Side-Channel Attacks on Optane Persistent Memory

Sihang Liu, **Suraaj Kanniwadi**, Martin Schwarzl, Andreas Kogler,
Daniel Gruss, Samira Khan

Usenix Security Symposium 2023

Overview: Motivation

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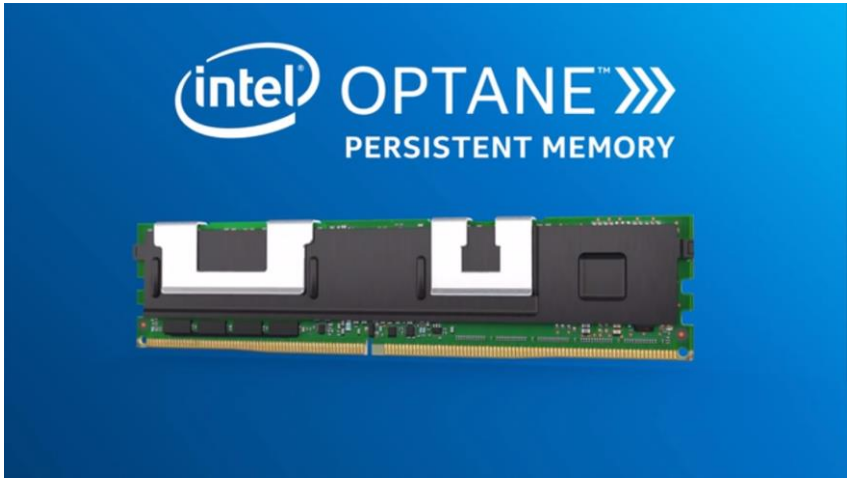

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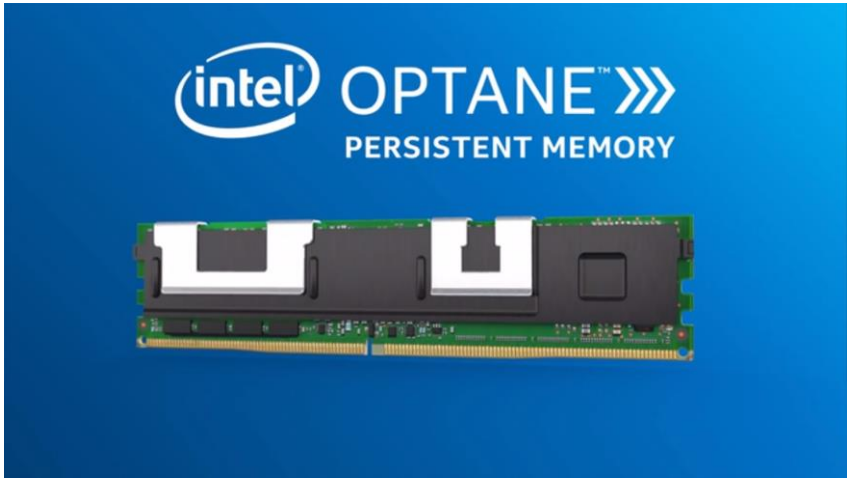

Overview: Contributions

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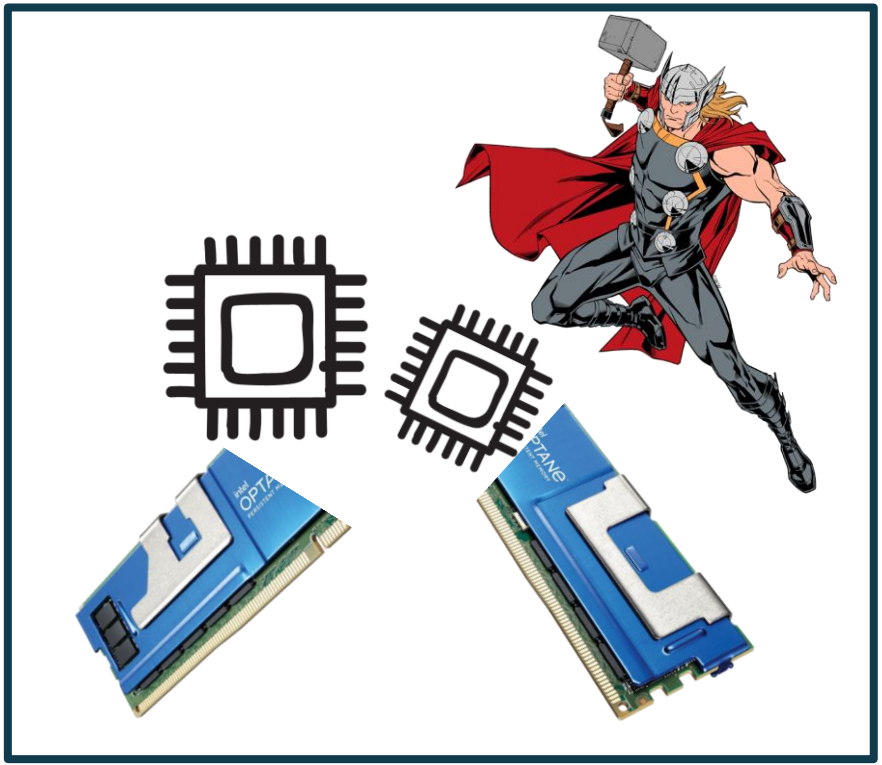

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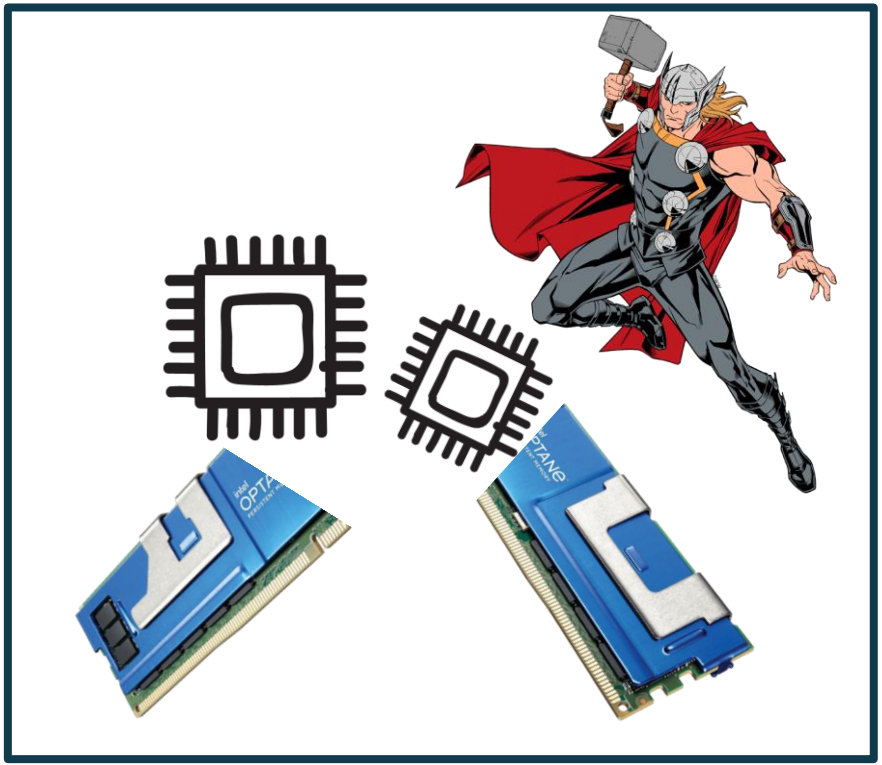

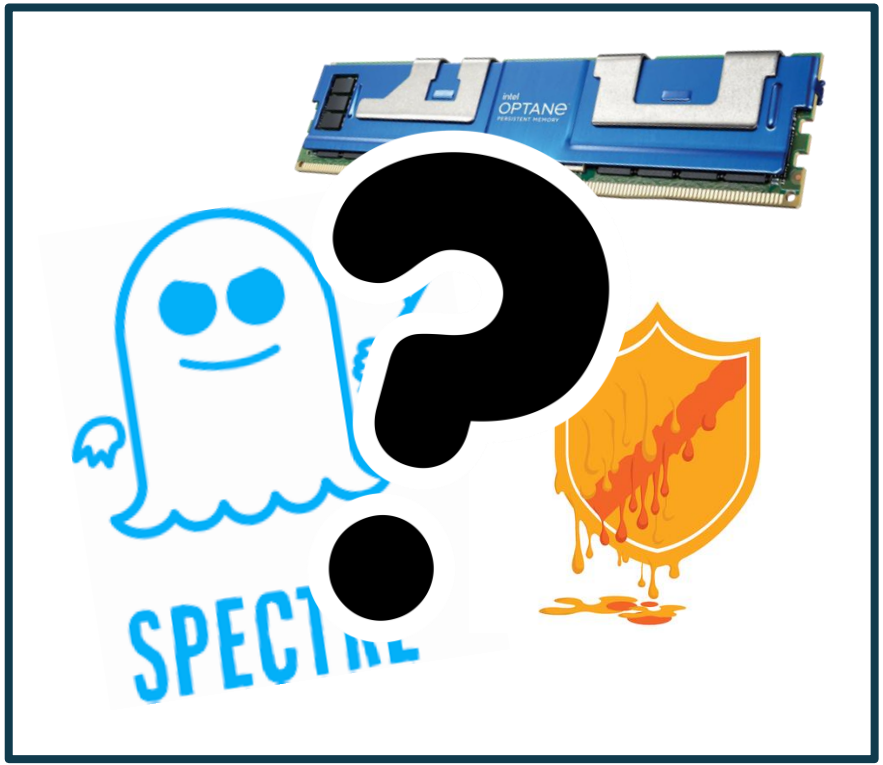

Background

Optane, Persistent Memory, and Side Channels

Optane Persistent Memory

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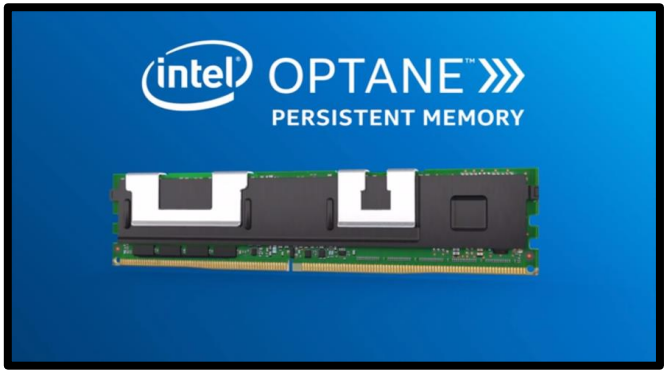

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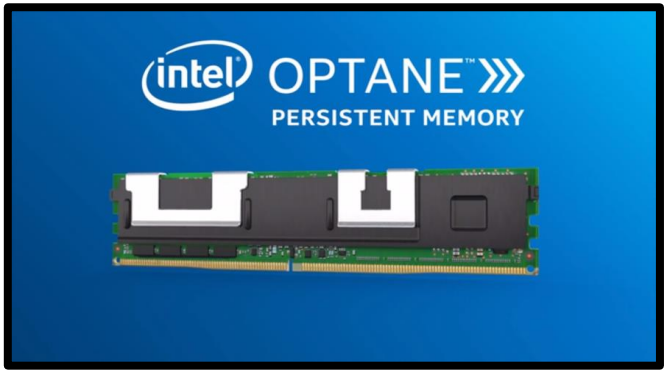

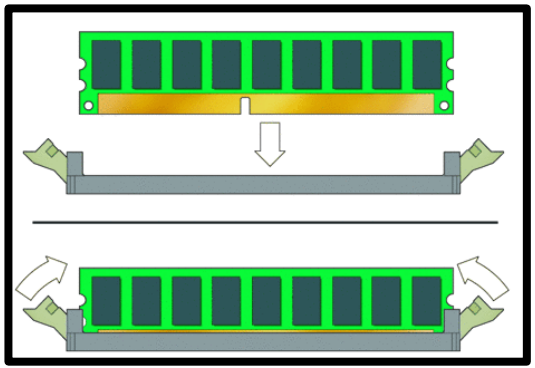

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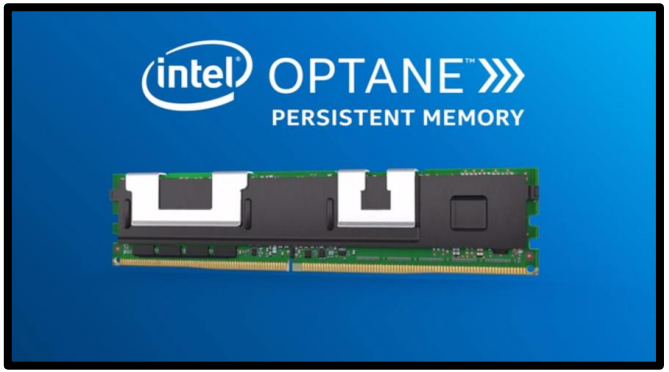

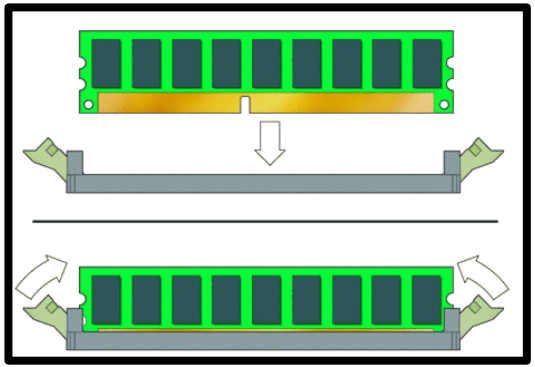

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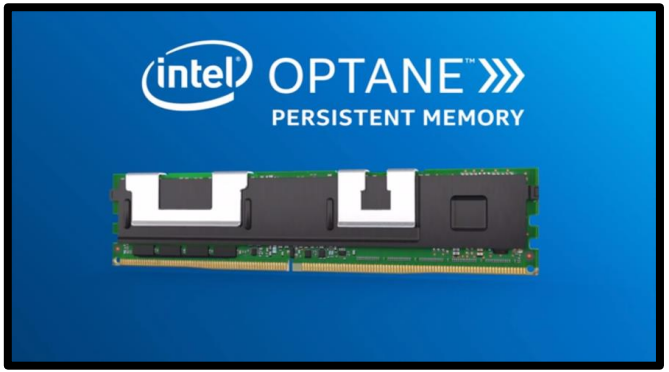

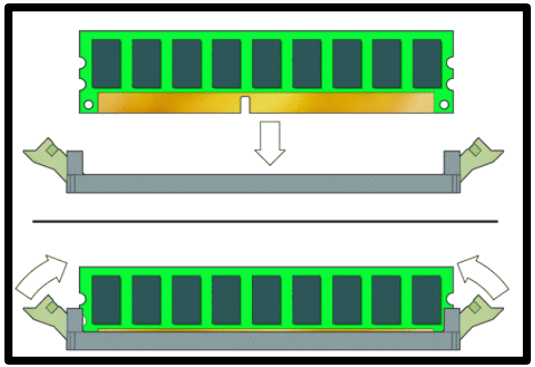

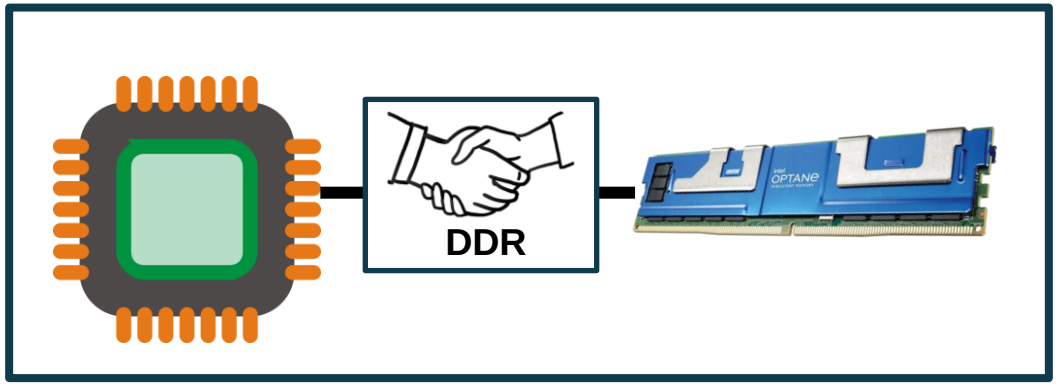

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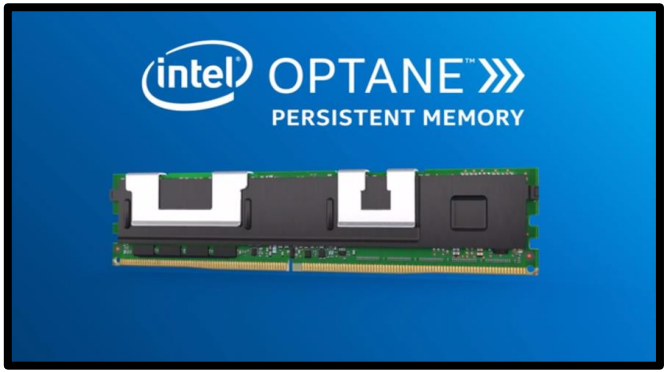

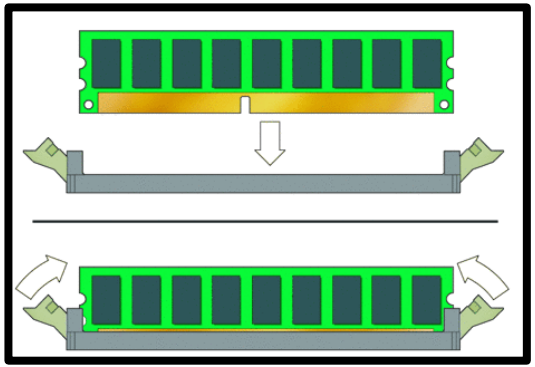

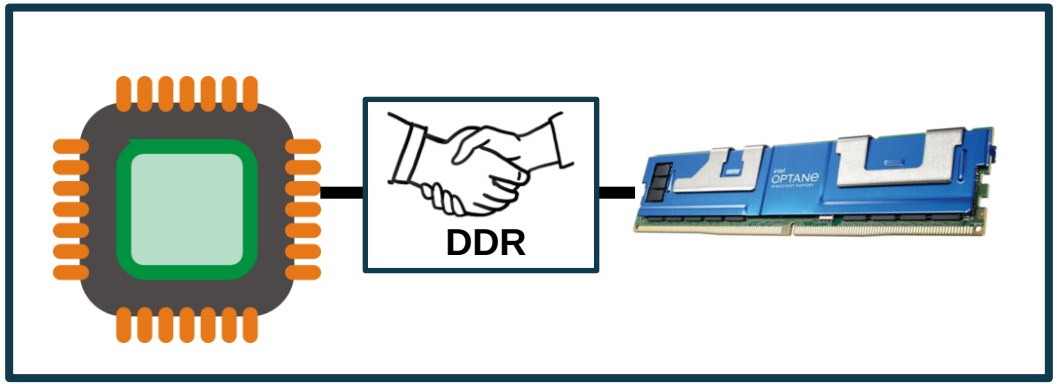

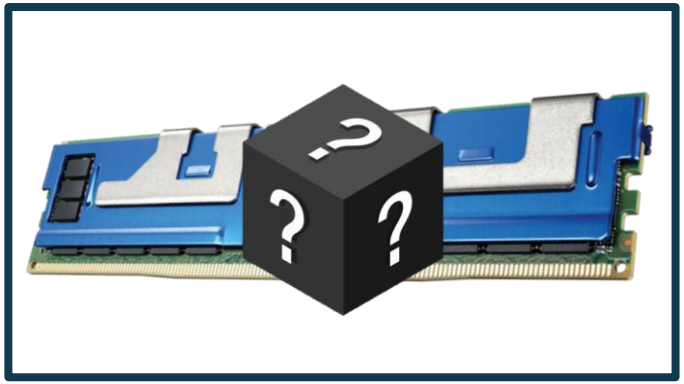

Stable storage with Direct Access

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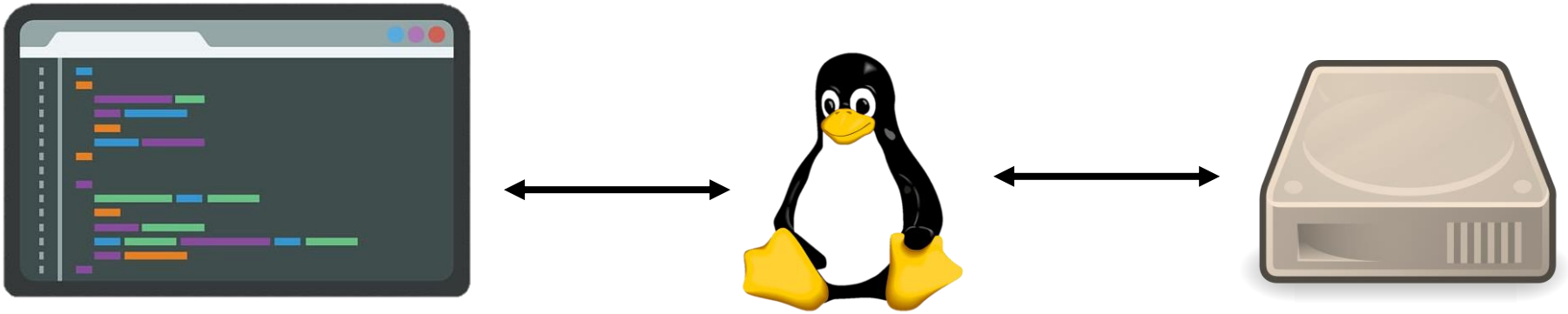

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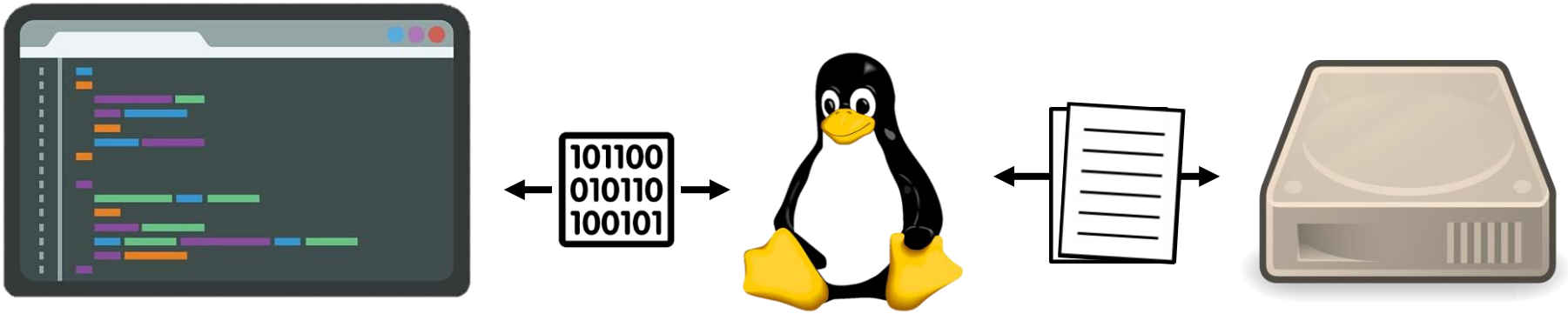

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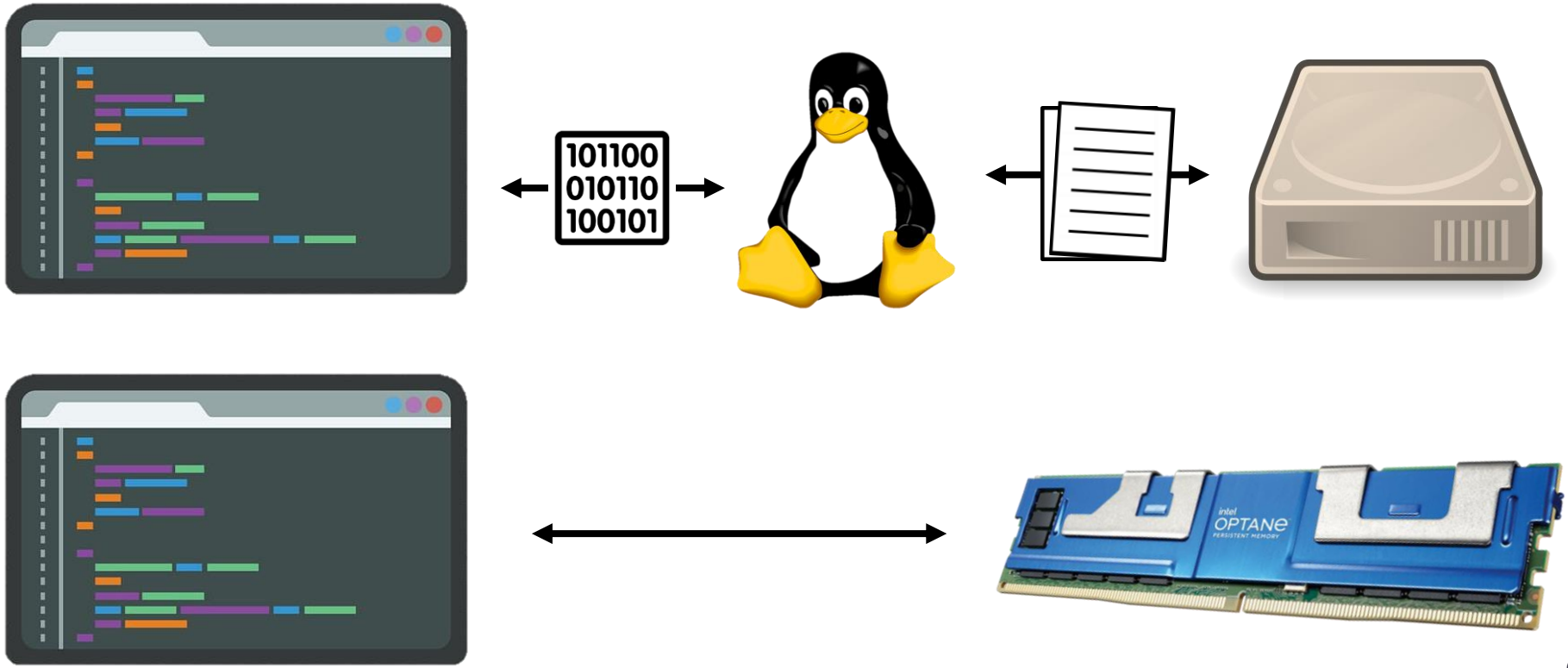

