IceClave: A Trusted Execution Environment for In-Storage Computing

Luyi Kang*†, **Yuqi Xue***, Weiwei Jia*, Xiaohao Wang, Jongryool Kim‡, Changhwan Youn‡, Myeong Joon Kang‡, Hyung Jin Lim‡, Bruce Jacob†, Jian Huang

*Co-primary authors.

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

† UNIVERSITY OF MARYLAND

‡ SK hynix

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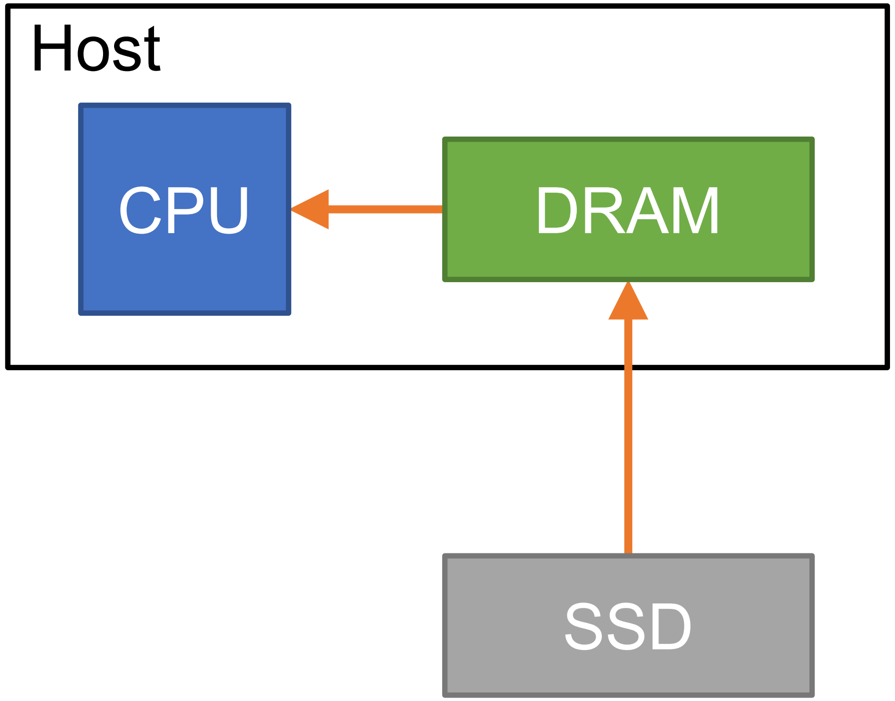
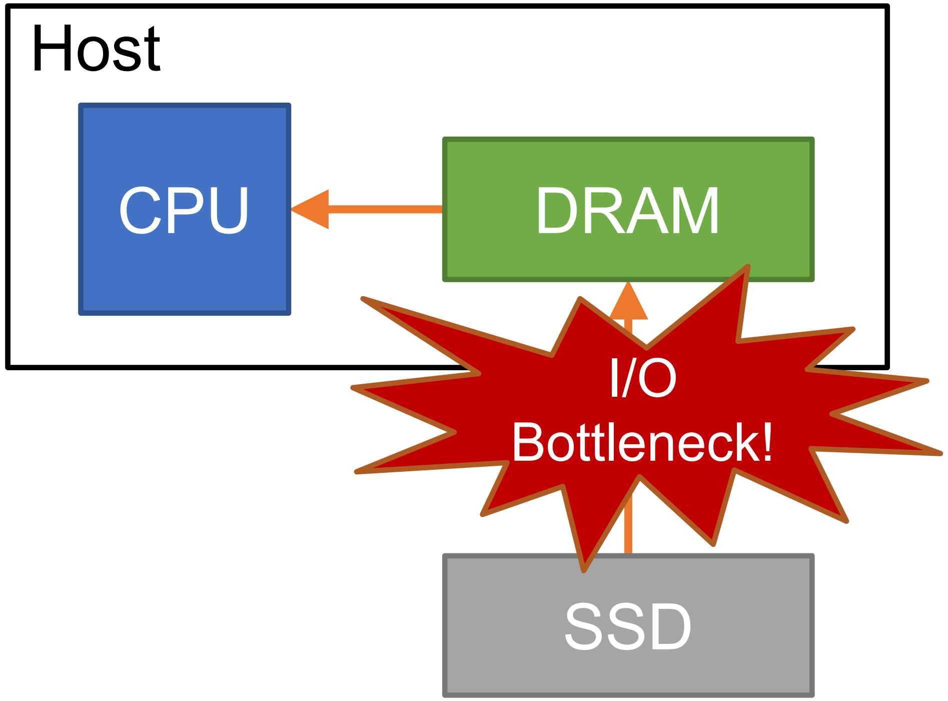
In-Storage Computing: A Promising Technique for I/O-Intensive Applications



Host-based Computing

In-Storage Computing: A Promising Technique for I/O-Intensive Applications



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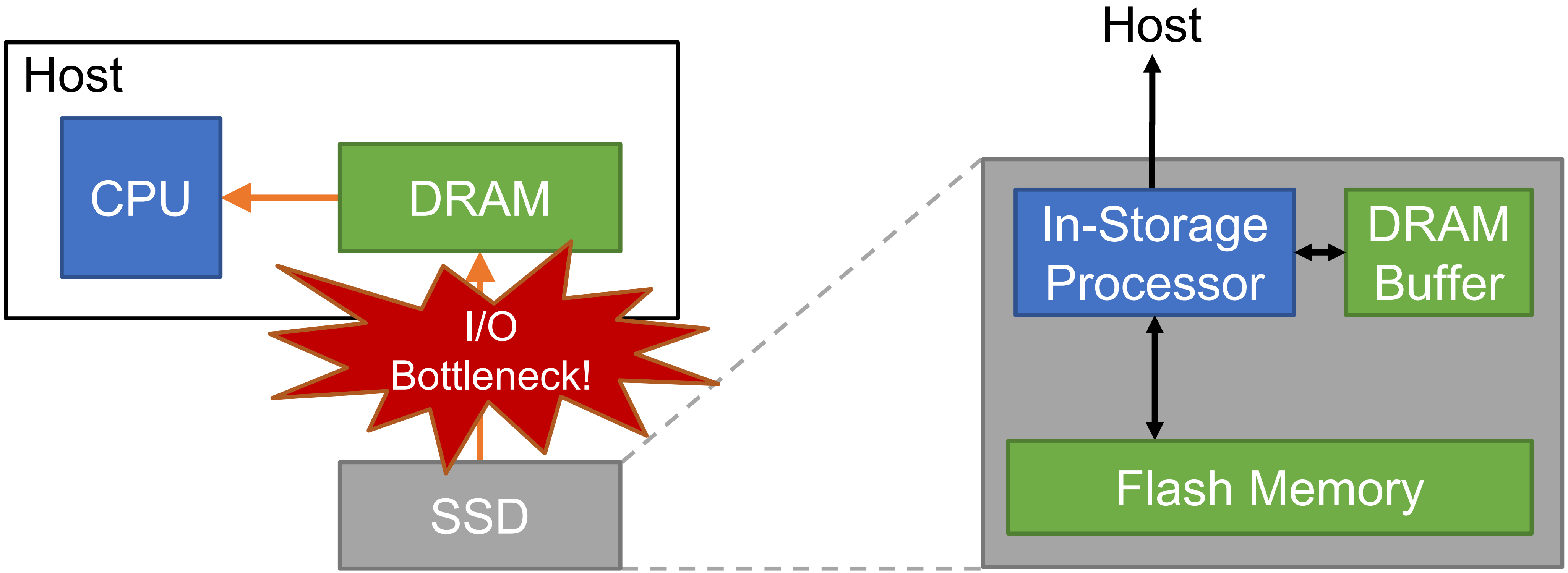

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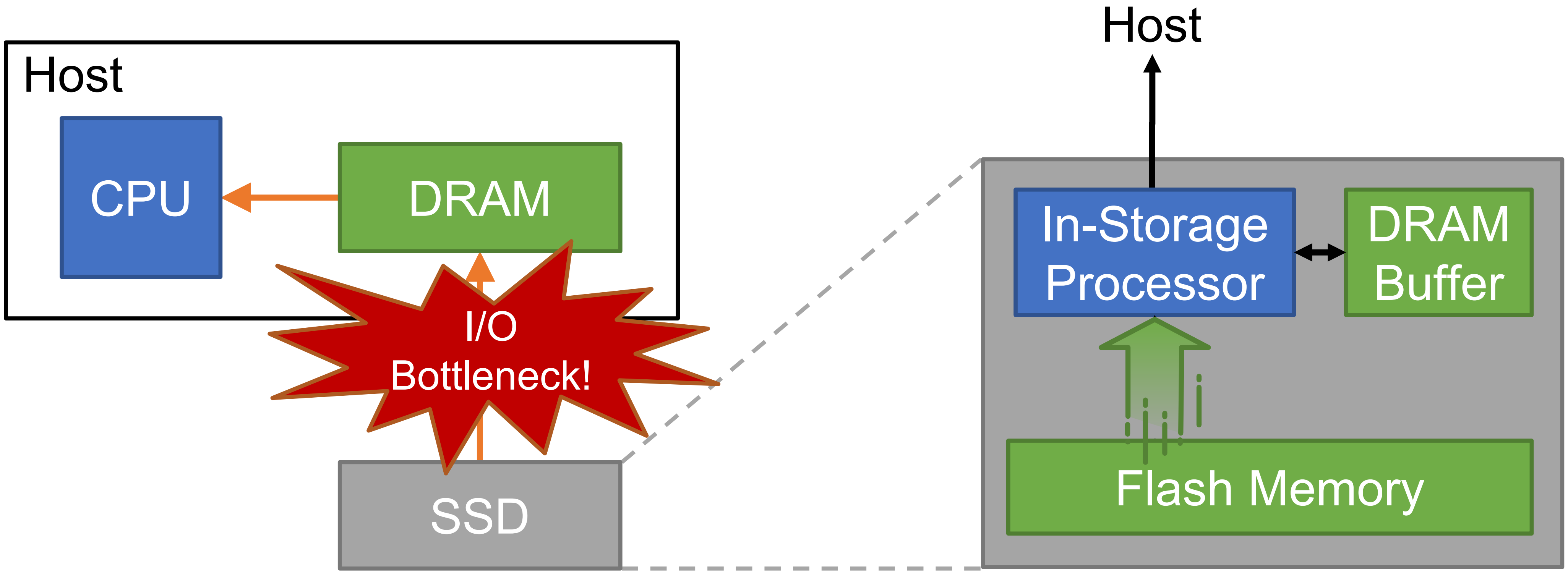

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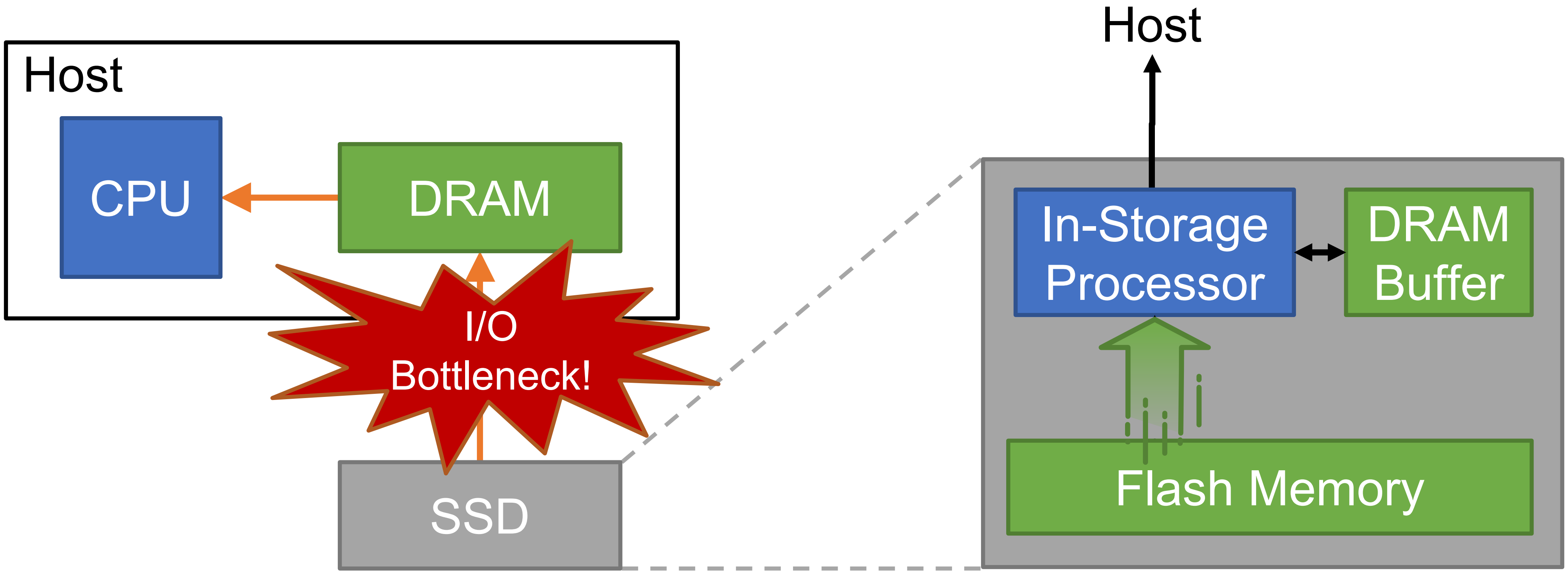
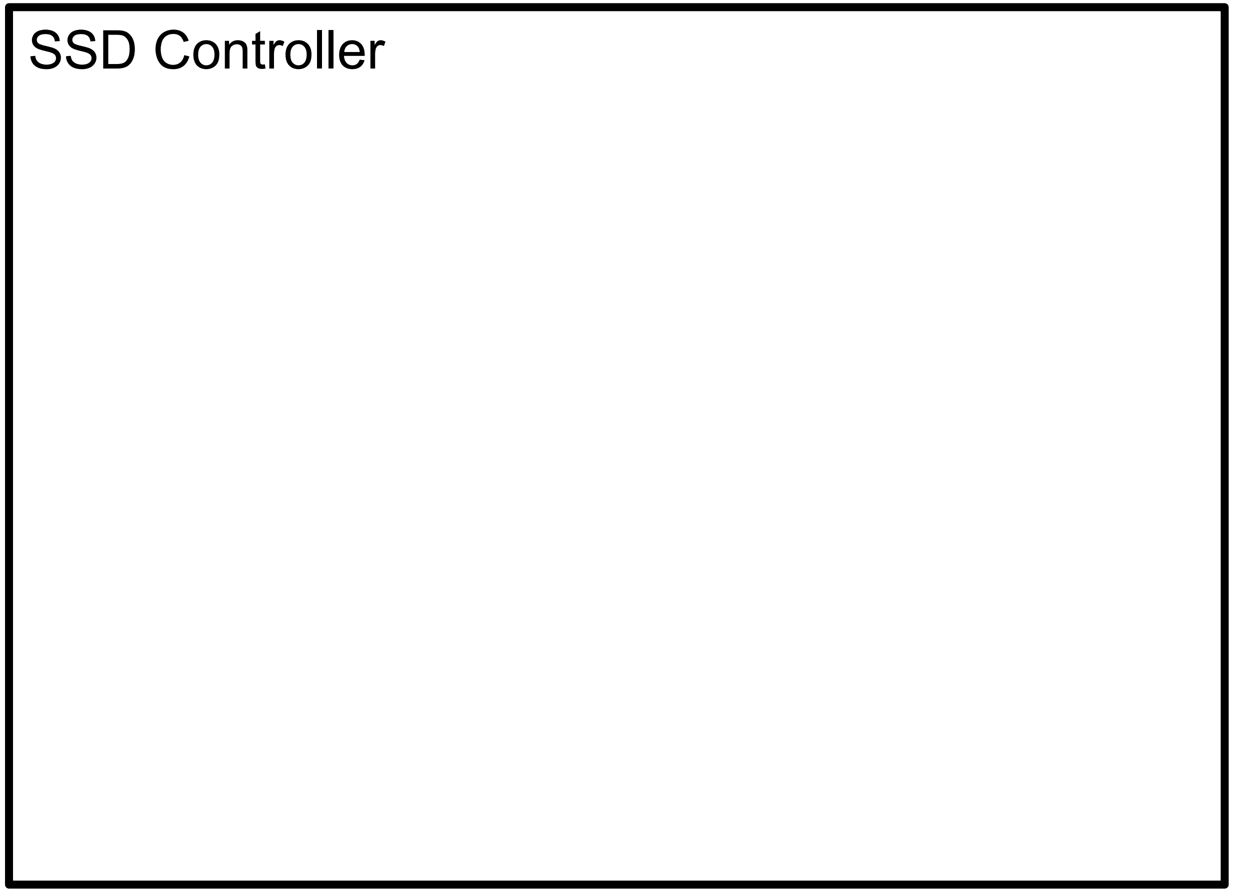


Host-based Computing

In-Storage Computing

In-storage computing offers an effective solution to alleviate the I/O bottleneck

SSD Architecture for In-Storage Computing



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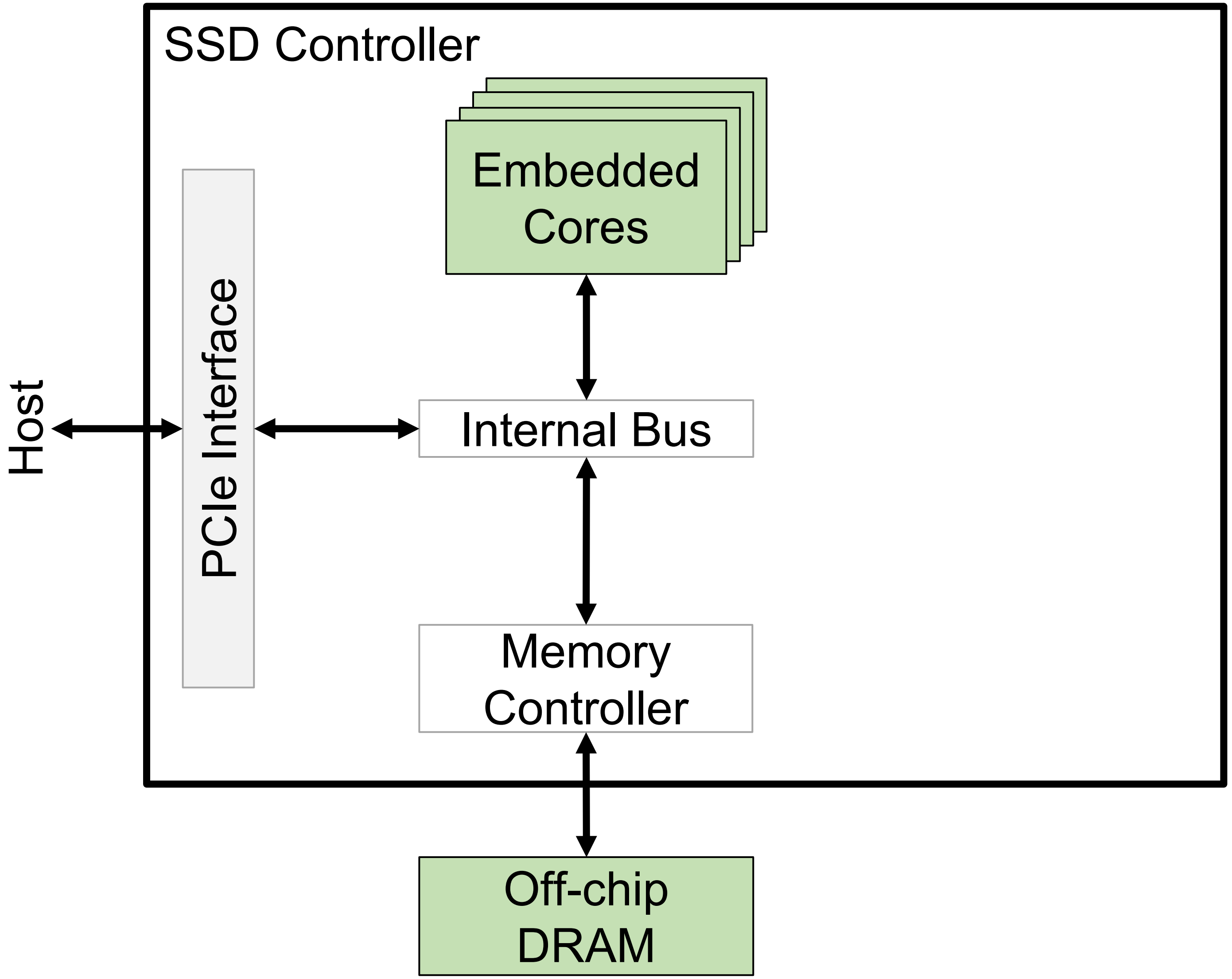

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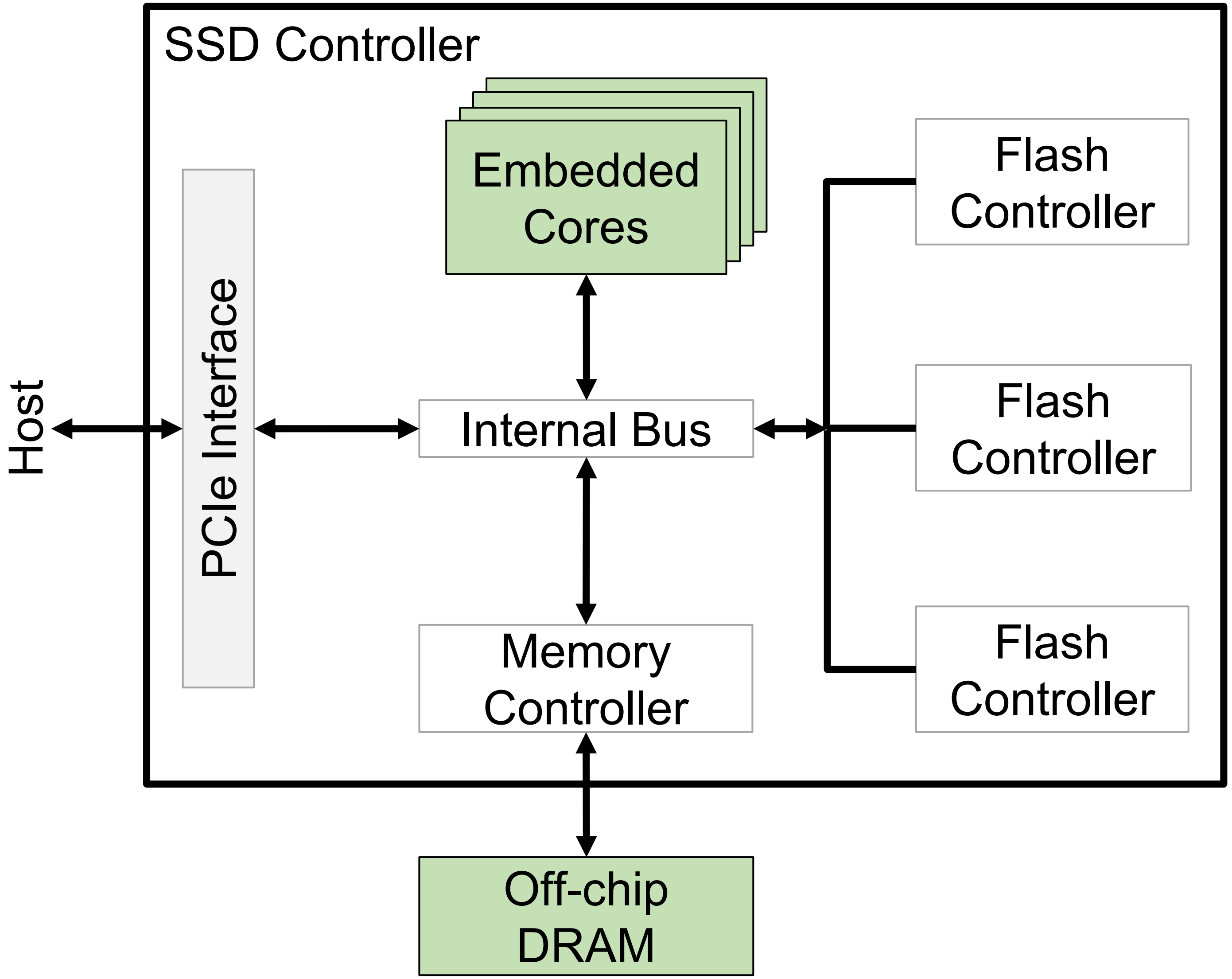

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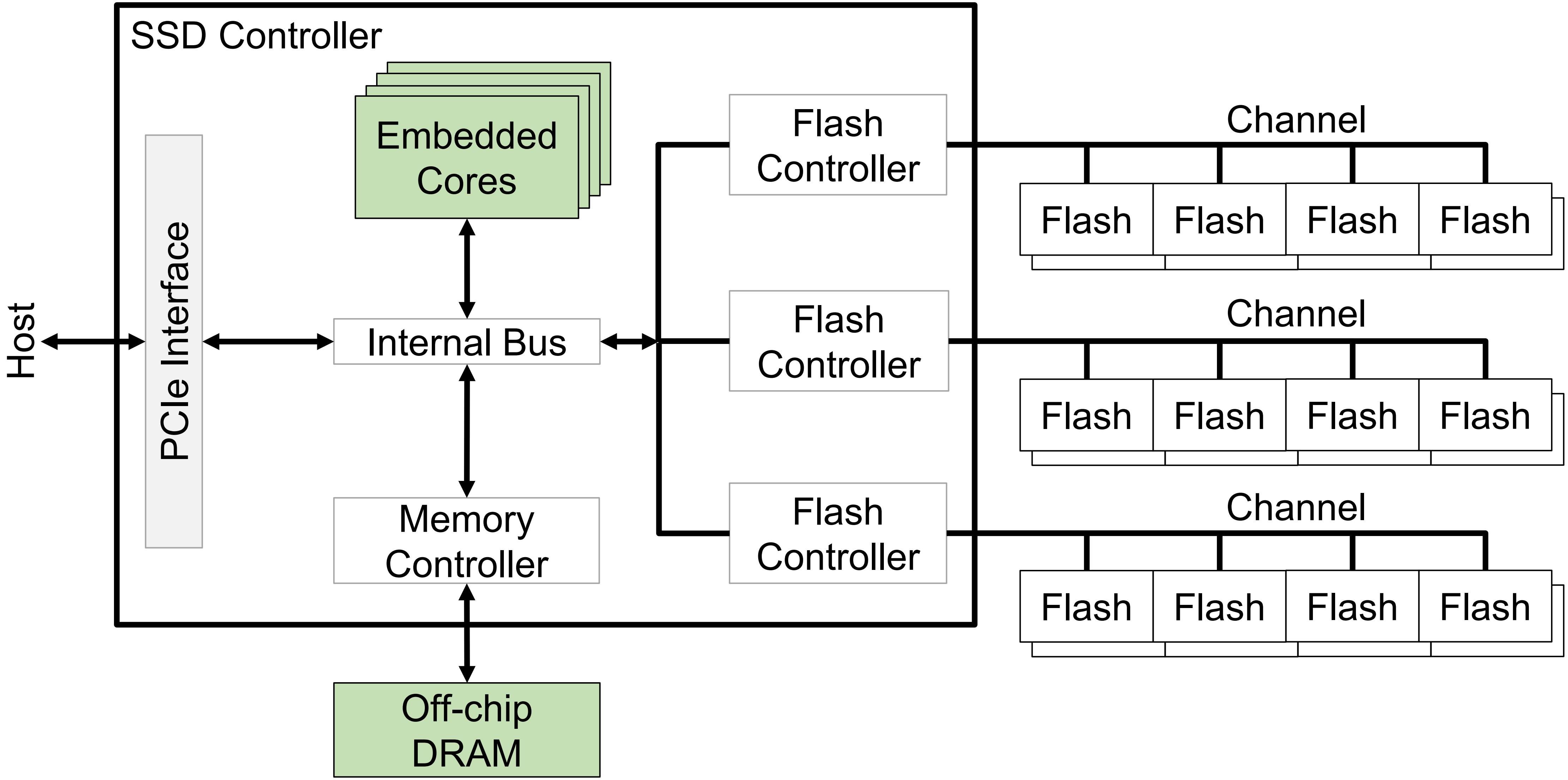

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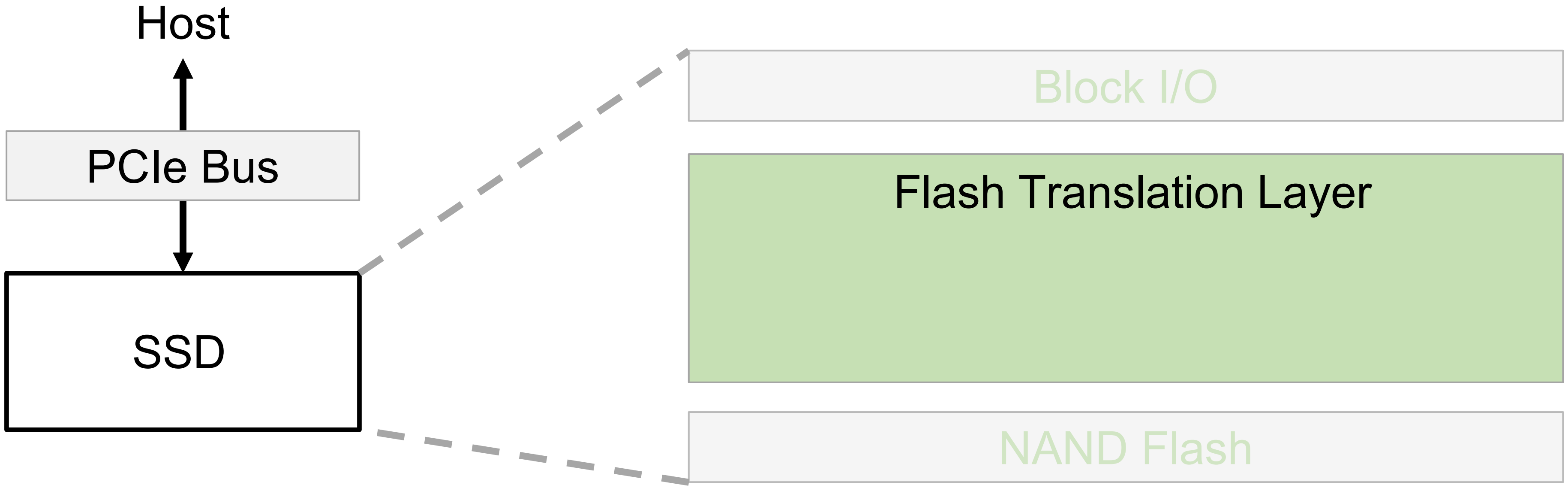

