IceClave: A Trusted Execution Environment for In-Storage Computing

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UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

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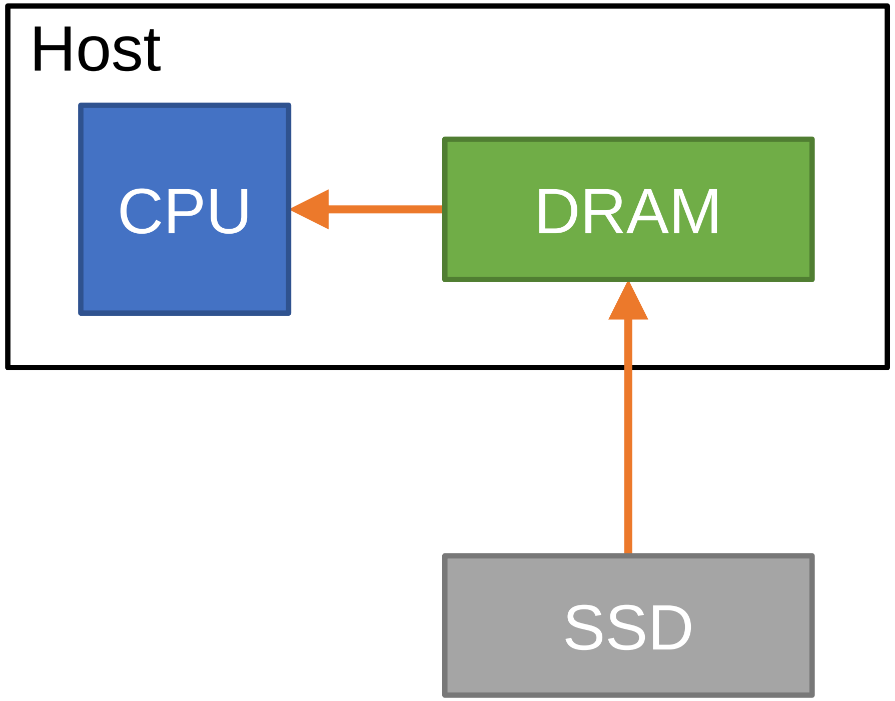
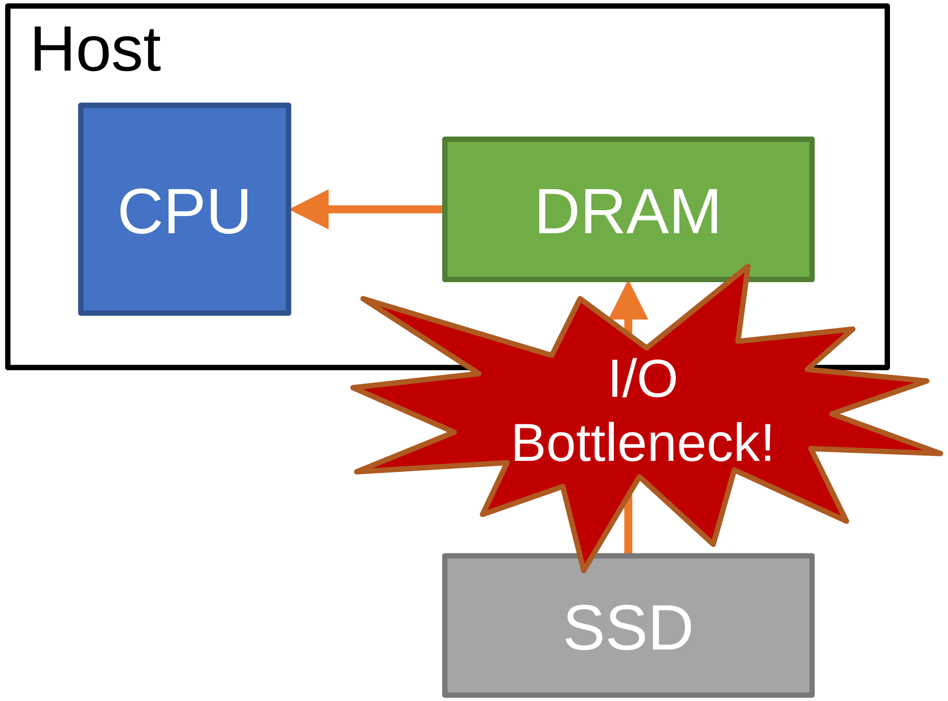
[‡] SK hynix

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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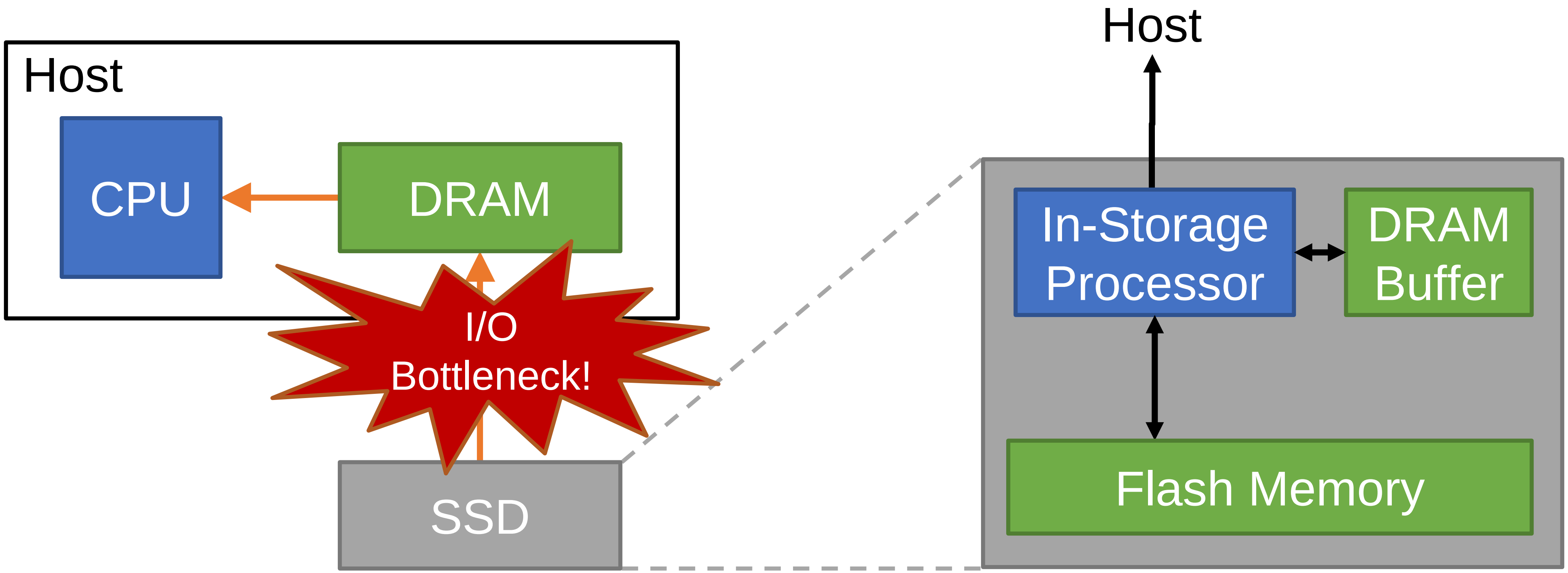

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In-Storage Computing

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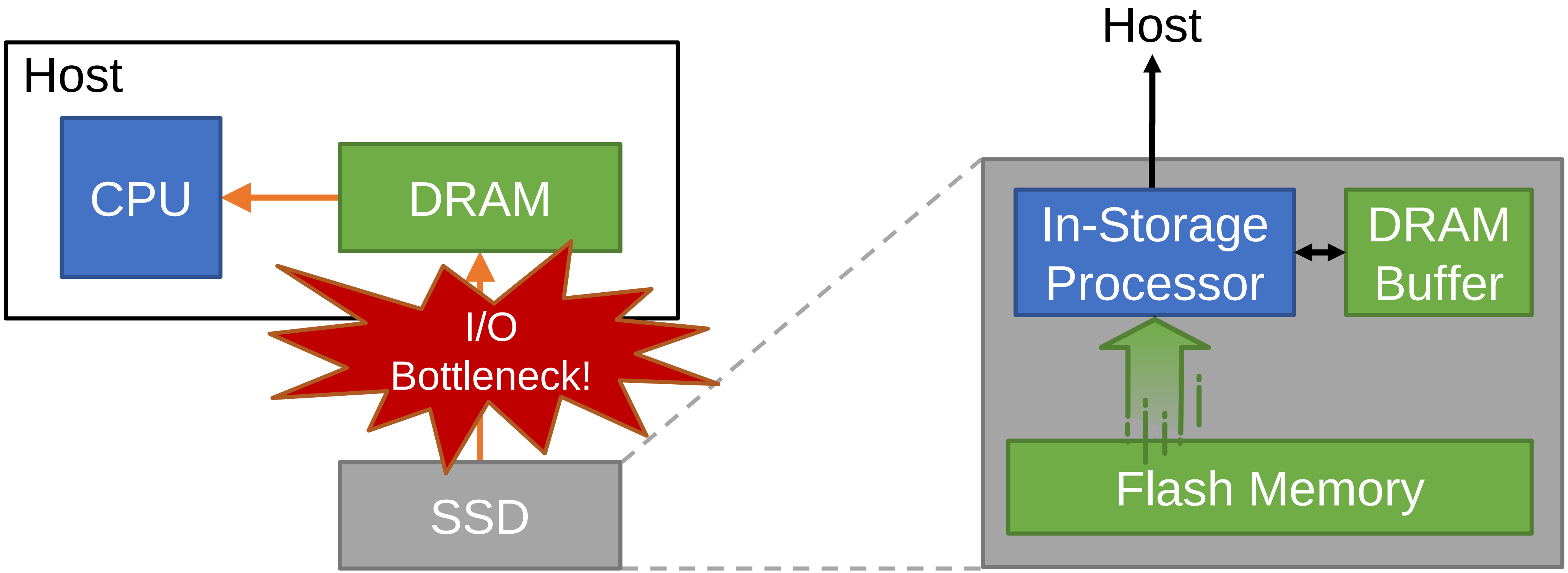

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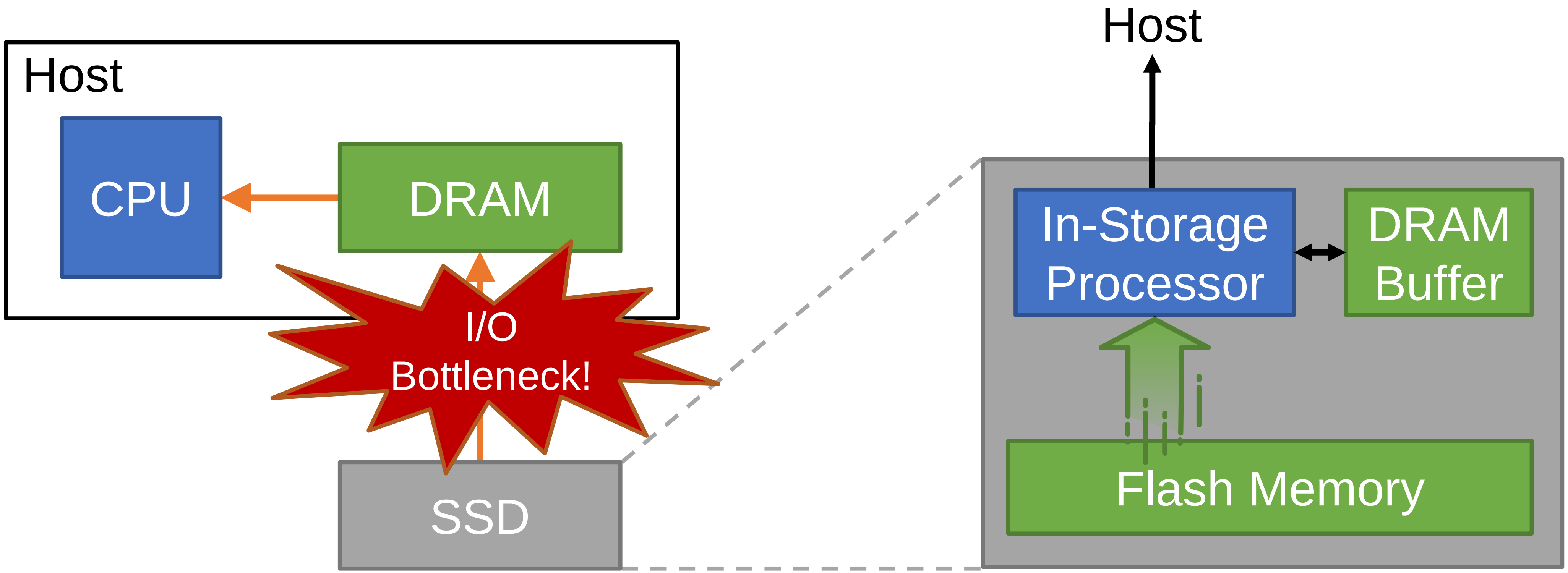
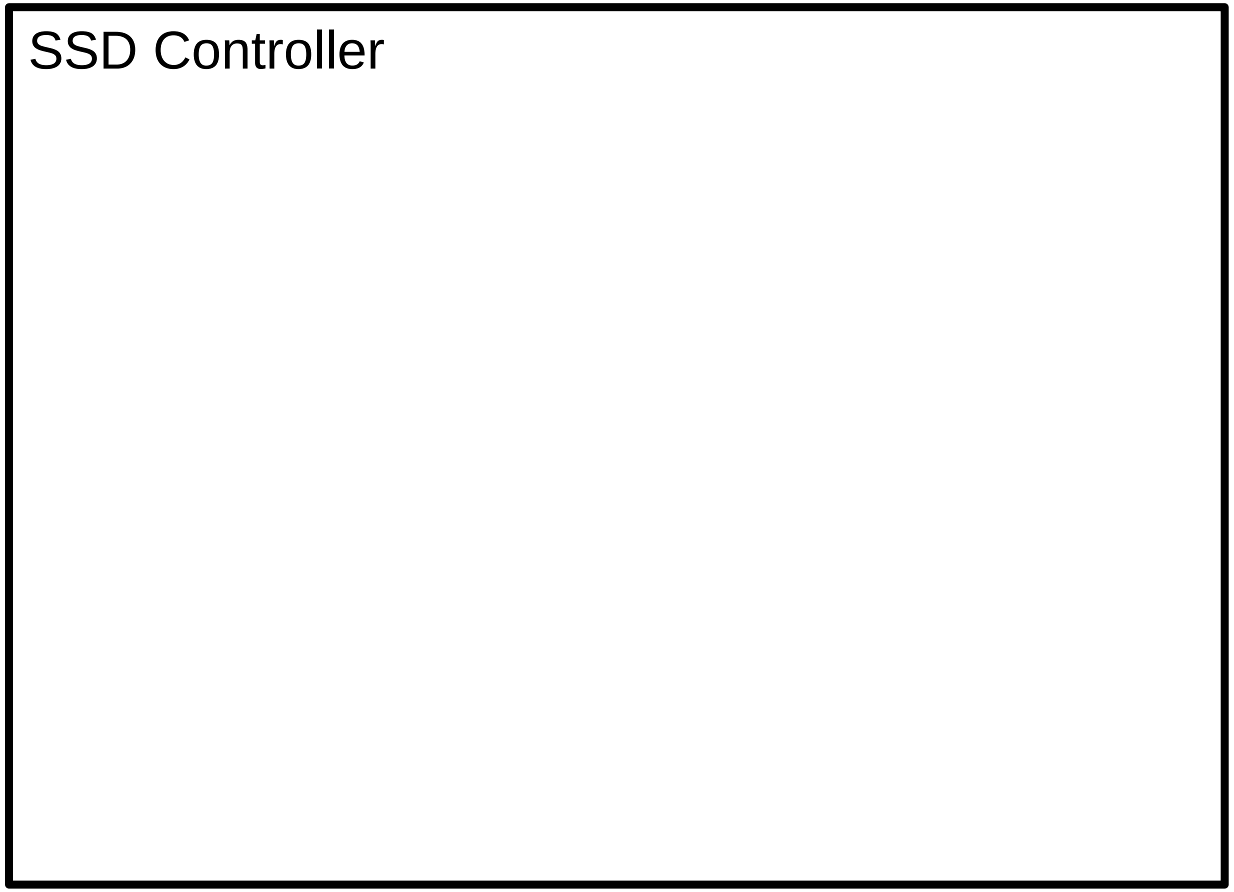


Host-based Computing

In-Storage Computing

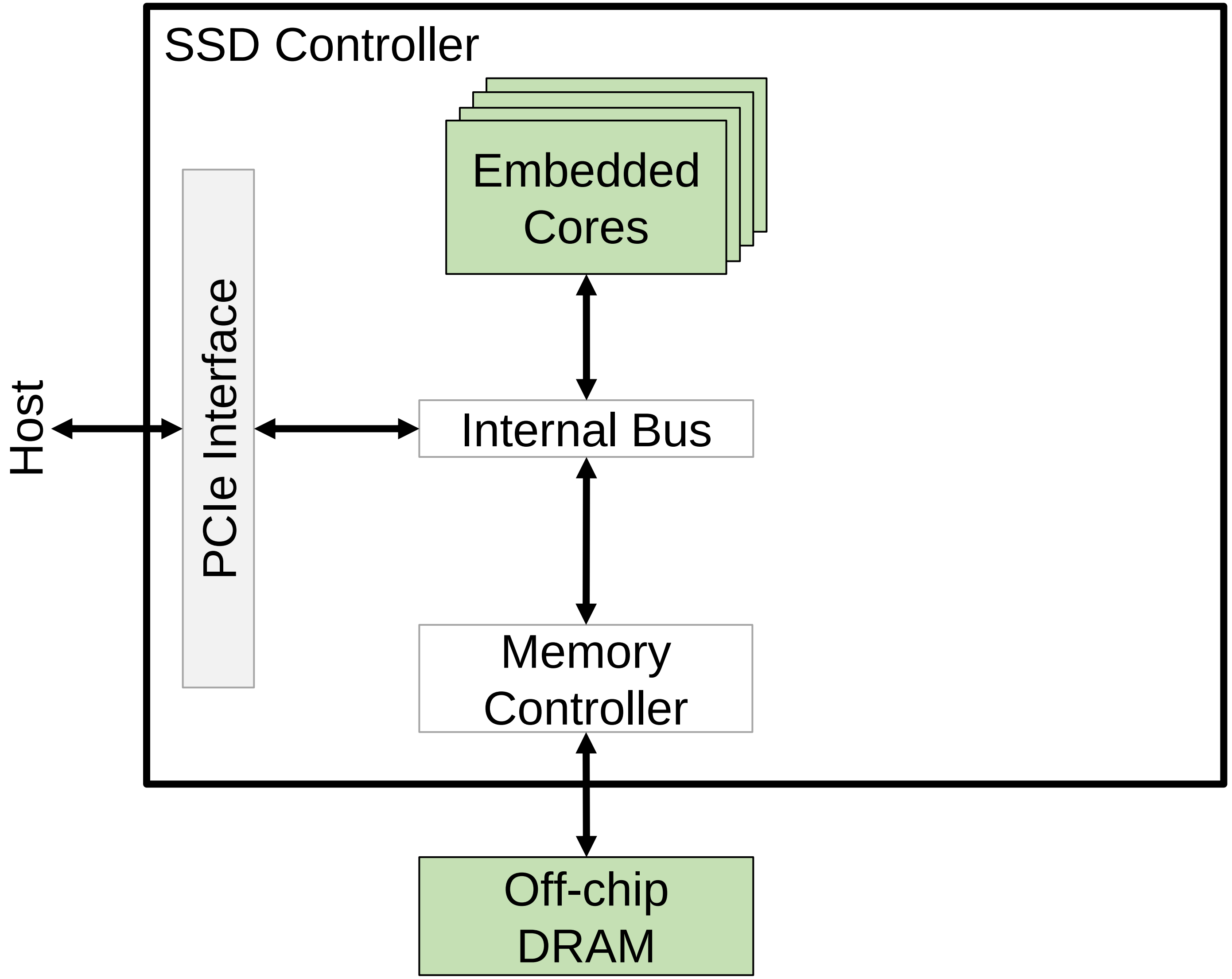
In-storage computing offers an effective solution to alleviate the I/O bottleneck

SSD Architecture for In-Storage Computing



SSD Controller

SSD Architecture for In-Storage Computing



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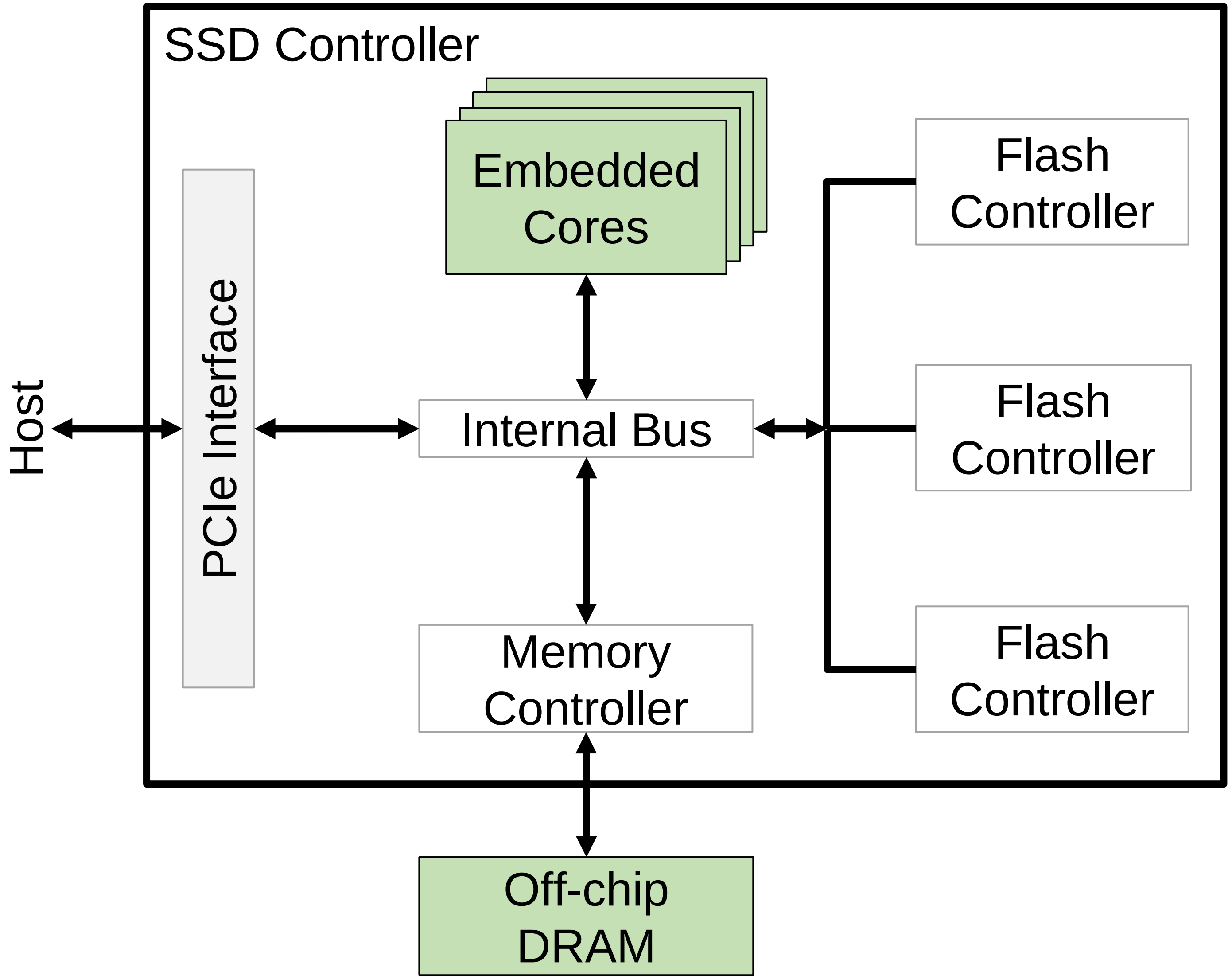

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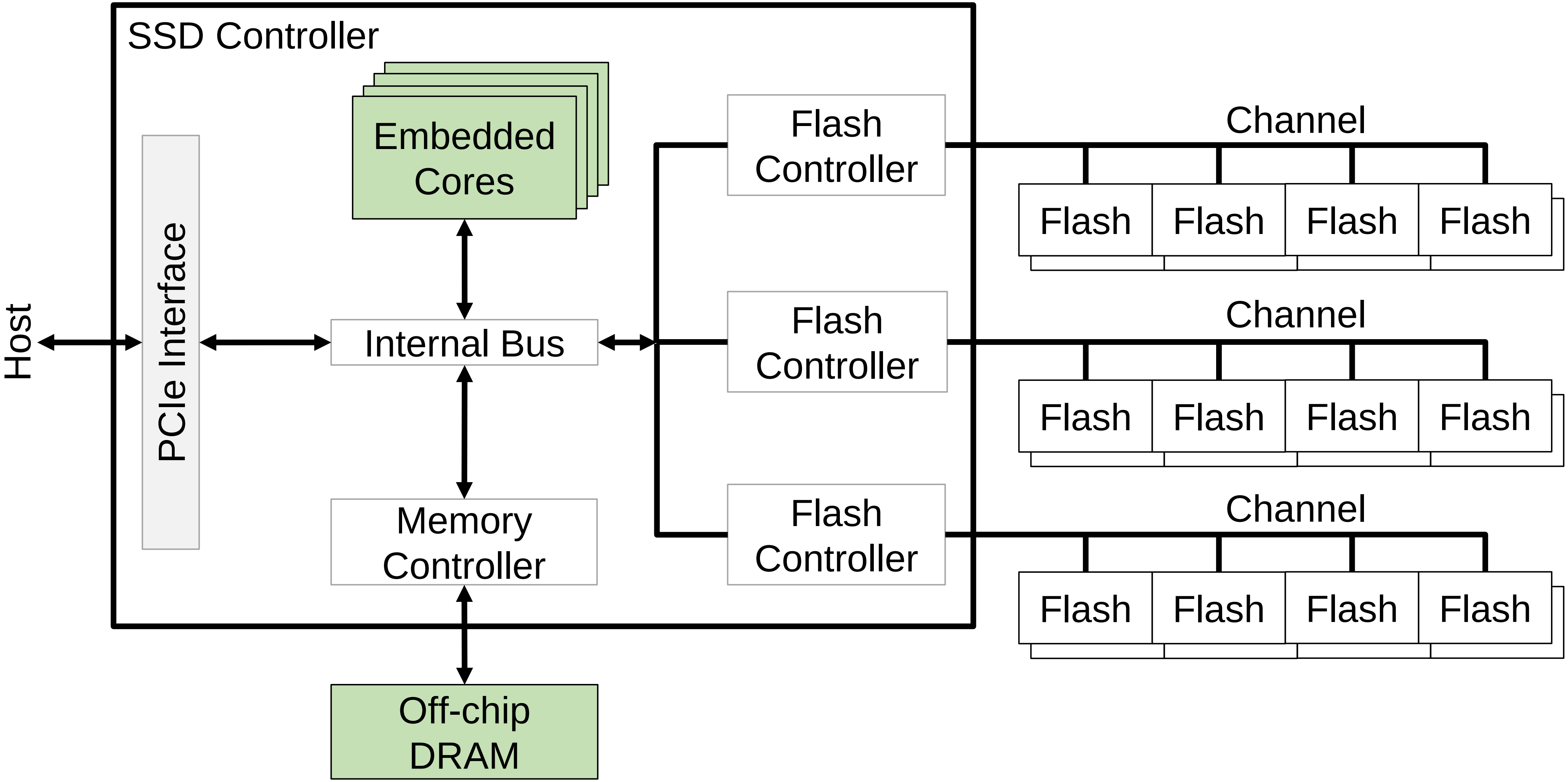

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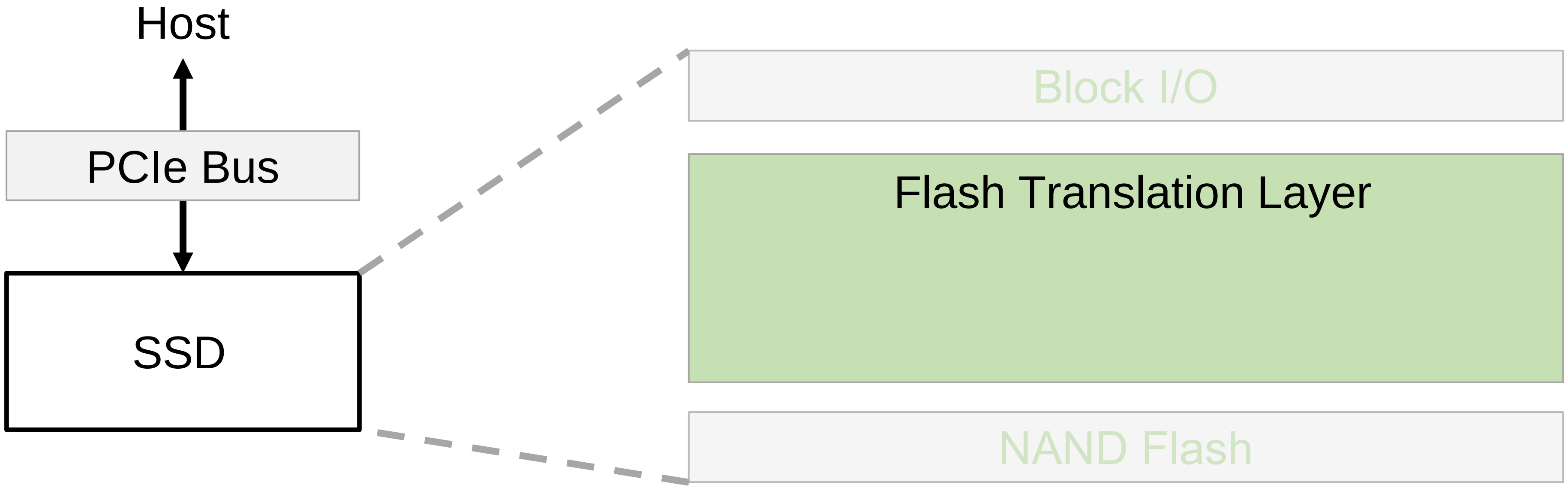

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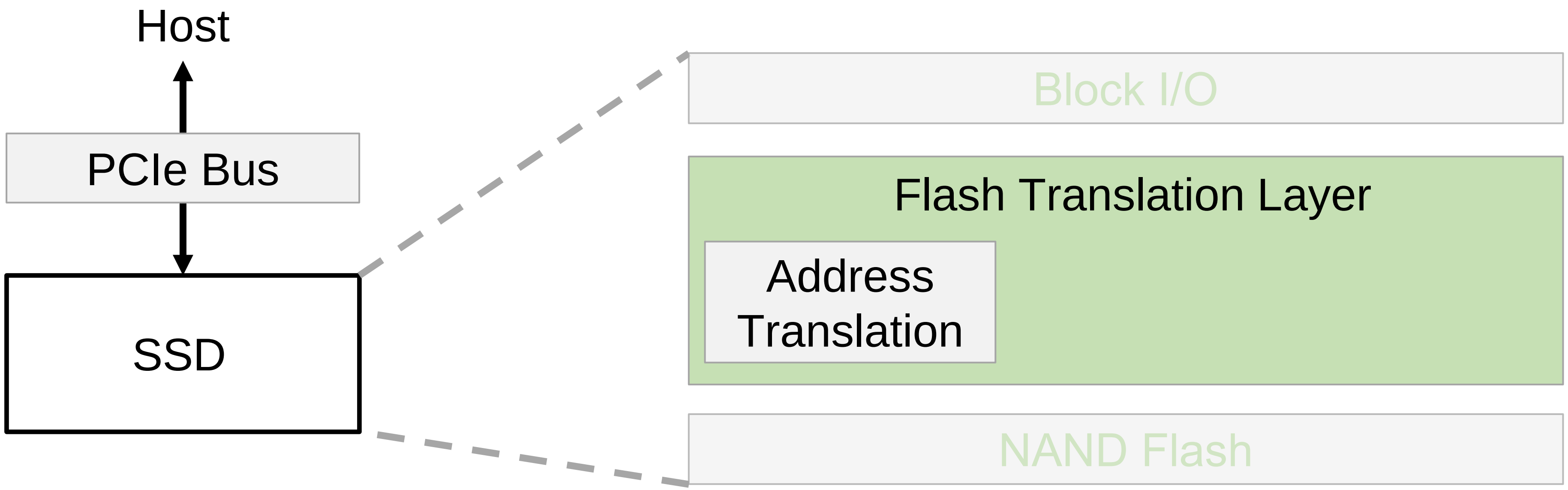

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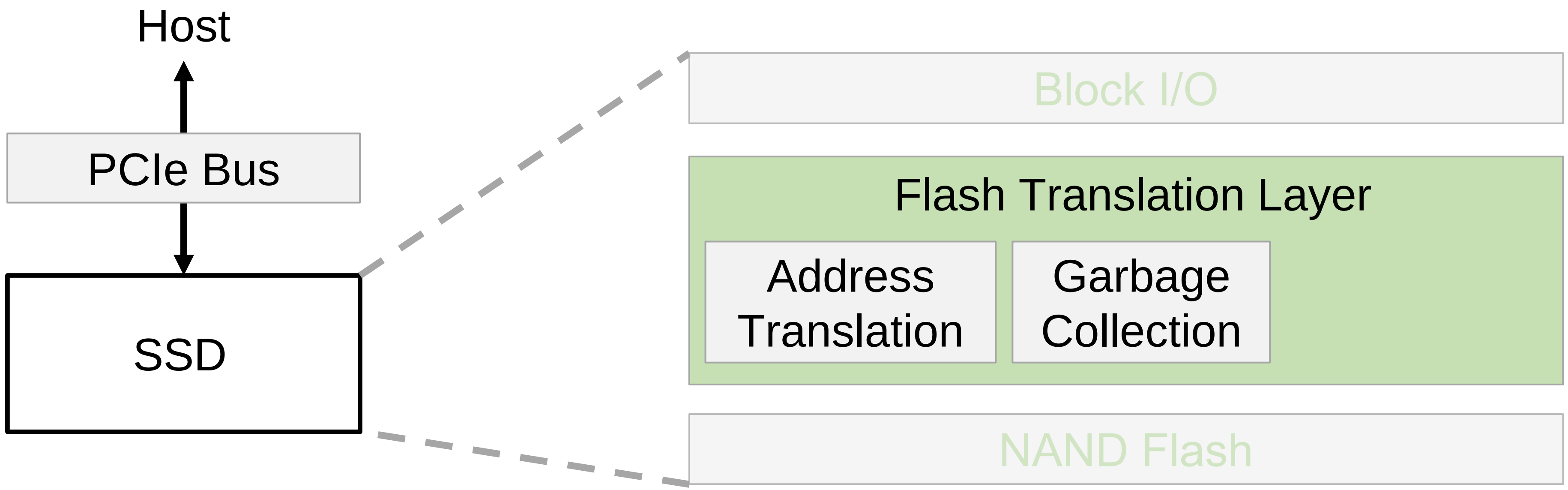