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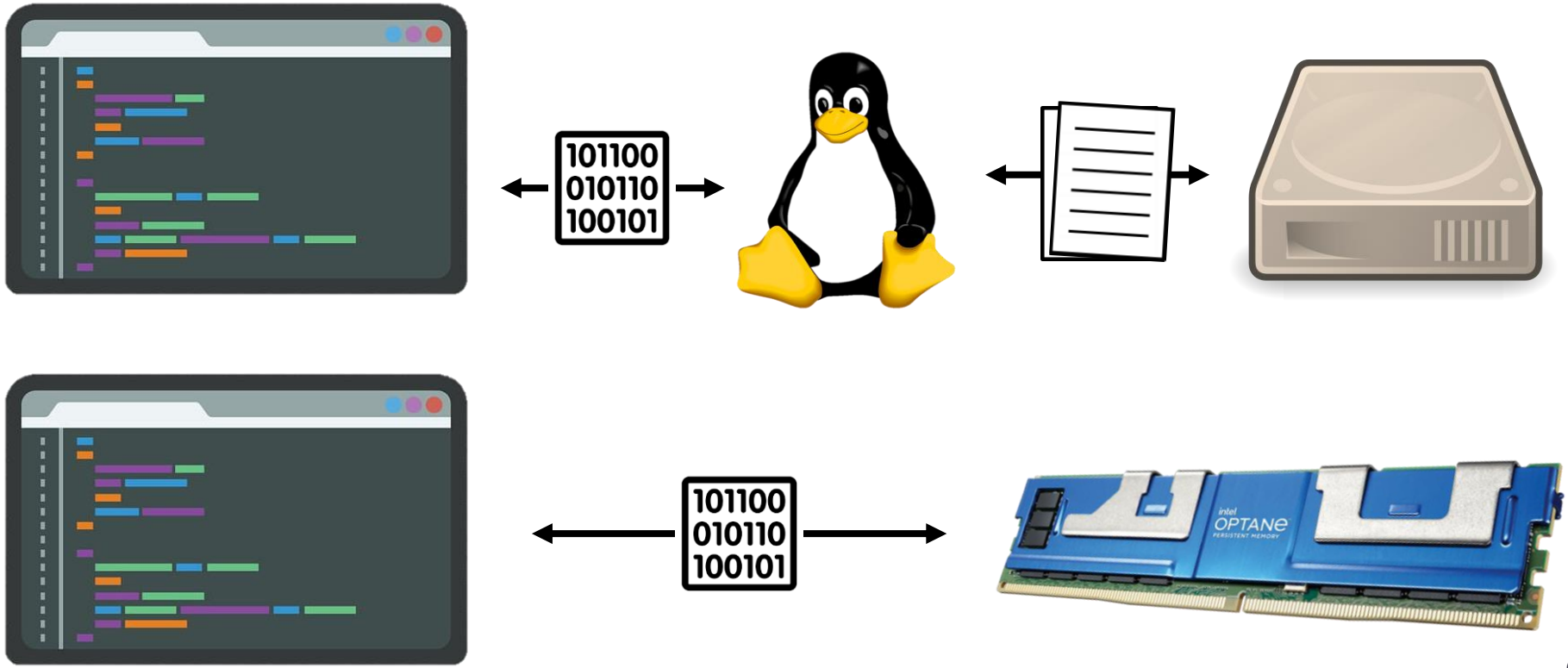
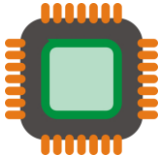
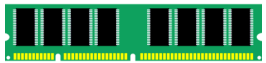


In the system heirarchy





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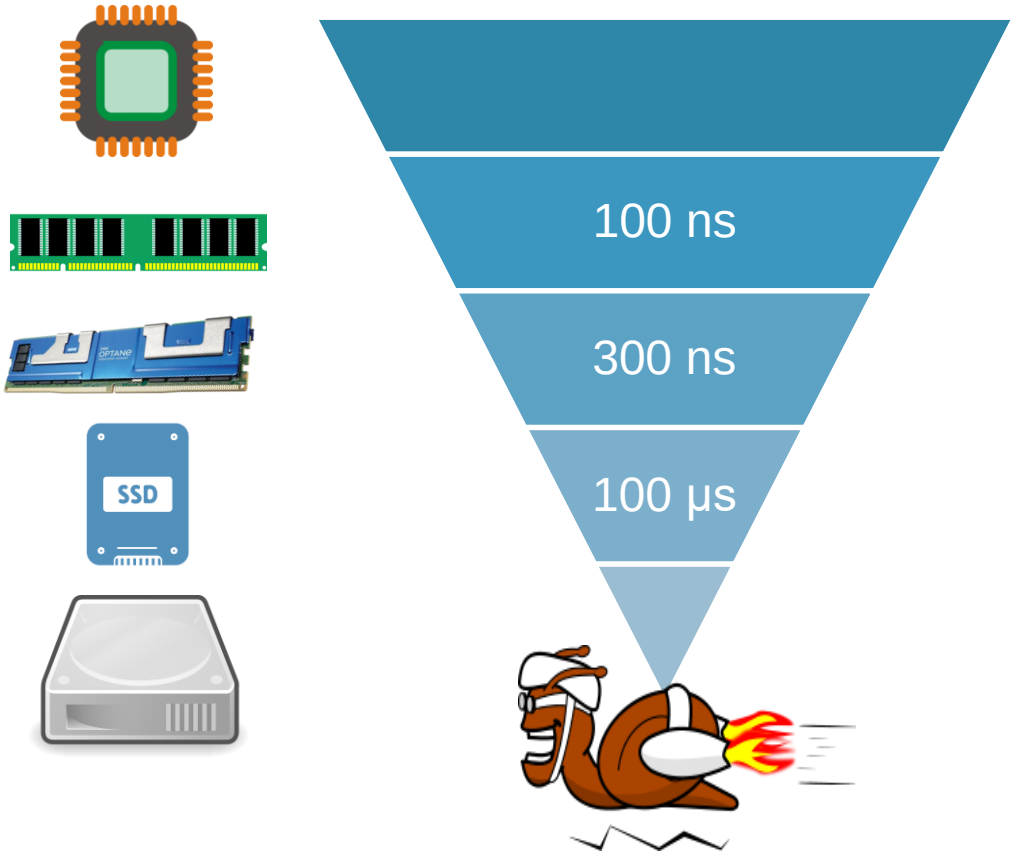

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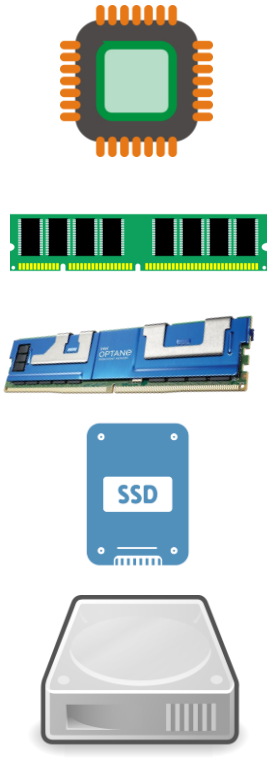

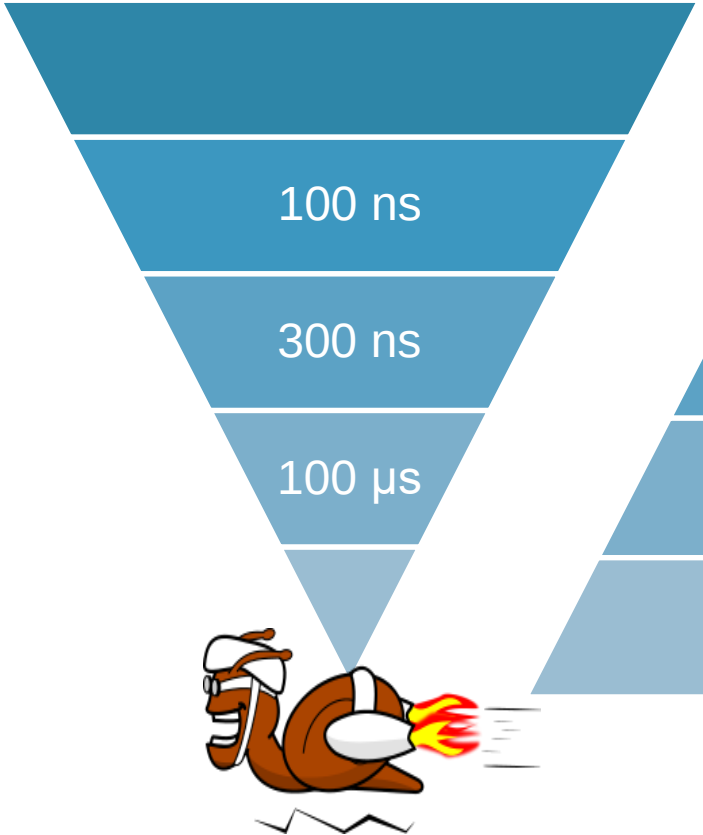

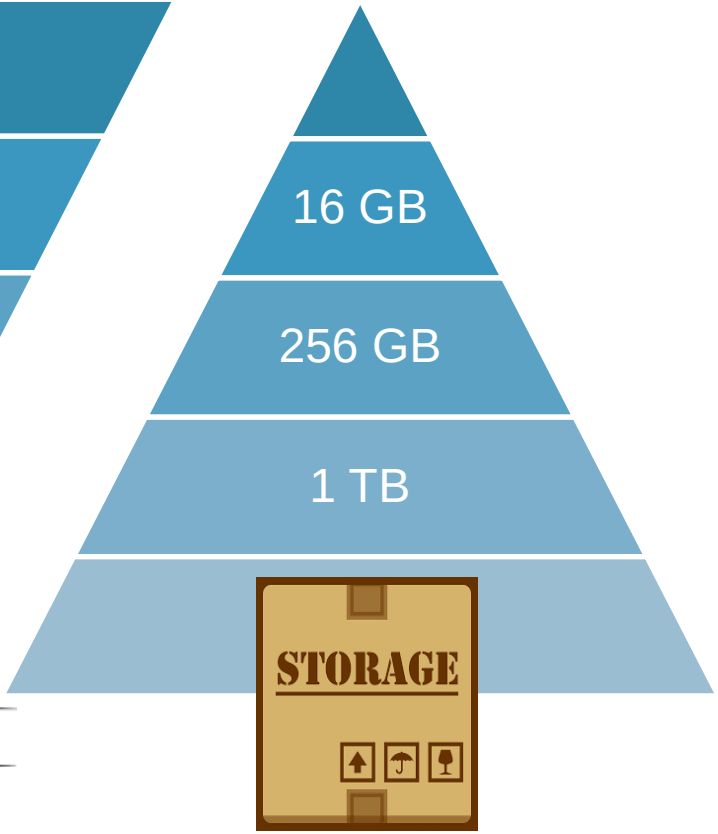

A Side Channel Attack?

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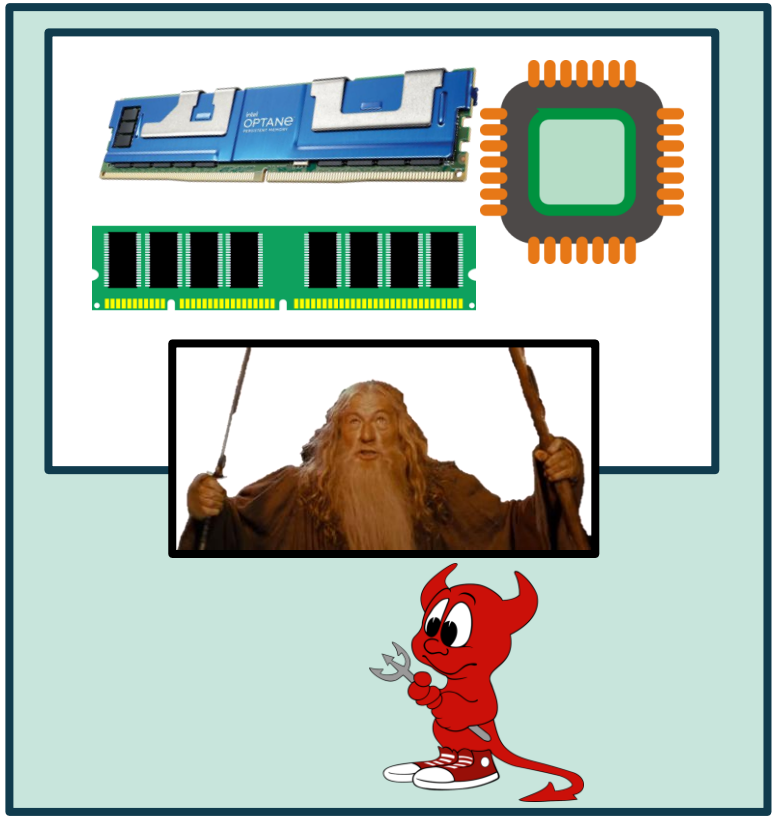

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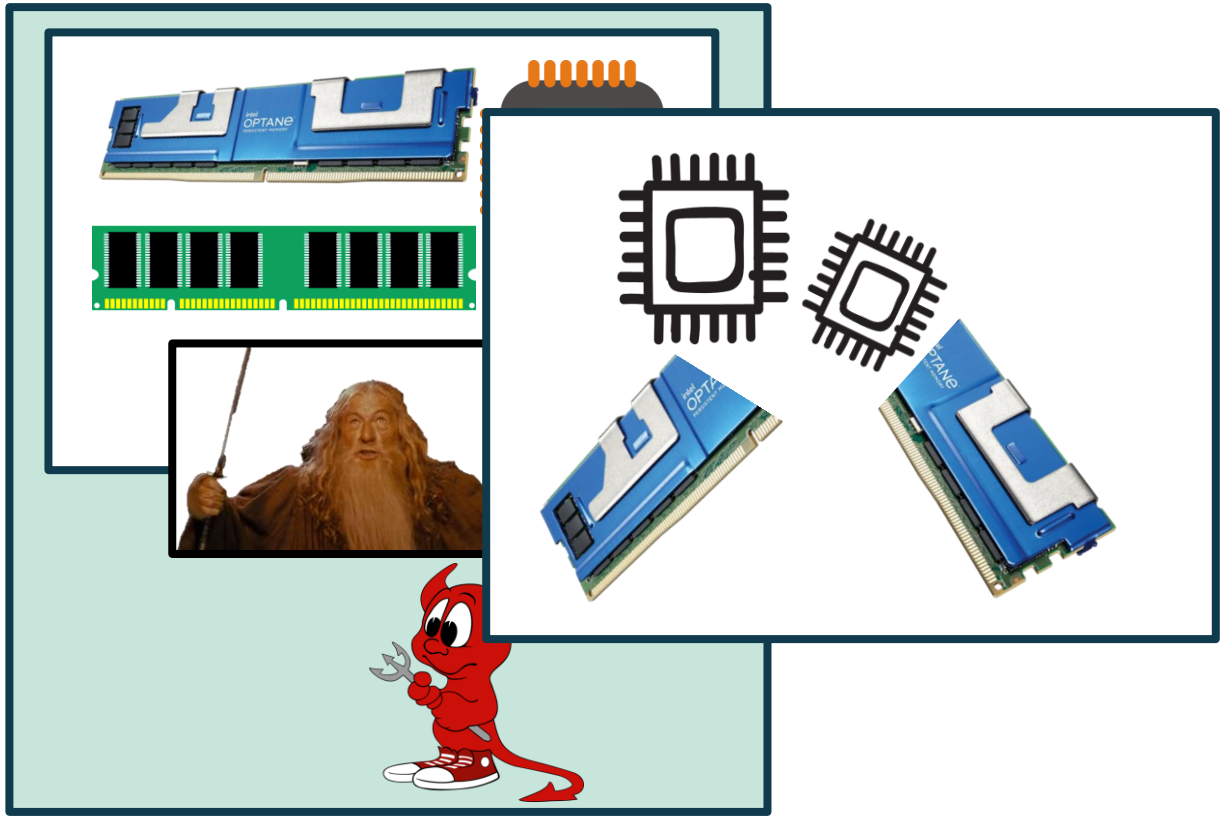

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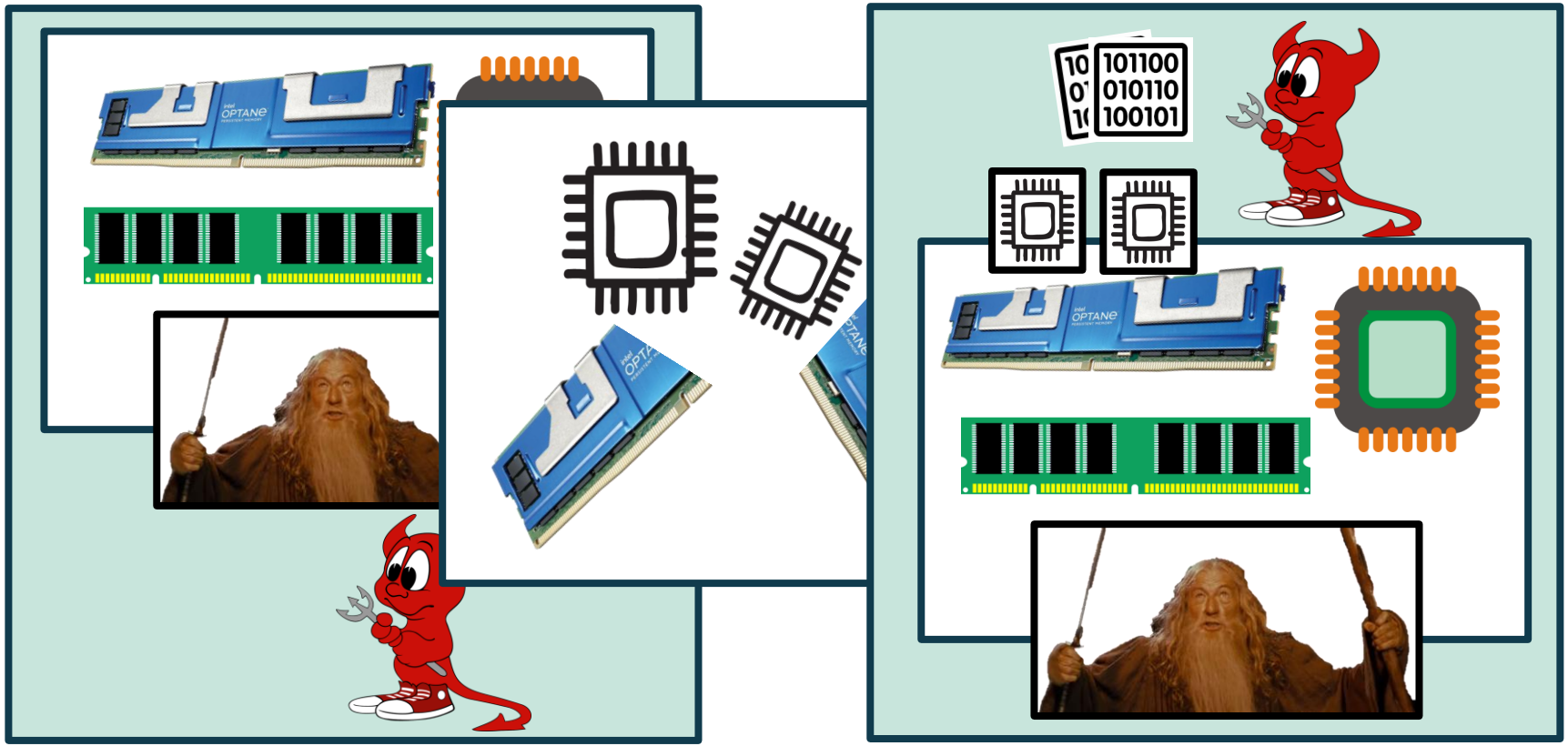

Reverse-Engineering of Optane

A glimpse into the Optane DIMM

Optane: Prior Work

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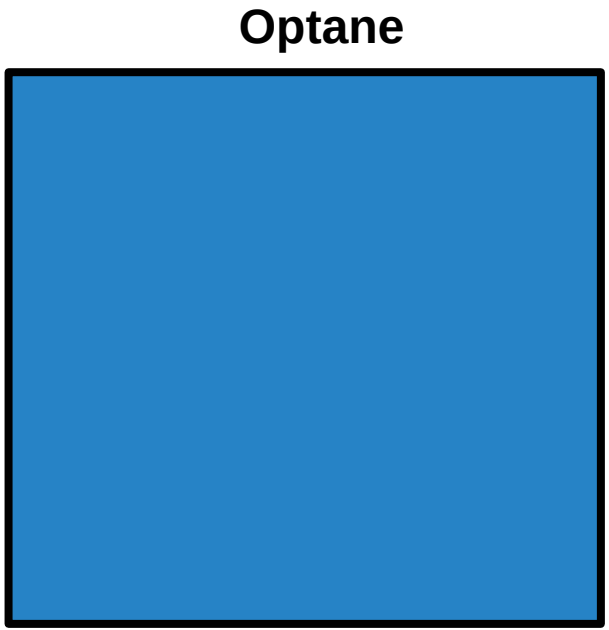

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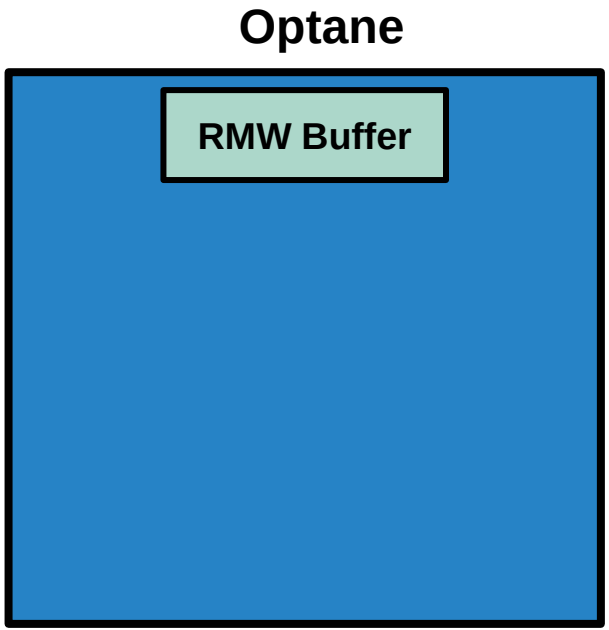

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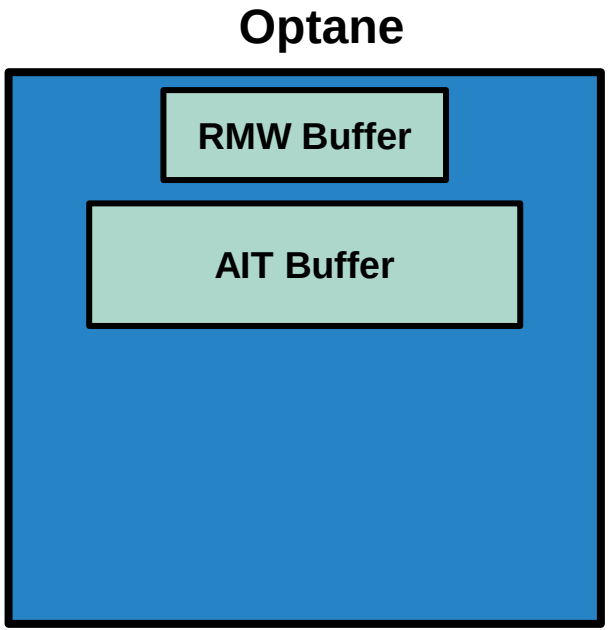

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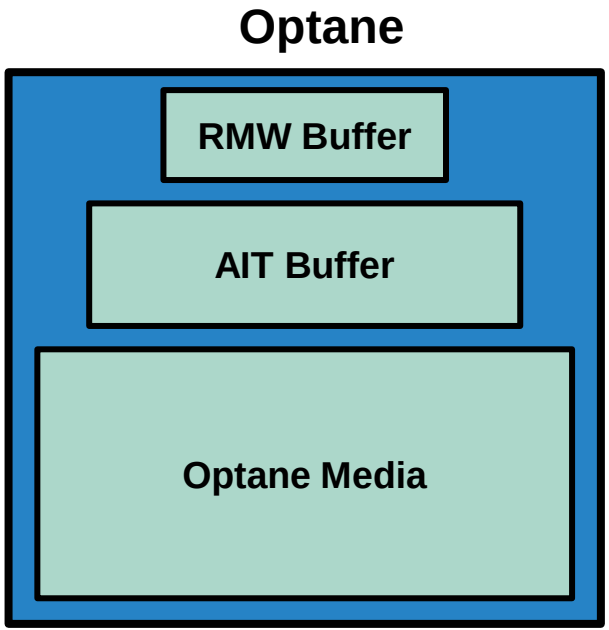