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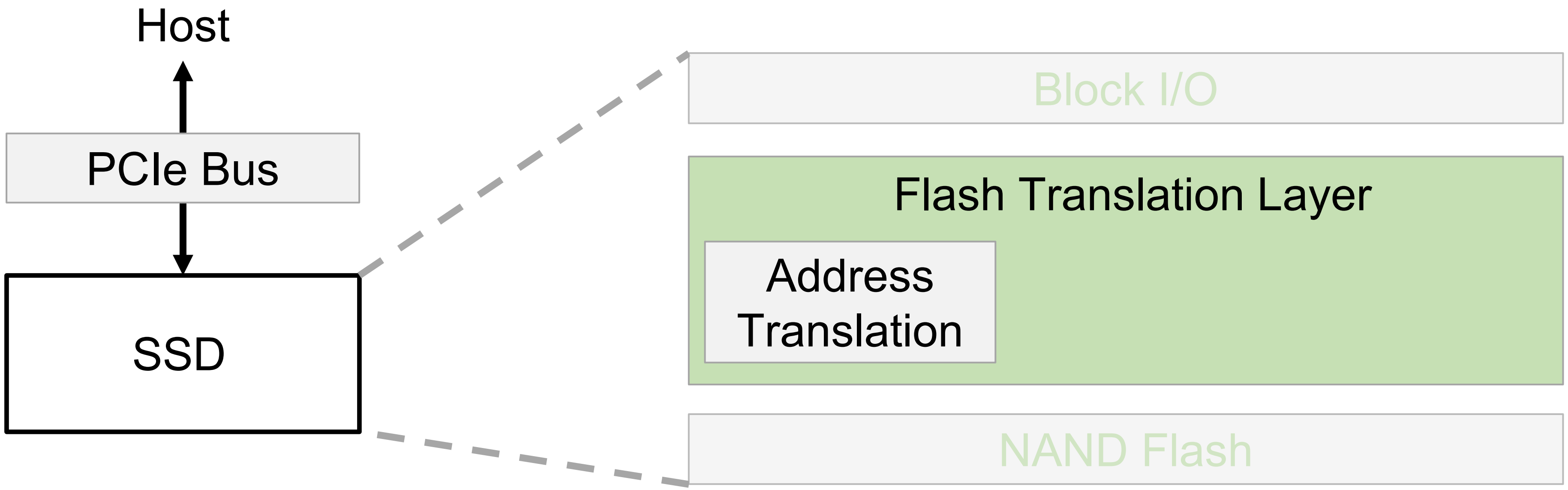

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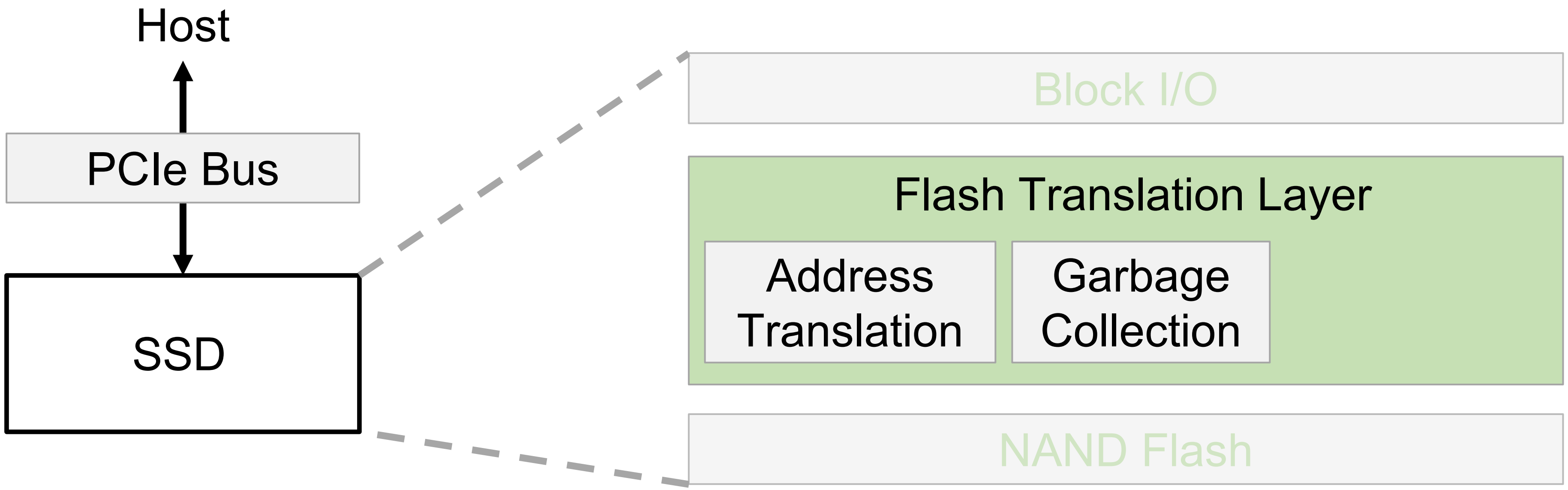

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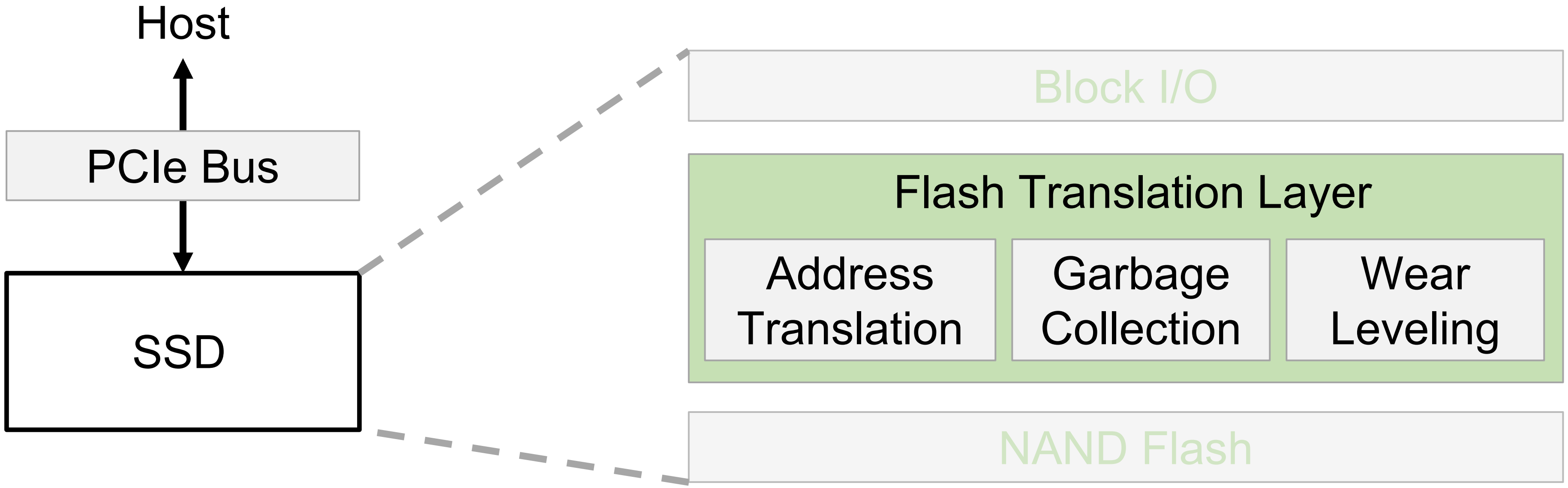
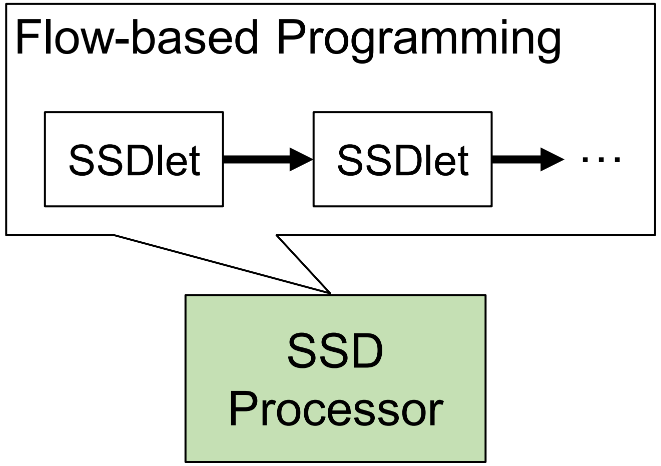


State-of-the-Art Frameworks for In-Storage Computing



MapReduce-based Framework

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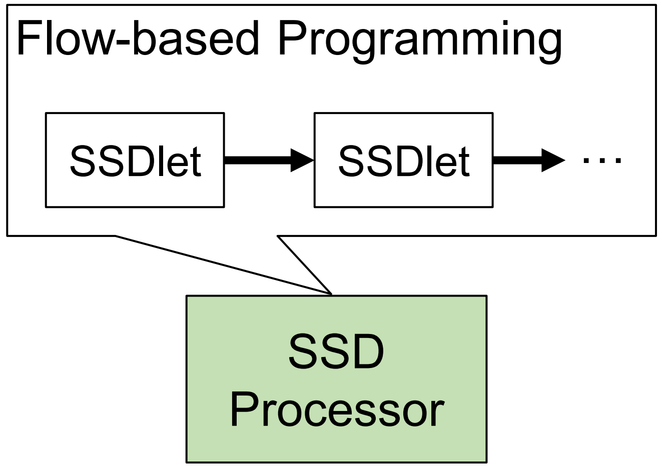

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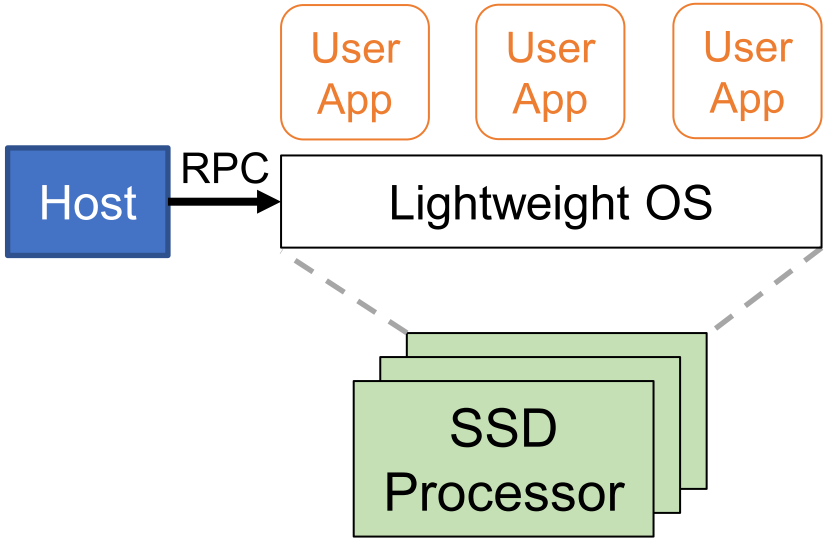

RPC-based Offloading

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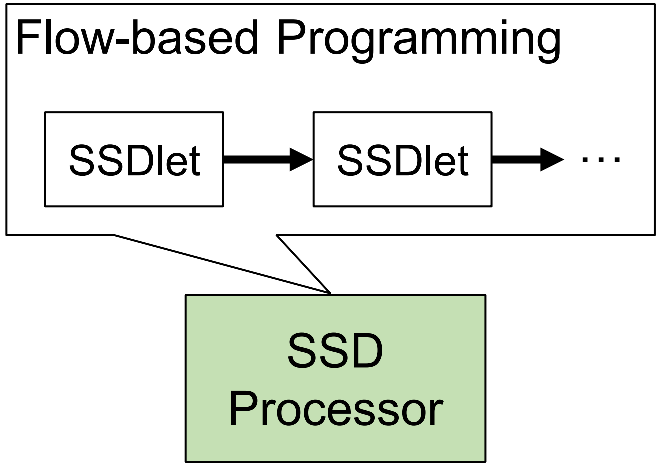

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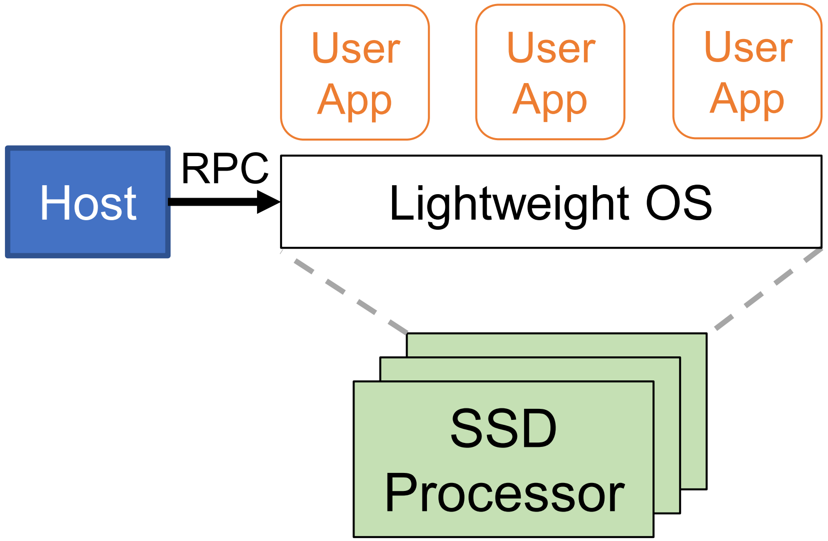

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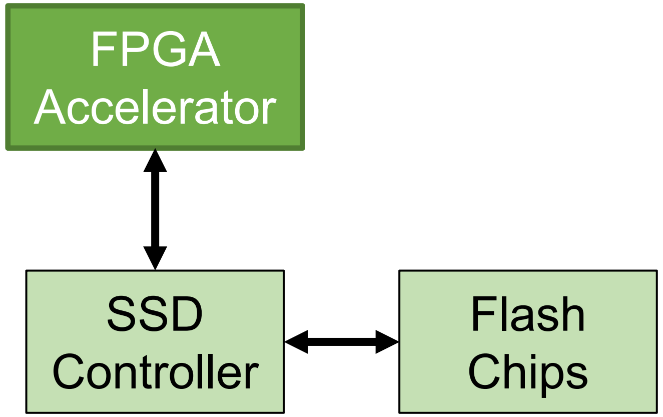

Industry SmartSSD

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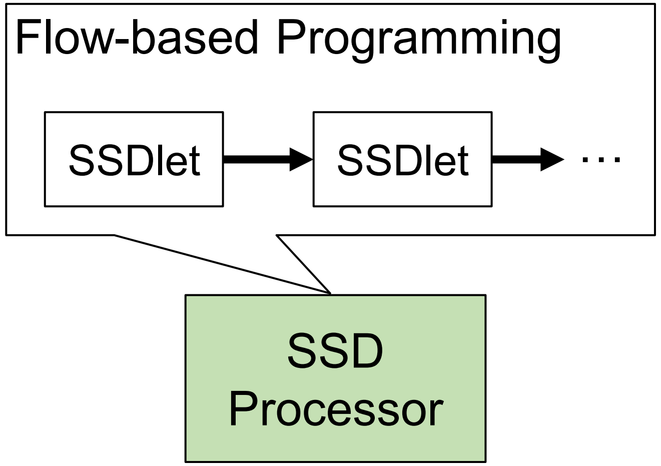

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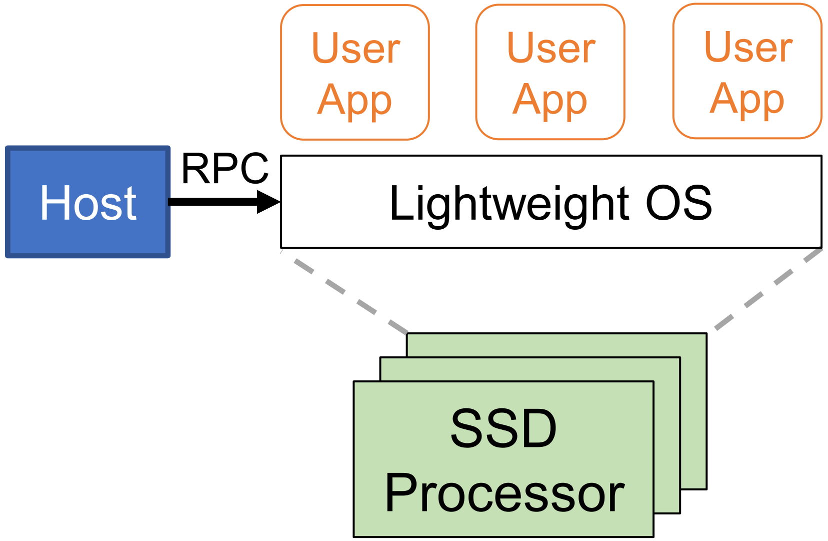

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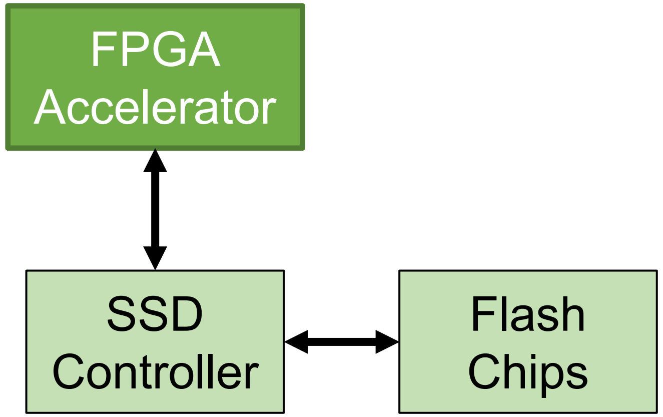

Industry SmartSSD

Most of the existing frameworks focus on performance and programmability

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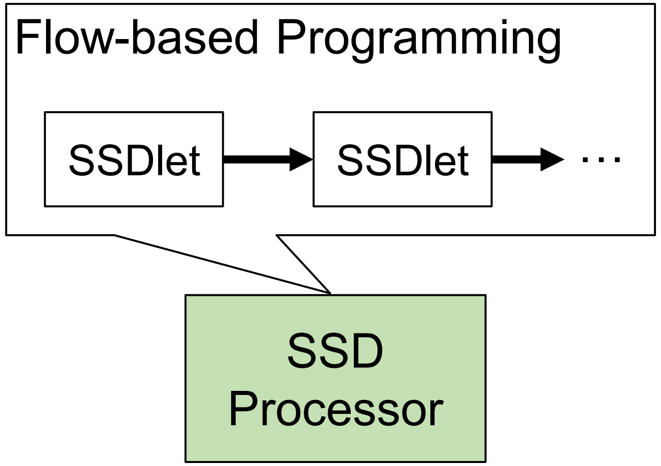

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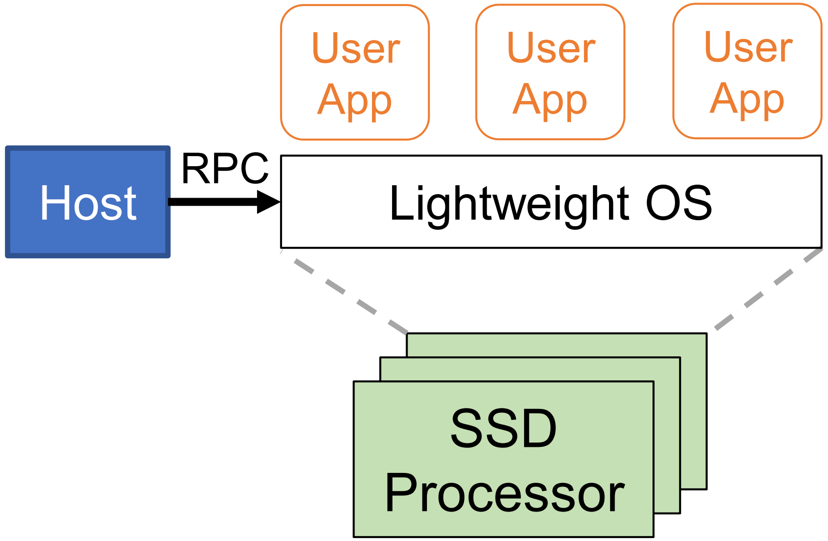

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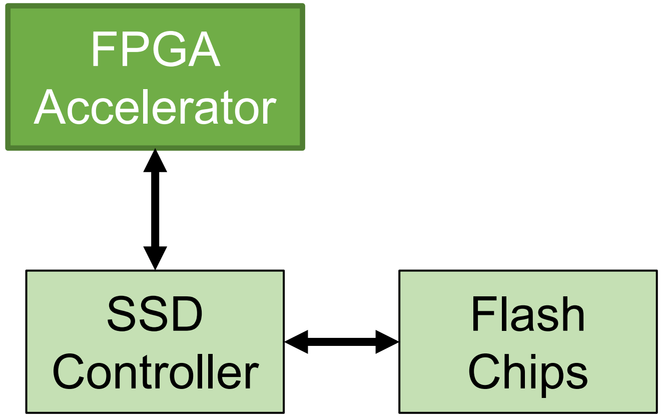
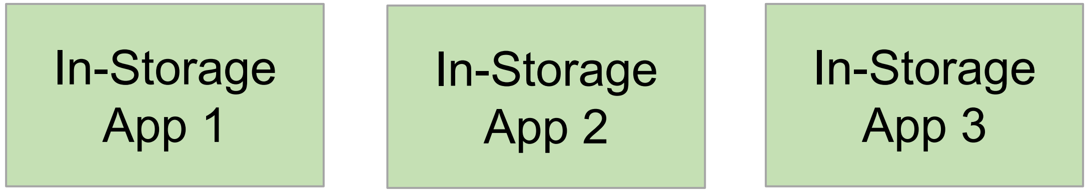


Industry SmartSSD

Most of the existing frameworks focus on performance and programmability

Few of them consider security as the first-class citizen

Why Should We Secure In-Storage Computing?



In-Storage App 1

In-Storage App 2

In-Storage App 3

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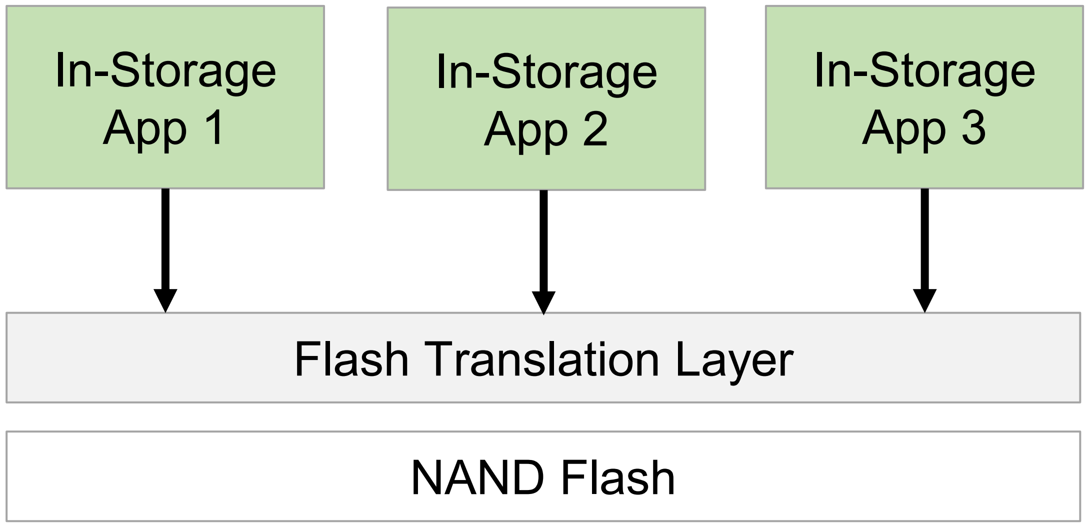

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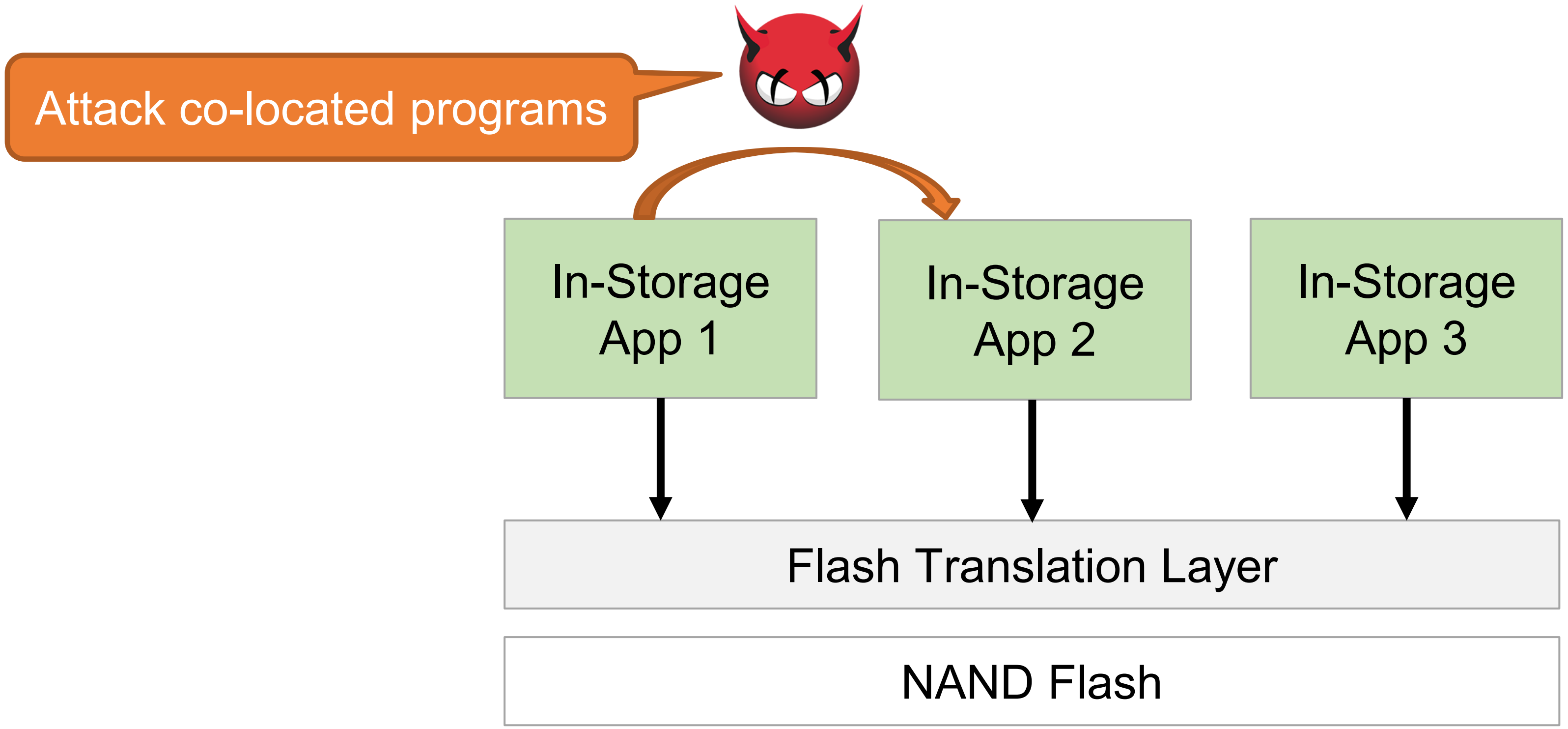

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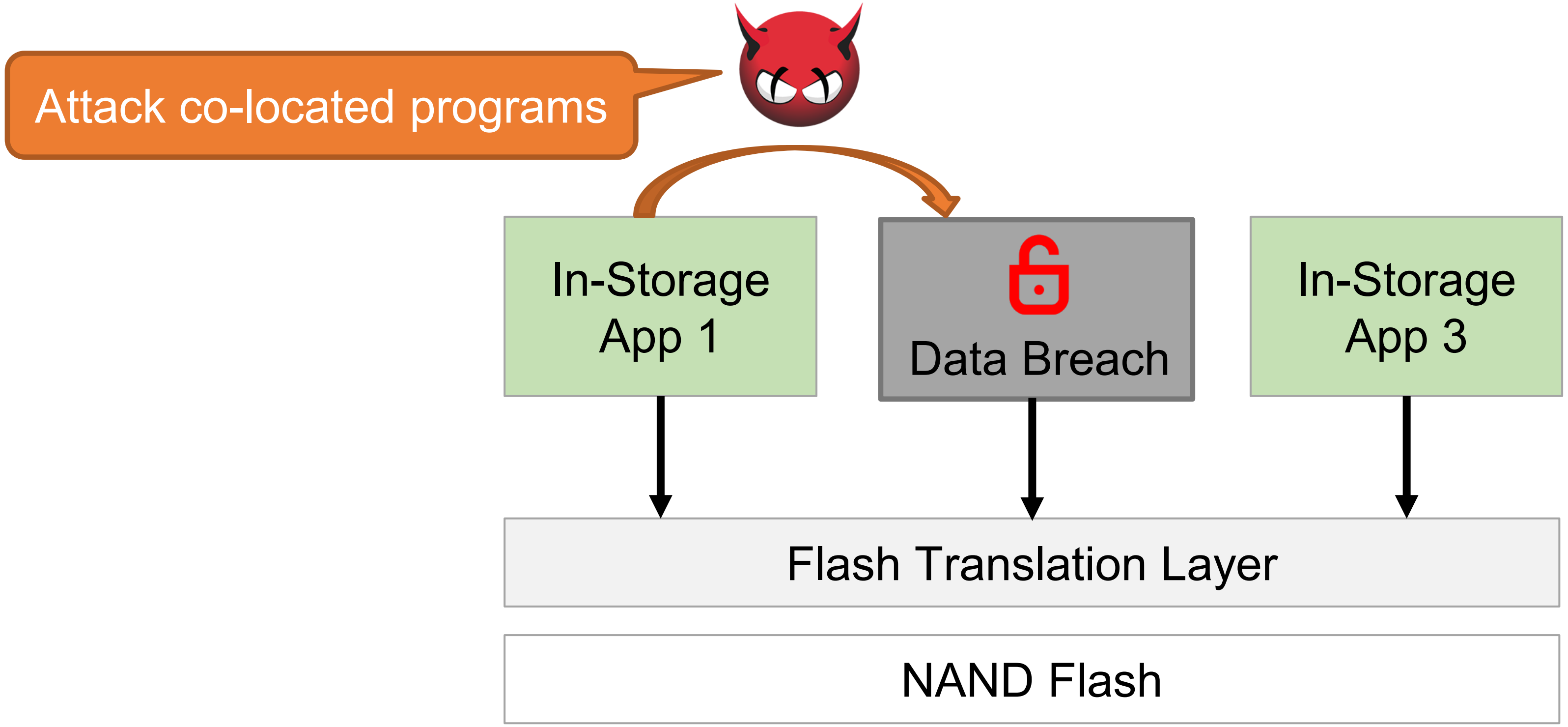

