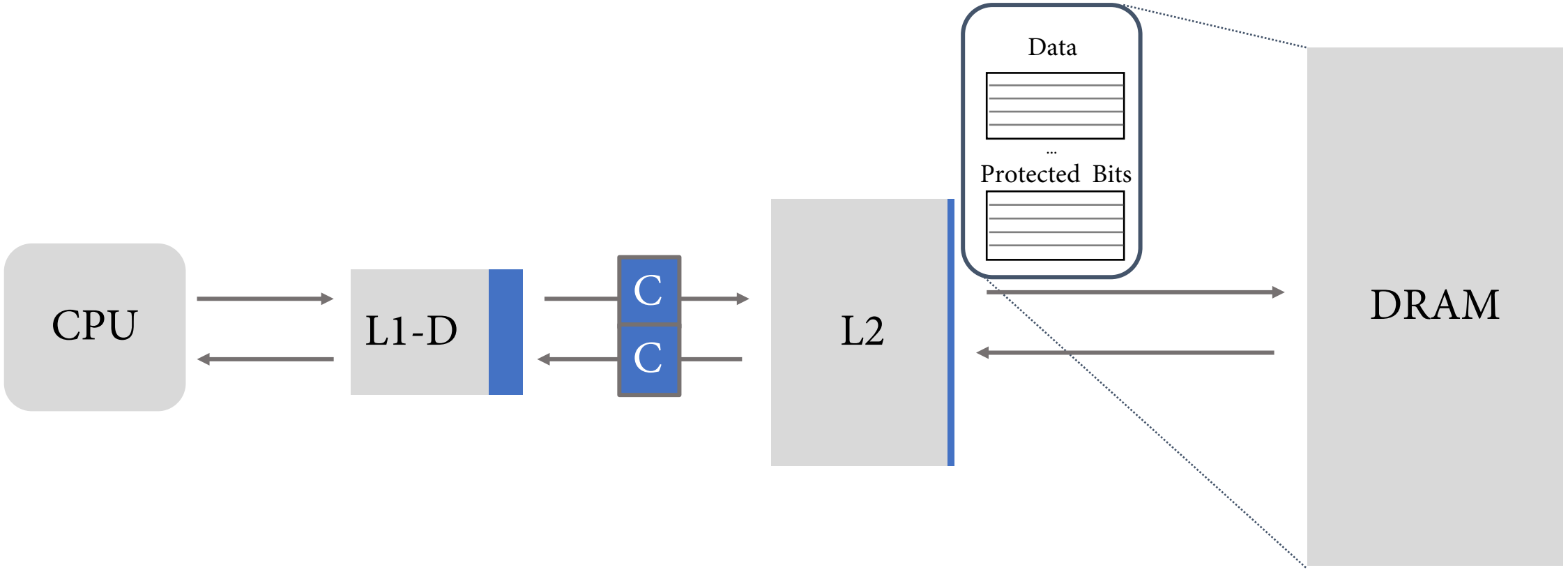
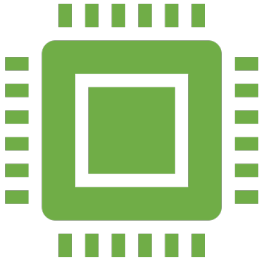


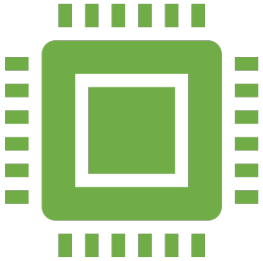
Performance

ZeRØ Performance Overheads



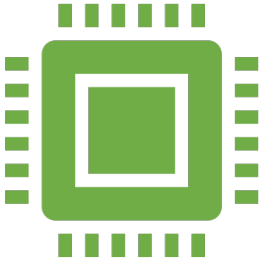
Hardware Modifications

ZeRØ Performance Overheads



Hardware Modifications
Our hardware measurements show minimal latency/area/power overheads.