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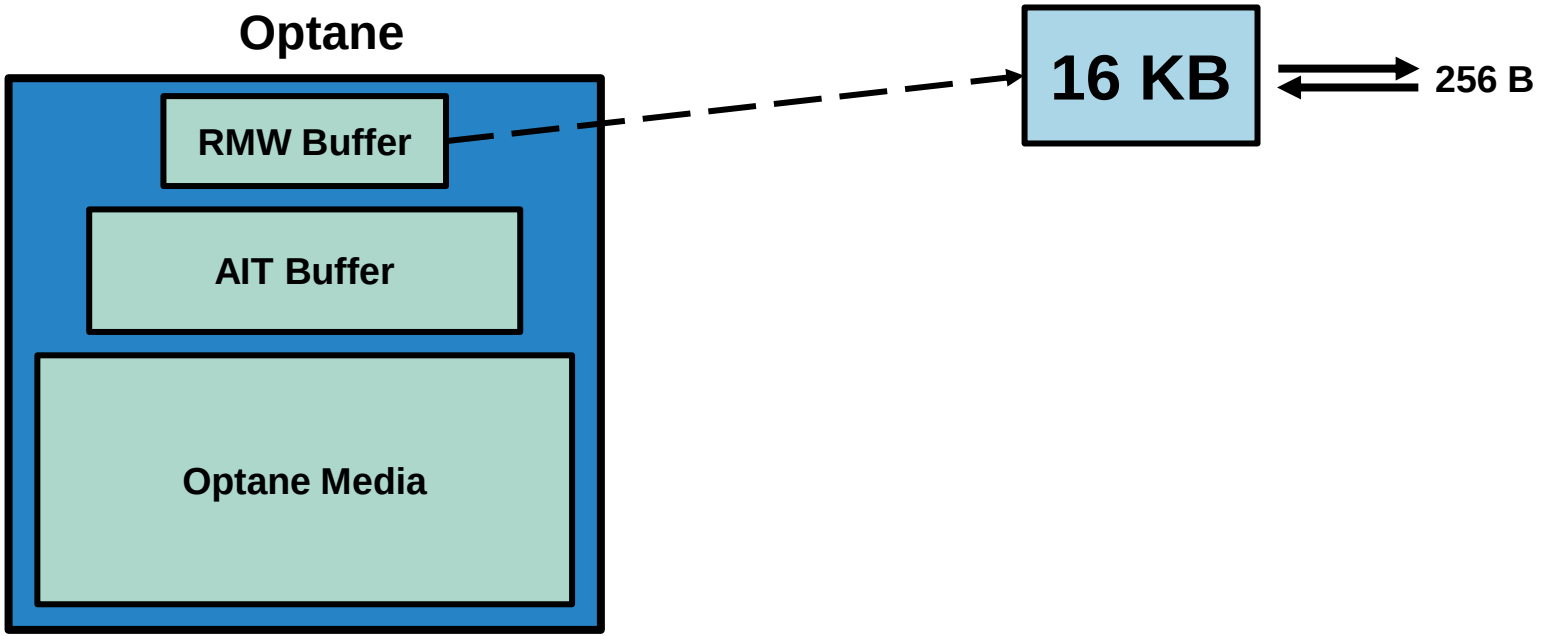

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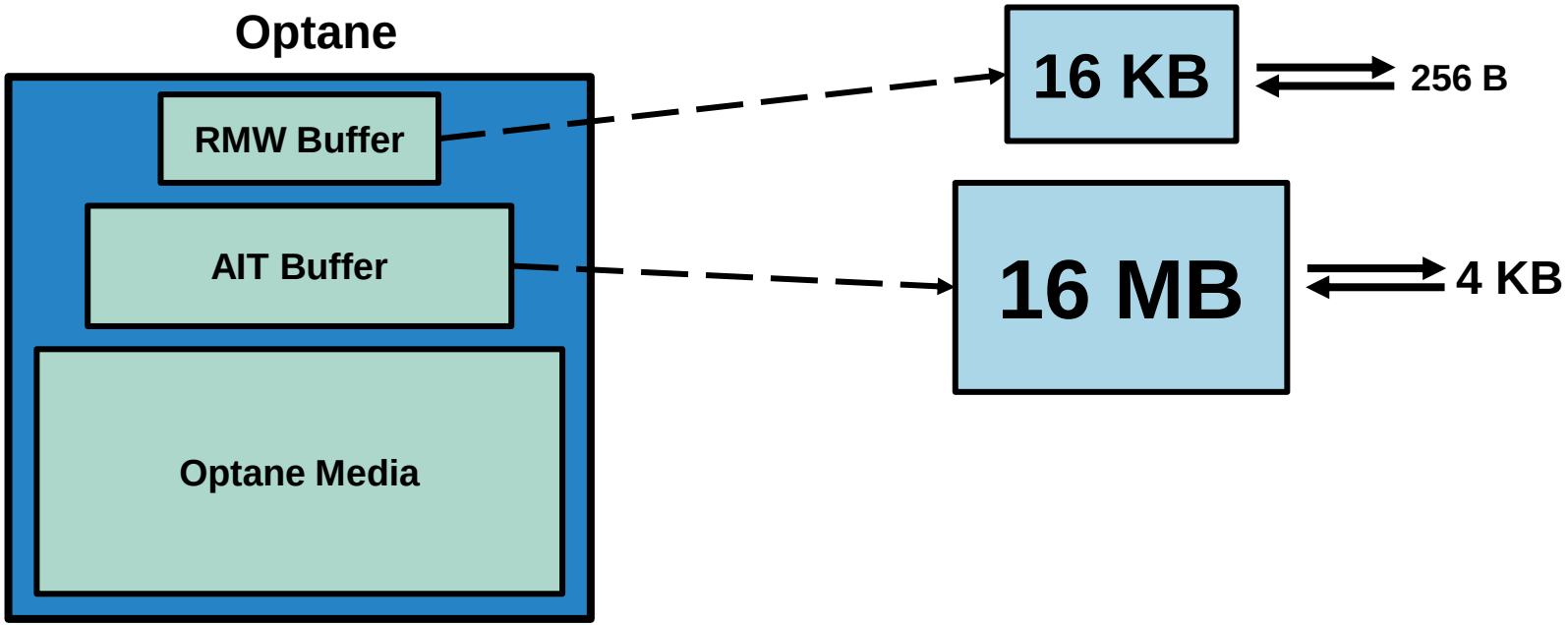

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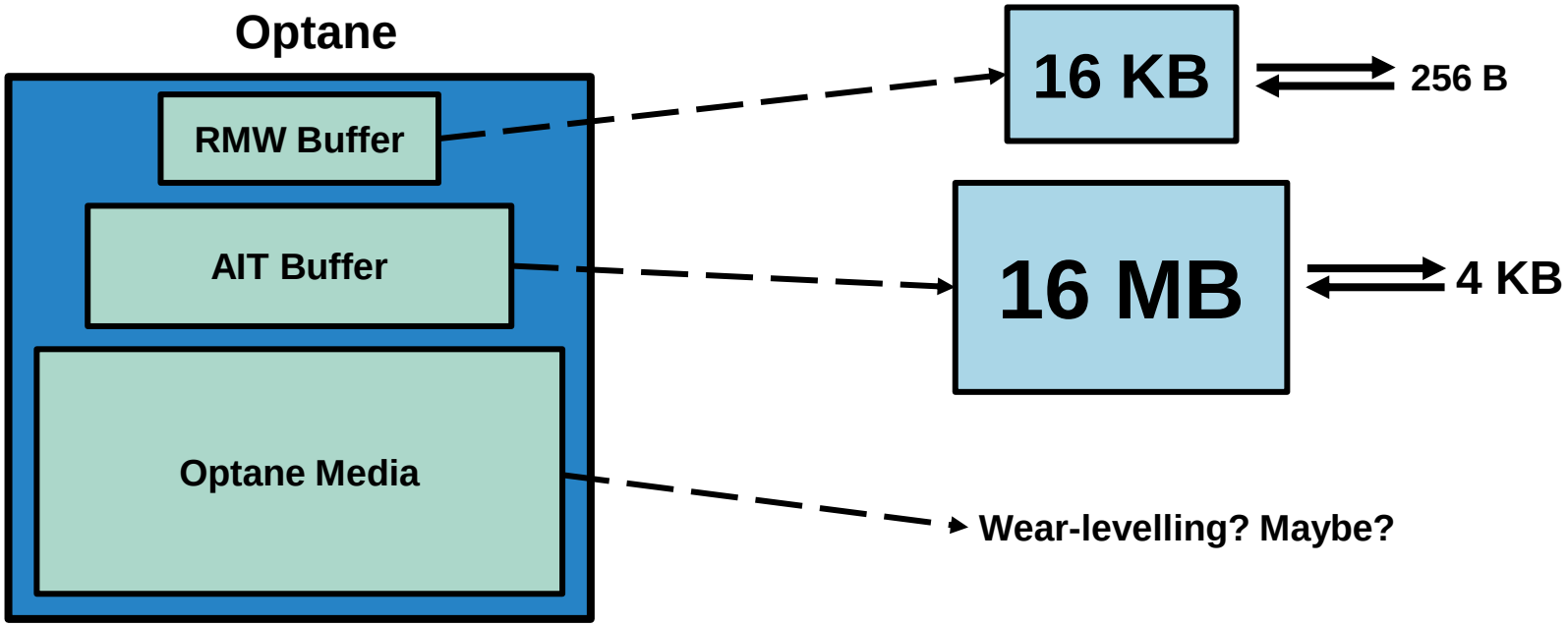
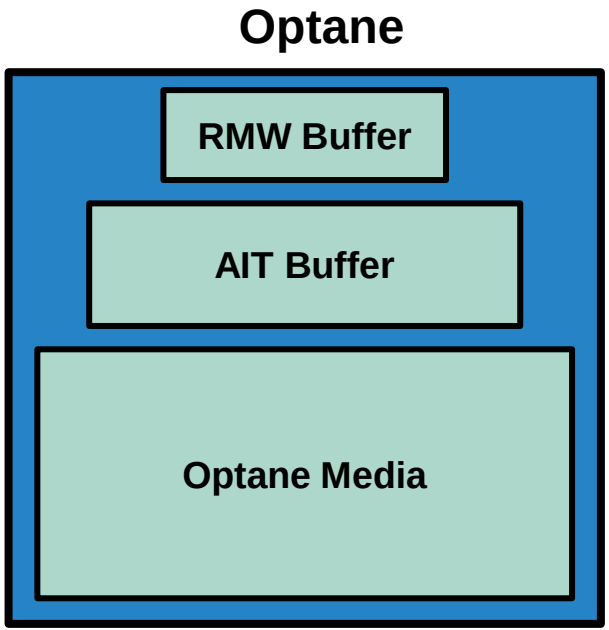


Optane: We have more!



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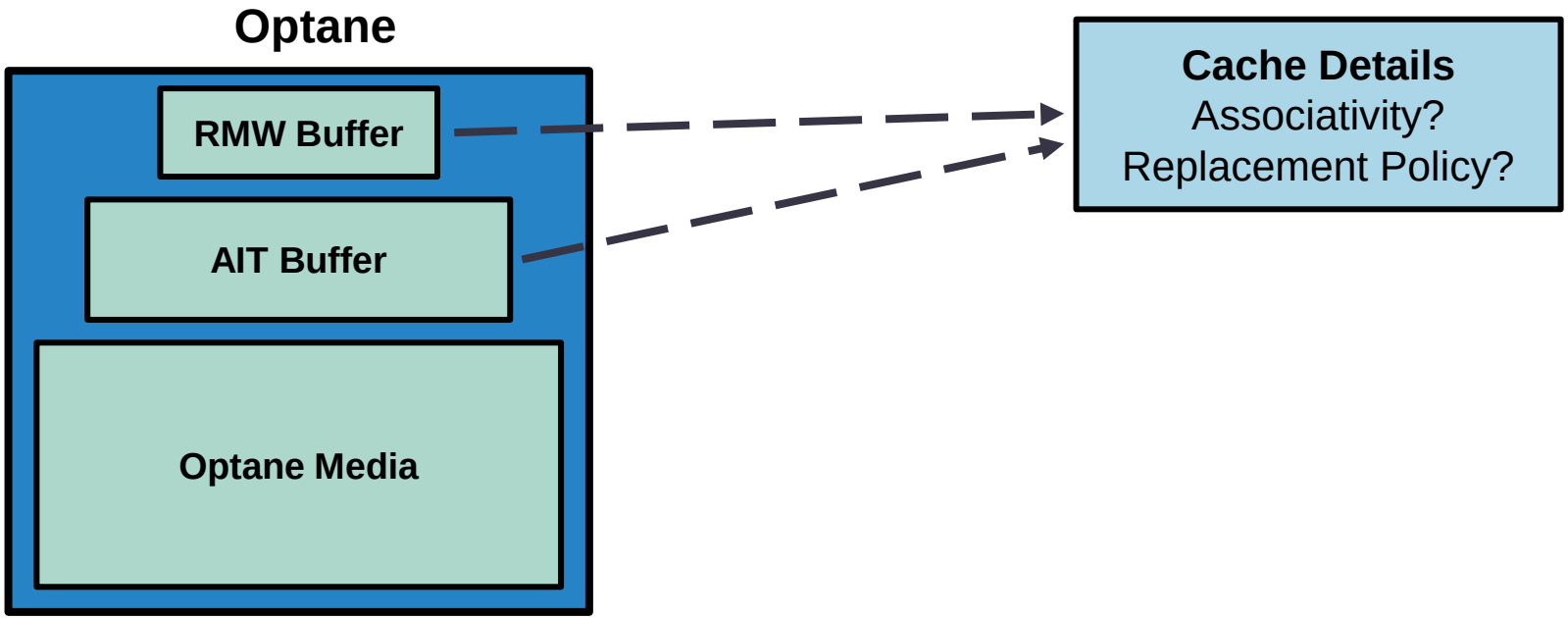

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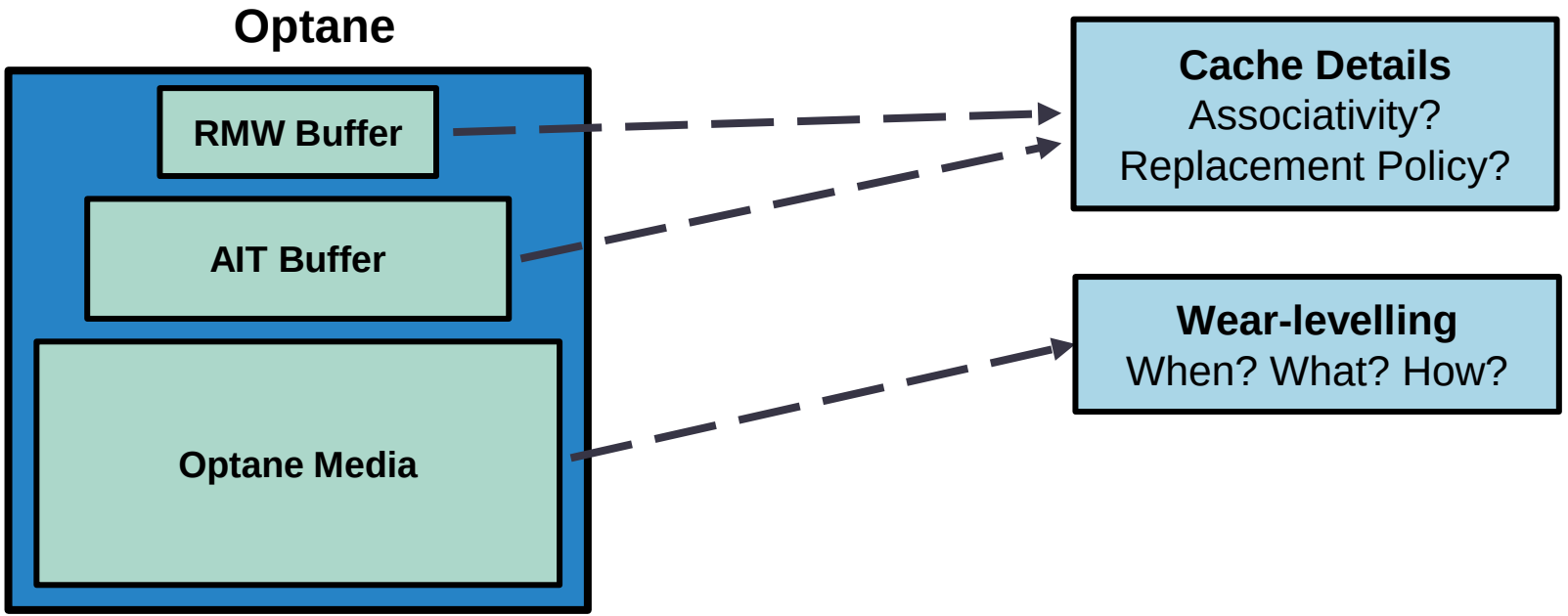

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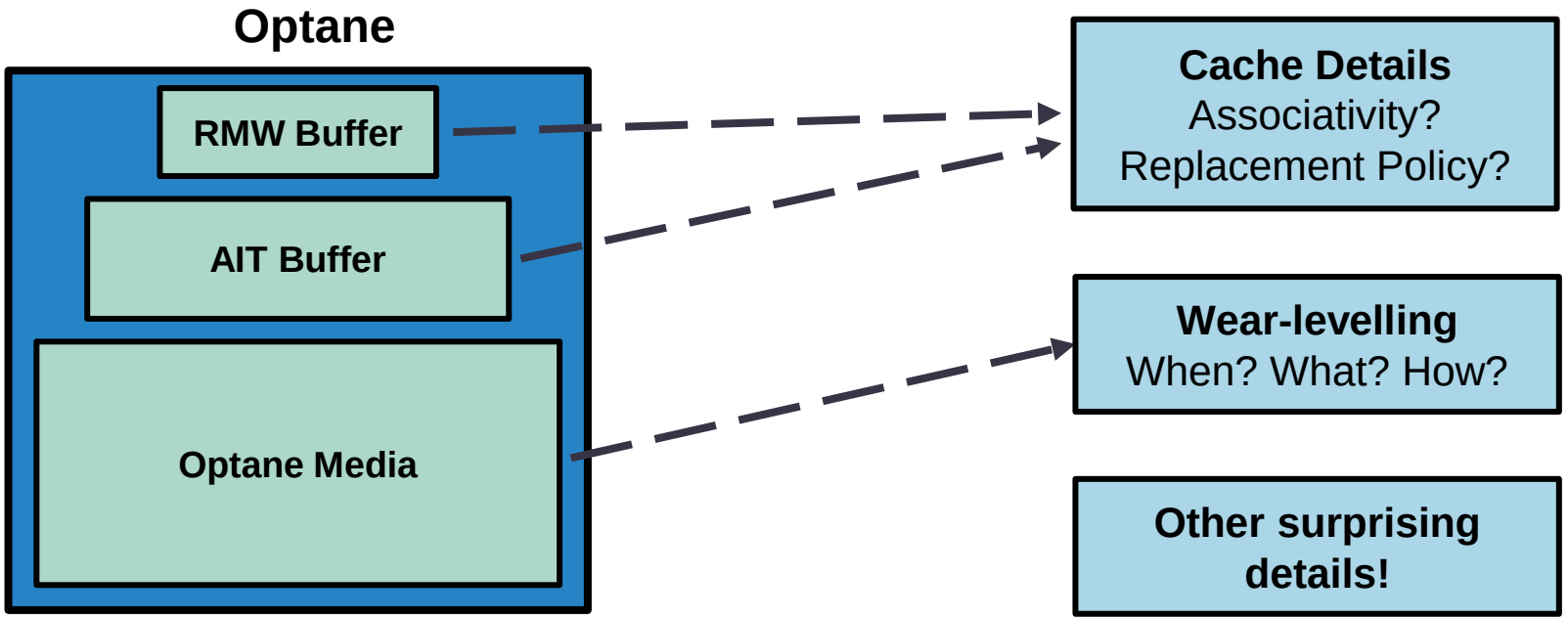
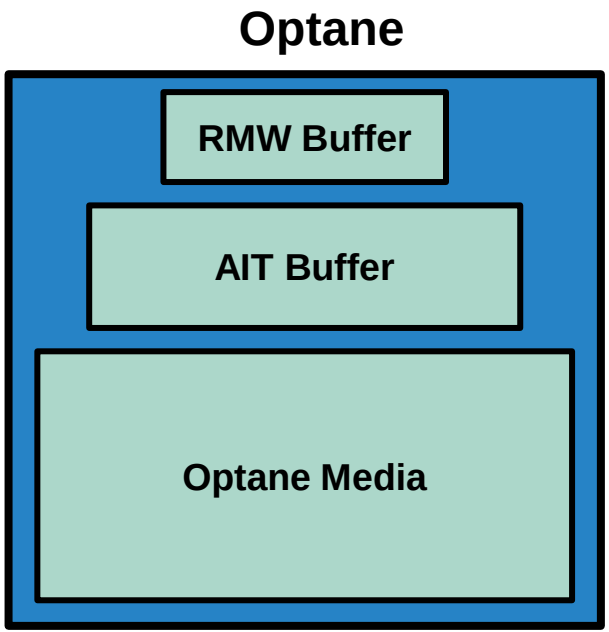


On-DIMM caches



16 KB ⇄ 256 B

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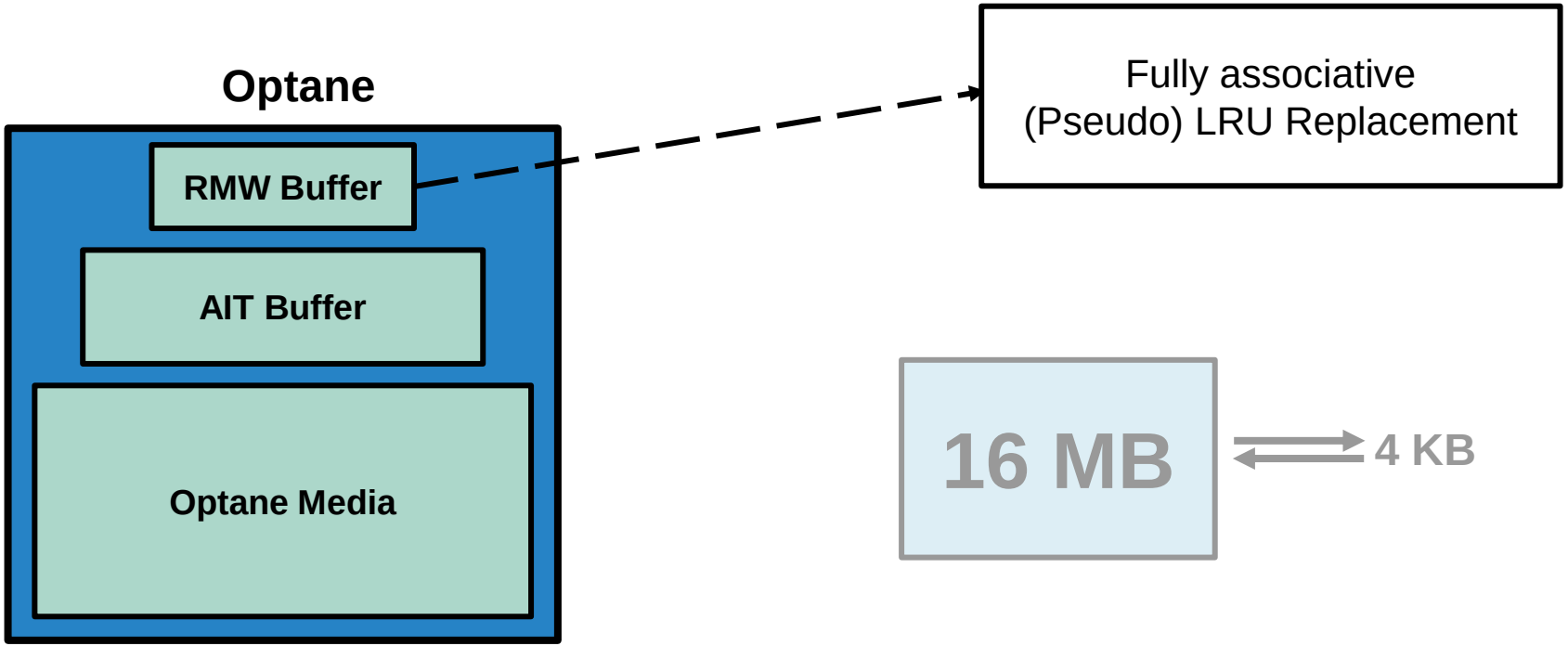