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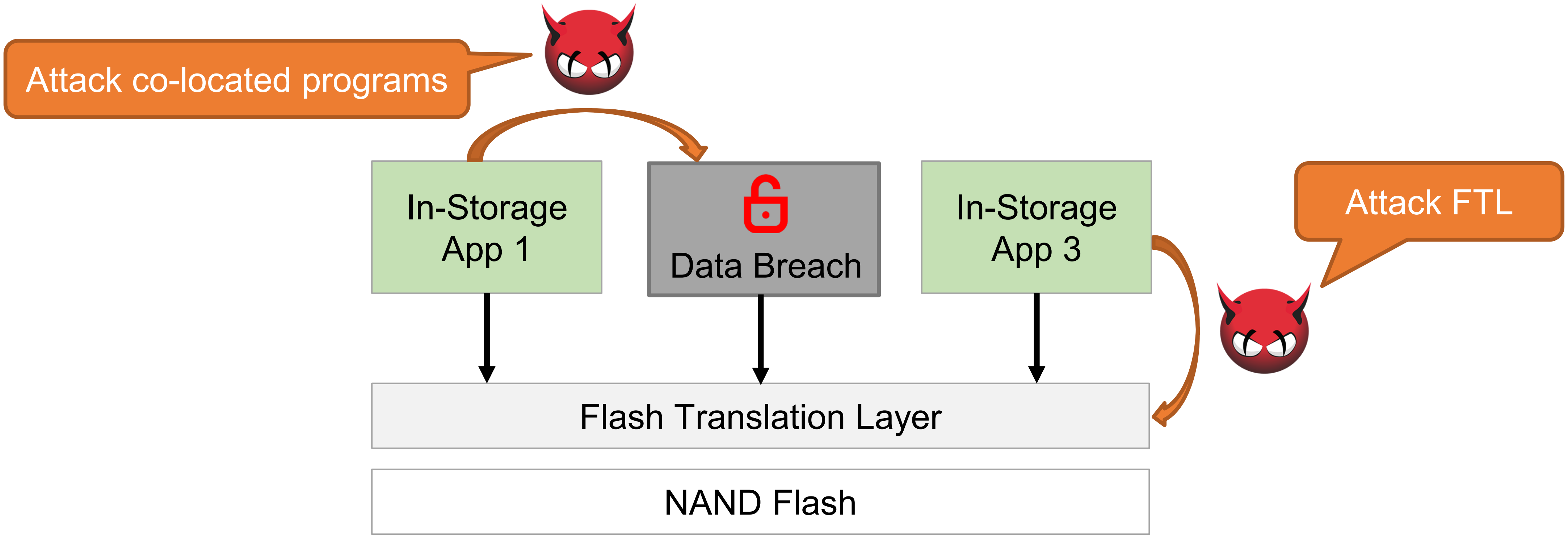

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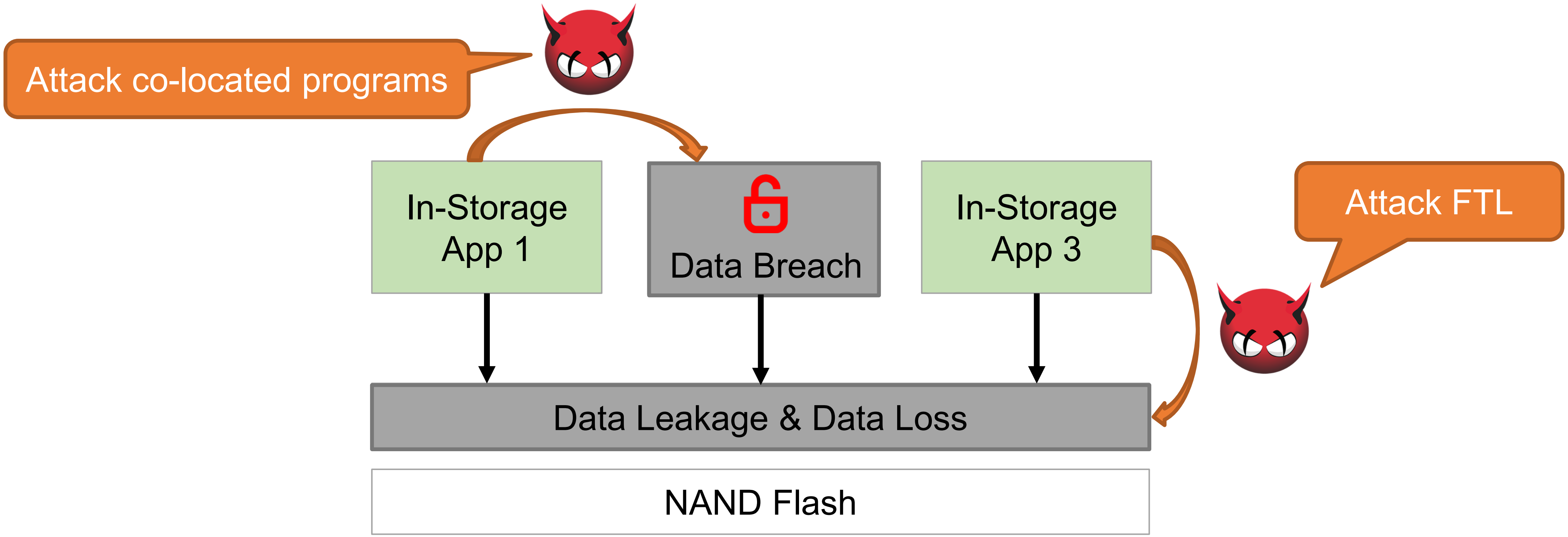

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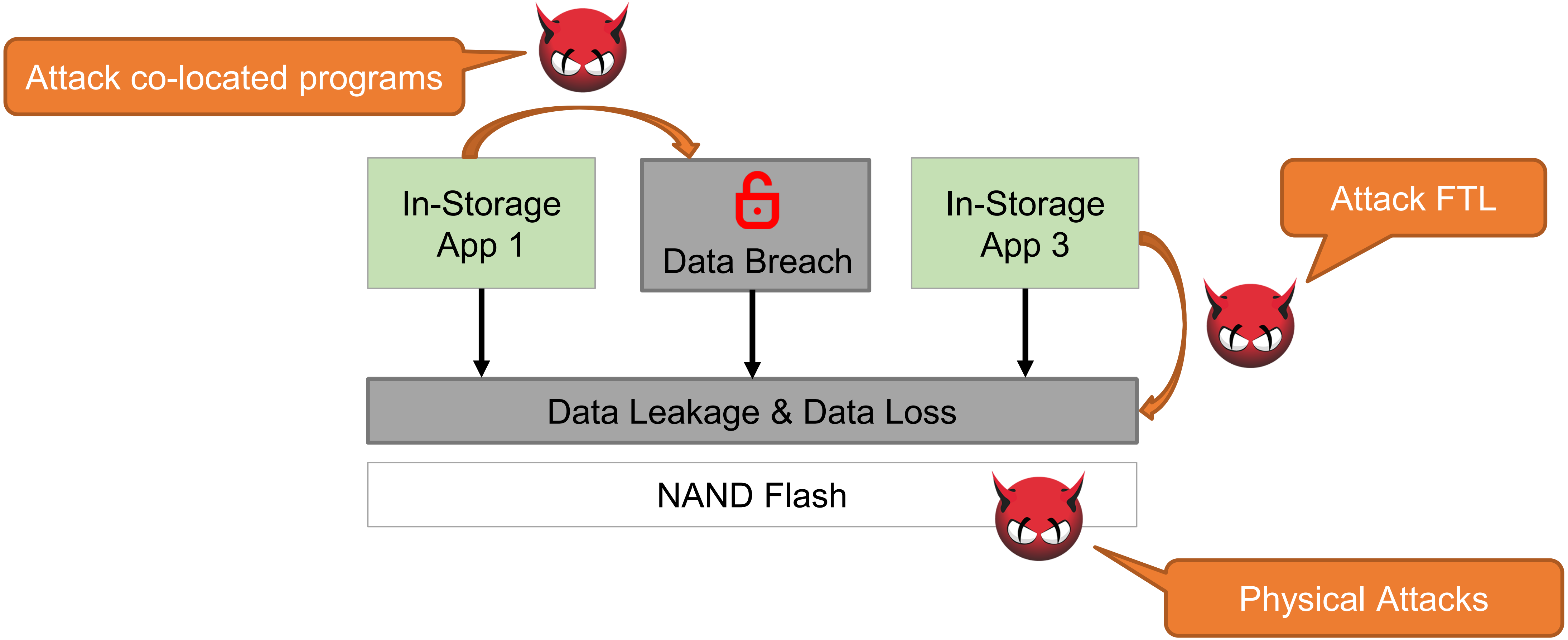

Attack co-located programs

In-Storage App 1

Data Breach

In-Storage App 3

Attack FTL

Data Leakage & Data Loss

NAND Flash

Physical Attacks

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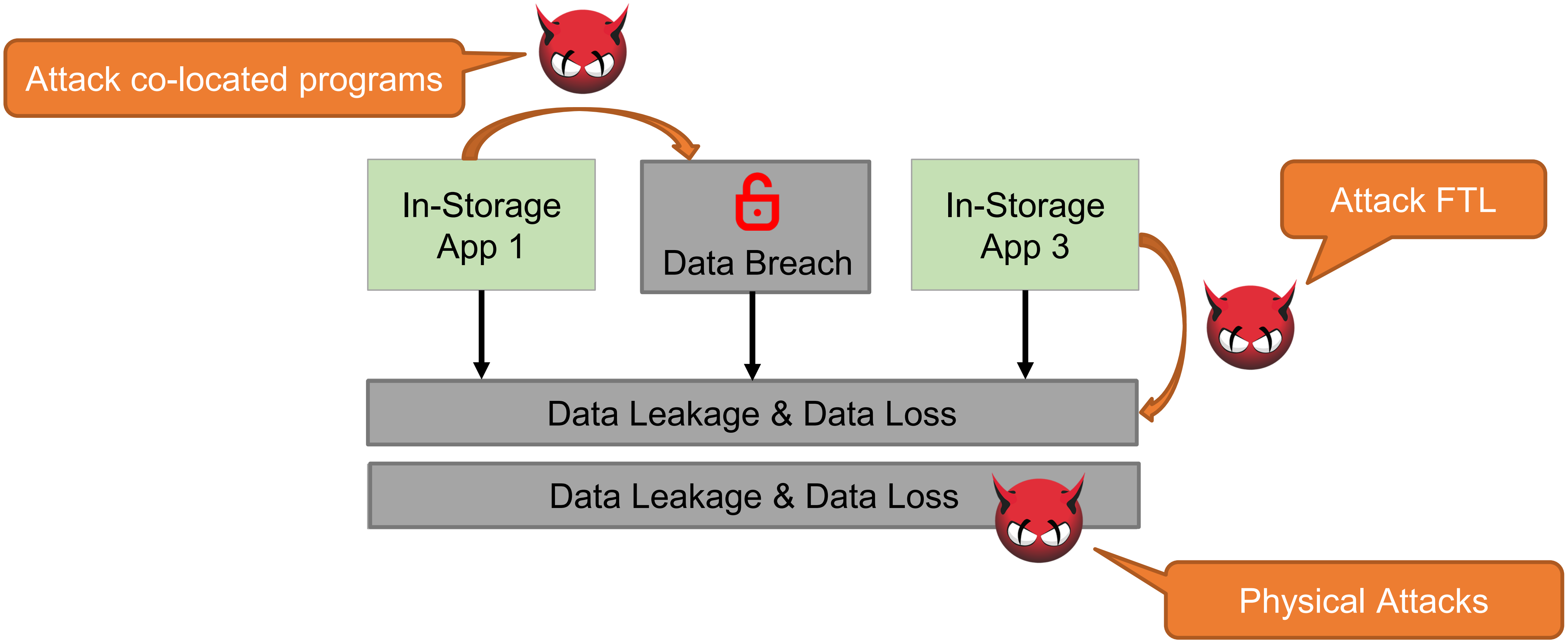

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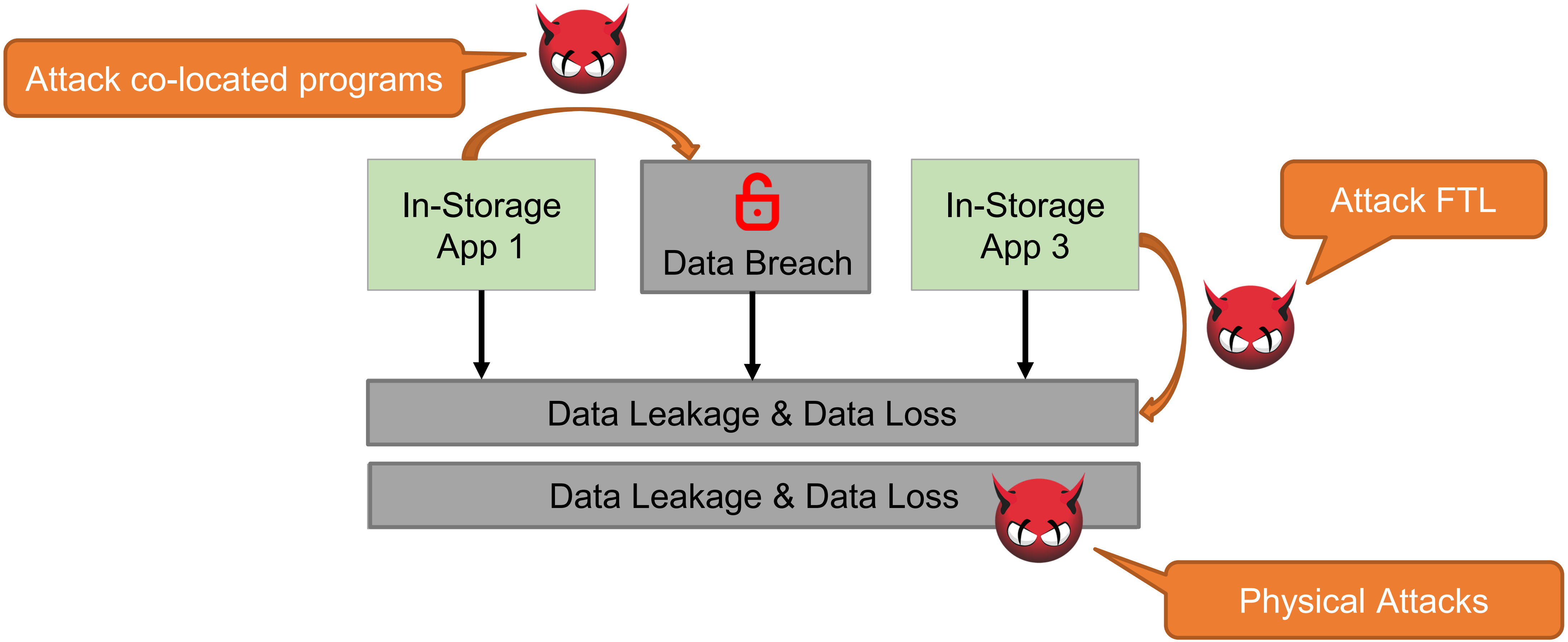

Attack co-located programs

In-Storage App 1

Data Breach

In-Storage App 3

Attack FTL

Data Leakage & Data Loss

Data Leakage & Data Loss

Physical Attacks

It is desirable to build a secure in-storage computing environment!

Existing TEEs Do Not Work For In-Storage Computing

Intel SGX is not available in storage processors

Existing TEEs Do Not Work For In-Storage Computing

intel SGX

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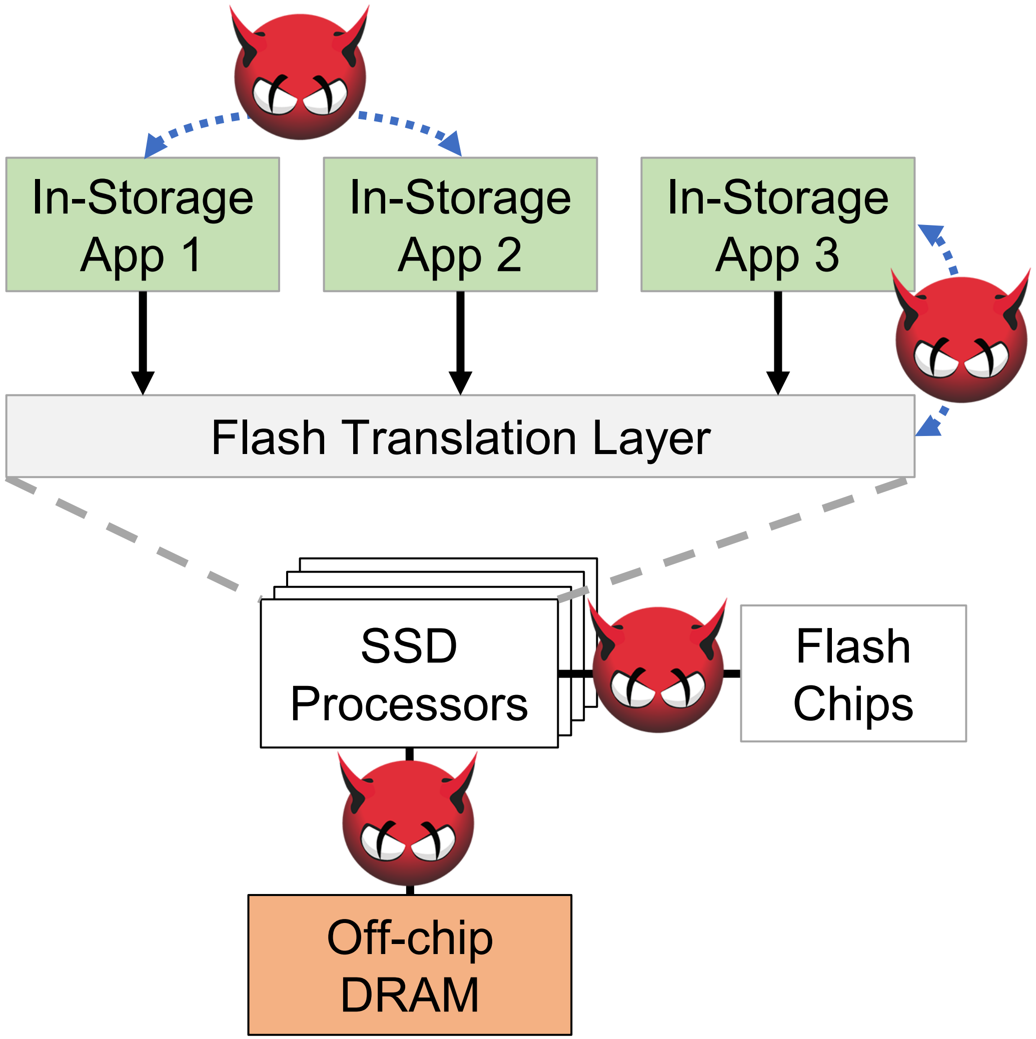
arm TRUSTZONE

Unclear how to apply ARM TrustZone to in-storage computing

IceClave: A Trusted Execution Environment for In-Storage Computing



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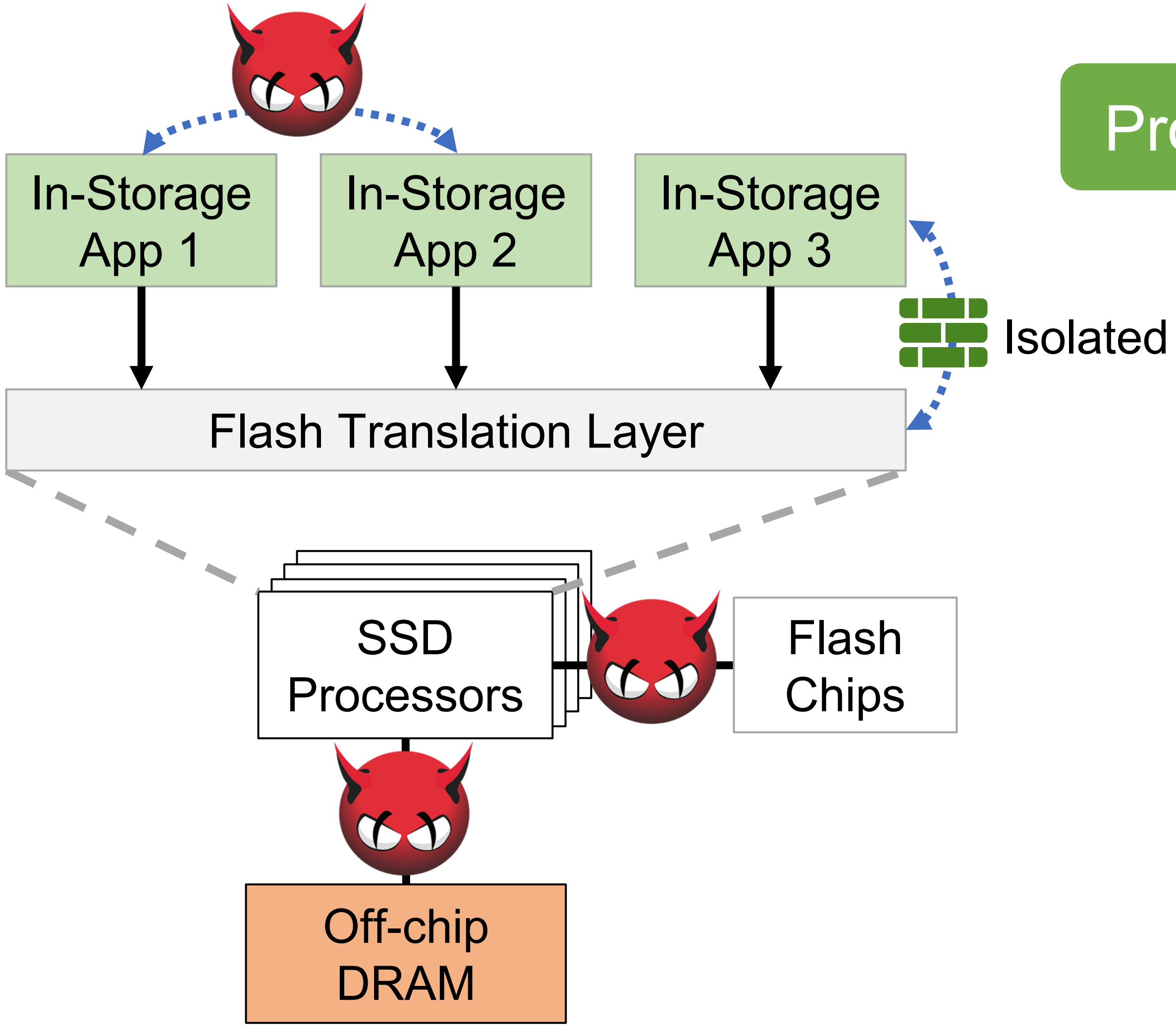

Protecting FTL from malicious in-storage apps

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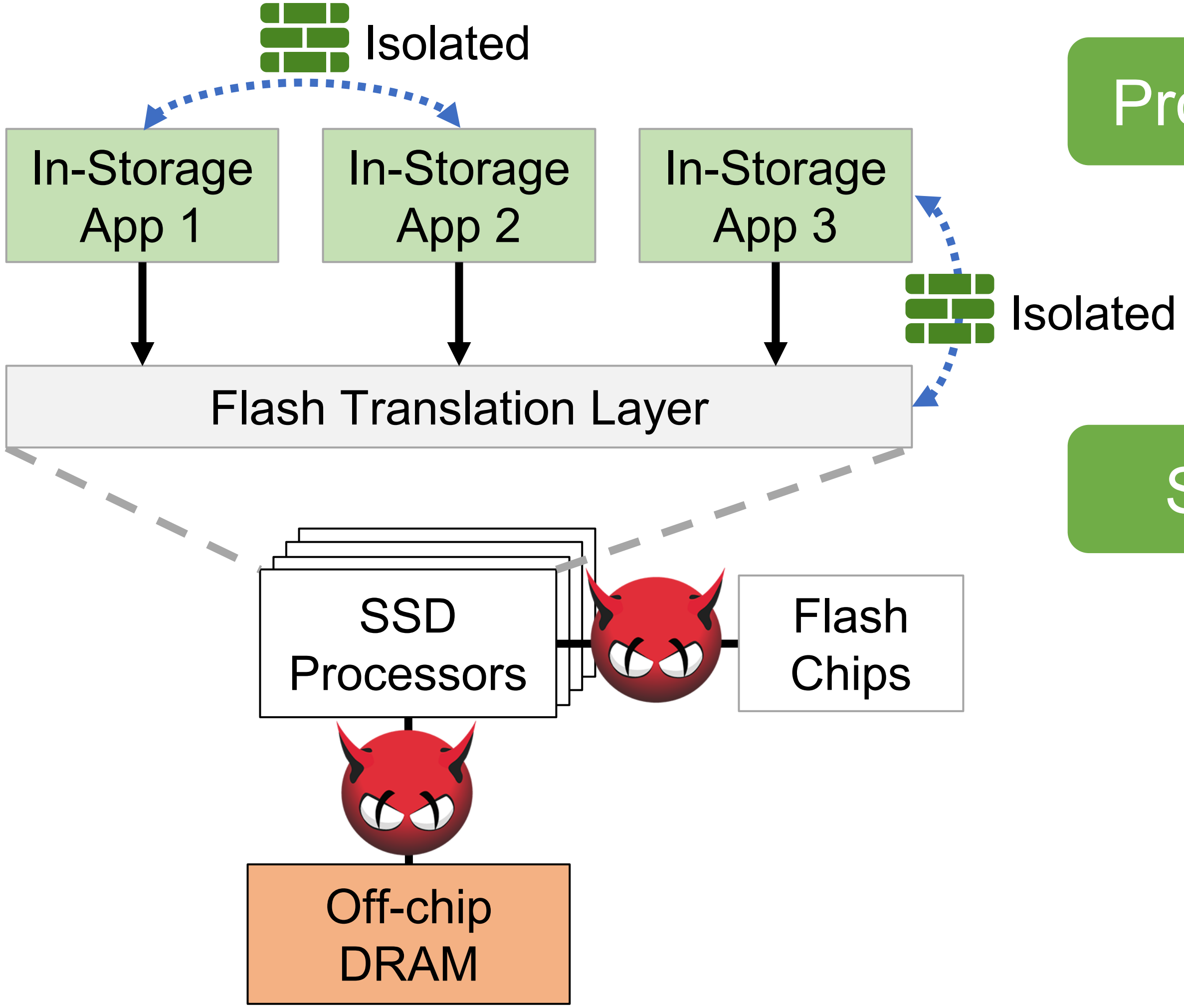

Protecting FTL from malicious in-storage apps

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Security isolation between in-storage apps

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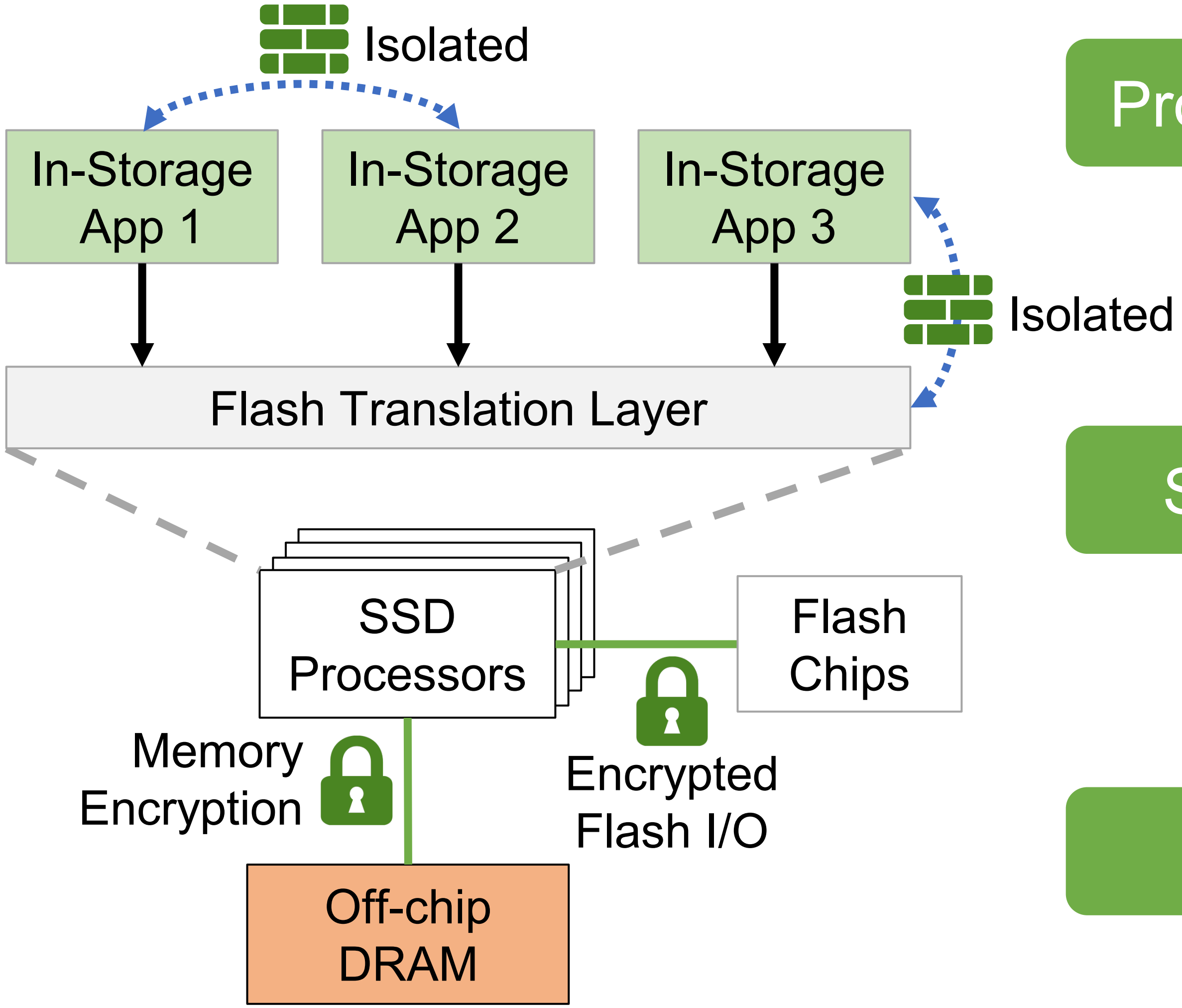

Protecting FTL from malicious in-storage apps

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Security isolation between in-storage apps

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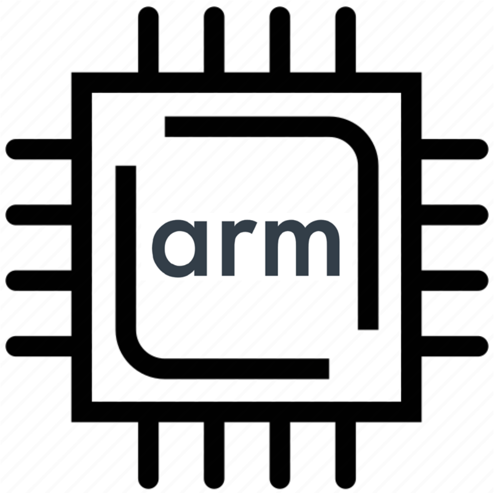
Securing data against physical attacks