ZeRØ Performance Overheads



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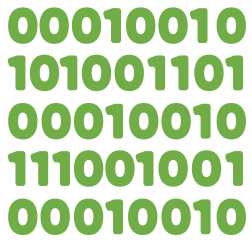
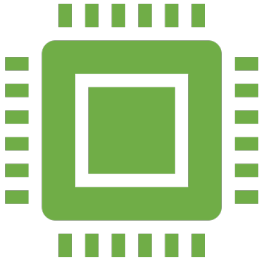


Software Modifications

ZeRØ Performance Overheads



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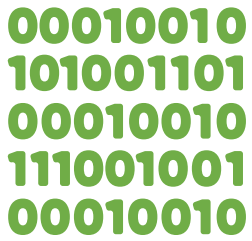

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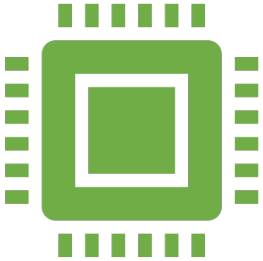

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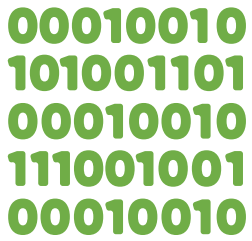
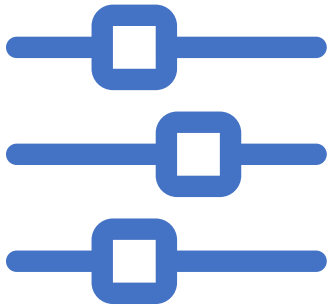


Software Modifications
- Our special load/stores do not change the binary size.
- The `ClearMeta` instructions are only called on memory deallocation.

Performance Results (x86_64)

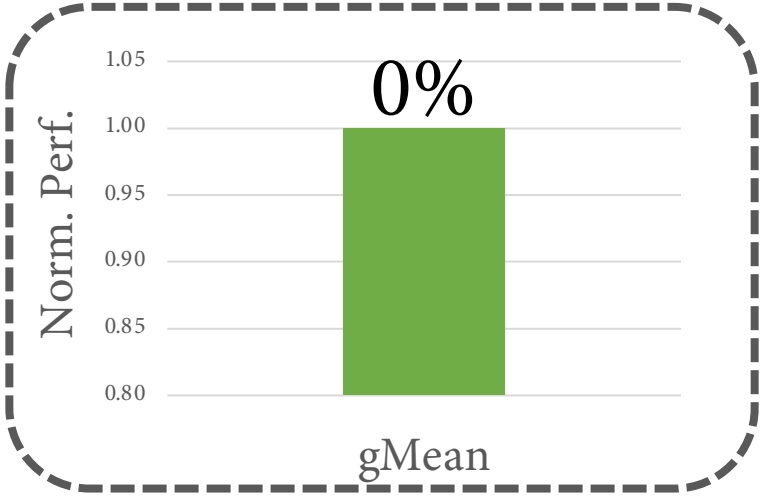


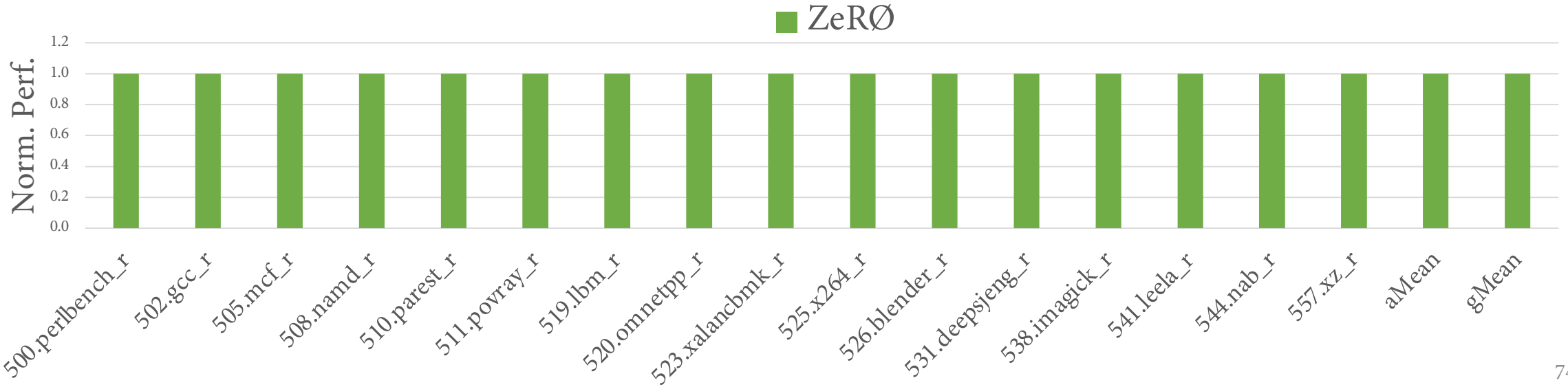
Experimental Setup

We use emulate ZeRØ on x86_64 by modifying LLVM to emit new instructions.