Host

PCIe Bus

SSD

Block I/O

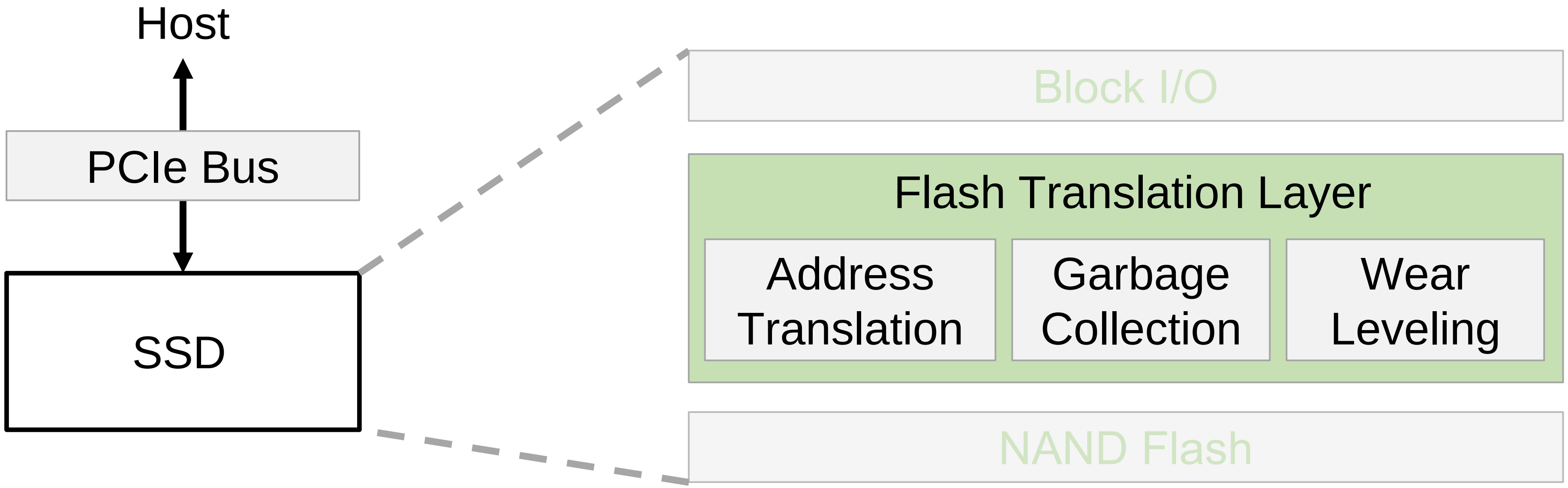
Flash Translation Layer

Address Translation

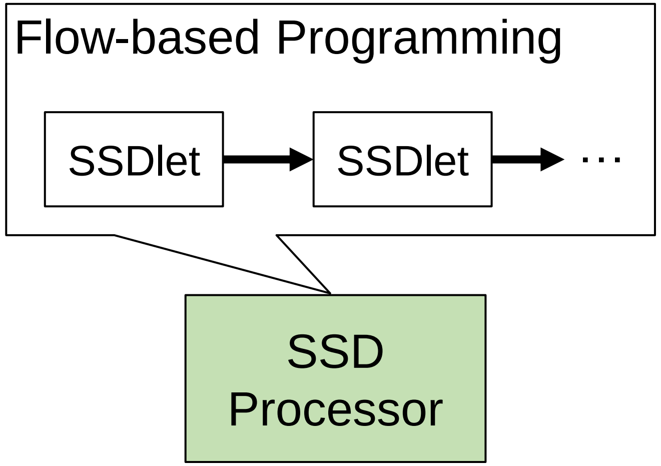
Garbage Collection

NAND Flash

SSD Architecture for In-Storage Computing



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



MapReduce-based Framework

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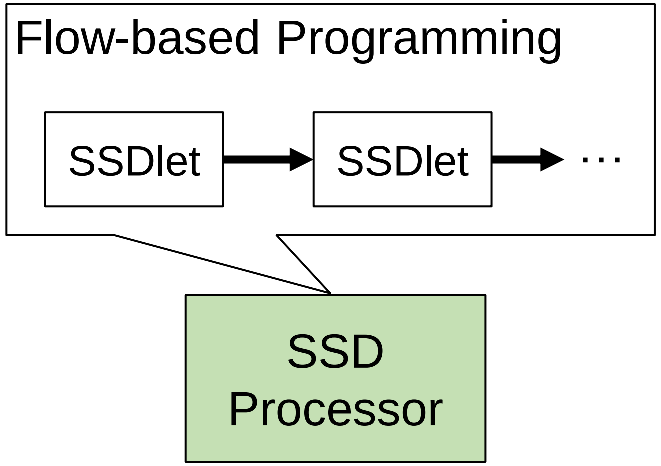

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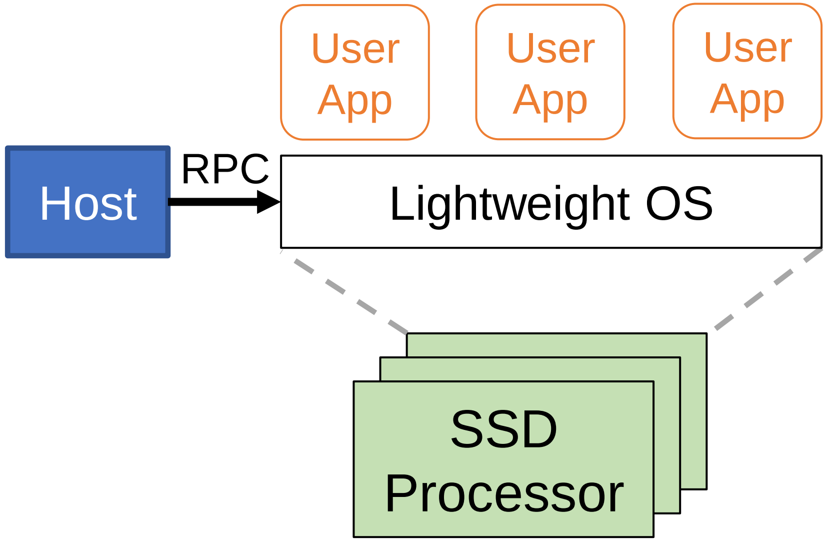

RPC-based Offloading

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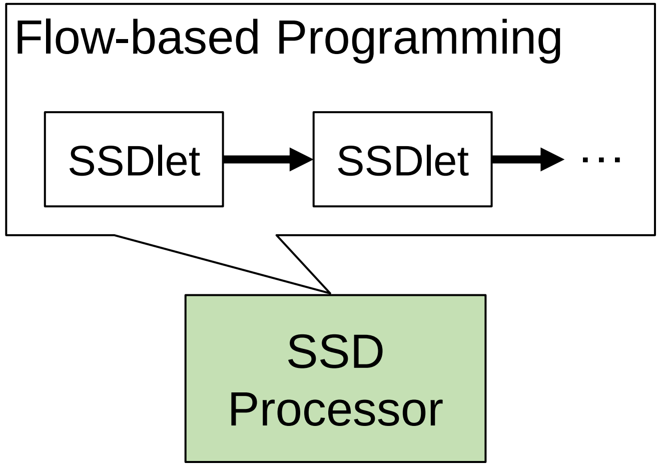

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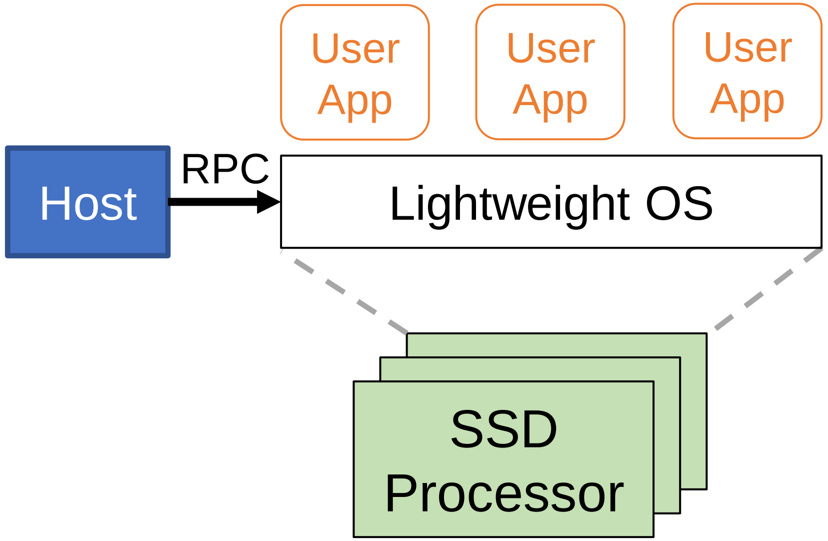

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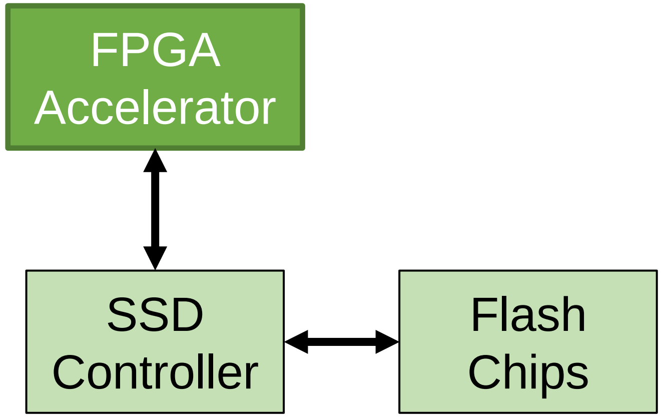

Industry SmartSSD

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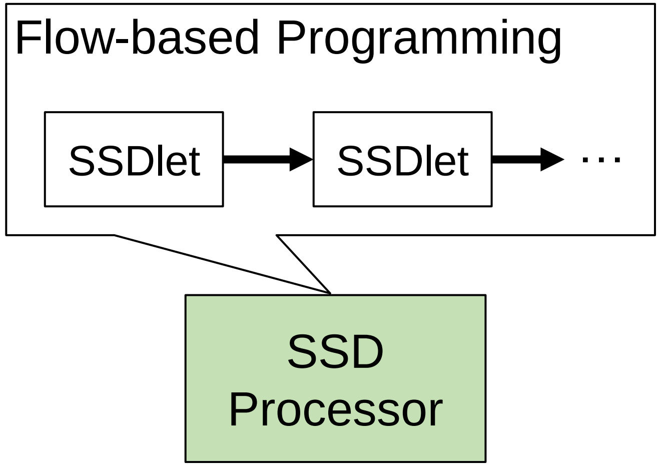

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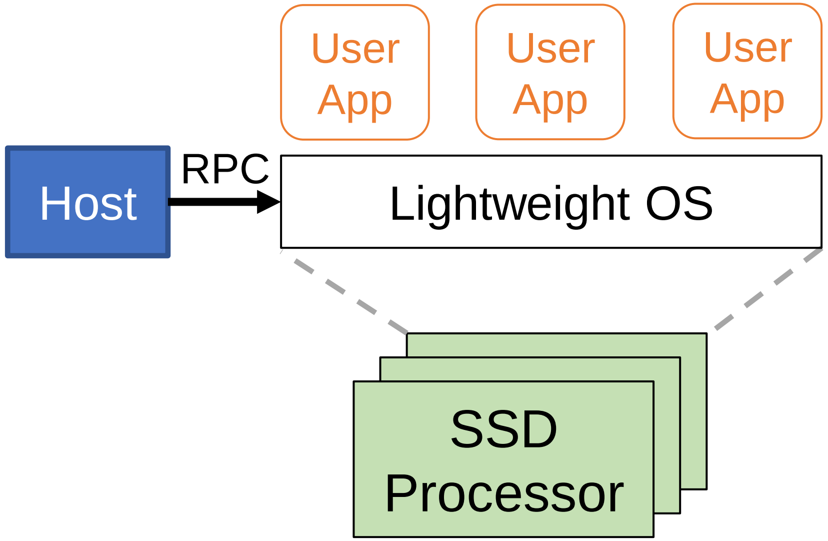

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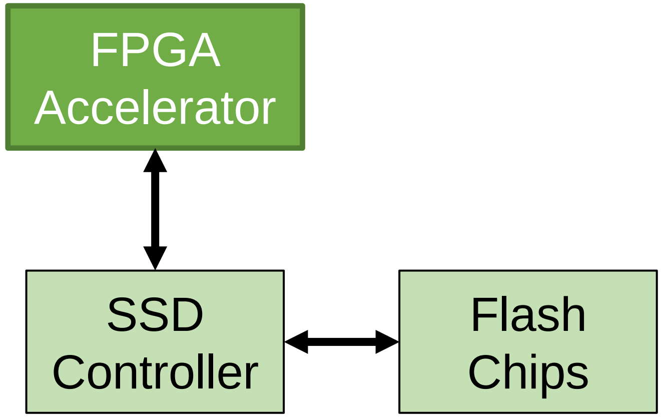

Industry SmartSSD

Most of the existing frameworks focus on performance and programmability

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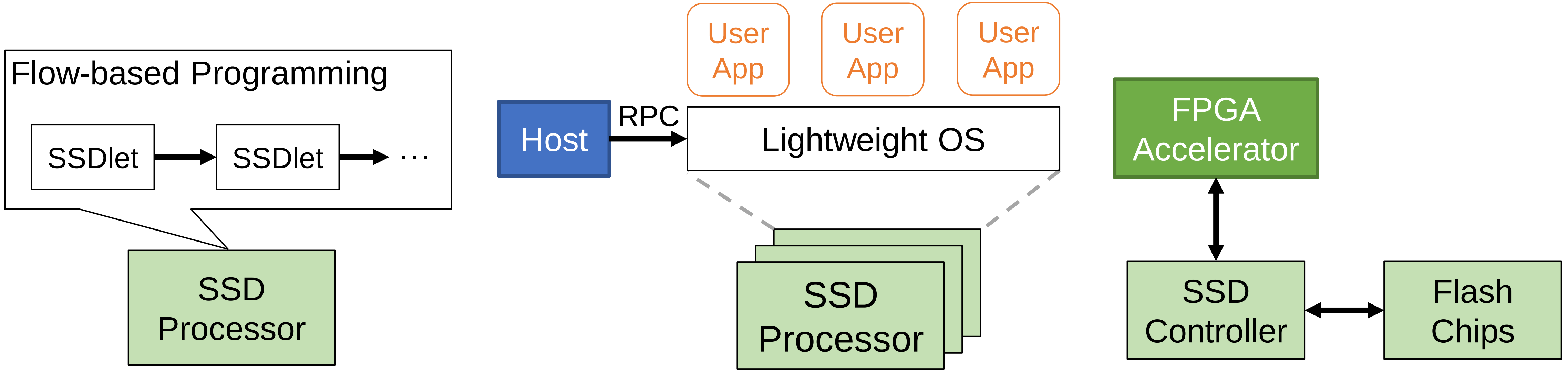


MapReduce-based Framework

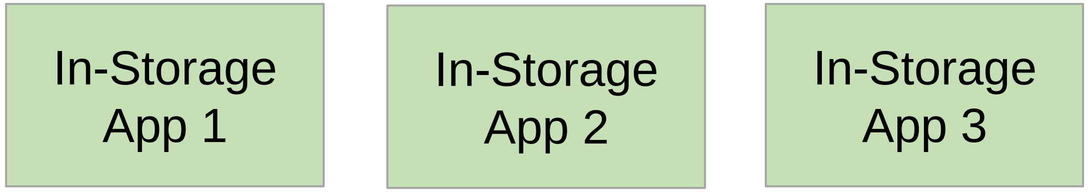
RPC-based Offloading

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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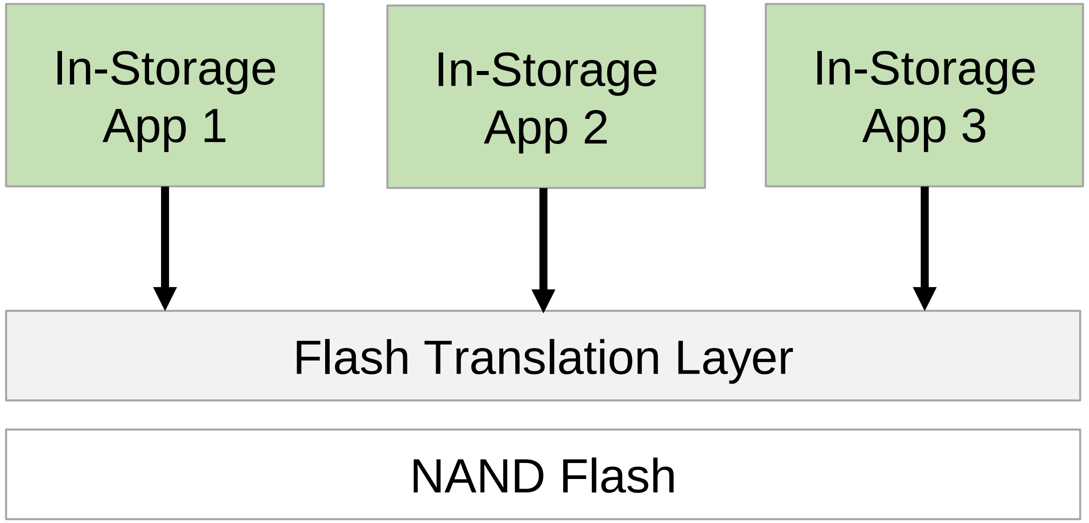

In-Storage App 1

In-Storage App 2

In-Storage App 3

Flash Translation Layer

NAND Flash

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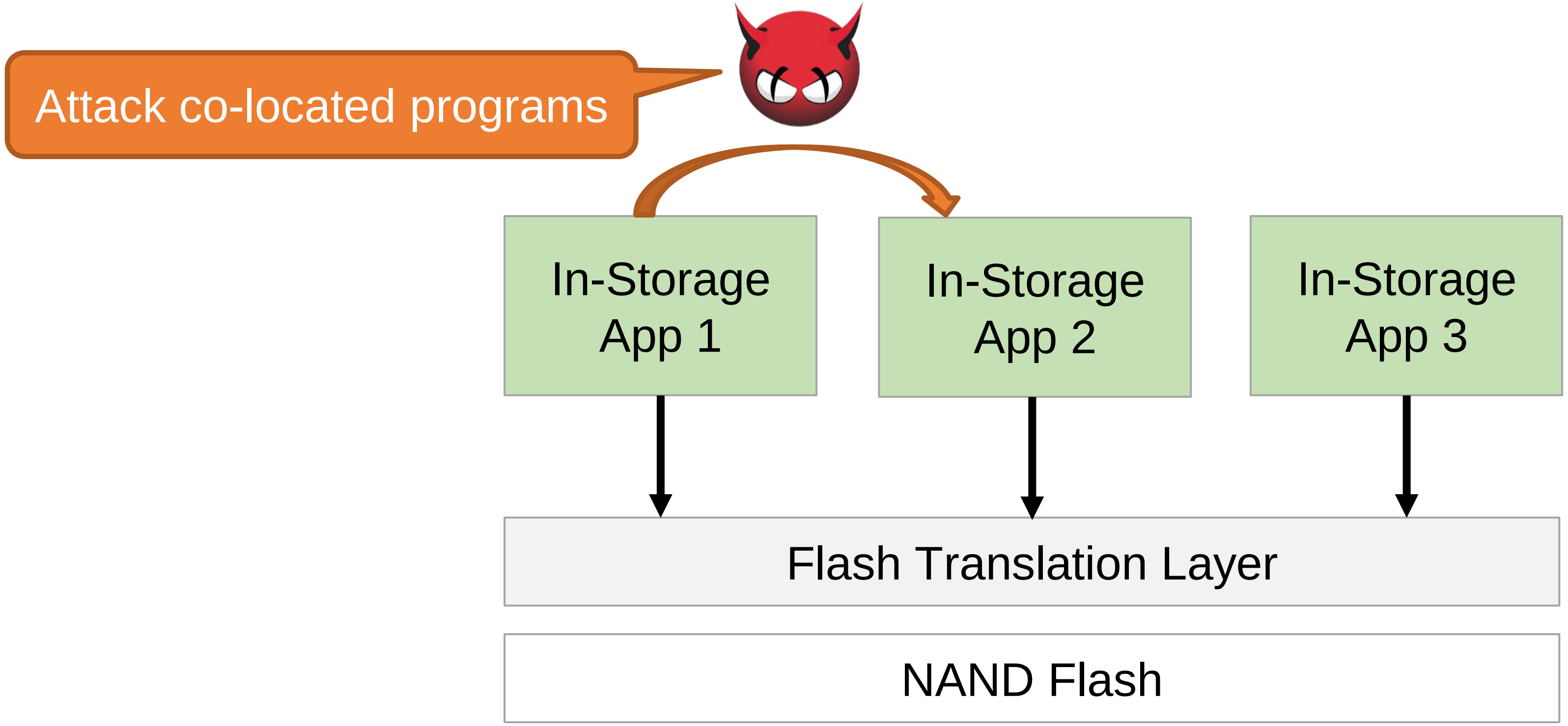

Attack co-located programs

In-Storage App 1

In-Storage App 2

In-Storage App 3

Flash Translation Layer

NAND Flash

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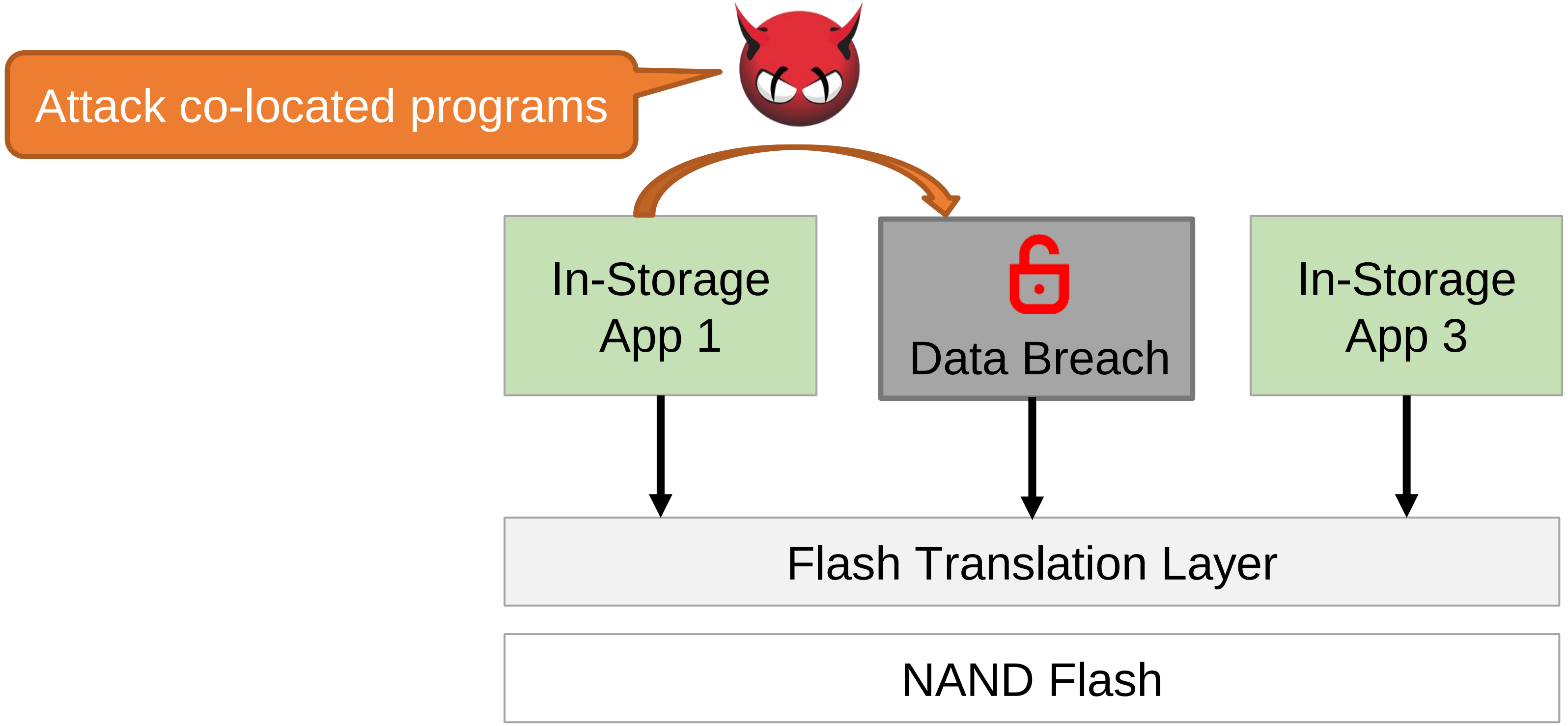

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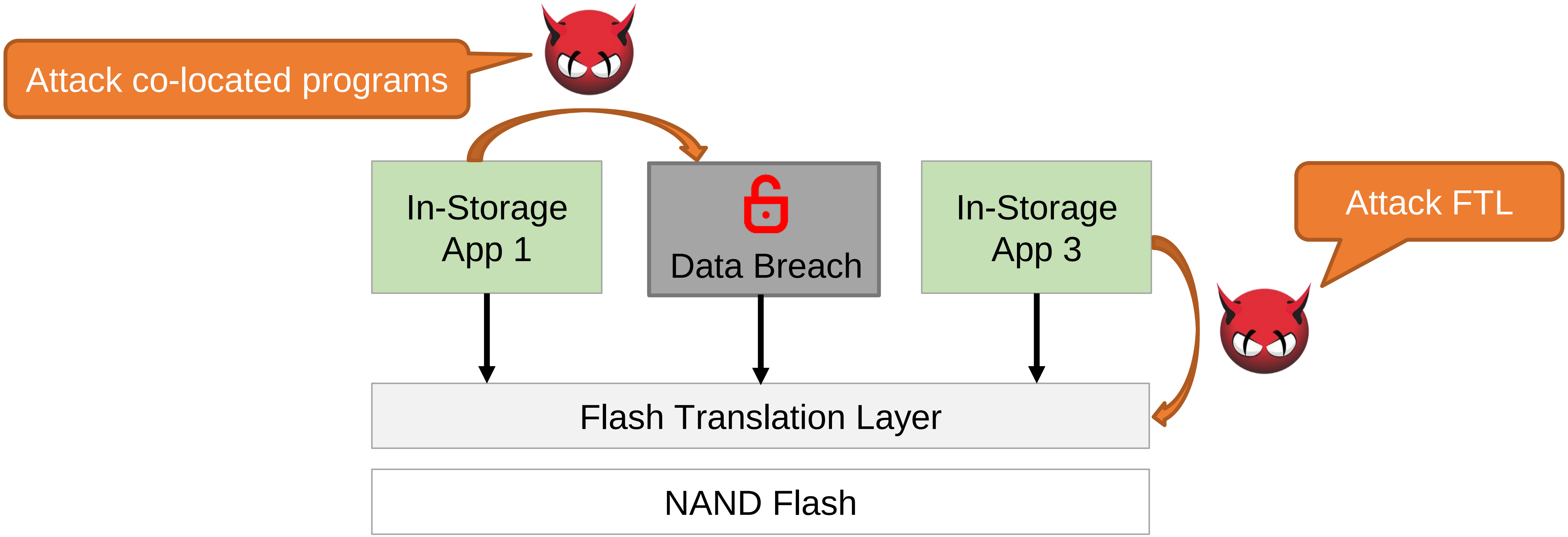

Attack co-located programs

Attack FTL

In-Storage App 1

Data Breach

In-Storage App 3

Flash Translation Layer

NAND Flash

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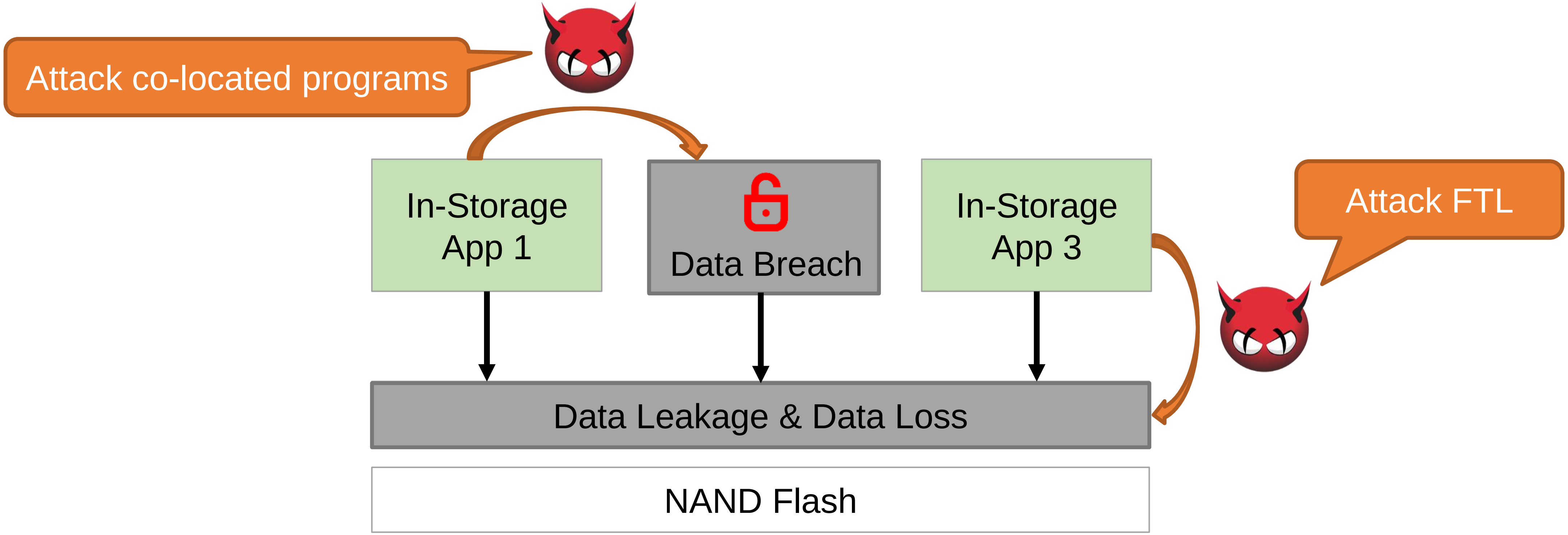

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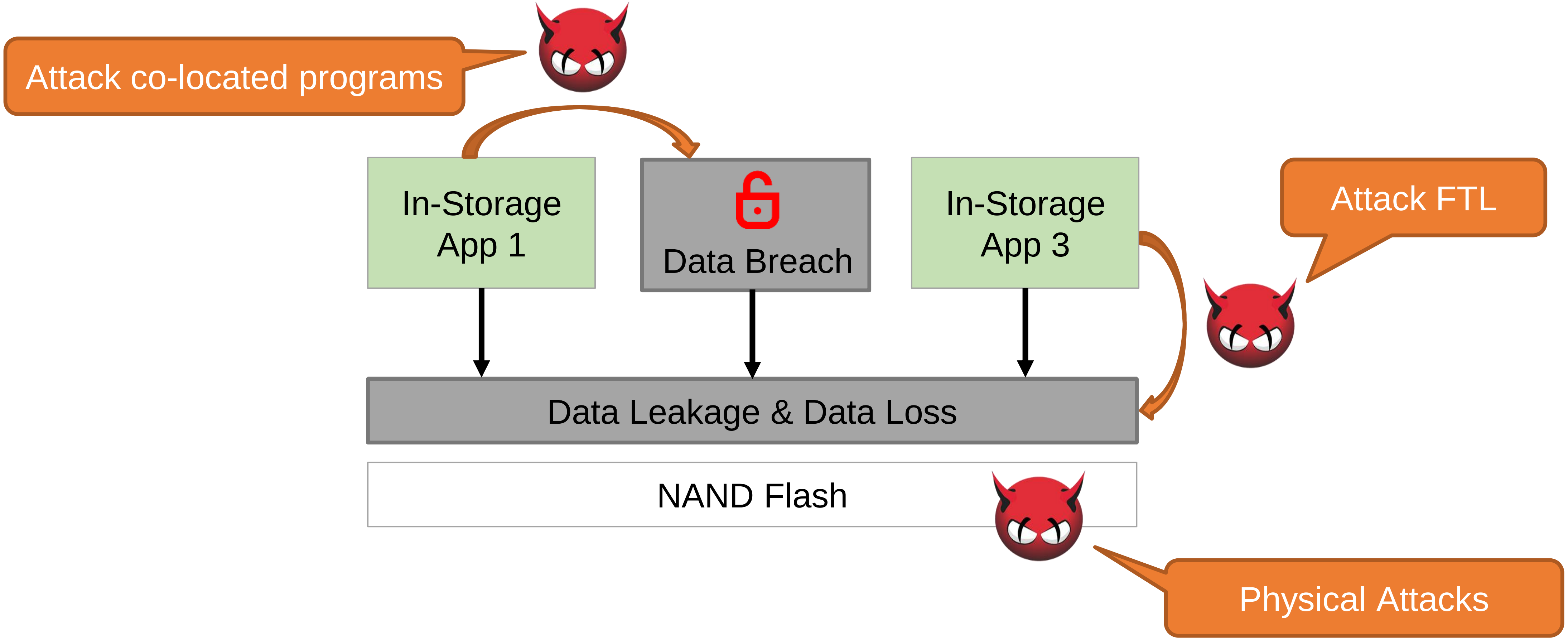

Attack co-located programs

In-Storage App 1

Data Breach

In-Storage App 3

Attack FTL

Data Leakage & Data Loss

NAND Flash

Physical Attacks

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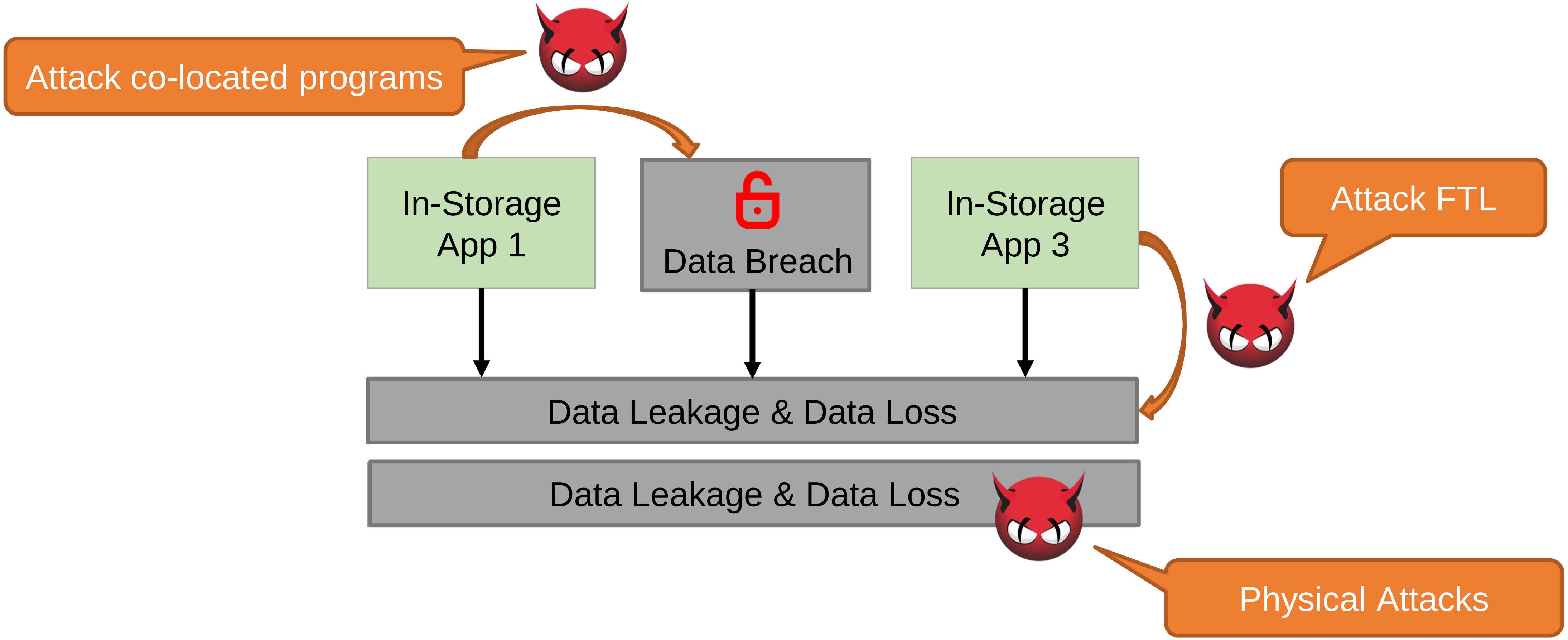

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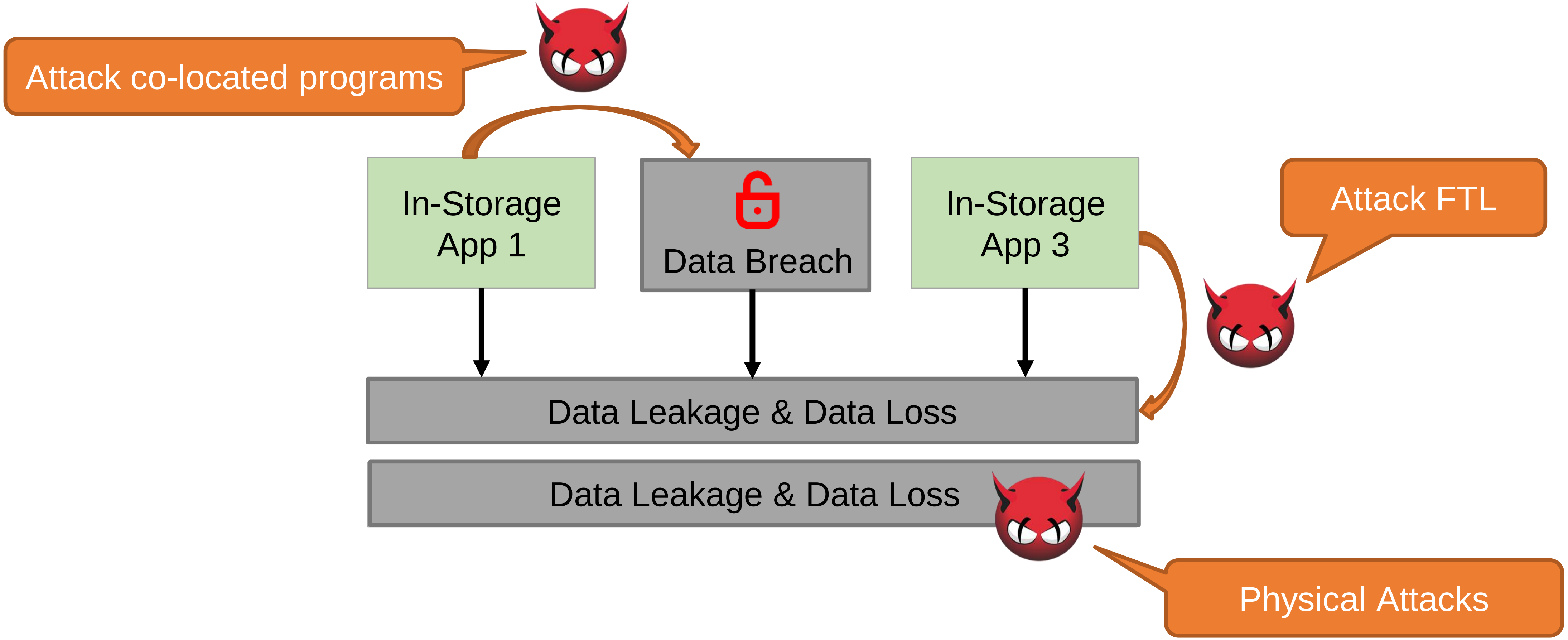