IceClave Design Challenges



Bare-metal Environment

IceClave Design Challenges

Bare-metal Environment

Efficient Flash Access

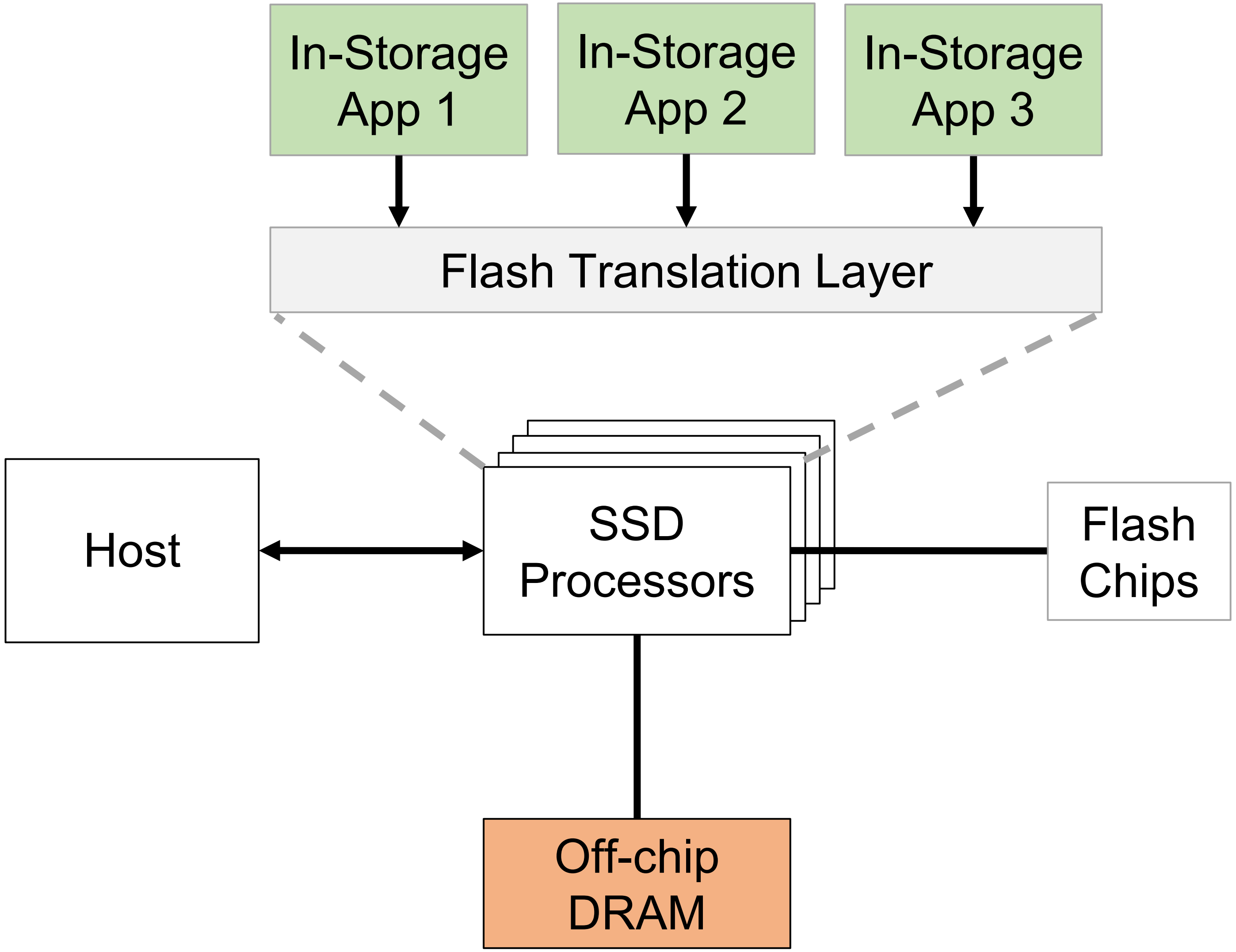
IceClave Design Challenges

Bare-metal Environment

Efficient Flash Access

Limited Resources in SSD Device

Threat Model



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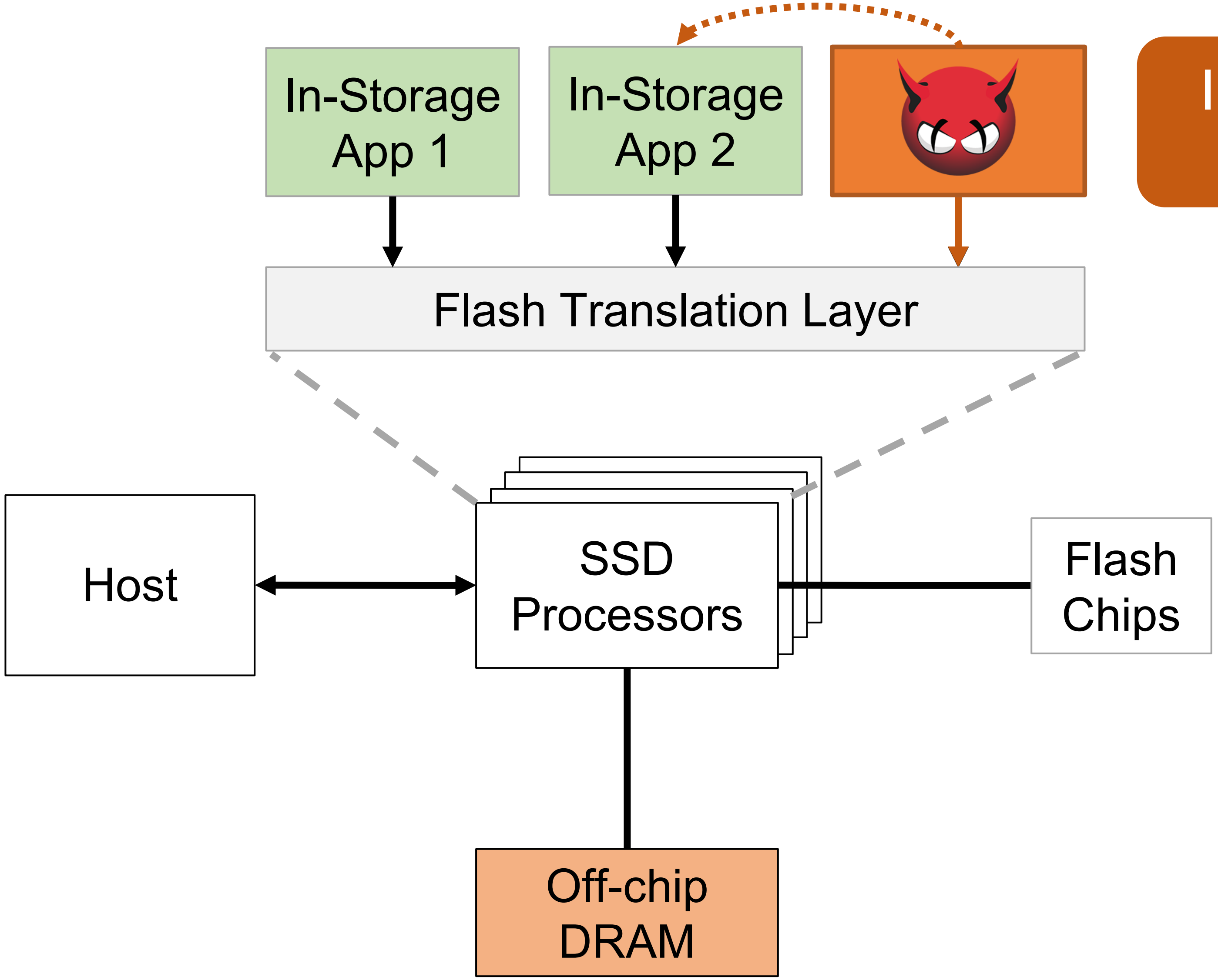
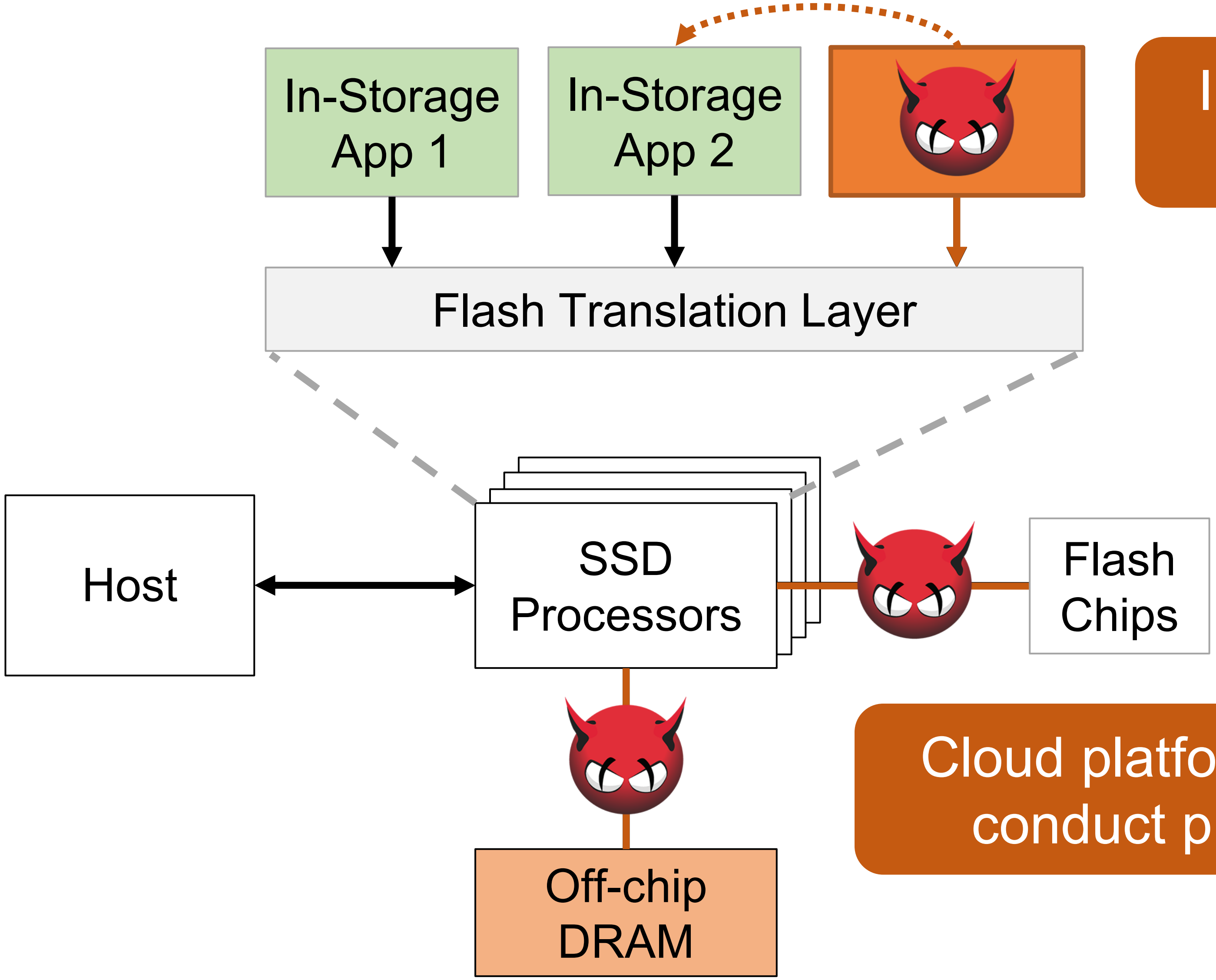


In-storage applications can be malicious

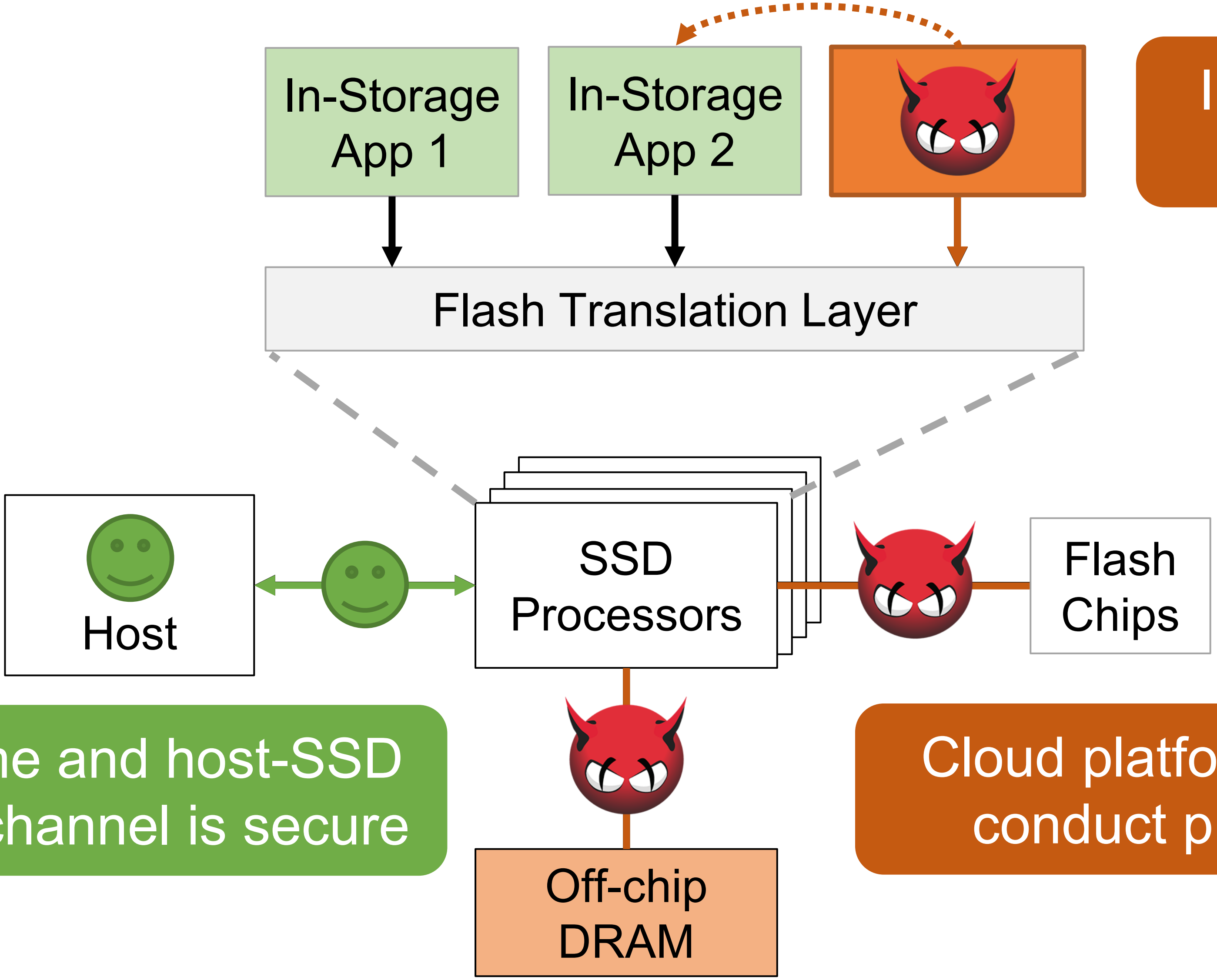
Threat Model



In-storage applications can be malicious

Cloud platform operator may conduct physical attacks

Threat Model

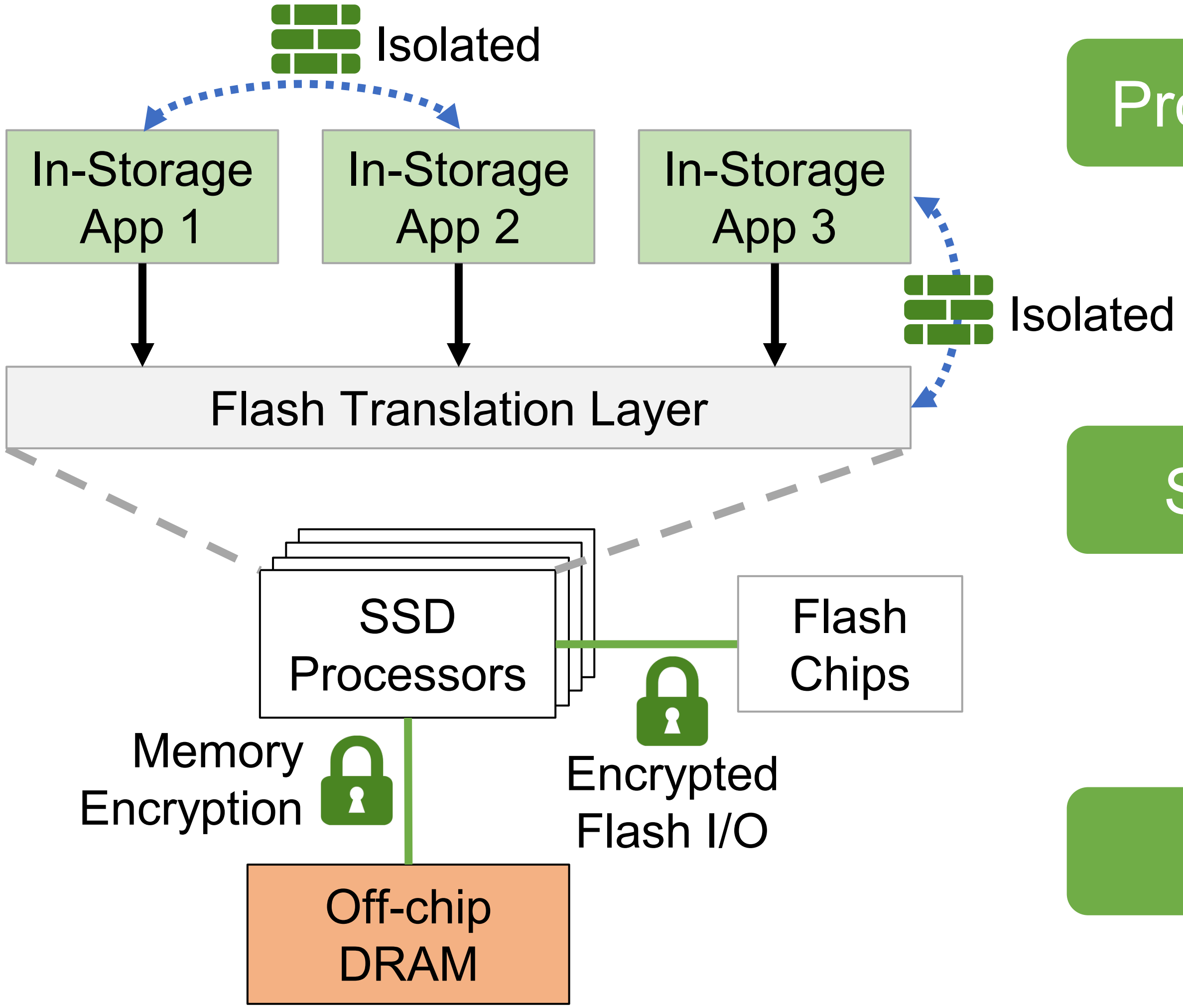


In-storage applications can be malicious

Host runtime and host-SSD offloading channel is secure

Cloud platform operator may conduct physical attacks

Protecting Flash Translation Layer



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Security isolation between in-storage apps

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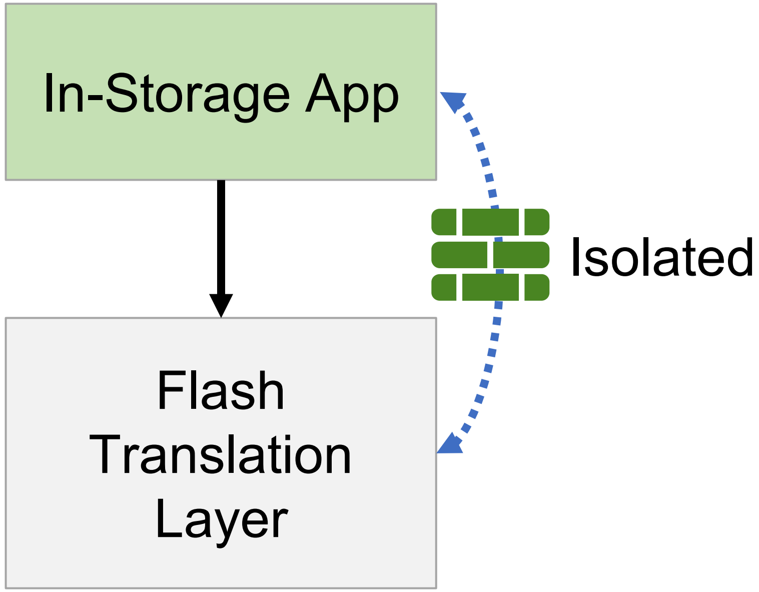

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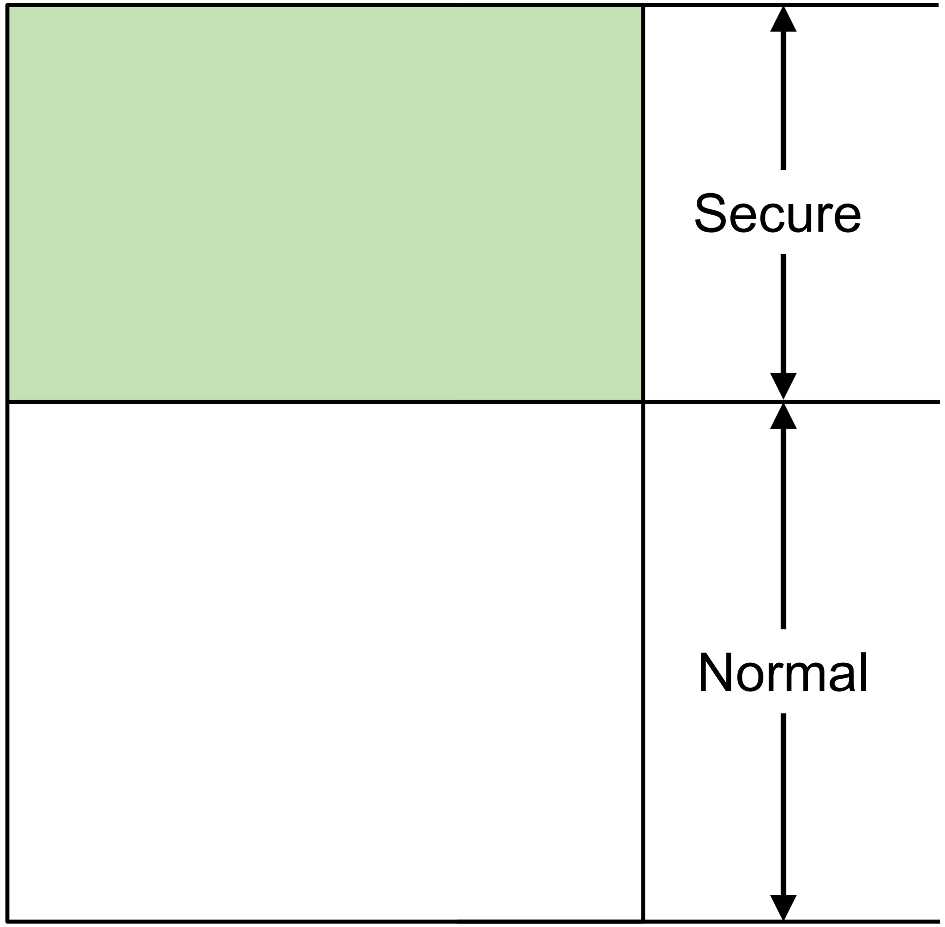

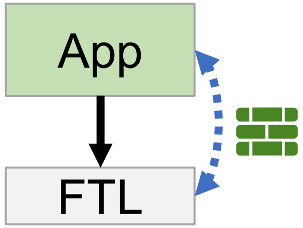

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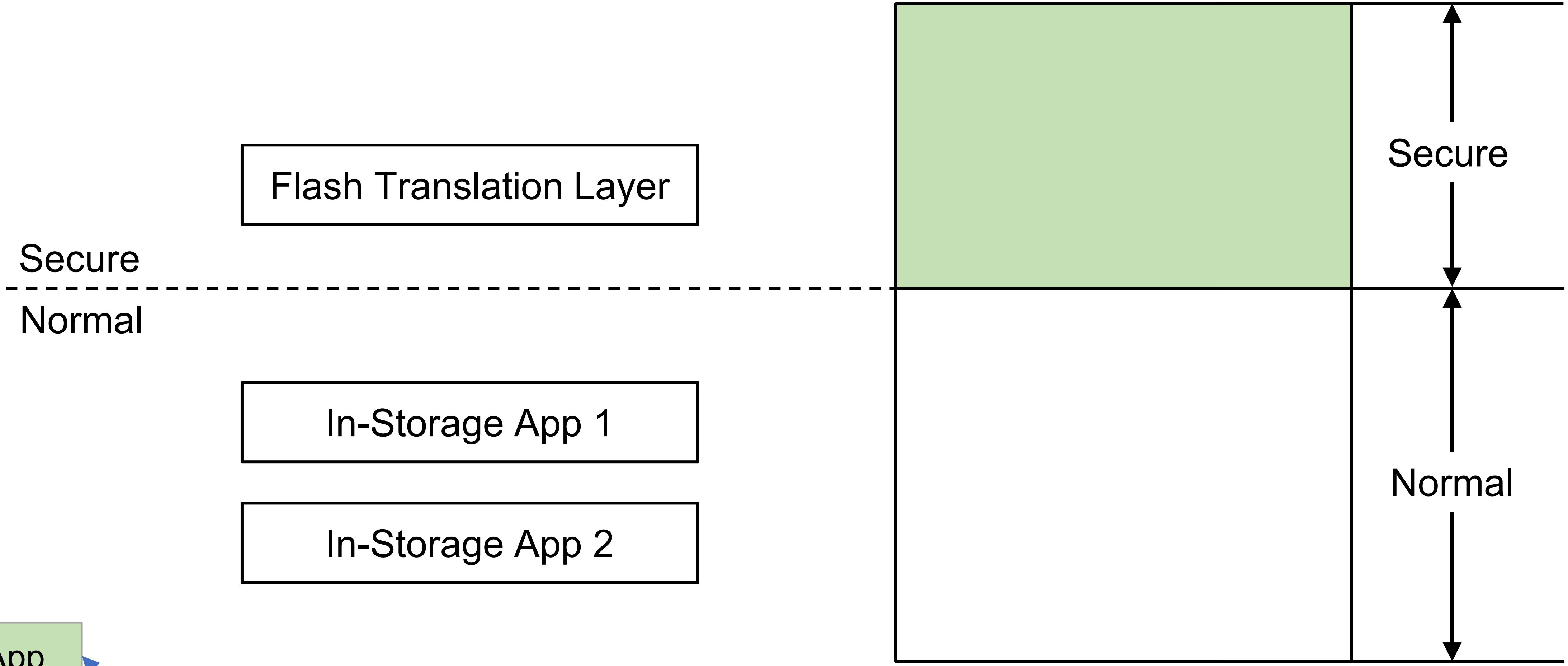