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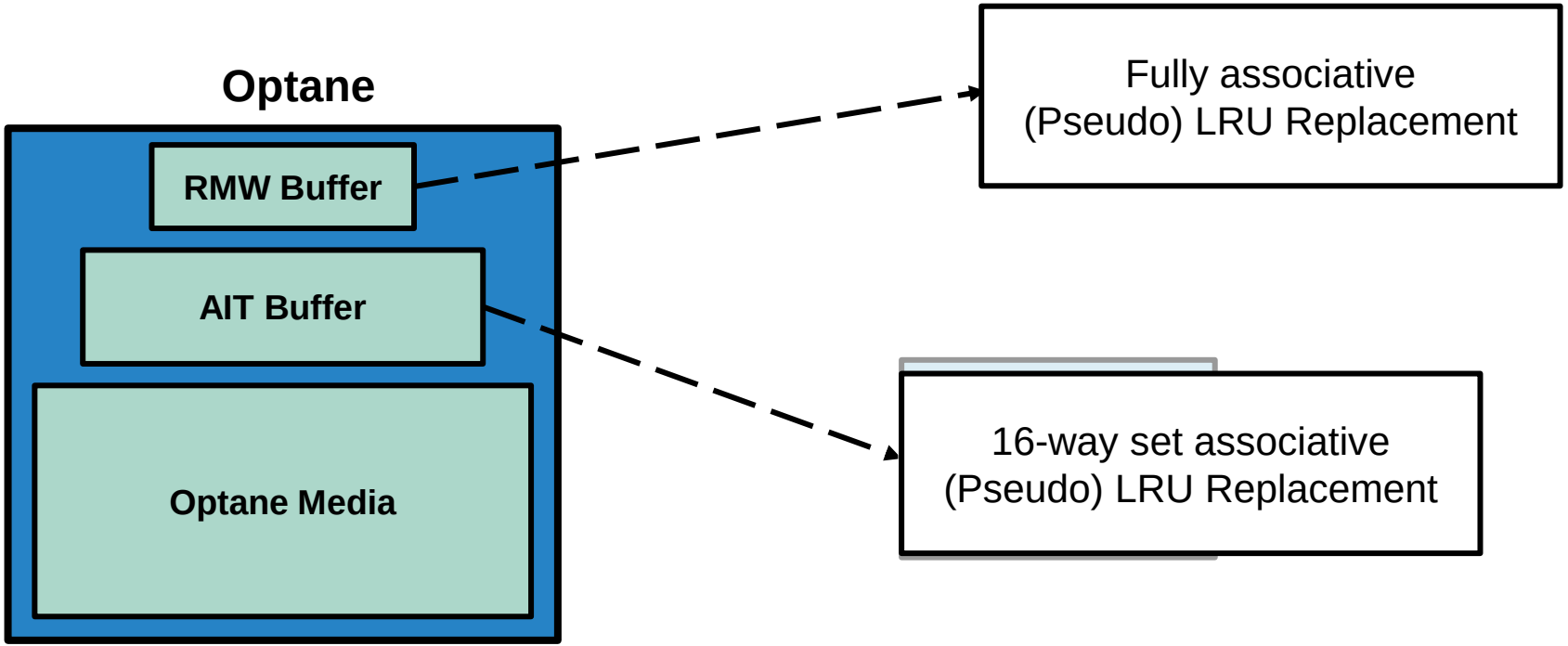
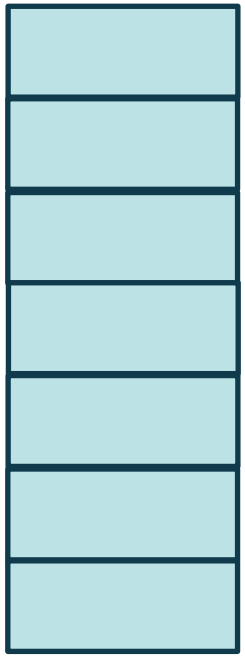
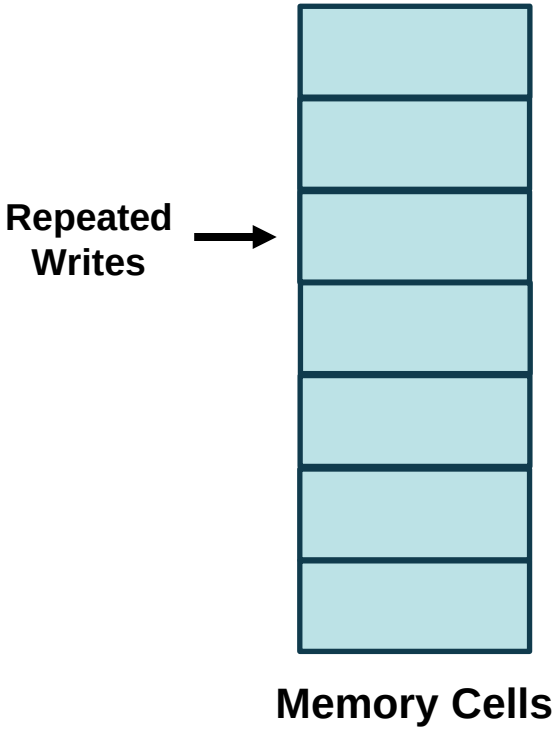


Wear-levelling in Memories



Memory Cells

Wear-levelling in Memories



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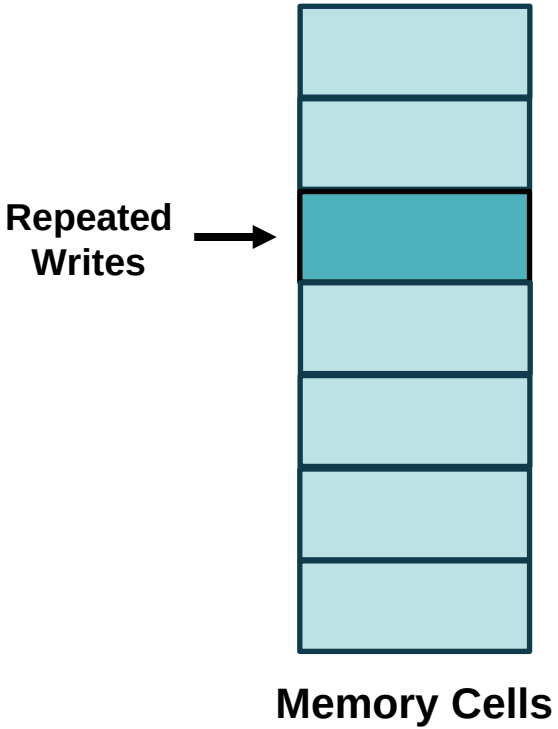

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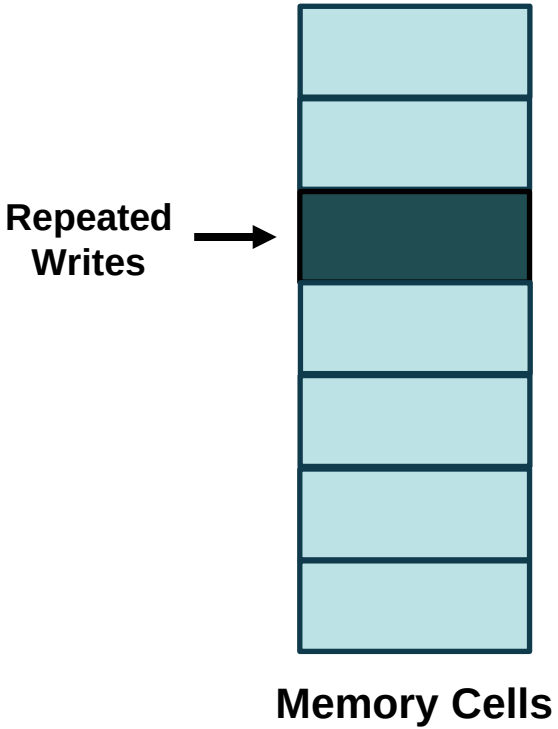

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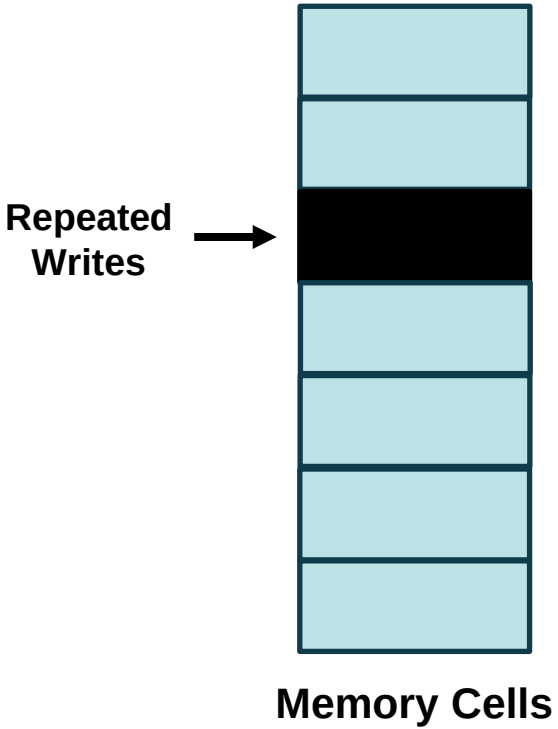

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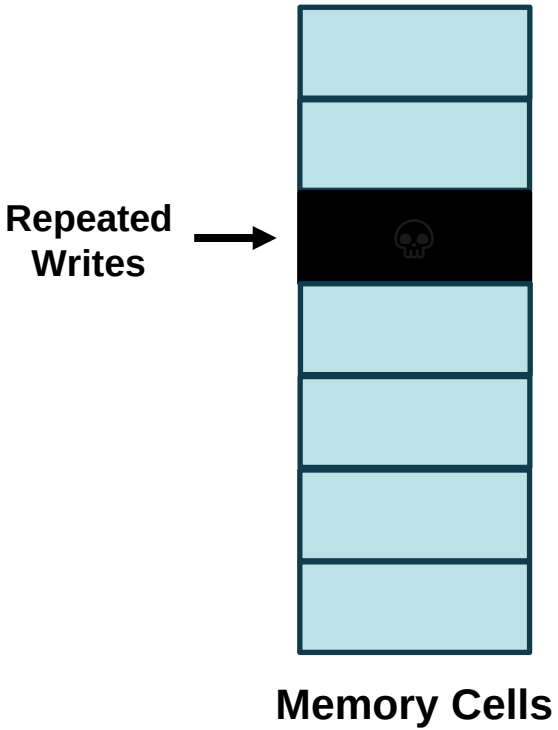

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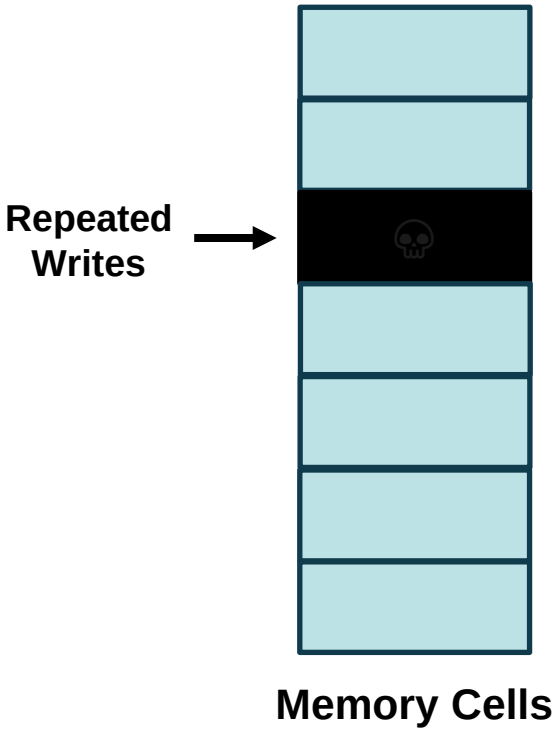
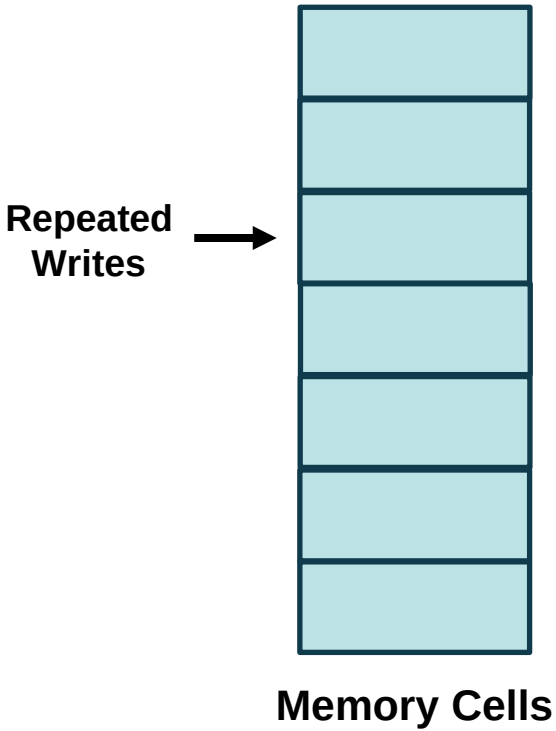


Wear-levelling to the rescue!



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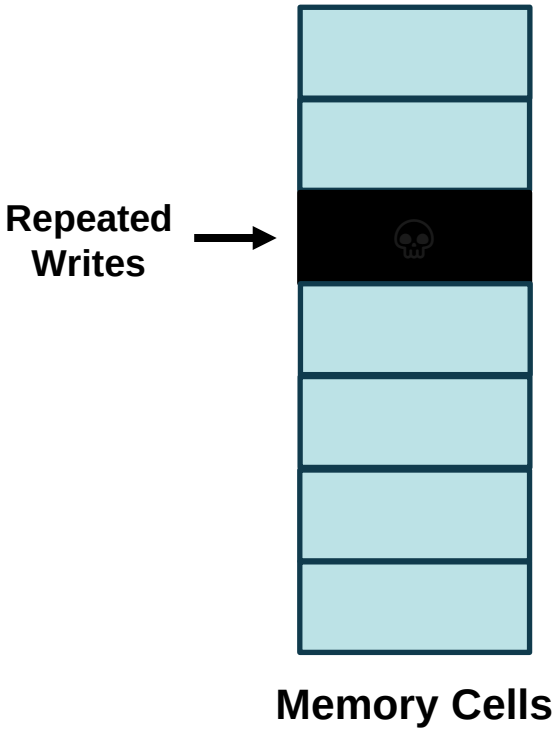

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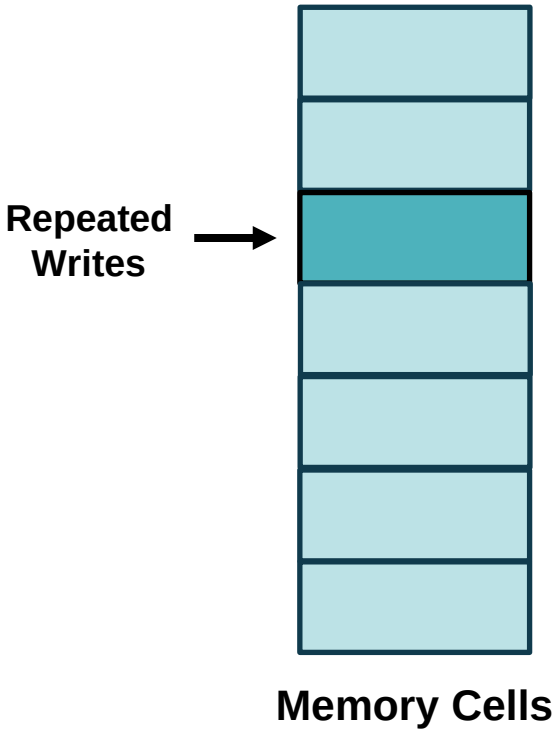

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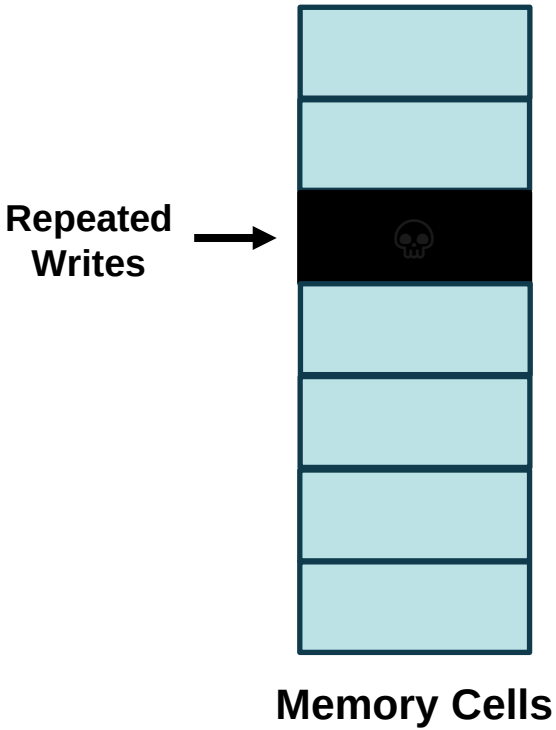

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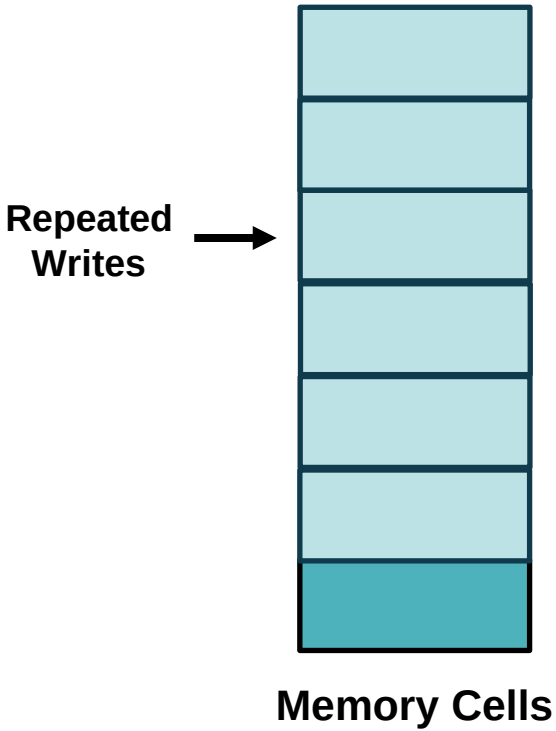

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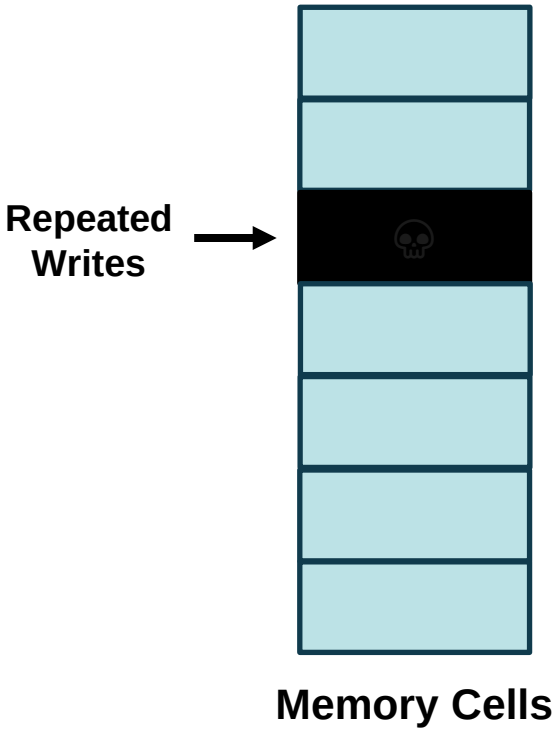
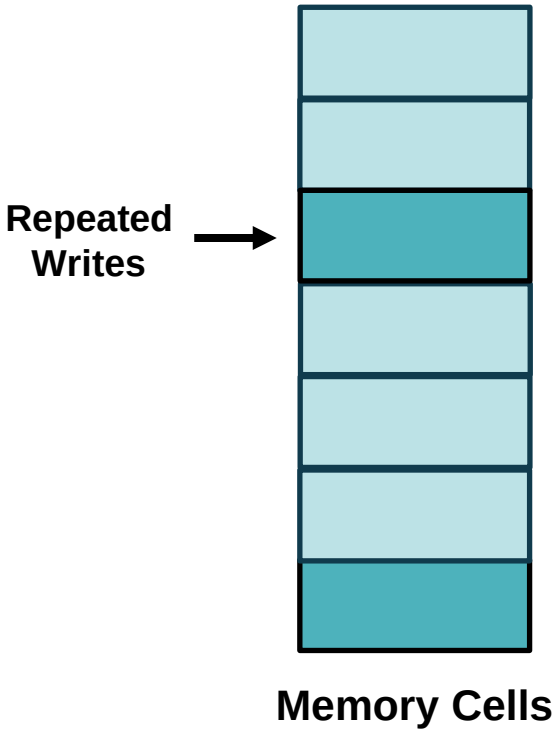
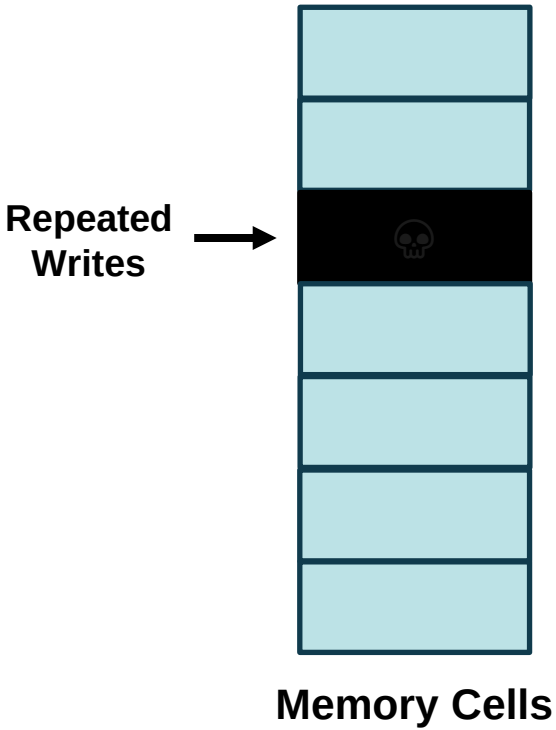


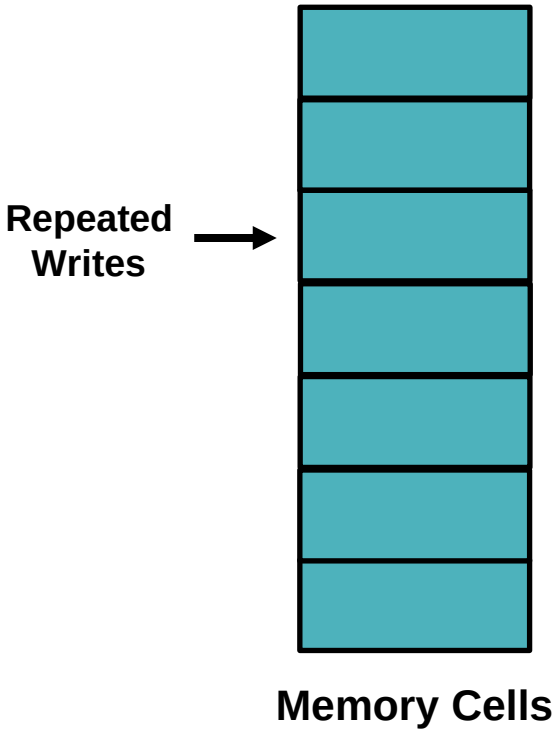
Wear-levelling to the rescue!



Wear-levelling in Memories

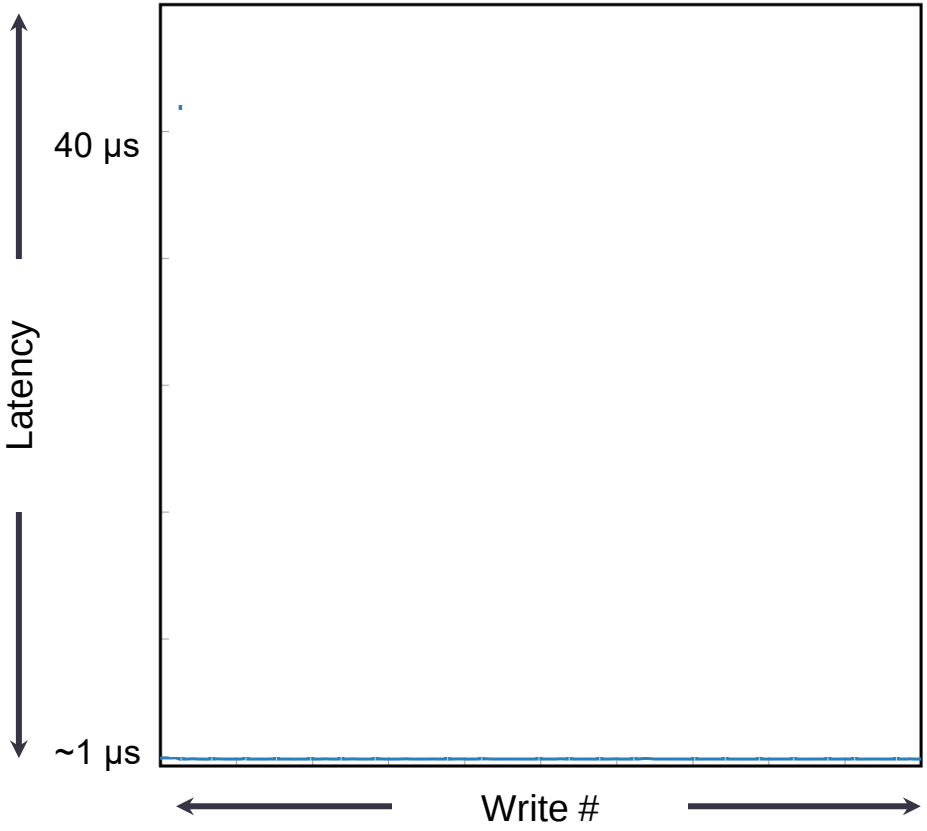


Wear-levelling to the rescue!