Attack co-located programs

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

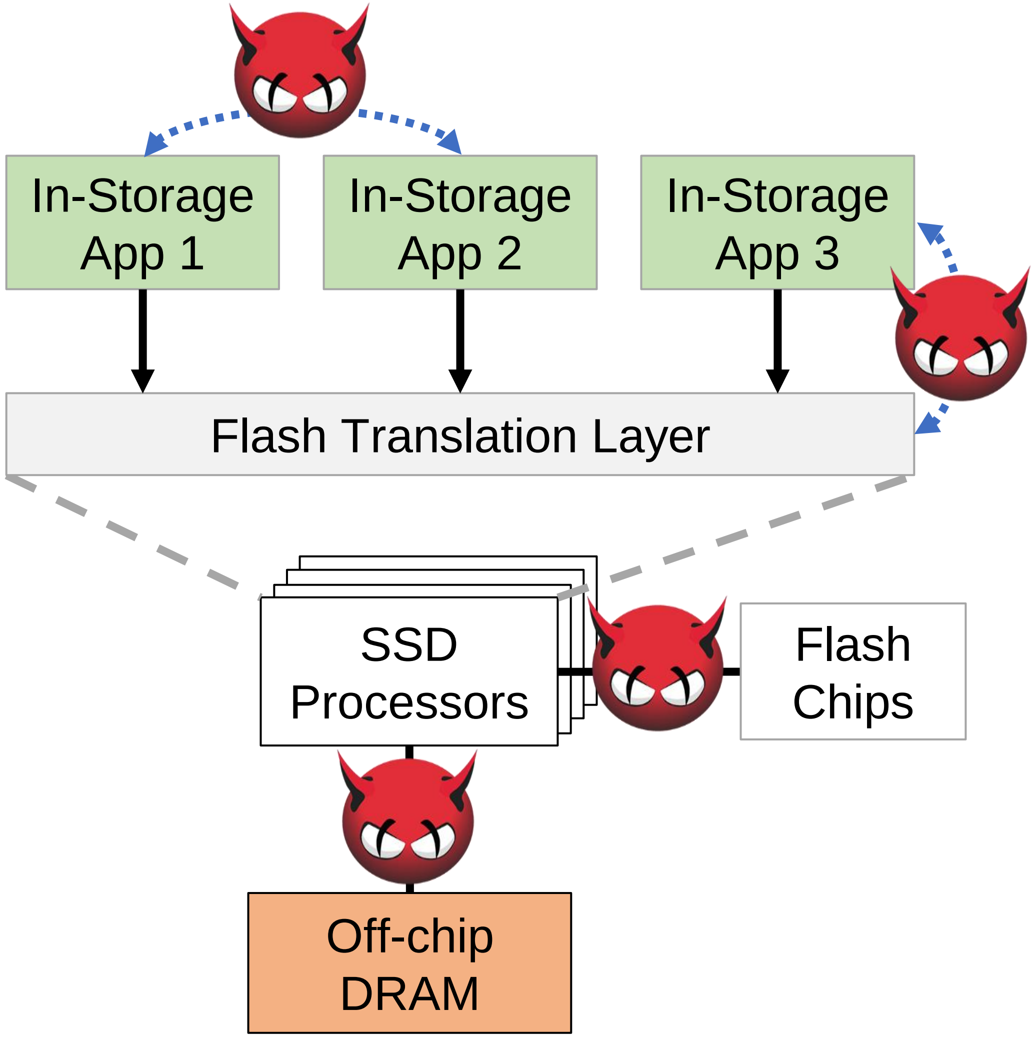
intel SGX

Intel SGX is not available in storage processors

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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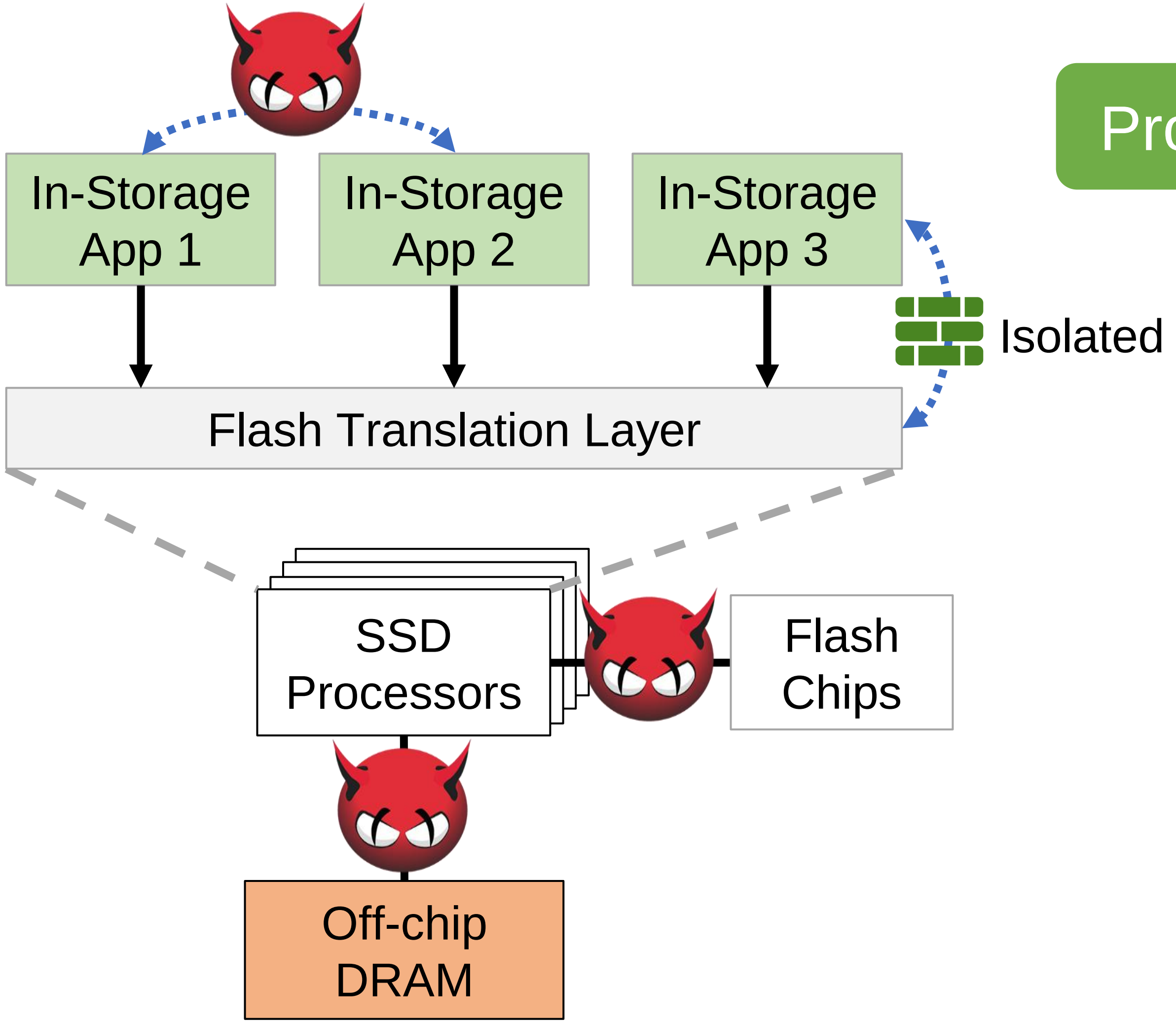

Protecting FTL from malicious in-storage apps

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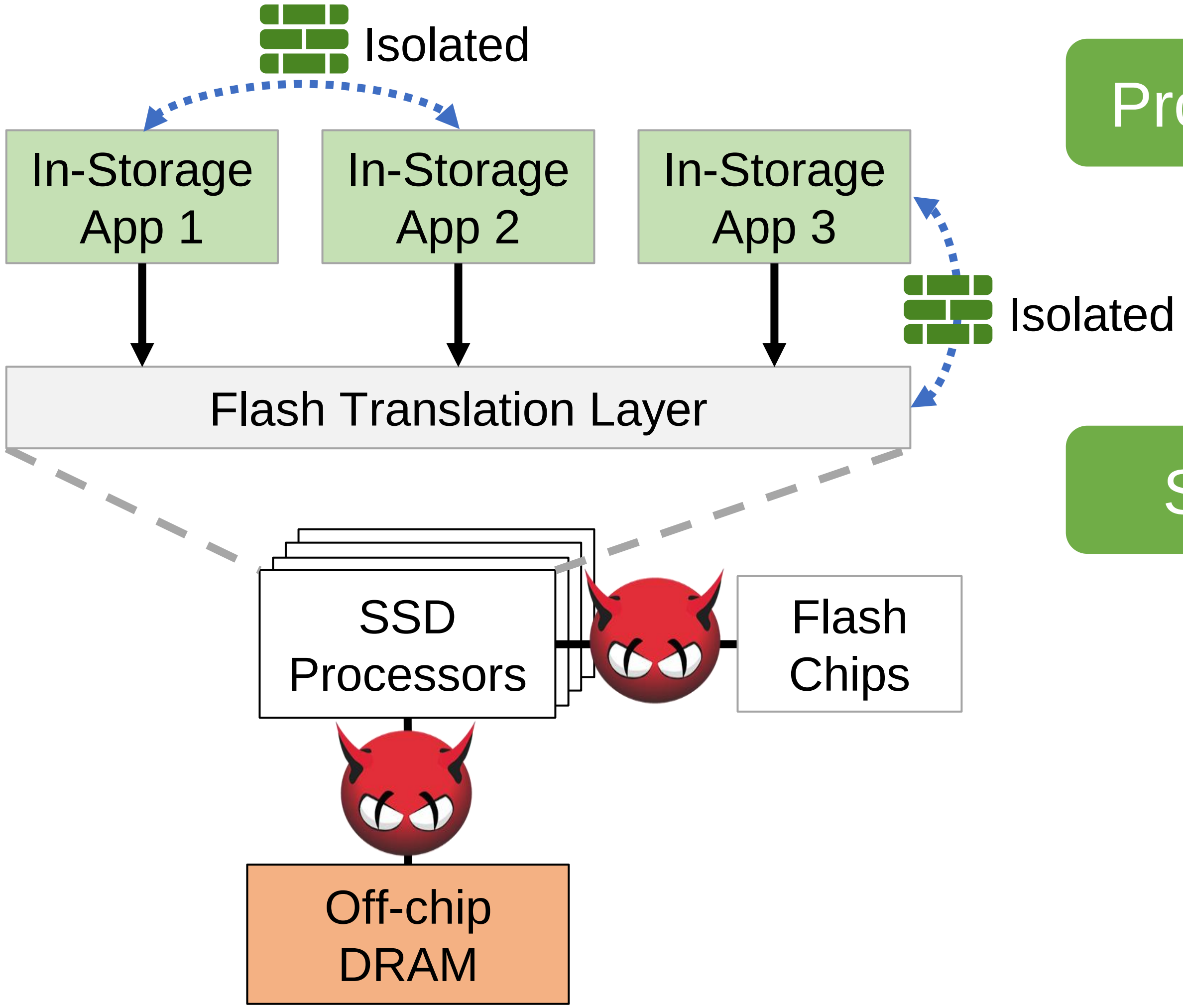

Protecting FTL from malicious in-storage apps

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Security isolation between in-storage apps

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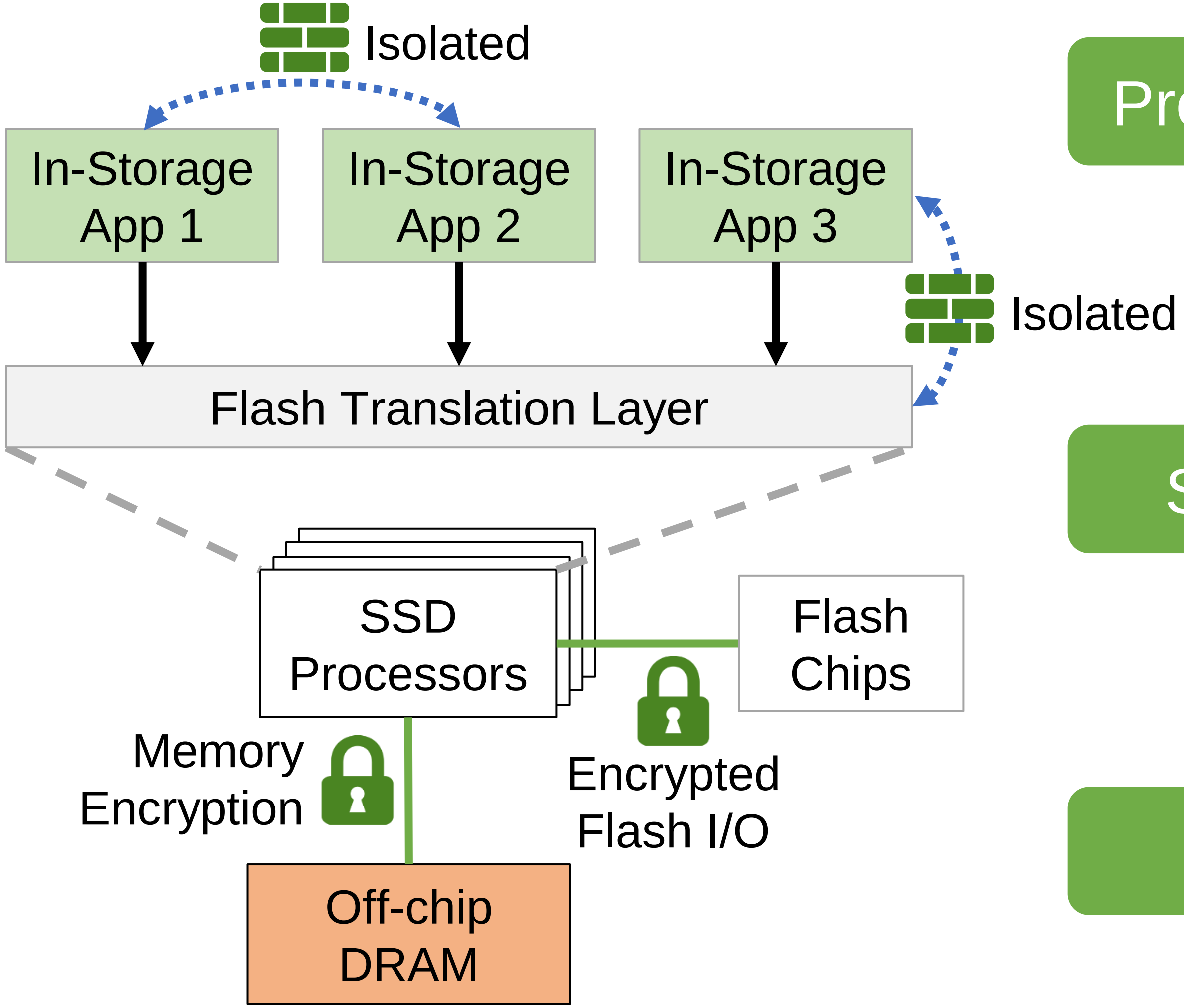

Protecting FTL from malicious in-storage apps

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Security isolation between in-storage apps

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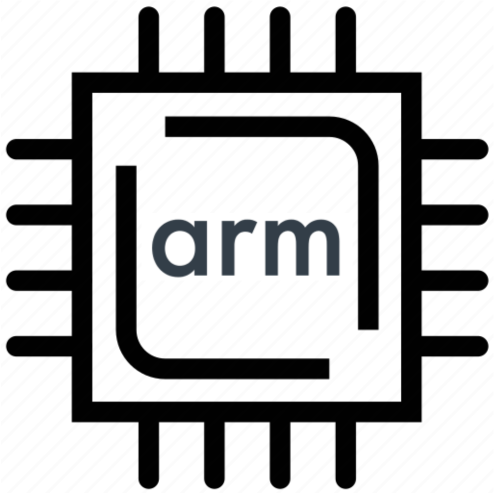
Securing data against physical attacks

IceClave Design Challenges



Bare-metal
Environment

IceClave Design Challenges

Bare-metal Environment

Efficient Flash Access

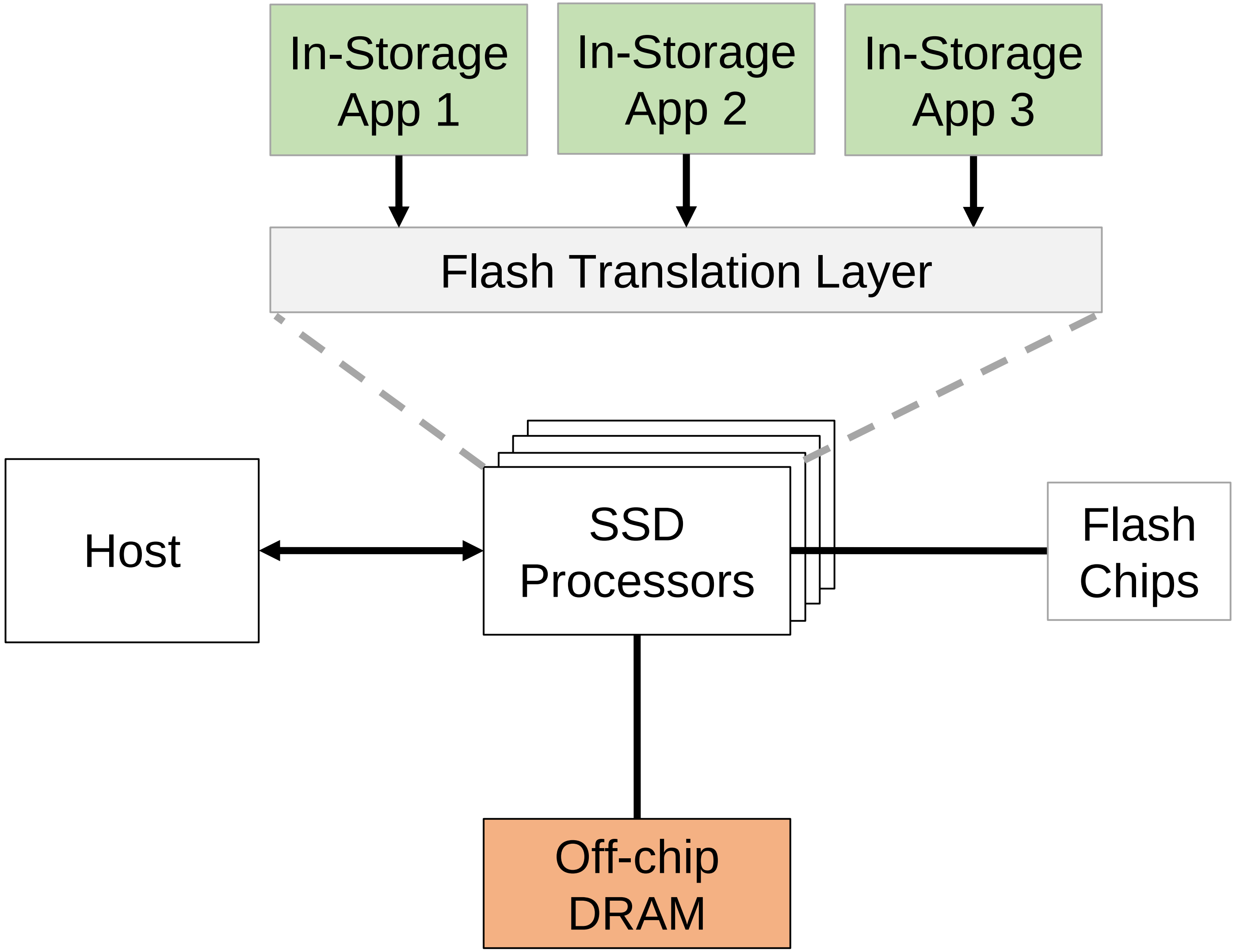
IceClave Design Challenges

Bare-metal Environment

Efficient Flash Access

Limited Resources in SSD Device

Threat Model



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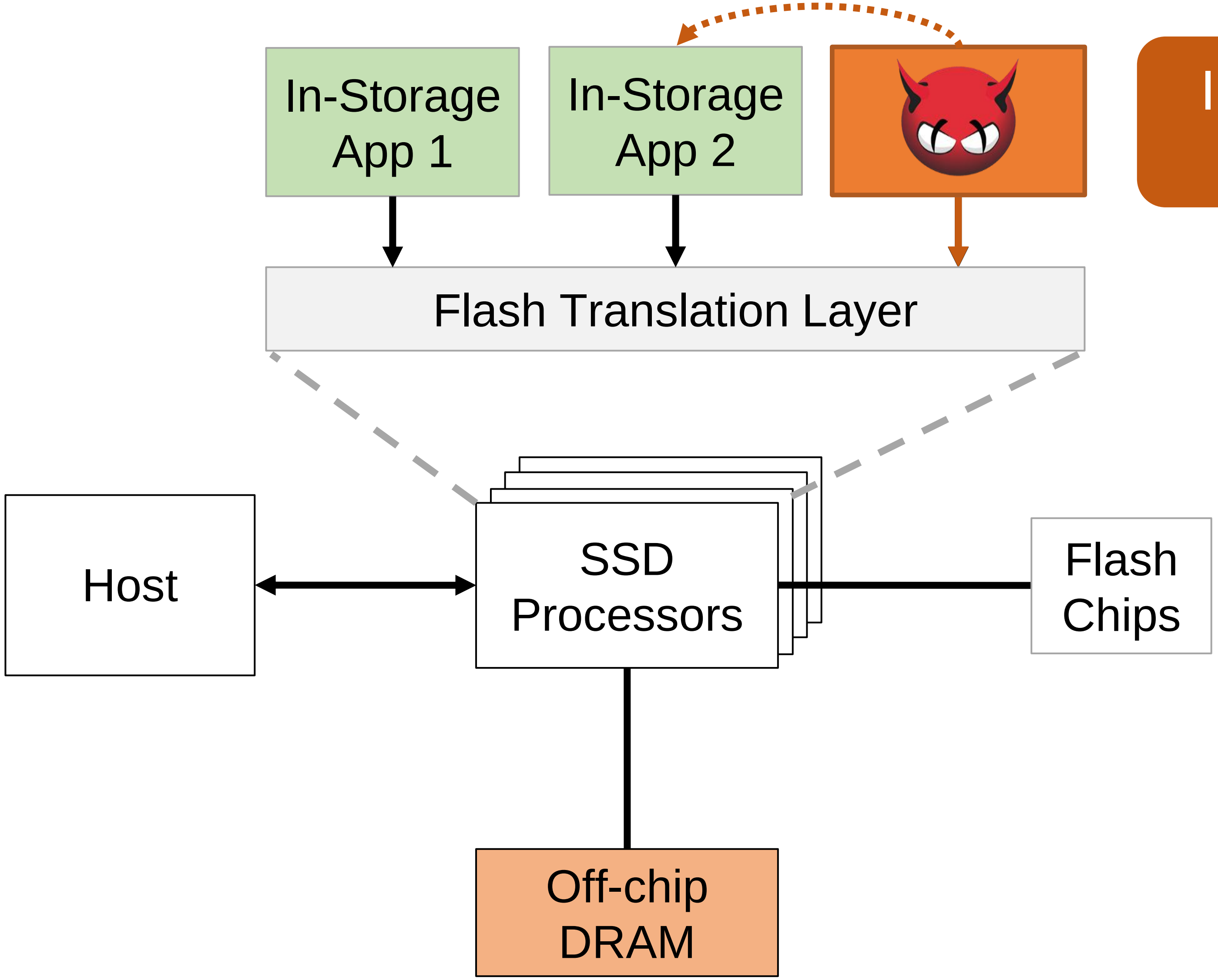
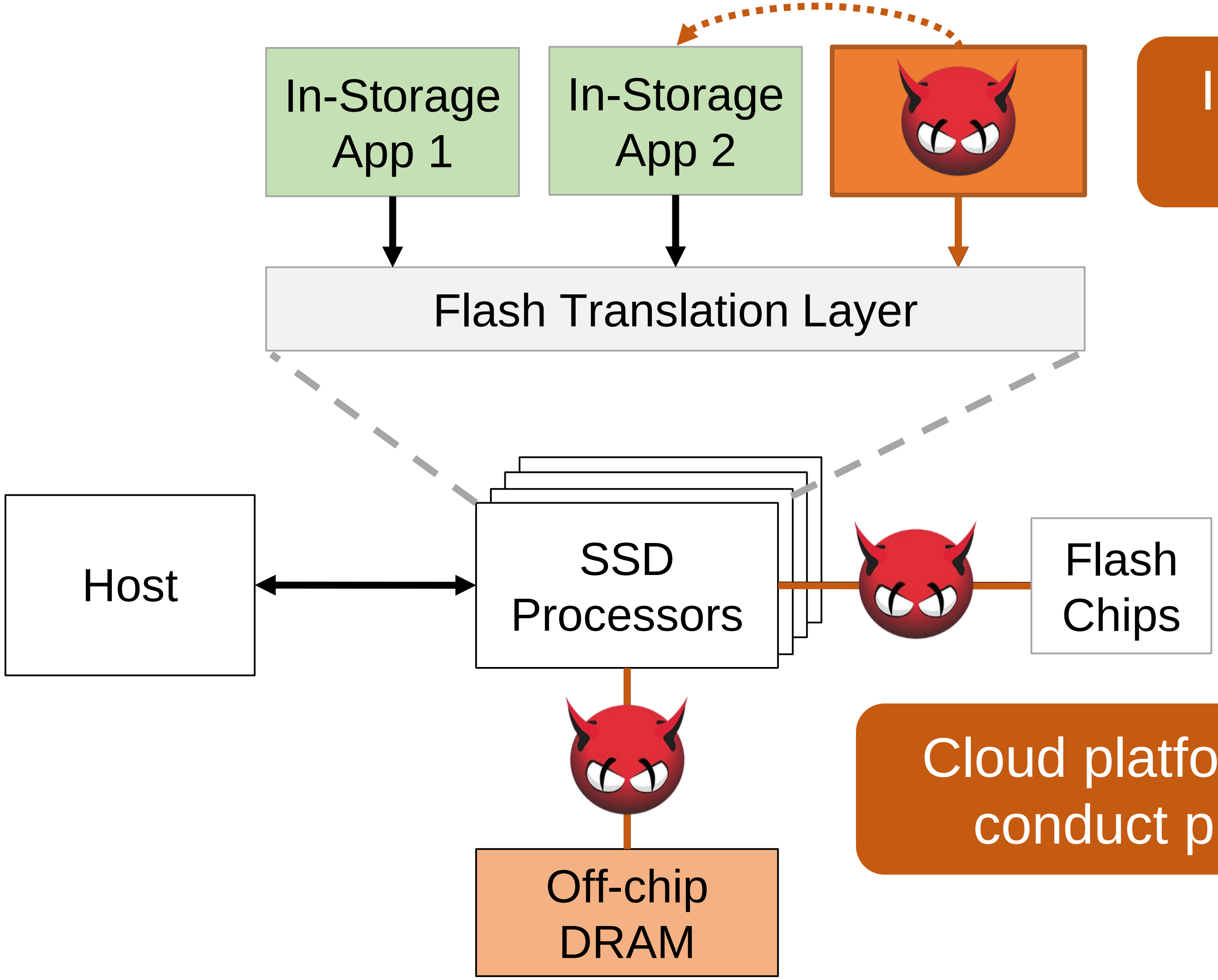


In-storage applications can be malicious

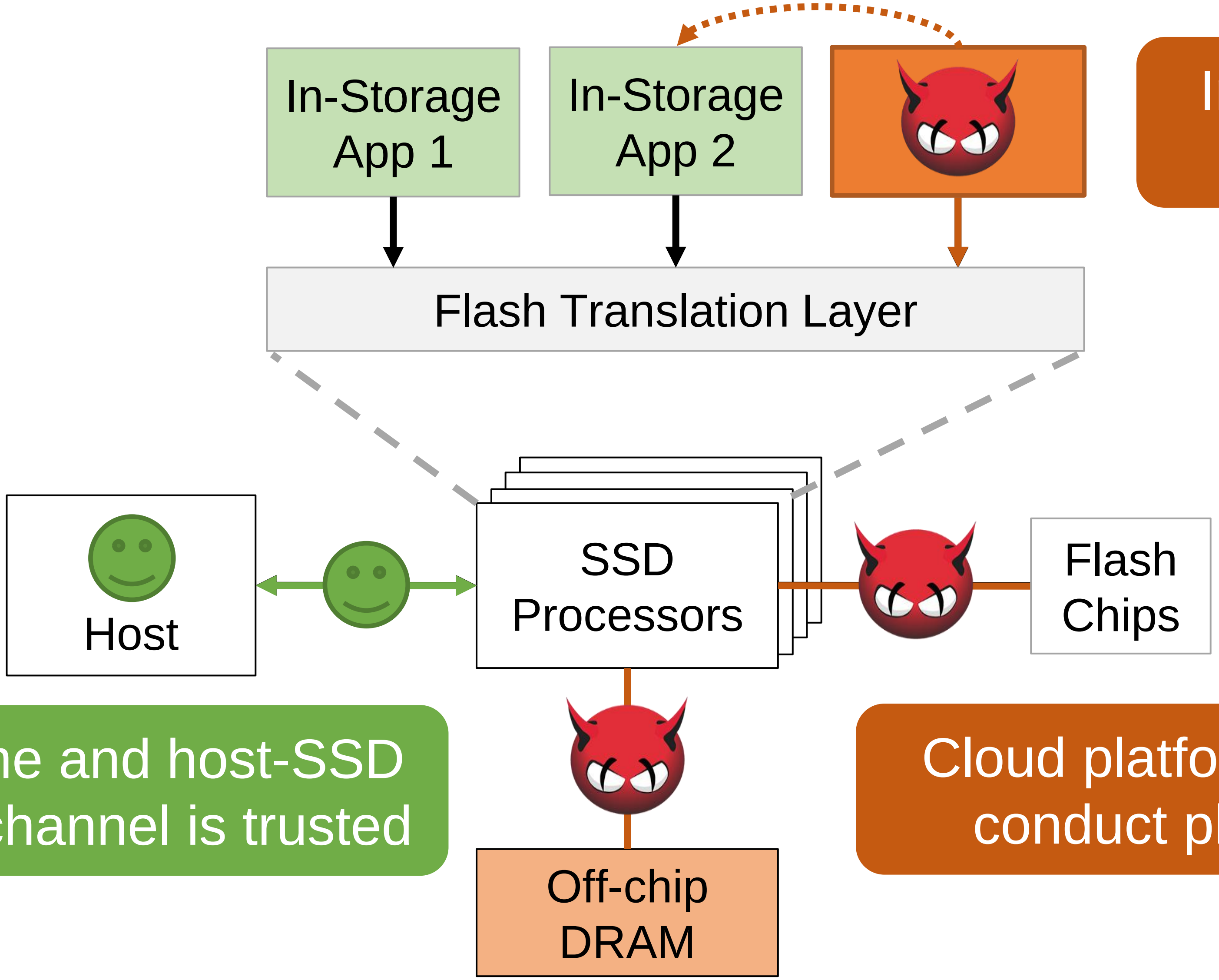
Threat Model



In-storage applications can be malicious

Cloud platform operator may conduct physical attacks

Threat Model

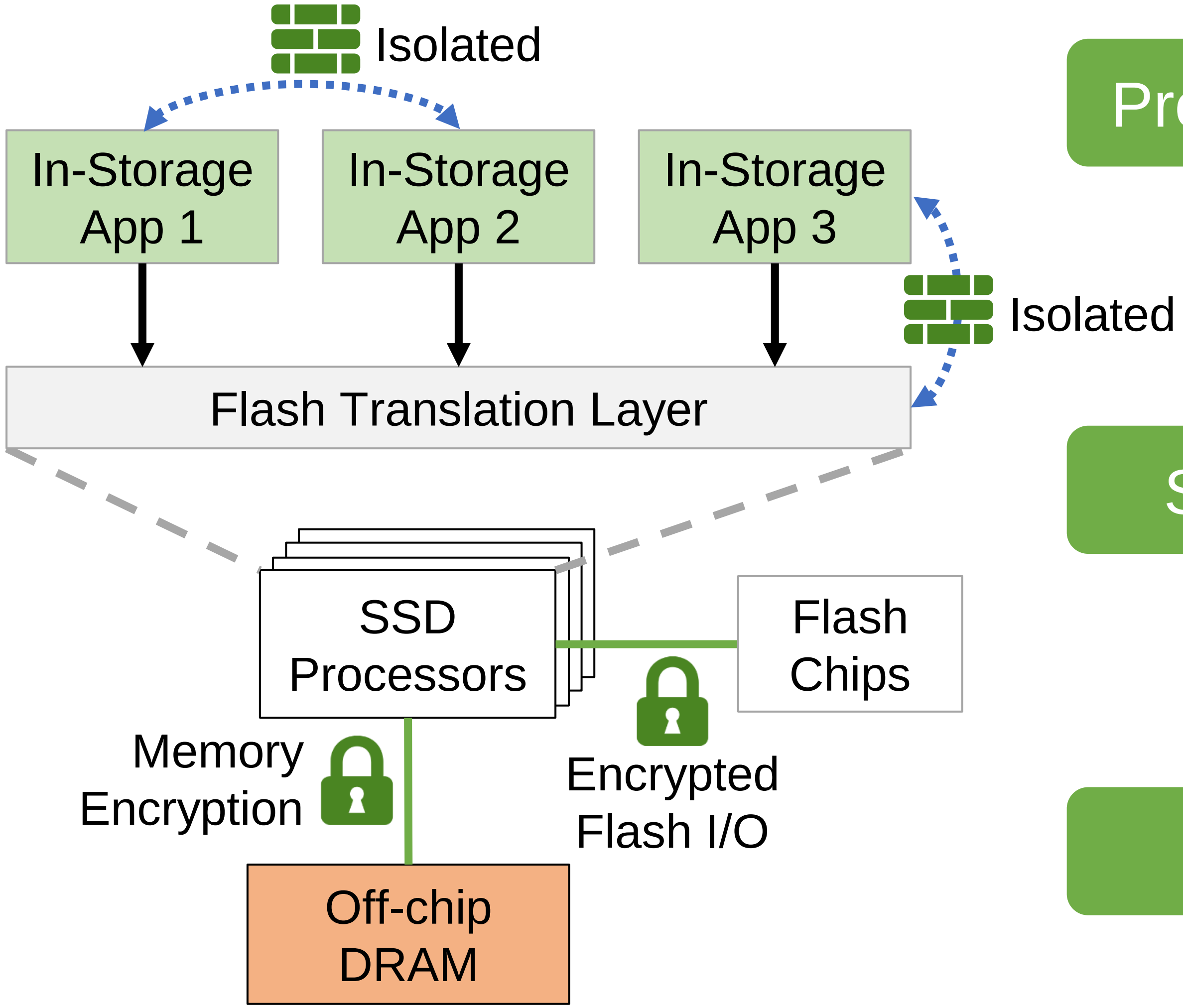


In-storage applications can be malicious

Host runtime and host-SSD offloading channel is trusted

Cloud platform operator may conduct physical attacks

Protecting Flash Translation Layer



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

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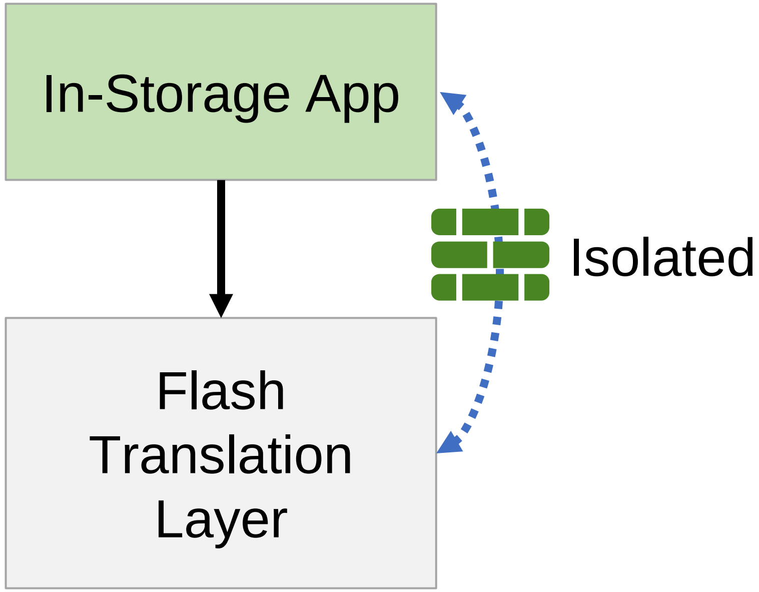