Flash Translation Layer

Secure

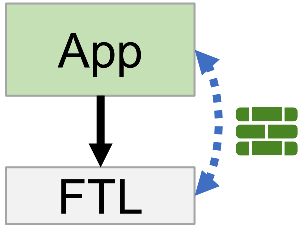
Normal

In-Storage App 1

In-Storage App 2

Secure

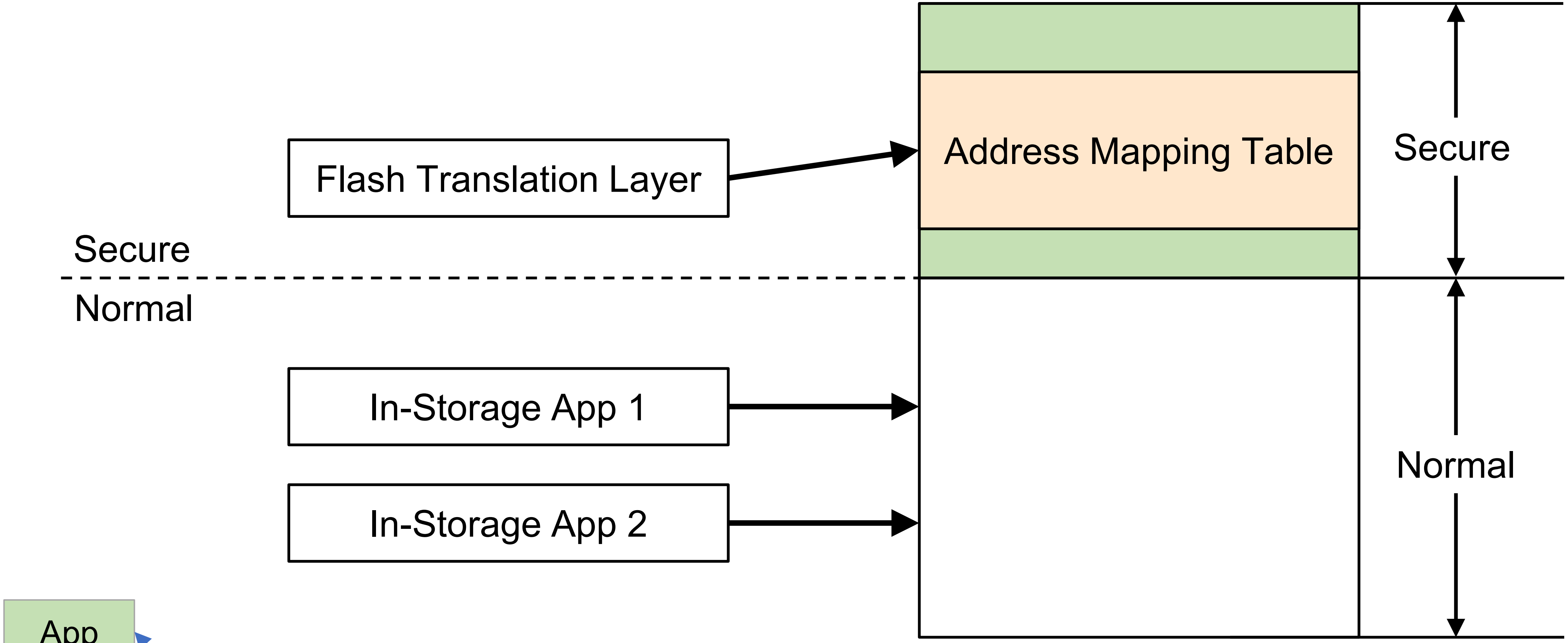
Normal

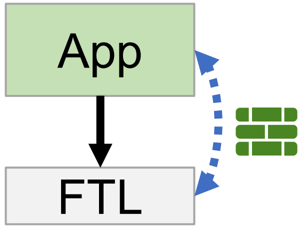


App

FTL

Protecting Flash Translation Layer





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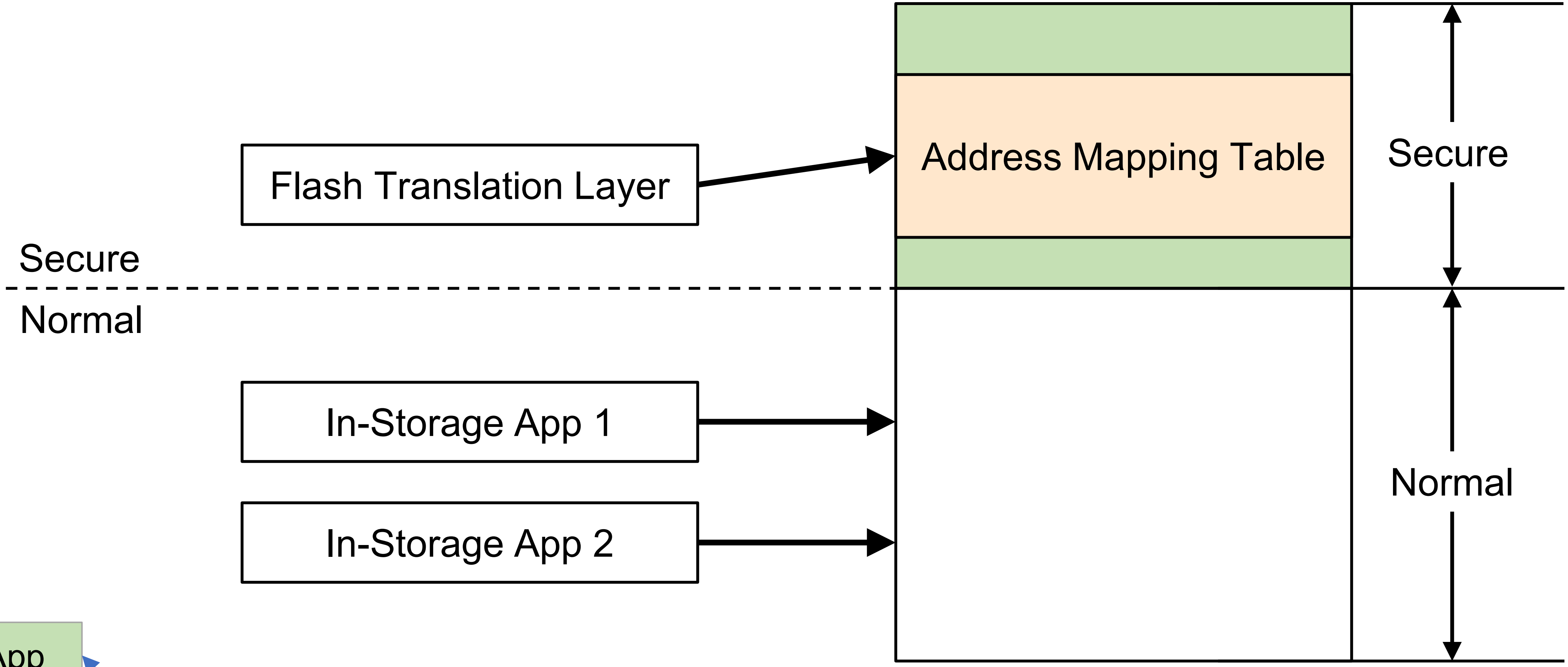
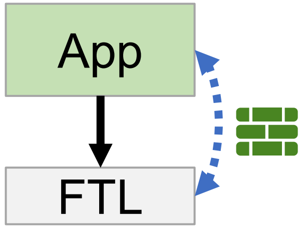
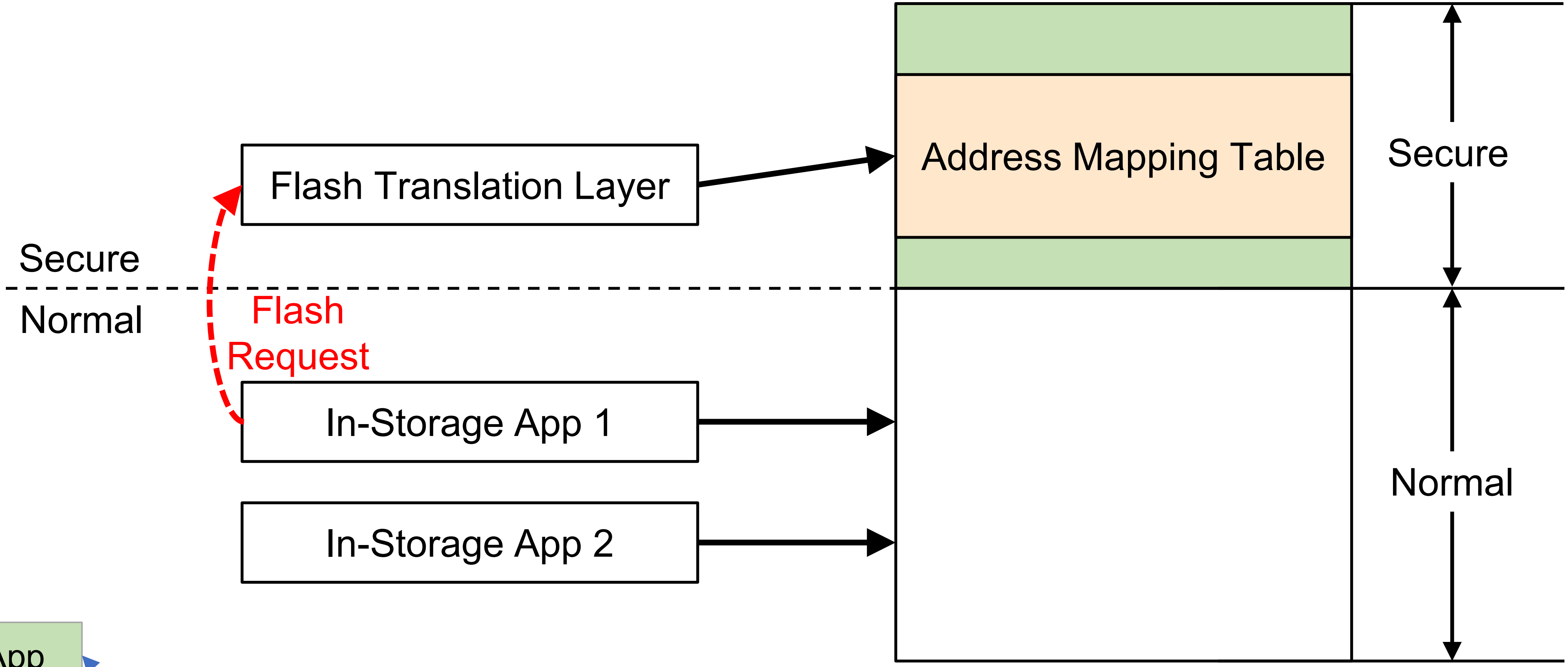
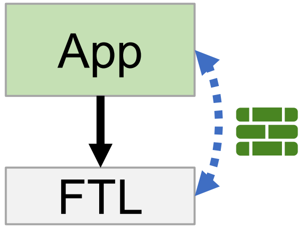




Naively applying TrustZone partitioning incurs significant performance penalty!

Protecting Flash Translation Layer





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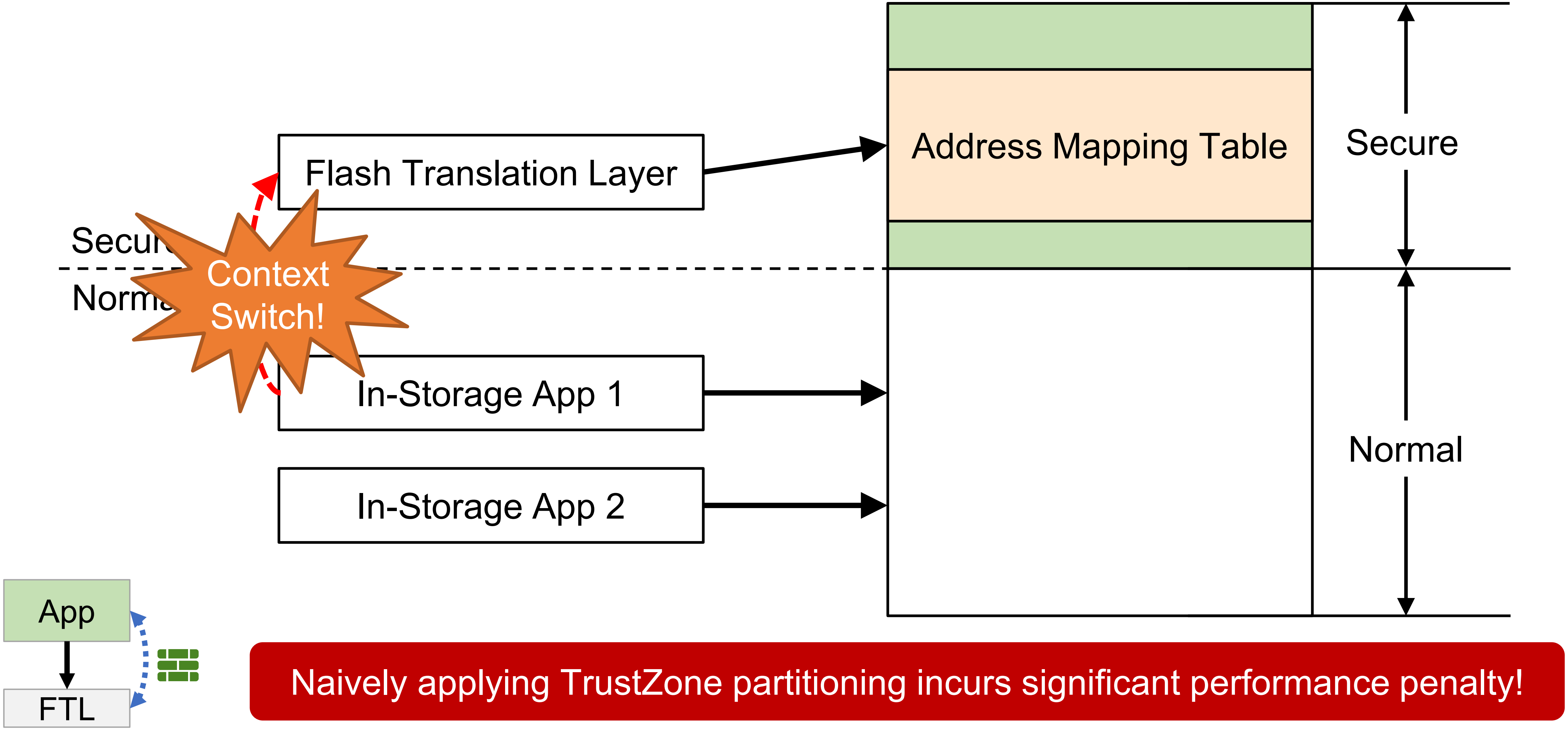

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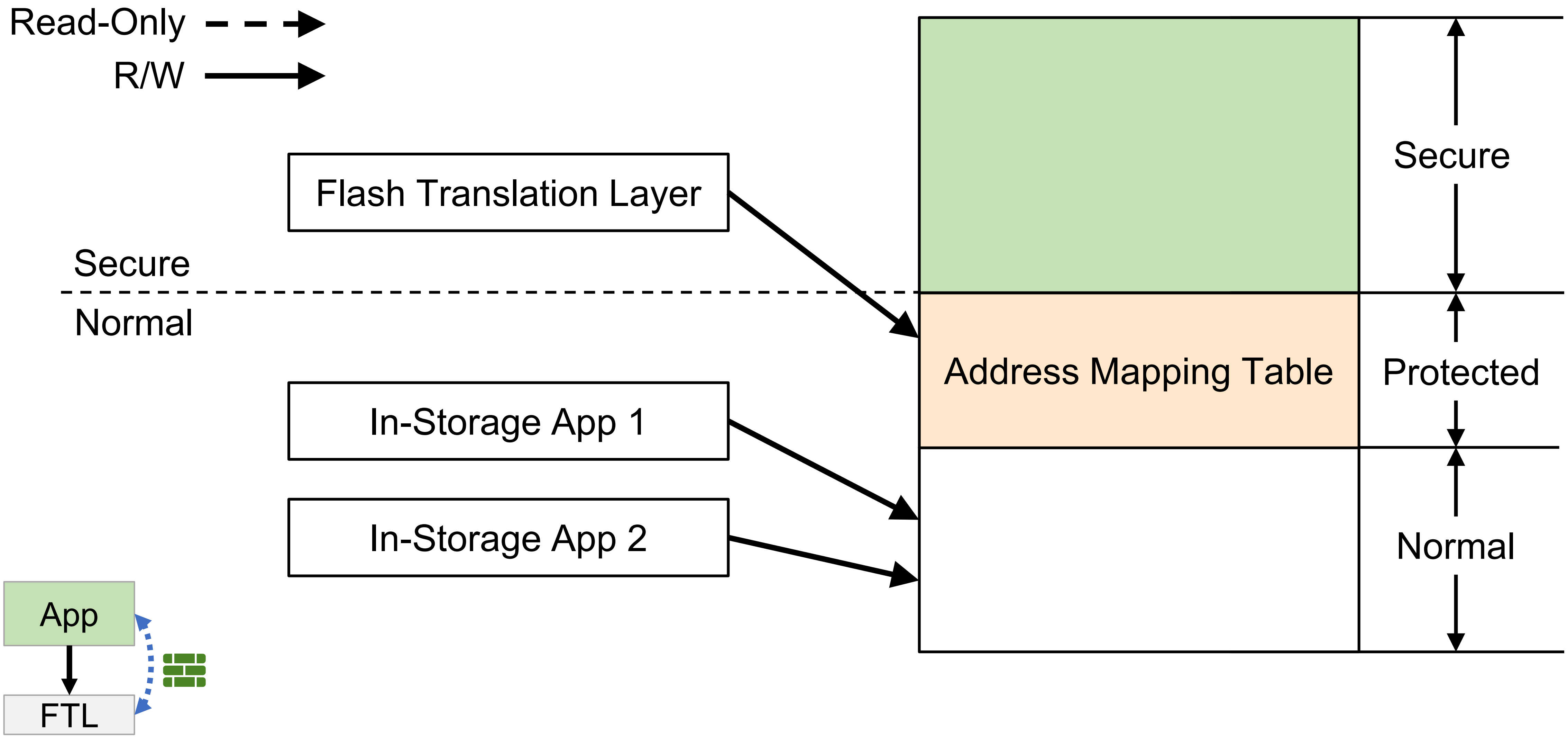

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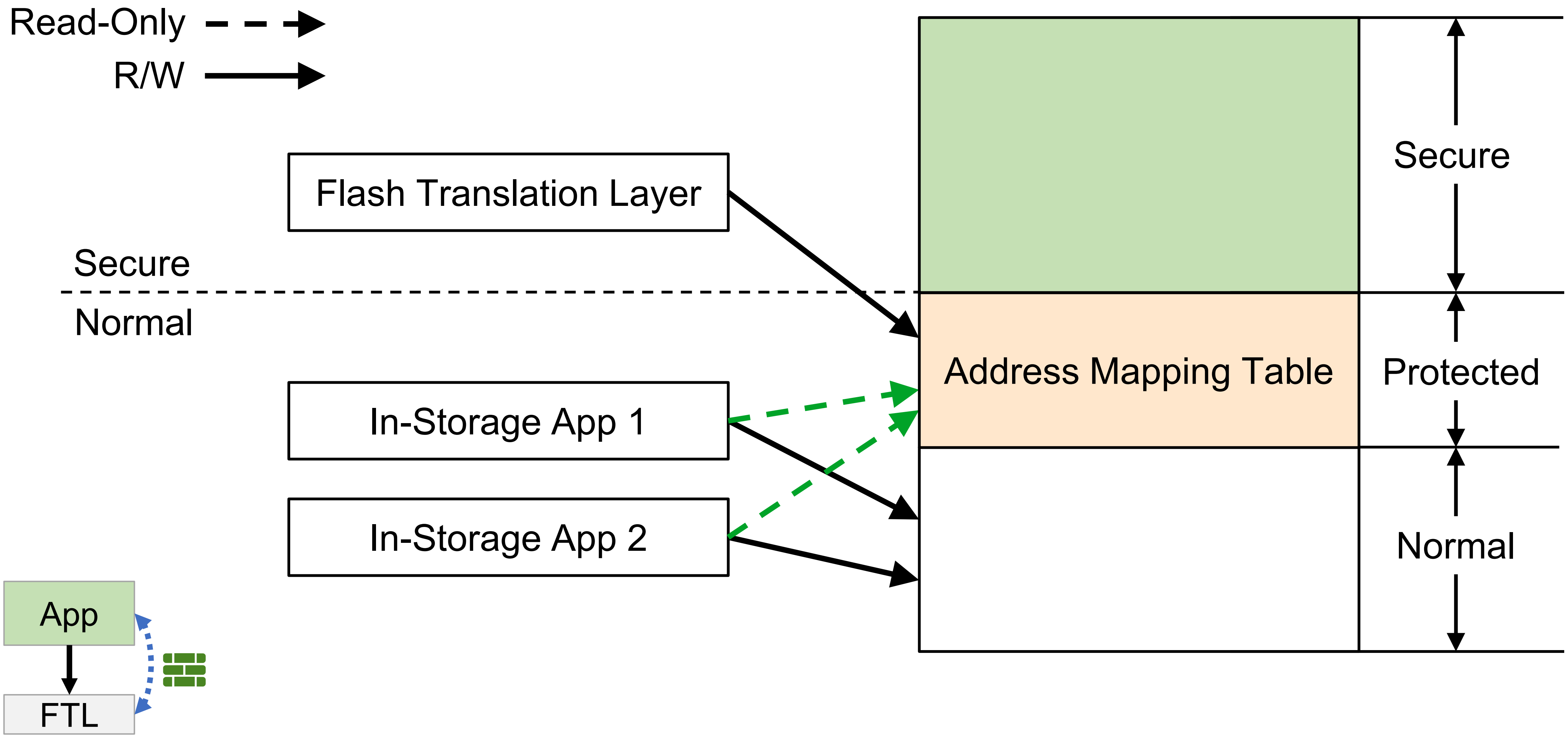
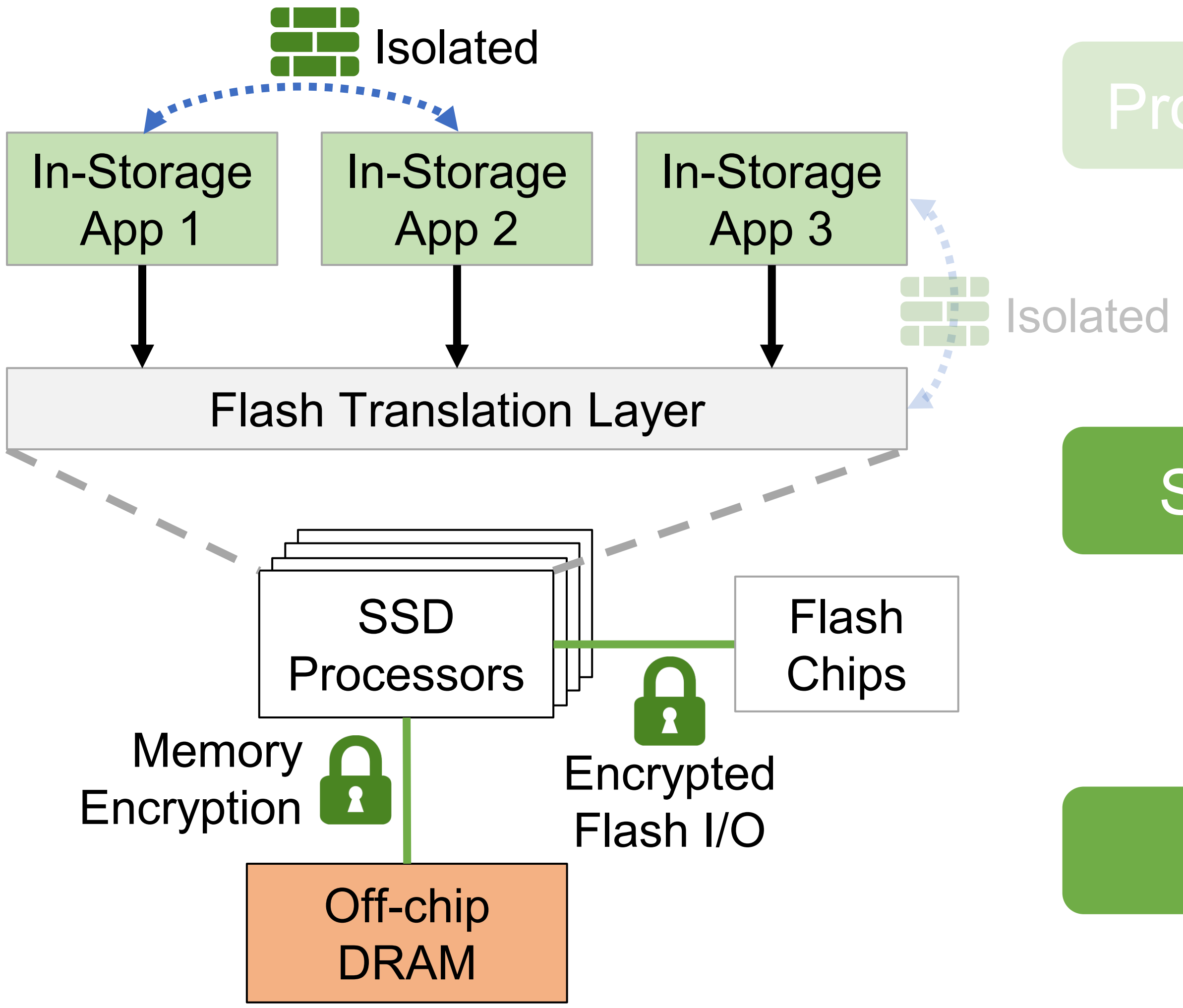


Isolating In-Storage Applications



Protecting FTL from malicious in-storage apps

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Security isolation between in-storage apps

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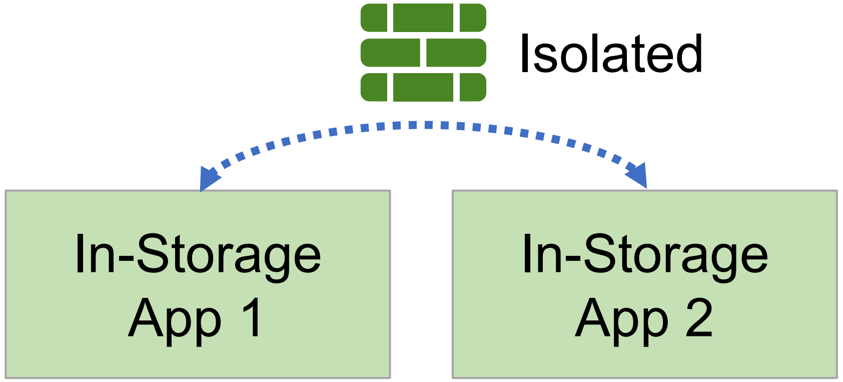
Securing data against physical attacks