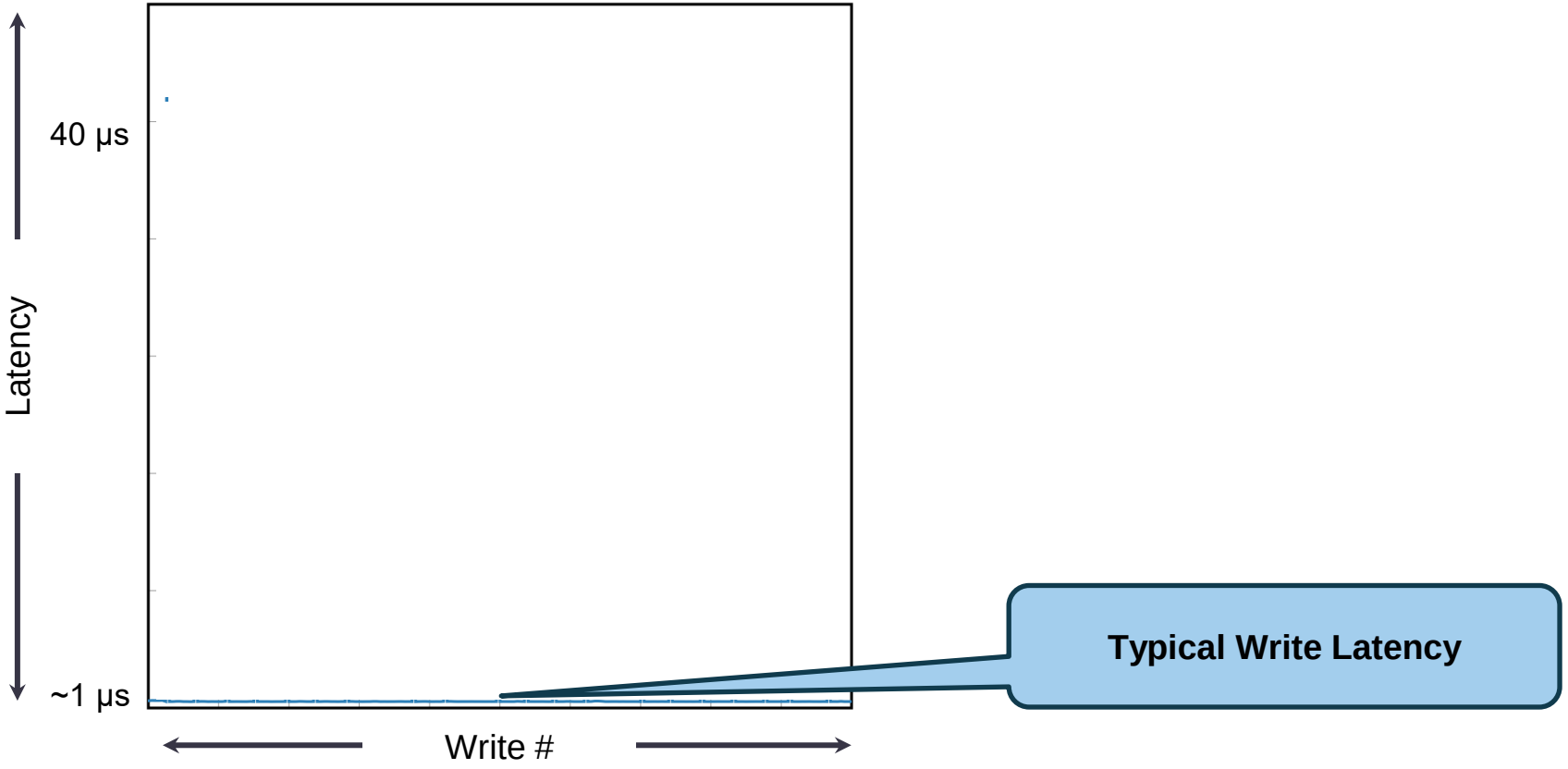


Wear-levelling in Optane: When/What?

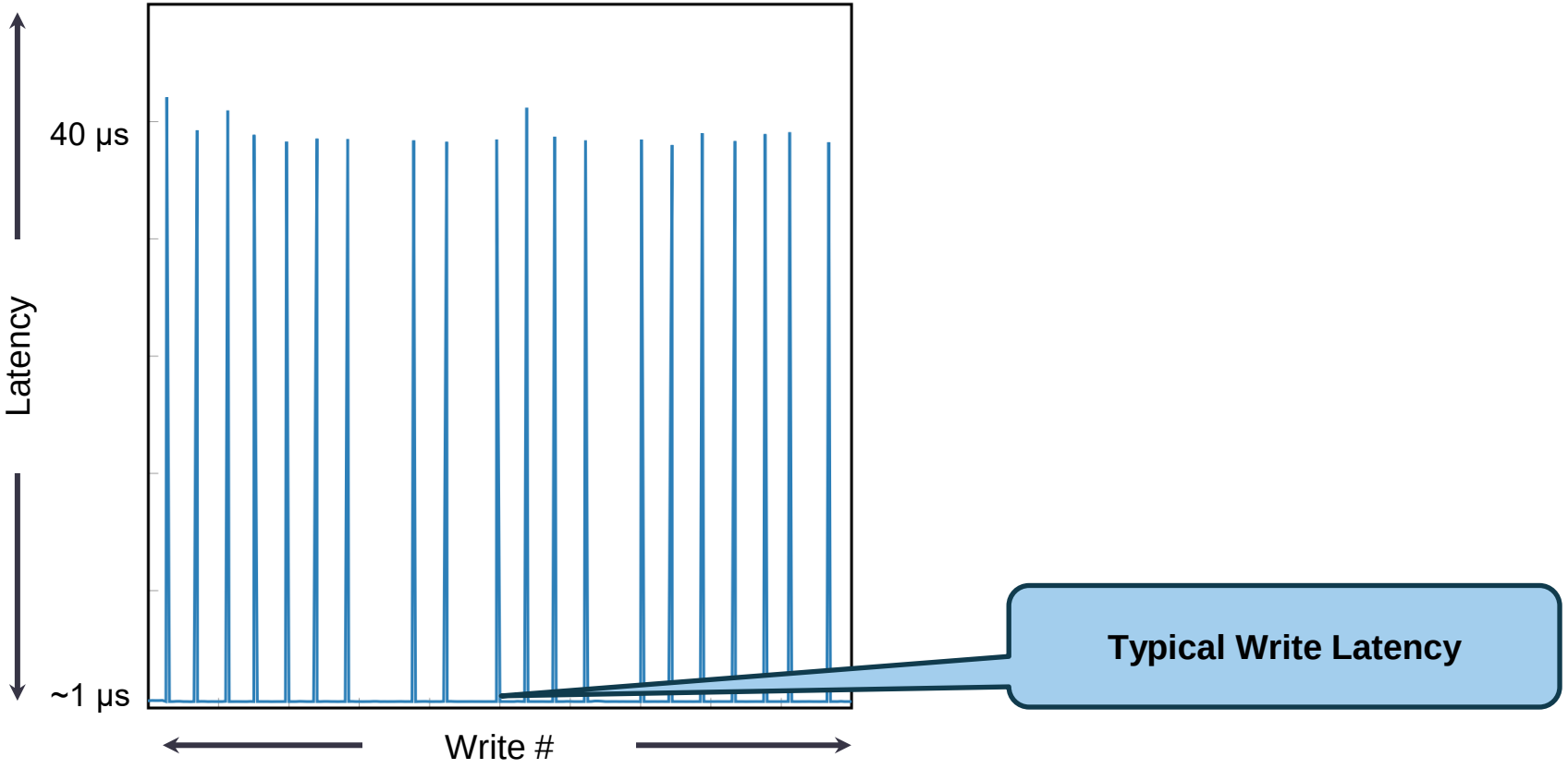
Wear-levelling in Optane: When/What?



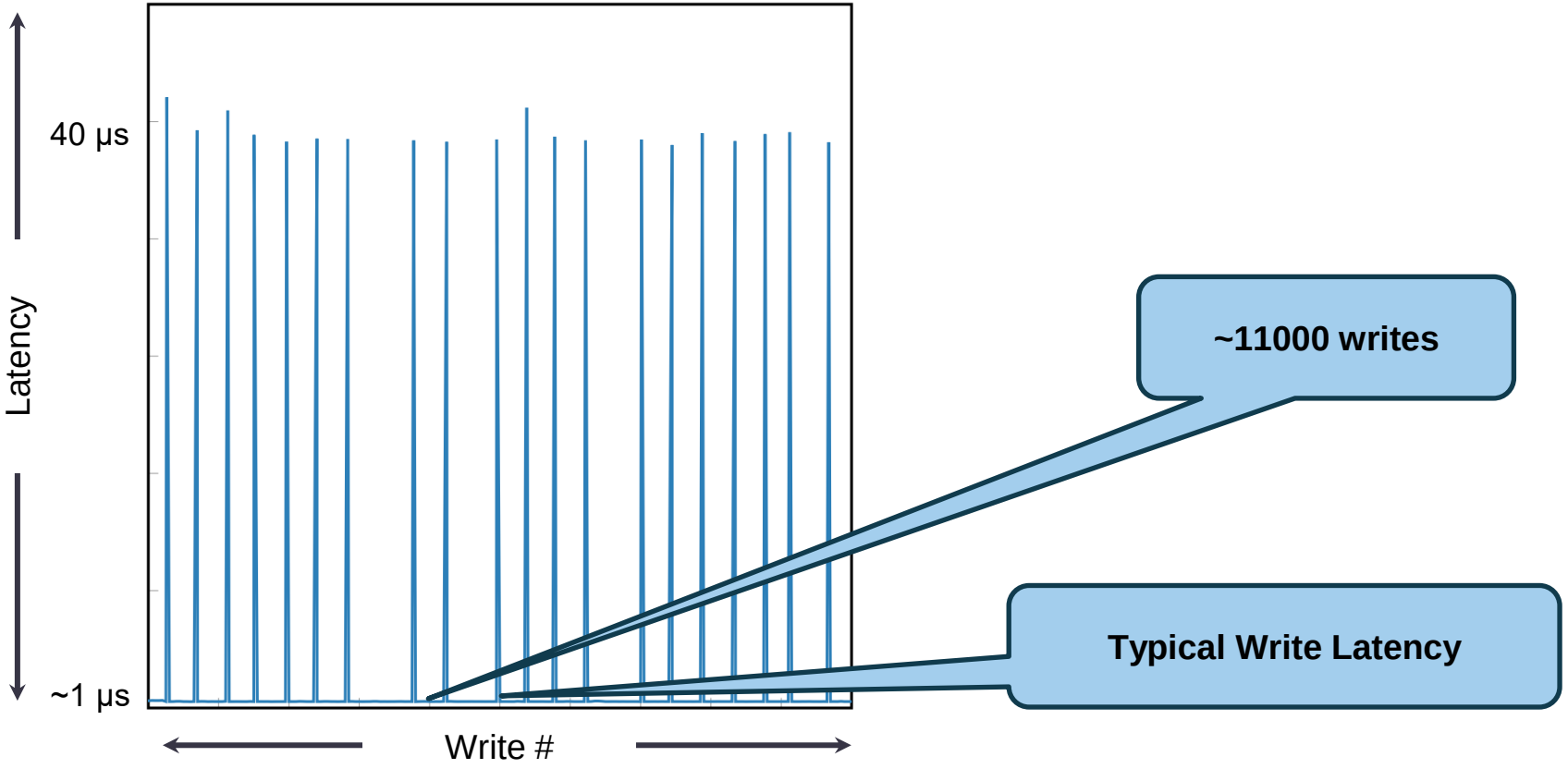
Wear-levelling in Optane: When/What?



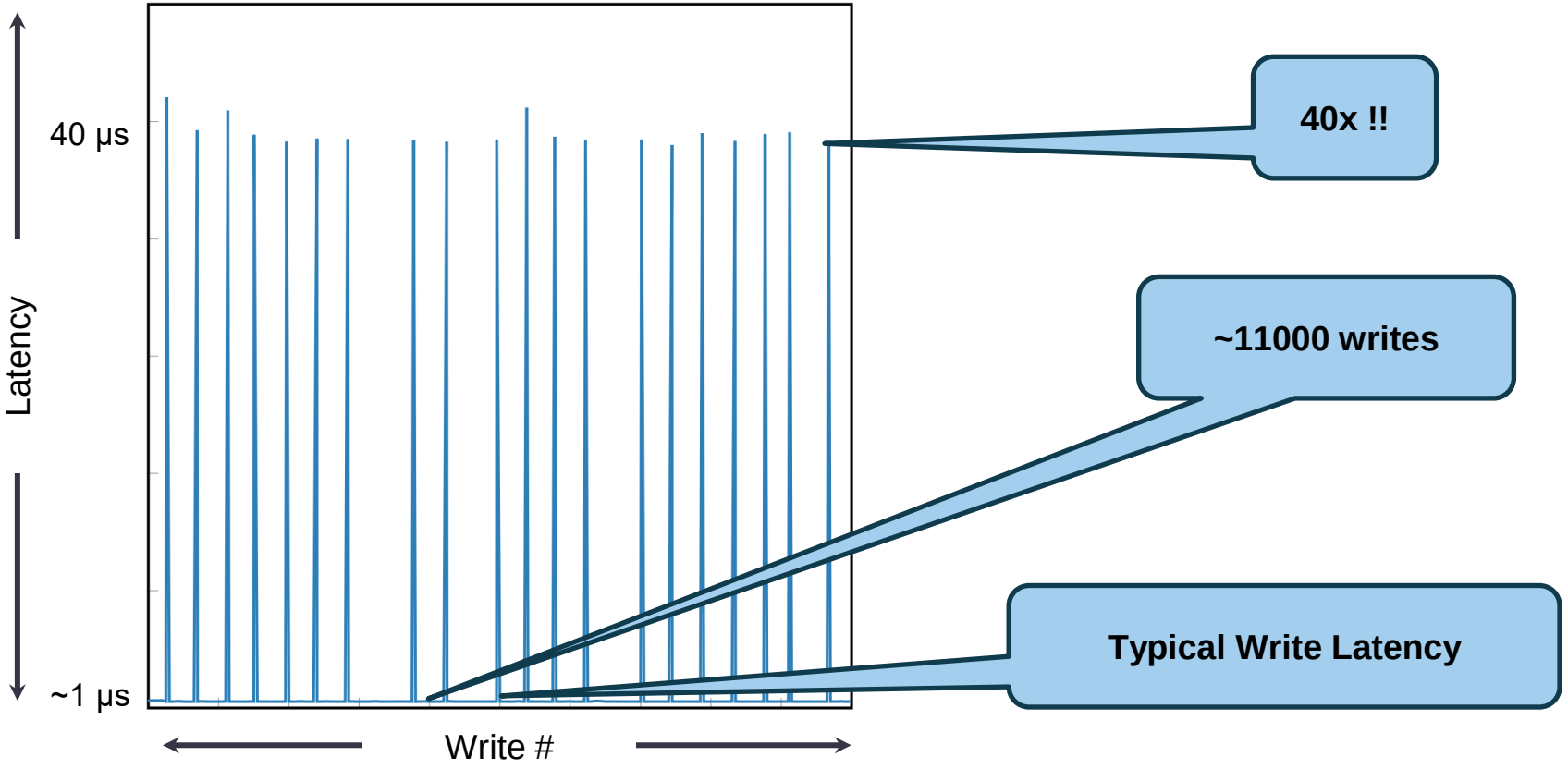
Wear-levelling in Optane: When/What?



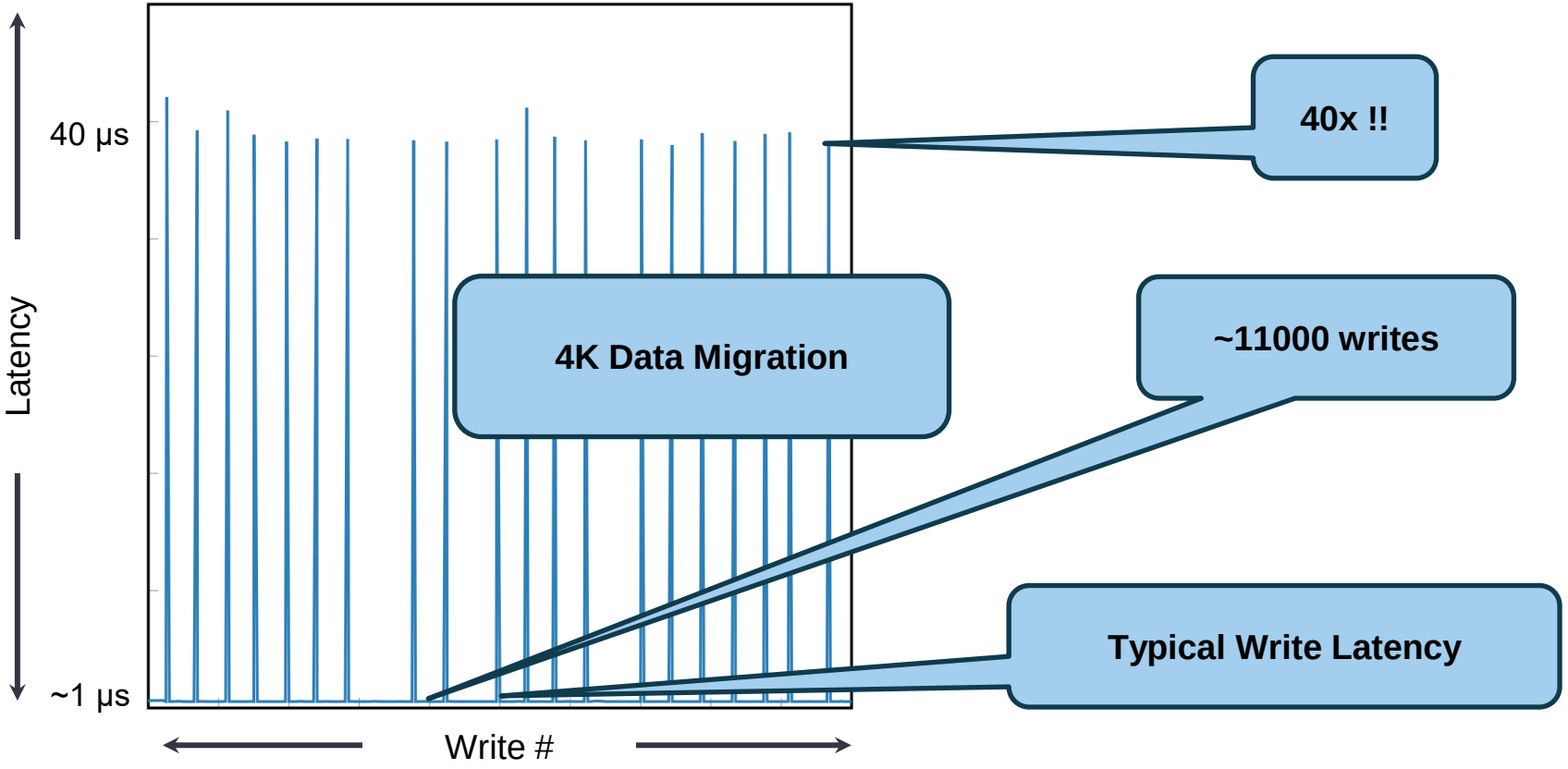
Wear-levelling in Optane: When/What?



Wear-levelling in Optane: When/What?



Wear-levelling in Optane: When/What?

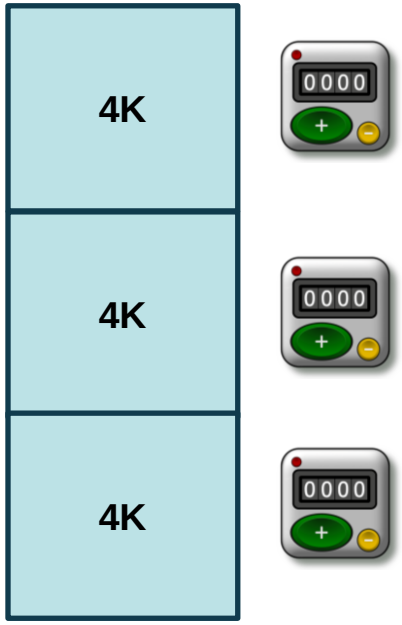


Wear-levelling in Optane: How?

Expectations	Reality

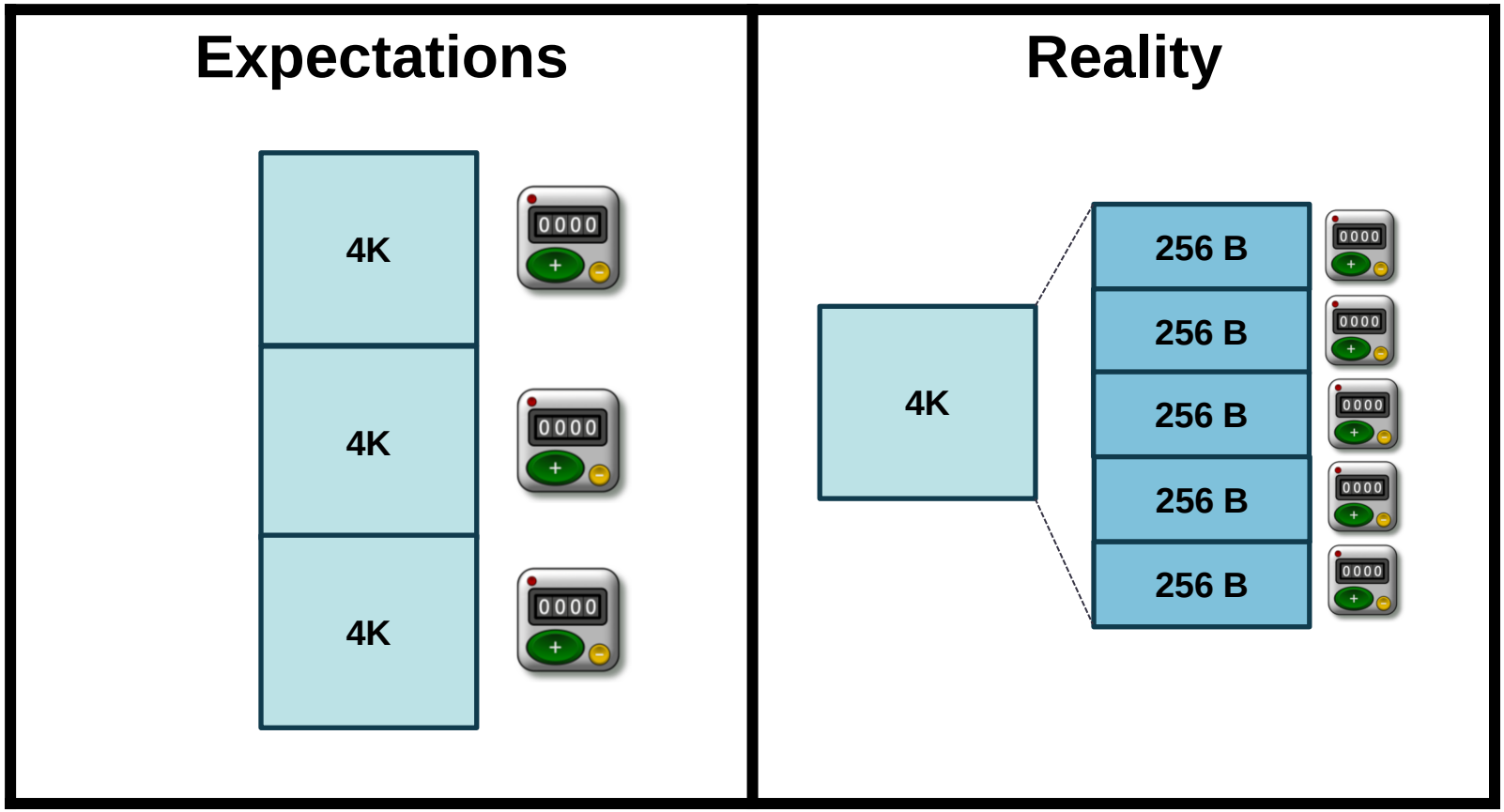
Wear-levelling in Optane: How?

Expectations



Reality

Wear-levelling in Optane: How?



An Optane Curveball: *clflush*

Expectations	Reality

An Optane Curveball: *clflush*

Expectations	Reality
cl == cache line	

An Optane Curveball: *clflush*

Expectations	Reality
cl == cache line == CPU cache line	

An Optane Curveball: *clflush*

Expectations	Reality
cl == cache line == CPU cache line **"*clflush* flushes only CPU caches"**	

An Optane Curveball: *clflush*

Expectations	Reality
cl == cache line	*clflush* reaches Optane!
== CPU cache line	
"*clflush* flushes only CPU caches"	

An Optane Curveball: *clflush*

Expectations	Reality
cl == cache line	*clflush* reaches Optane!
== CPU cache line	Flushes RMW Buffer!
"*clflush* flushes only CPU caches"	

An Optane Curveball: *clflush*

Expectations

cl == cache line

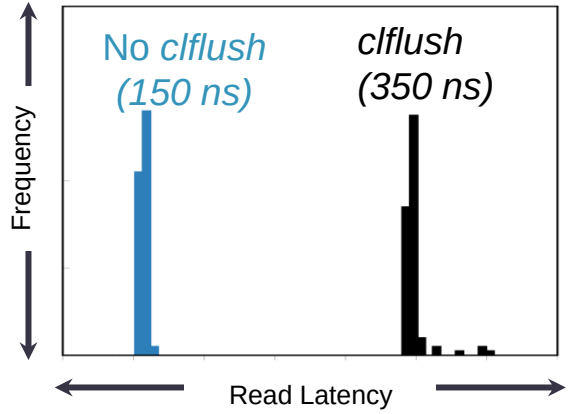
== CPU cache line

“*clflush* flushes only CPU caches”

Reality

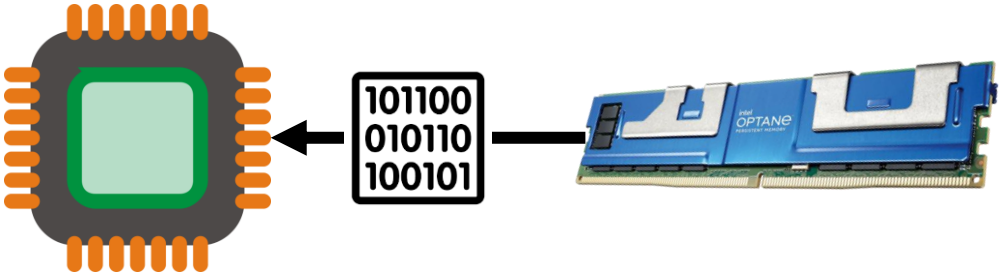
clflush reaches Optane!