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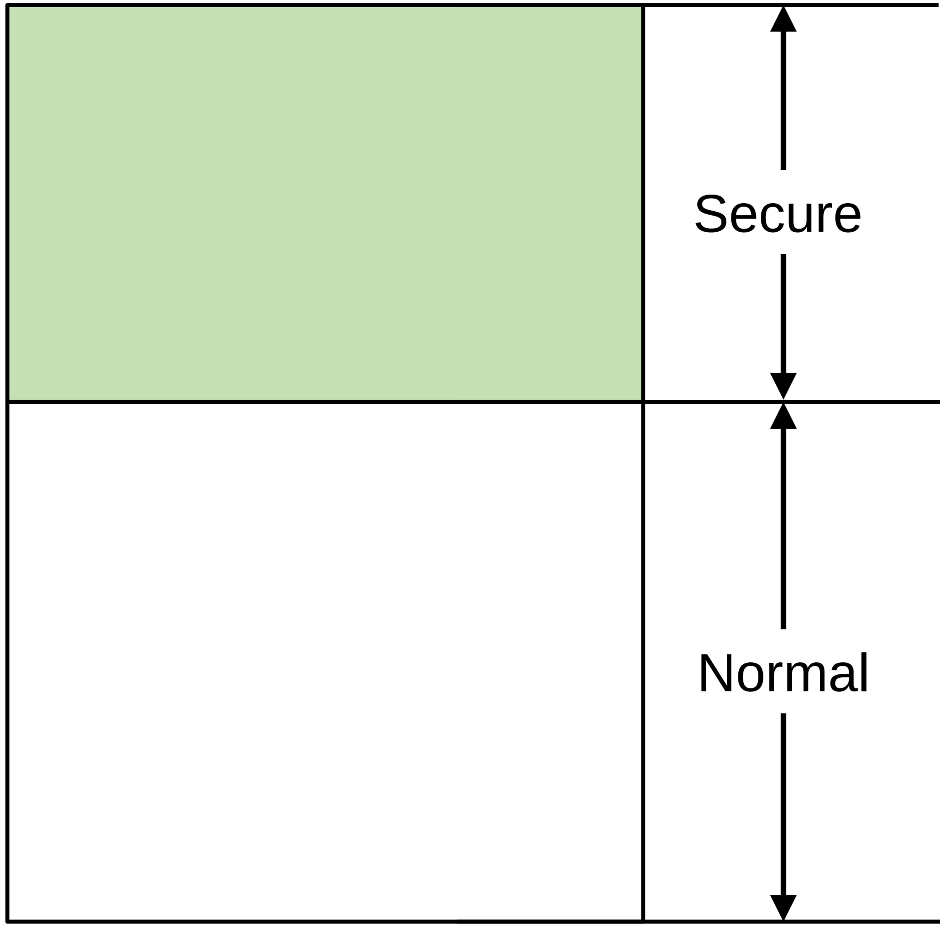

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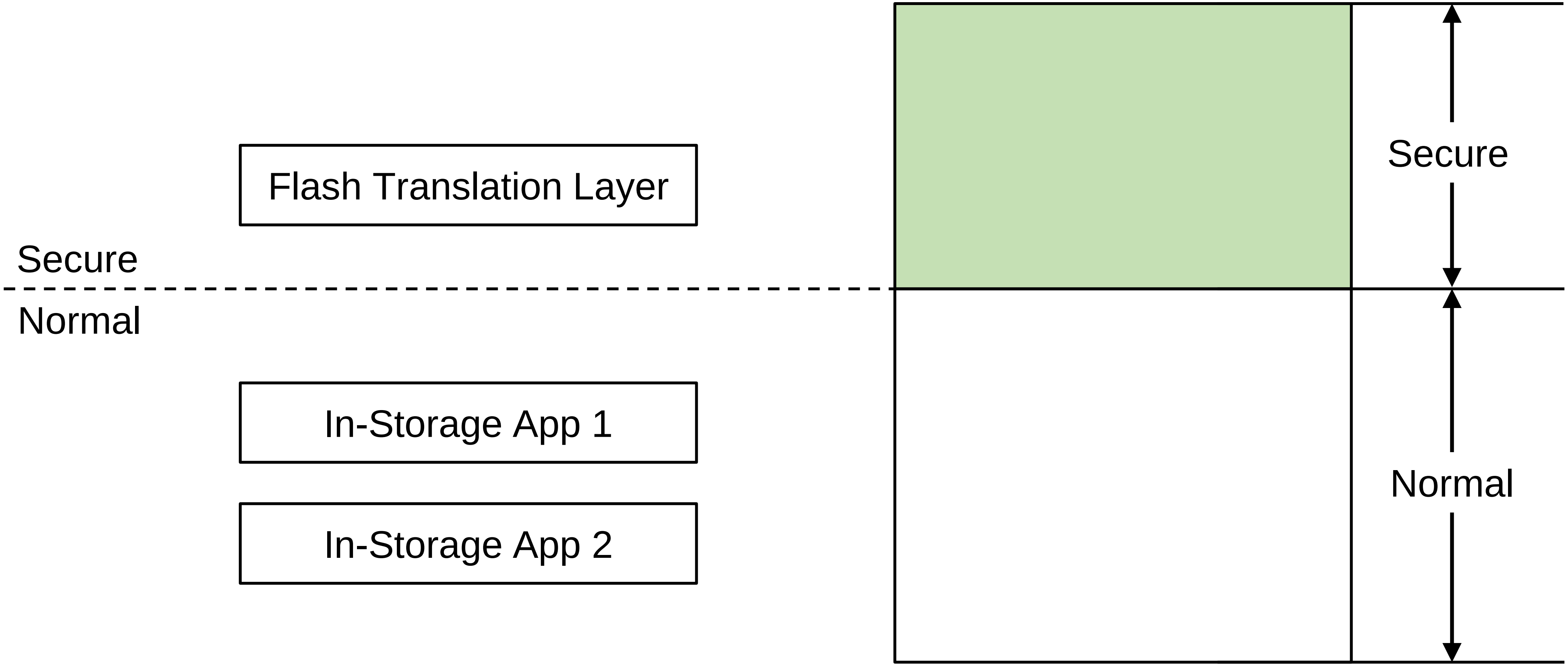

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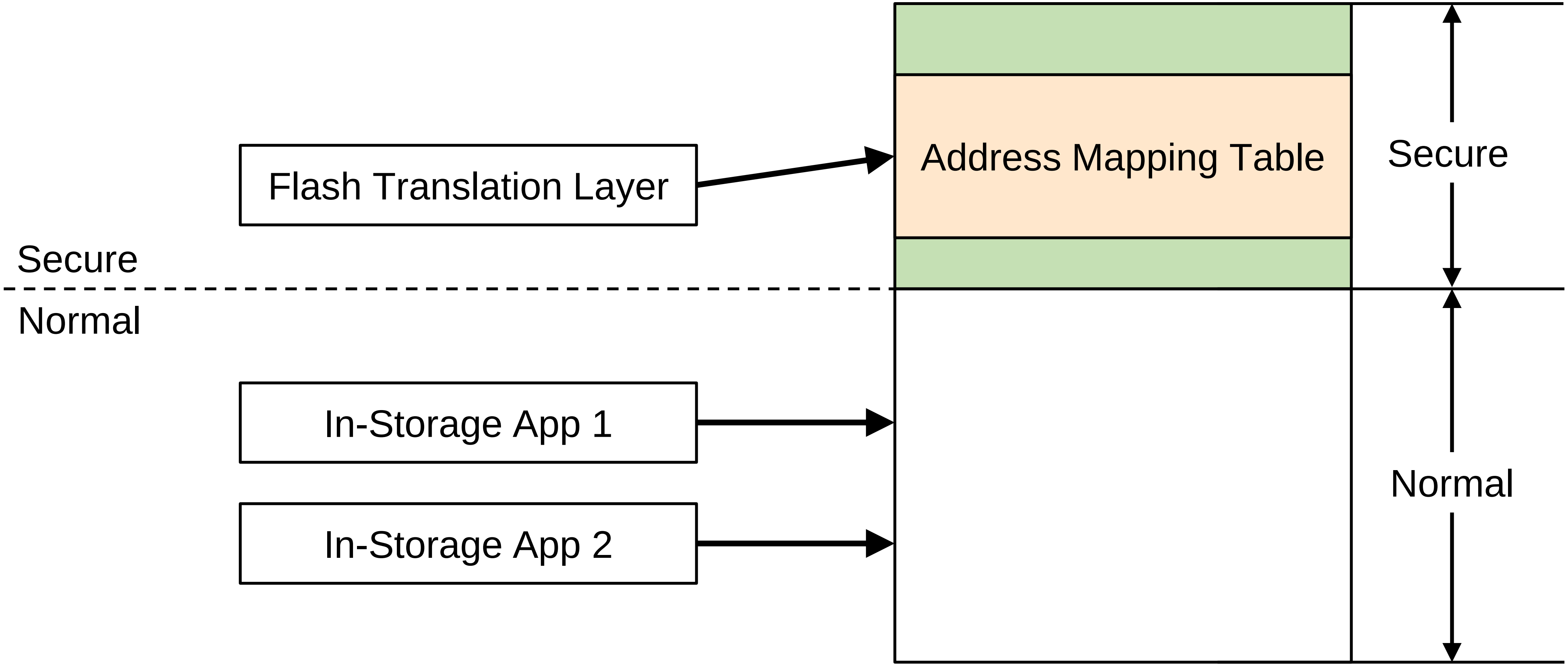

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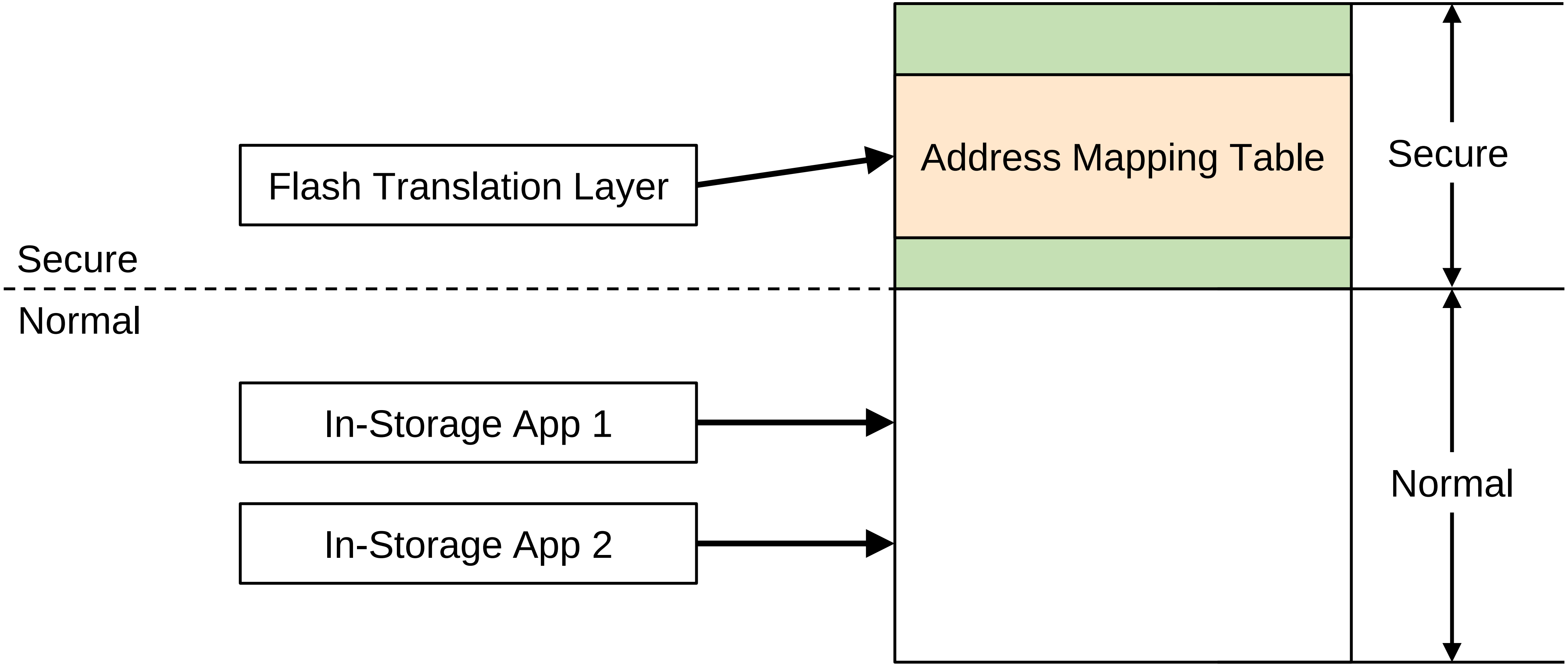
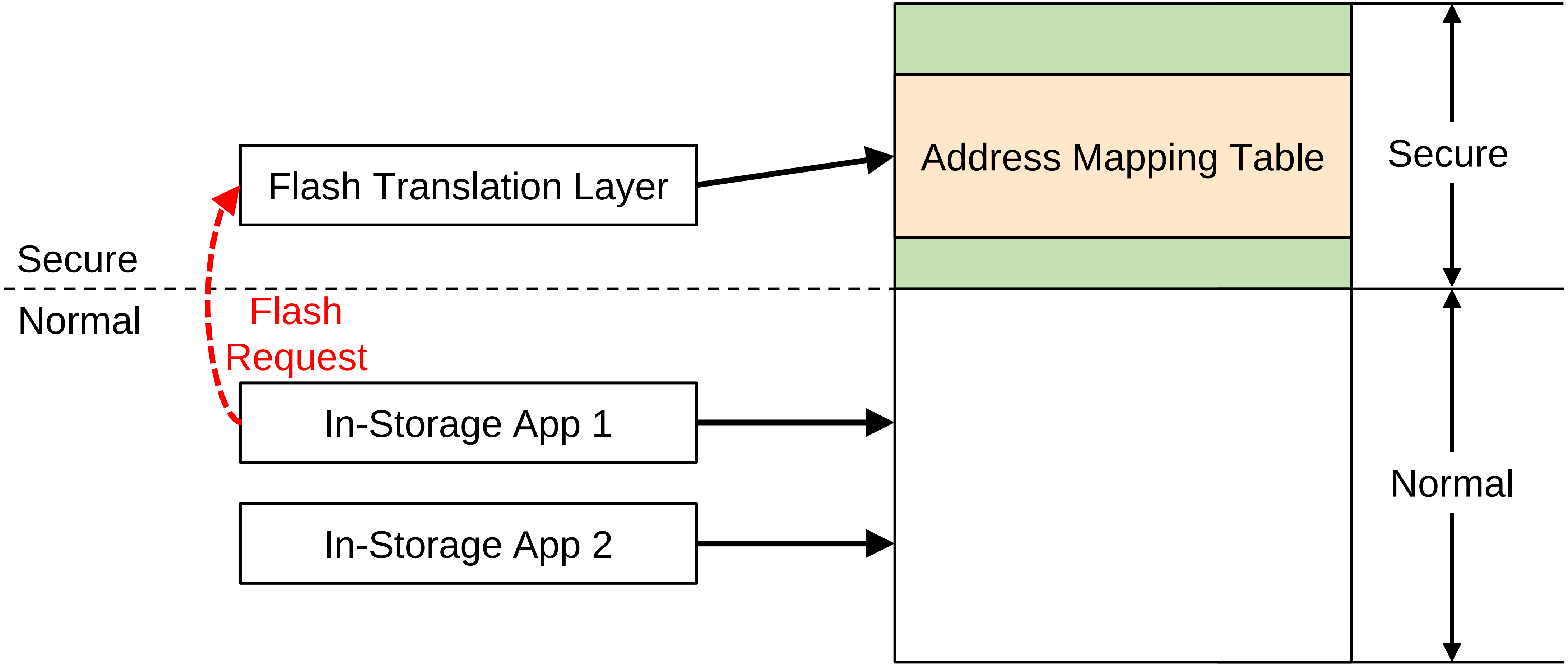


Naively applying TrustZone partitioning incurs significant performance penalty!

Protecting Flash Translation Layer



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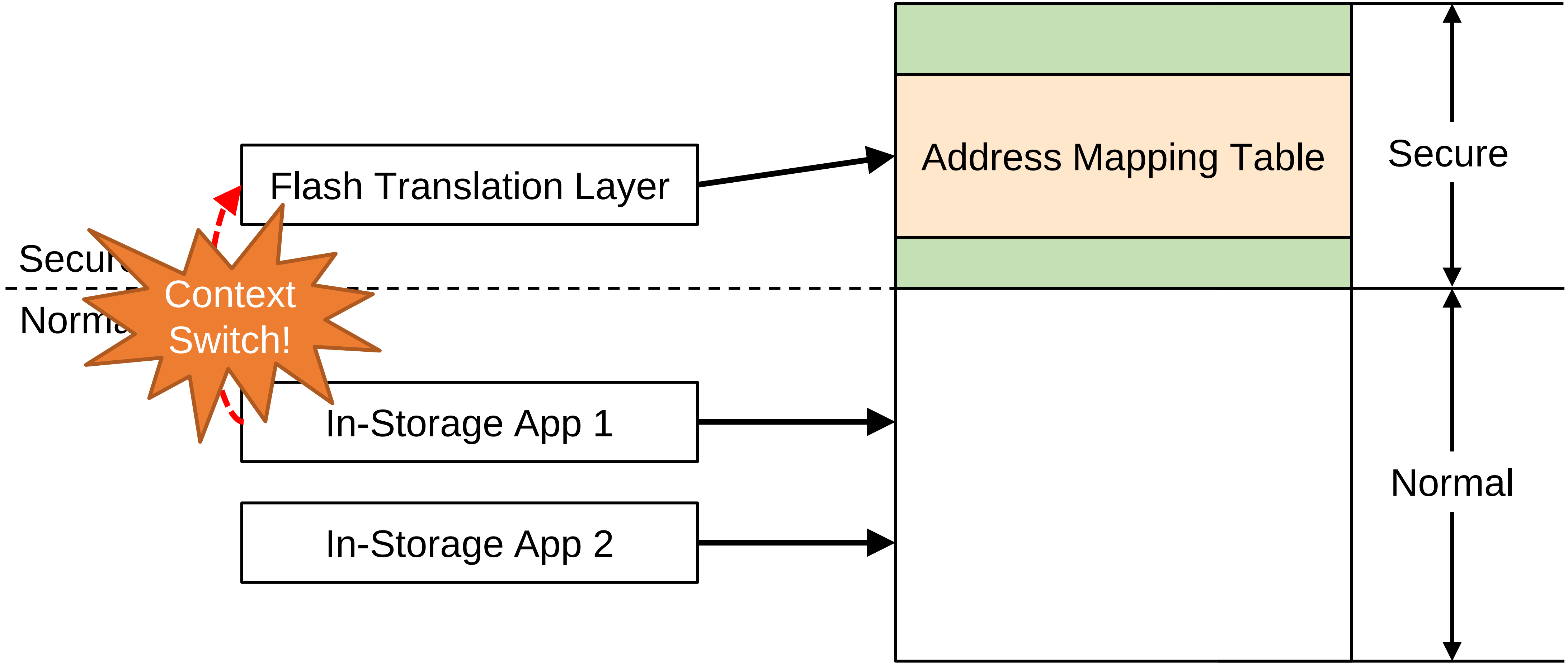

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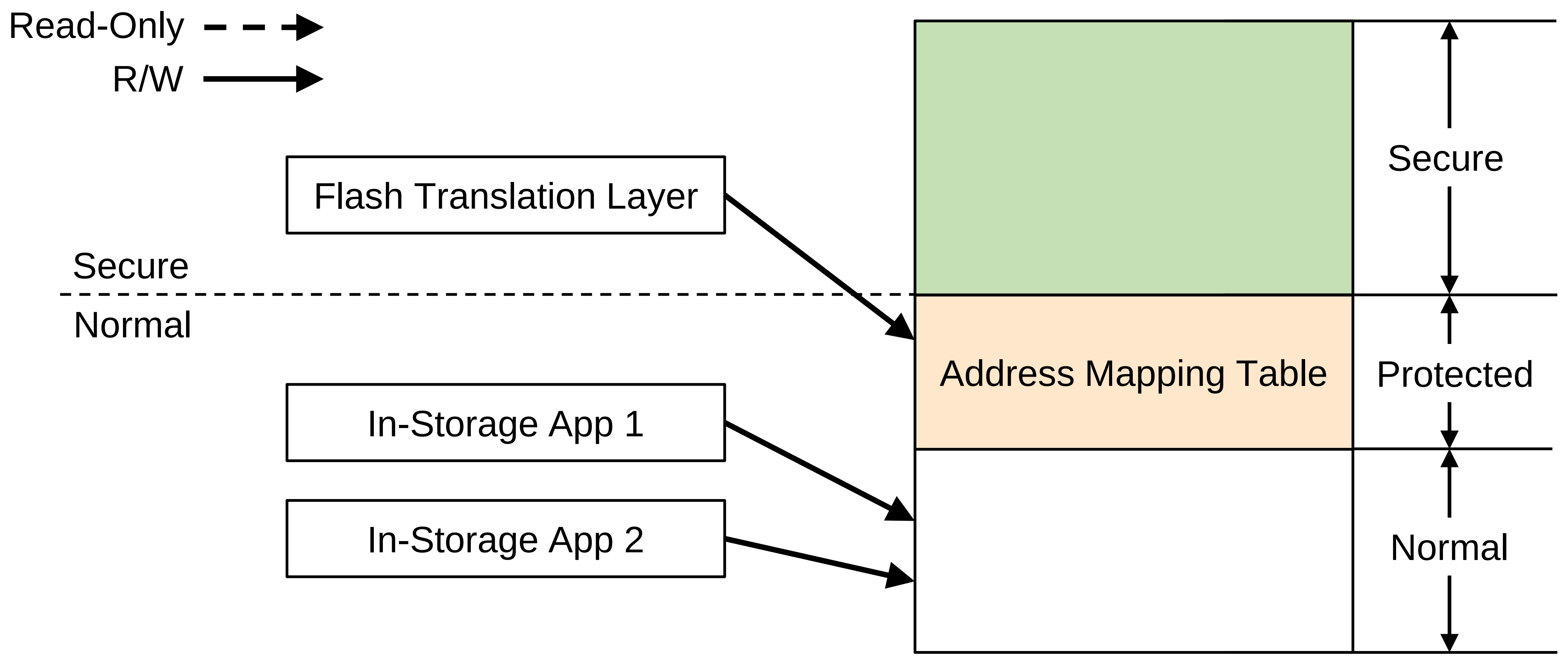


Read-Only

R/W

Flash Translation Layer

Secure

Normal

In-Storage App 1

In-Storage App 2

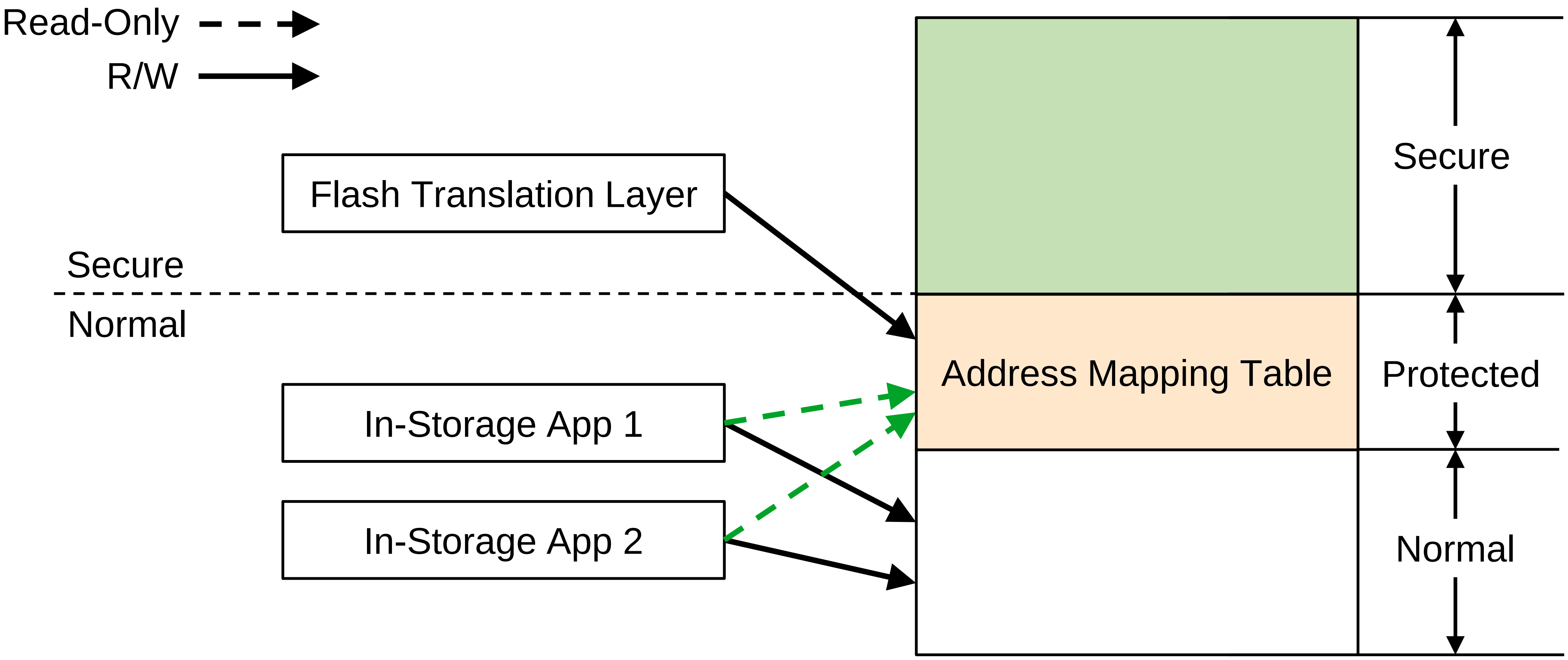
Address Mapping Table

Secure

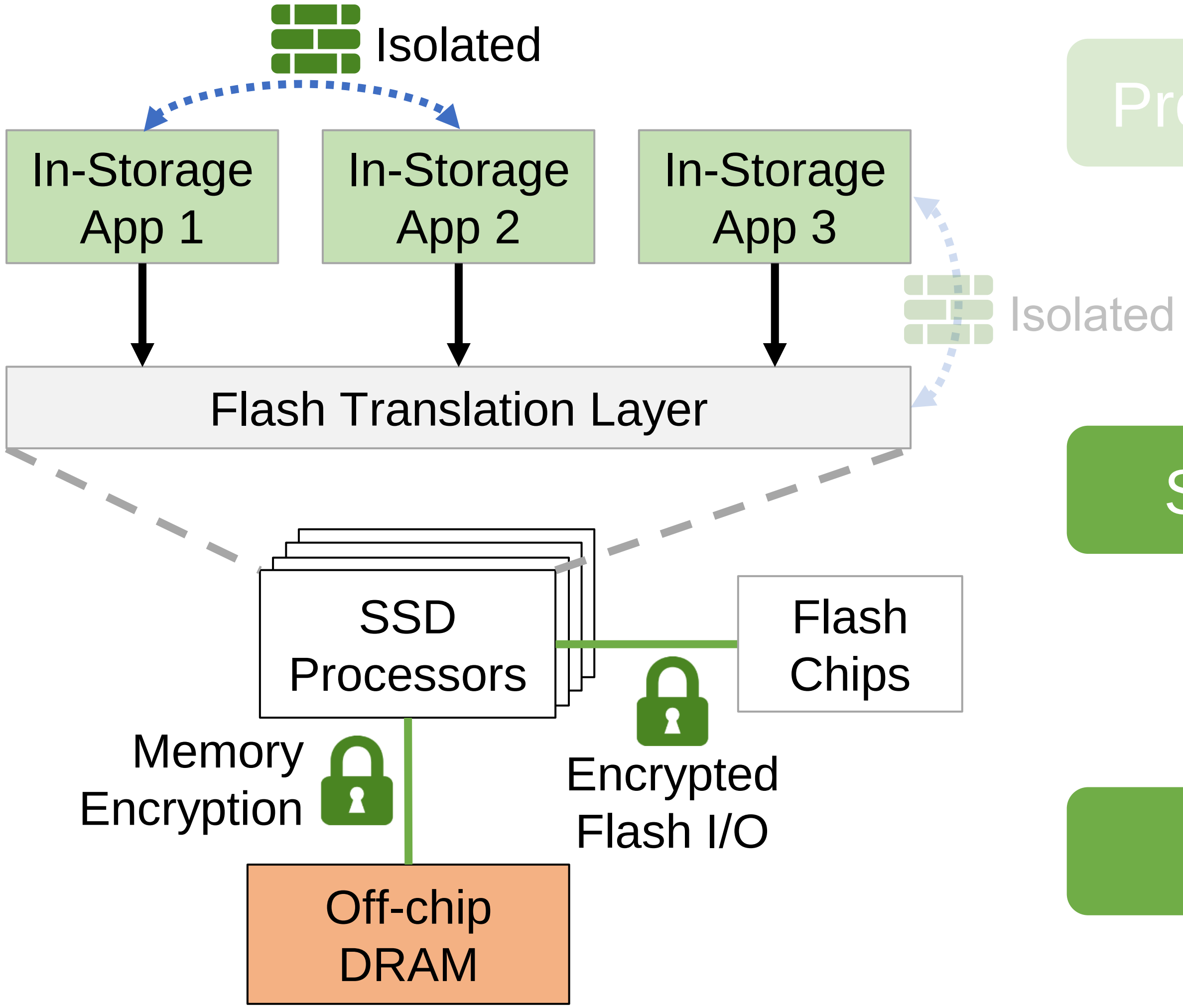
Protected

Normal

Protecting Flash Translation Layer



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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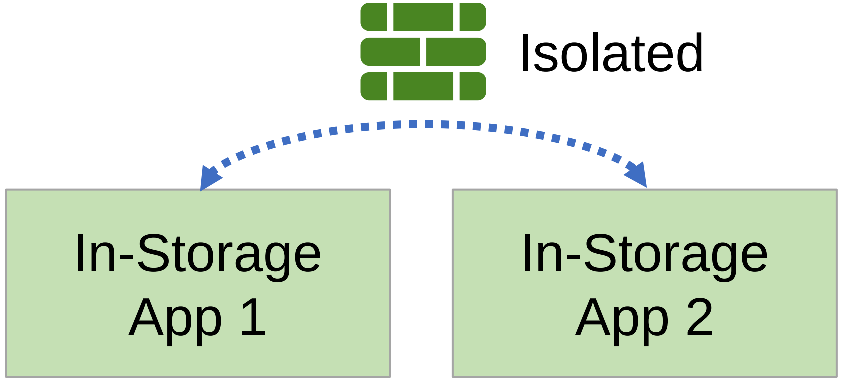
Securing data against physical attacks

Isolating In-Storage Applications



Security isolation between in-storage apps

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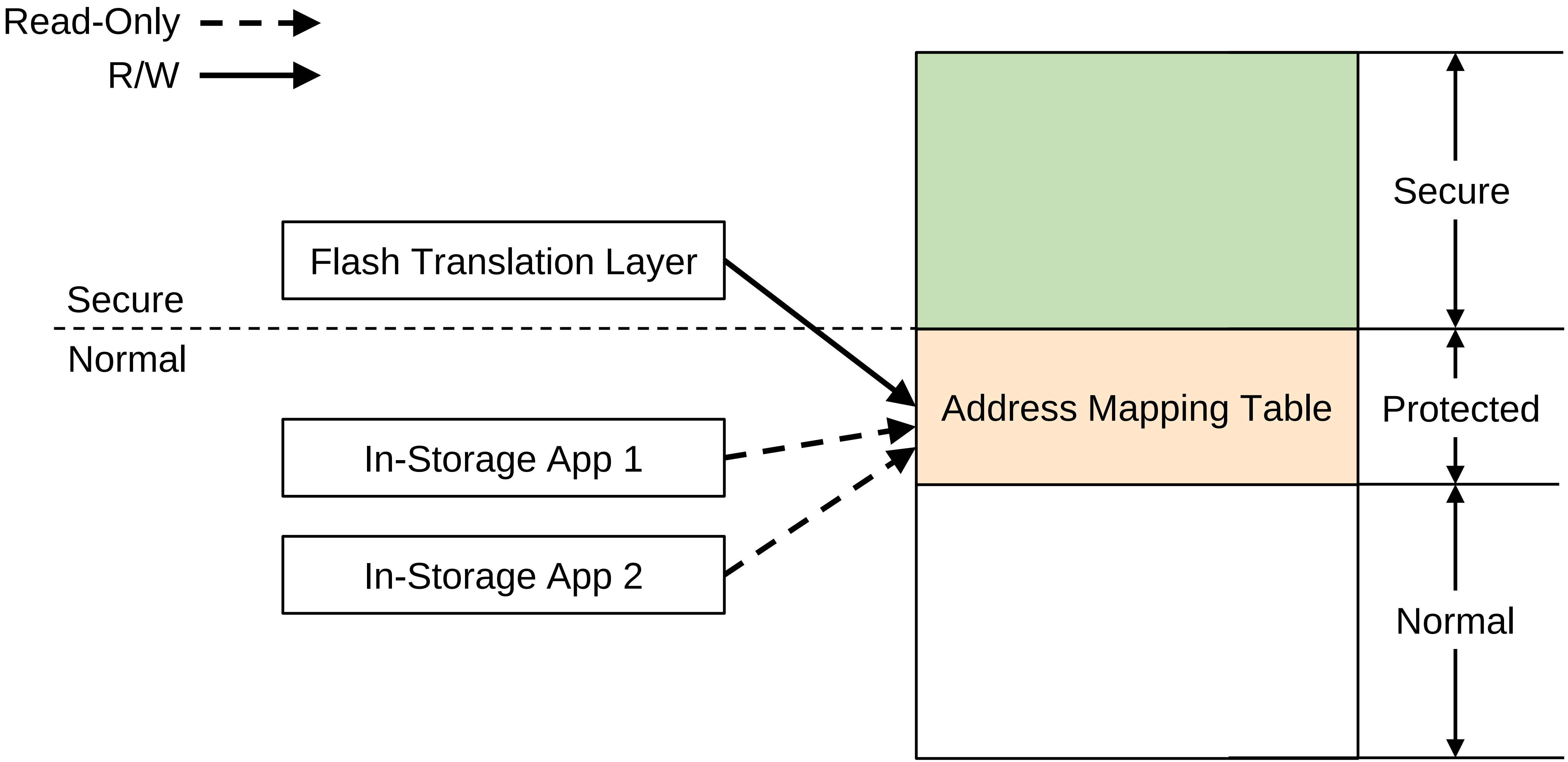

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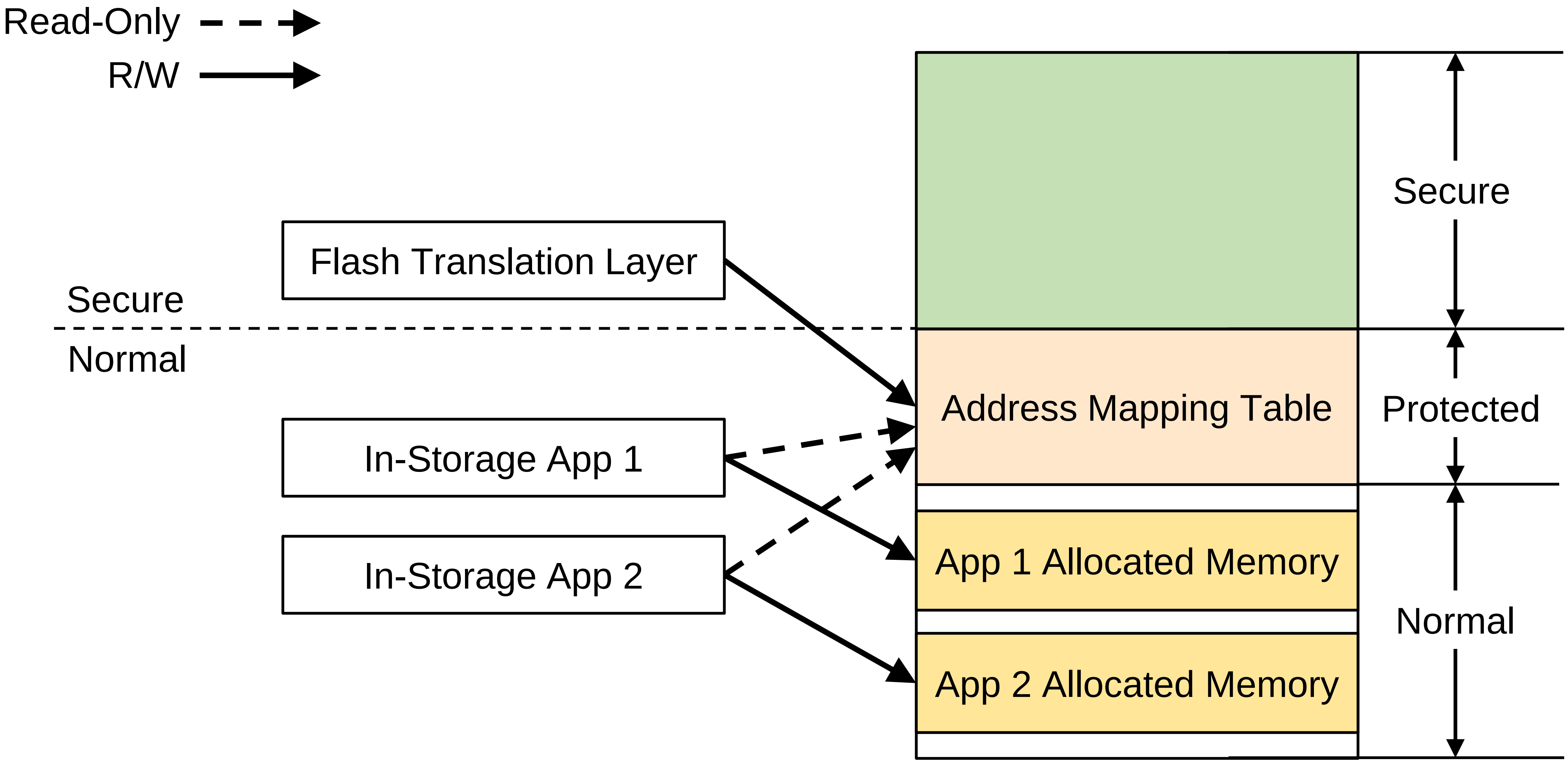