Isolating In-Storage Applications



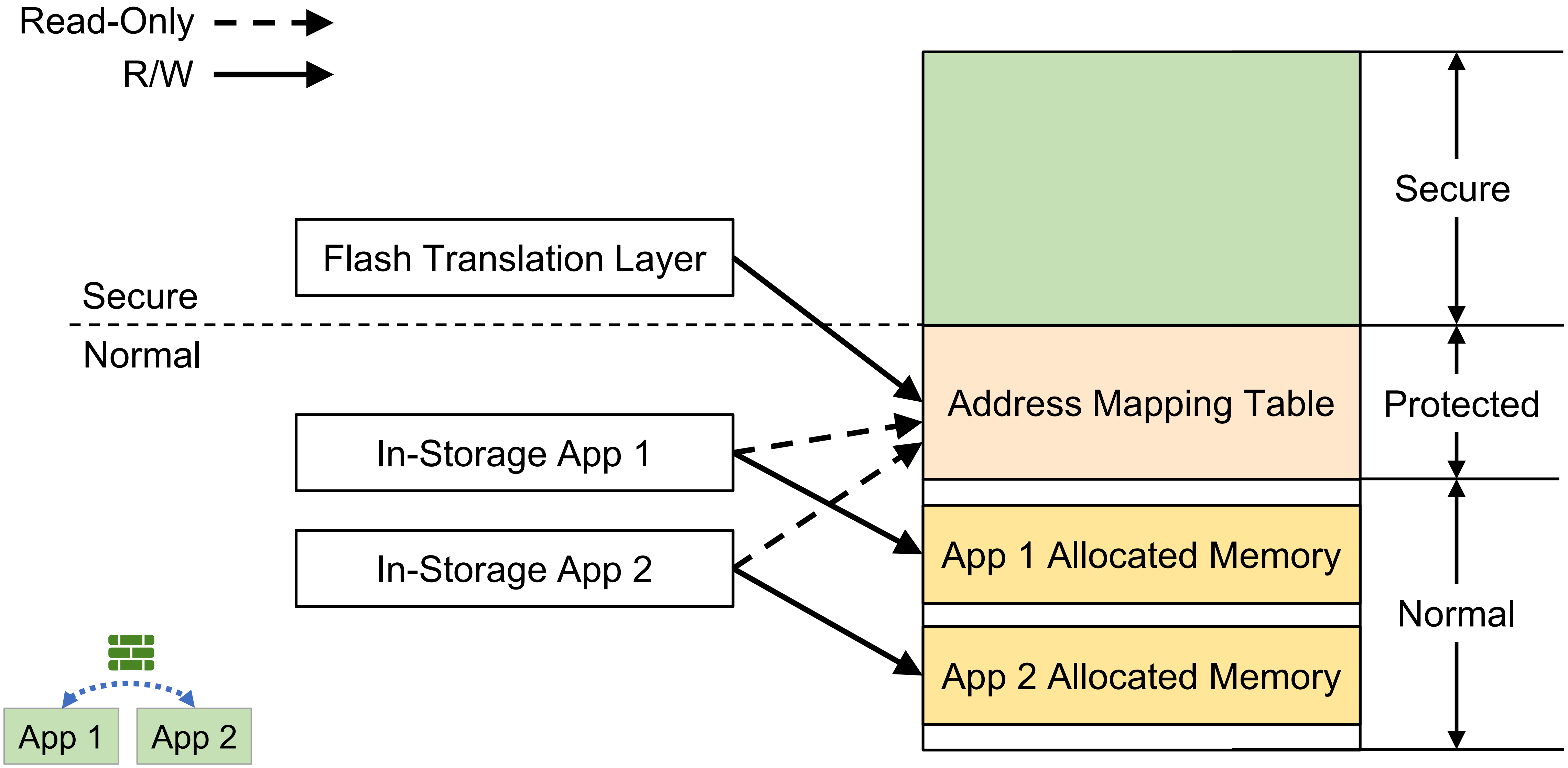
Isolated

In-Storage App 1

In-Storage App 2

Security isolation between in-storage apps

Isolating In-Storage Applications



Read-Only

R/W

Secure

Normal

Flash Translation Layer

In-Storage App 1

In-Storage App 2

Address Mapping Table

App 1 Allocated Memory

App 2 Allocated Memory

Secure

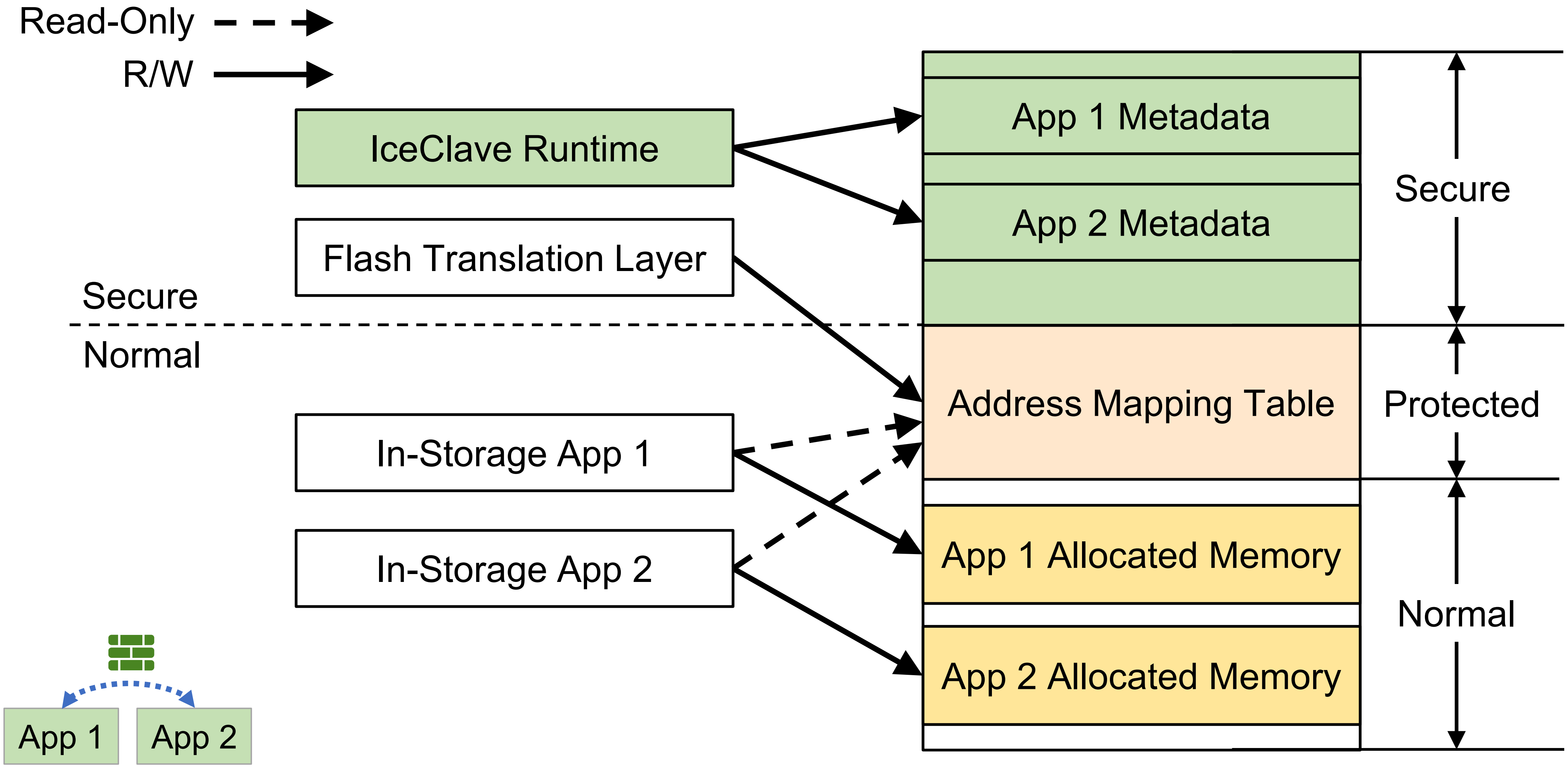
Protected

Normal

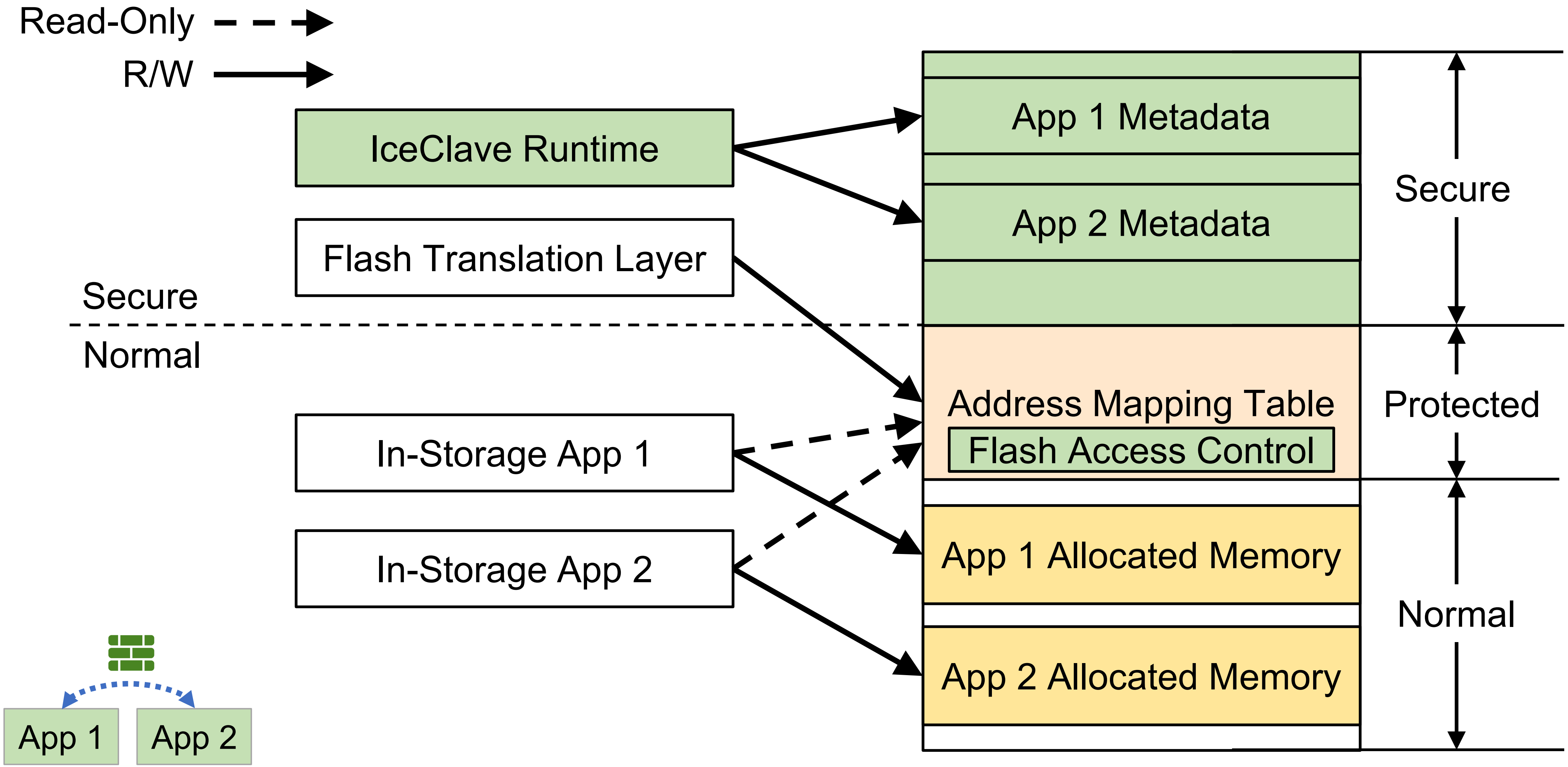
App 1

App 2

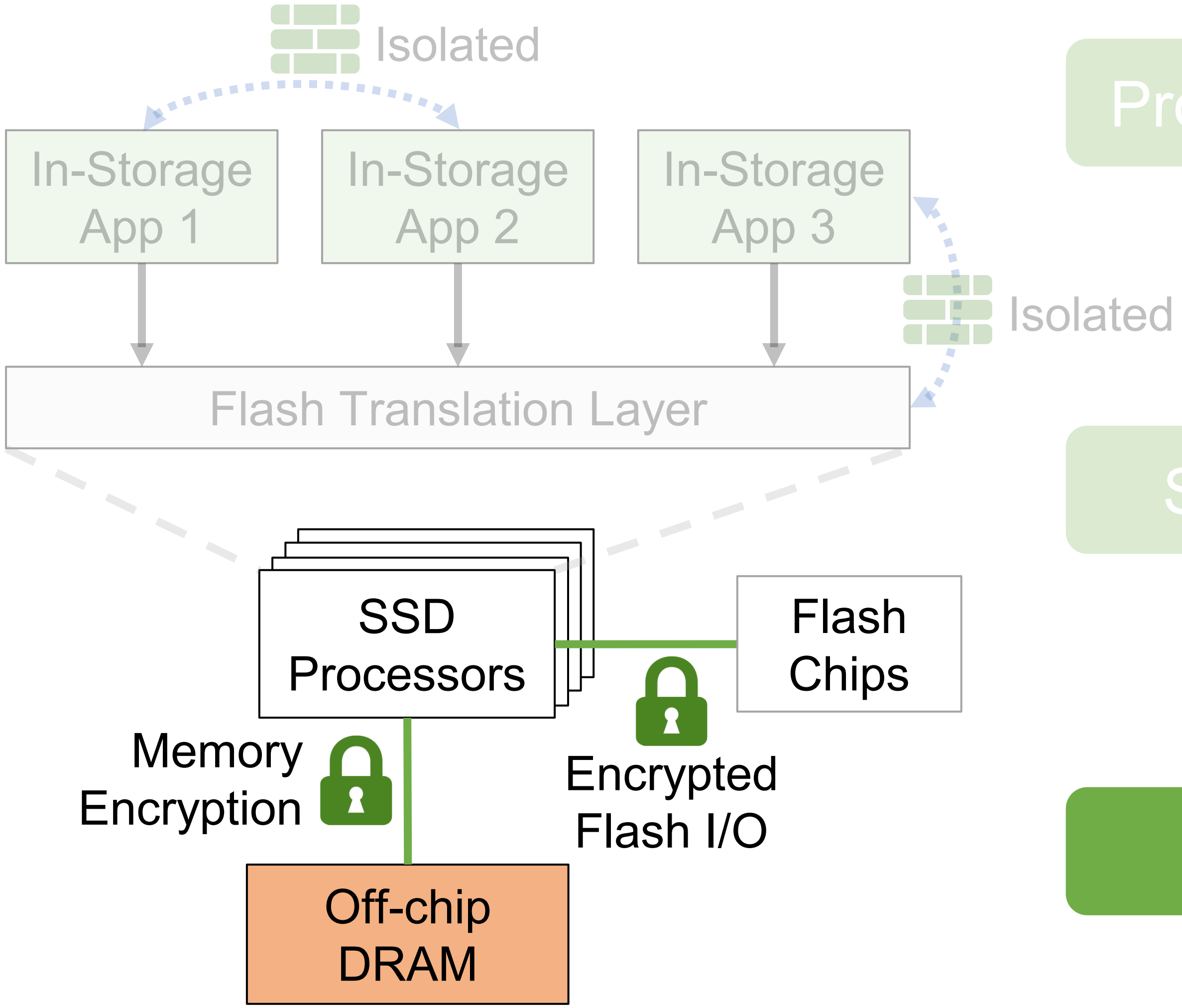
Isolating In-Storage Applications



Isolating In-Storage Applications



Protecting Against Physical Attacks



Protecting FTL from malicious in-storage apps

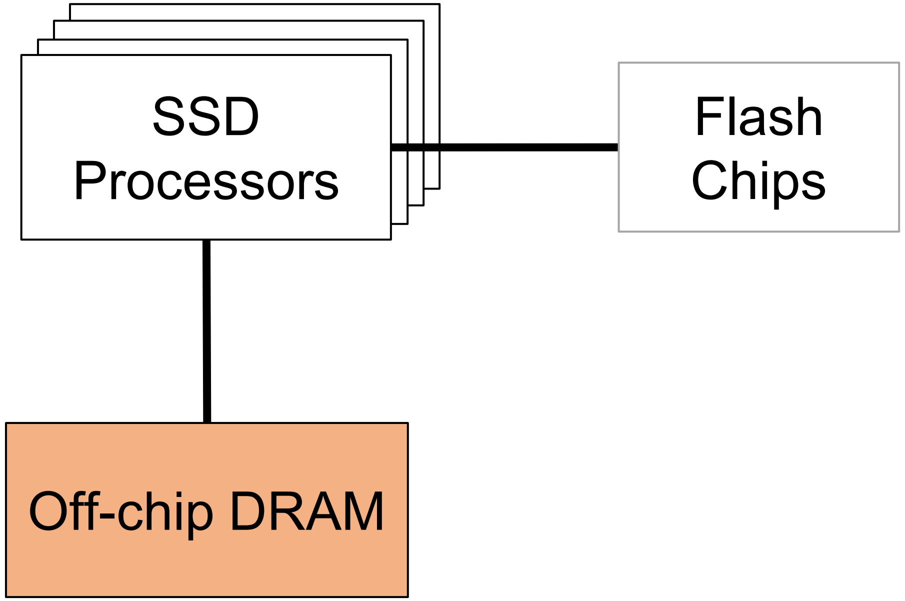
+

Security isolation between in-storage apps

+

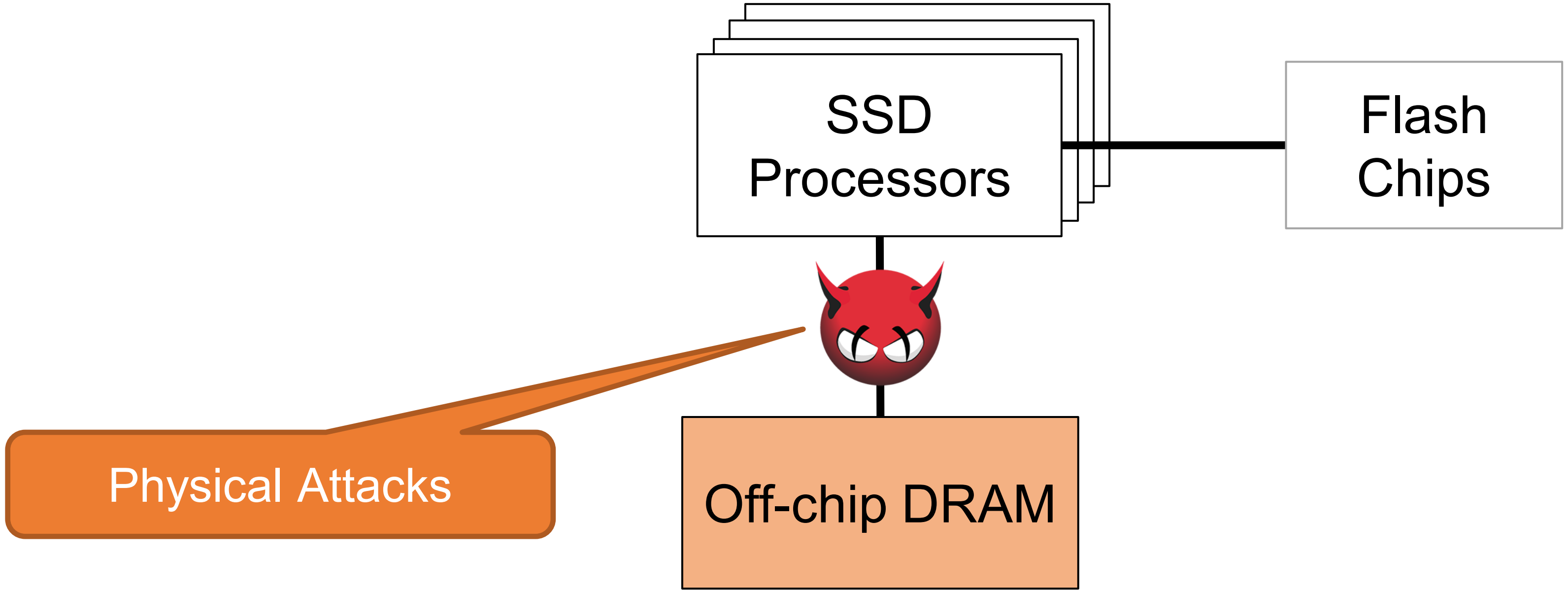
Securing data against physical attacks

Protecting Against Physical Attacks



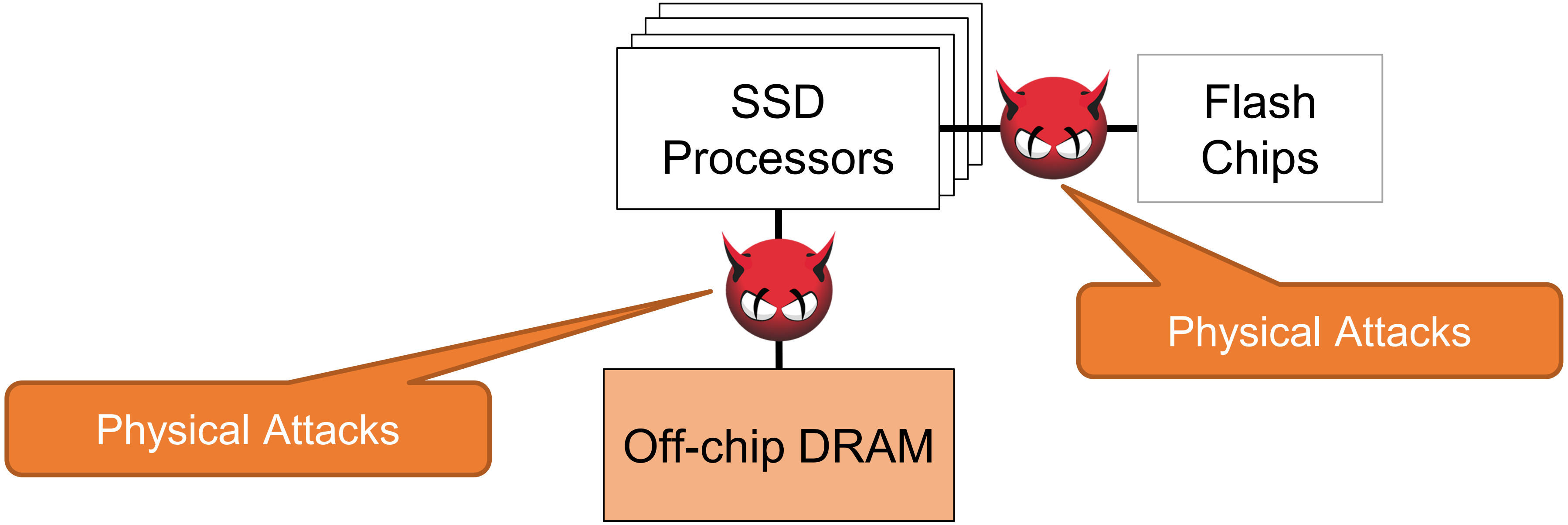
Securing data against physical attacks

Protecting Against Physical Attacks



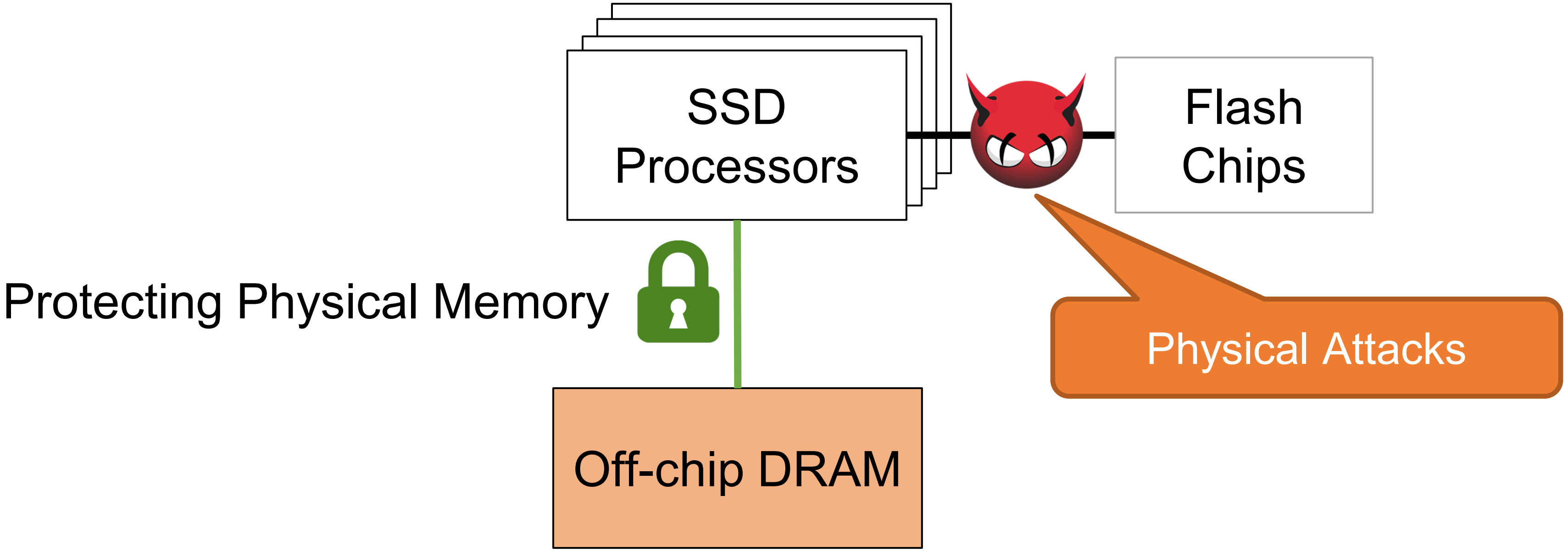
Securing data against physical attacks

Protecting Against Physical Attacks



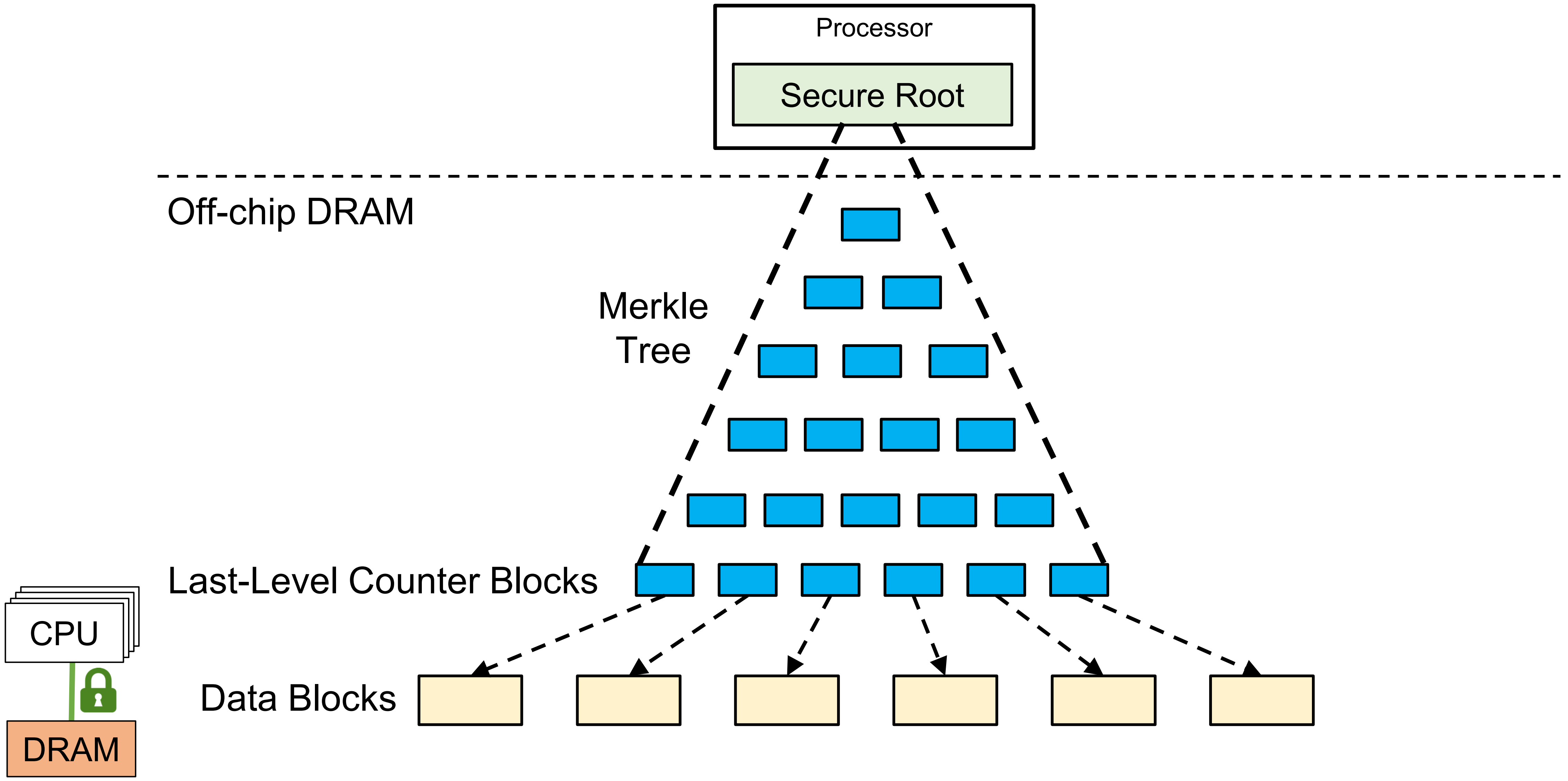
Securing data against physical attacks

Protecting Against Physical Attacks

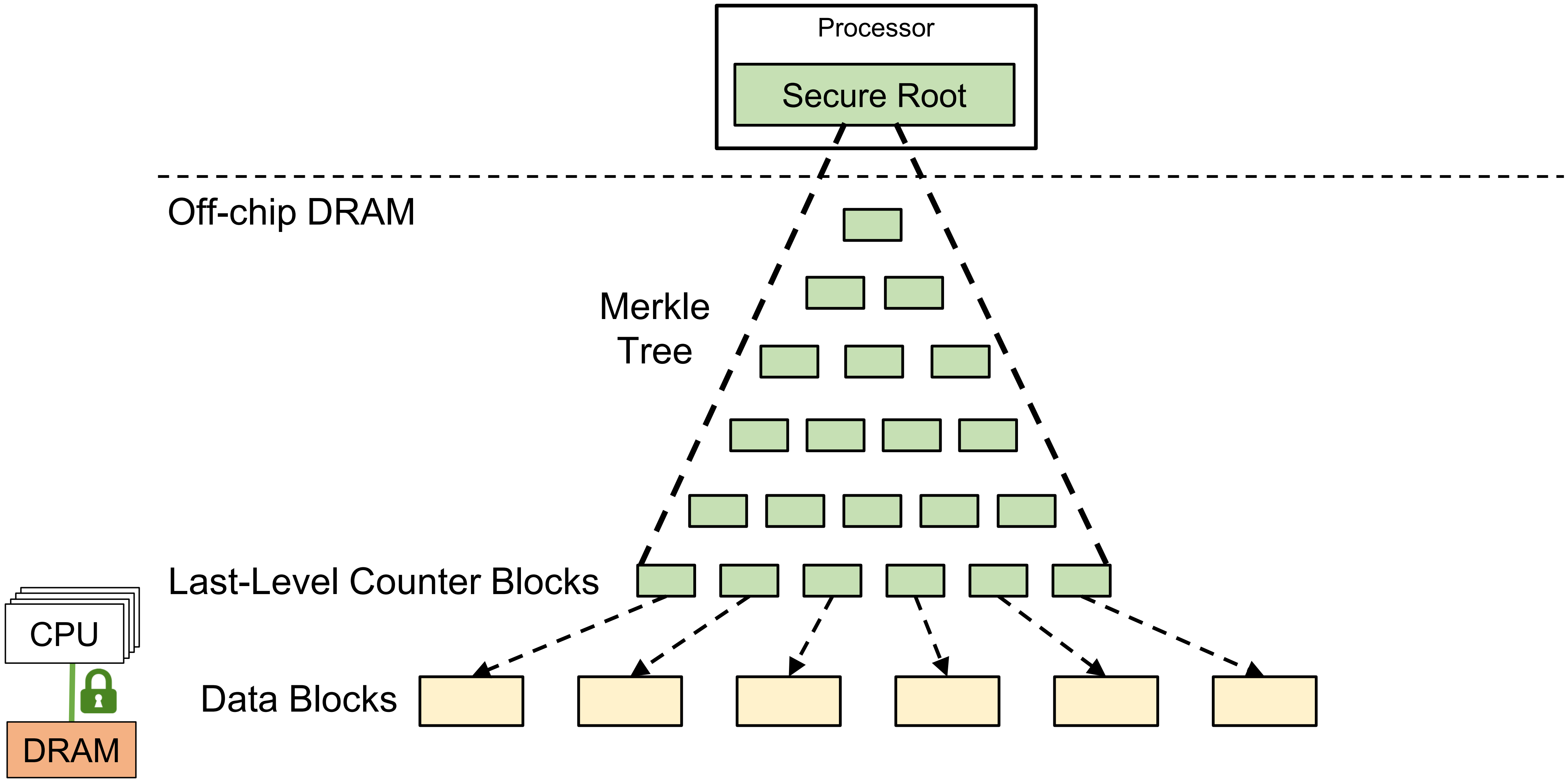


Securing data against physical attacks

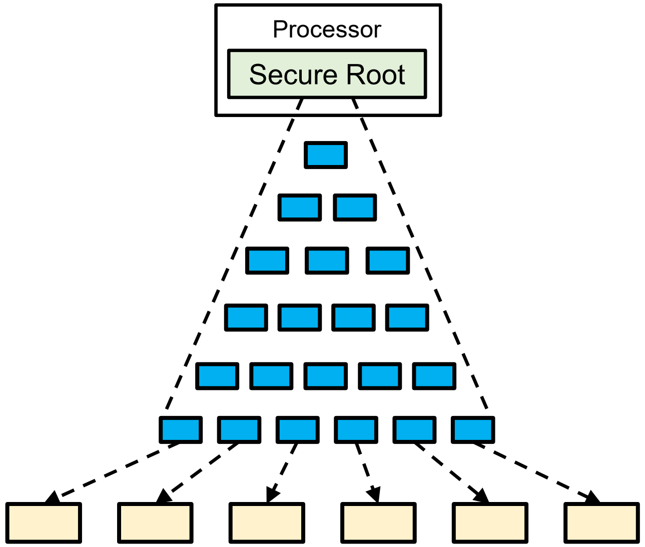
Protecting Physical Memory

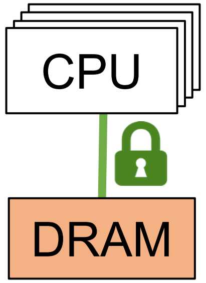


Protecting Physical Memory

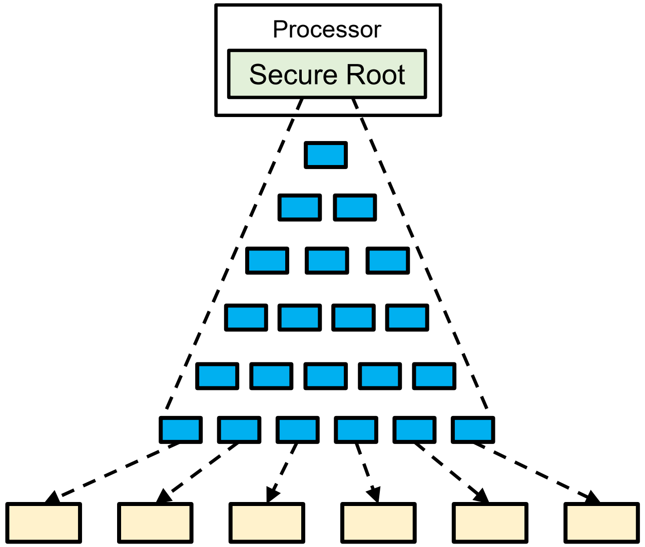


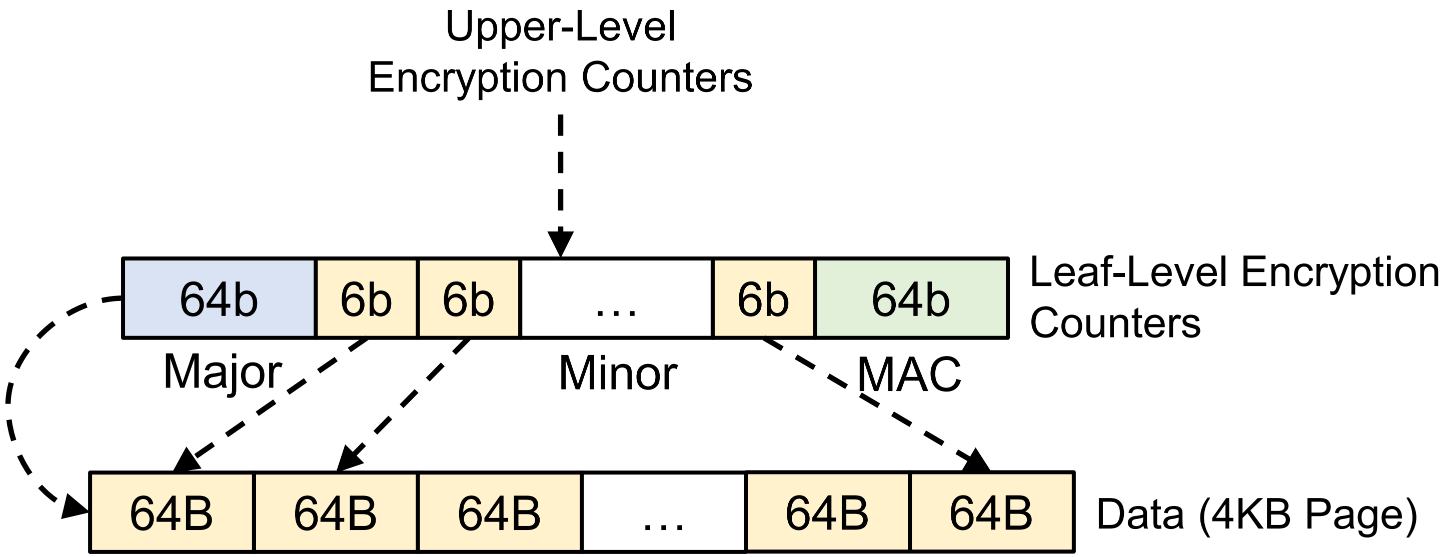
Protecting Physical Memory



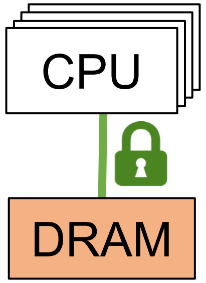


Protecting Physical Memory

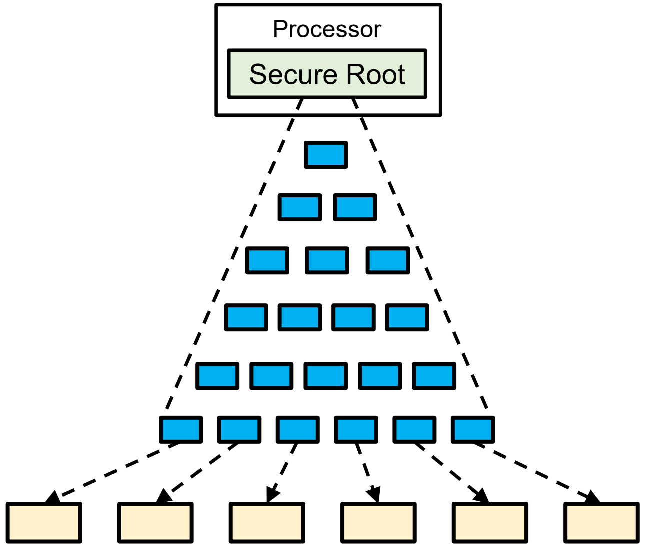


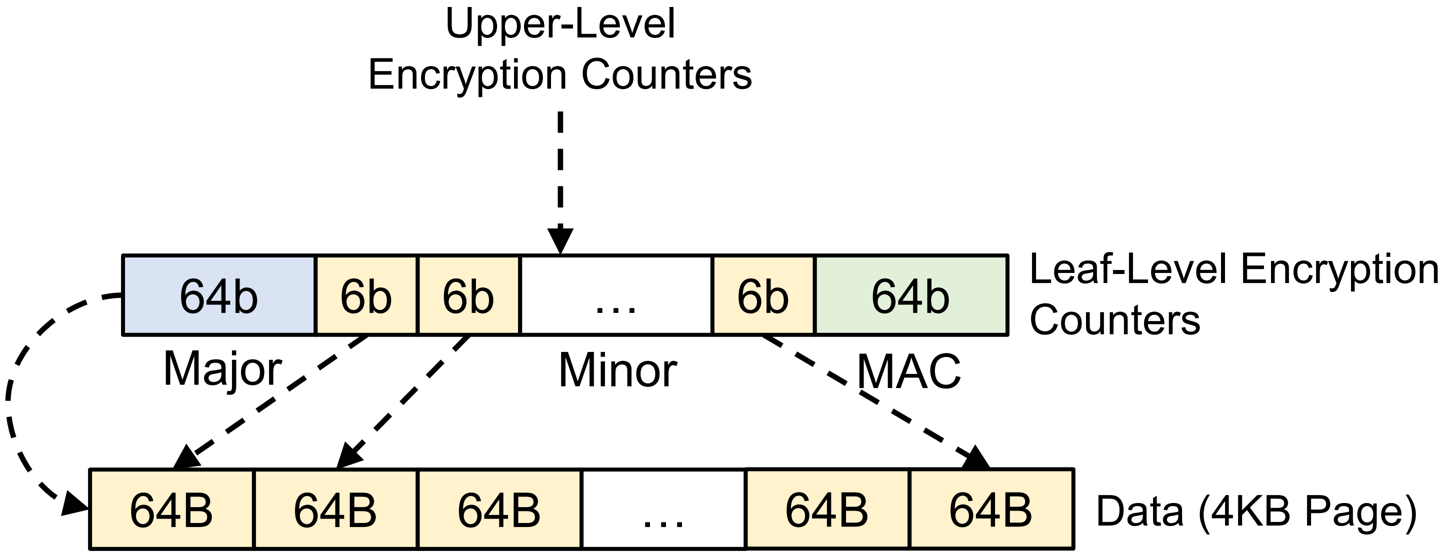


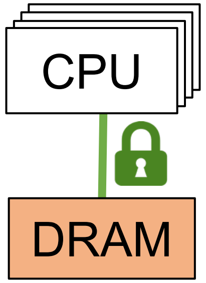
Split Counter Mode (ISCA’06)