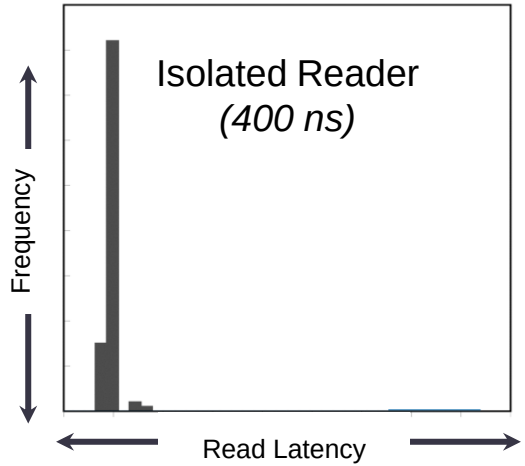
Flushes RMW Buffer!



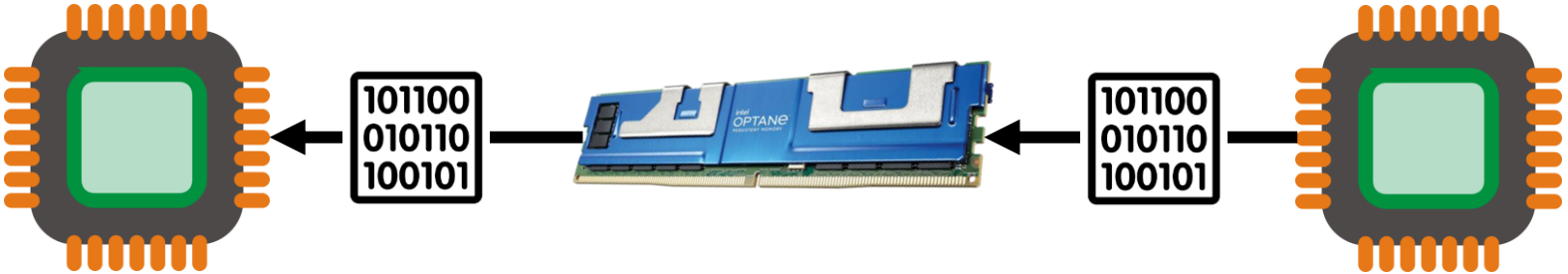
An Optane Curveball: R/W Contention

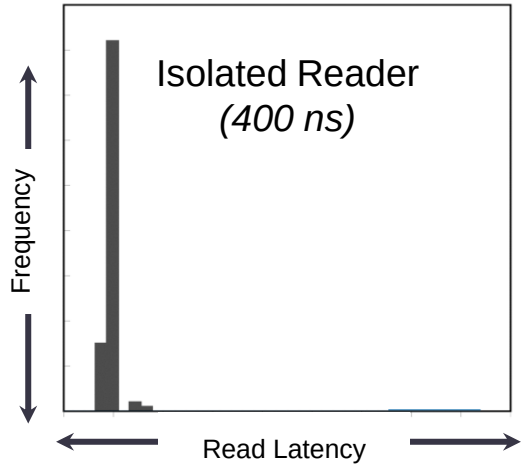
An Optane Curveball: R/W Contention

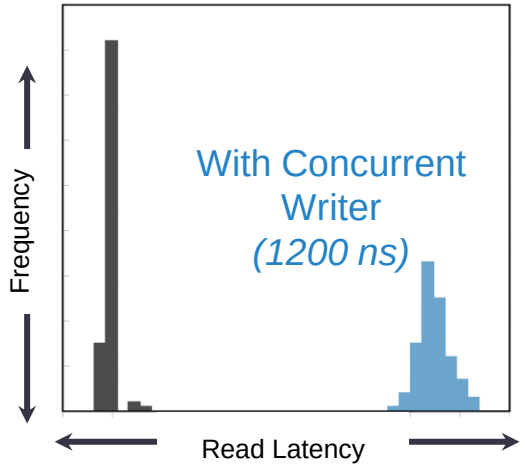




An Optane Curveball: R/W Contention







The Attacks

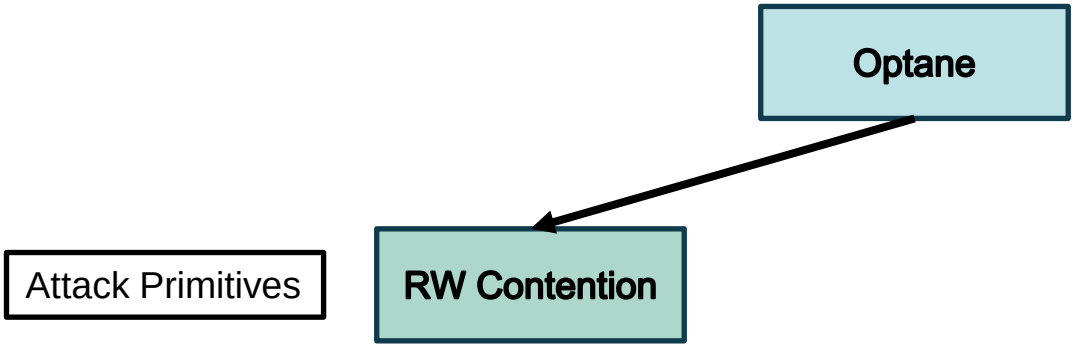
Exploring the security implications of our new attack primitives

A Bird’s Eye view

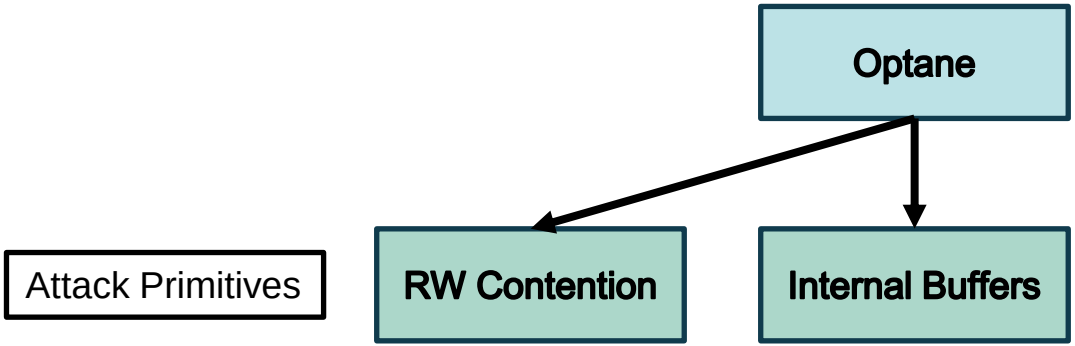
A Bird’s Eye view

A Bird’s Eye view

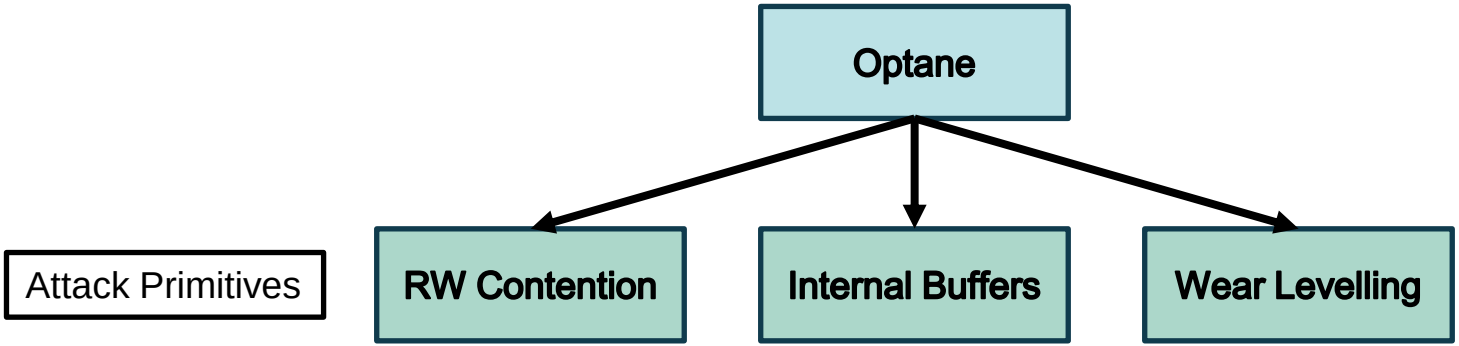
A Bird’s Eye view



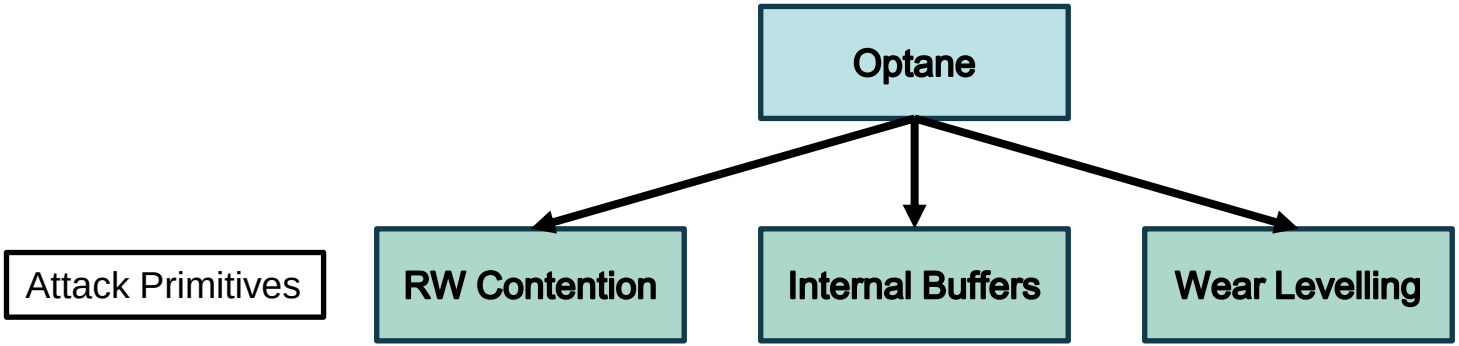
A Bird’s Eye view



A Bird’s Eye view

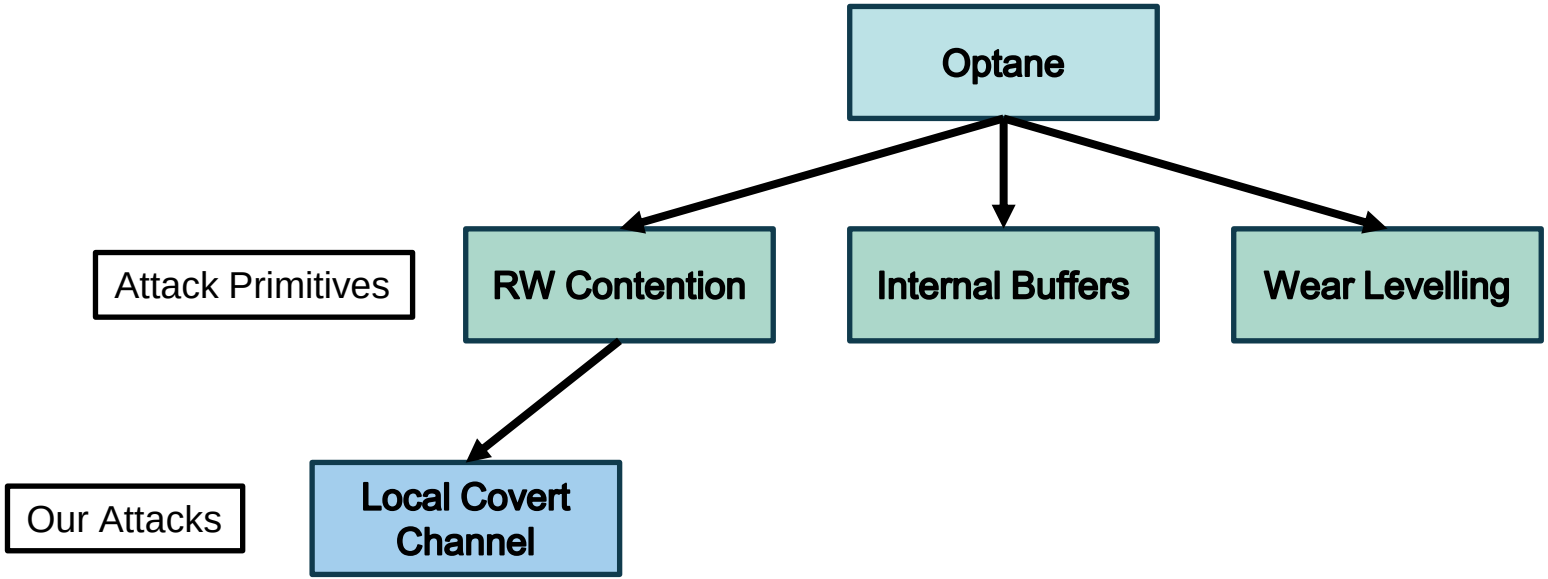


A Bird’s Eye view

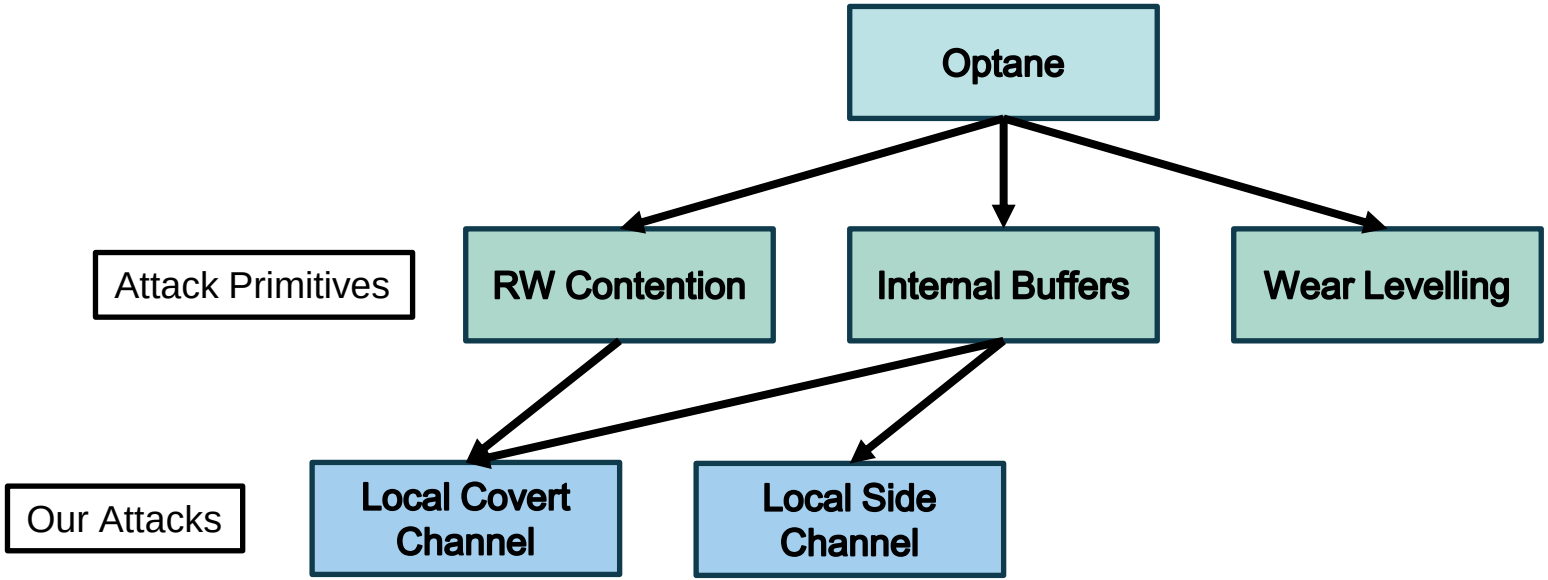


Our Attacks

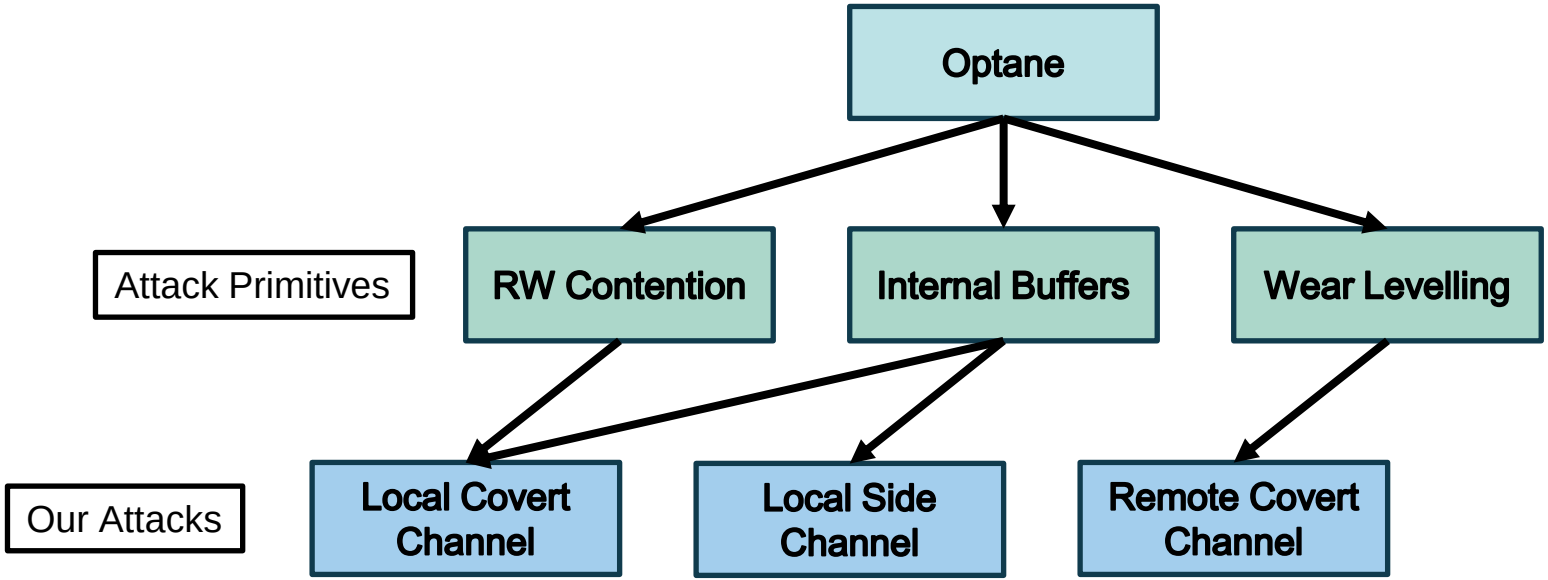
A Bird’s Eye view



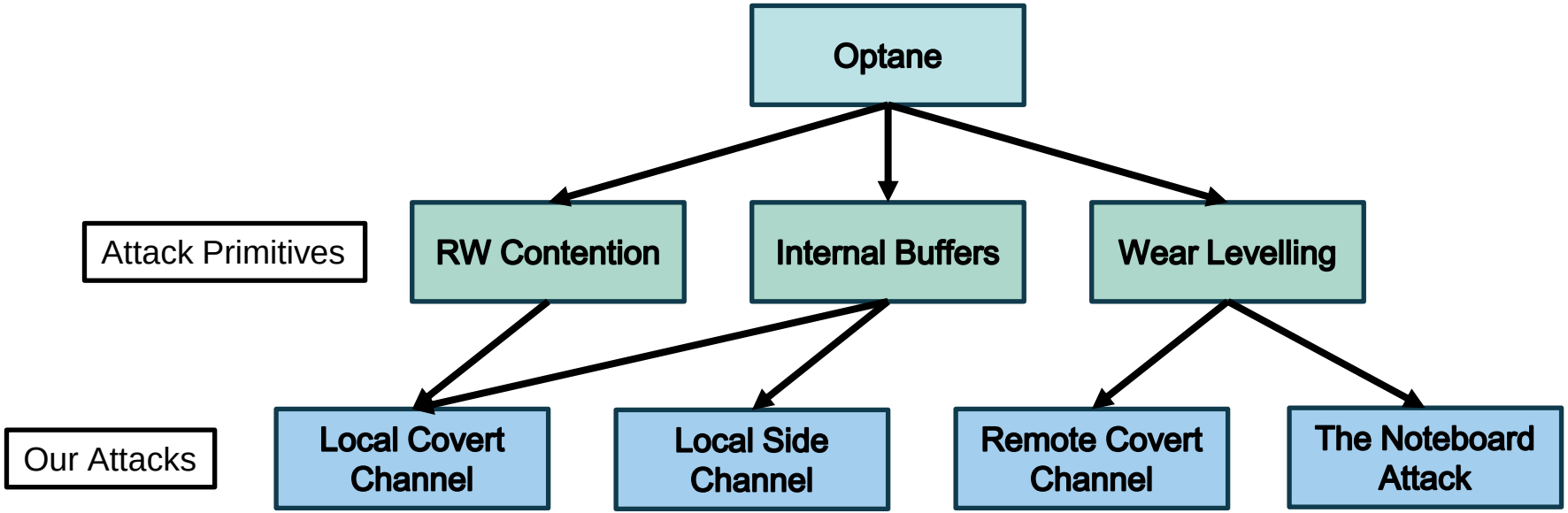
A Bird’s Eye view



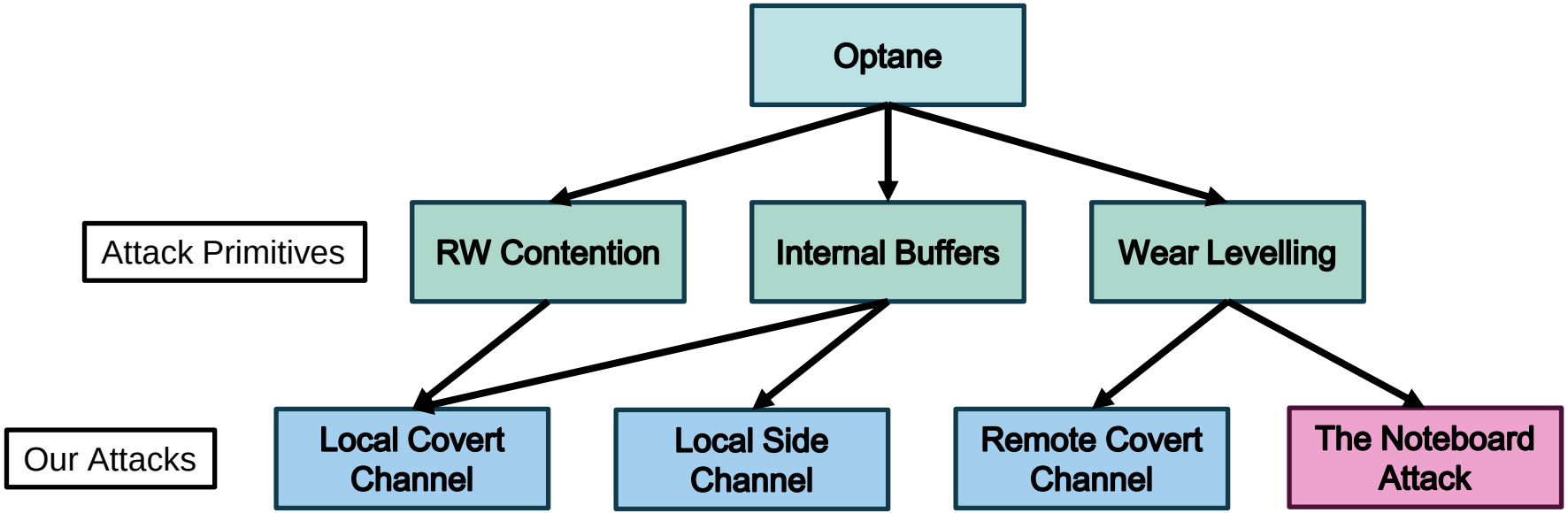
A Bird's Eye view



A Bird’s Eye view



A Bird's Eye view



Attack: Noteboard Covert Channel

Encoding secret messages on Optane’s wear-levelling metadata

The Idea

The Idea

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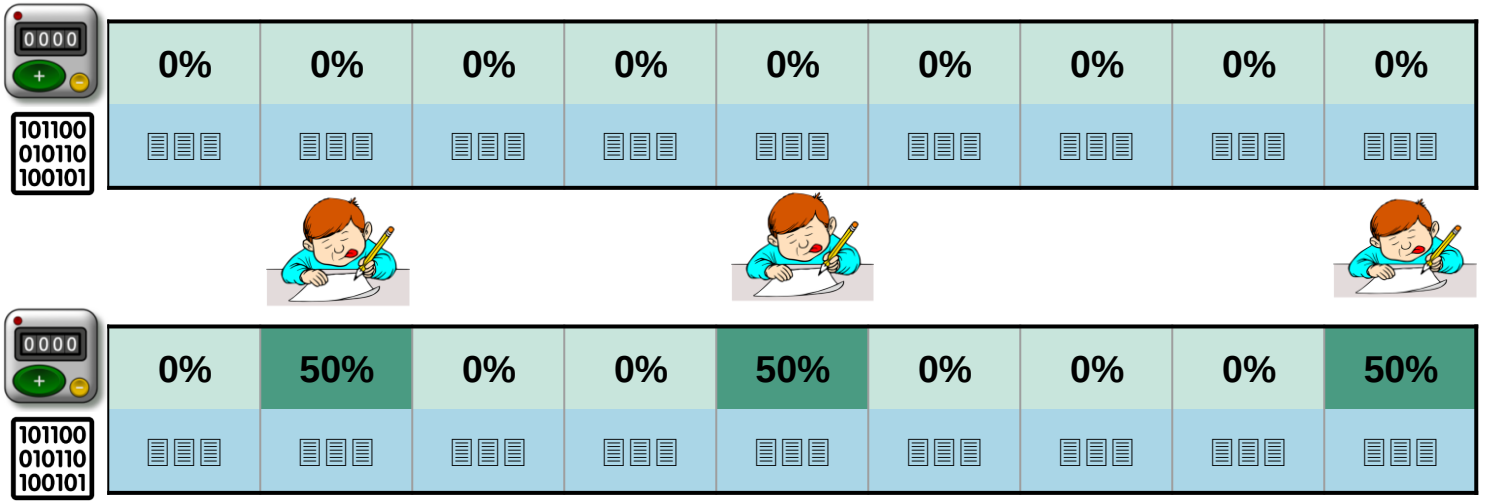
The Idea