- `ClearMeta` is emulated using dummy stores.

Performance Results (x86_64)





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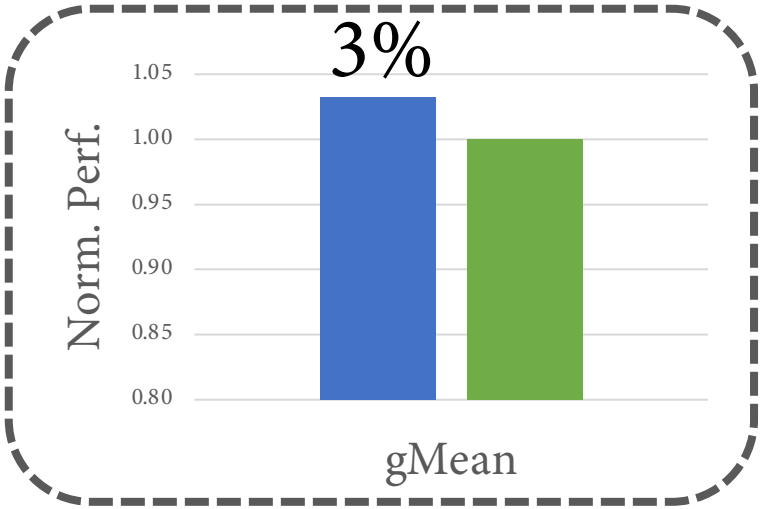