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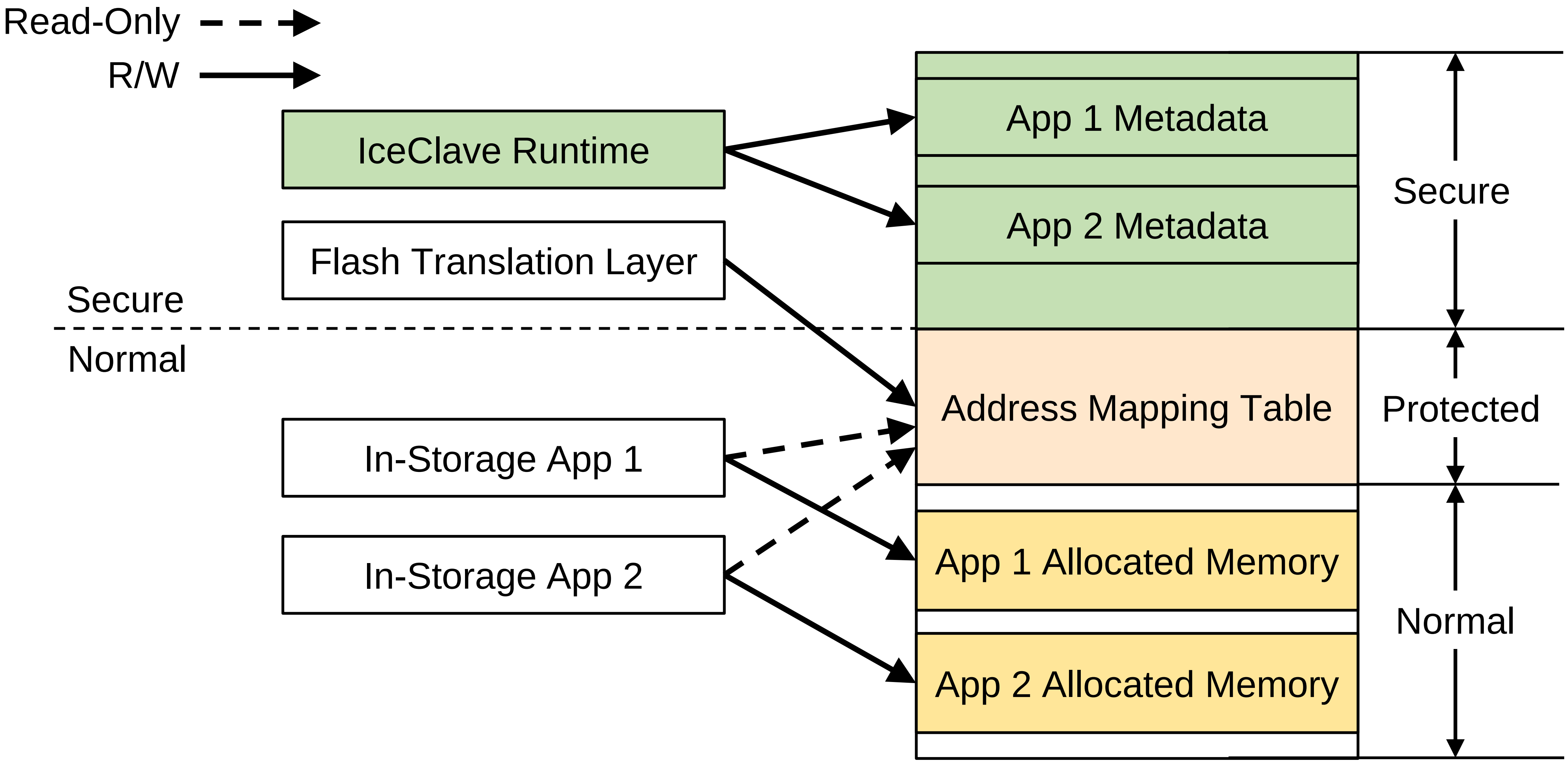

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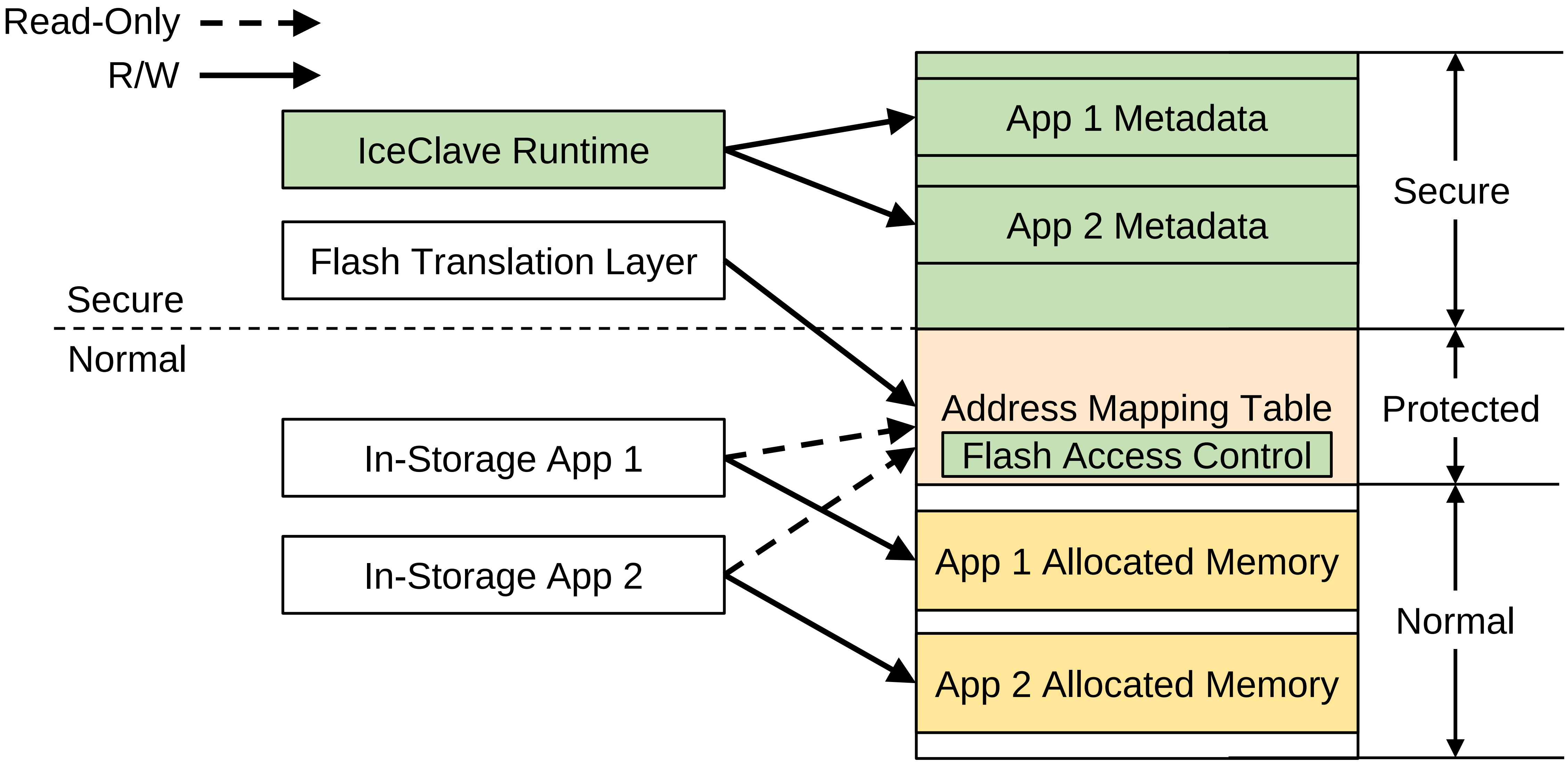
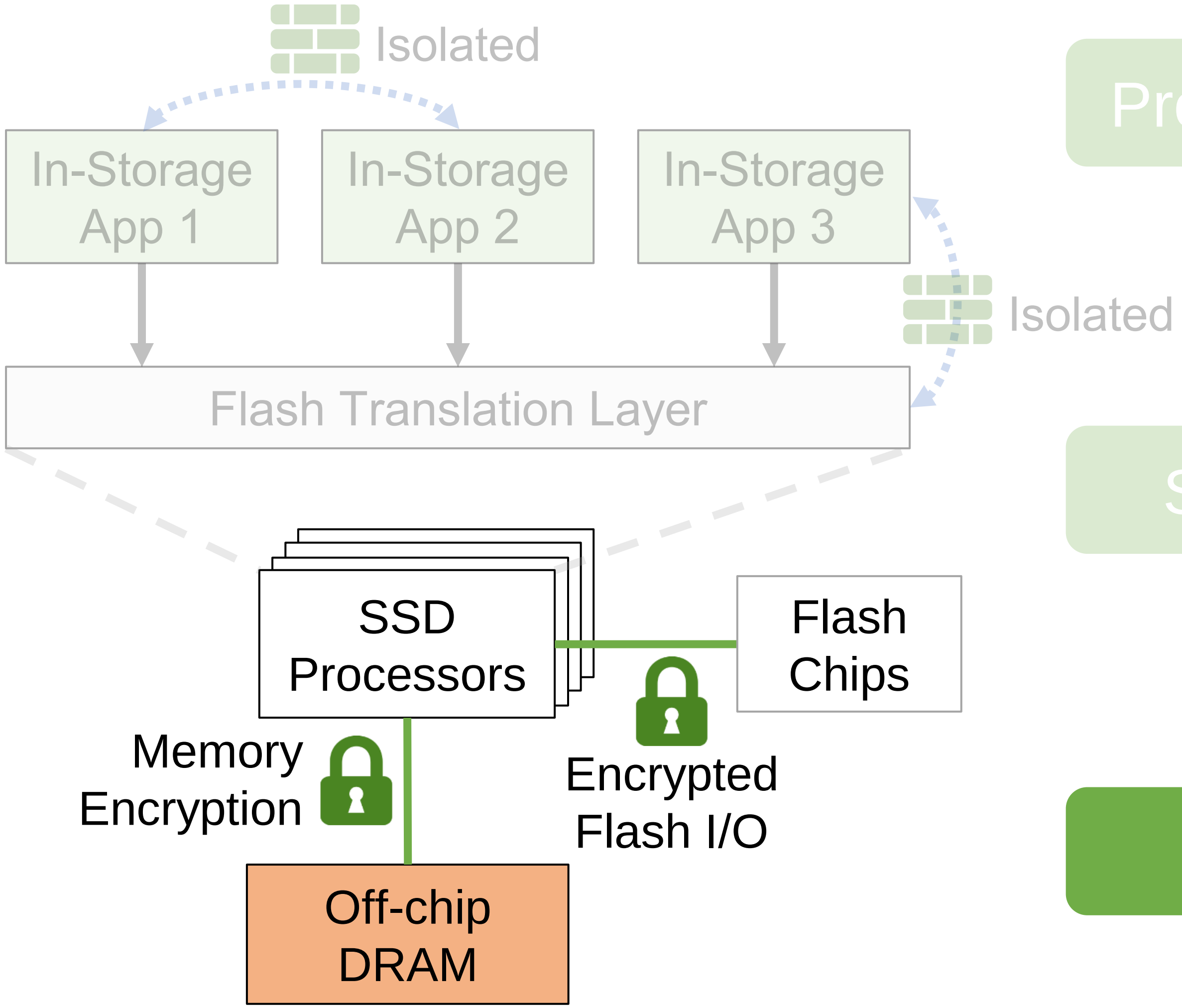


Protecting Against Physical Attacks



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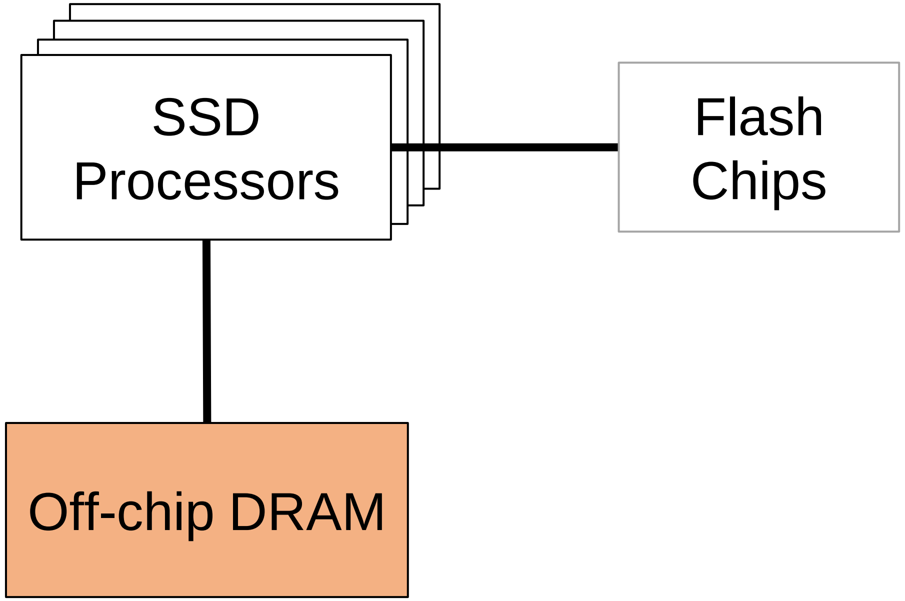

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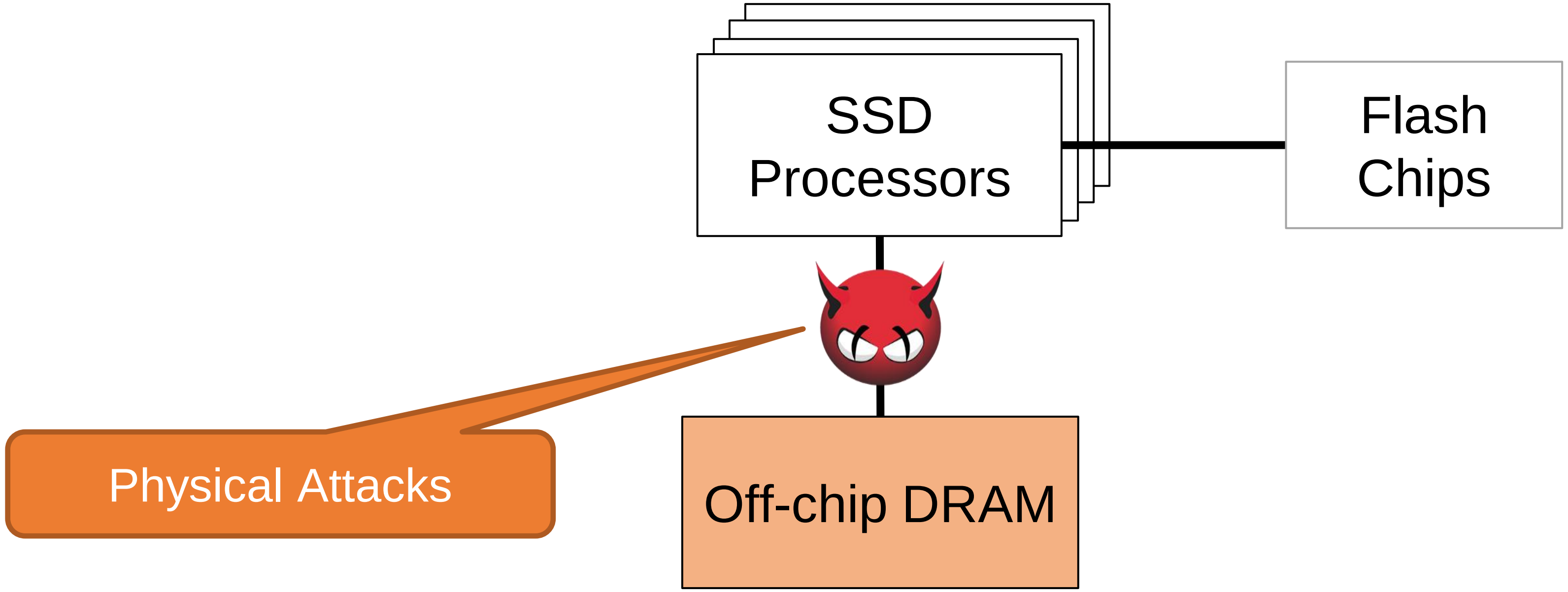

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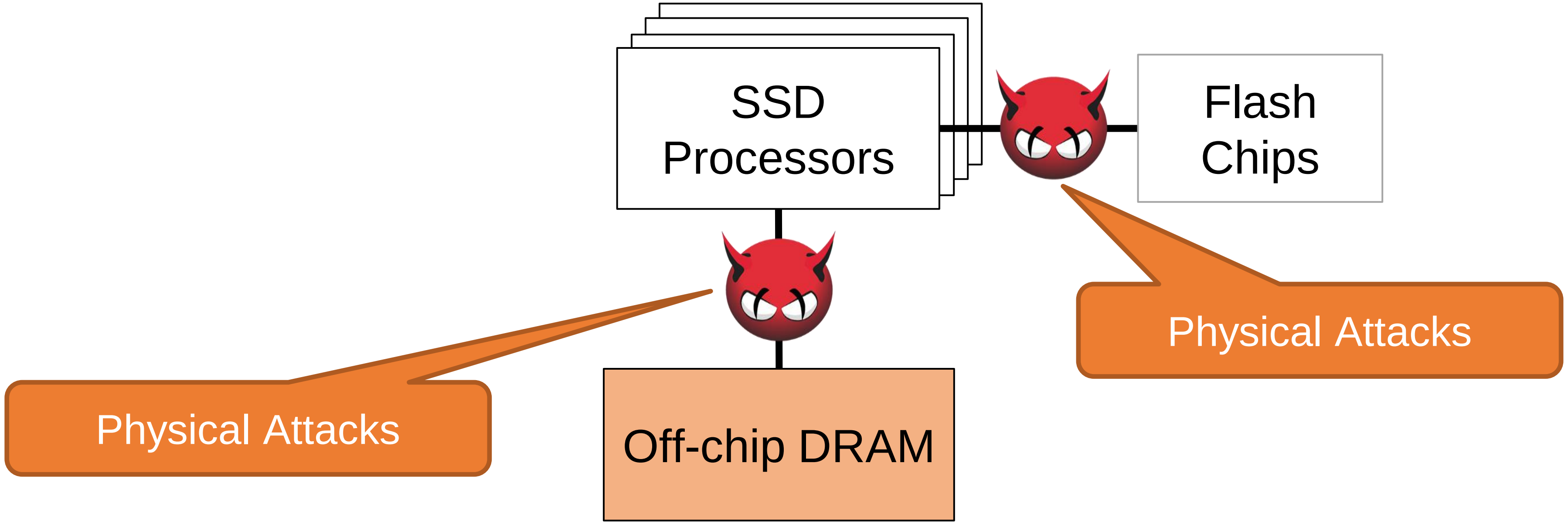
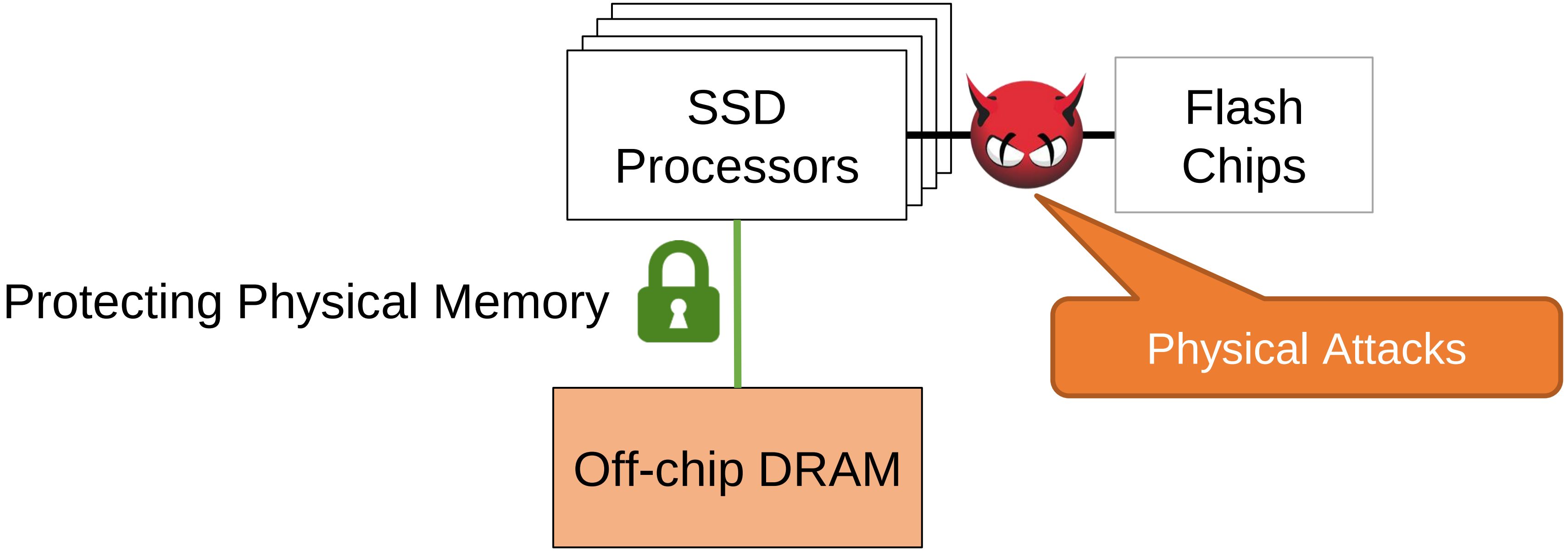


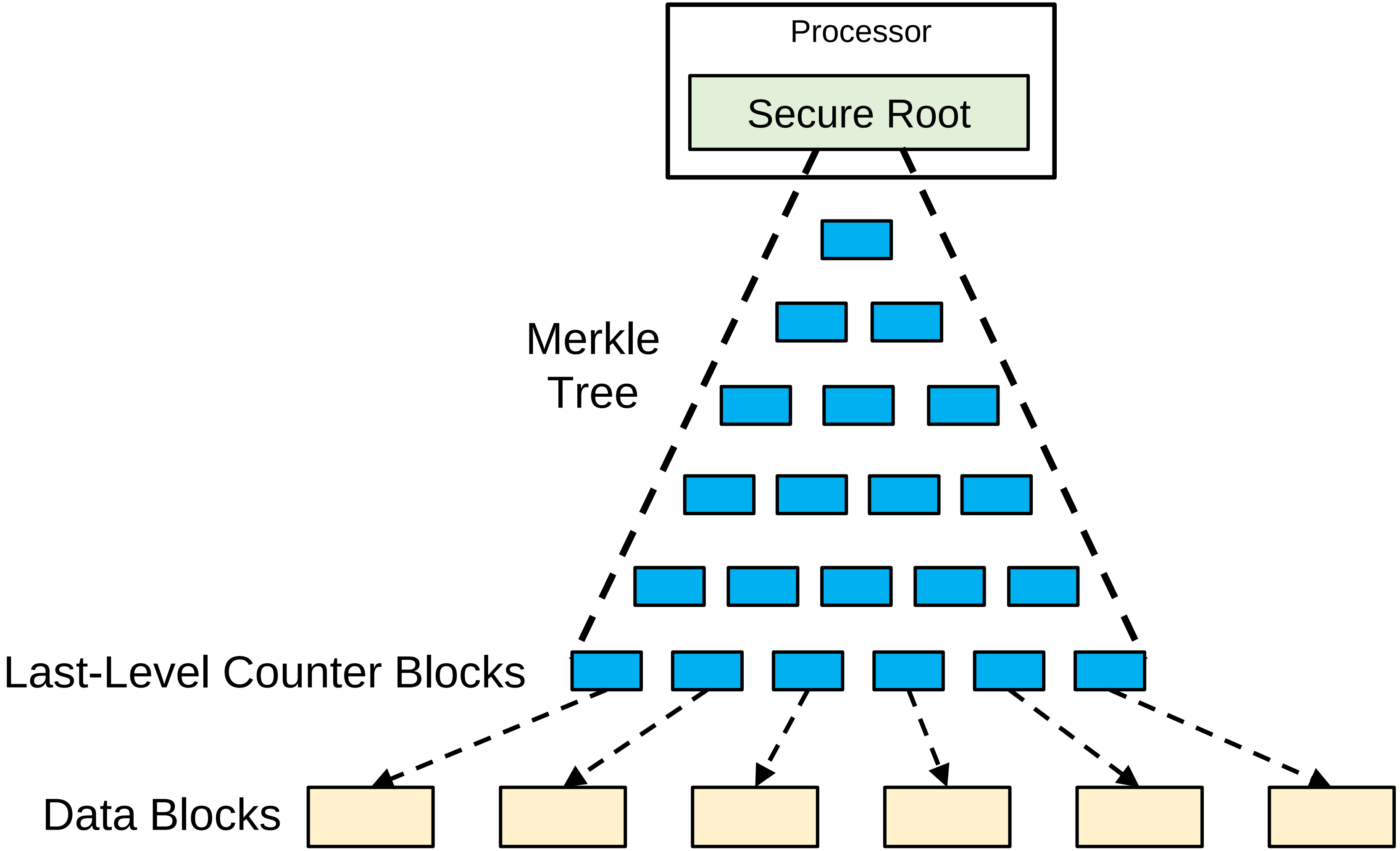
Securing data against physical attacks

Protecting Against Physical Attacks

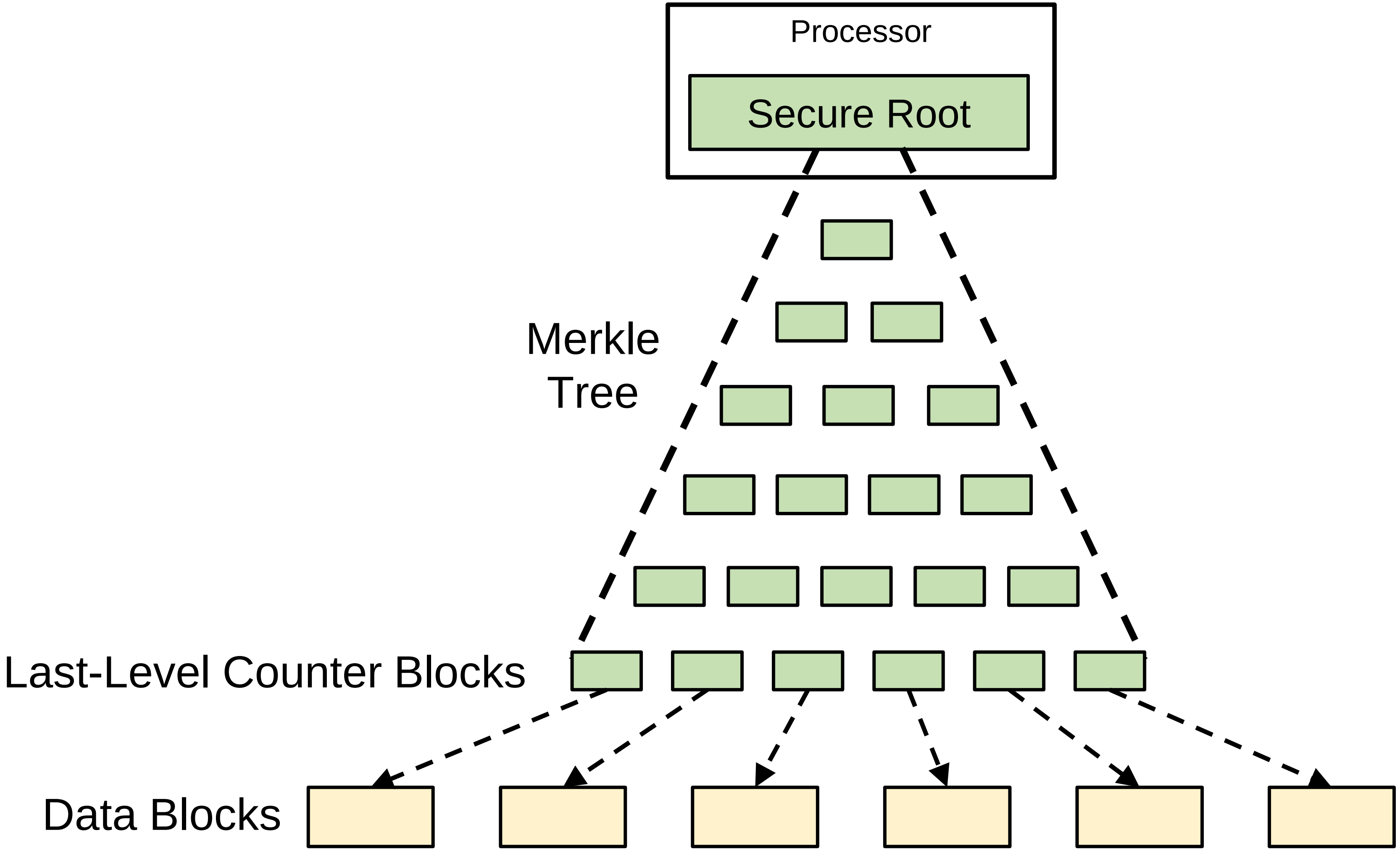


Securing data against physical attacks

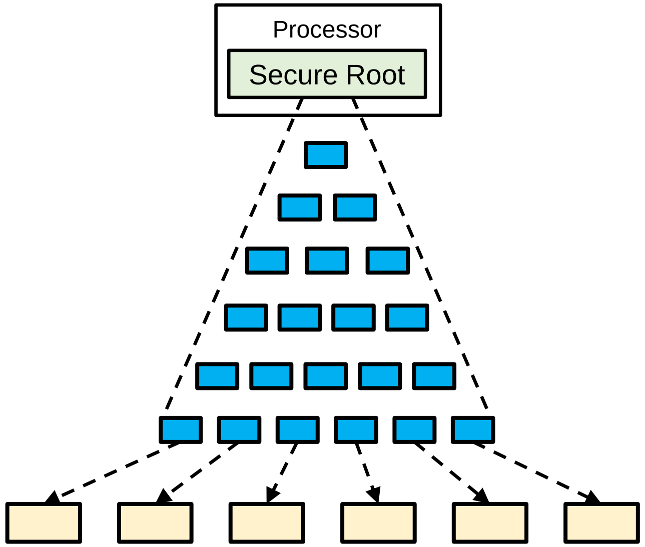
Protecting Physical Memory



Protecting Physical Memory

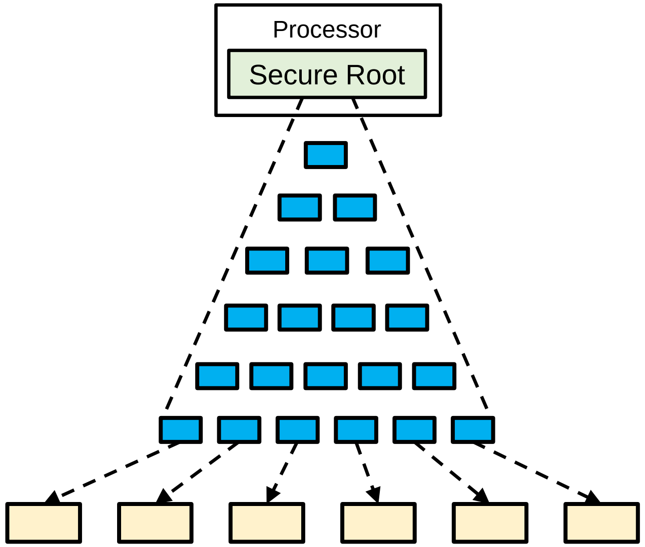


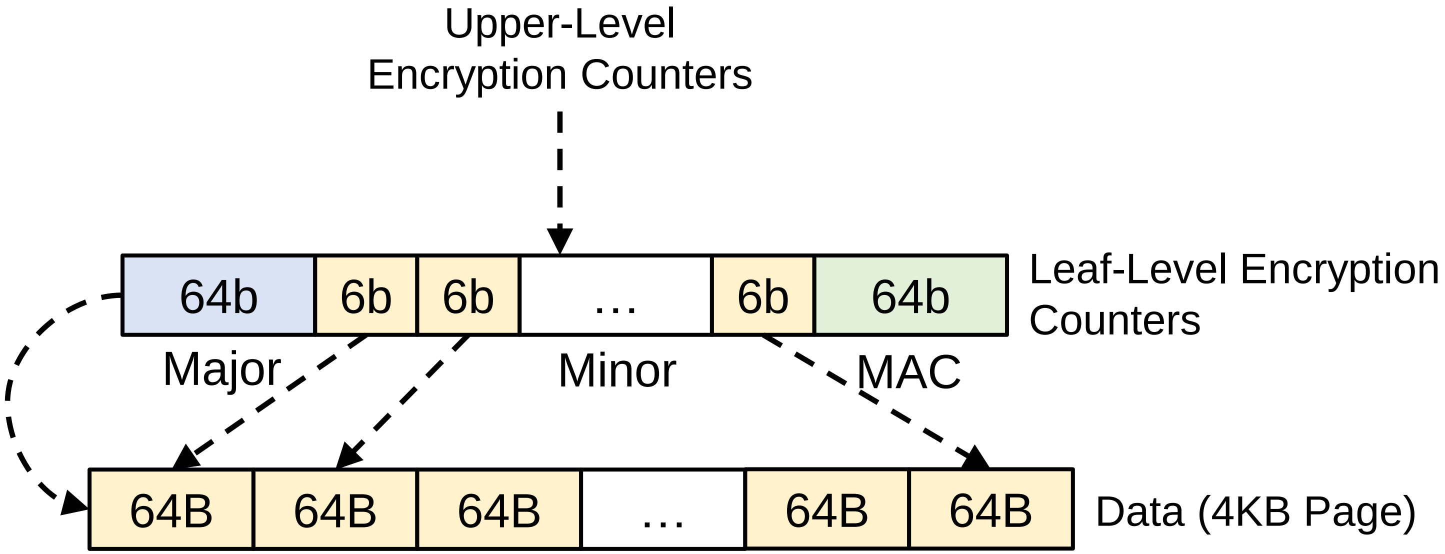
Protecting Physical Memory



Split Counter Mode (ISCA’06)

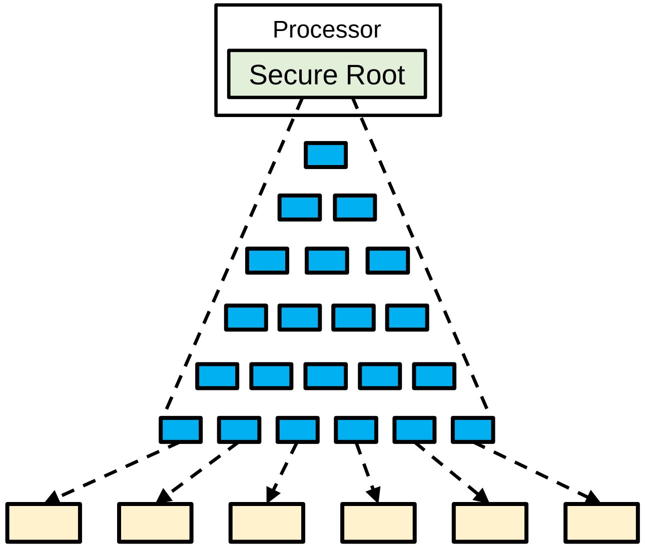
Protecting Physical Memory

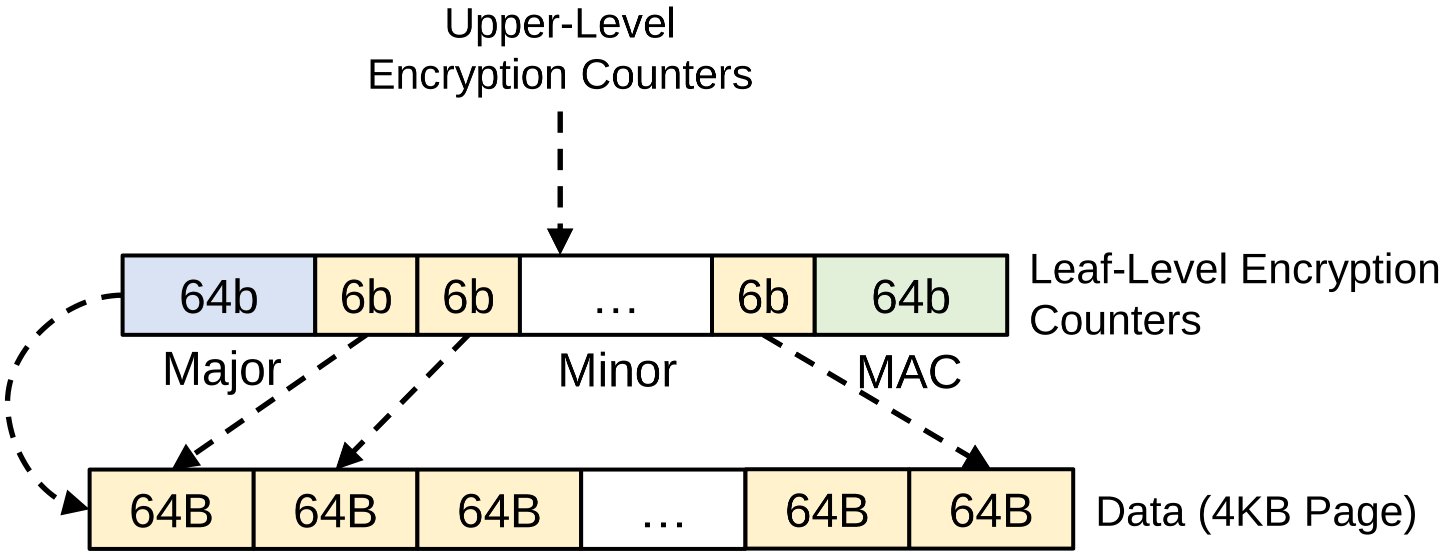




Split Counter Mode (ISCA’06)

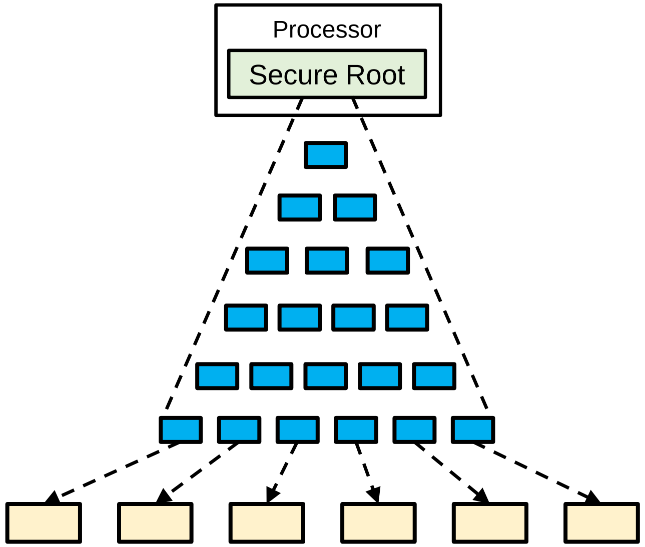
Protecting Physical Memory

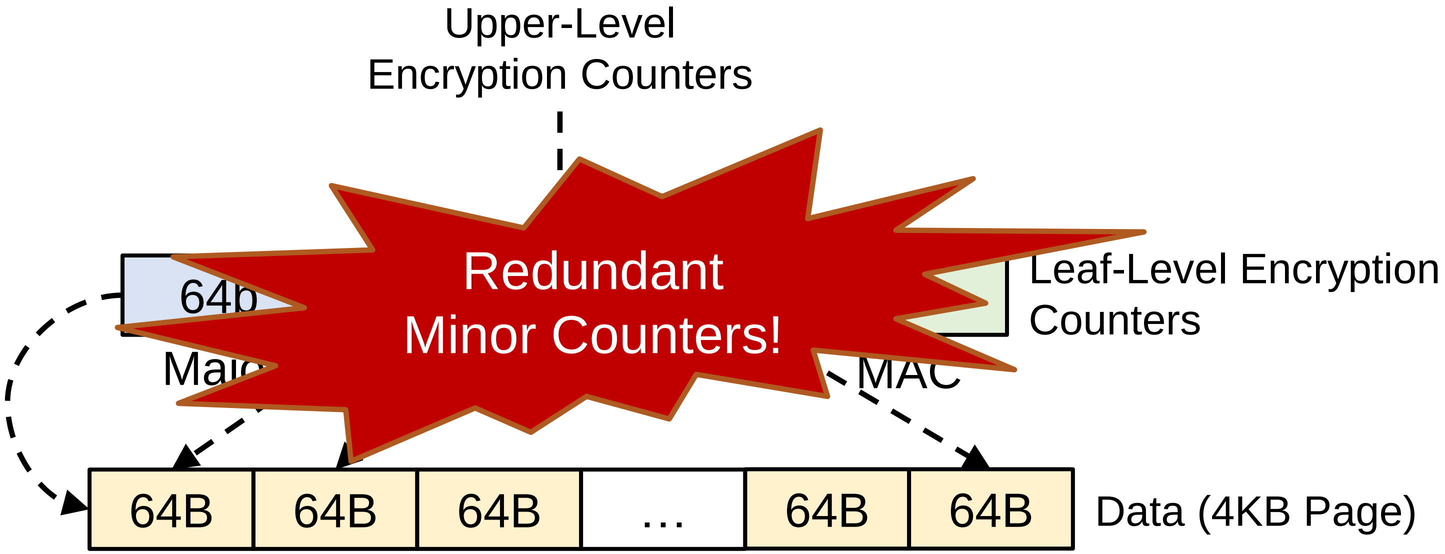




In-storage programs are read-intensive

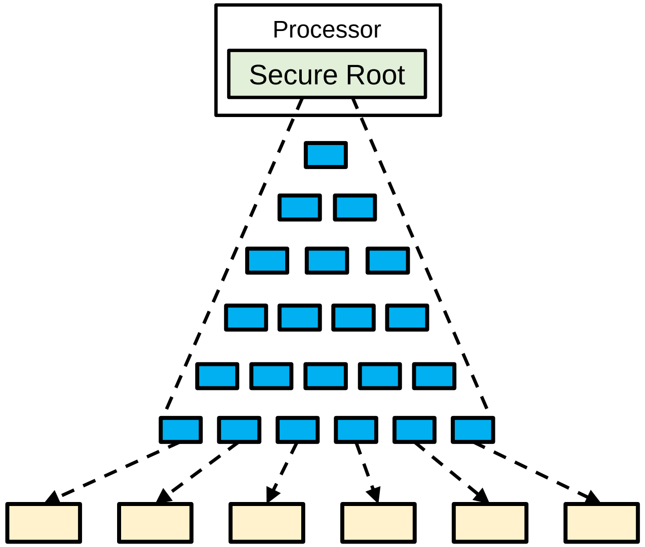
Protecting Physical Memory

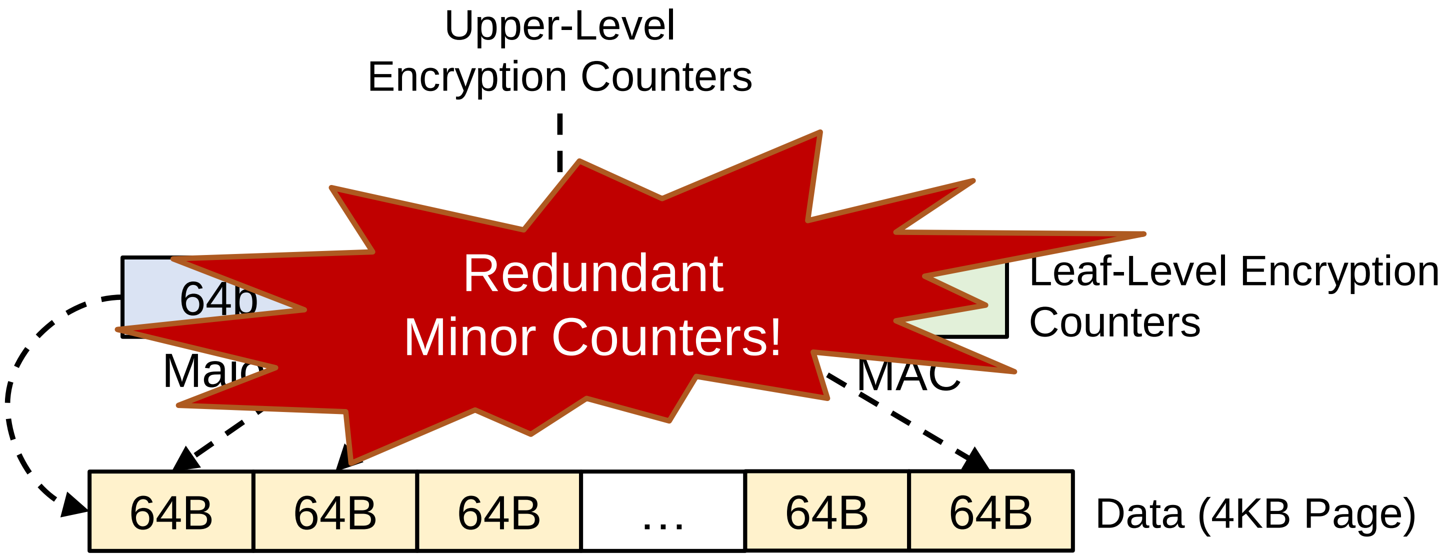




In-storage programs are read-intensive

Protecting Physical Memory

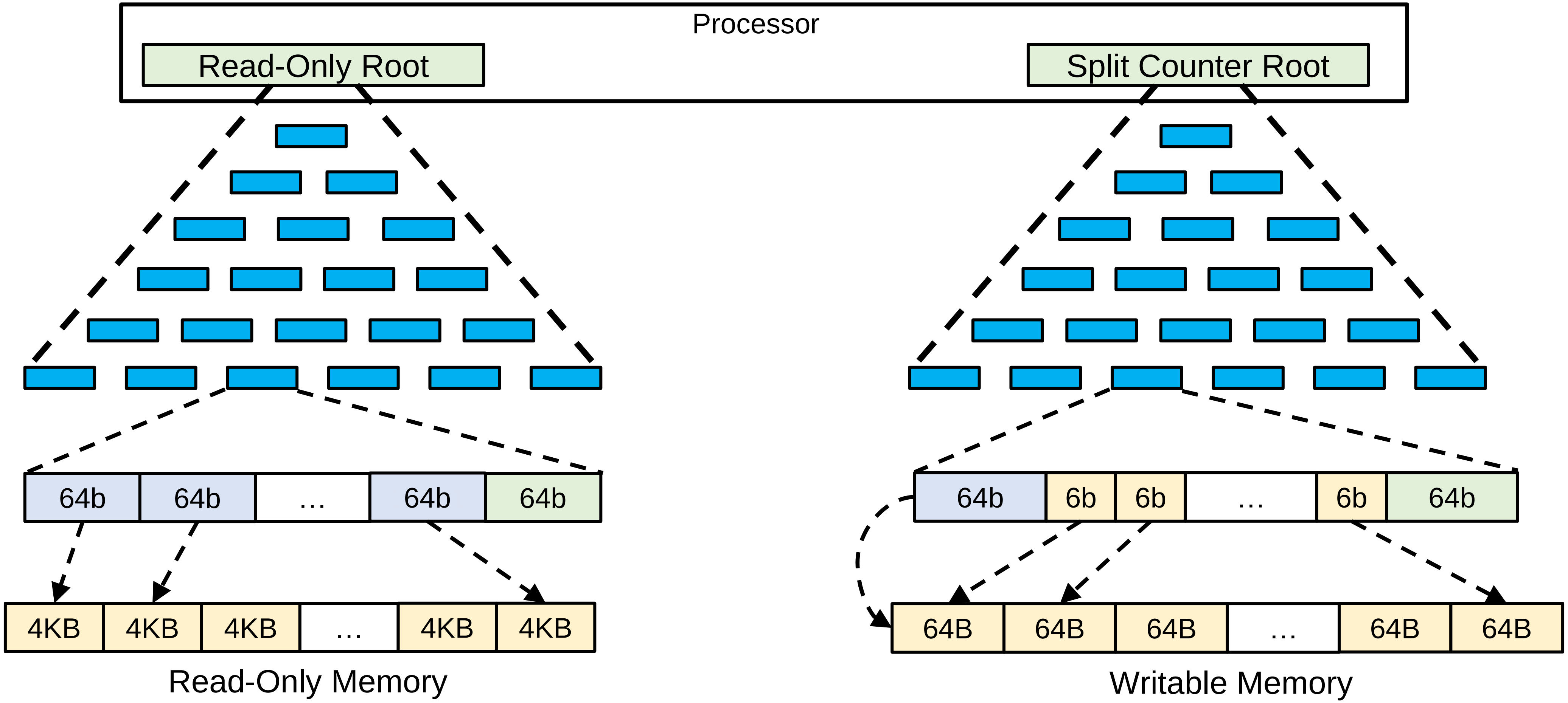




In-storage programs are read-intensive

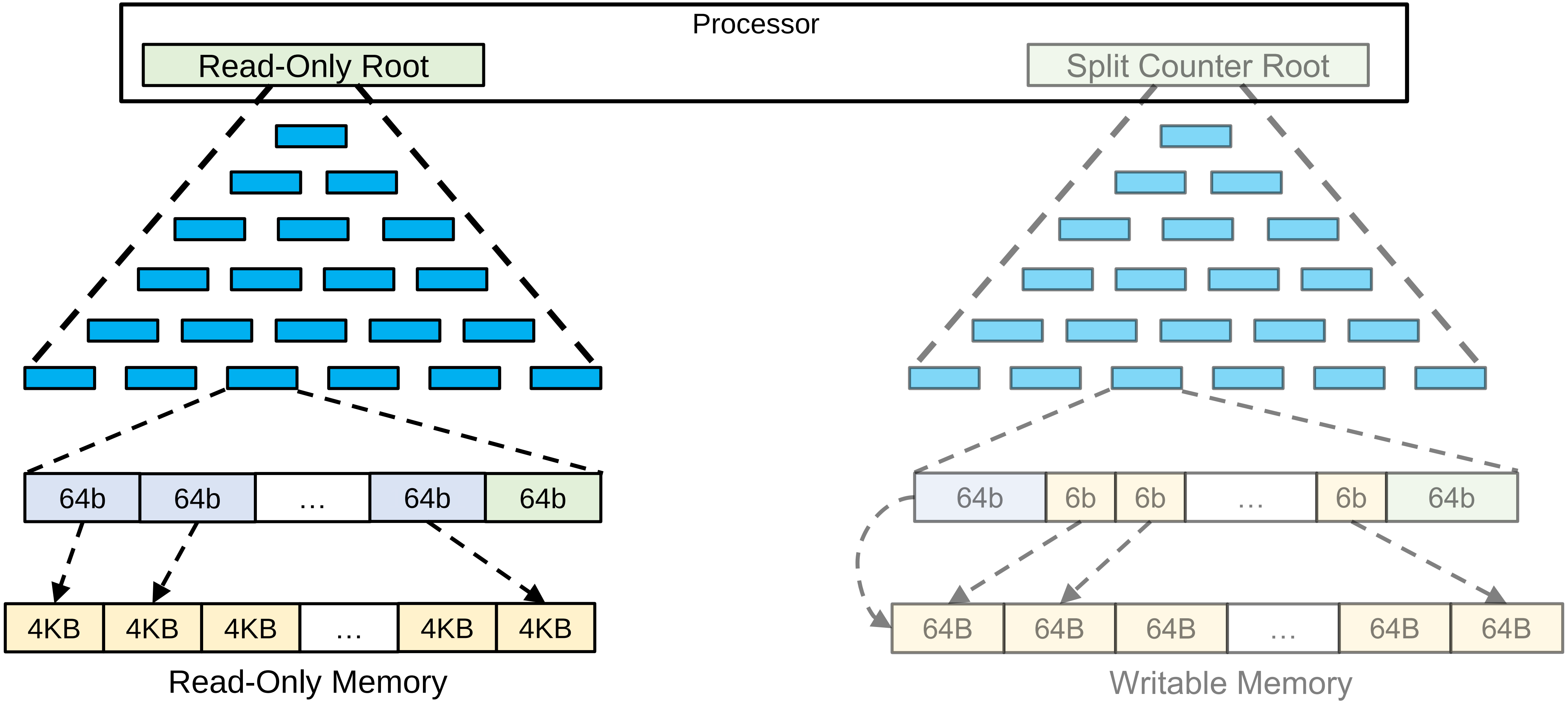
State-of-the-art Split Counter Mode is not optimal for in-storage computing

Protecting Physical Memory



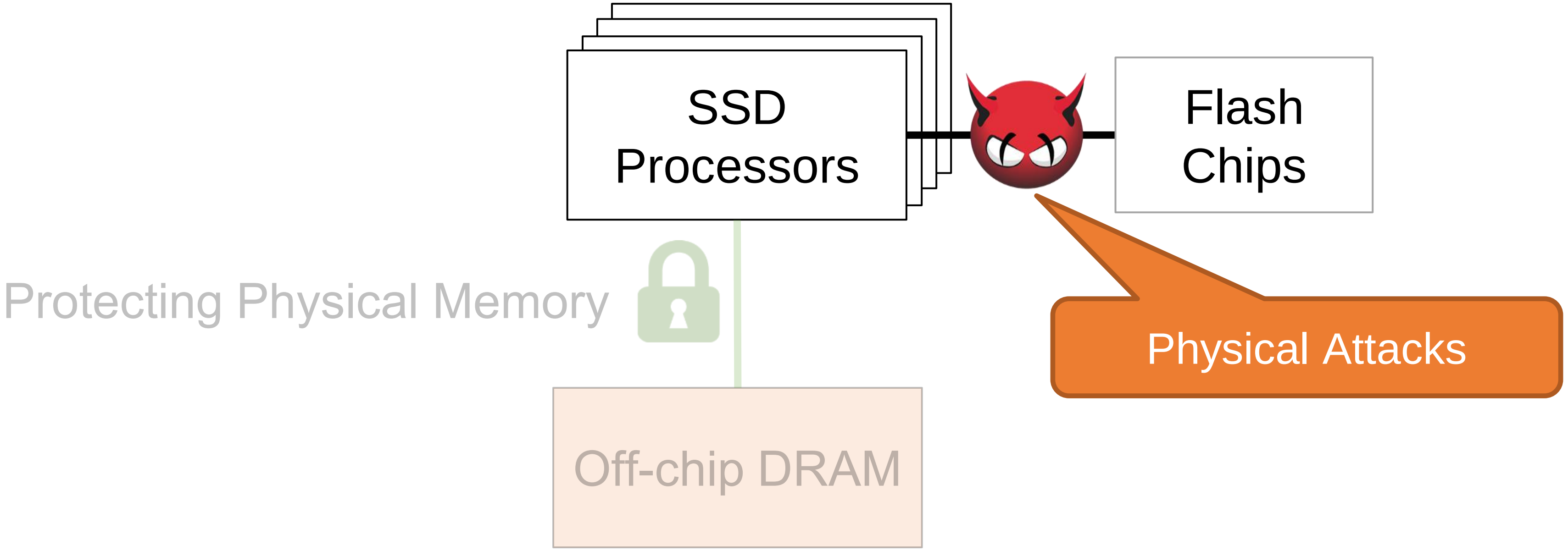
IceClave Hybrid Counter

Protecting Physical Memory



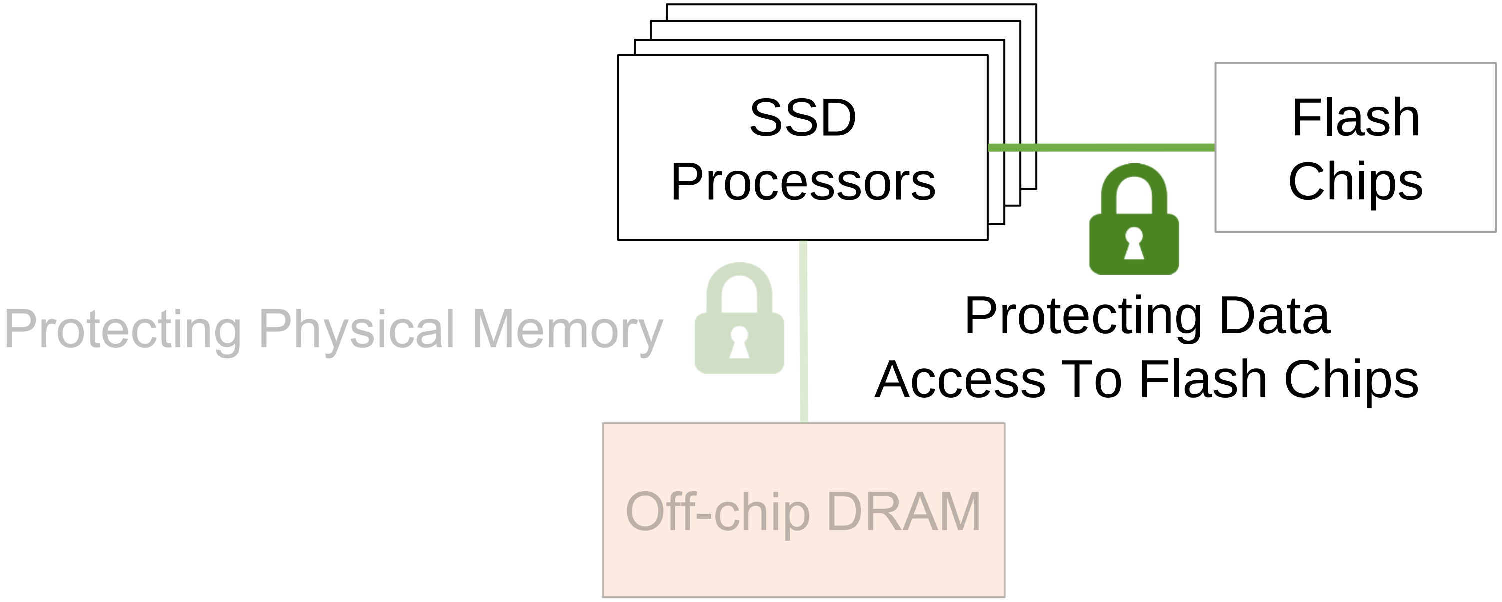
IceClave Hybrid Counter

Protecting Against Physical Attacks



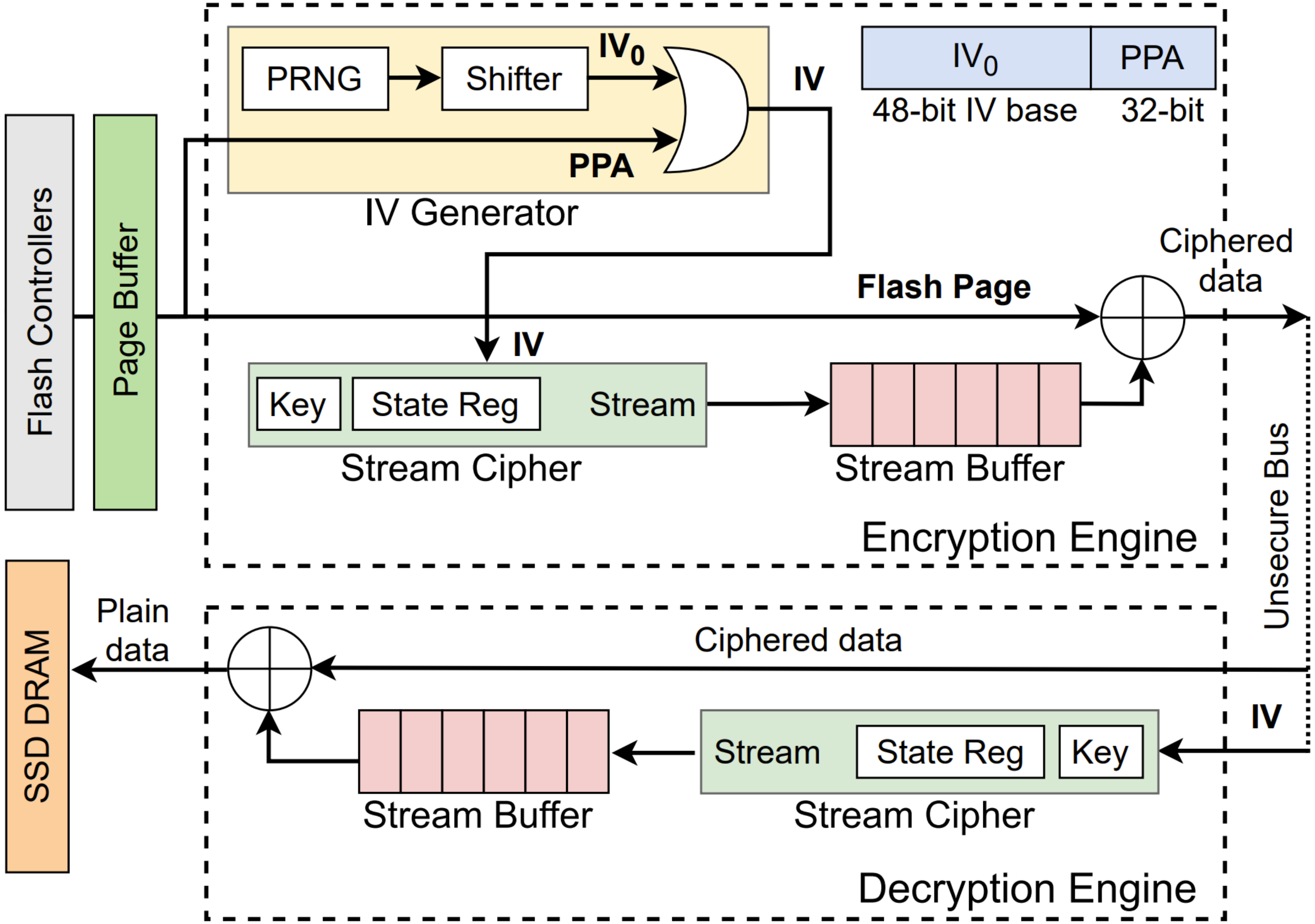
Securing data against physical attacks

Protecting Against Physical Attacks

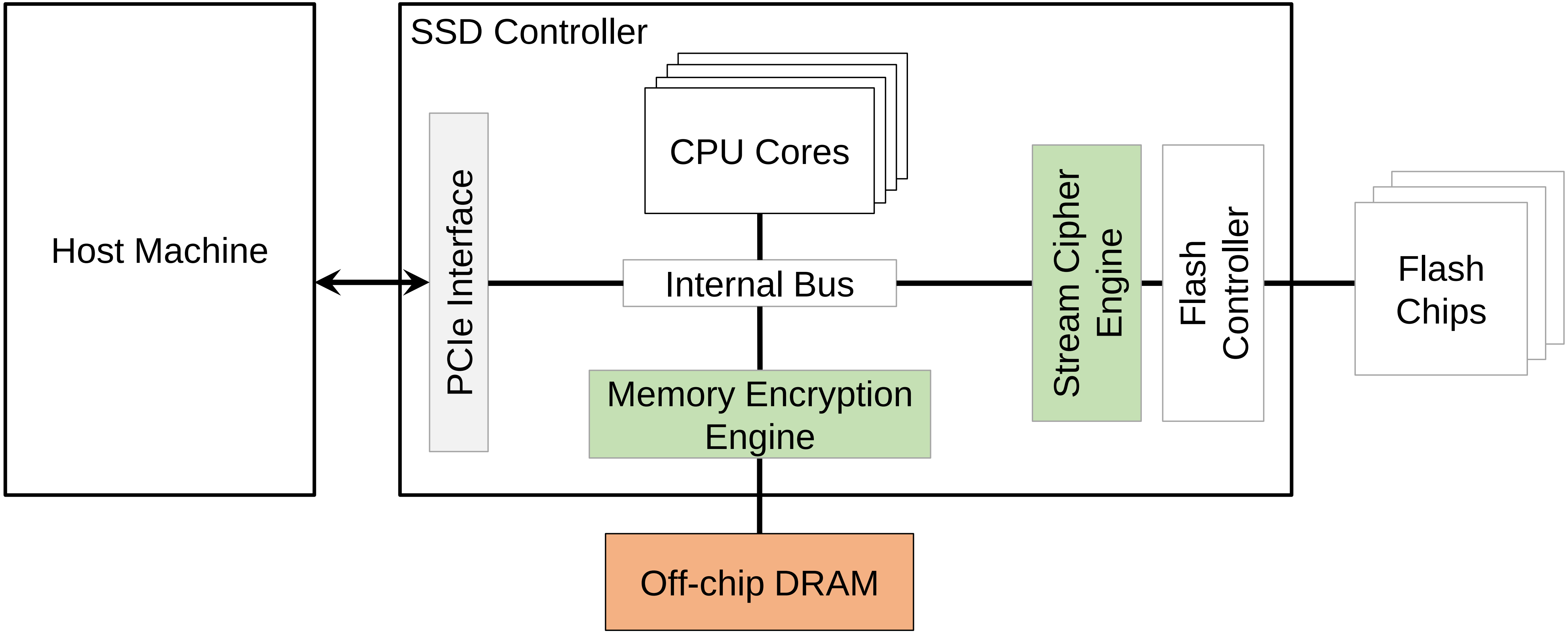

SSD Processors
Flash Chips
Protecting Physical Memory
Protecting Data Access To Flash Chips
Off-chip DRAM

Securing data against physical attacks

Protecting Data Access To Flash Chips



Put It All Together



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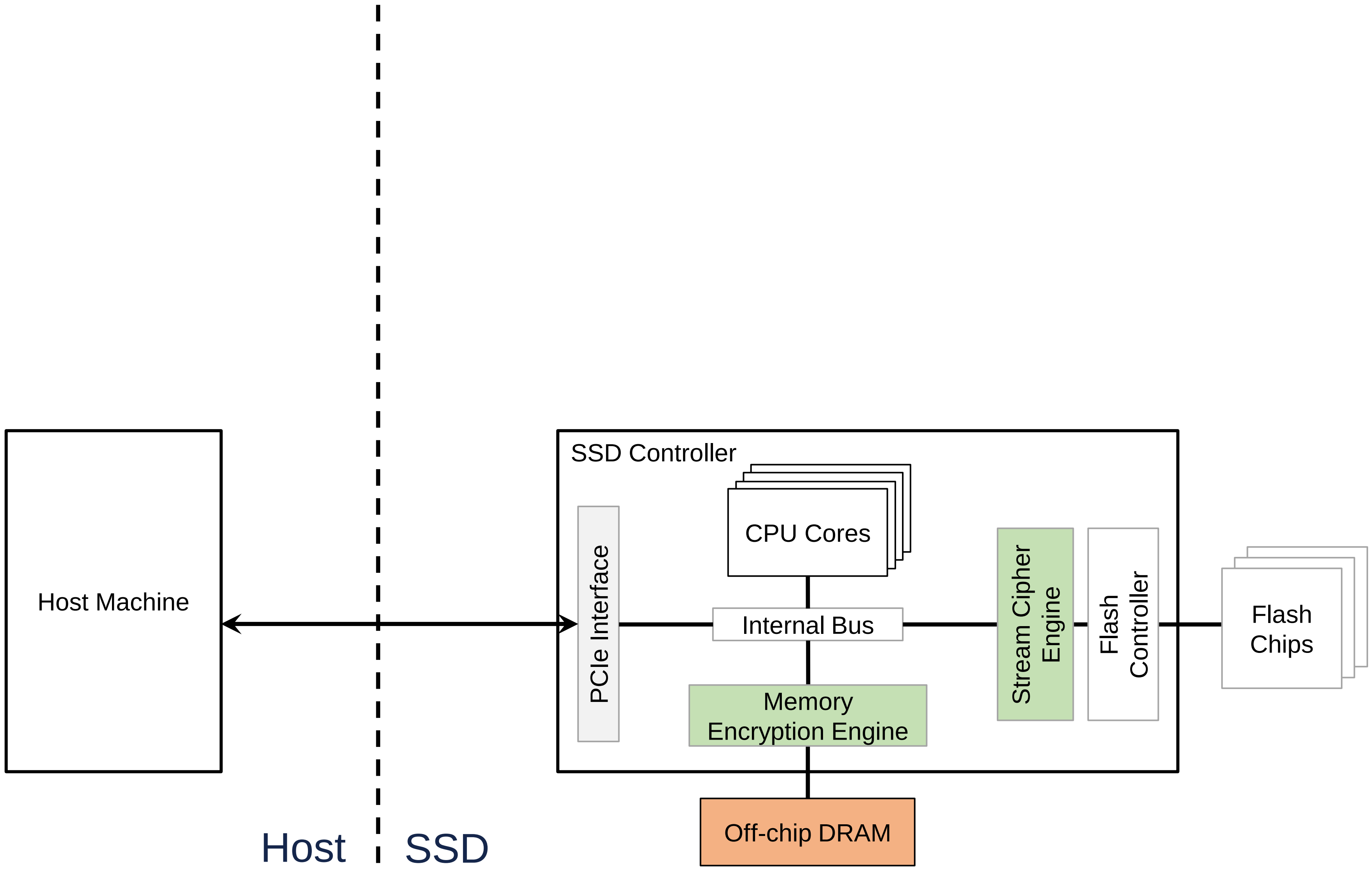

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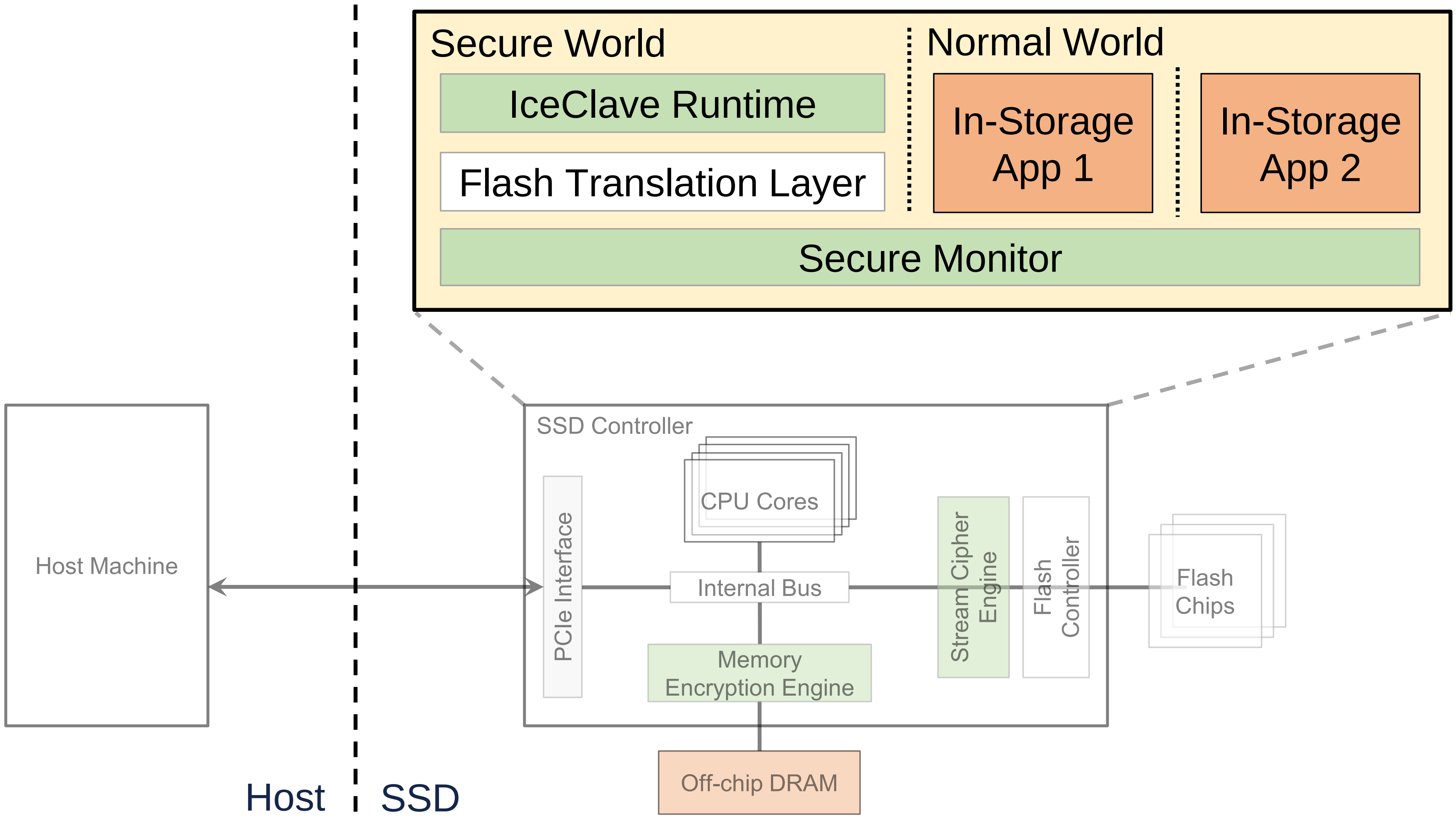

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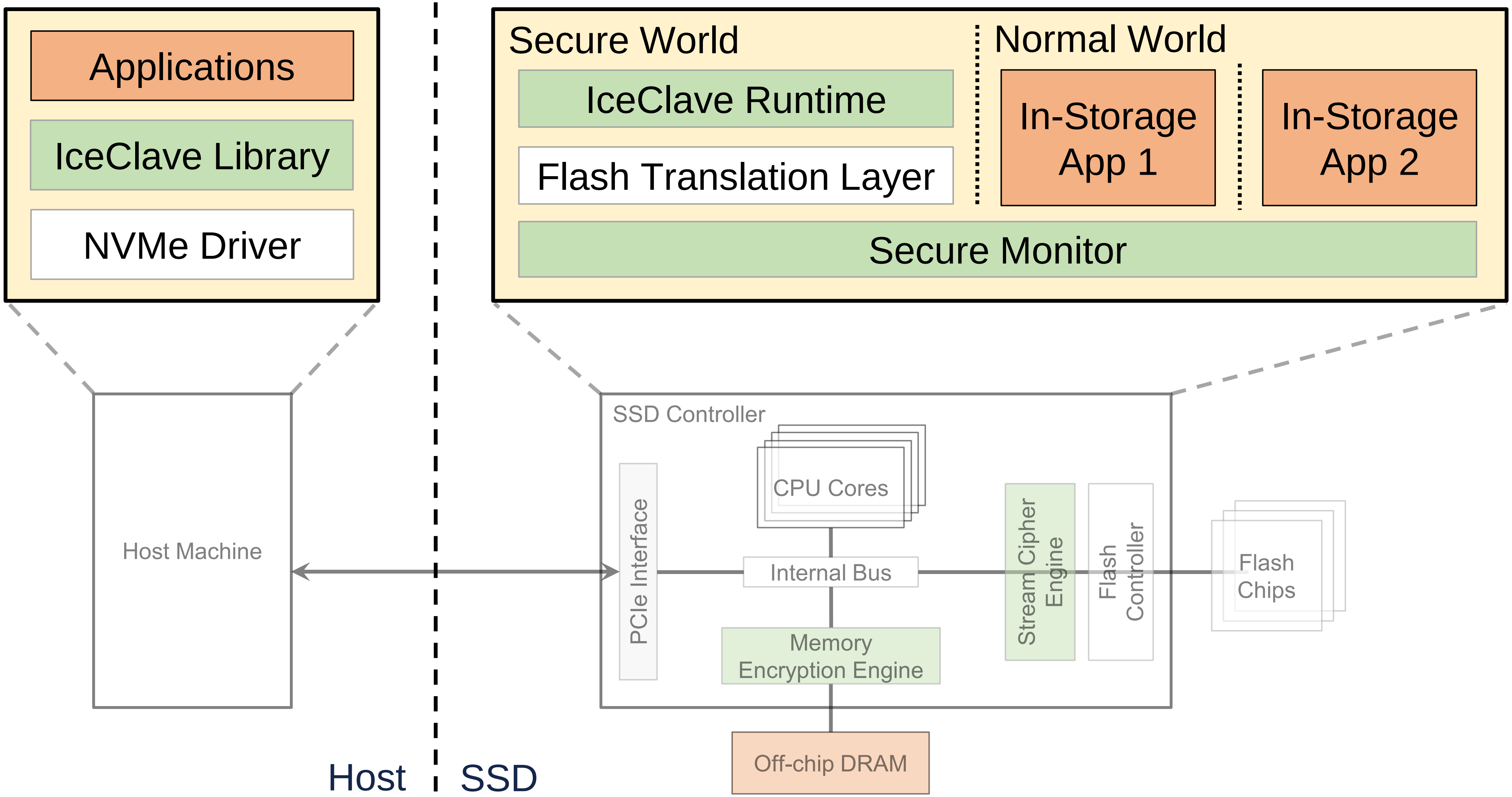
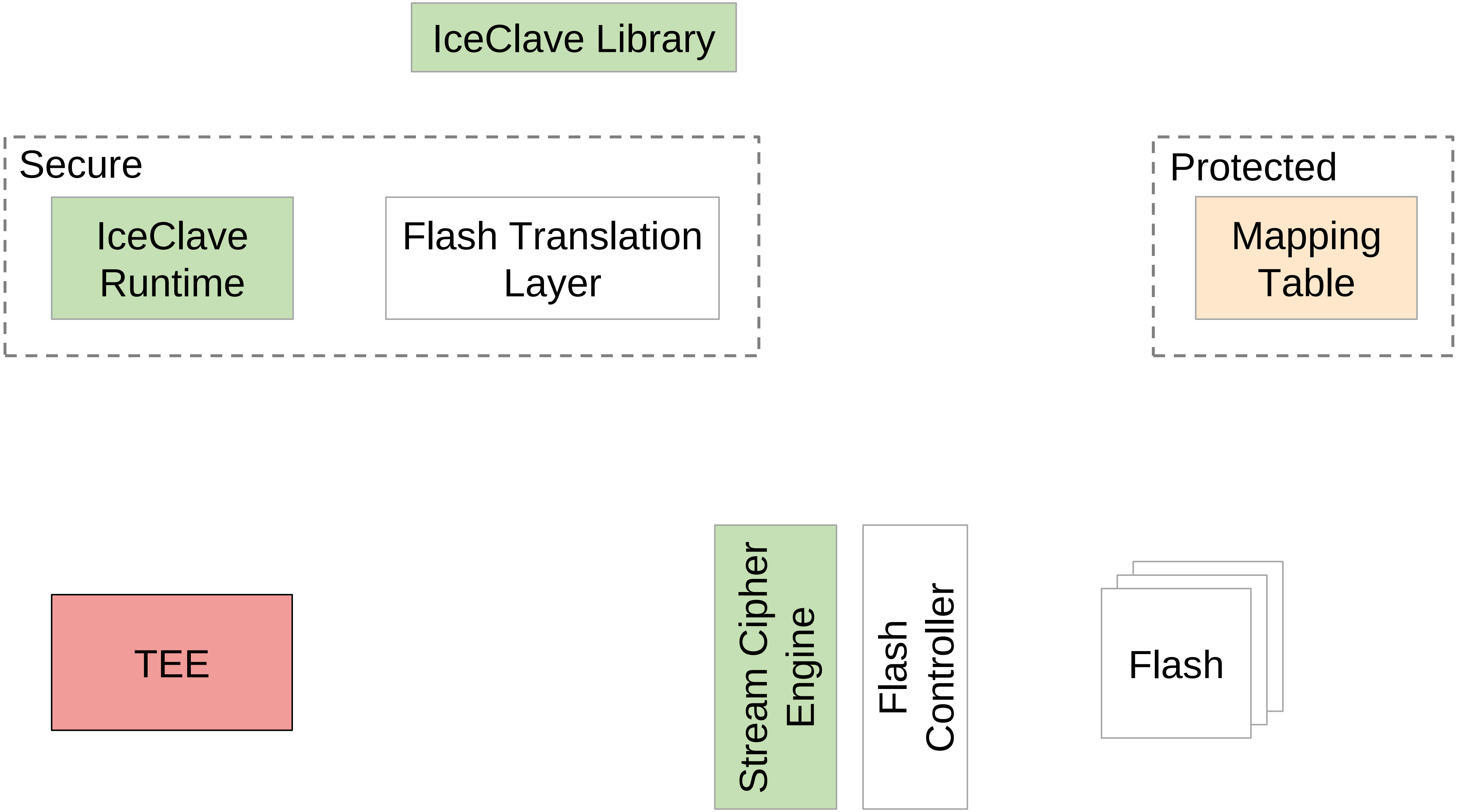
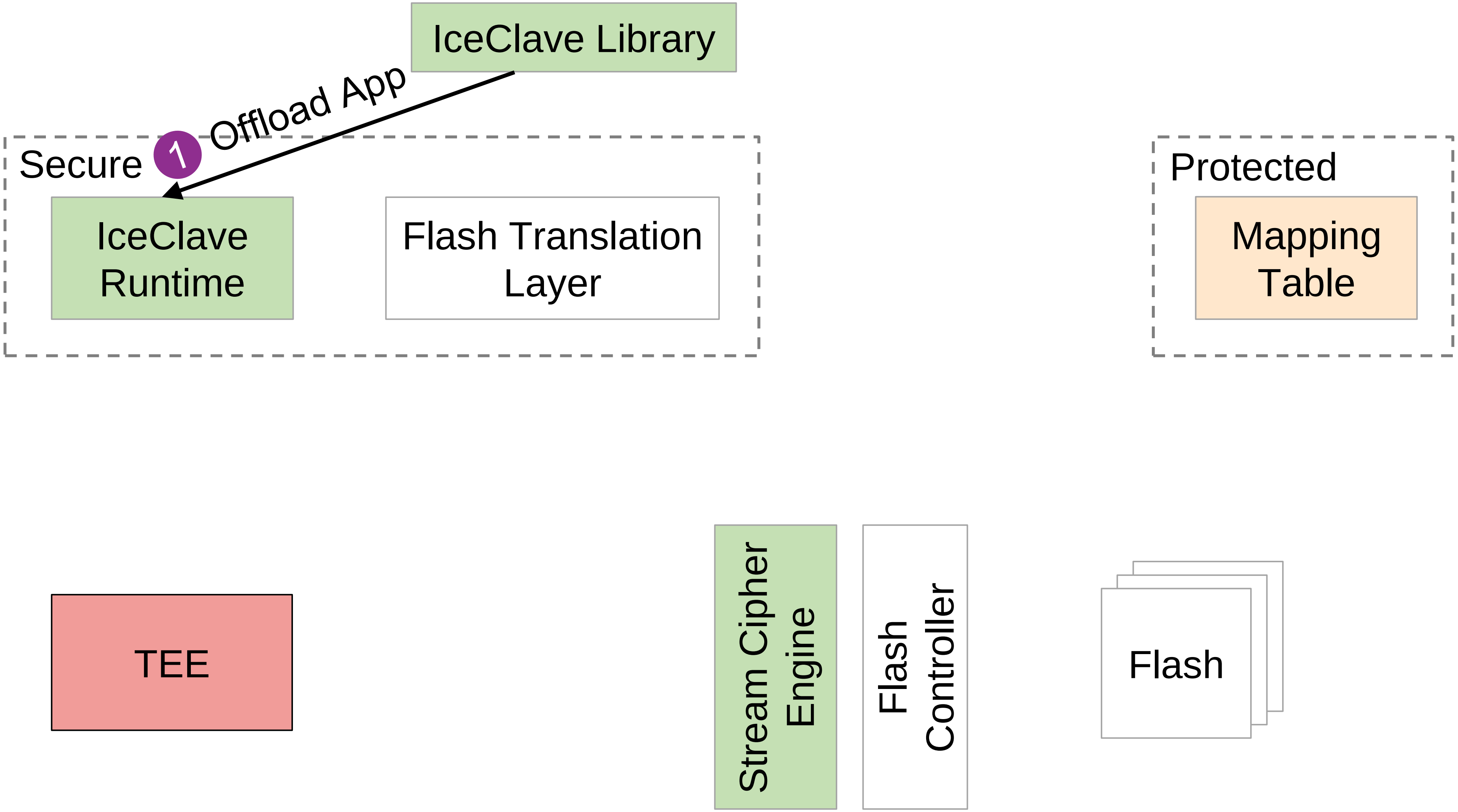


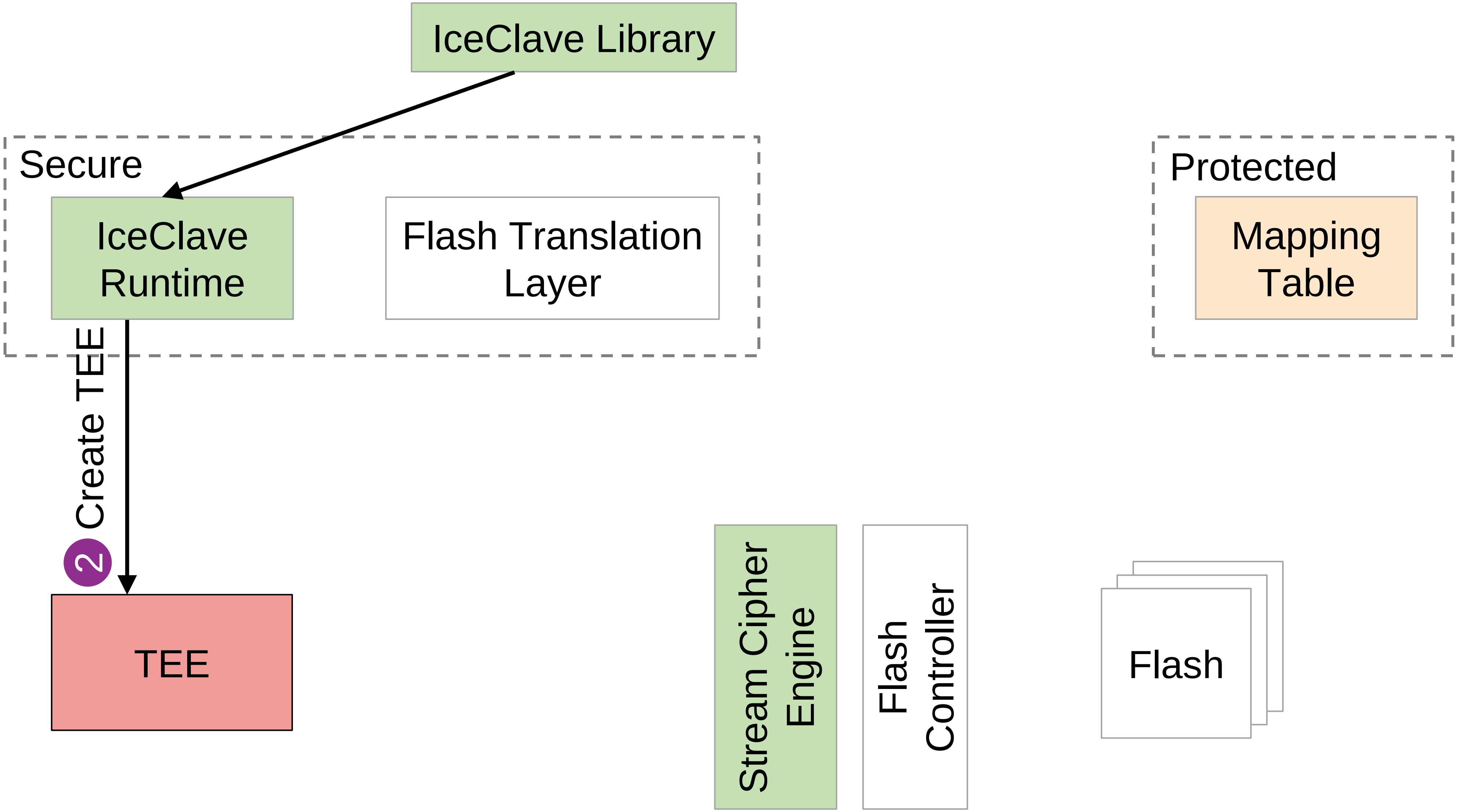
IceClave Workflow



IceClave Workflow



IceClave Workflow



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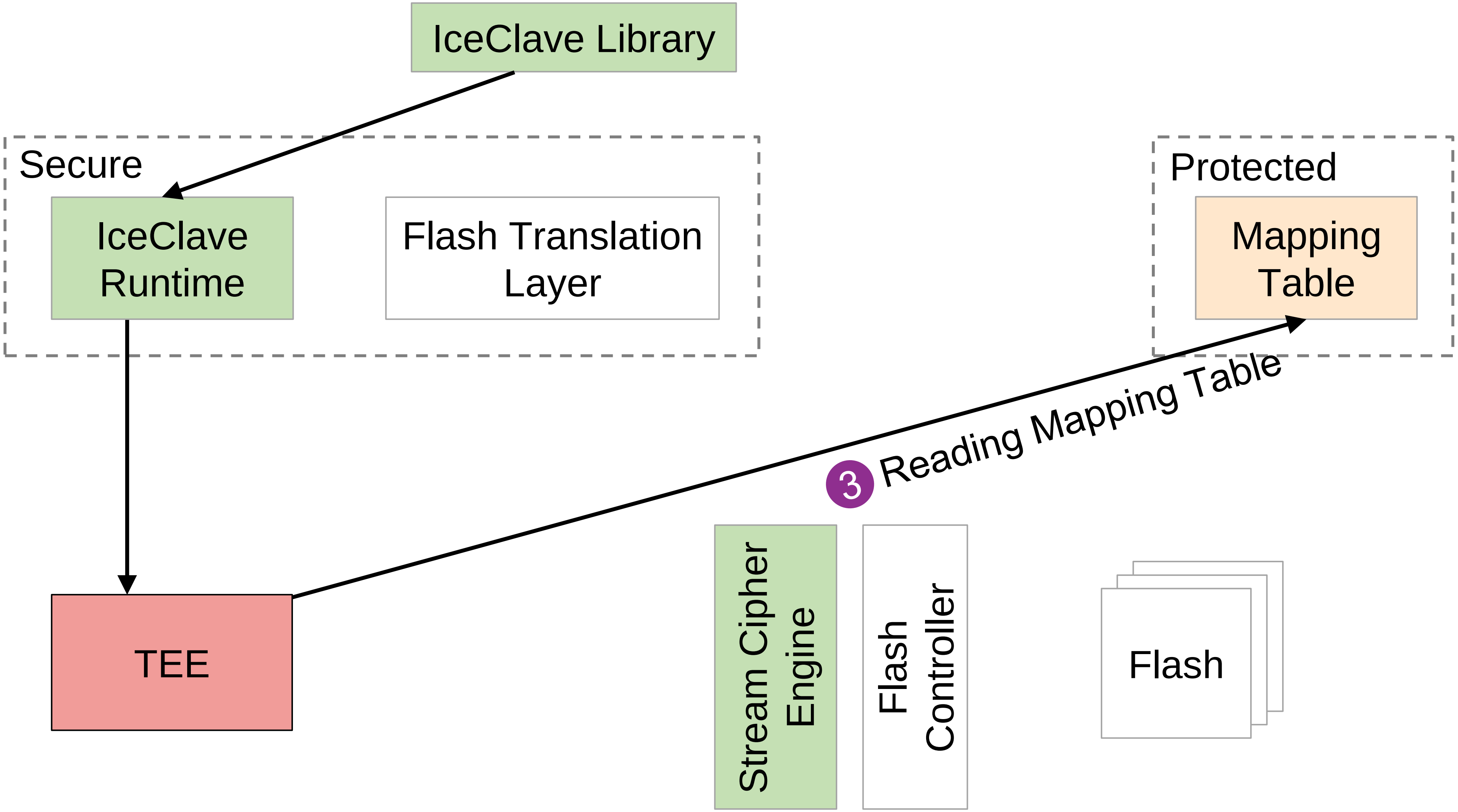

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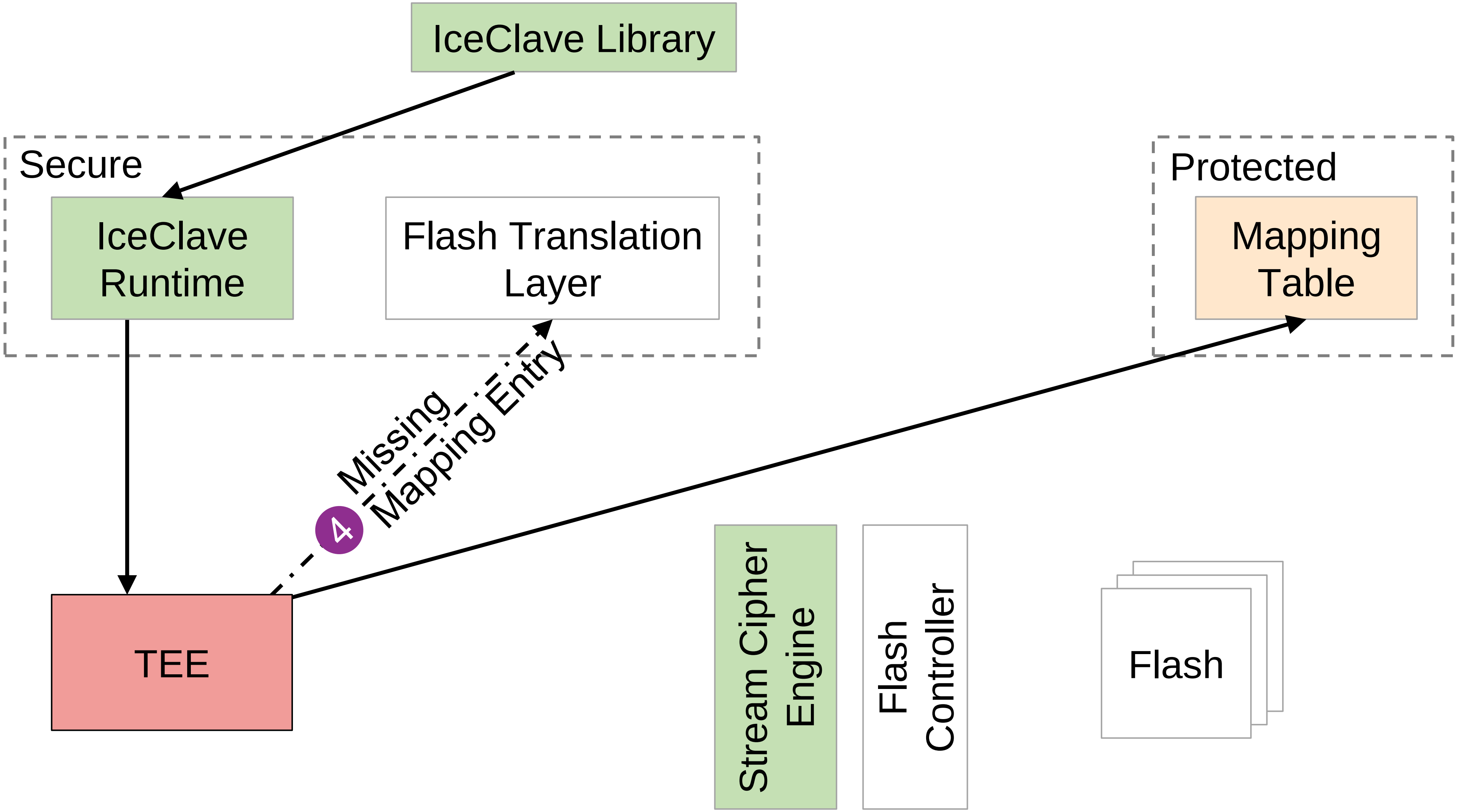

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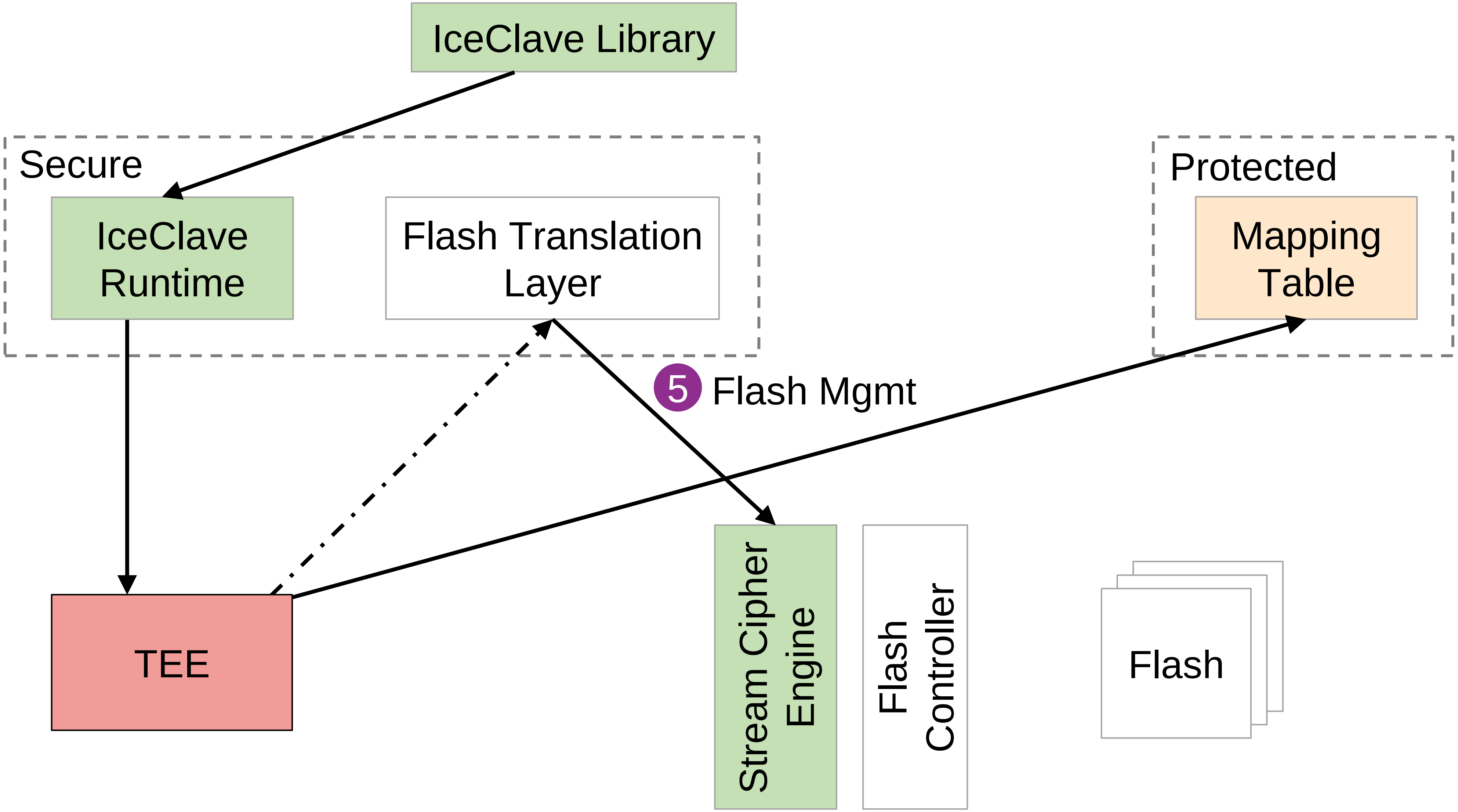

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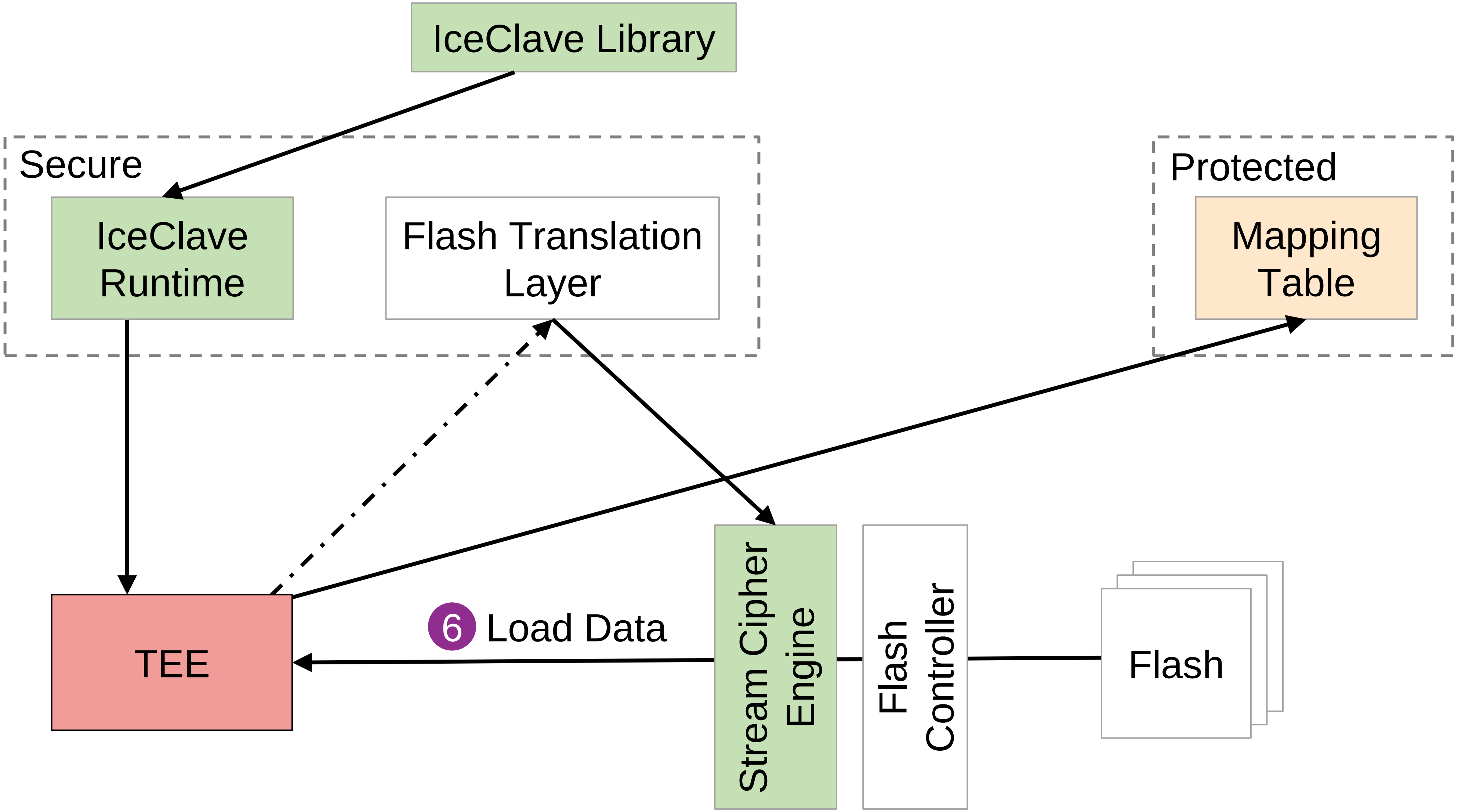

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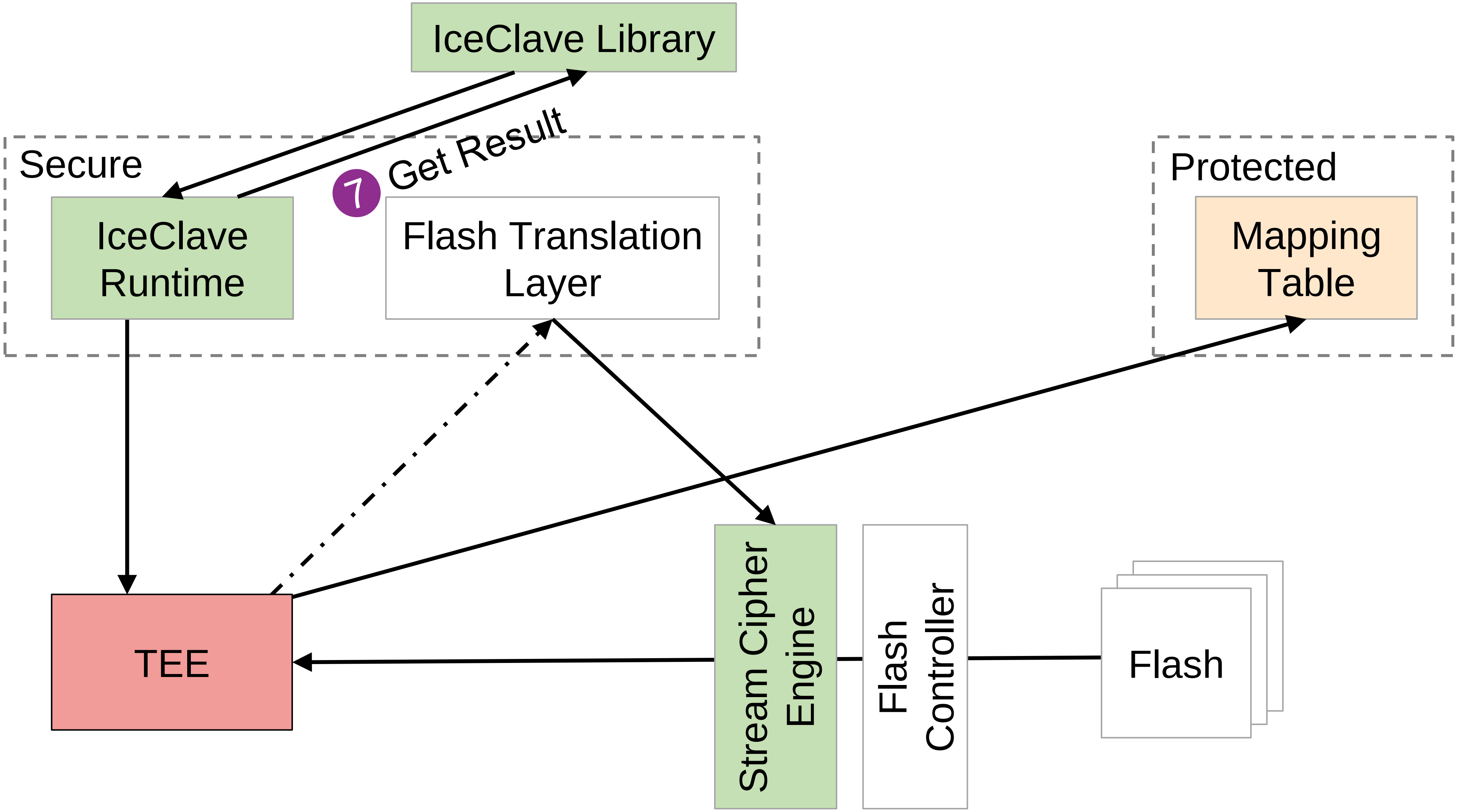

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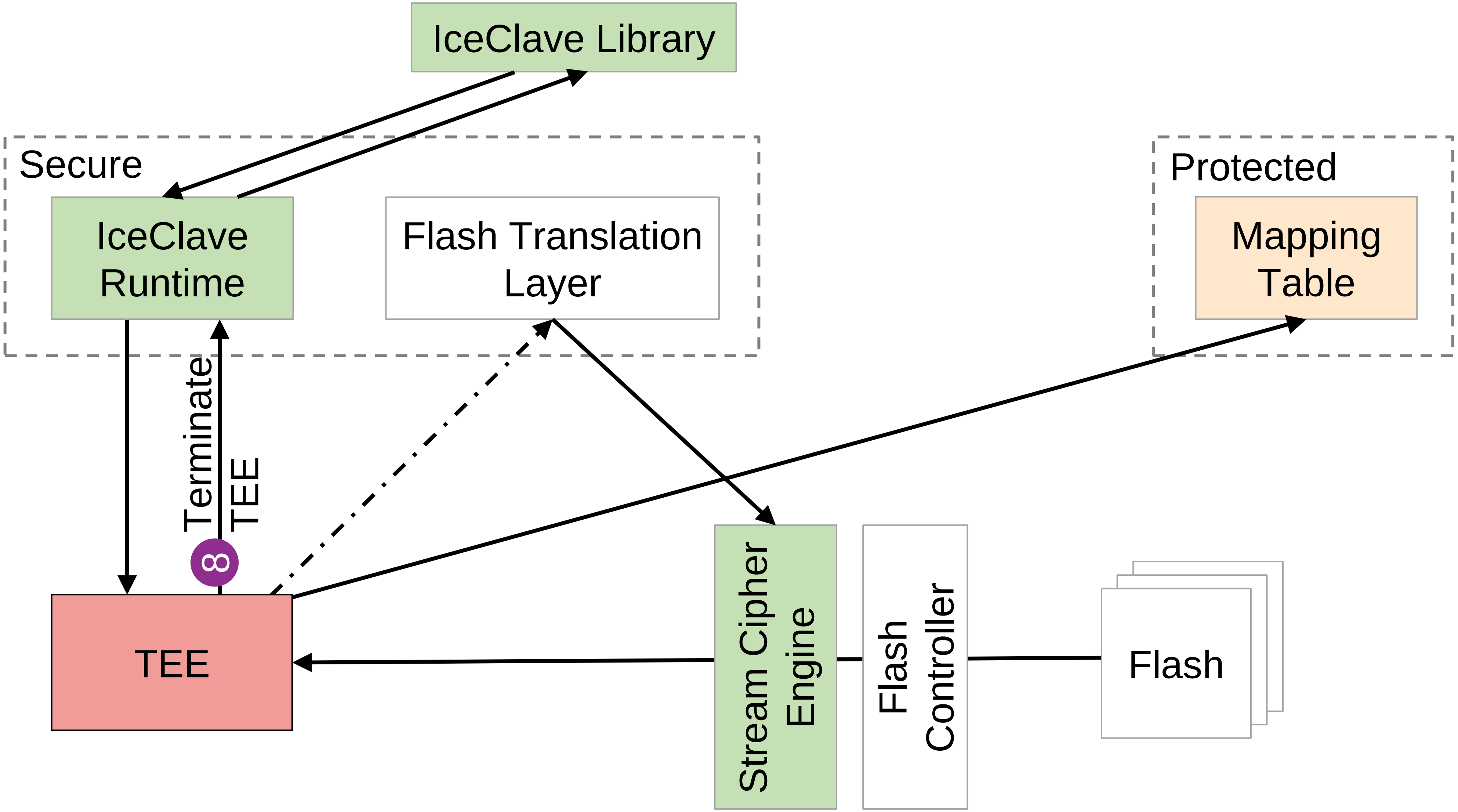
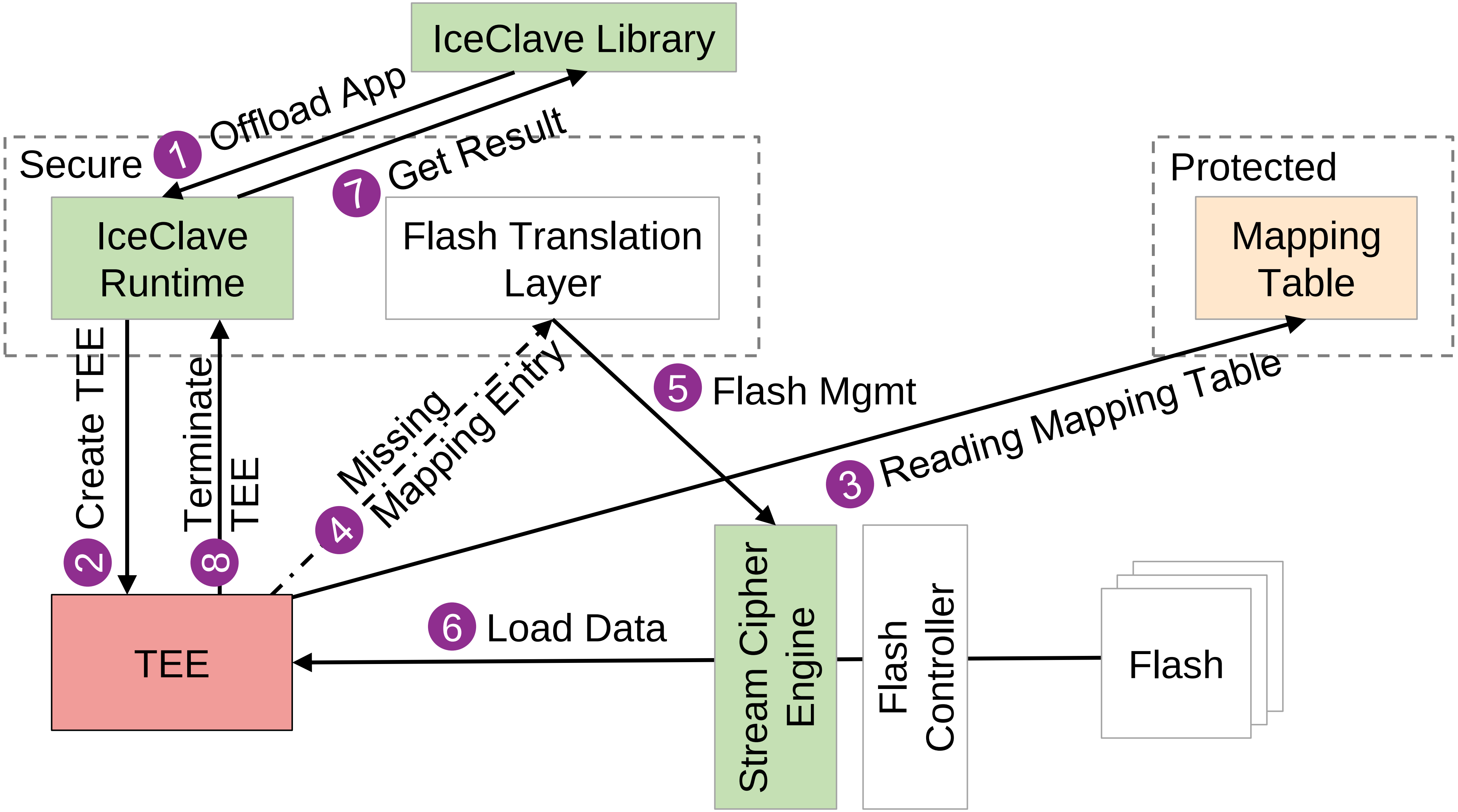


IceClave Workflow



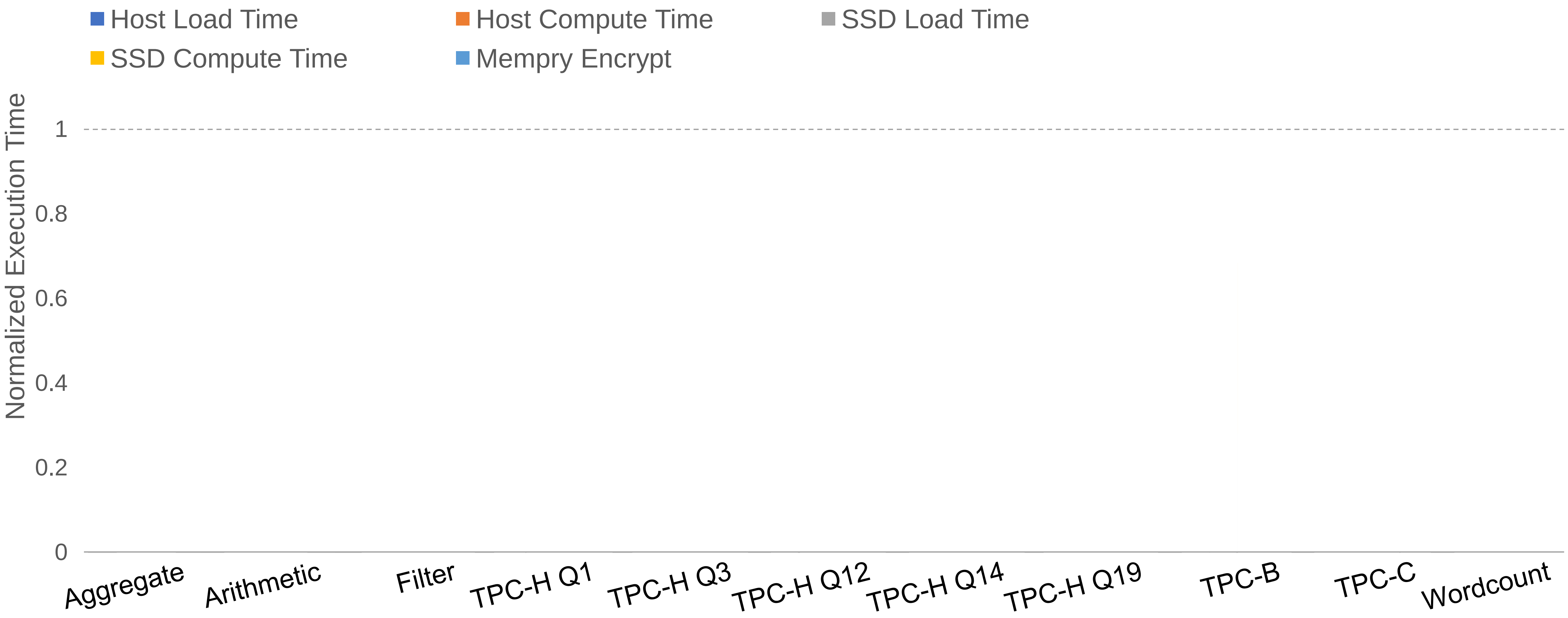
IceClave Implementation

Simulator	gem5 + USIMM + SimpleSSD
Prototype	OpenSSD Cosmos+ FPGA

Experimental Setup

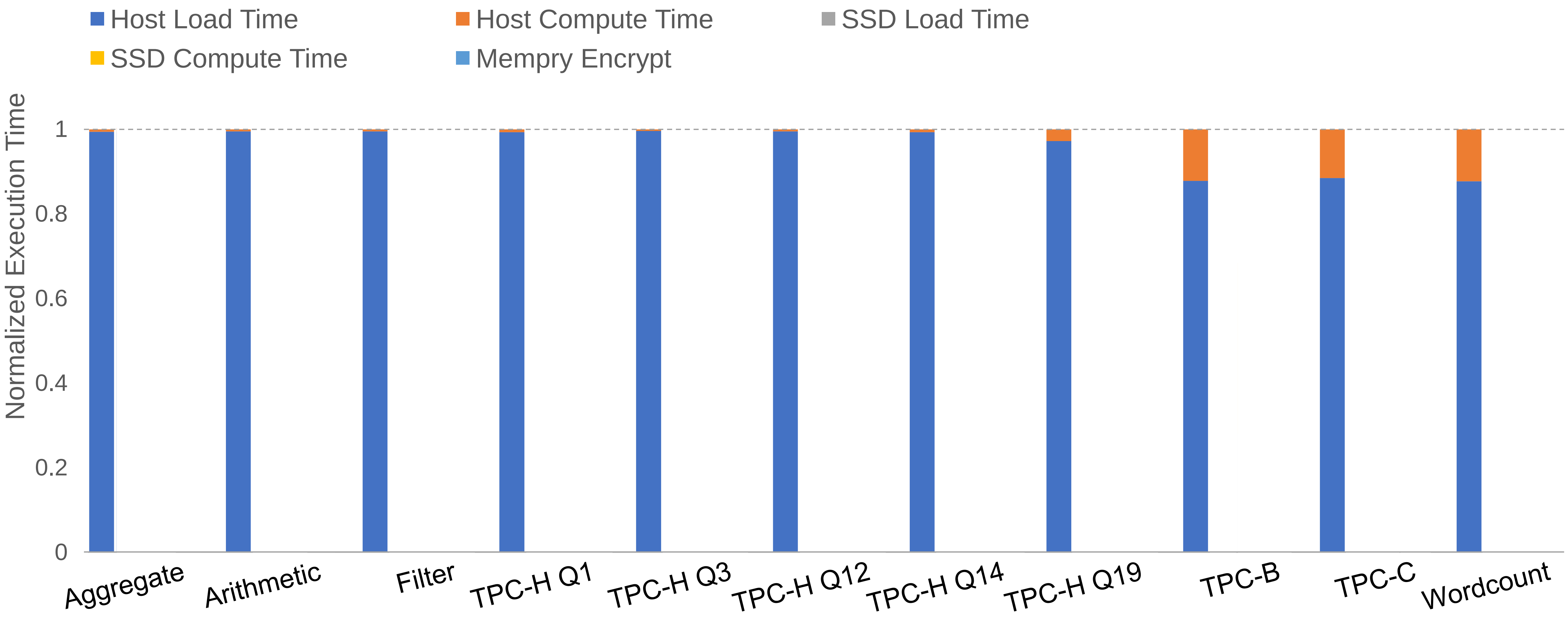
Synthetic Workloads	Arithmetic, Aggregate, Filter, Wordcount
Real-world Workloads	TPC-H, TPC-B, TPC-C

IceClave Overall Performance



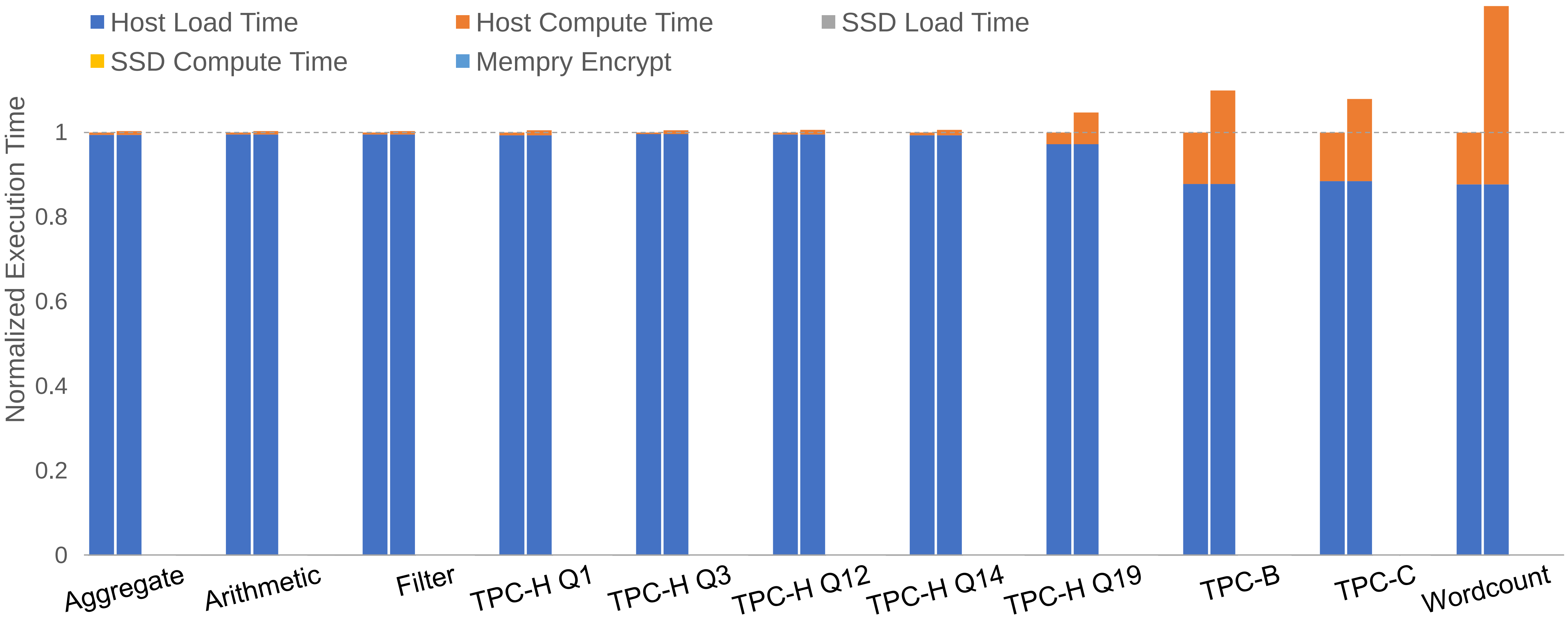
Left to Right:

IceClave Overall Performance



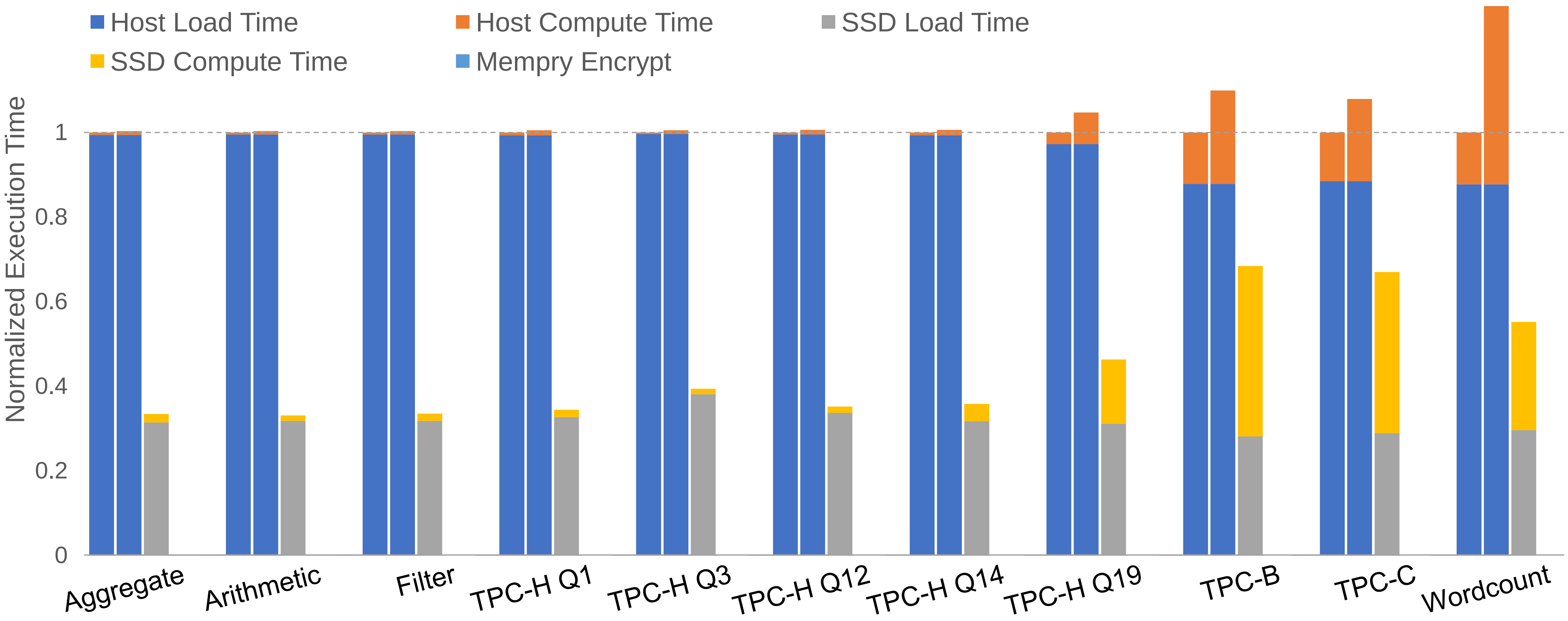
Left to Right: **Host**

IceClave Overall Performance



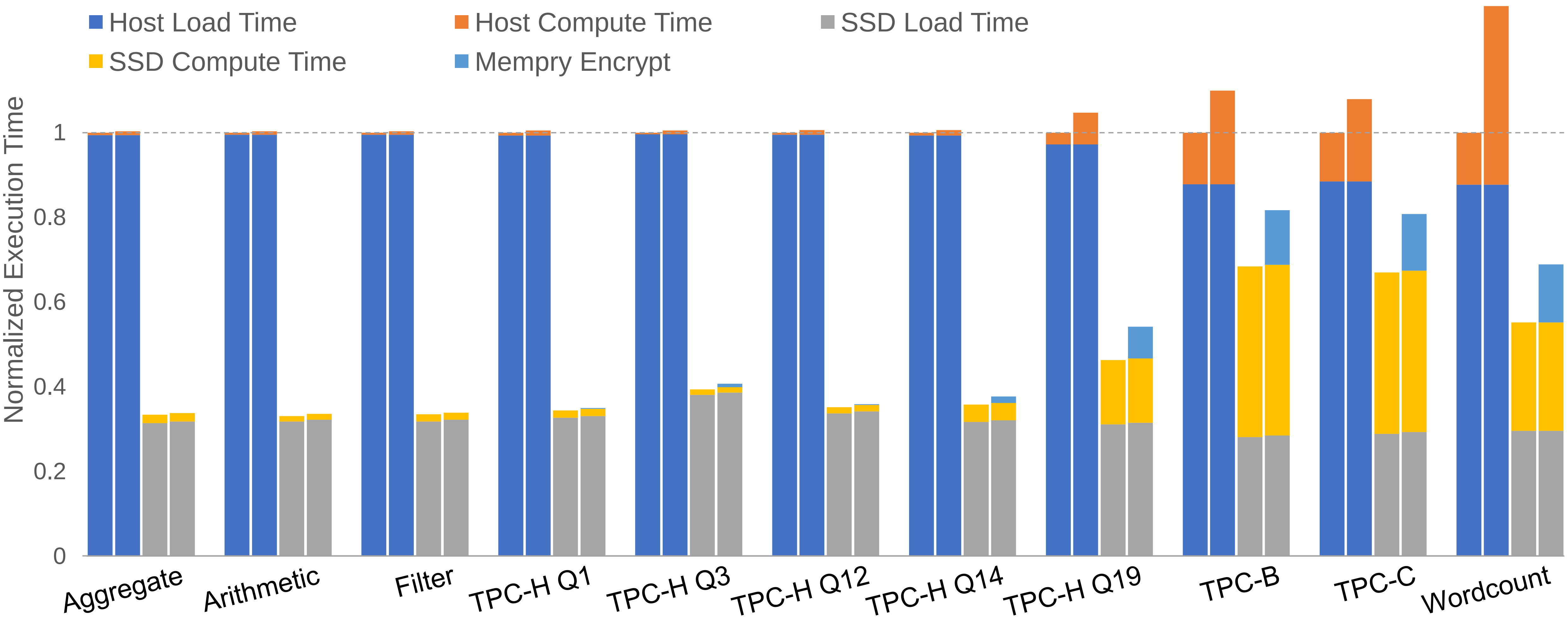
Left to Right: **Host** **Host+SGX**

IceClave Overall Performance



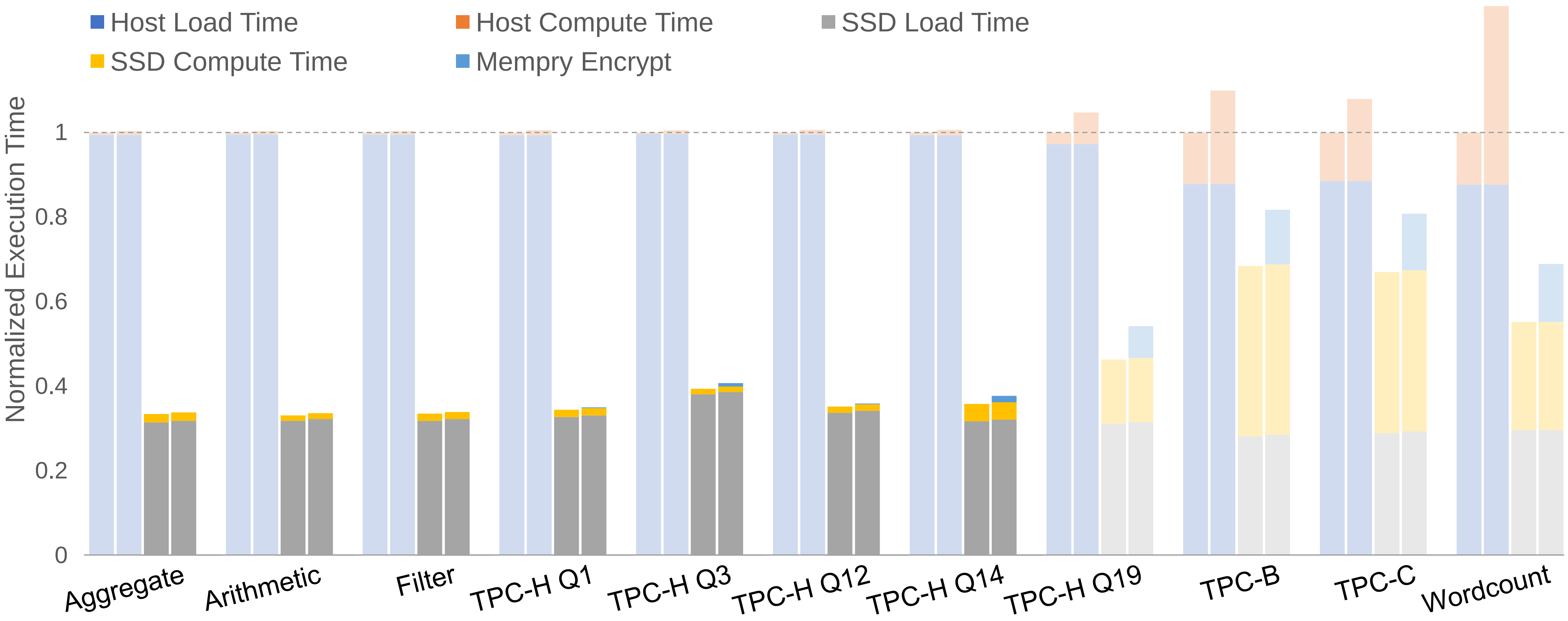
Left to Right: **Host** **Host+SGX** **ISC**

IceClave Overall Performance



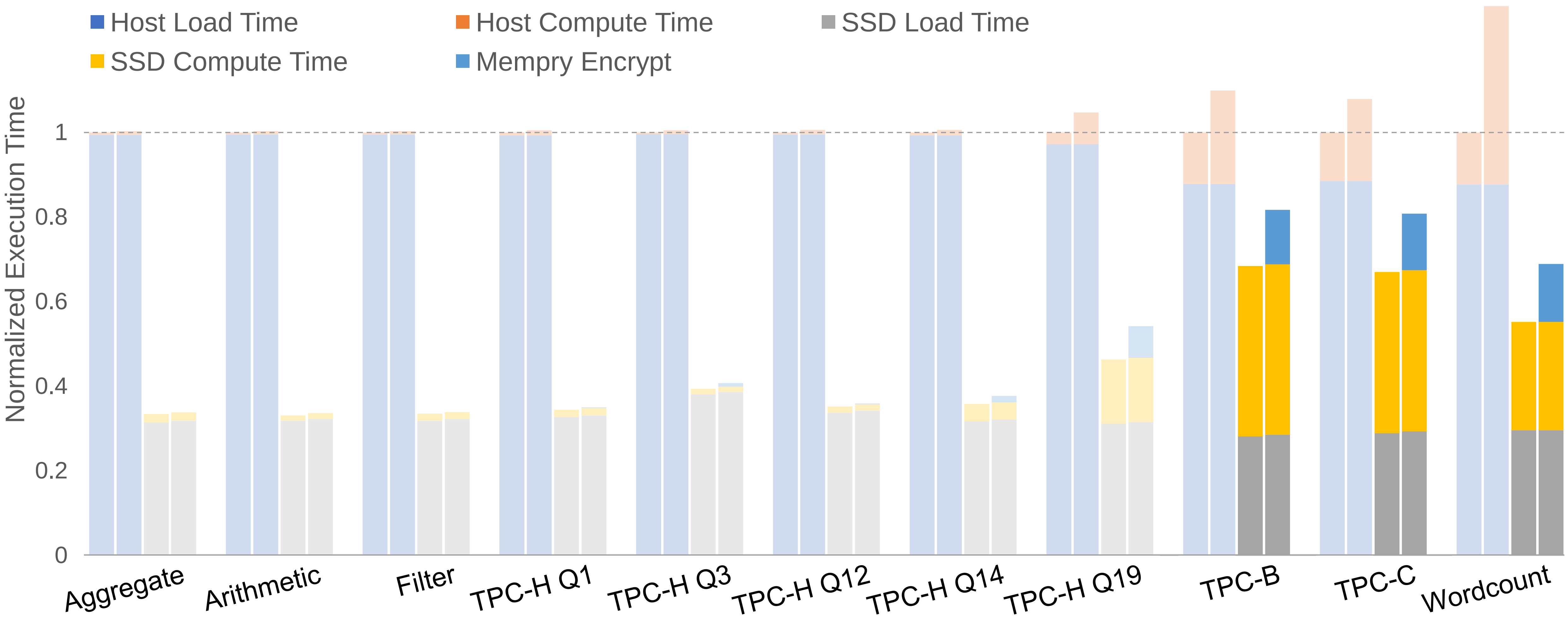
Left to Right: **Host** **Host+SGX** **ISC** **IceClave**

IceClave Overall Performance



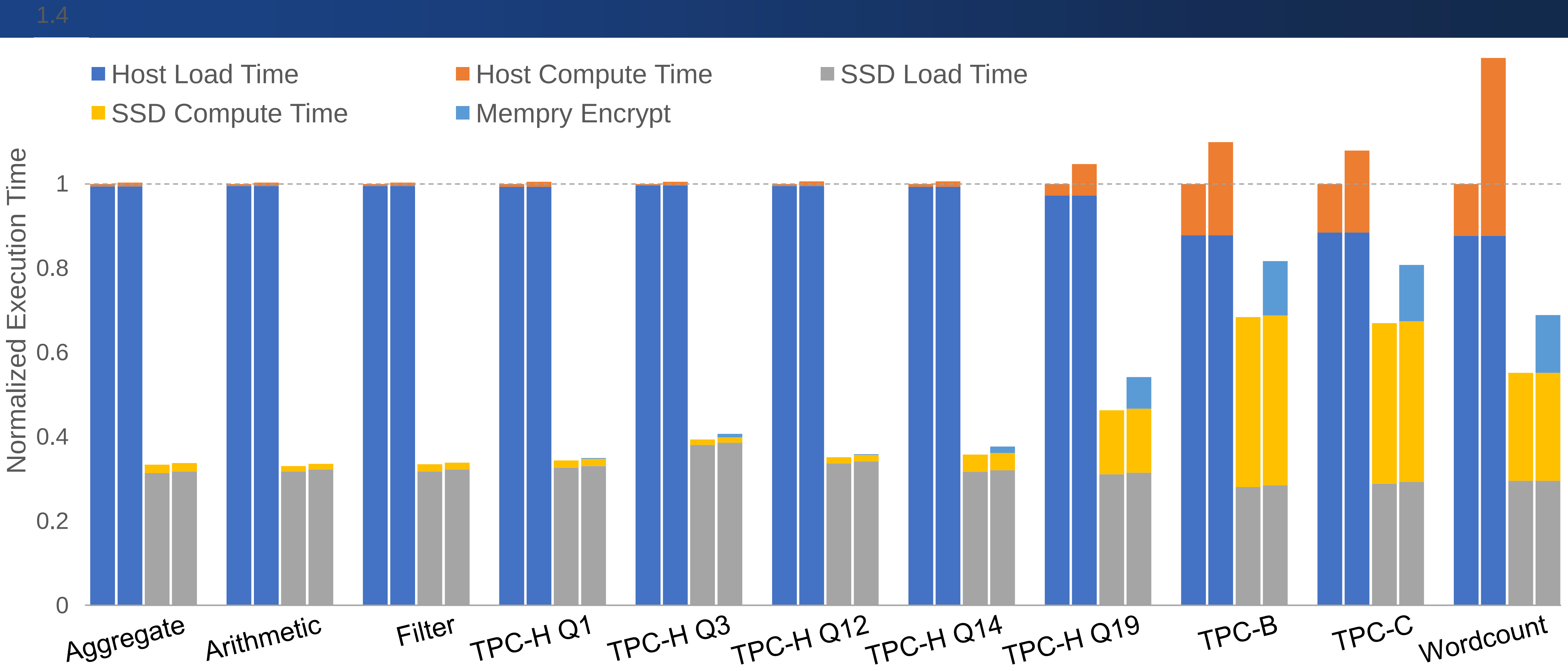
Left to Right: **Host** **Host+SGX** **ISC** **IceClave**

IceClave Overall Performance



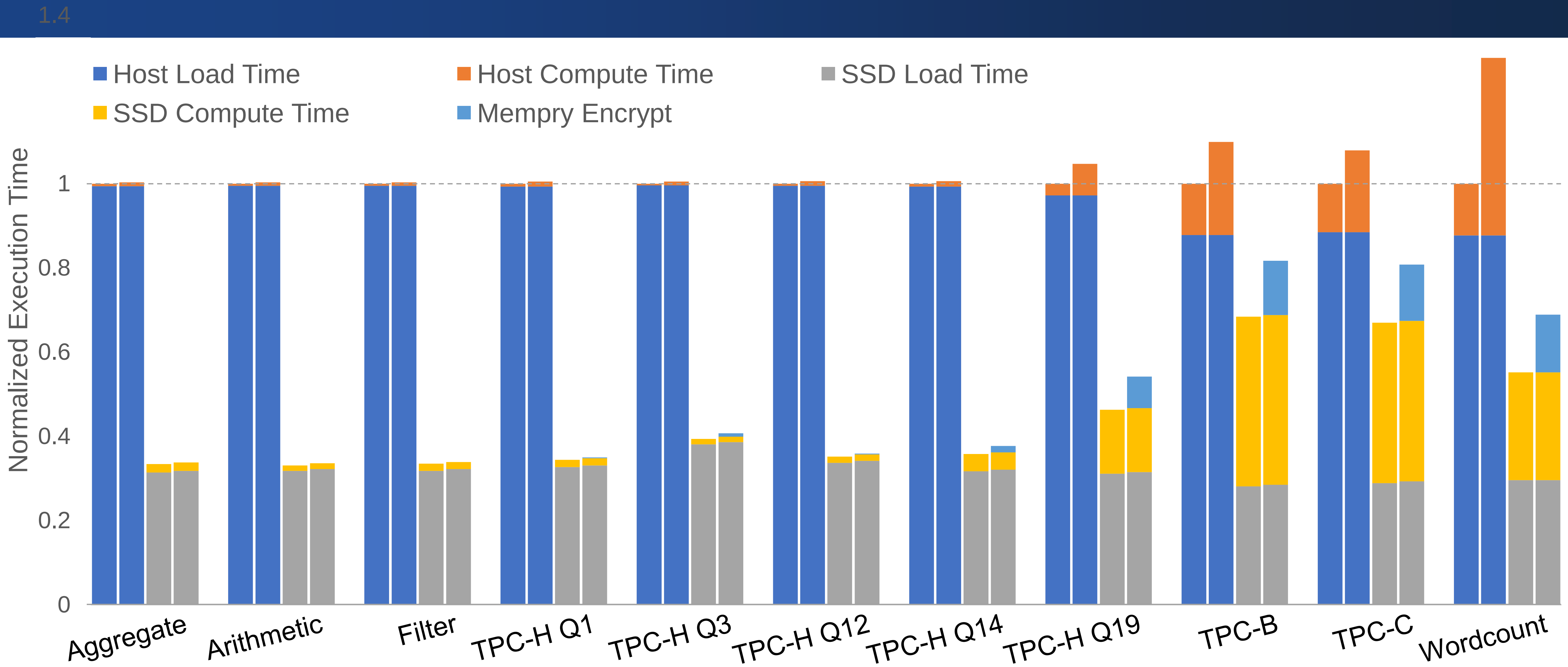
Left to Right: **Host** **Host+SGX** **ISC** **IceClave**

IceClave Overall Performance



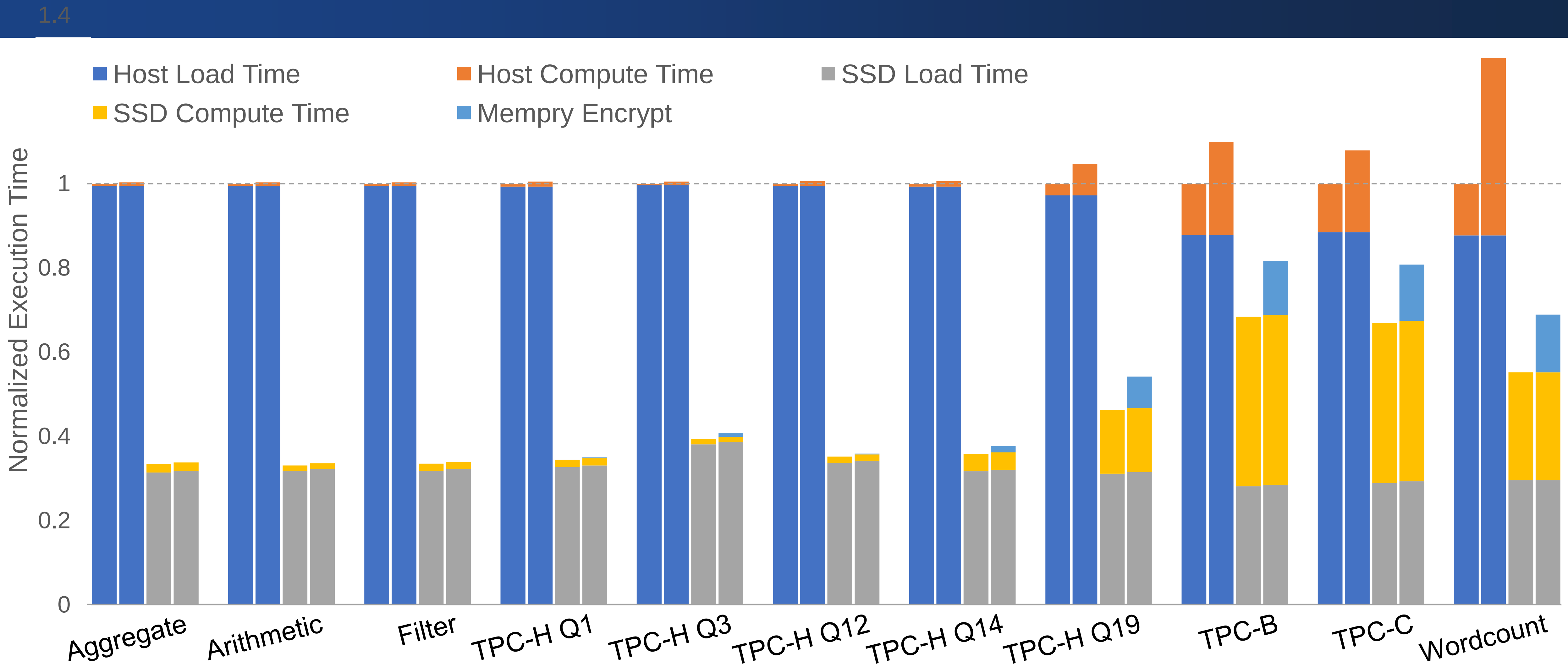
Left to Right: **Host** **Host+SGX** **ISC** **IceClave**

IceClave Overall Performance



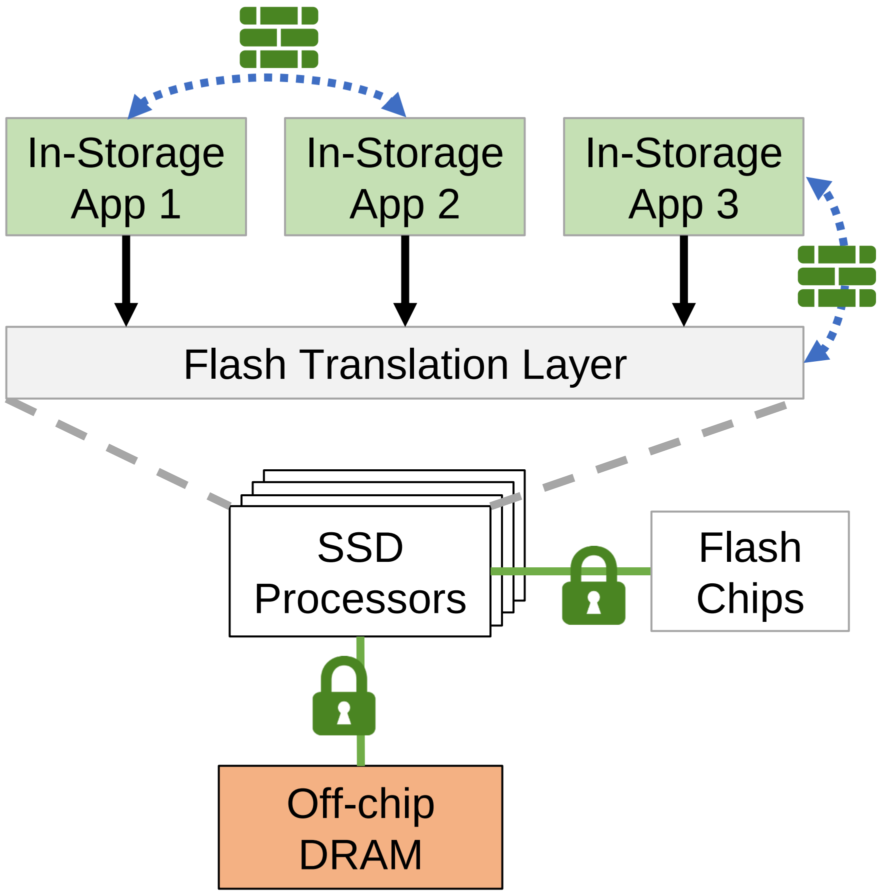
IceClave introduces minimal overhead while providing strong security

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!

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

[†] yuqixue2@illinois.edu

Systems Platform Research Group

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