0%	0%	0%	0%	0%	0%	0%	0%	0%

The Idea


TOP
SECRET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The Idea

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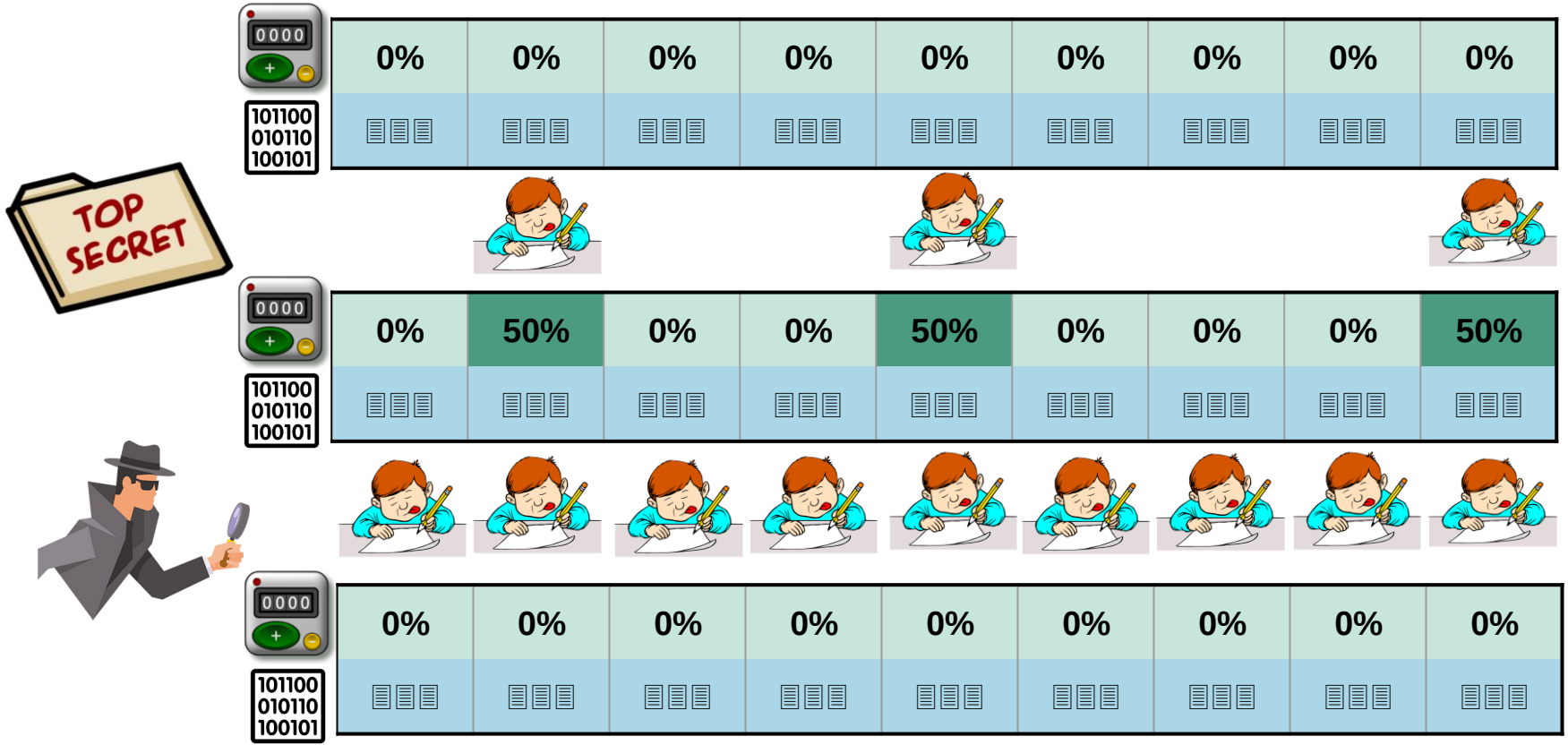
The Idea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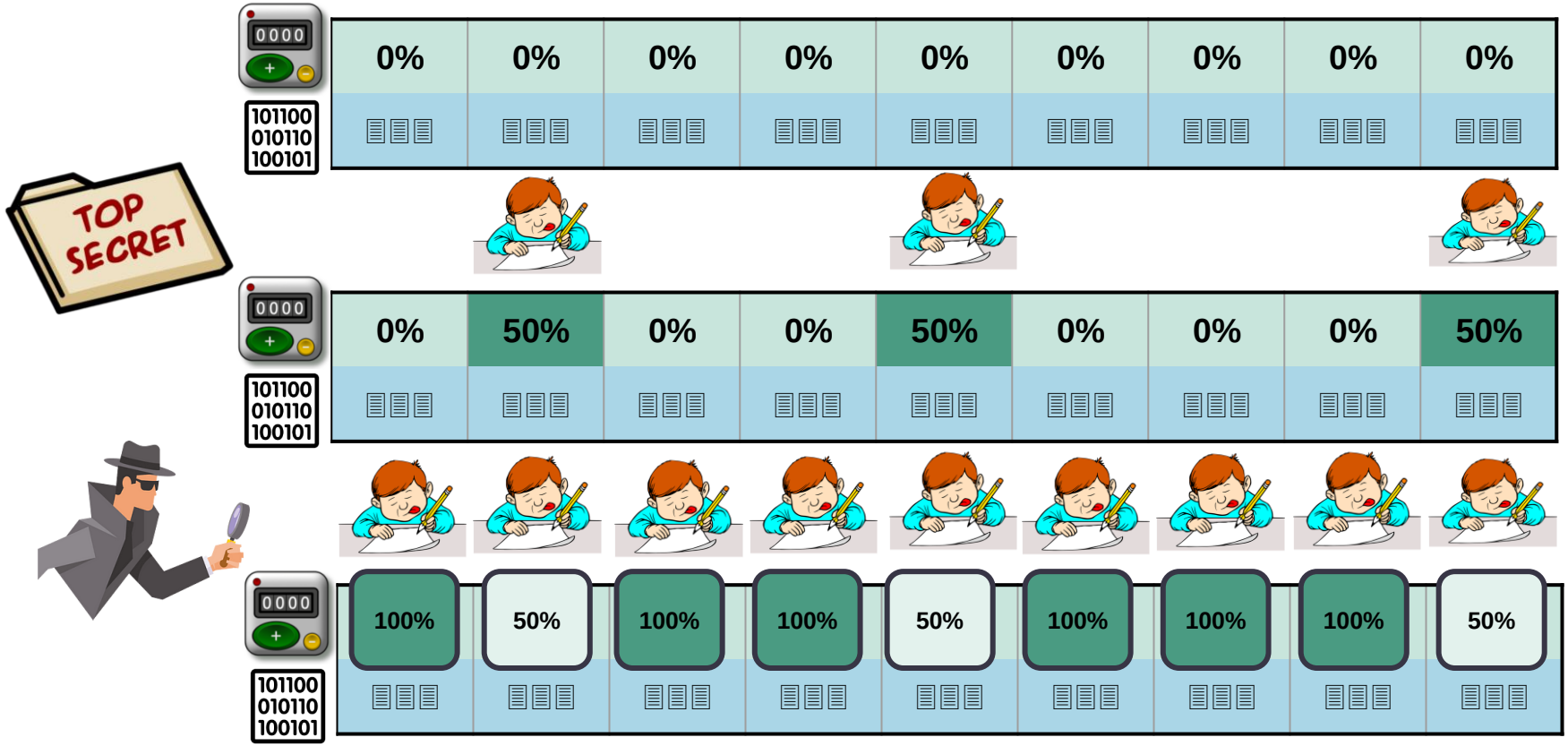
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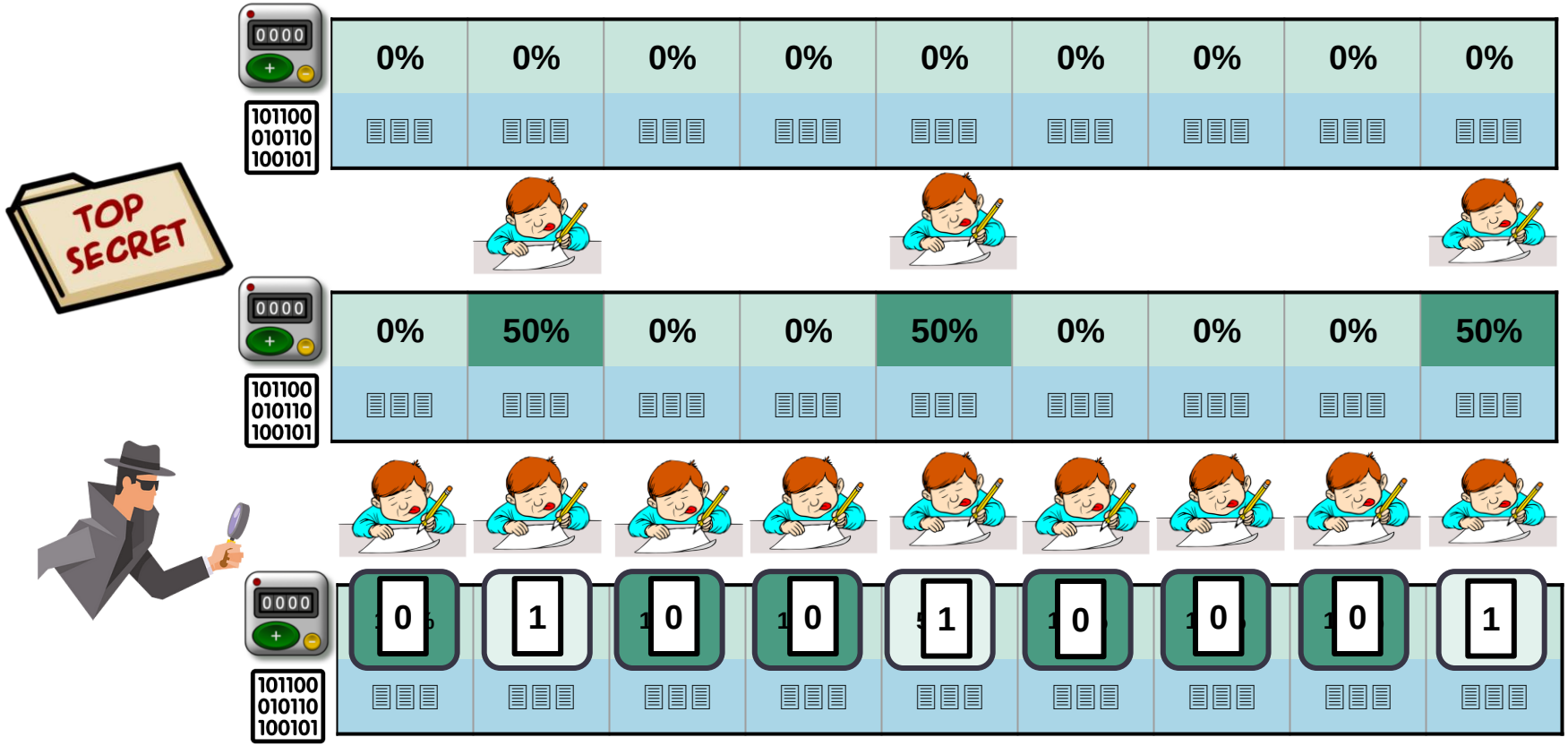
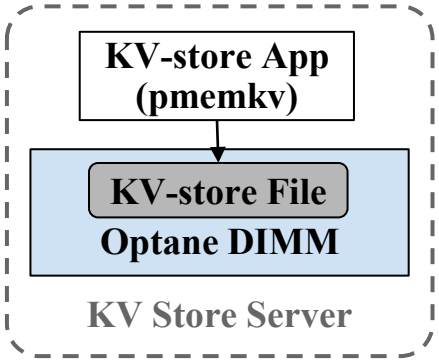


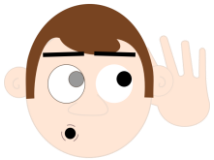
A Realization

A Realization

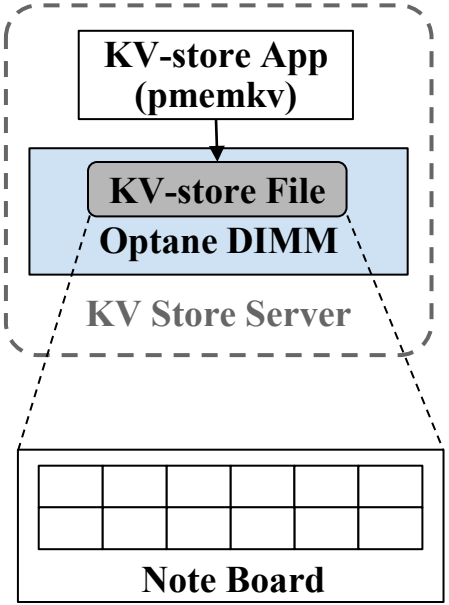


A Realization

Remote Sender



Remote Receiver



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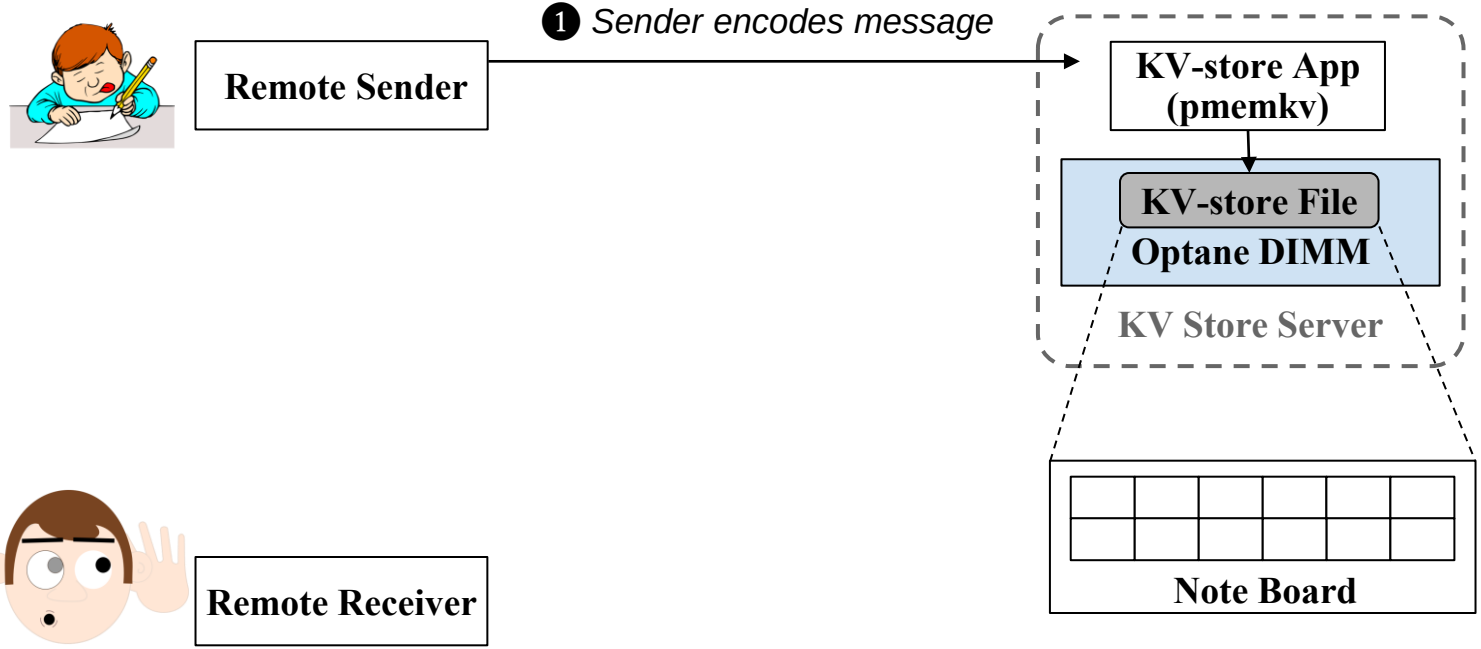

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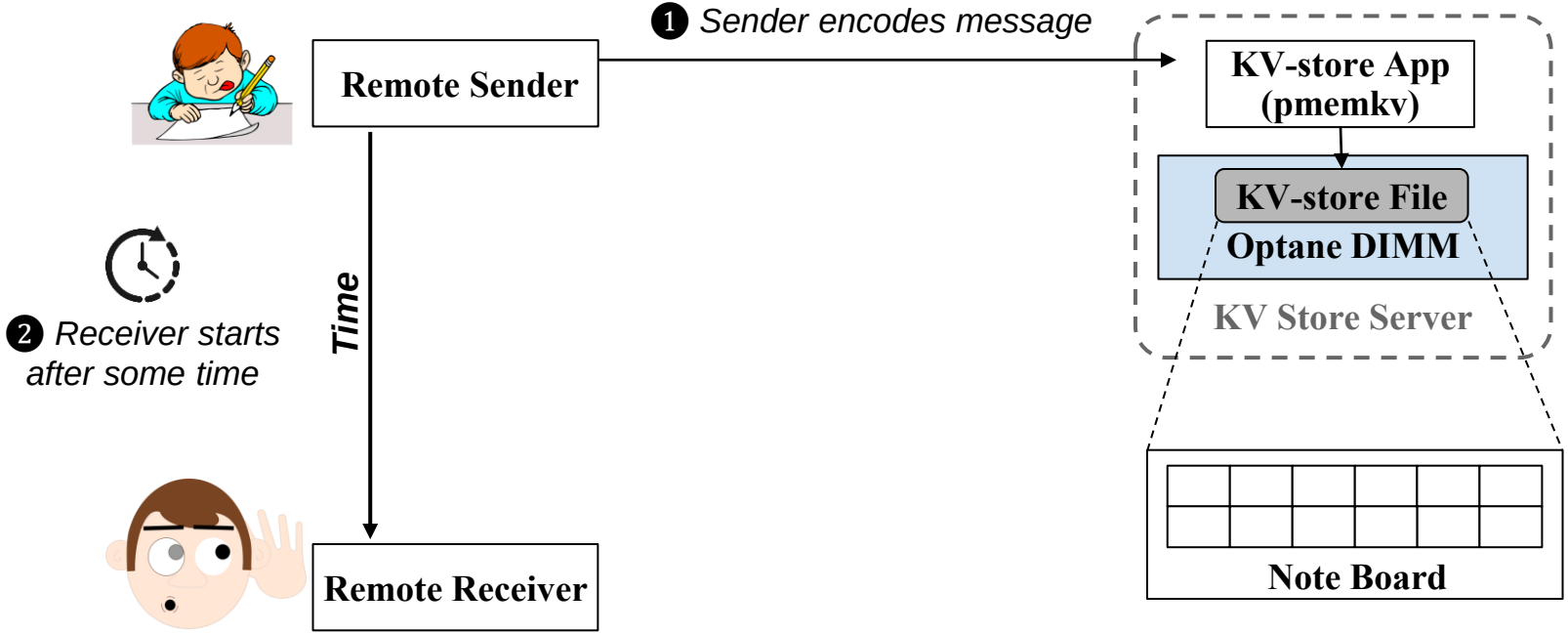

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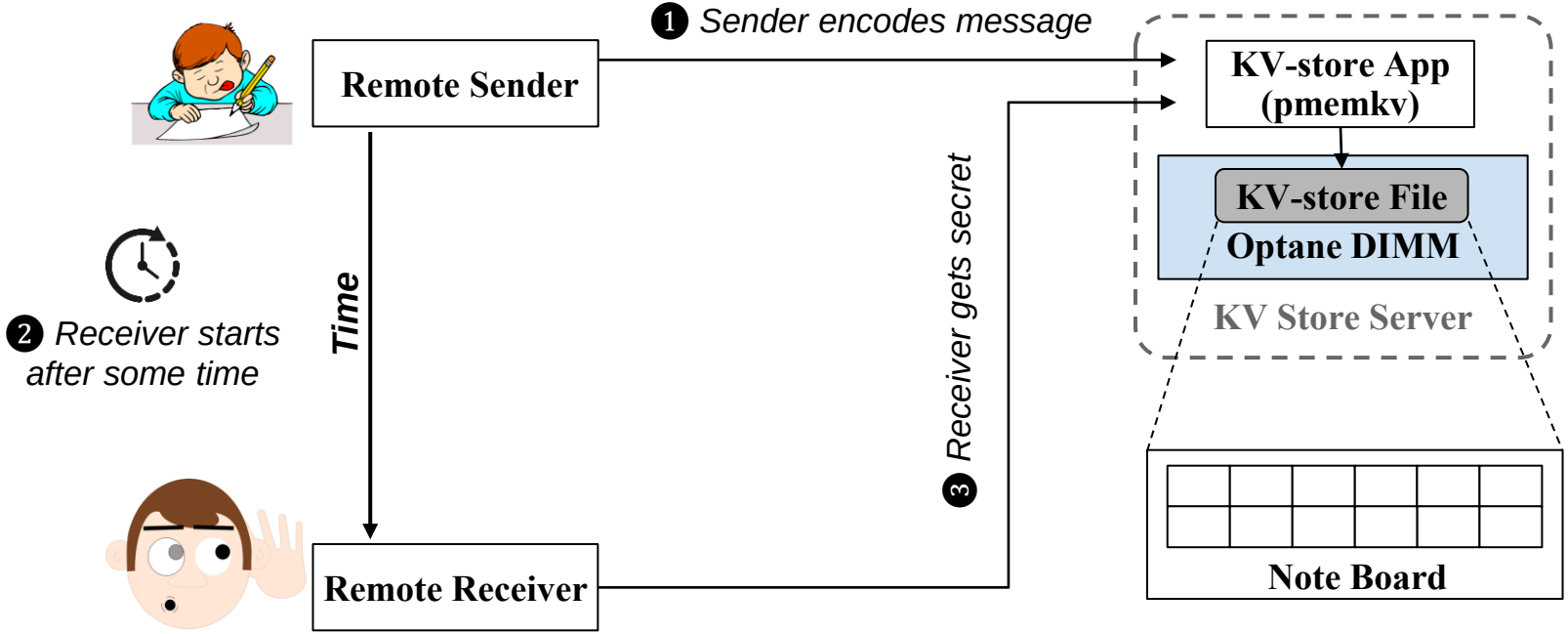

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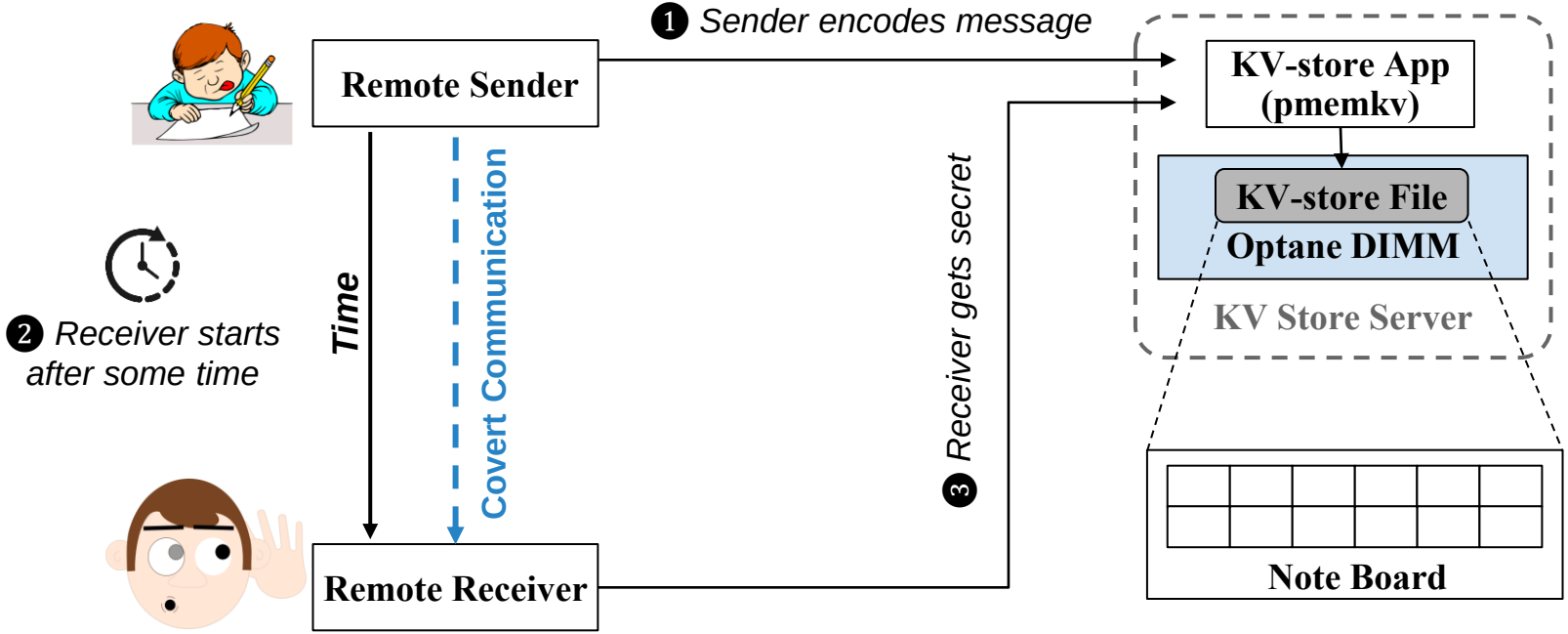


A Realization

Result

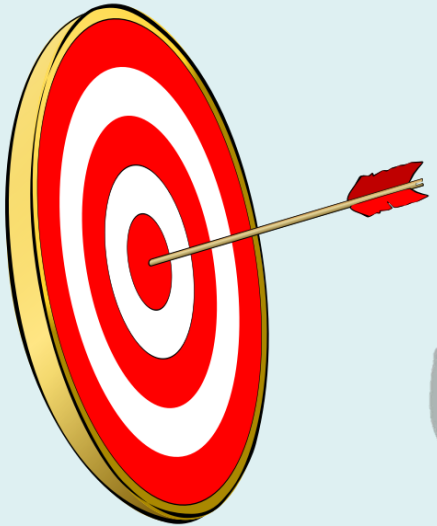
A Realization

Result

A Realization

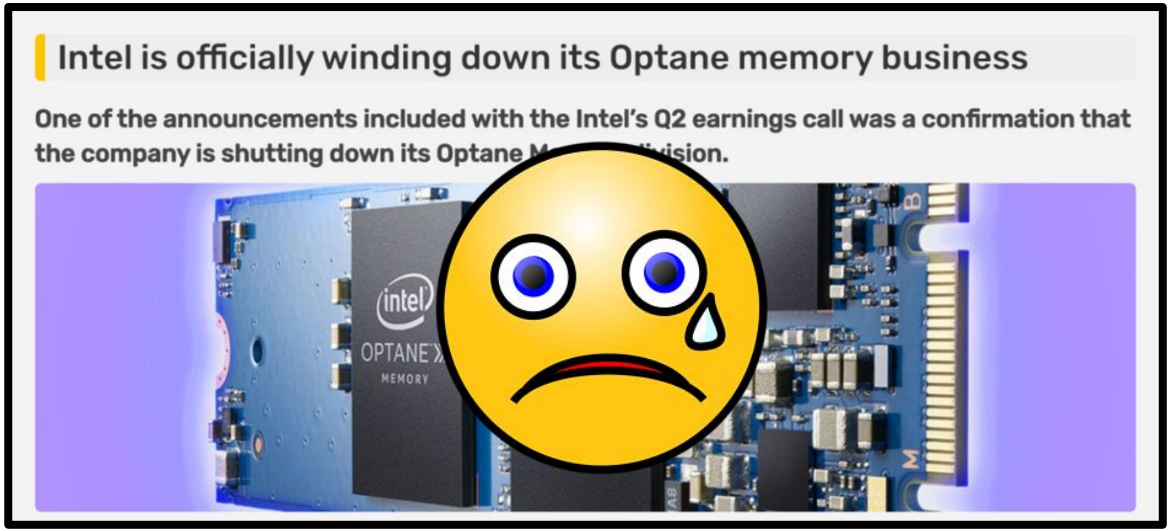
A Realization

Result

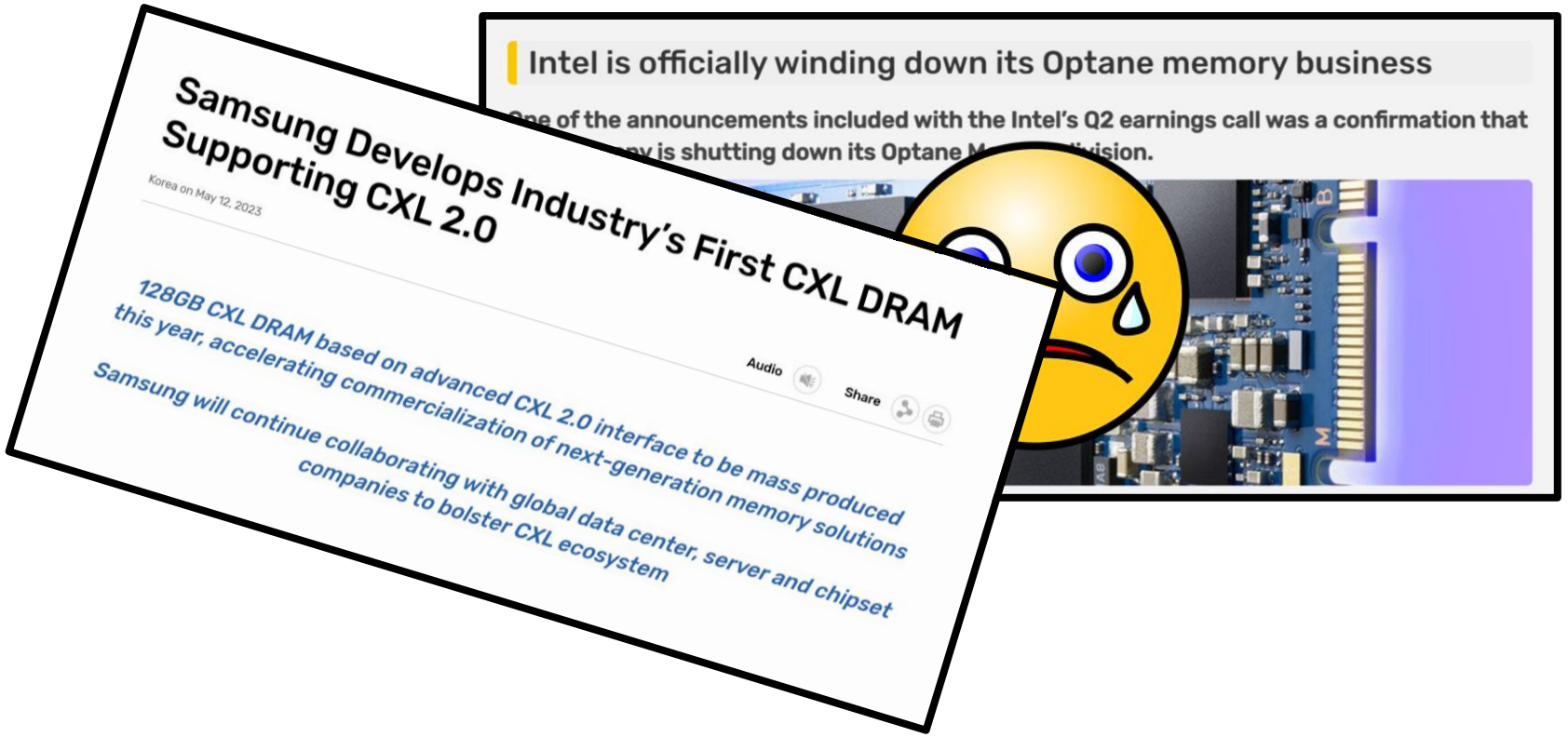


Looking at the Future

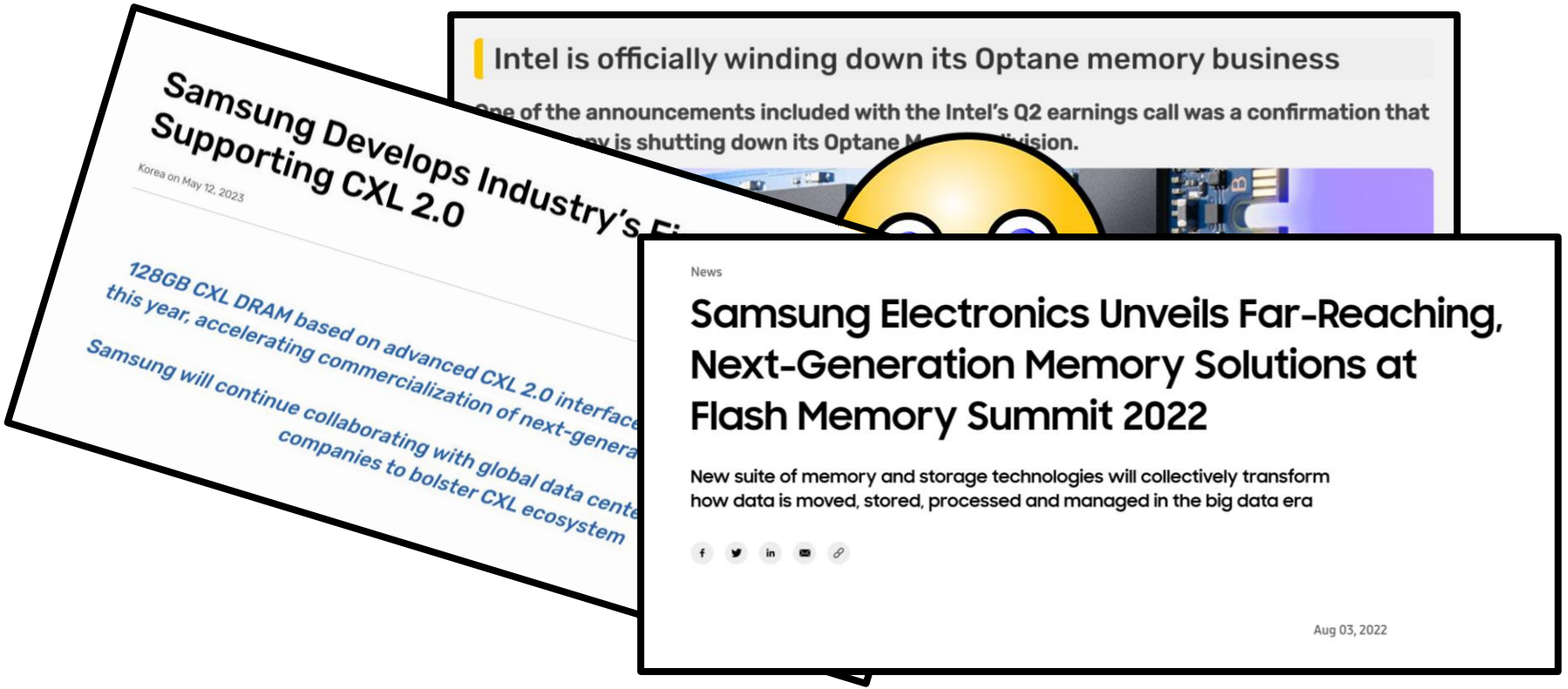
Looking at the Future



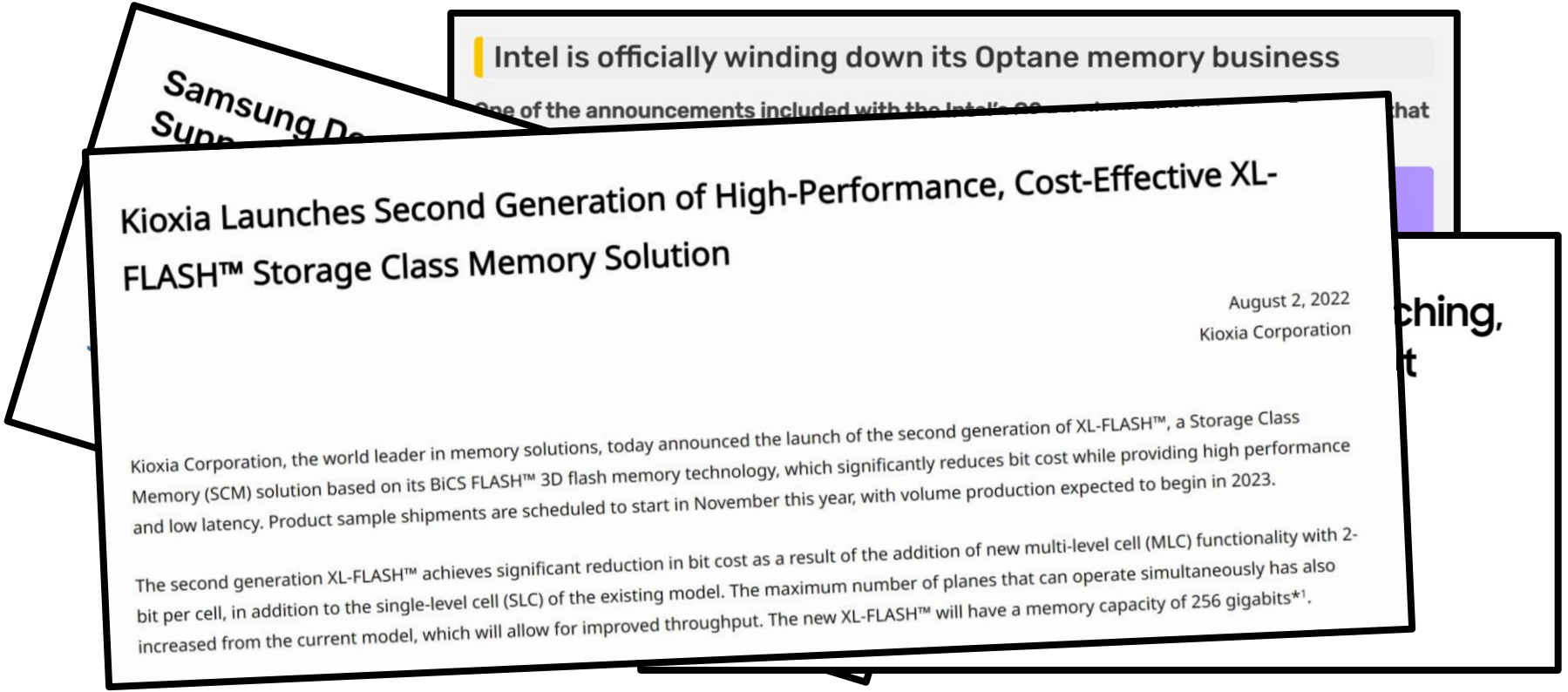
Looking at the Future



Looking at the Future

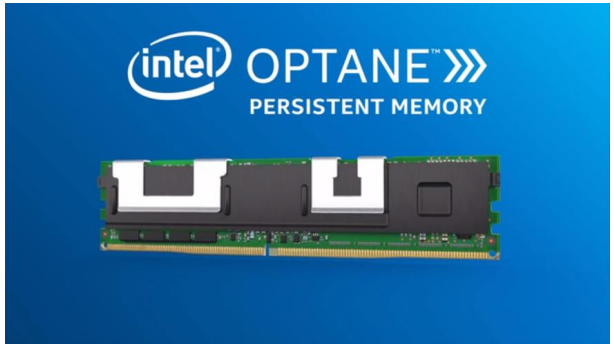


Looking at the Future



Summary

Summary



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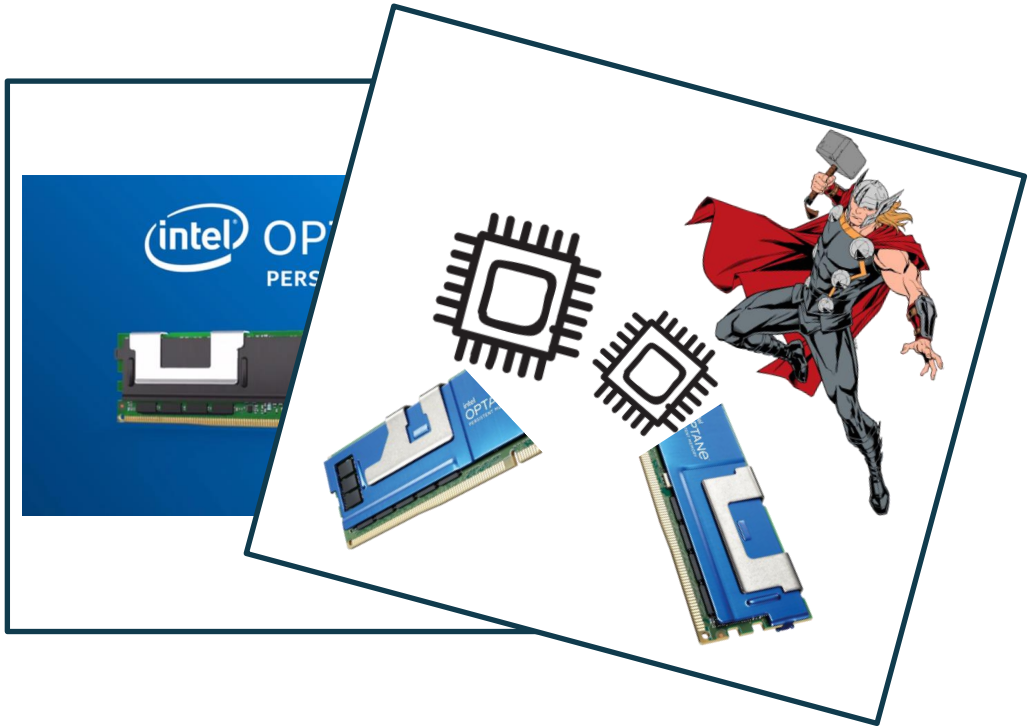
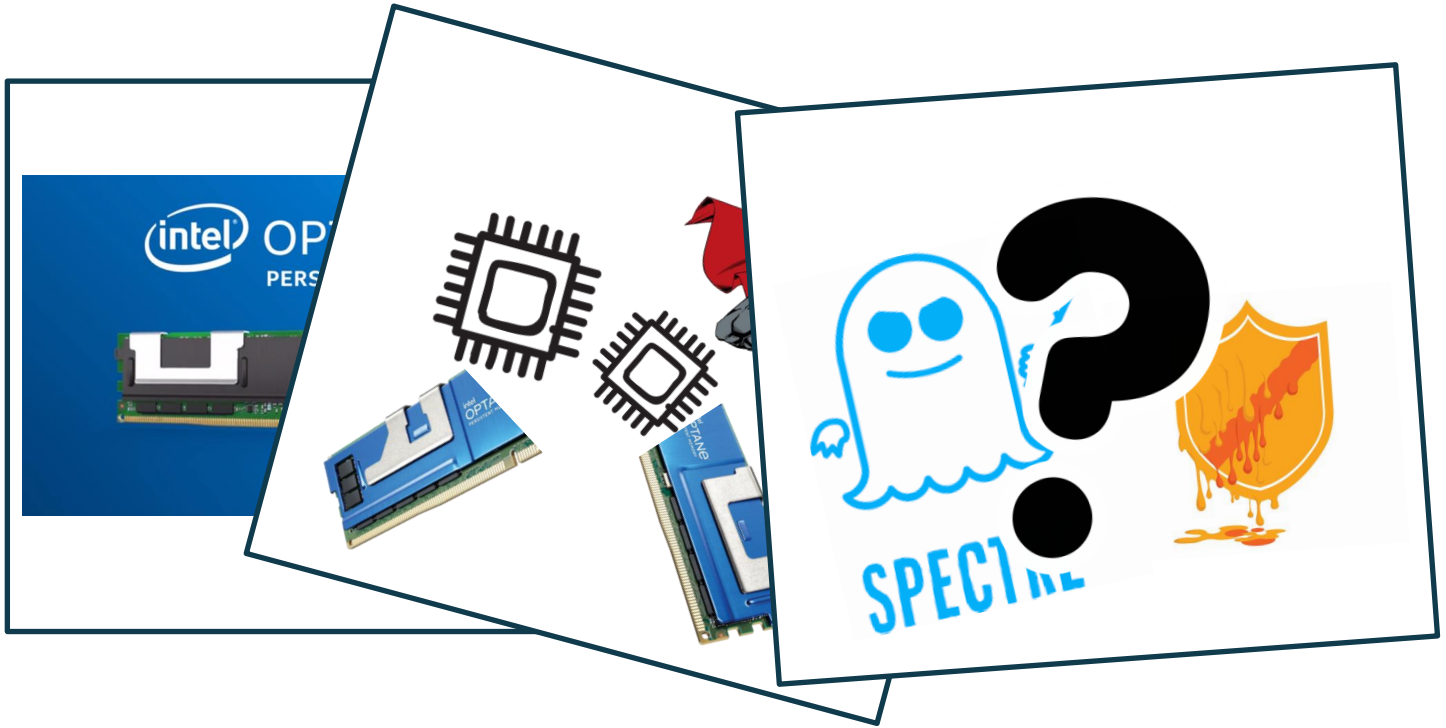
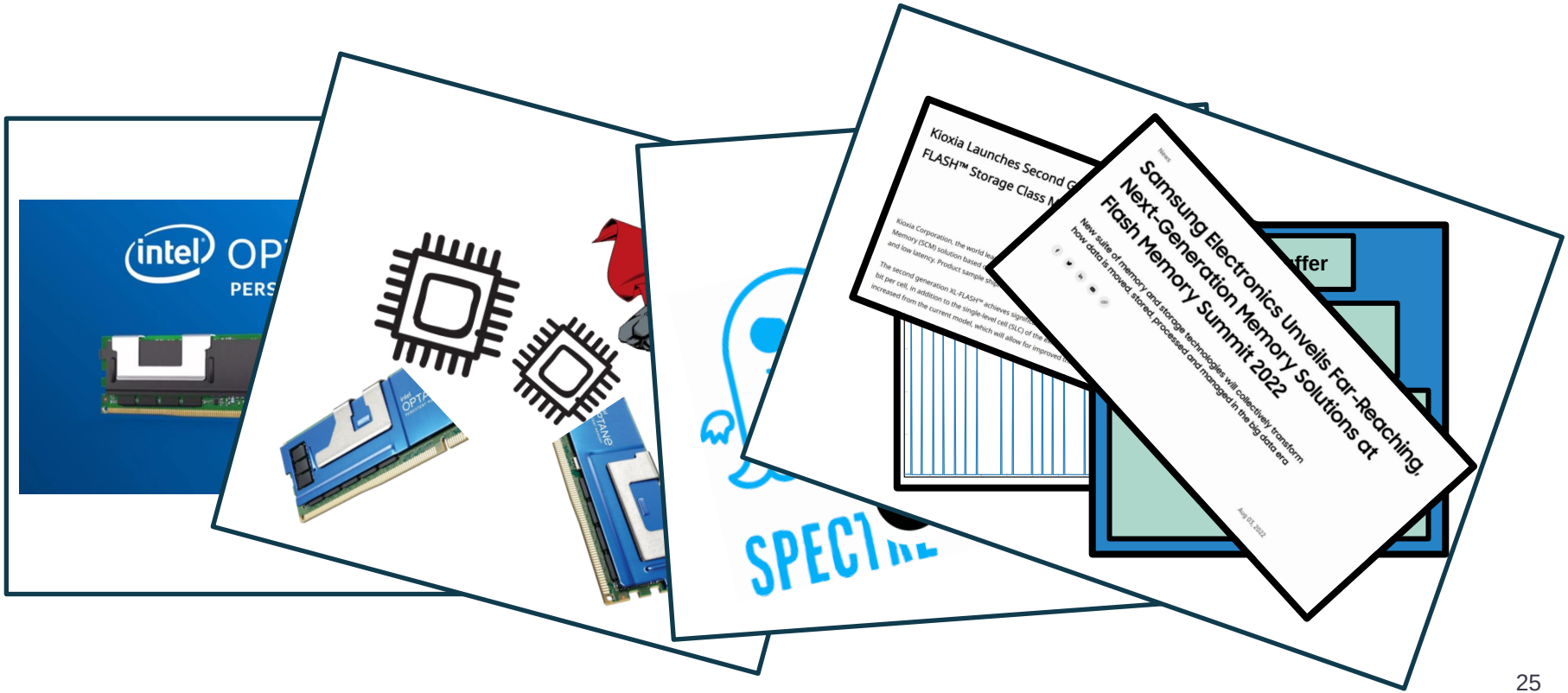


Summary



Summary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Kioxia Launches Second G
FLASH™ Storage Class M
Samsung Electronics Unveils Far-Reaching, Next-Generation Memory Solutions at Flash Memory Summit 2022
New suite of memory and storage technologies will collectively transform how data is moved, stored, processed and managed in the big data era
Aug 03, 2022
SPECTRE

Side-Channel Attacks on Optane Persistent Memory

Sihang Liu, **Suraaj Kanniwadi**, Martin Schwarzl, Andreas Kogler,
Daniel Gruss, Samira Khan

Usenix Security Symposium 2023