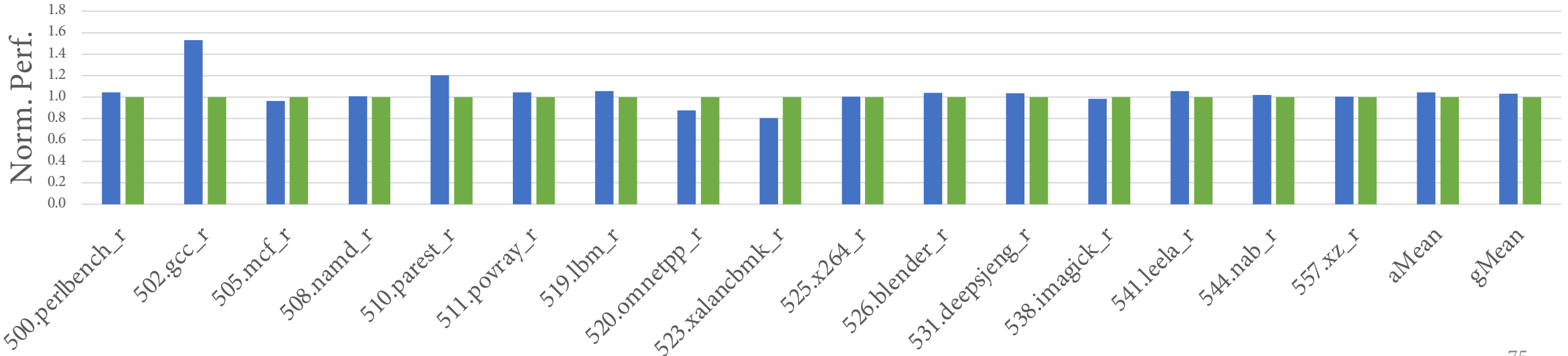

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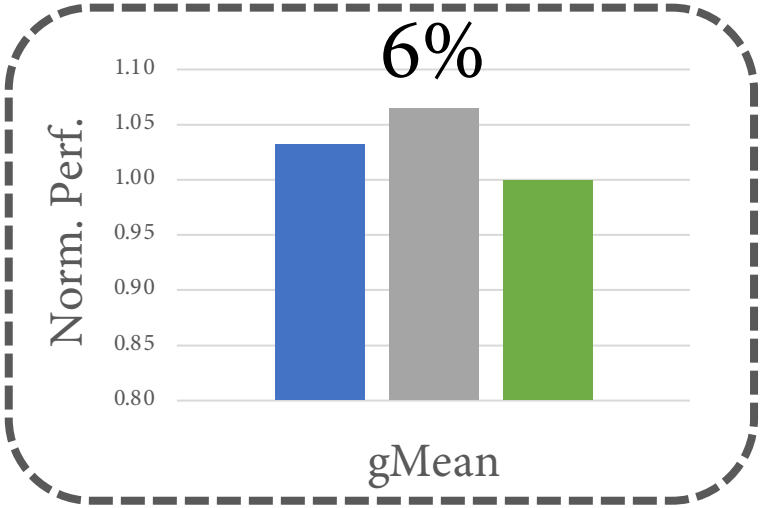

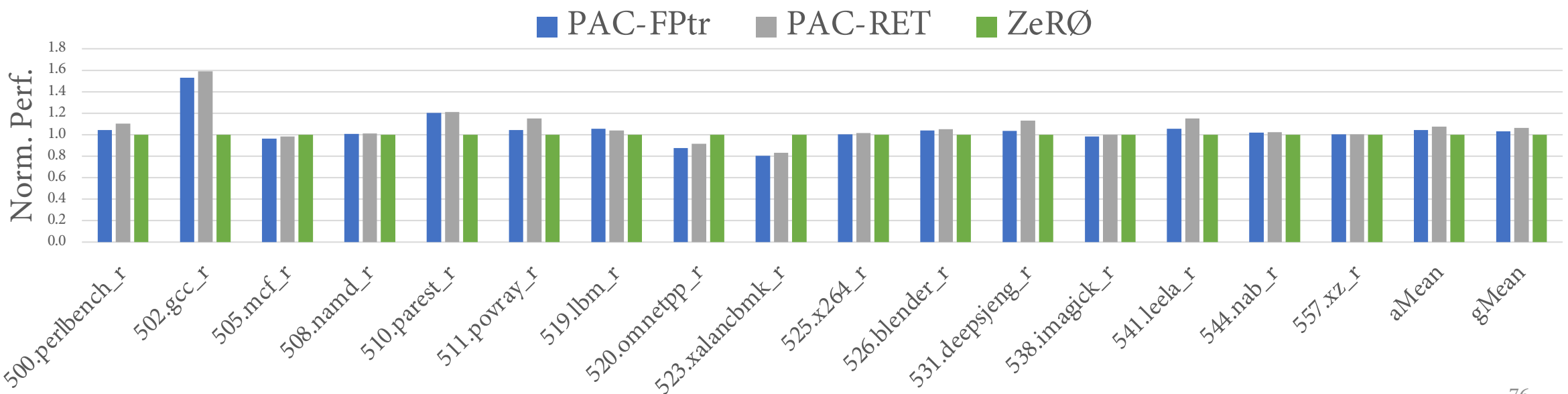

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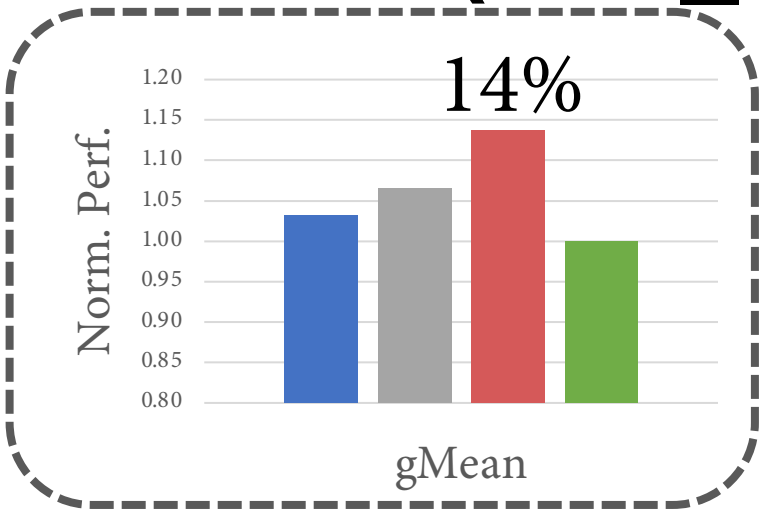

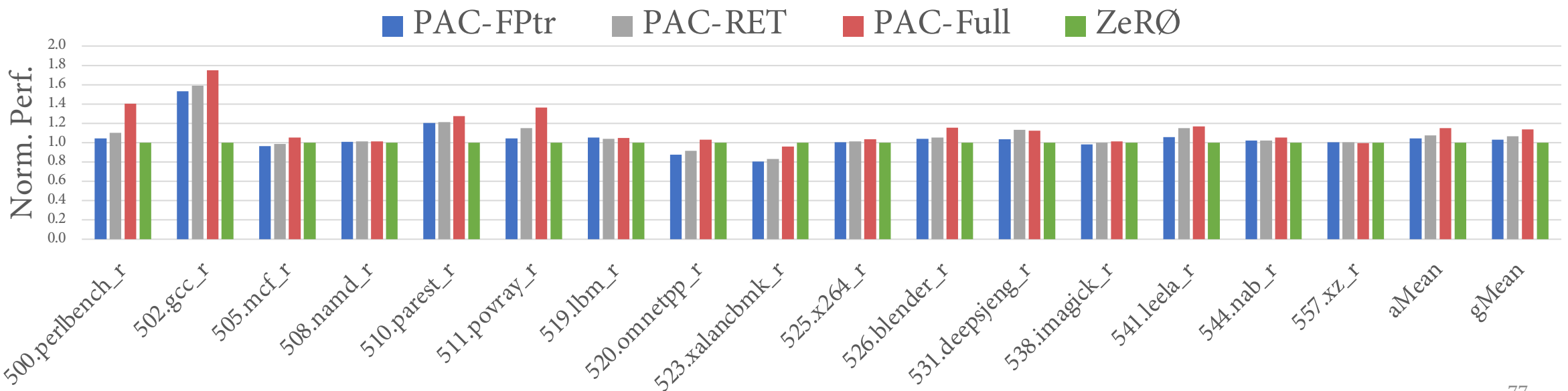

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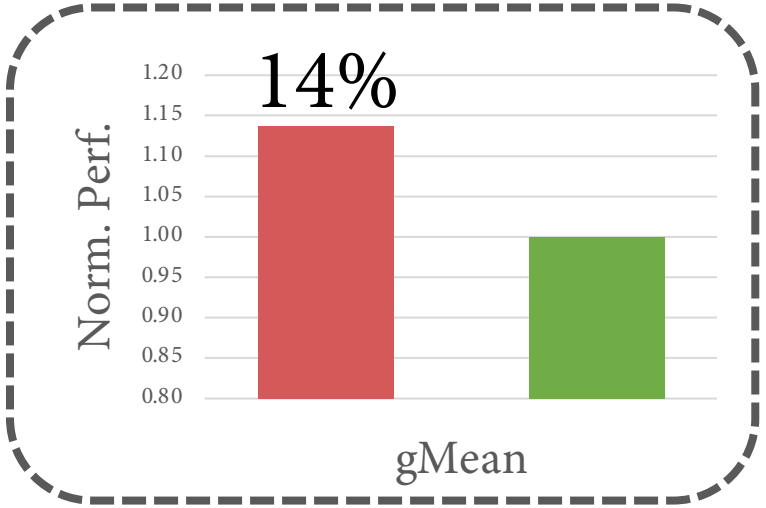
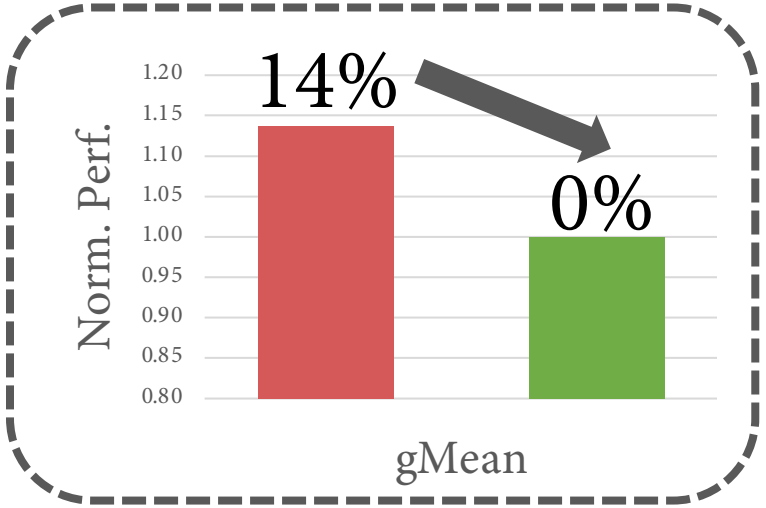


PAC's overheads are attributed to the extra QARMA invocations upon pointer loads/stores.

Performance Results (x86_64)



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

ZeRØ does not compromise on security

No Pointer Manipulation
Protects against all known pointer manipulation attacks (e.g. ROP, JOP/COP, COOP, DOP).

Handling Security Violations

Advisory Exceptions

- Skip faulty instructions.
- Do NOT crash the running process.

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Permit List
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Permit List
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- Avoid false alarms for non-type aware functions (e.g., `memcpy` and `memmove`)

Limitations

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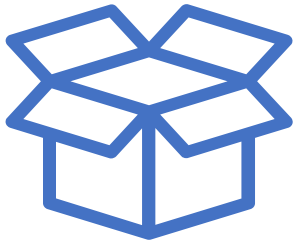

Third-Party Code

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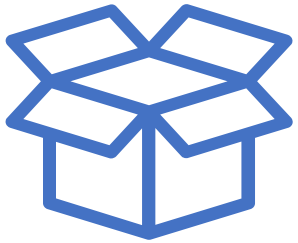

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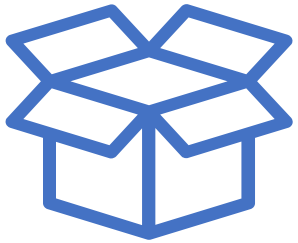

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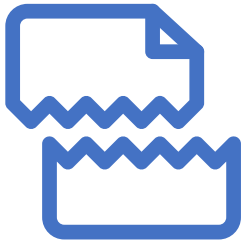
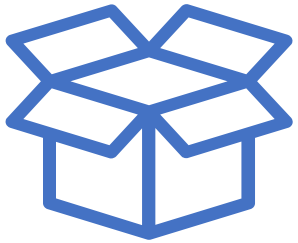


Non-pointer Data Corruption

Limitations



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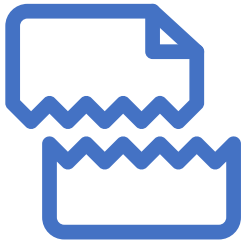
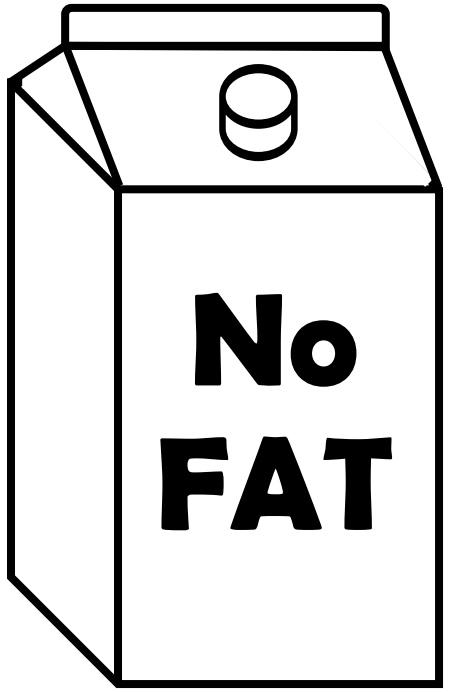


Non-pointer Data Corruption

These attacks require a full memory safety solution.

No-FAT: Low Overhead Memory Safety Checks



Full Memory Safety
No-FAT is well suited for cloud/server deployments away from the end user.

Checkout our paper & talk!
https://isca21.arroyo.me

An efficient pointer integrity mechanism

An ideal candidate for end-user deployment.

- ✓ **Easy to Implement**
- ✓ **No Runtime Overheads**
- ✓ **Offers Robust Security**

Backup Slides