Protecting Physical Memory

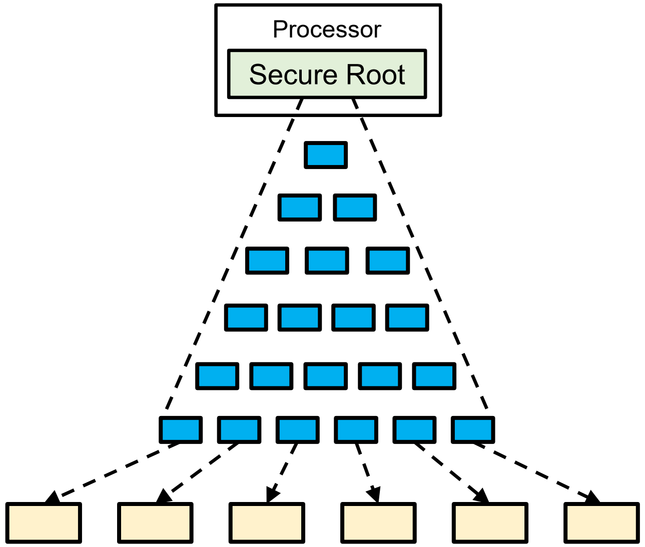


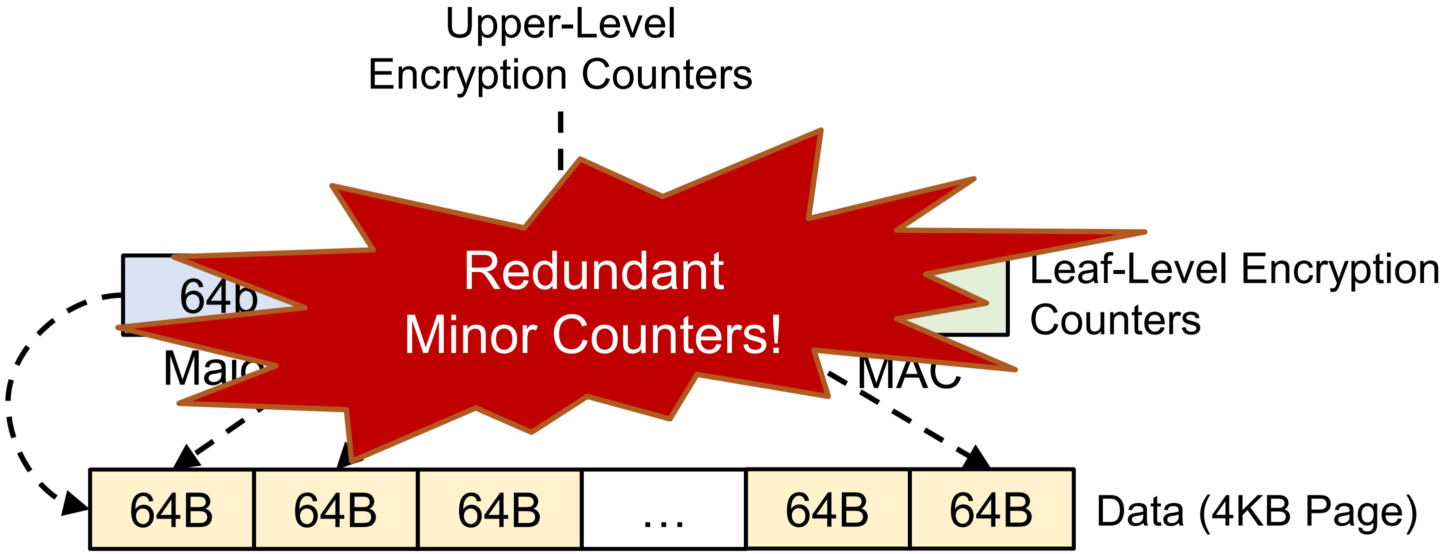




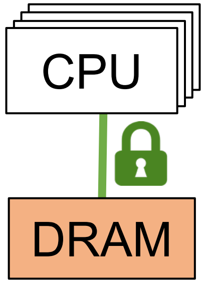
In-storage programs are read-intensive

Protecting Physical Memory



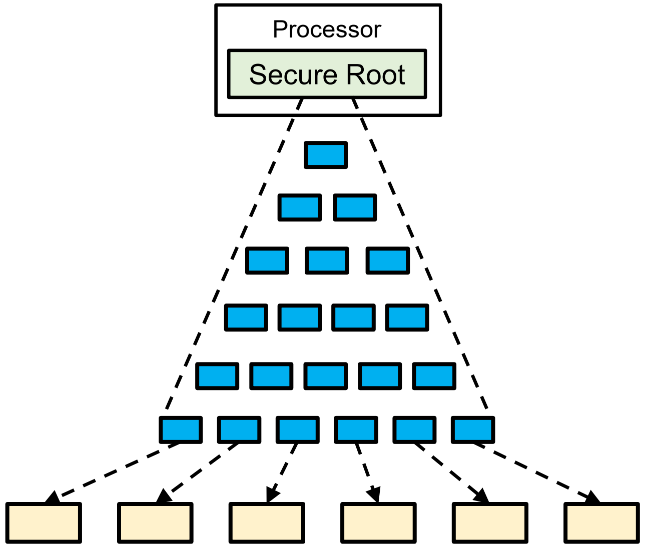


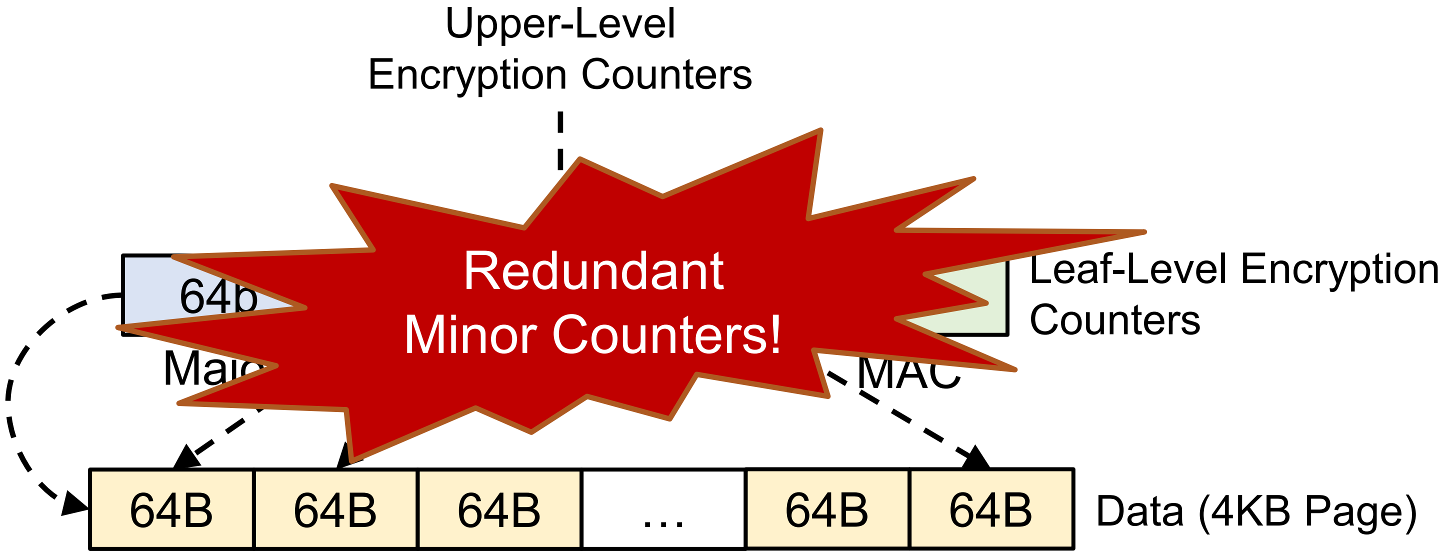
Redundant
Minor Counters!

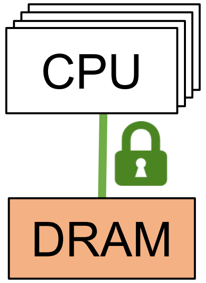


In-storage programs are read-intensive

Protecting Physical Memory



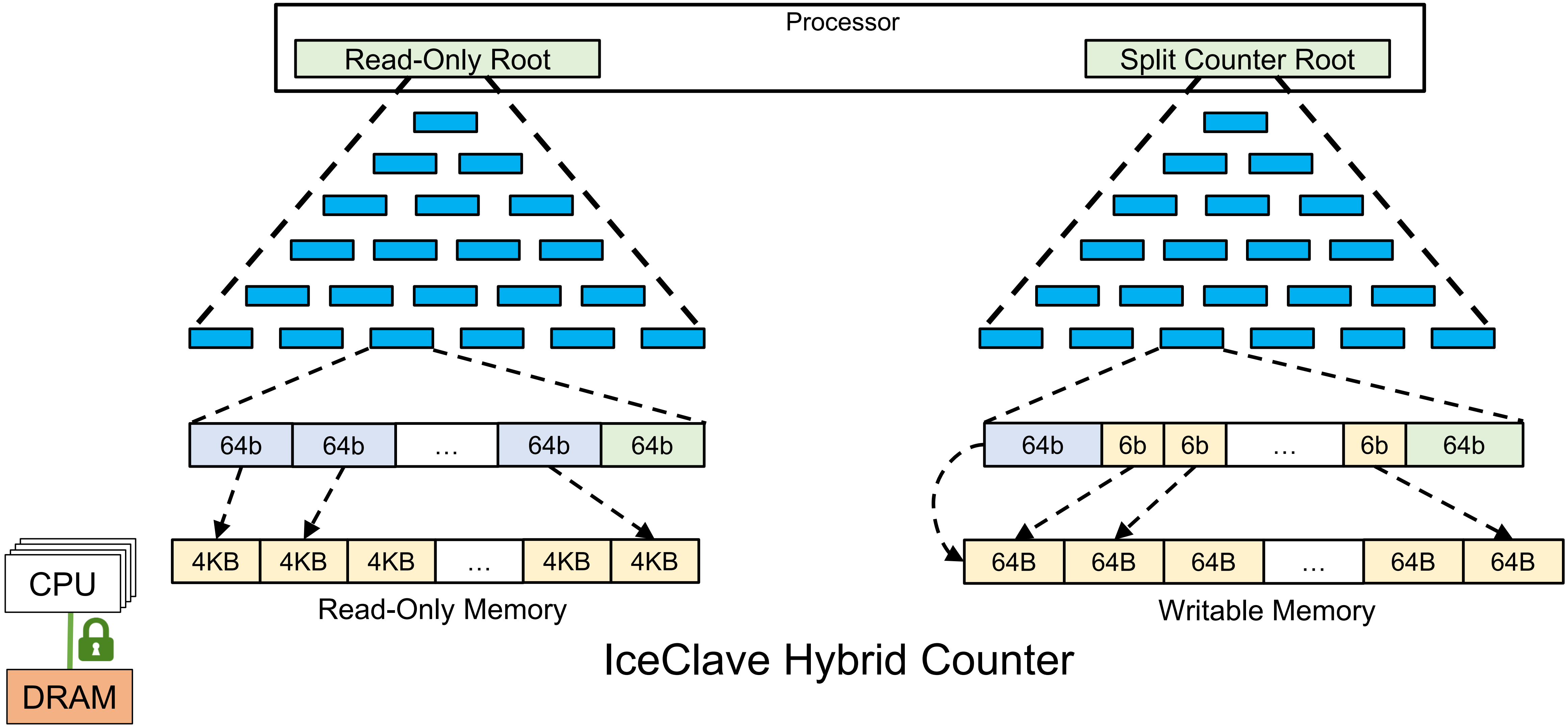




In-storage programs are read-intensive

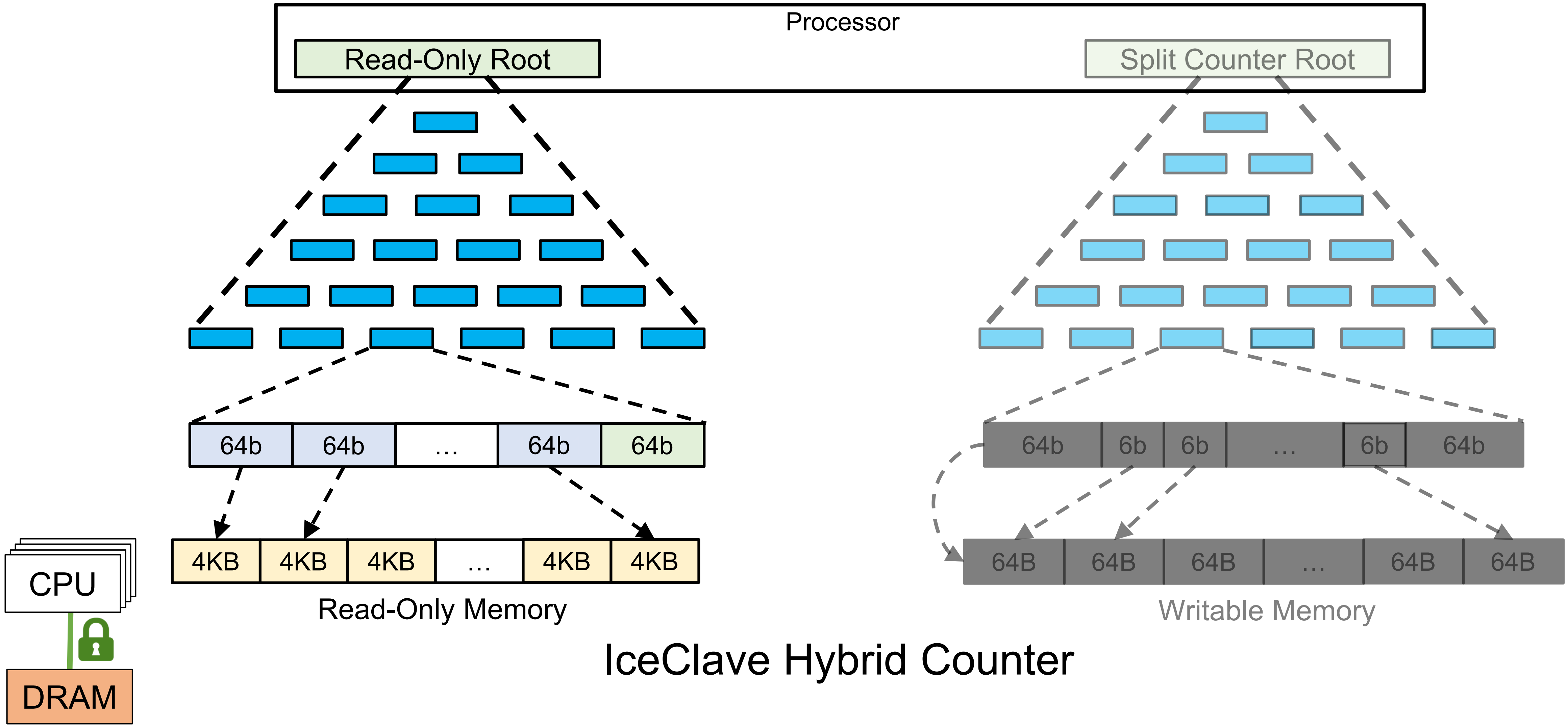
State-of-the-art Split Counter is not optimal for in-storage computing

Protecting Physical Memory



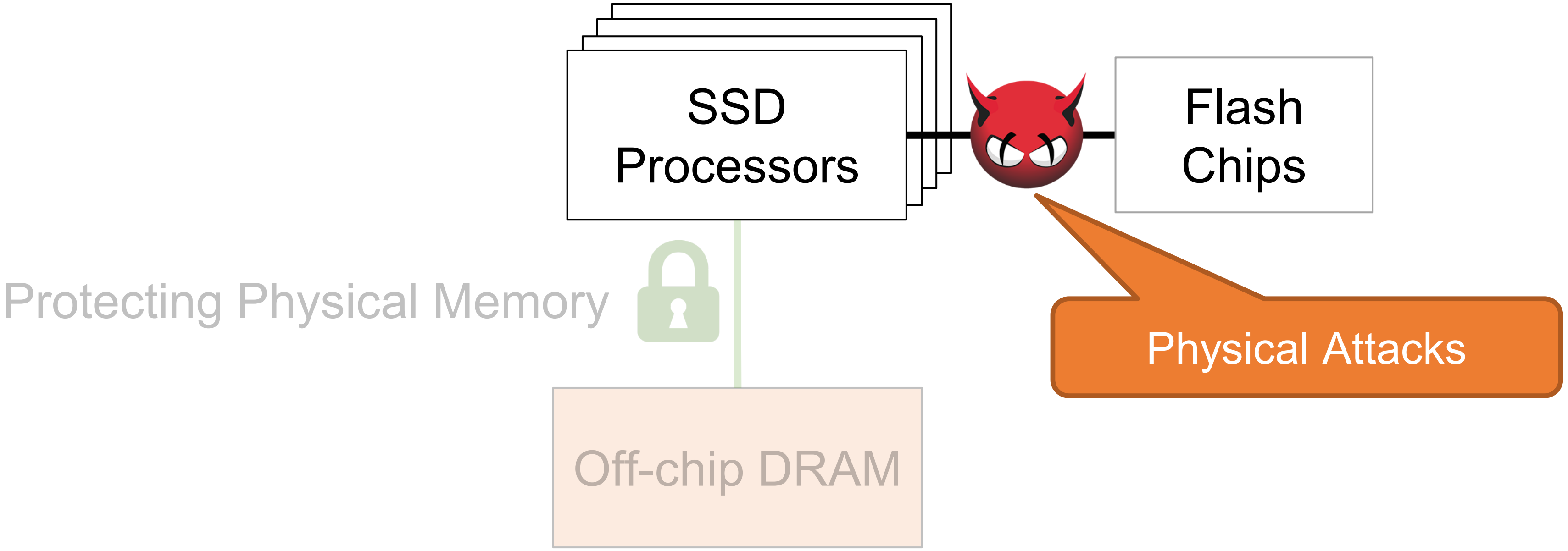
IceClave Hybrid Counter

Protecting Physical Memory



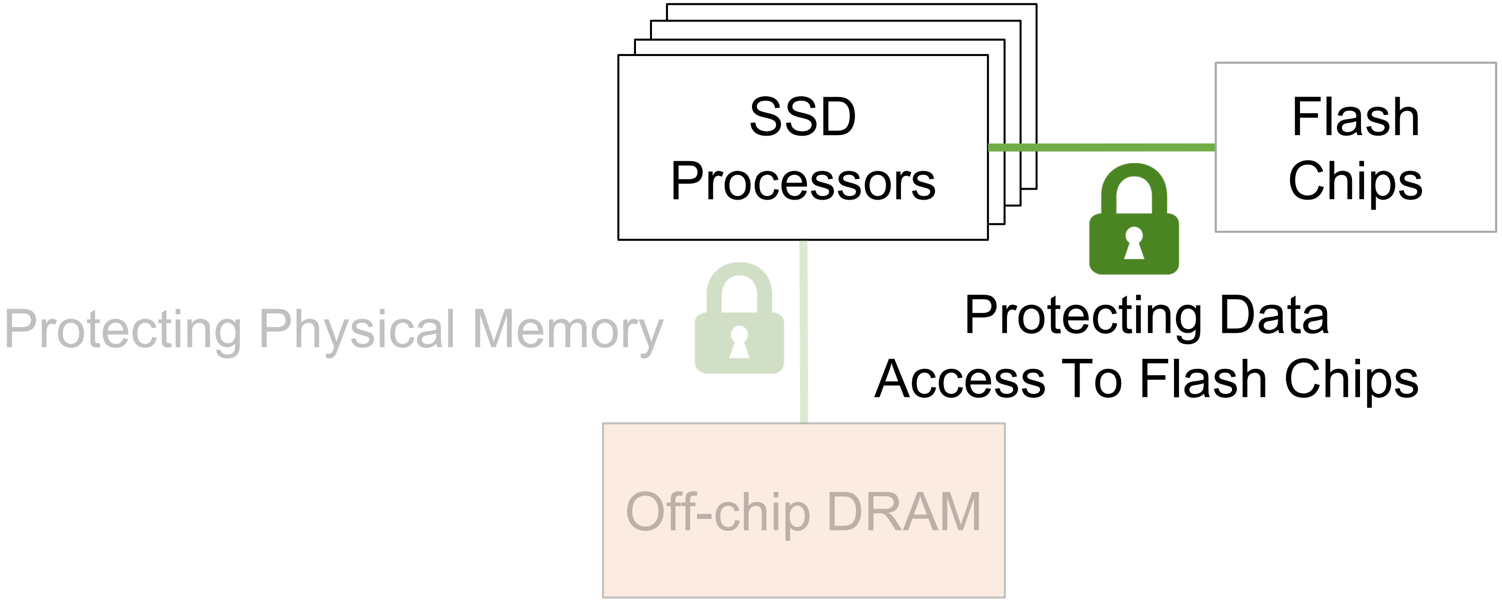
IceClave Hybrid Counter

Protecting Against Physical Attacks



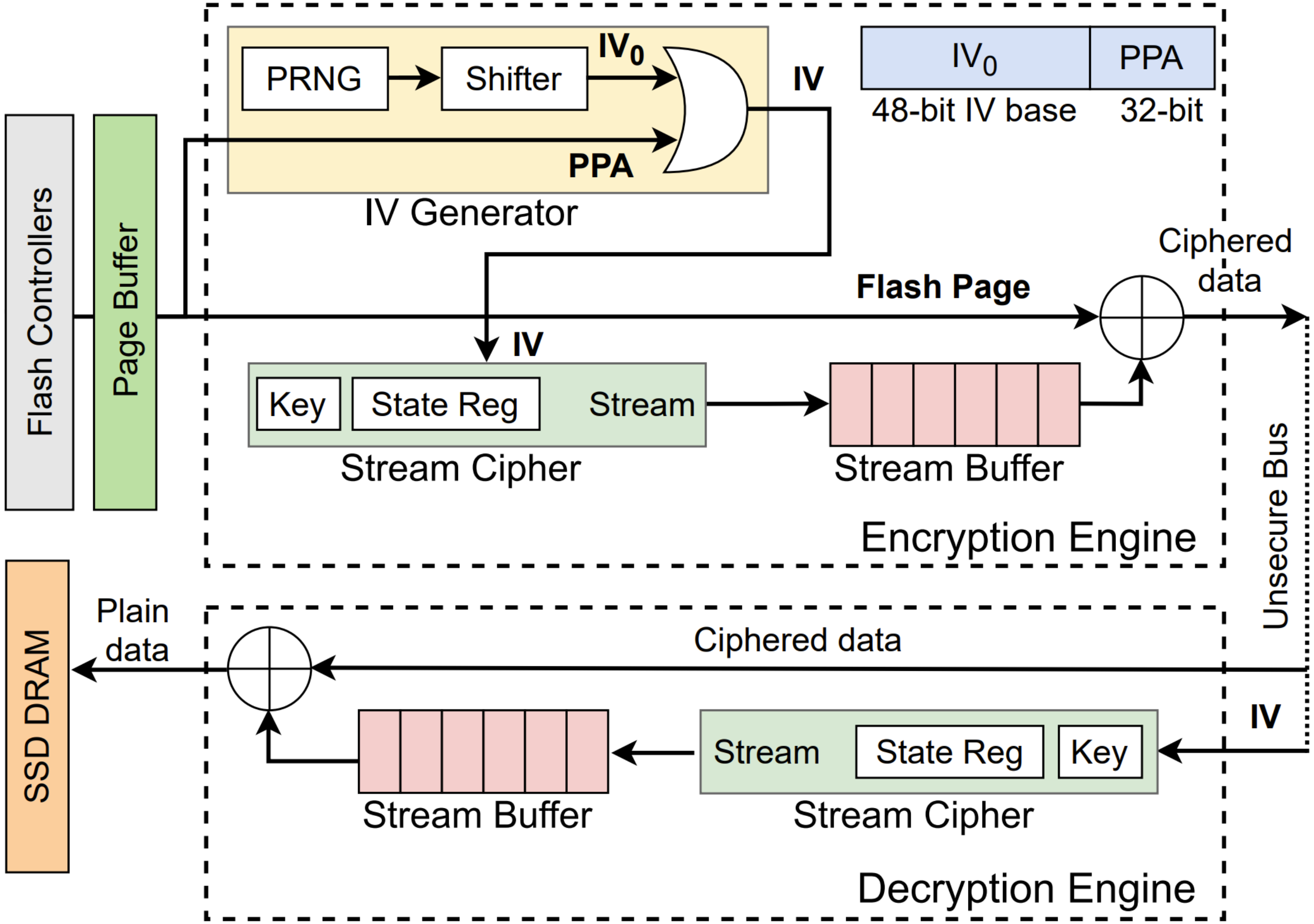
Securing data against physical attacks

Protecting Against Physical Attacks


SSD Processors
Flash Chips
Protecting Data Access To Flash Chips
Protecting Physical Memory
Off-chip DRAM

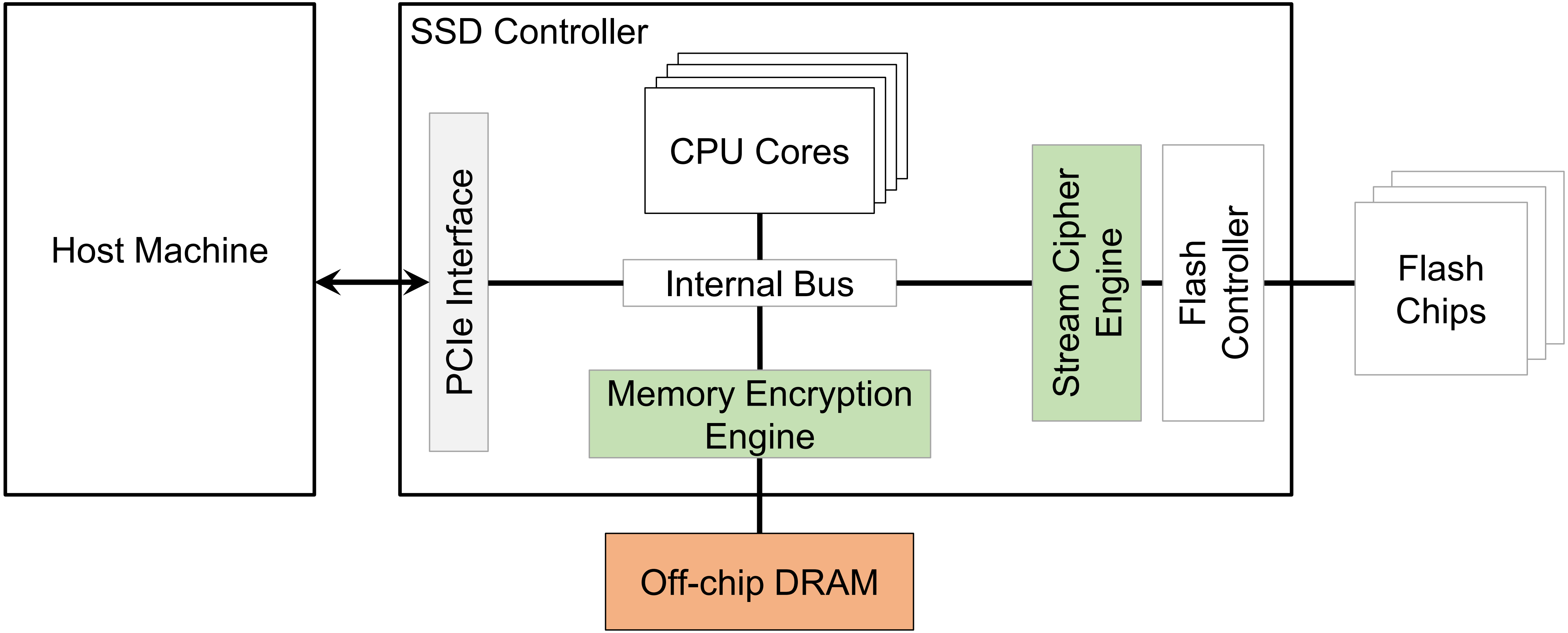
Securing data against physical attacks

Protecting Data Access To Flash Chips

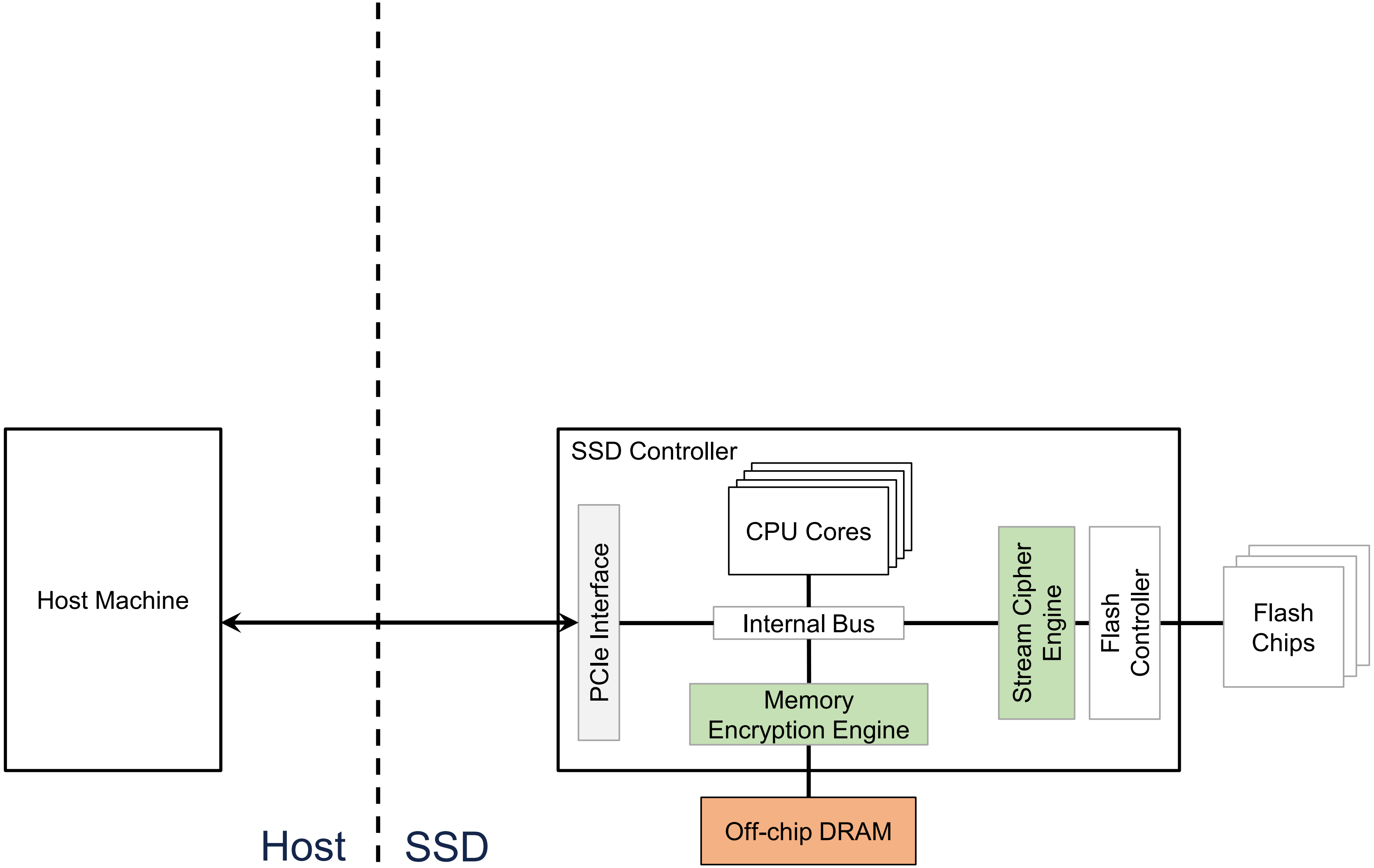


CPU
Flash Chips

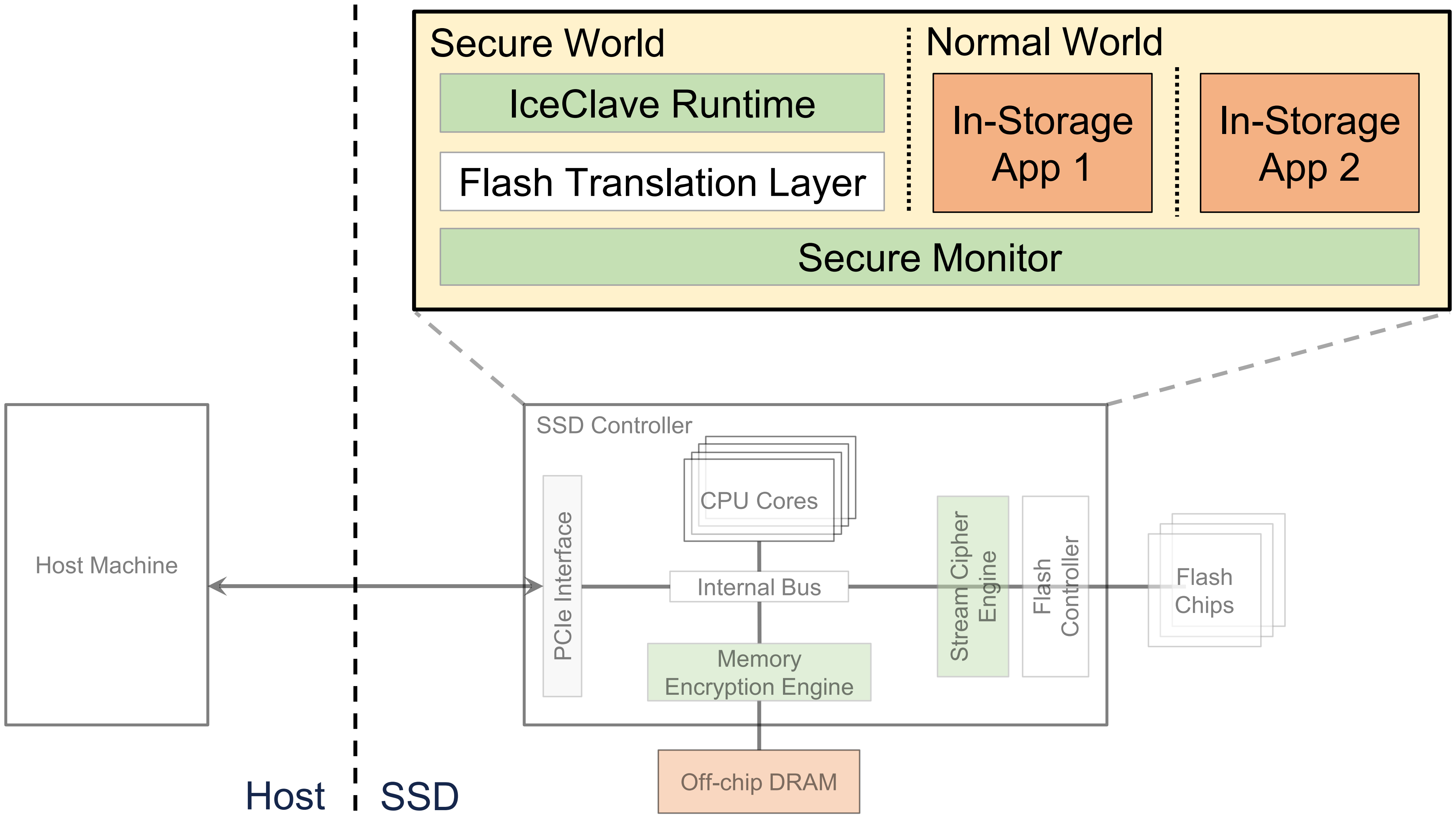
Put It All Together



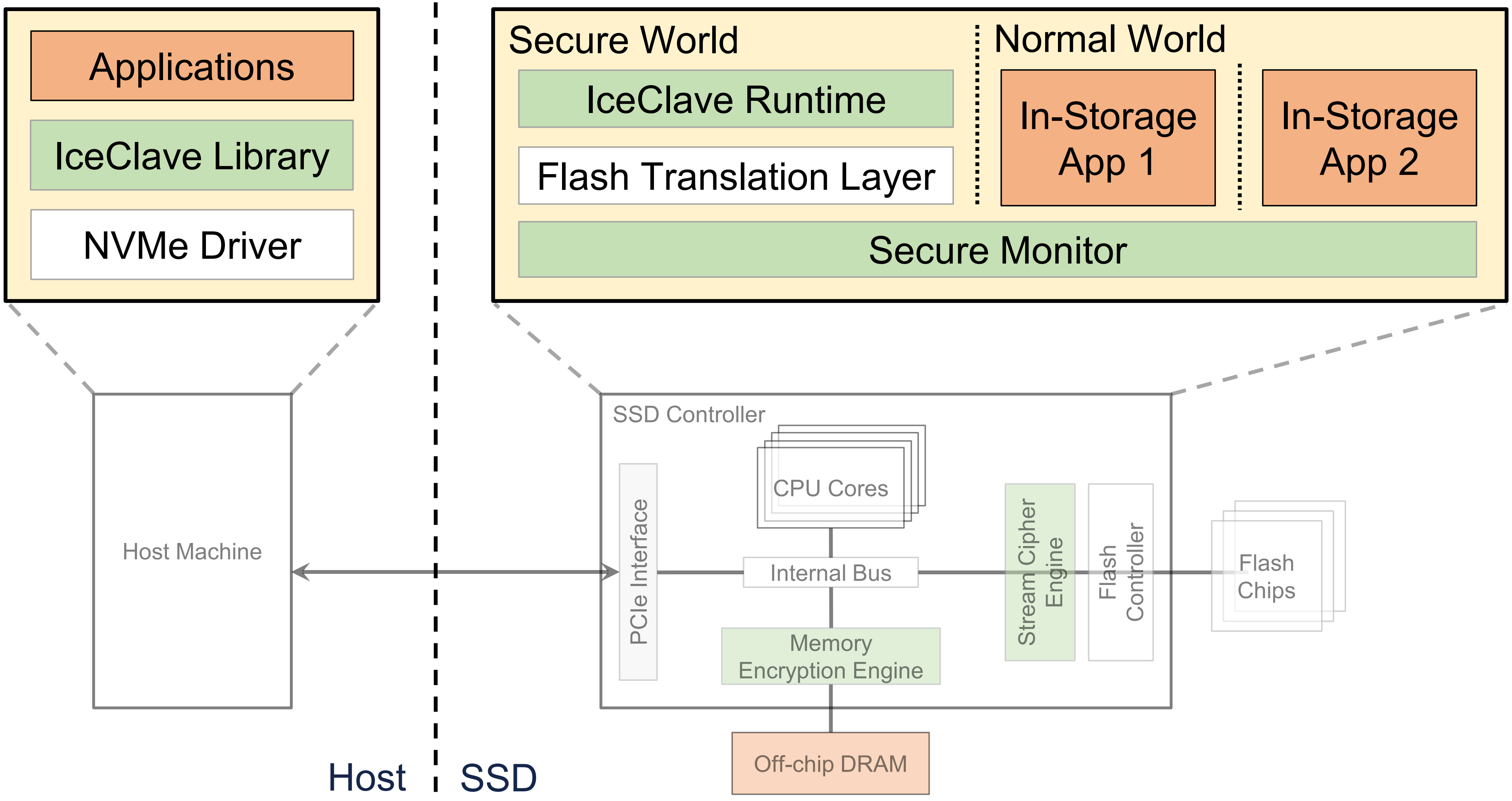
Put It All Together



Put It All Together



Put It All Together



IceClave Implementation

Simulator	gem5 + USIMM + SimpleSSD
Prototype	OpenSSD Cosmos+ FPGA

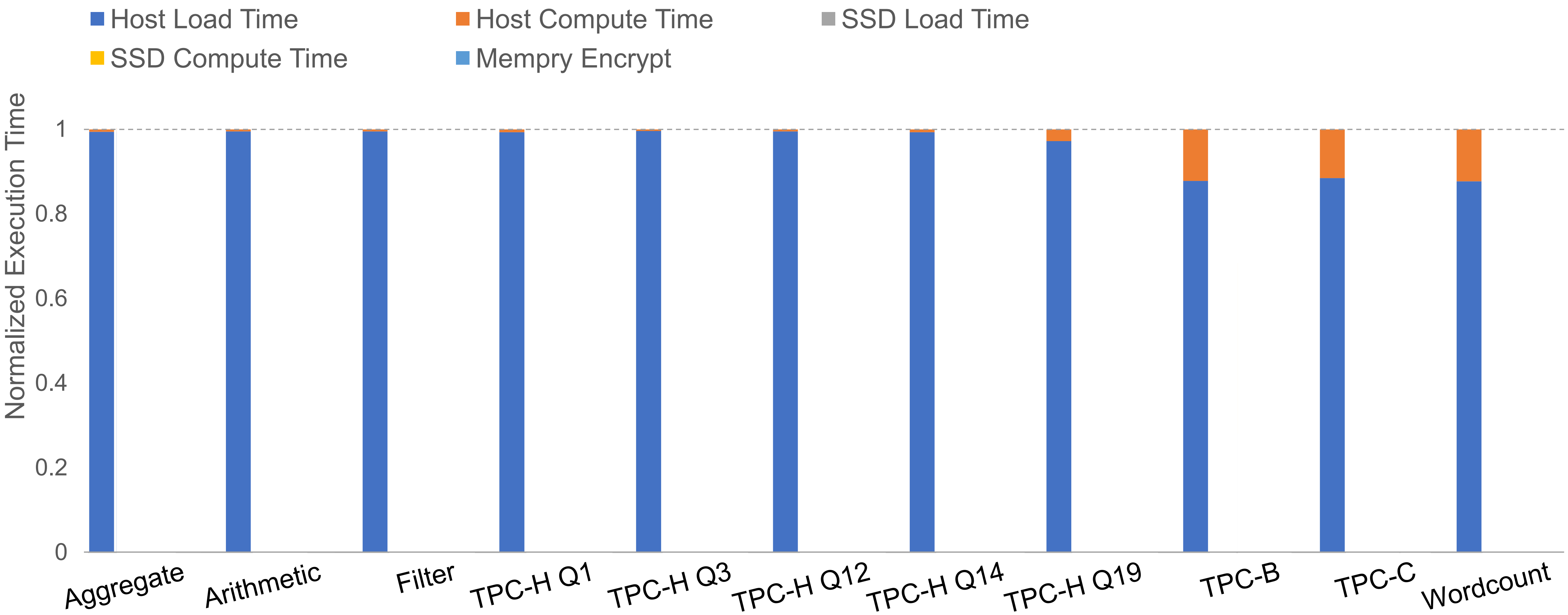
Experimental Setup

Synthetic Workloads	Arithmetic, Aggregate, Filter, Wordcount
Real-world Workloads	TPC-H, TPC-B, TPC-C

IceClave Overall Performance

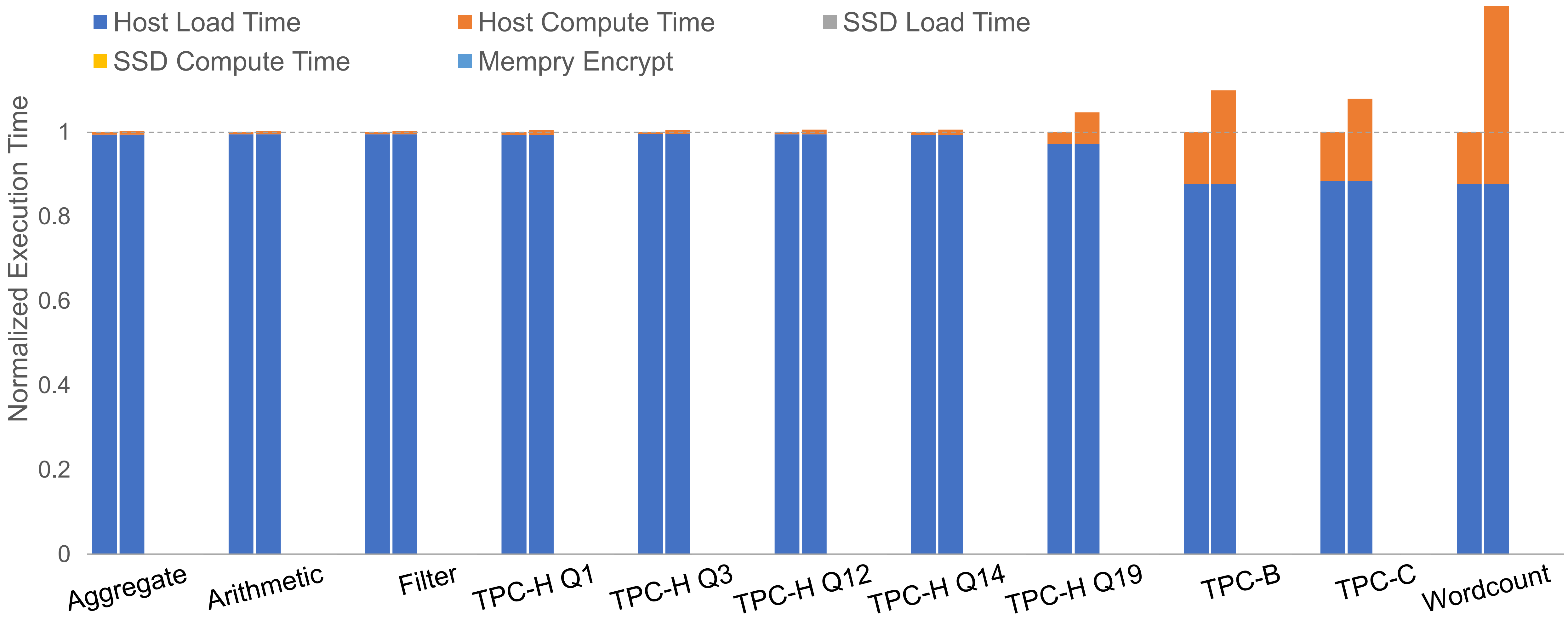
Left to Right:

IceClave Overall Performance



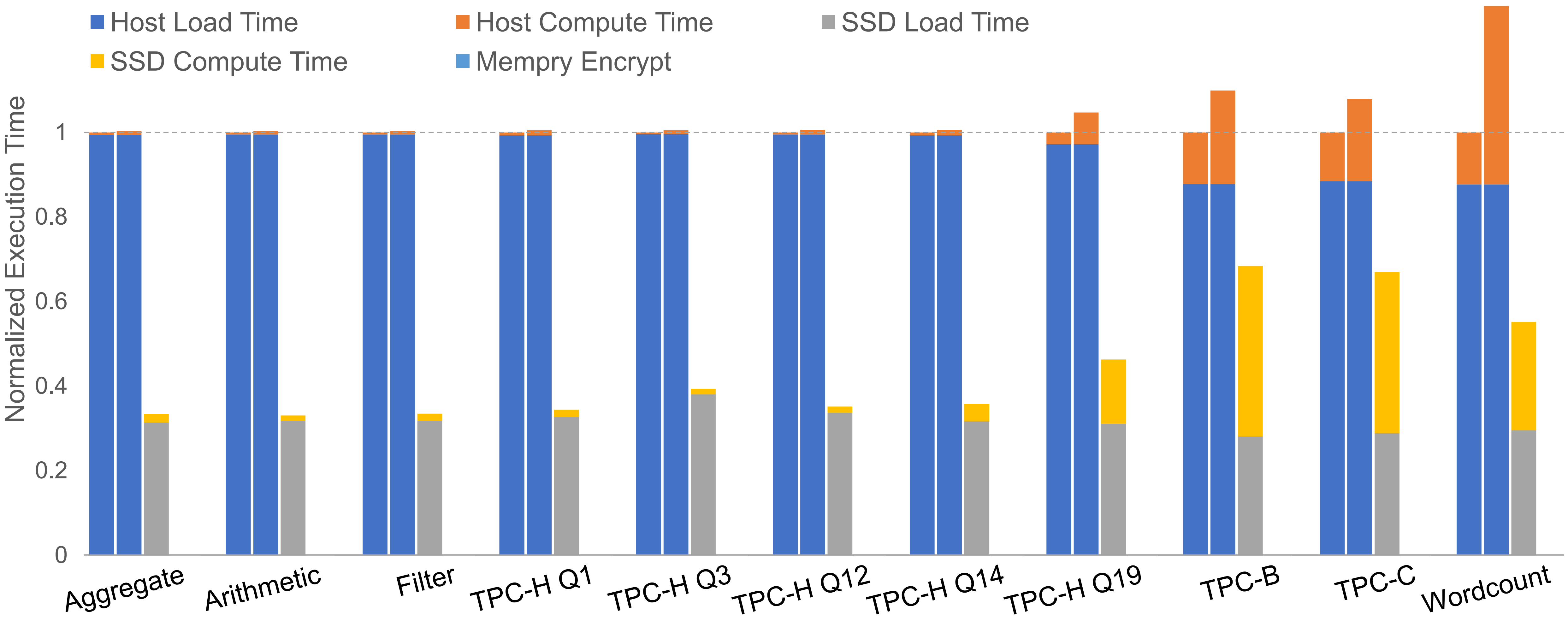
Left to Right: **Host**

IceClave Overall Performance



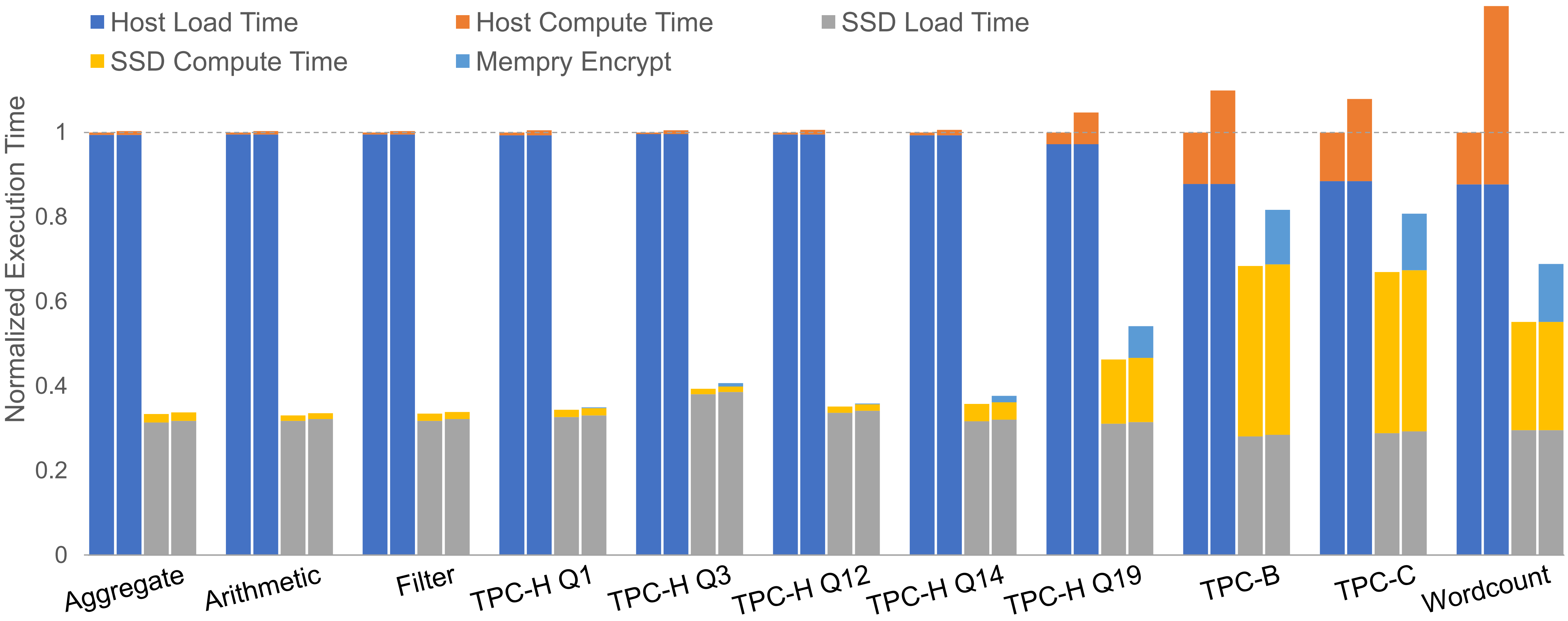
Left to Right: **Host** **Host+SGX**

IceClave Overall Performance



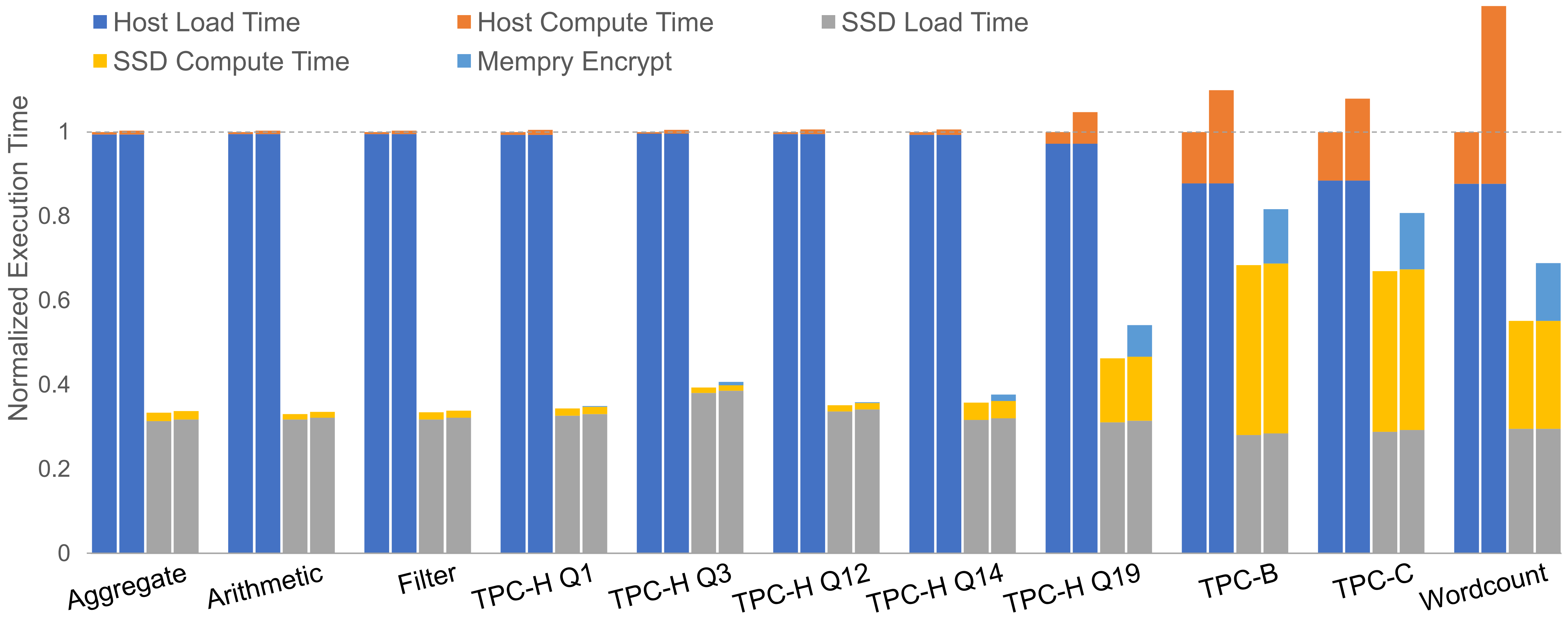
Left to Right: **Host** **Host+SGX** **ISC**

IceClave Overall Performance



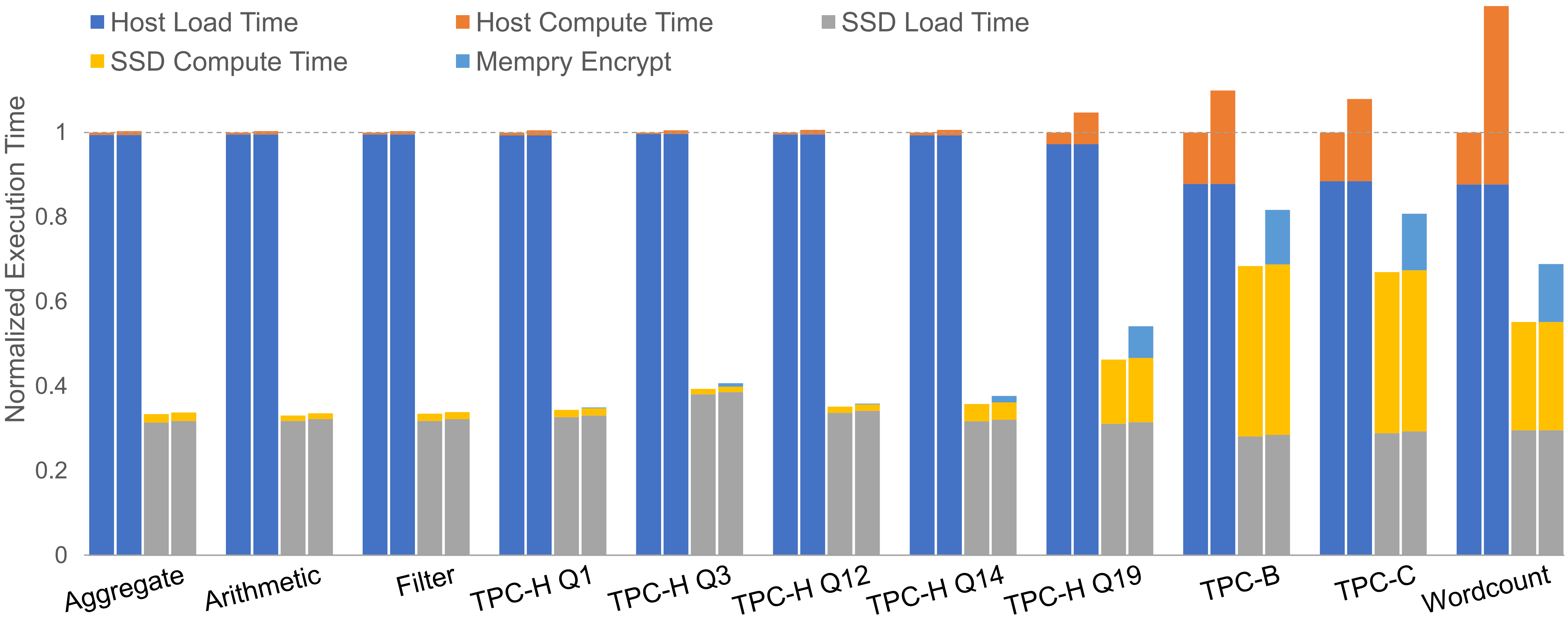
Left to Right: **Host** **Host+SGX** **ISC** **IceClave**

IceClave Overall Performance



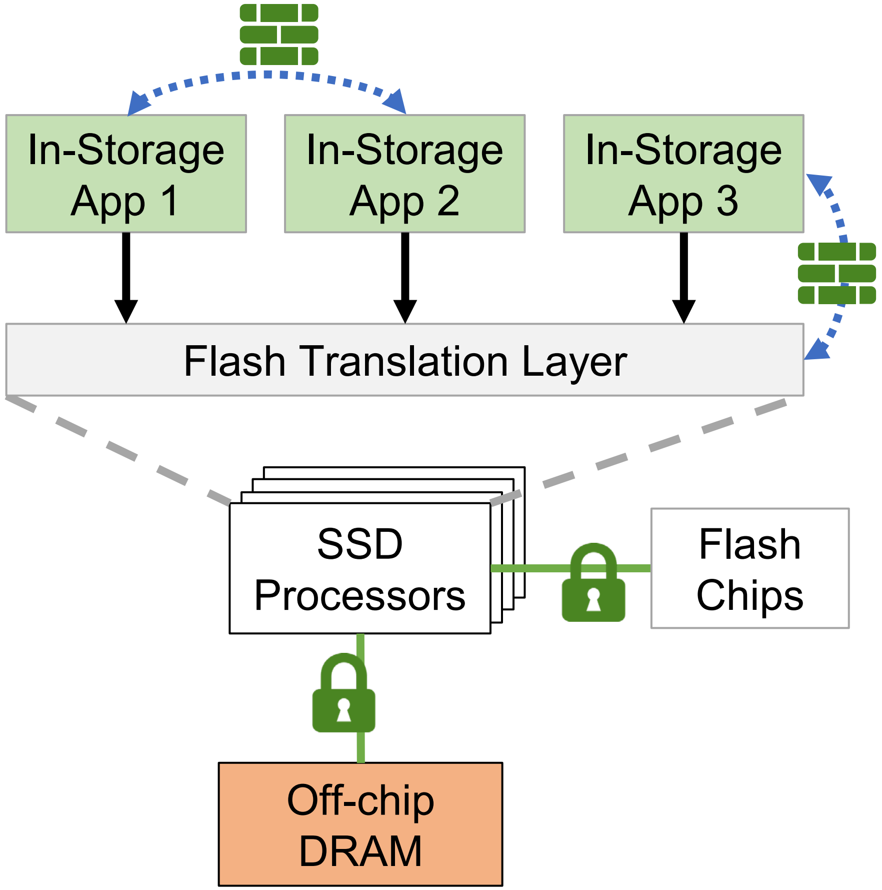
IceClave introduces minimal overhead while providing strong security

IceClave Overall Performance



More evaluations in the paper!

IceClave Summary



First Trusted Execution Environment for In-Storage Computing

2.3× Faster Than Host-based Computing

Thank you!

Yuqi Xue

yuqixue2@illinois.edu

Systems Platform Research Group

UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN