Sanctuary: ARMing TrustZone with User-space Enclaves

Ferdinand Brasser, David Gens, Patrick Jauernig, Ahmad-Reza Sadeghi, Emmanuel Stapf
Technische Universität Darmstadt

intel | Research Institute for Collaborative Autonomous and Resilient Systems

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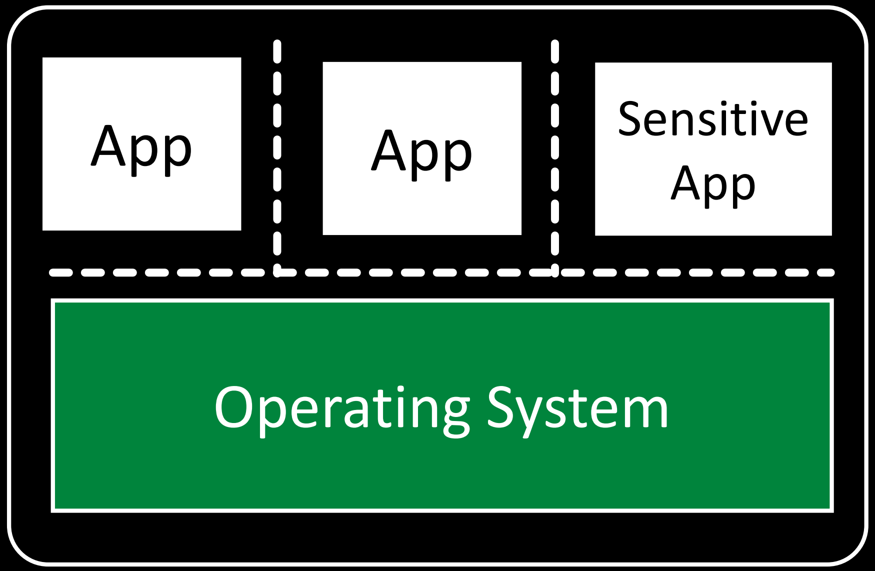
Research Problem

How can we construct an ecosystem of mutually distrusted enclaves on mobile devices?

Commodity OS



Trusted Untrusted Compromised

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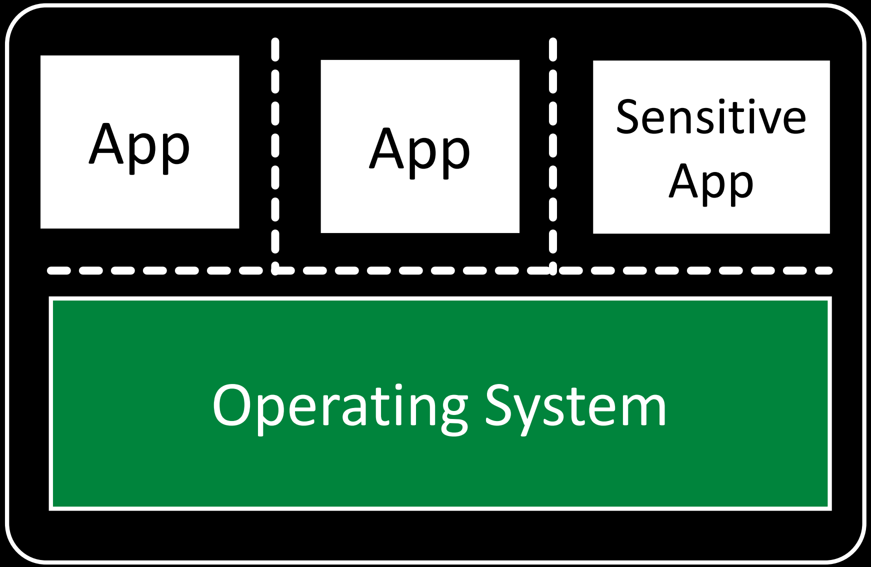

- OS large attack surface
- Insufficient sensitive app protection

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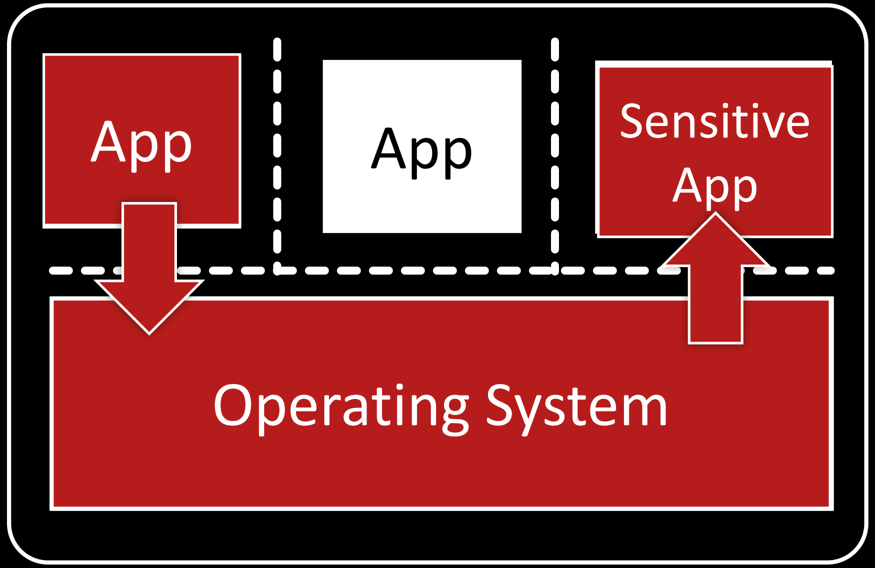

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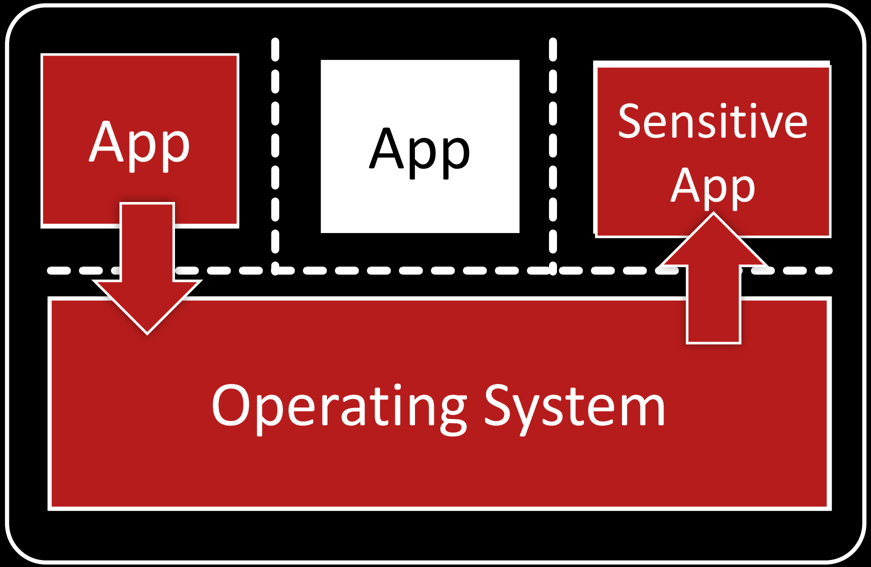

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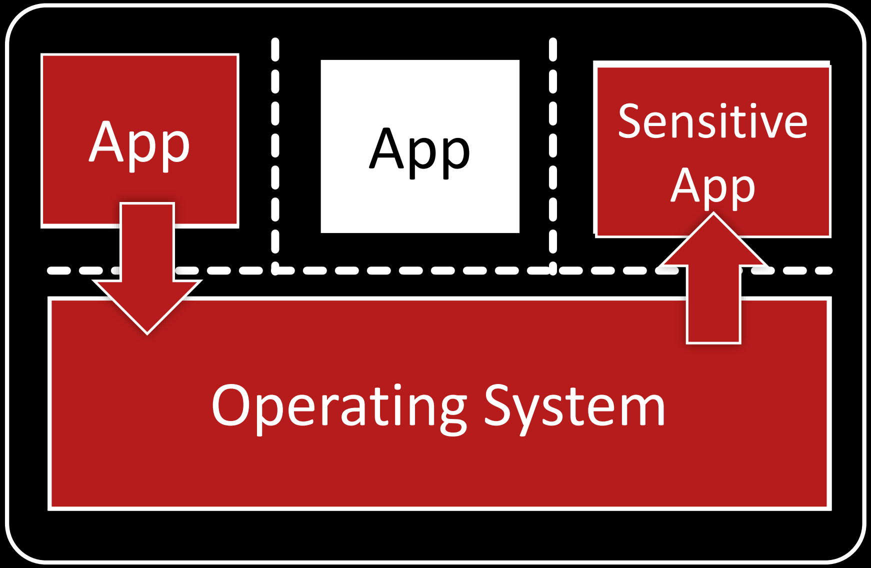

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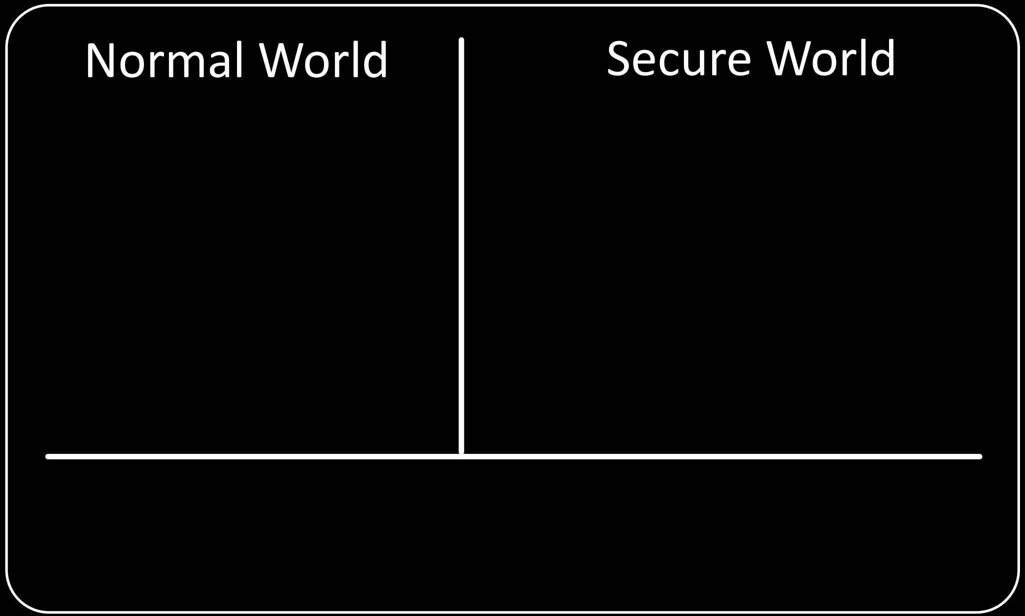

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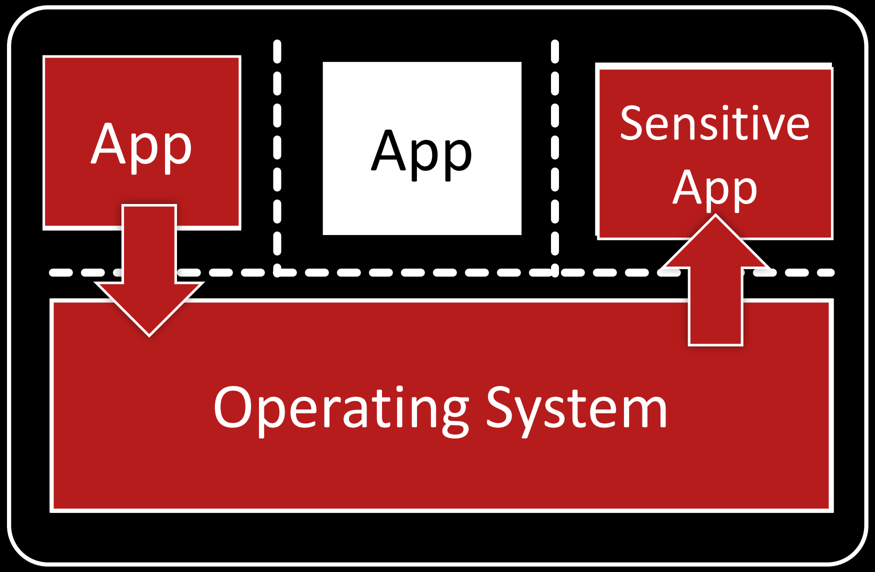

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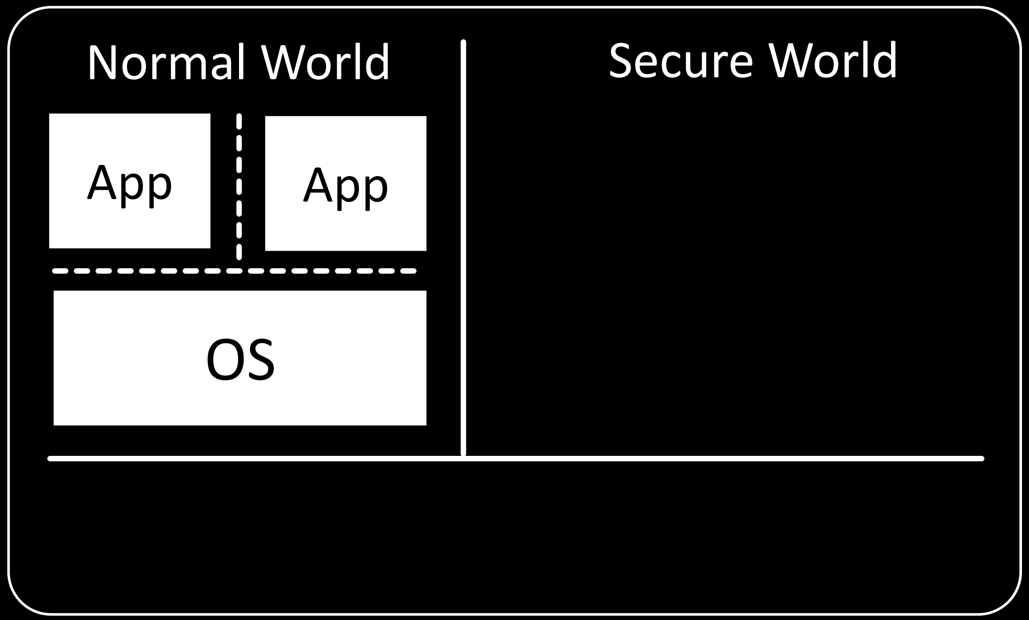

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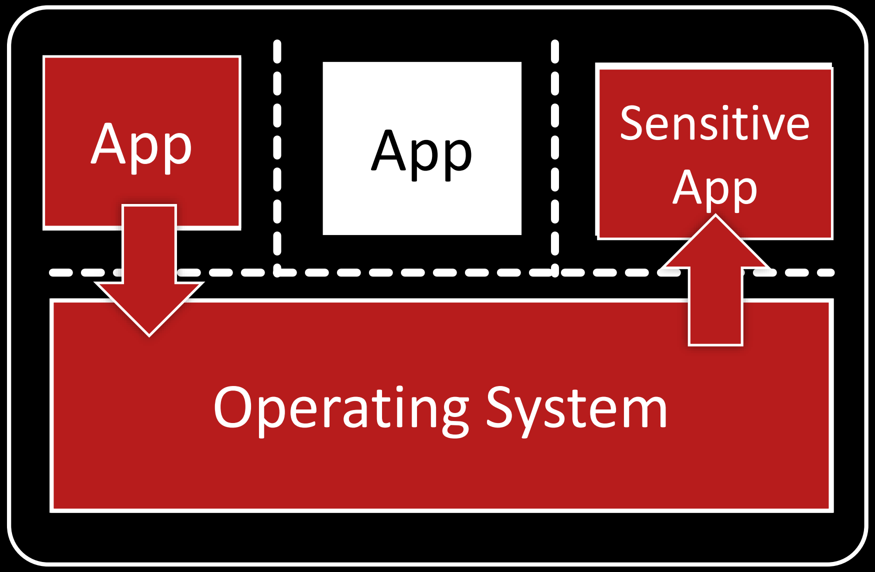

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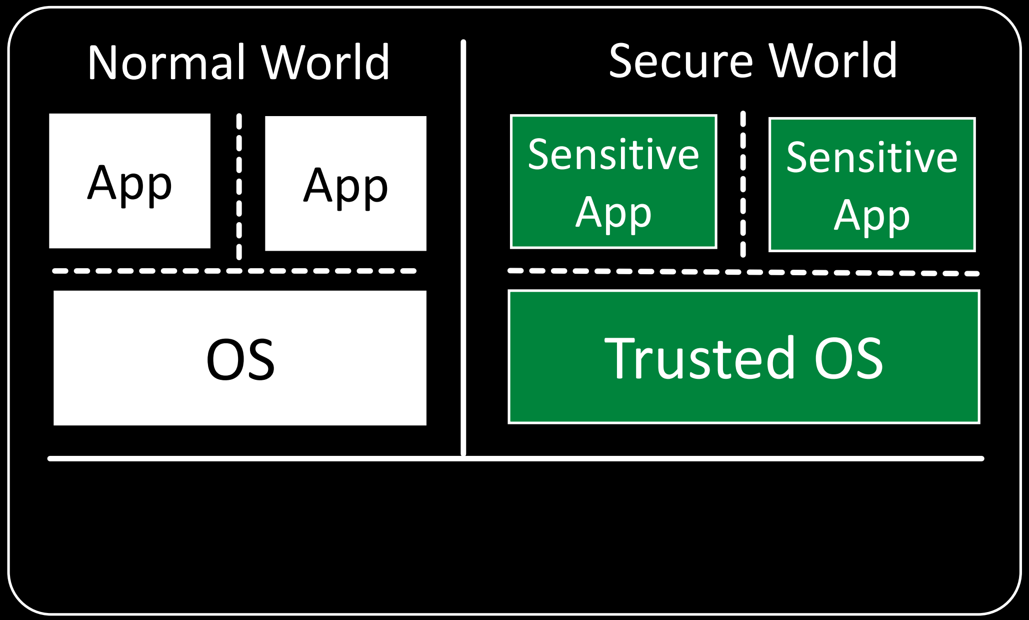

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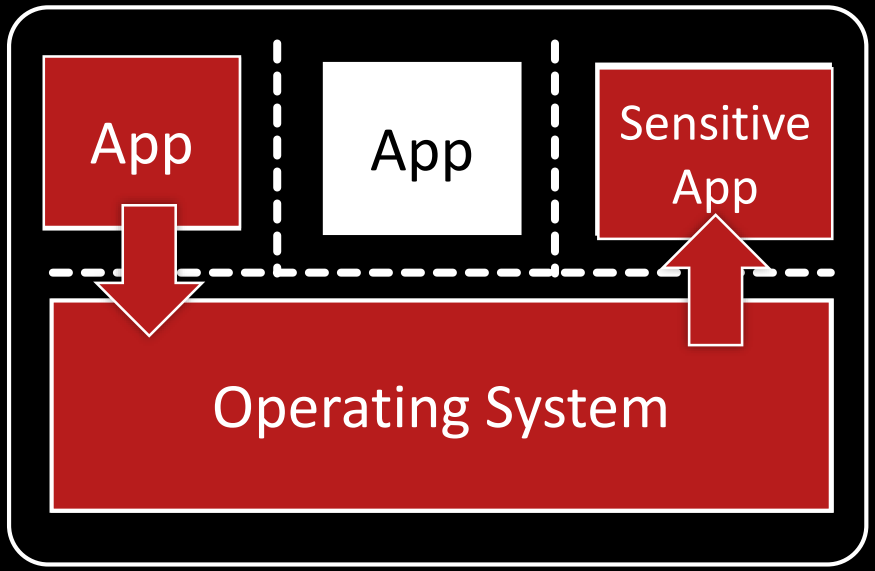

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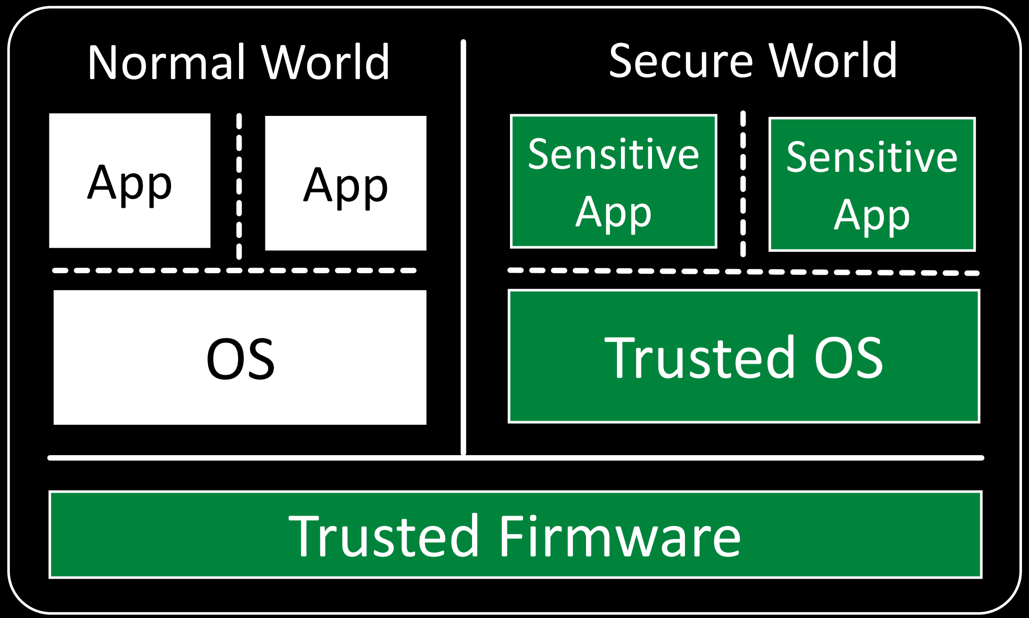

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ARM TrustZone
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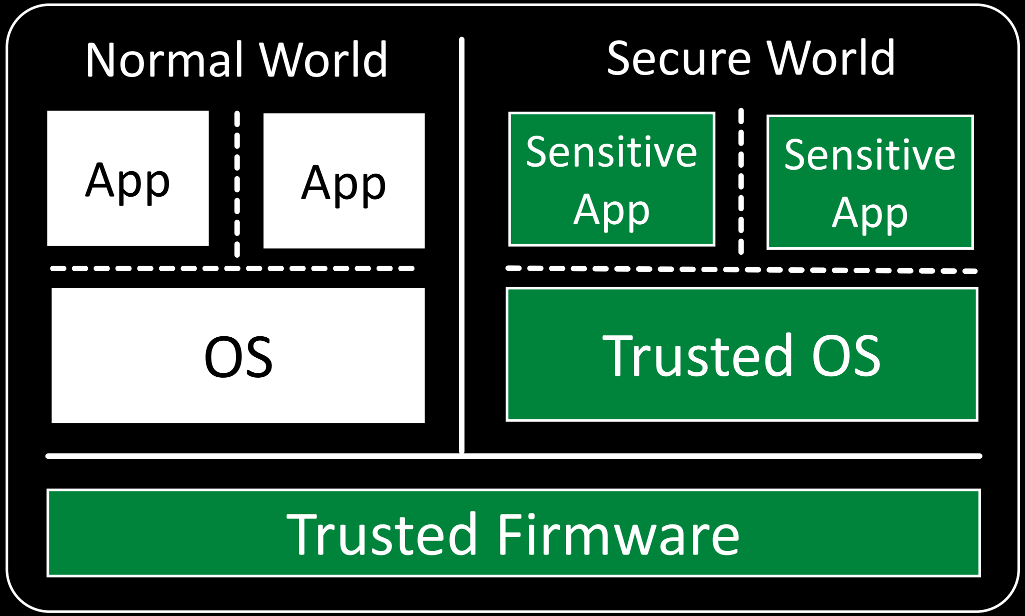

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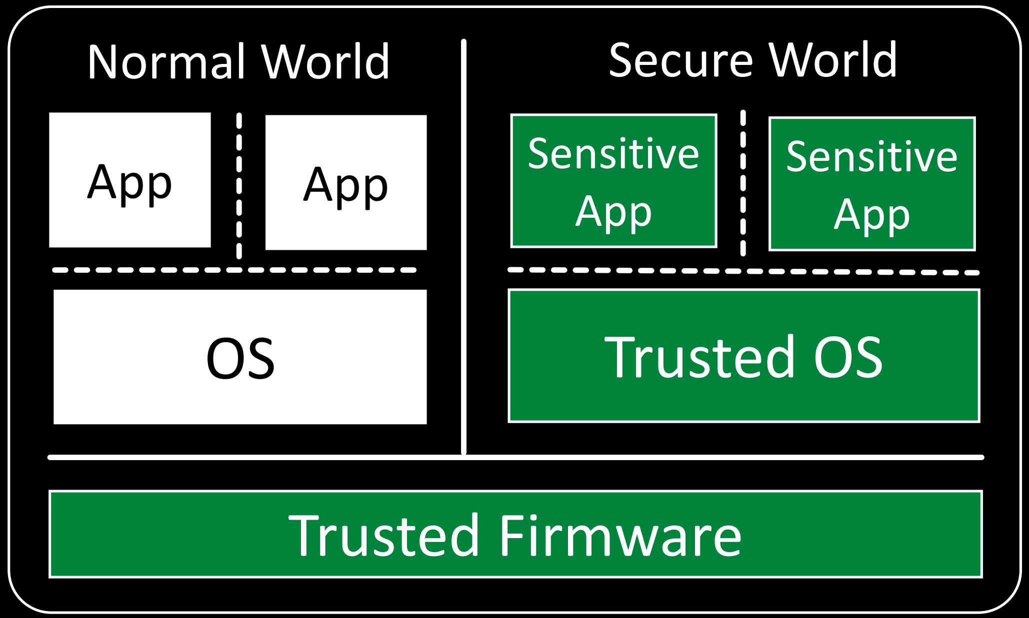

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- High costs to protect apps with TrustZone
- Main problem: Single security domain

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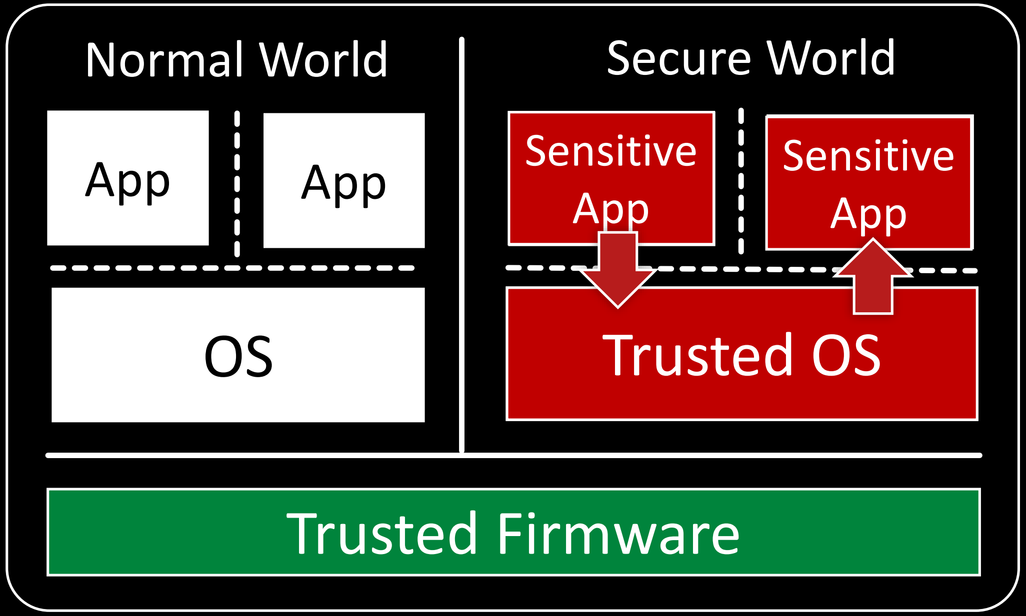

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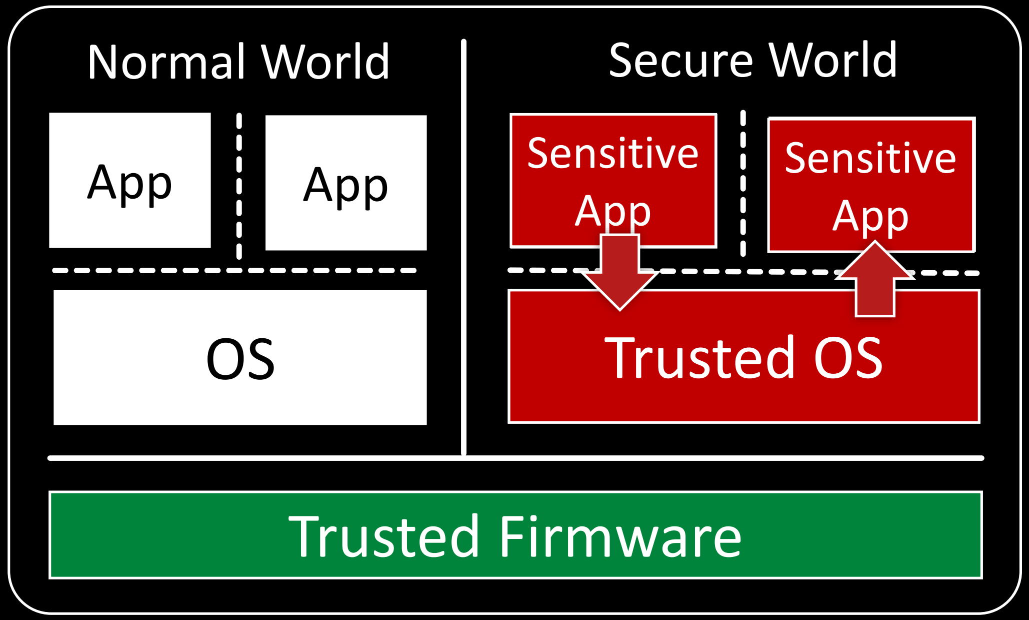

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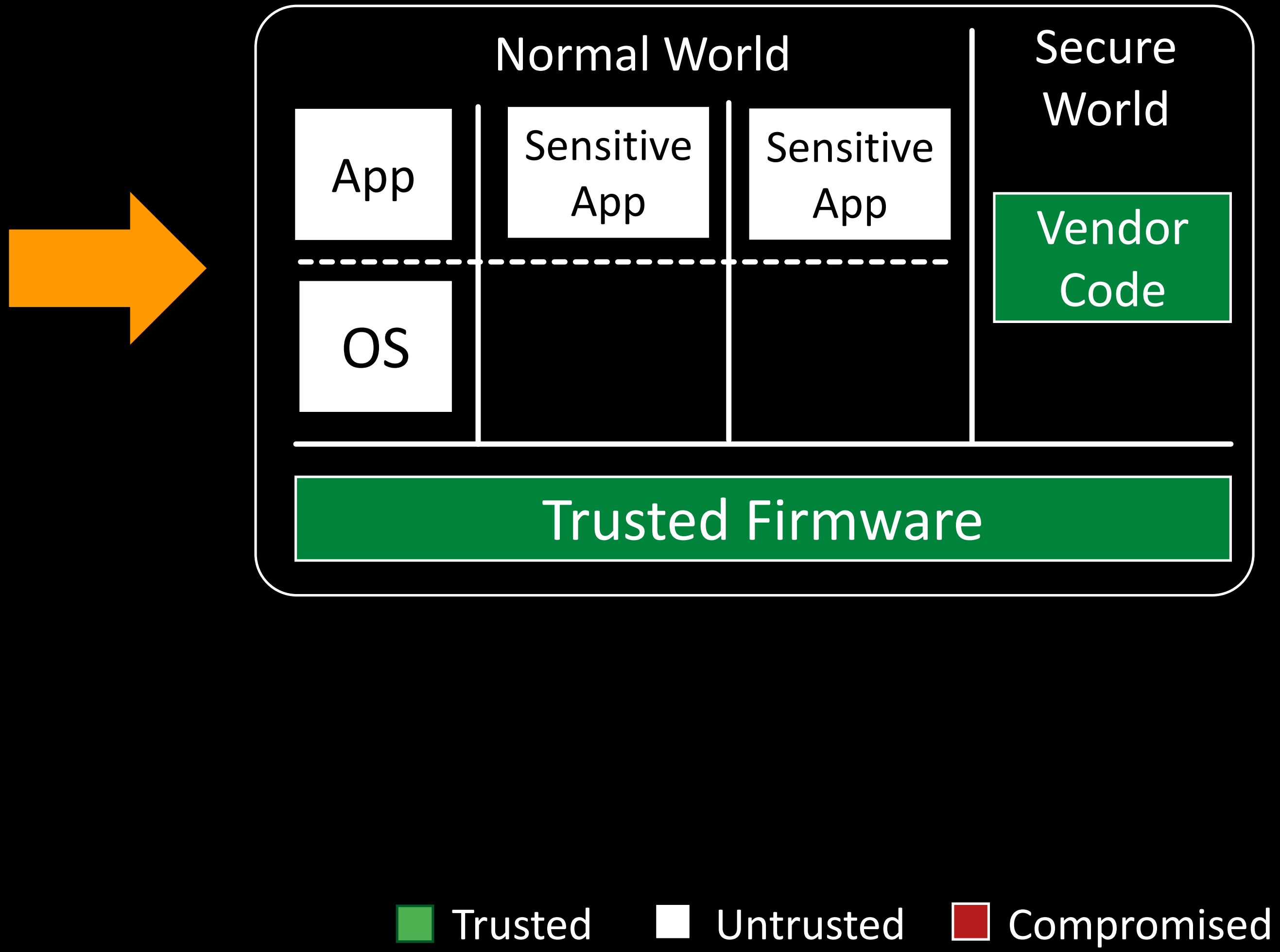
Sanctuary
Multiple Security Domains



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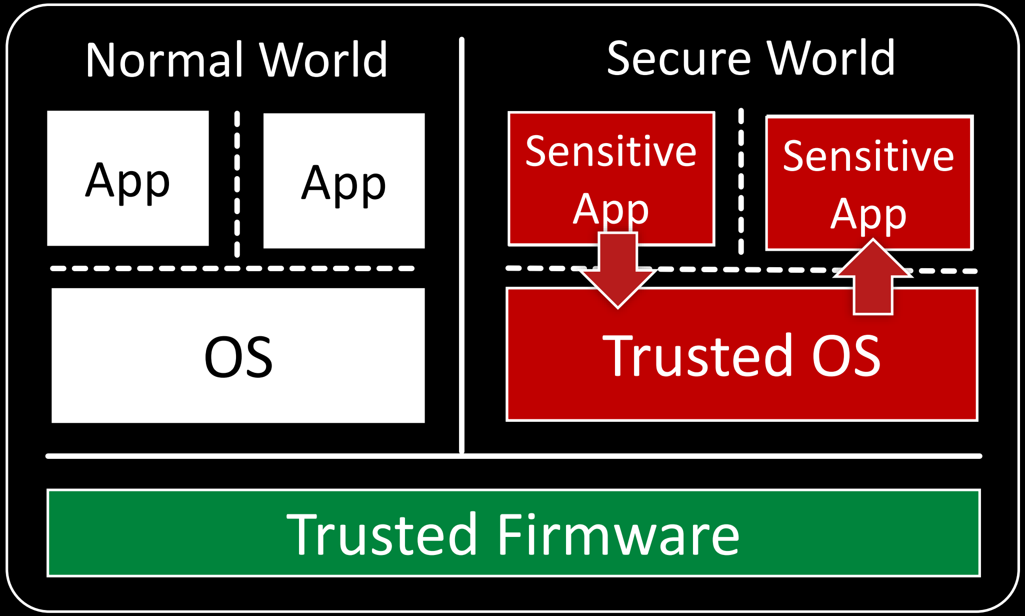

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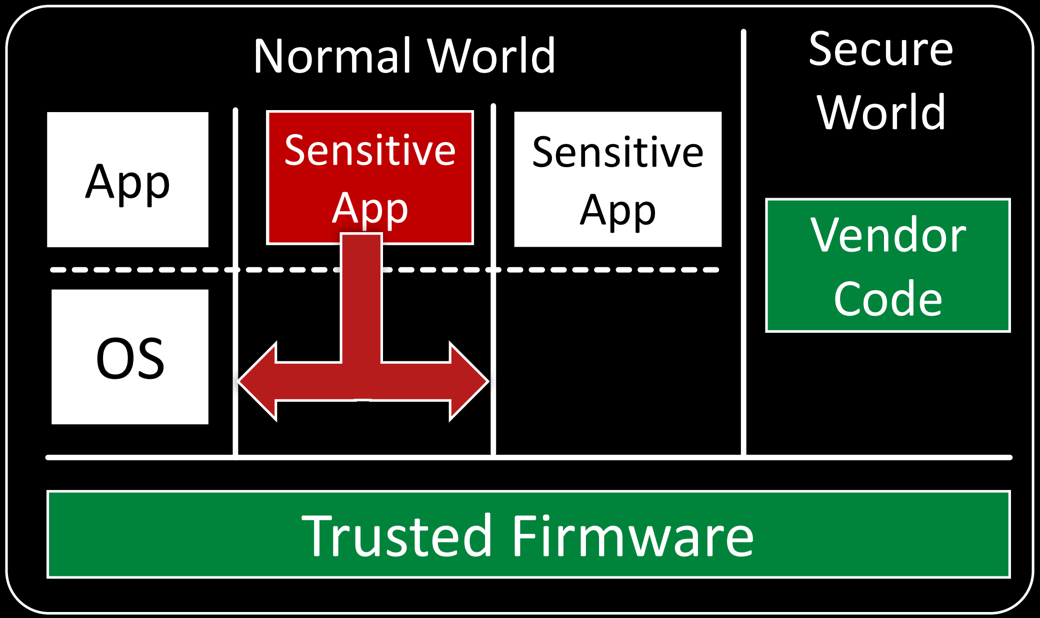

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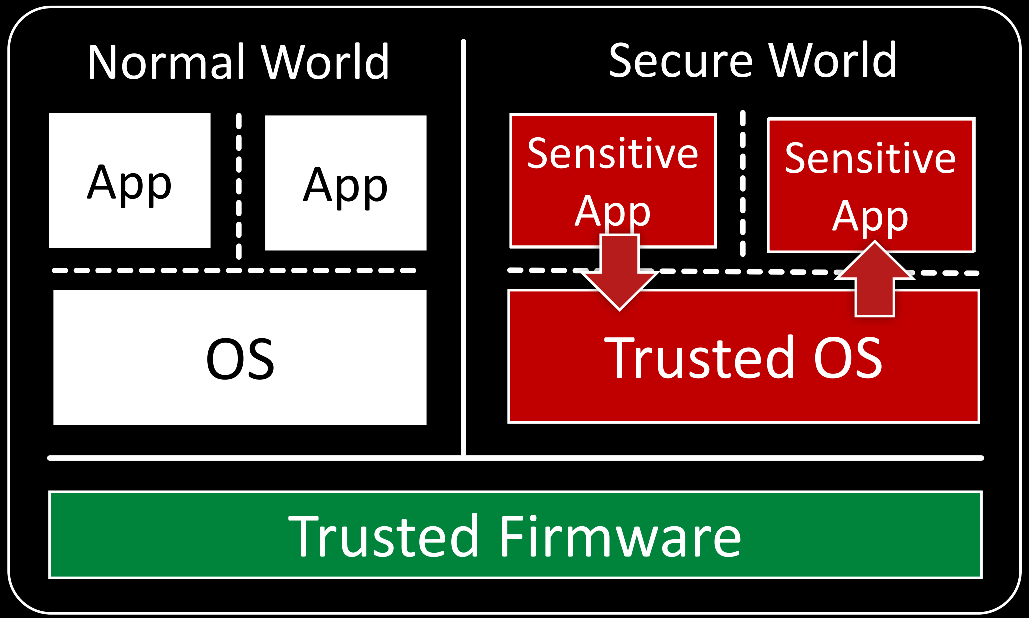

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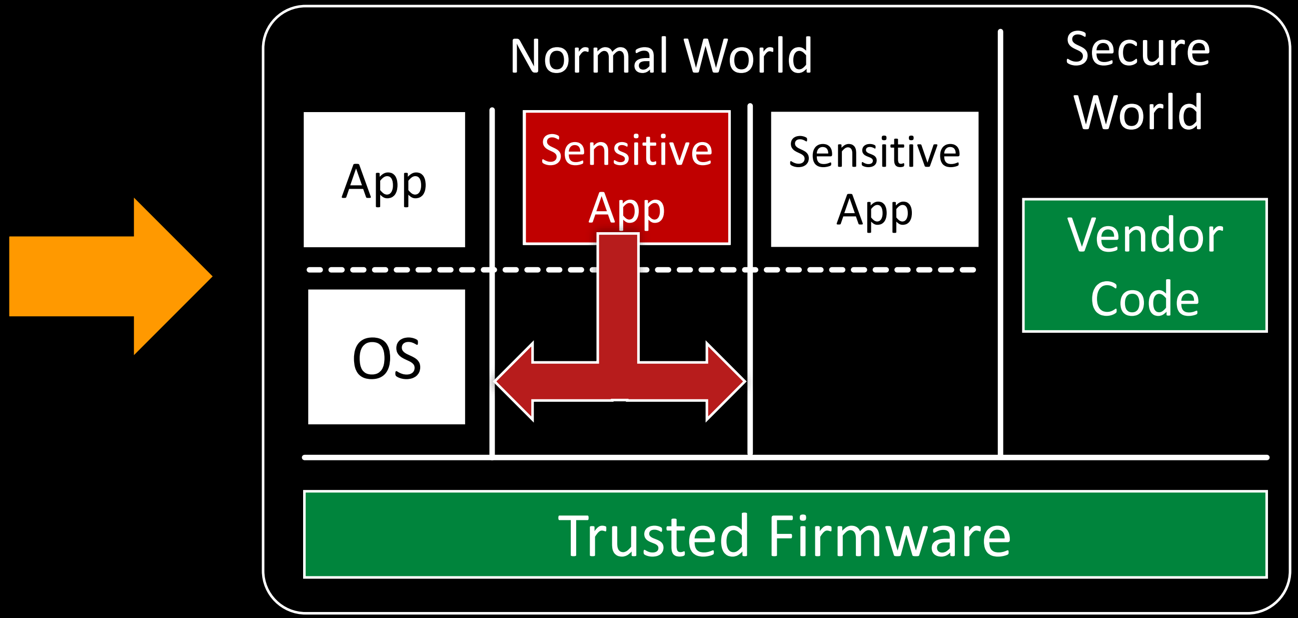

- Sensitive apps can remain untrusted
- Make TrustZone protection available to third parties

Trusted Untrusted Compromised

ARM TrustZone
The Solution?

Sanctuary
Multiple Security Domains

Challenges

- No new hardware components
- No replacement of existing code bases (e.g. Trusted OS)
- Only minor impact on commodity OS

Norma

App

Trusted Firmware

Secure World

Vendor Code

Trusted Firmware

- Trusted OS still large attack surface
- High costs to protect apps with TrustZone
- Main problem: Single security domain

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Trusted · Untrusted · Compromised

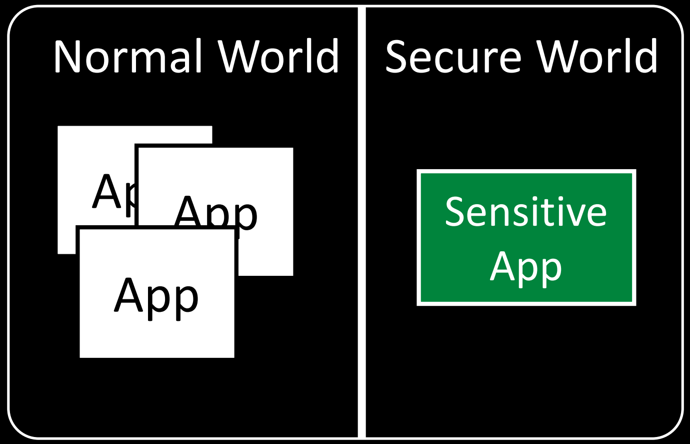
Adversary Model

- Adversary can
  - compromise normal-world software at all privilege levels
  - run malicious sensitive apps
- Adversary cannot
  - compromise TrustZone (trust anchor)
  - perform physical attacks

Related Work

Existing Research Proposals

Software Approaches
Utilizing TrustZone



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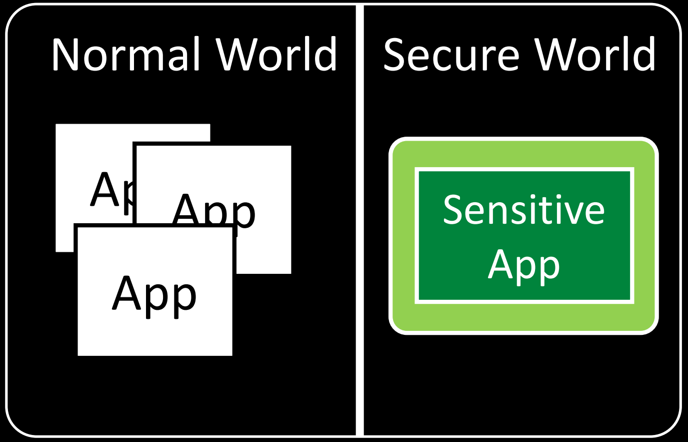

Improve isolation of sensitive apps without add. HW features

among others,

[Ferraiuolo et al., SOSP 2017]

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Existing Research Proposals

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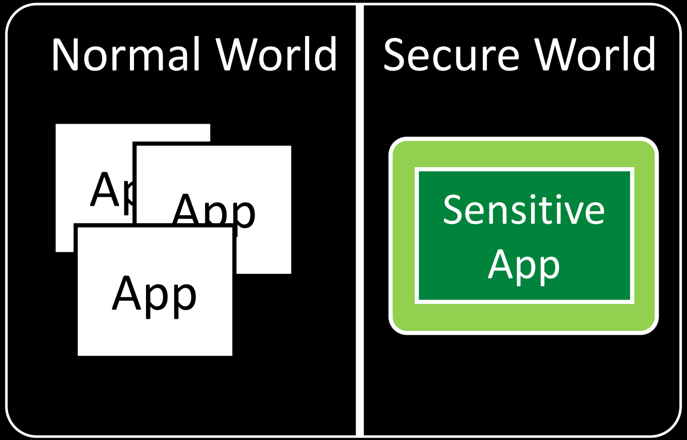

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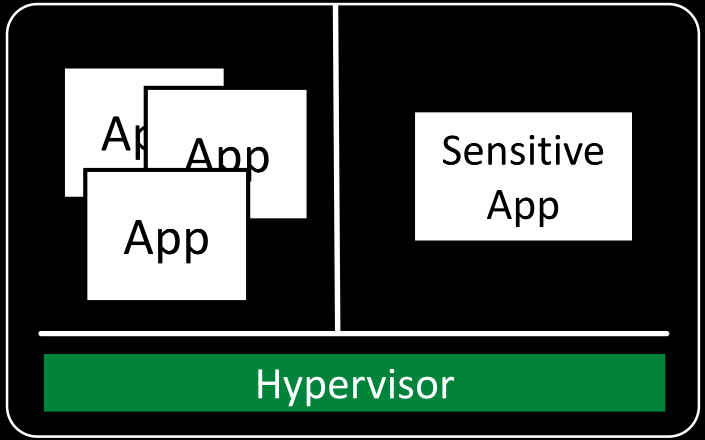
Hypervisor-based Isolation Utilizing TrustZone



Use virtualization to protect sensitive apps.
Use TrustZone as trust anchor

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Existing Research Proposals

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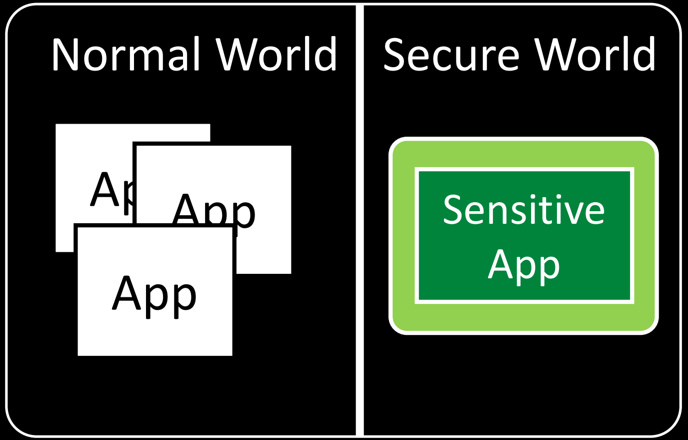

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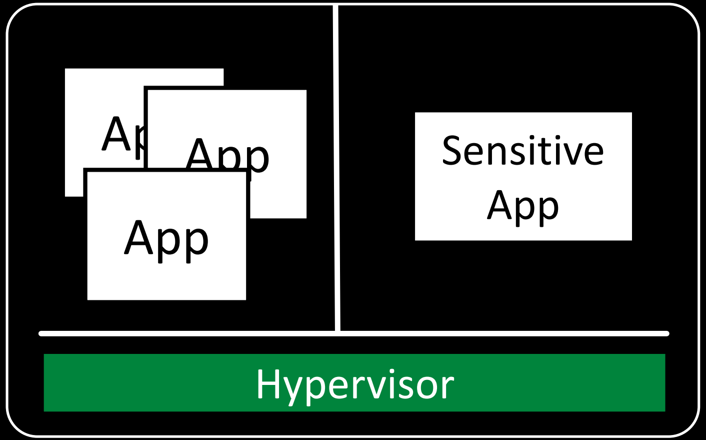

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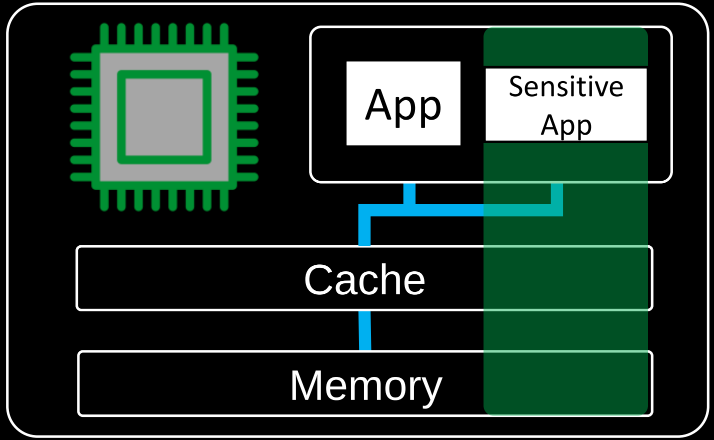


Overcome TrustZone's shortcomings with own HW

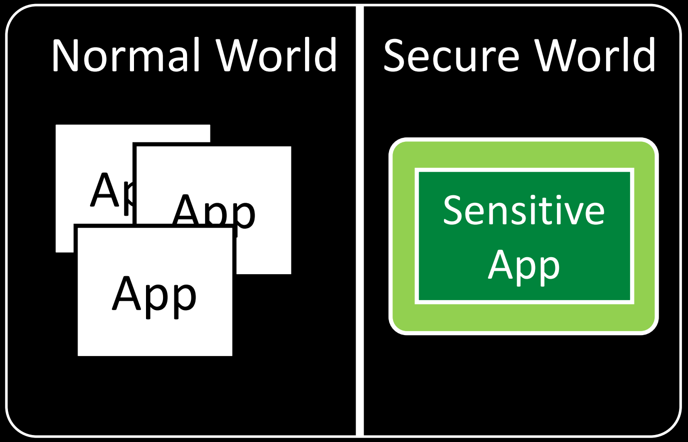
among others,

[Costan et al., USENIX 2016]

[Evtyushkin et al., MICRO 2014]

Existing Research Proposals - Problems

Software Approaches Utilizing TrustZone



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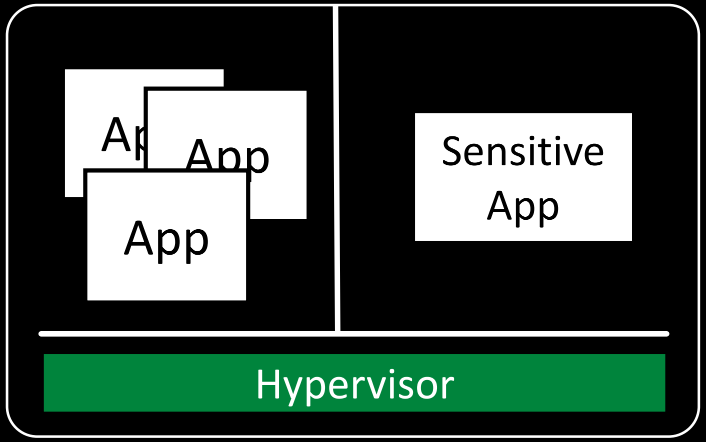

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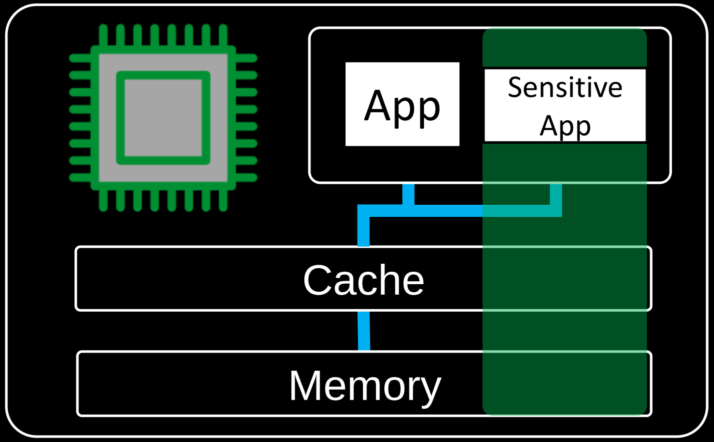


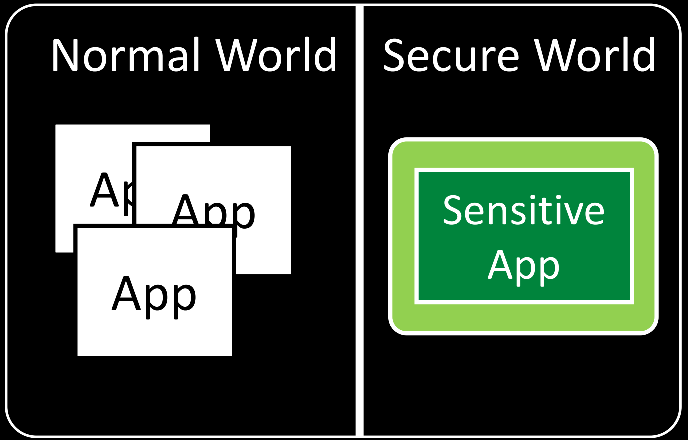
Replaces existing code base

Hypervisor blocked

New hardware design

Existing Research Proposals - Problems

Software Approaches Utilizing TrustZone



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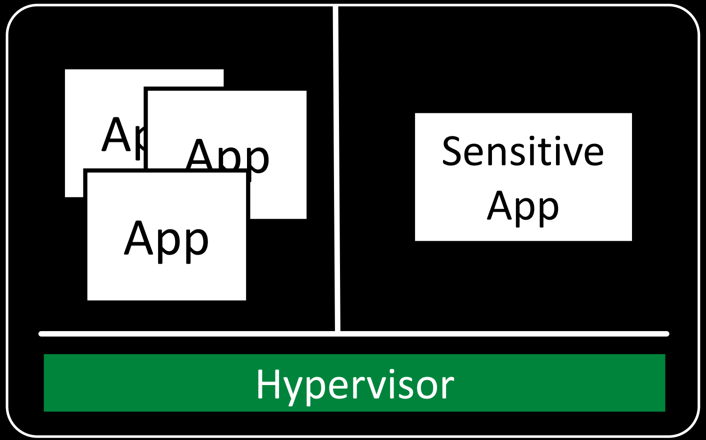

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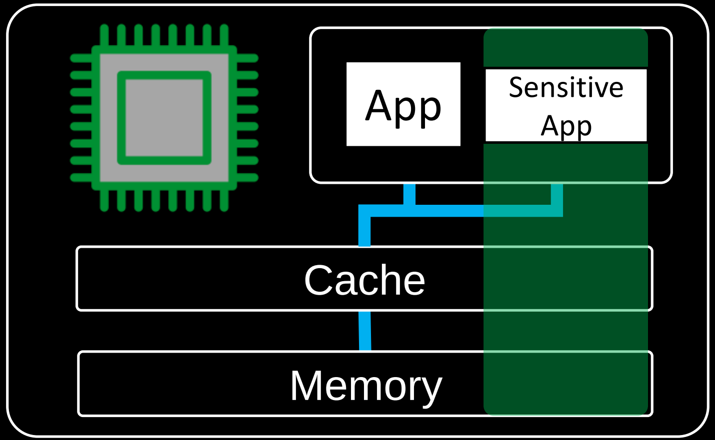


Replaces existing code base

OS needs to be suspended

No support for multi-core environments

Hypervisor blocked

Slows down commodity OS

Additional TCB component

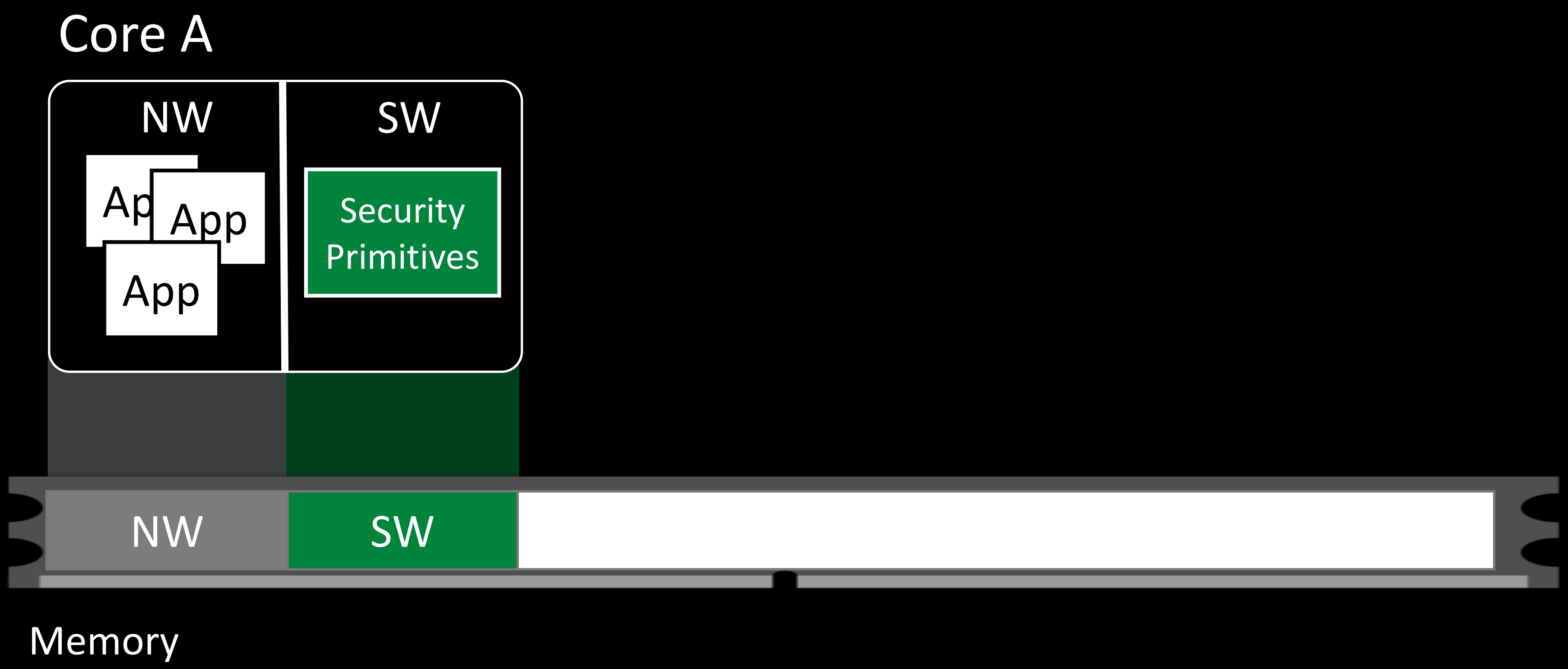
Additional HW for DMA access control

New hardware design

High deployment costs

Low adoption by industry

Sanctuary provides Multi-Domain Isolation



NW = Normal World
SW = Secure World

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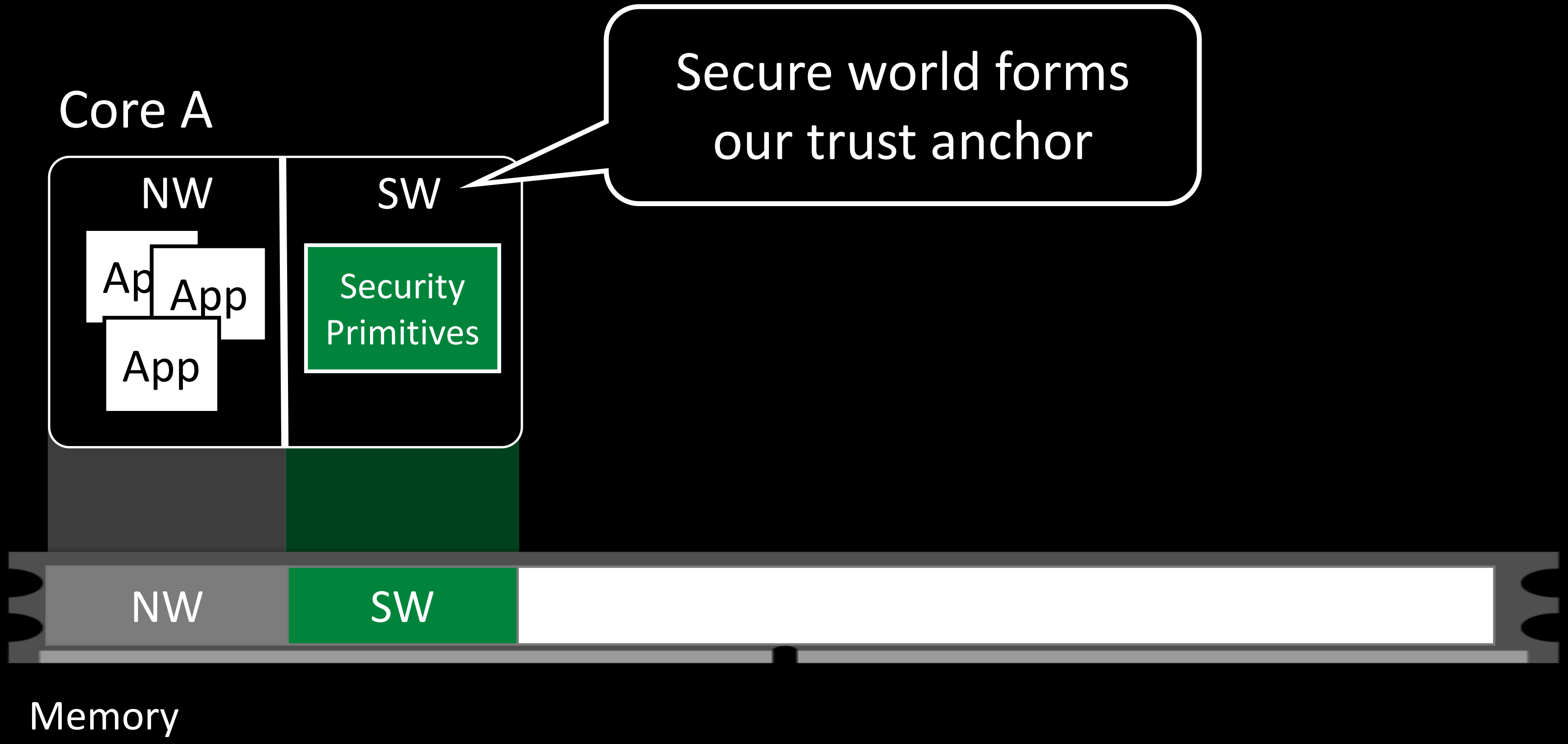

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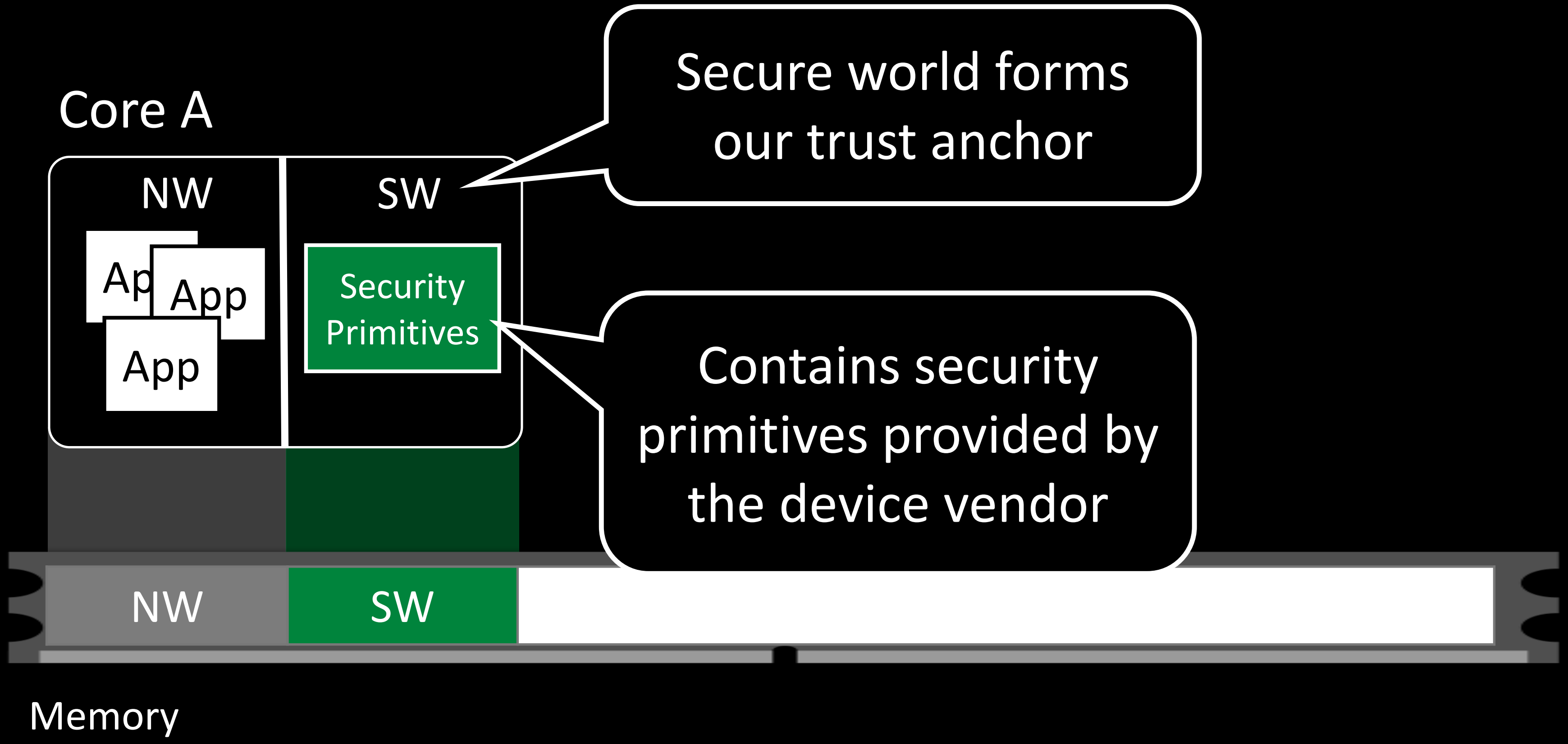

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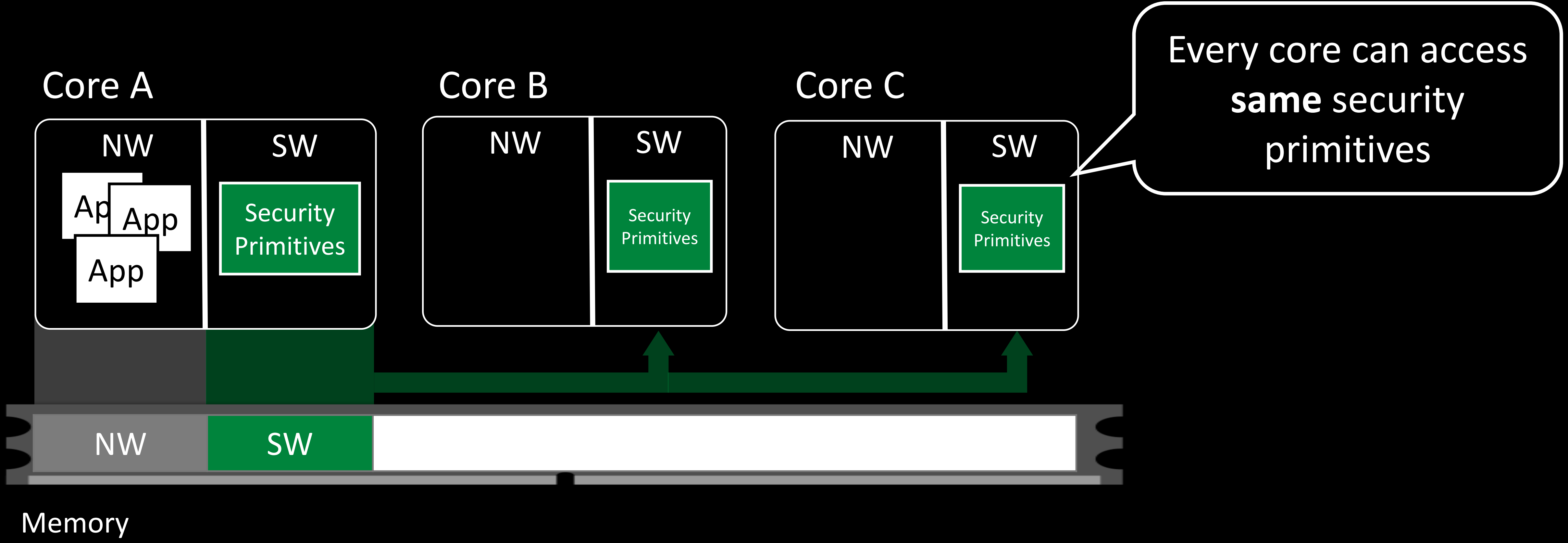

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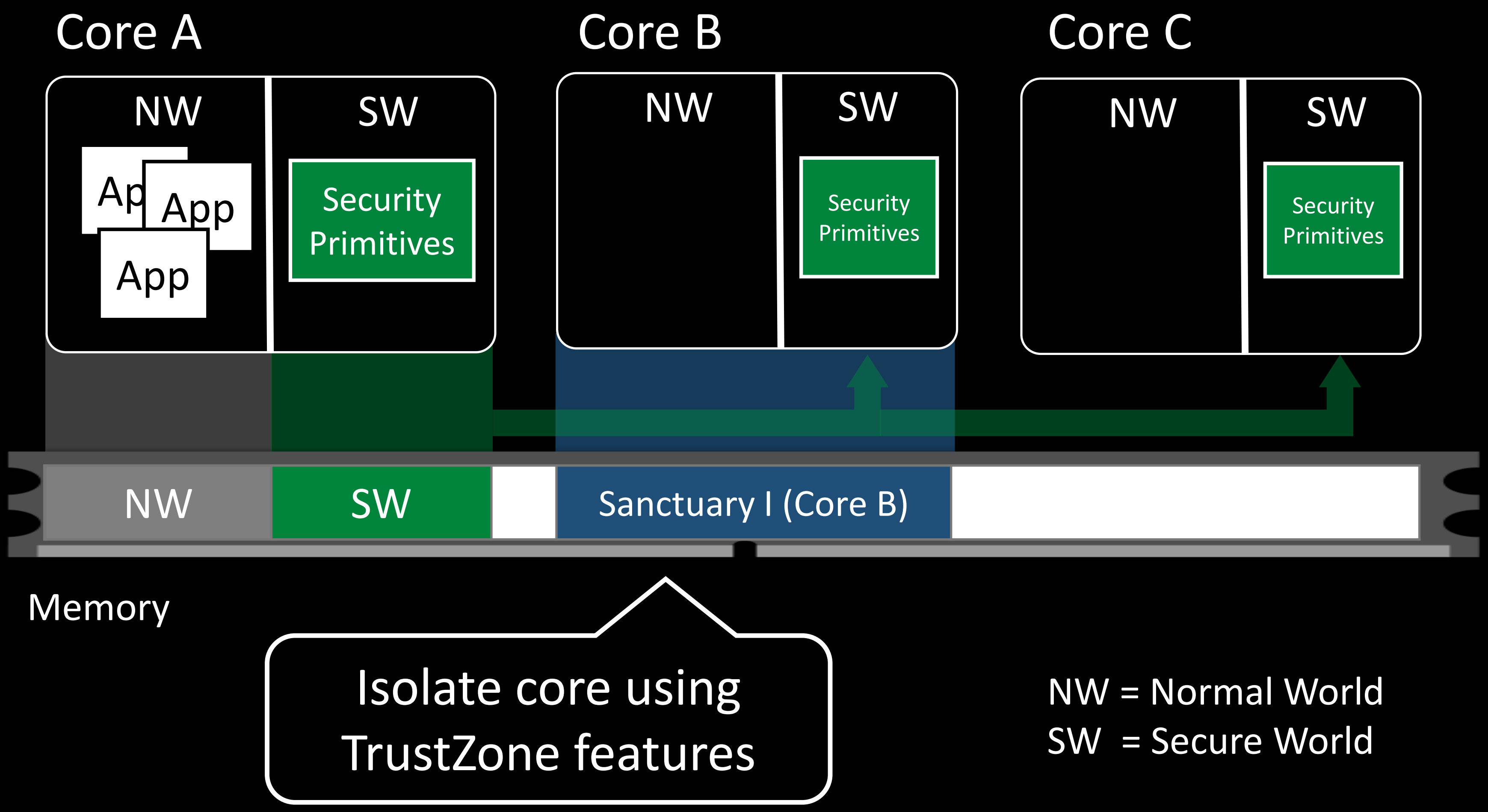

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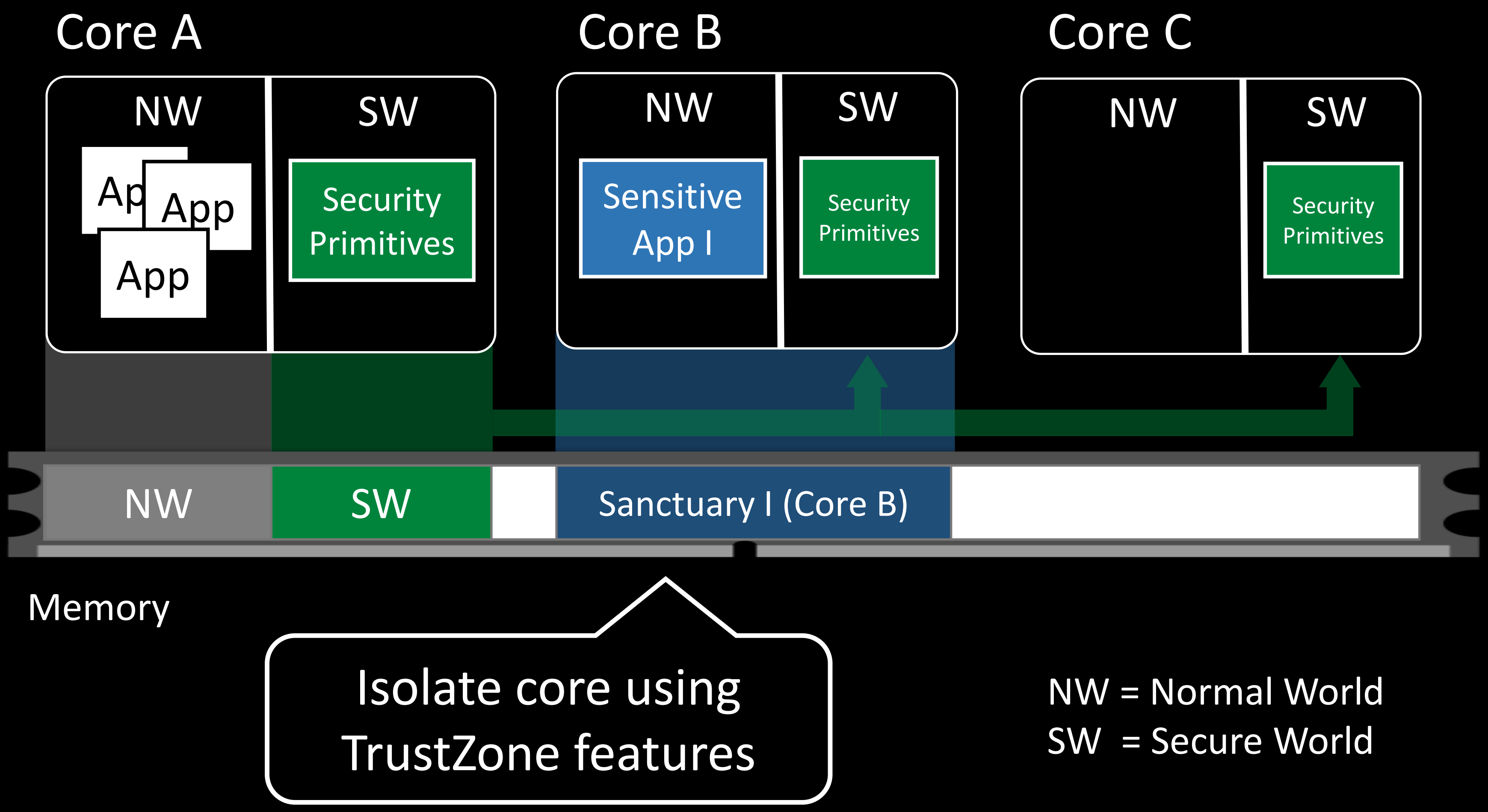

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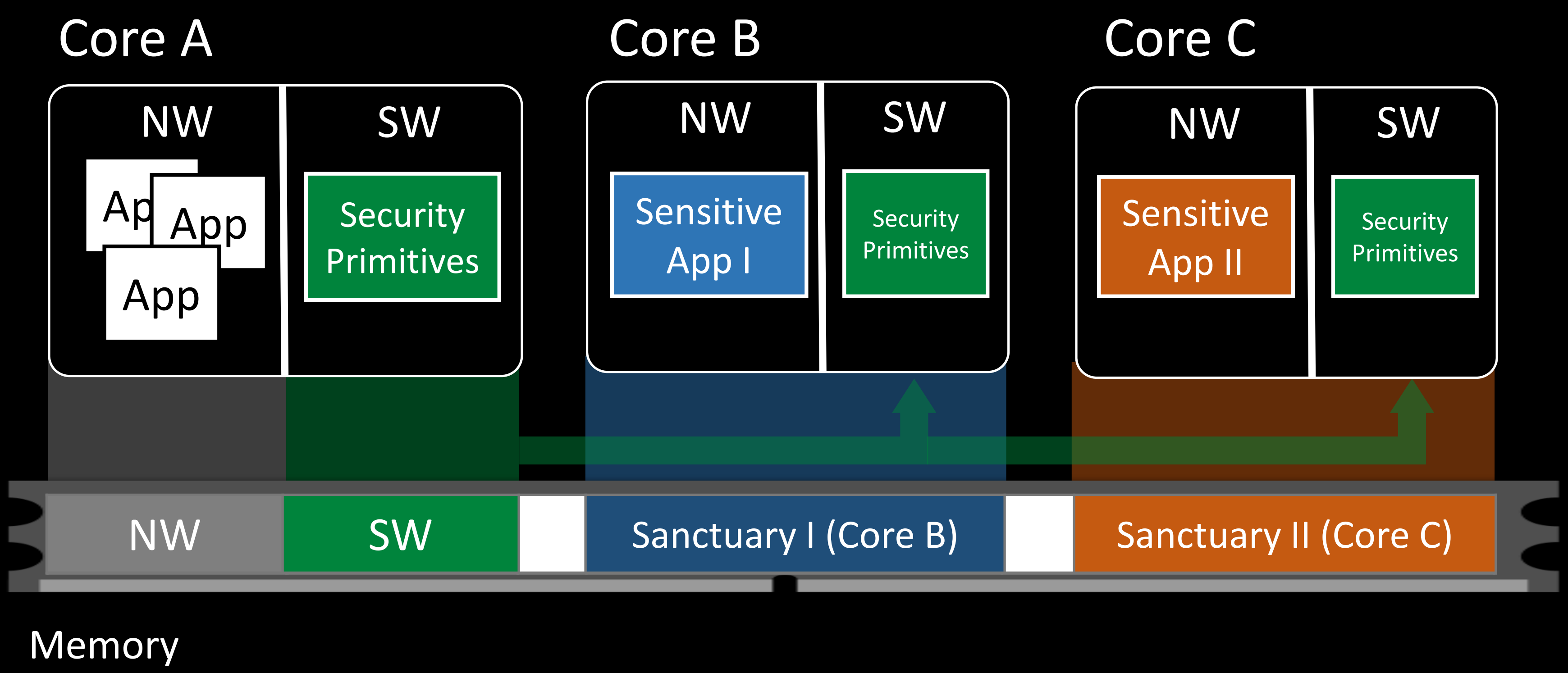

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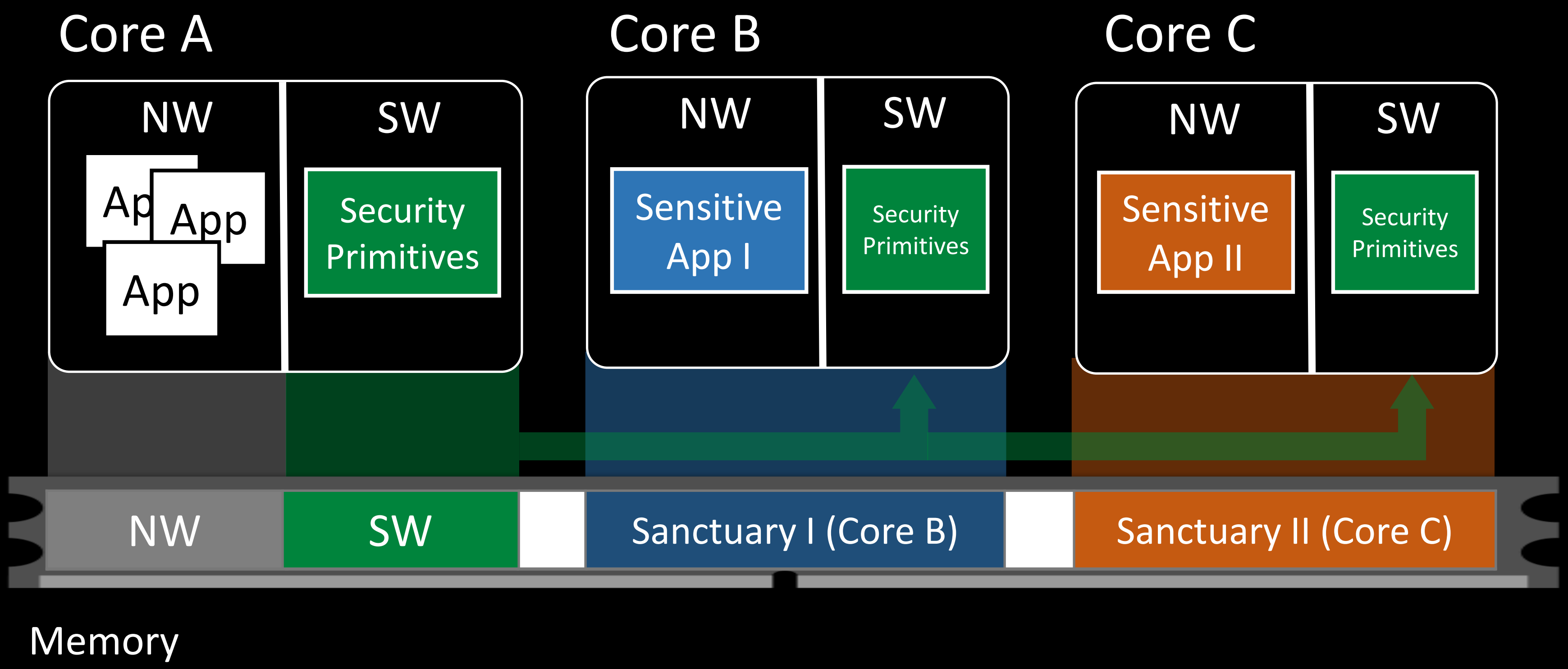

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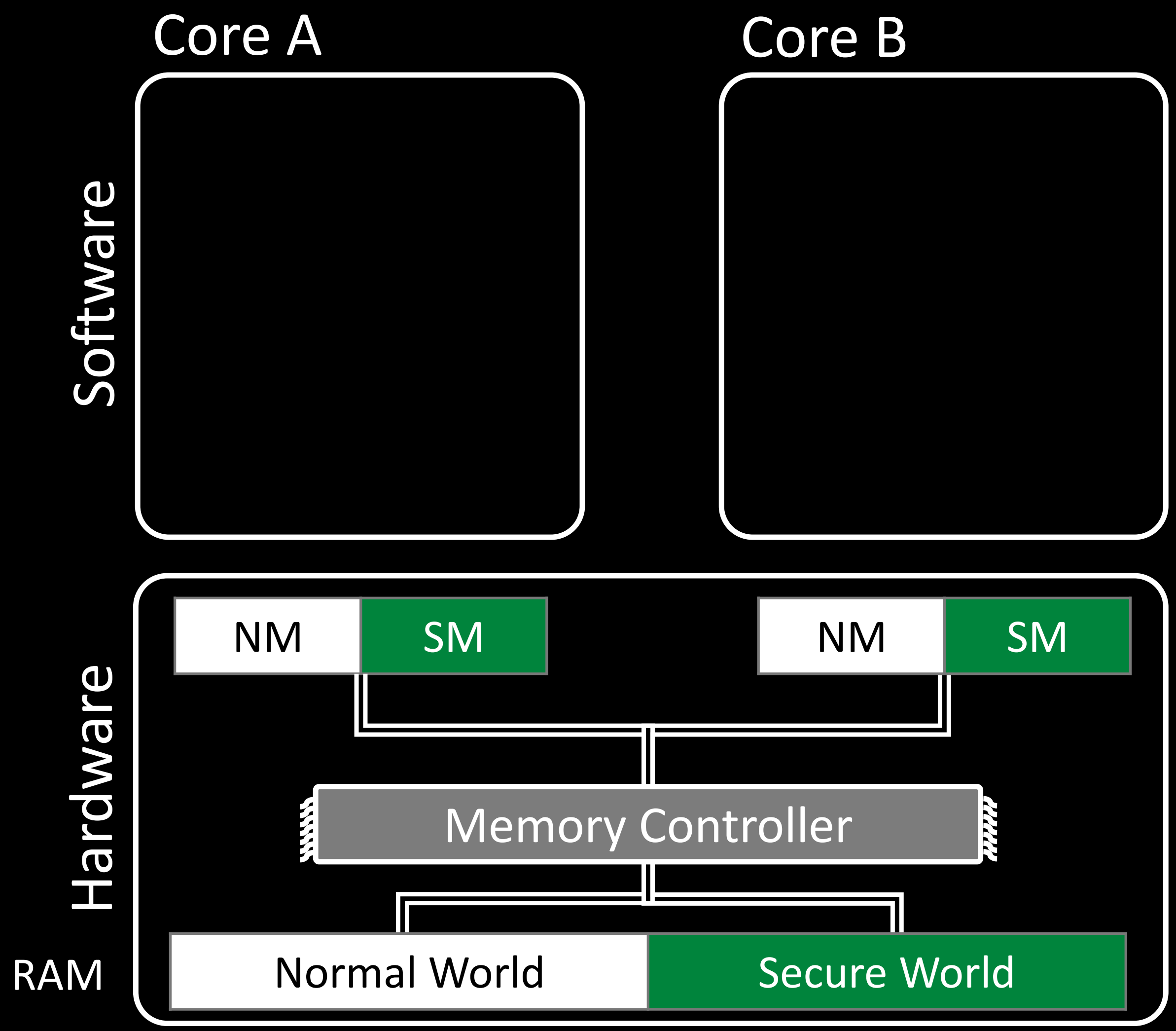
Challenges revisited

- Only using TrustZone features.
  No new HW design
- Vendor can keep existing code in SW
- No heavy influence on commodity OS

Technical Details of Sanctuary

Going Beyond TrustZone …



NM = Normal Mode

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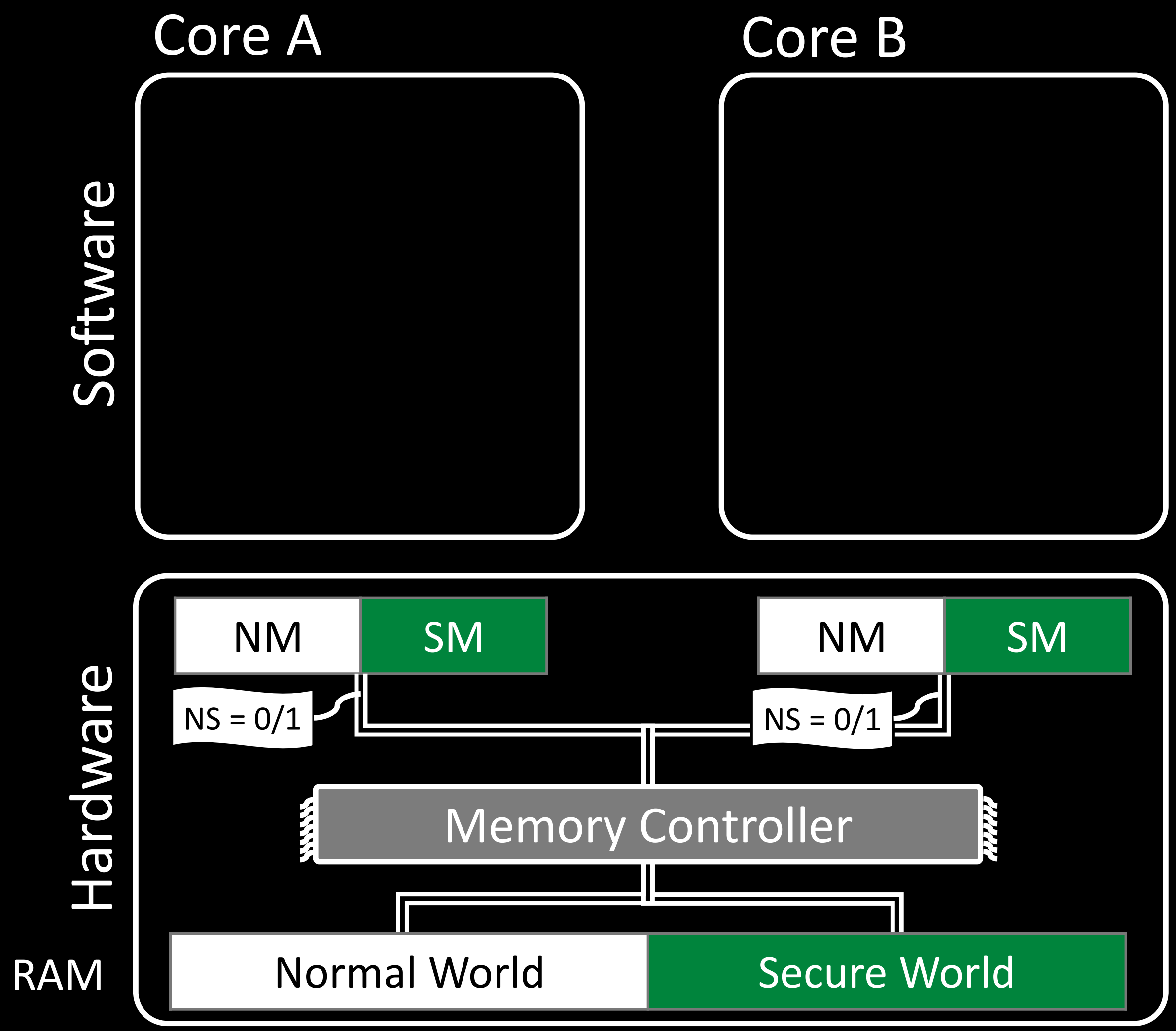

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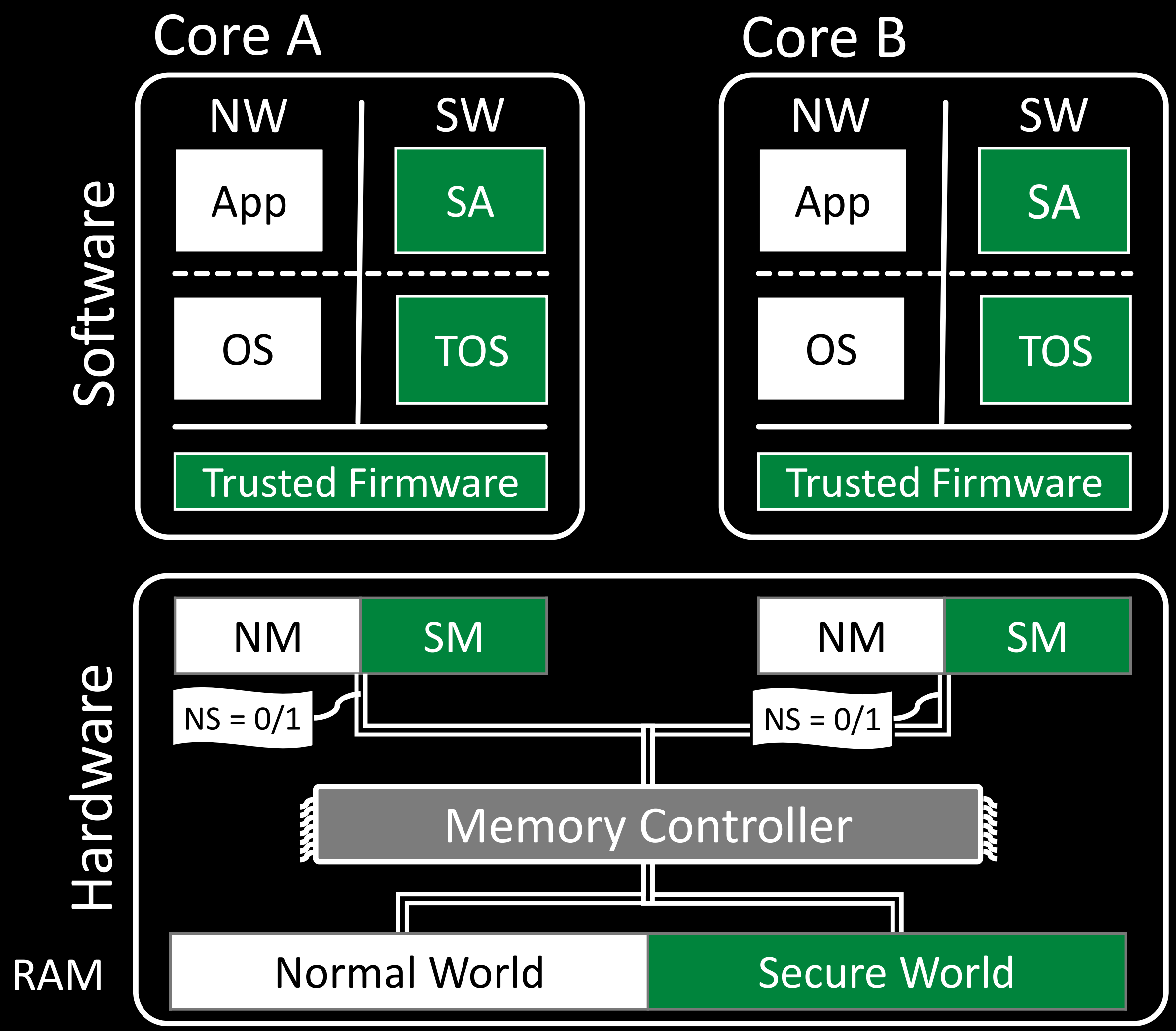

SA = Sensitive App

TOS = Trusted OS

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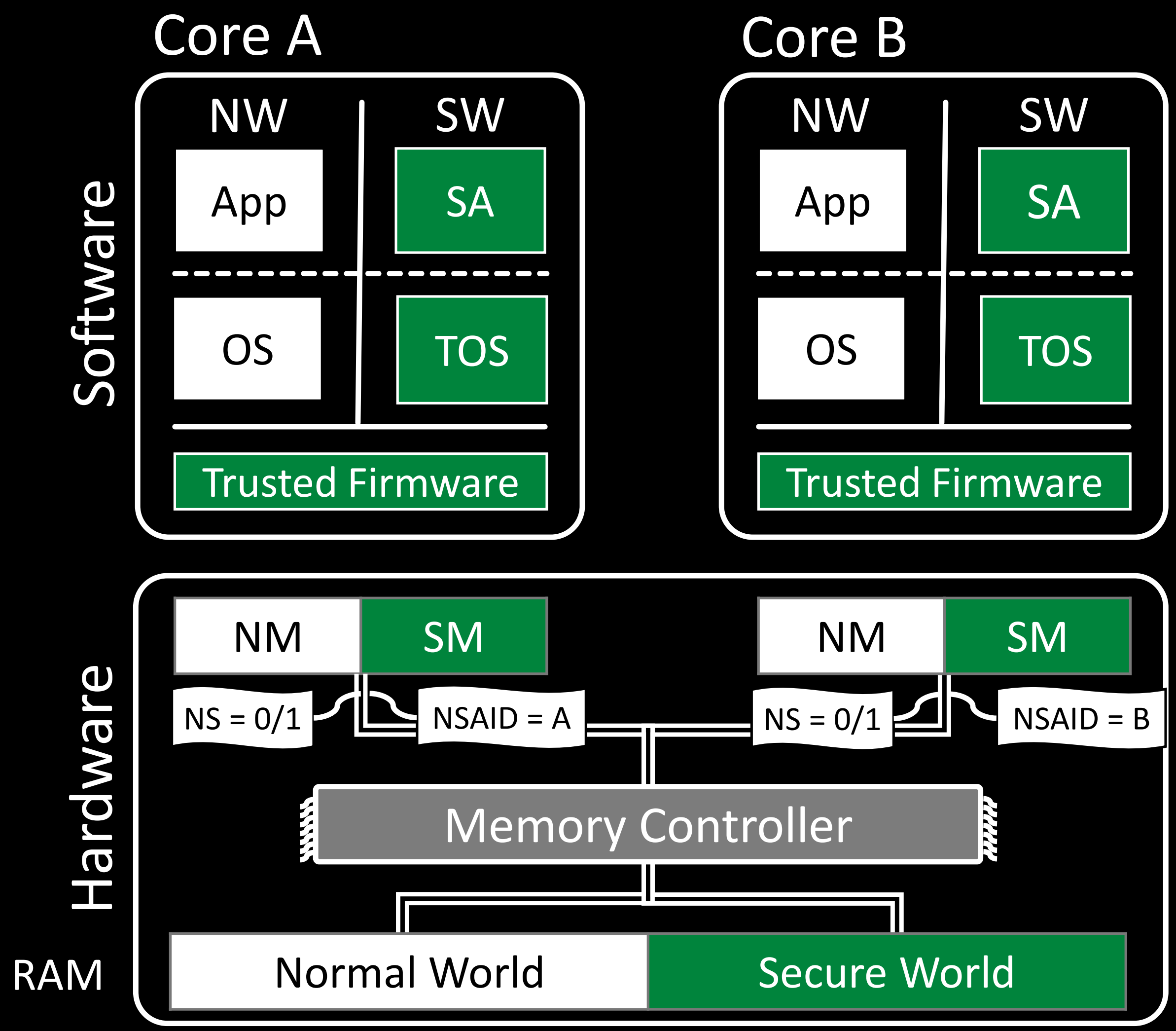

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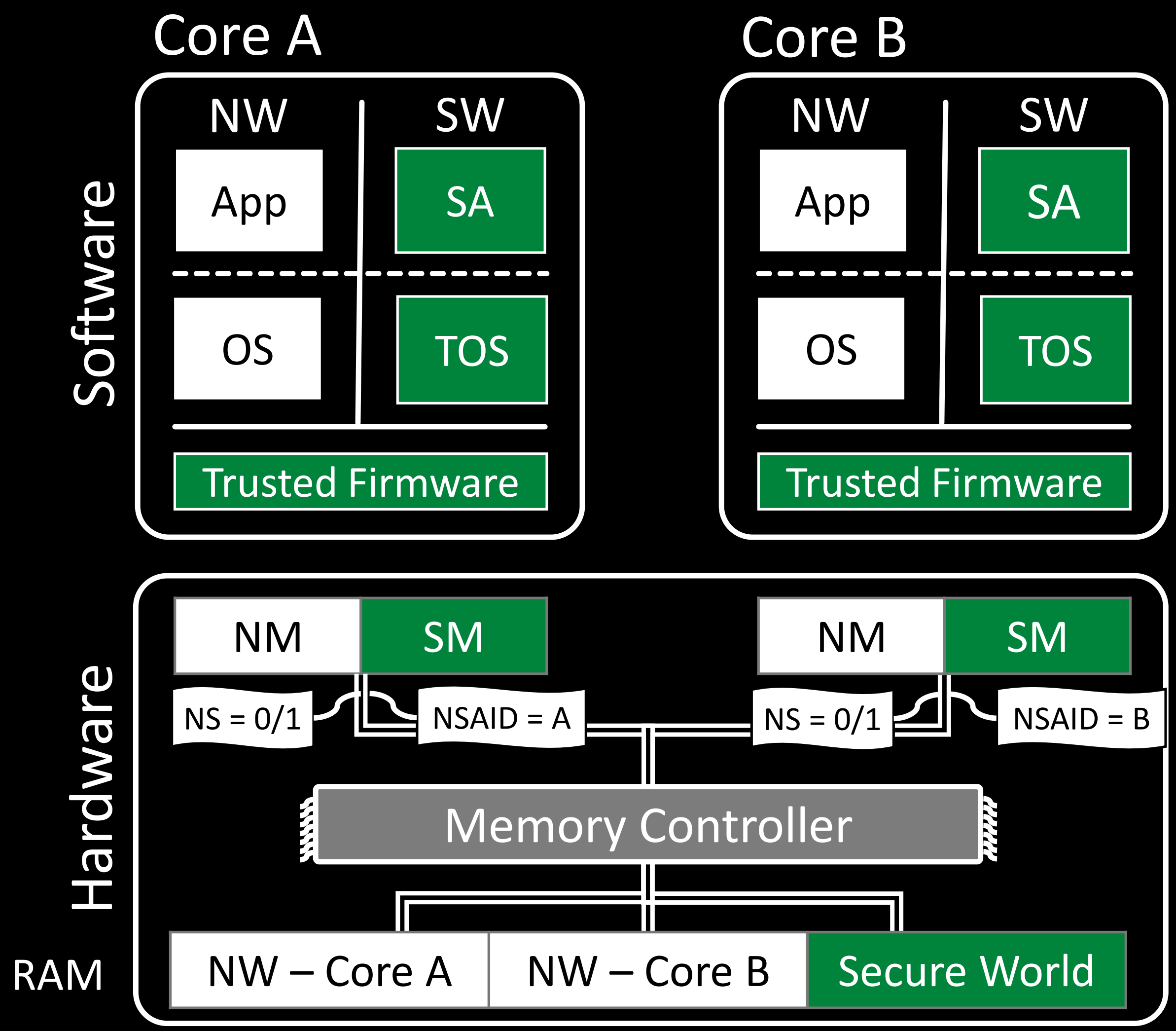

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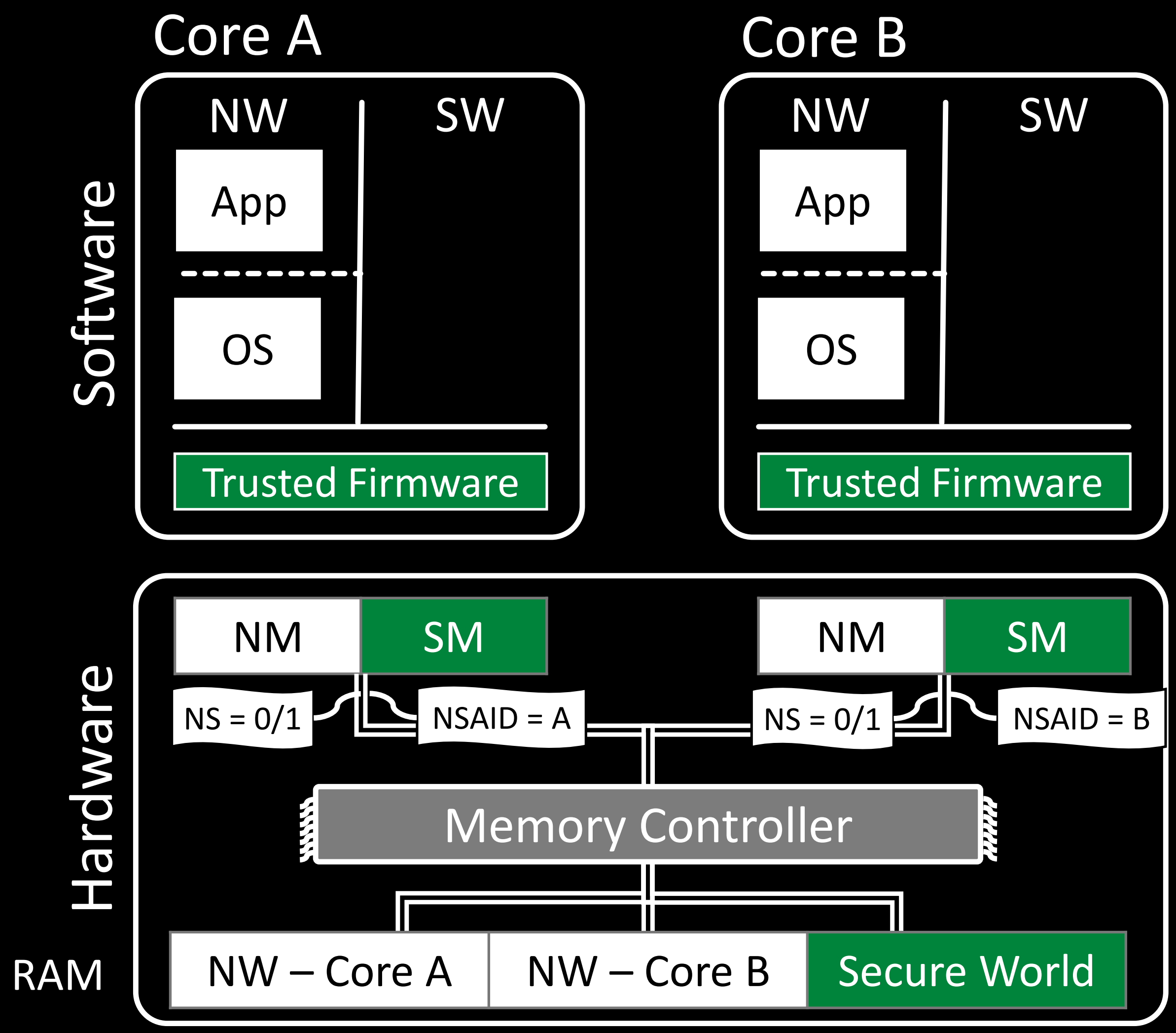

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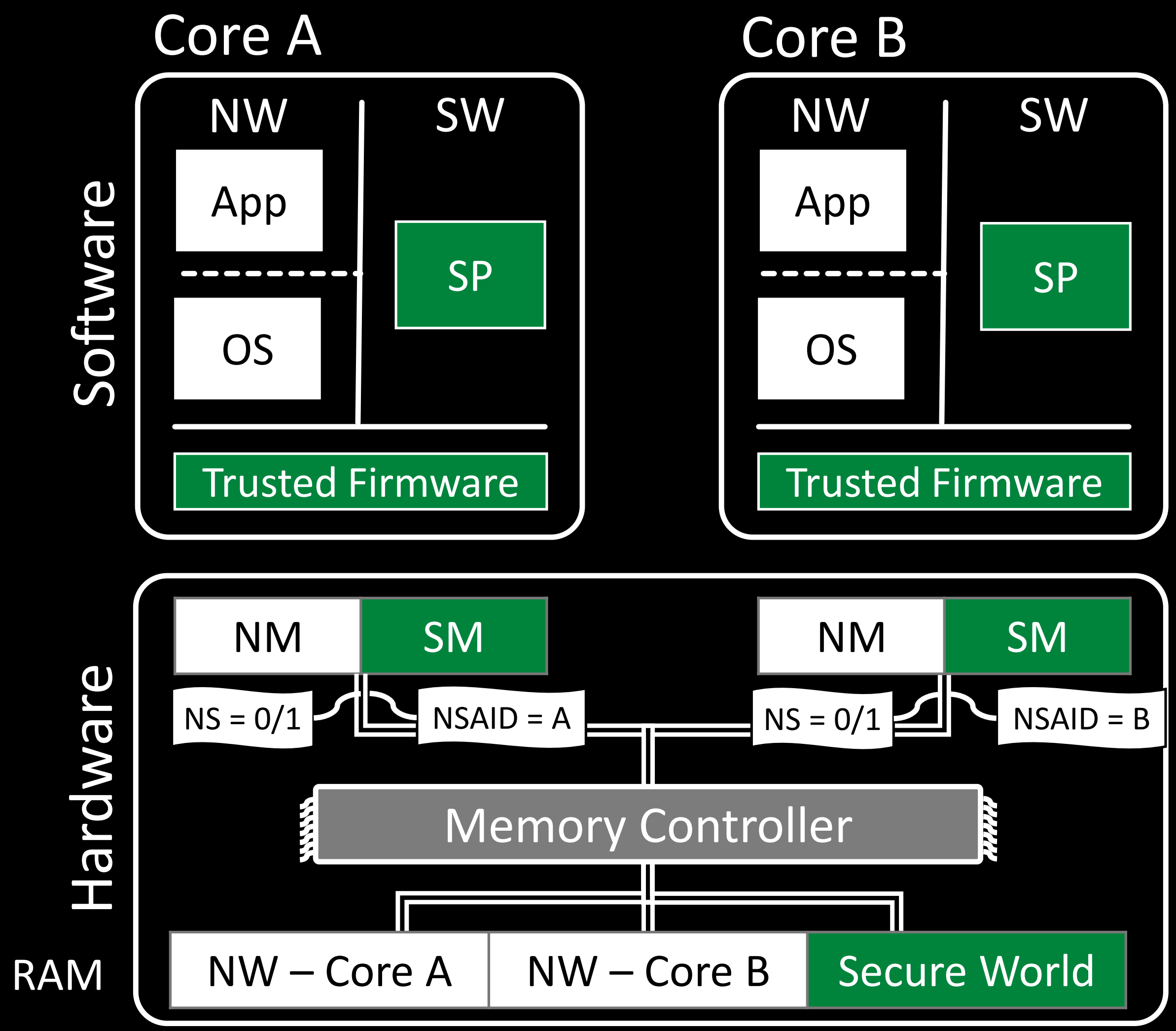

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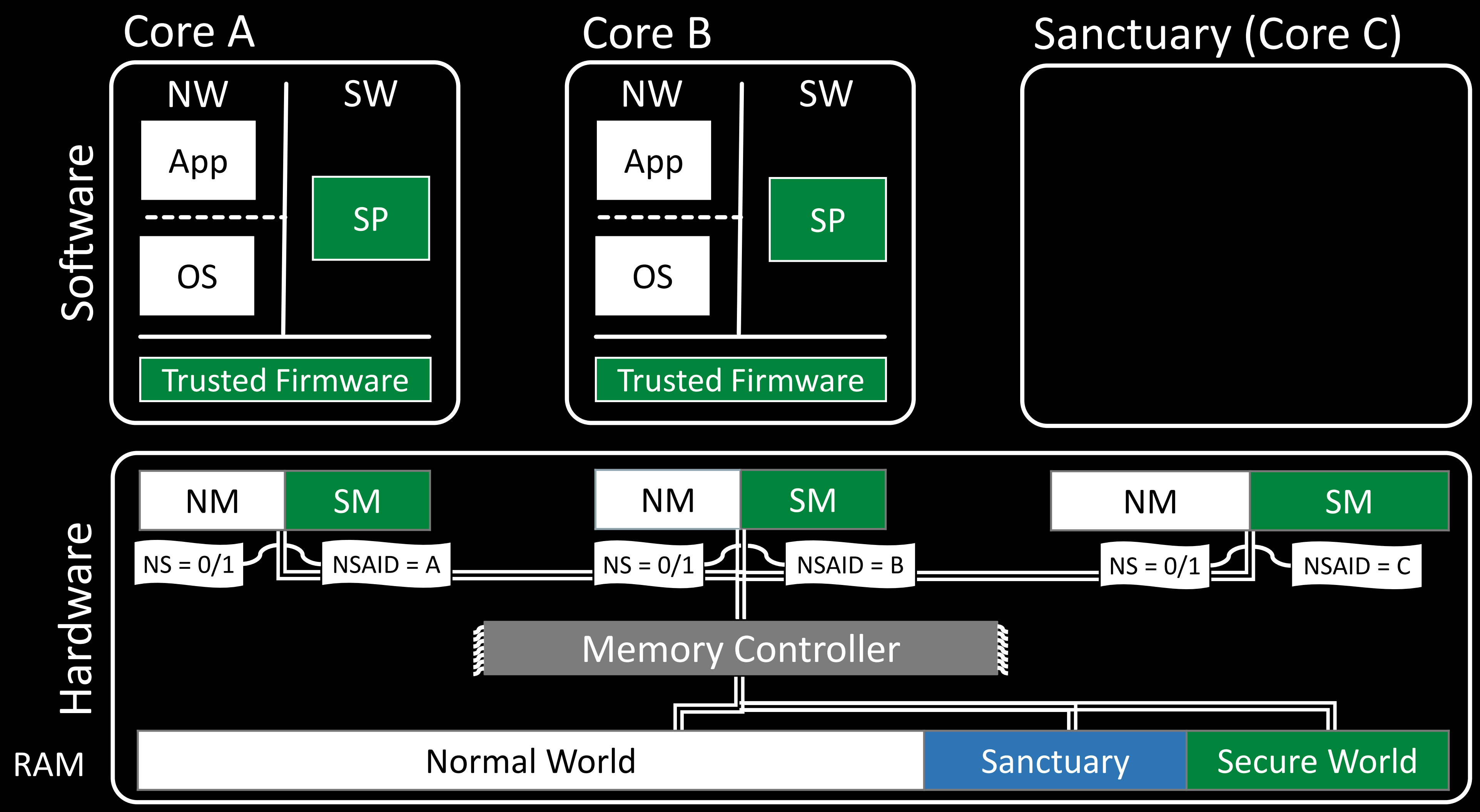

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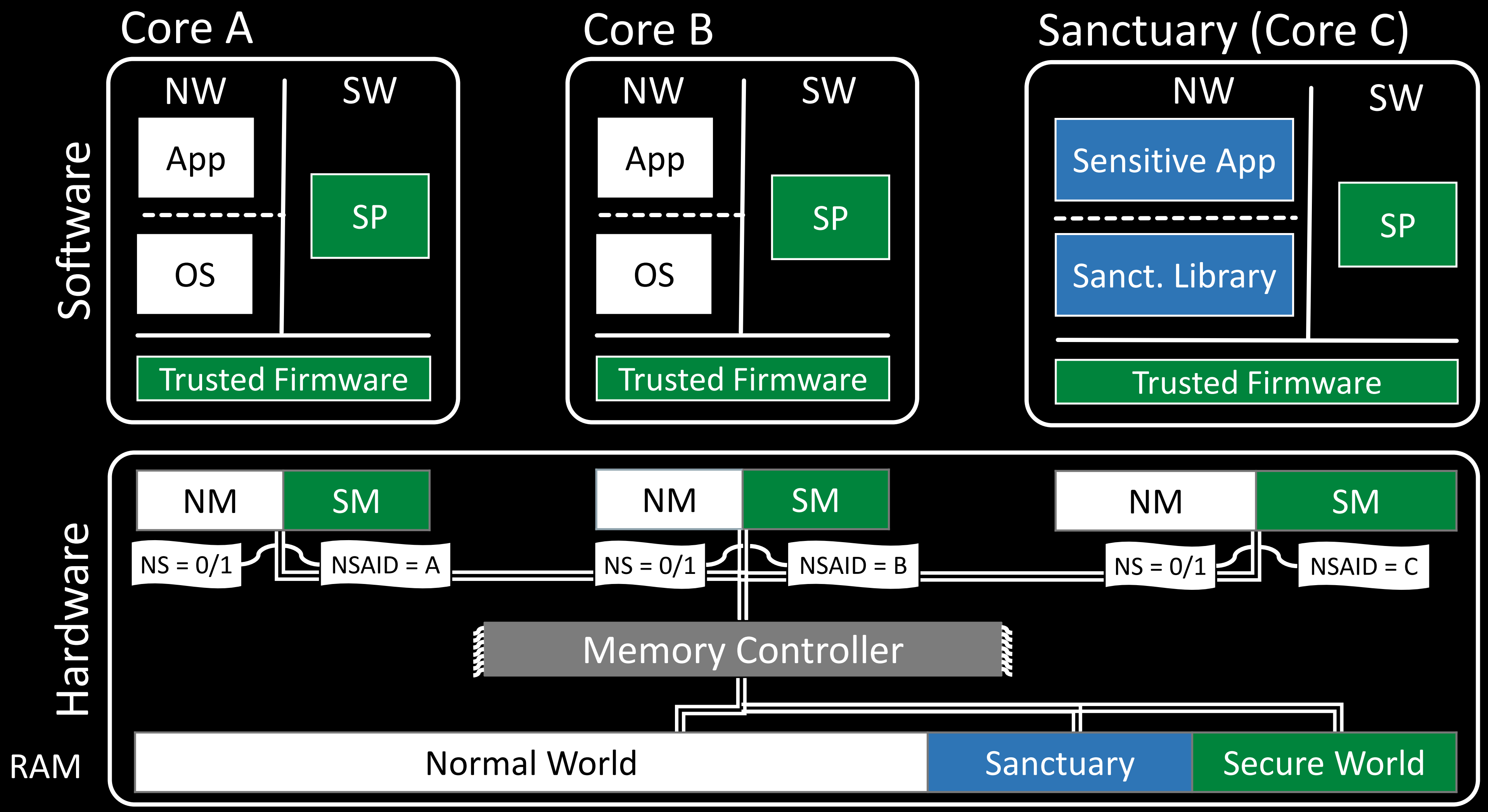

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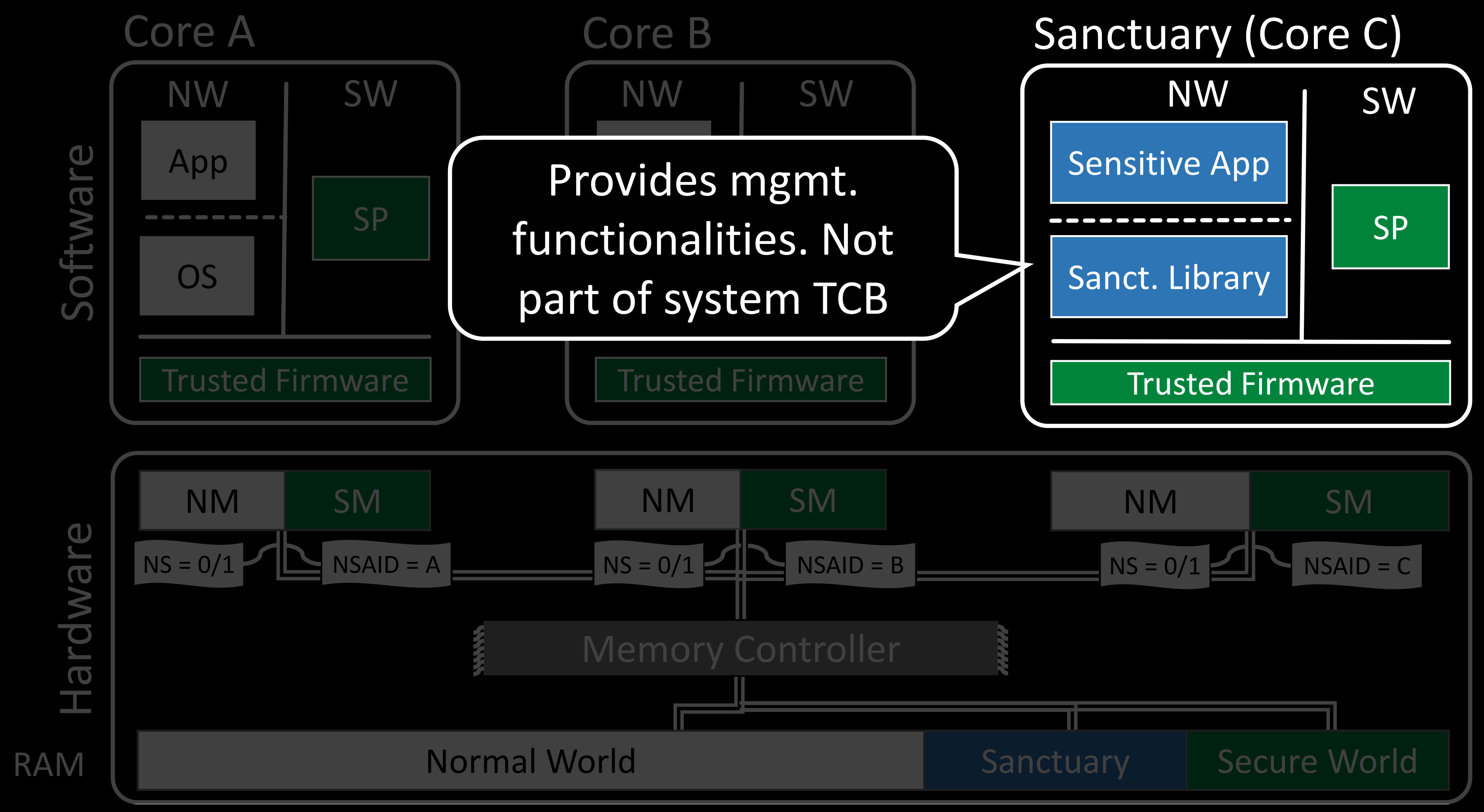

Evaluation of Sanctuary PoC

Security Considerations

- ✓ Protection from compromised OS
  before, after and during runtime of sensitive app
- ✓ Protection from malicious sensitive app
  sensitive app isolated from OS and other sensitive apps
- ✓ Protection from cache-side channel attacks
  flush exclusive caches, exclude sensitive apps from shared caches

Performance Evaluation

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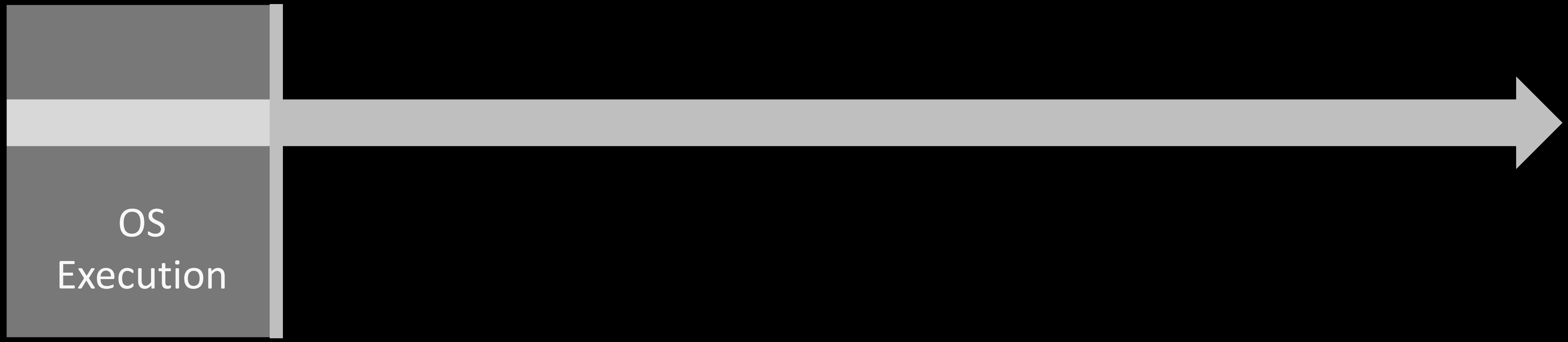
Sanctuary Life Cycle

Performance Evaluation

Sanctuary Life Cycle



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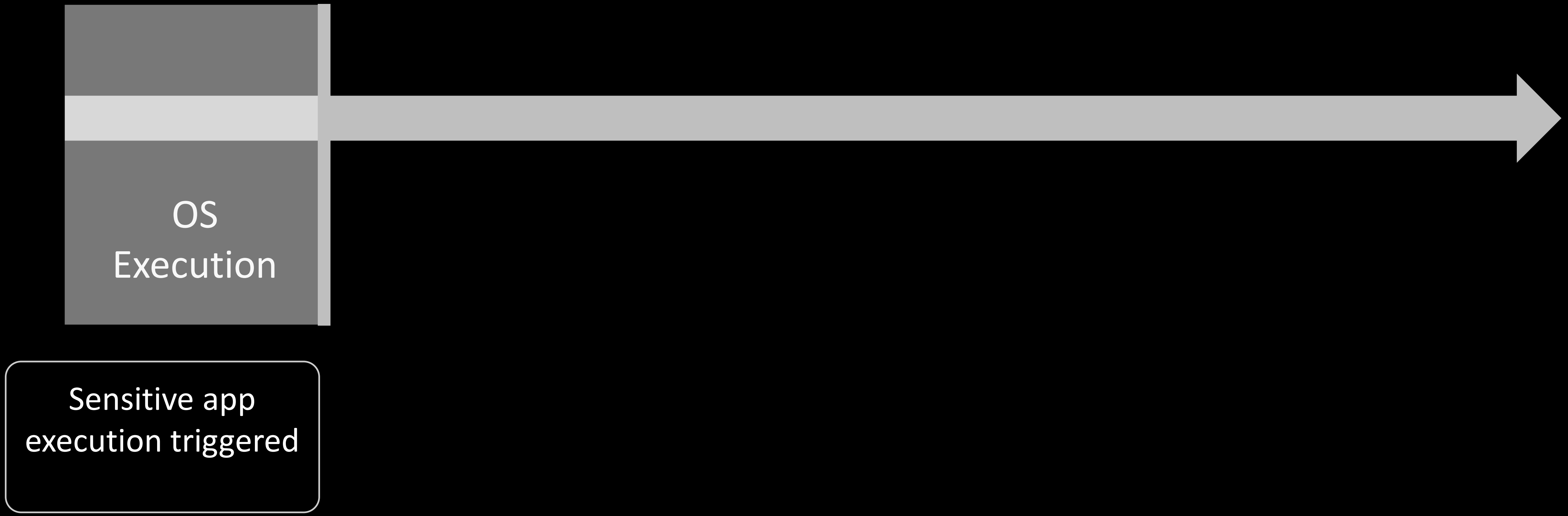

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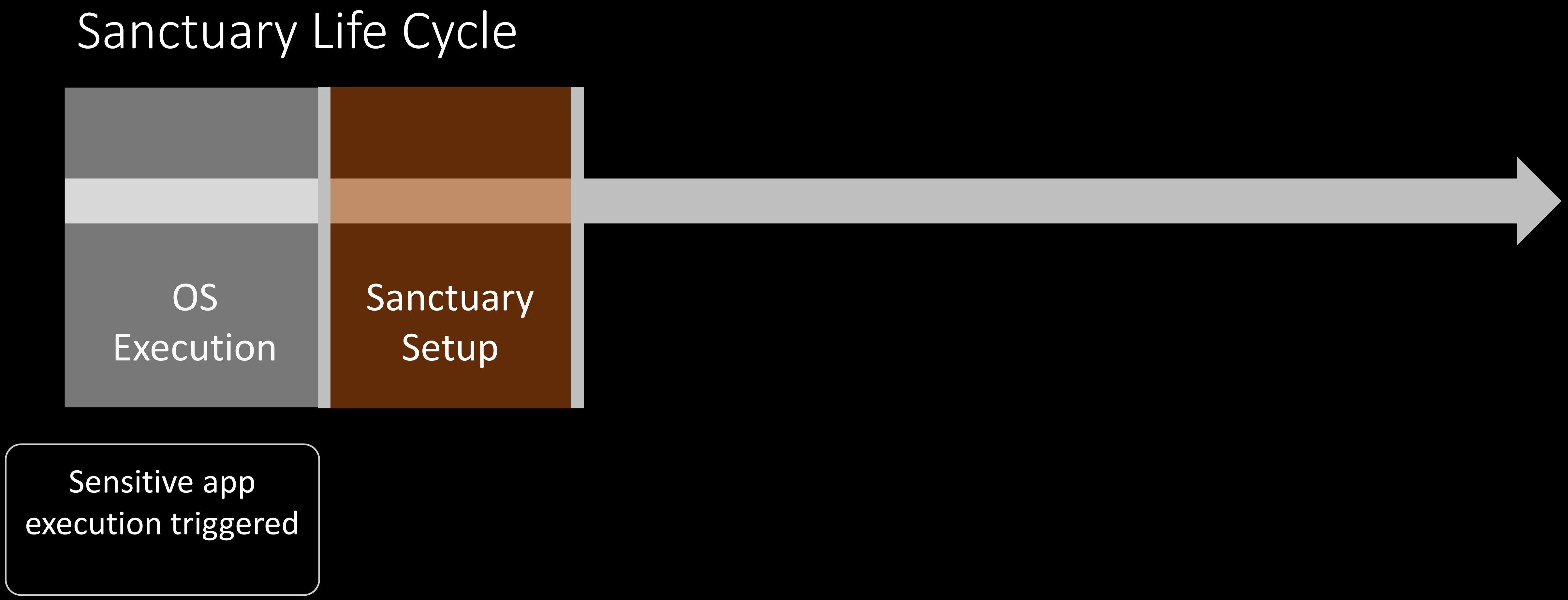

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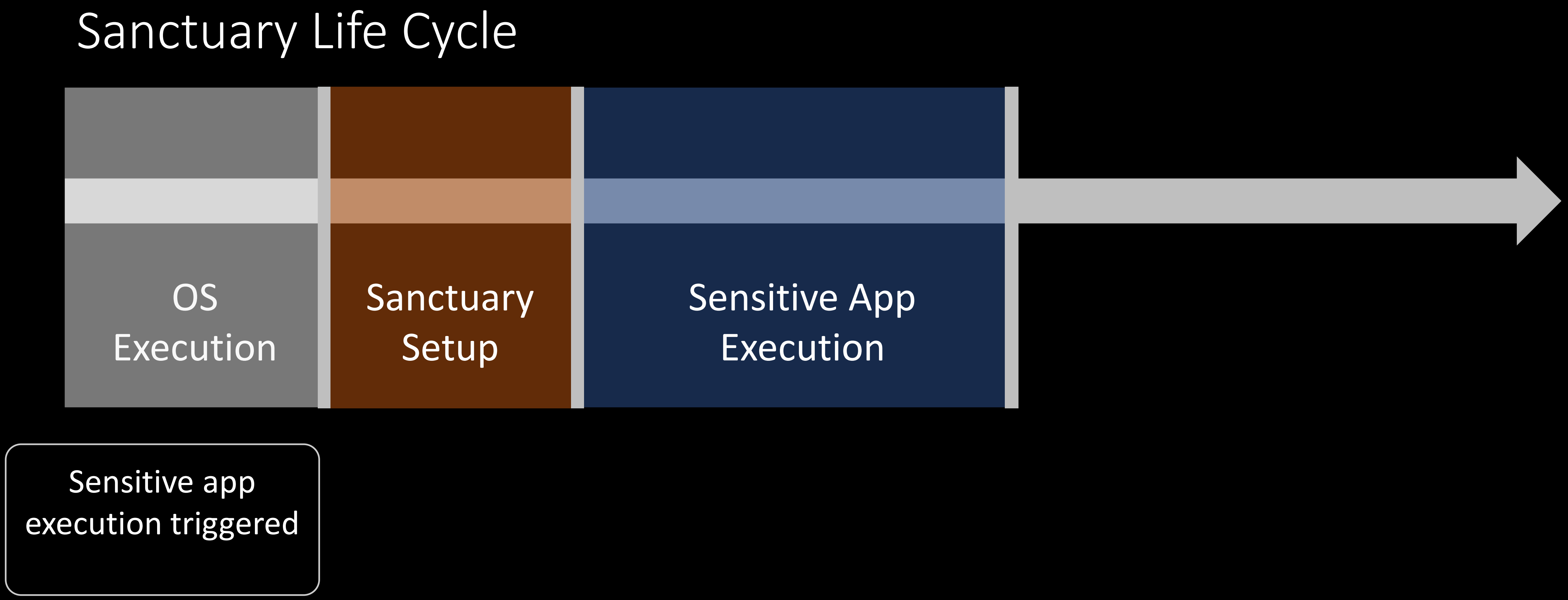

Performance Evaluation

Sanctuary Life Cycle

Sensitive app execution triggered

OS still runs in parallel on other cores

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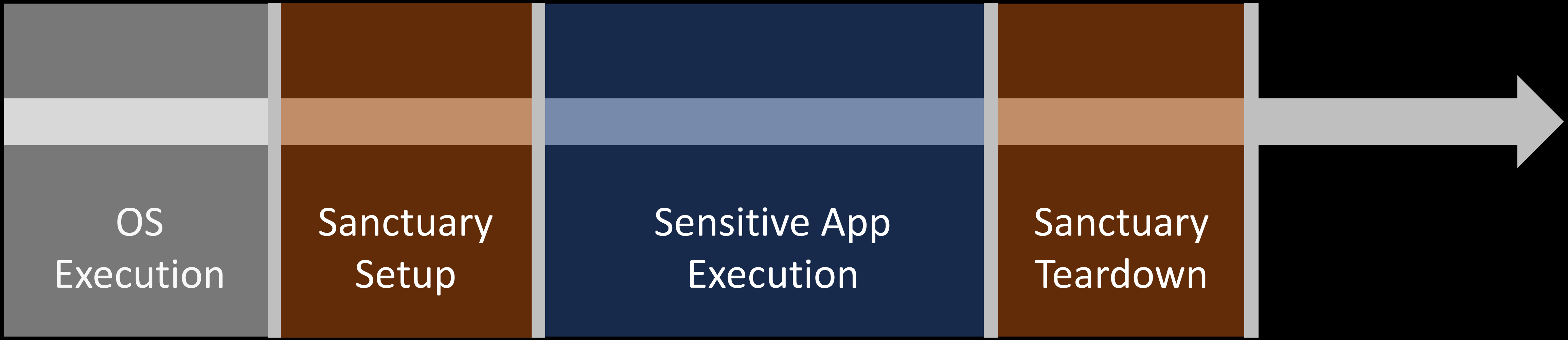

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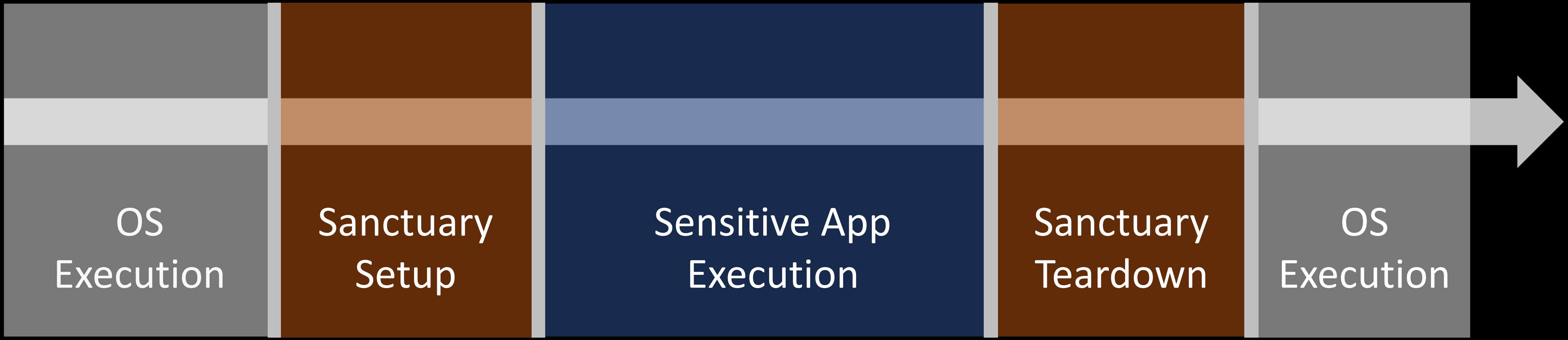
Performance Evaluation

Sanctuary Life Cycle



Sensitive app execution triggered

OS still runs in parallel on other cores

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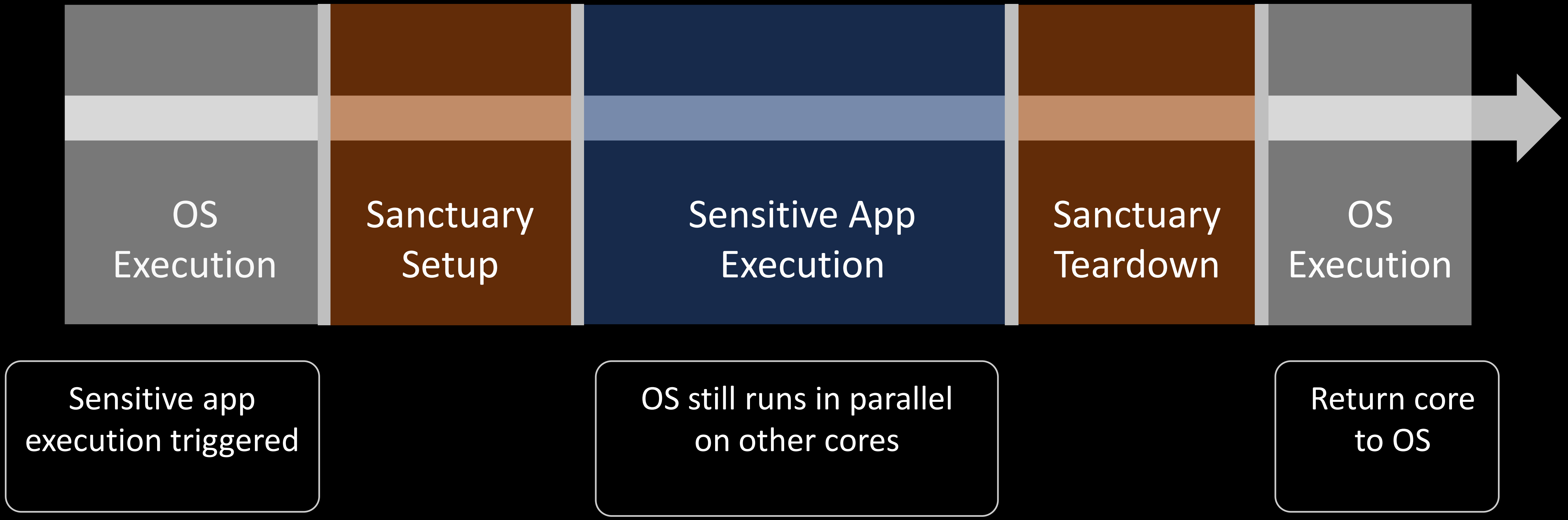

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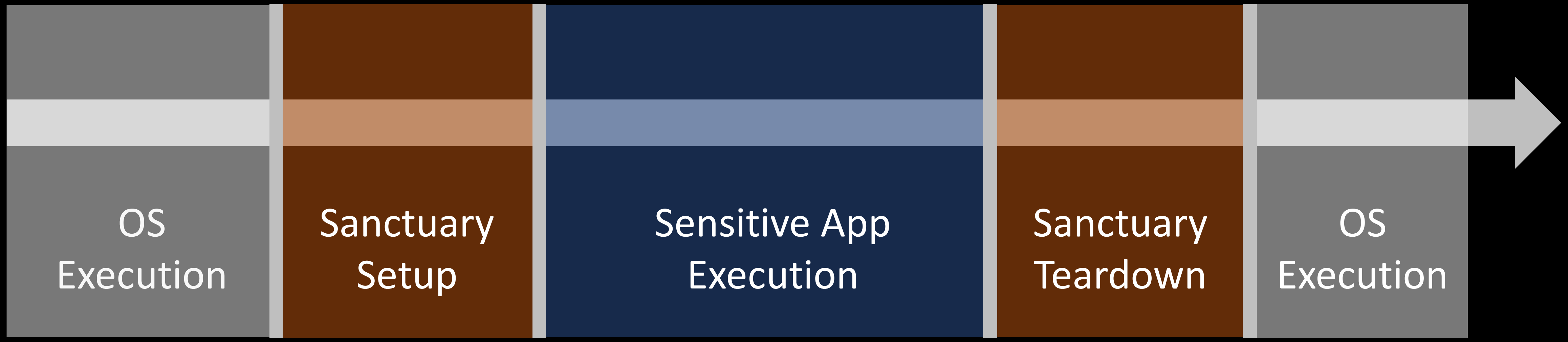

Sensitive app execution triggered	**440 ms** w/o shared cache	OS still runs in parallel on other cores	**110 ms** w/o shared cache	Return core to OS

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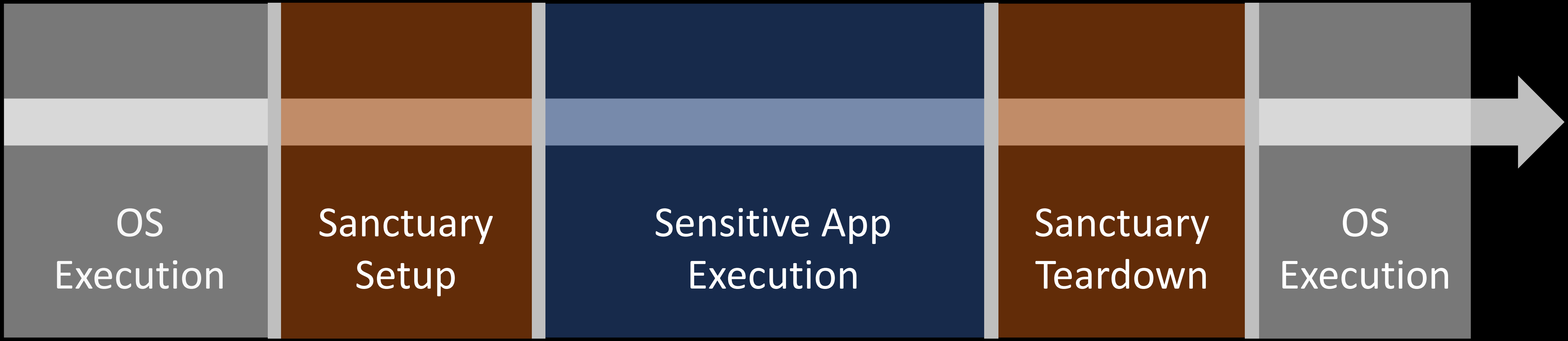


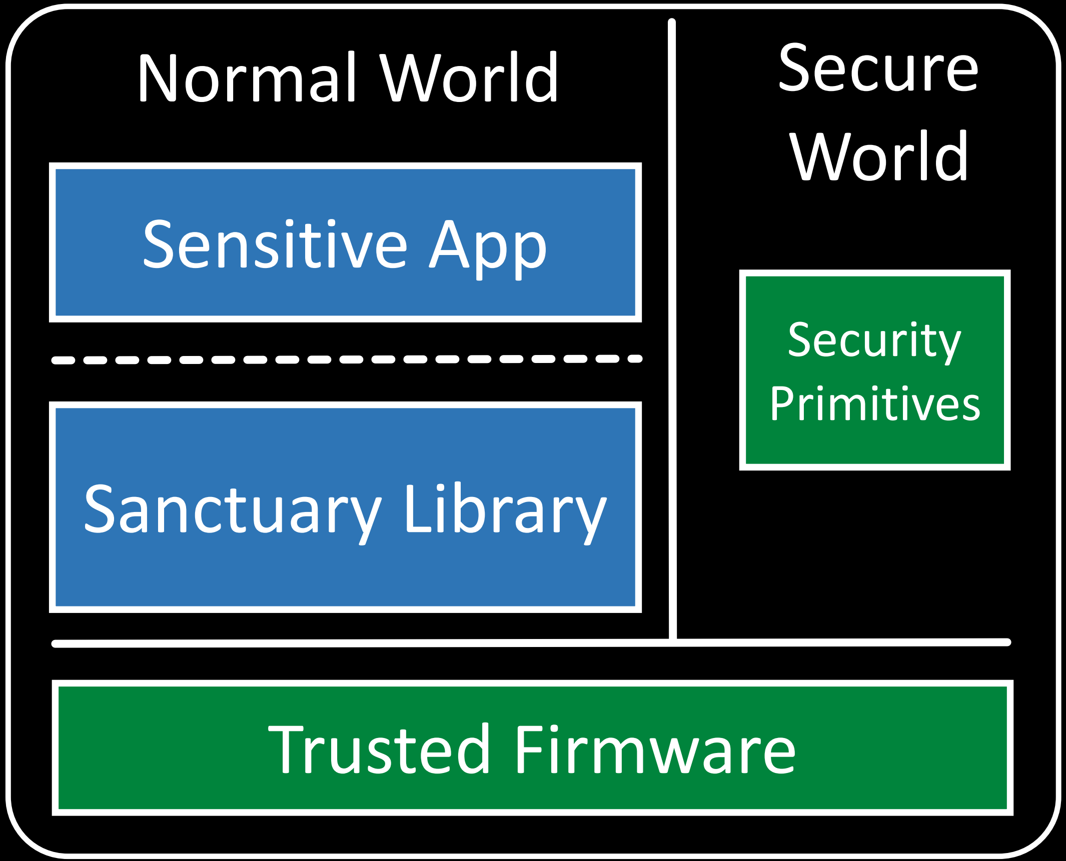
Sensitive app execution triggered

<u>Provision OTP Key:</u>
1.2 s (w/o shared cache)

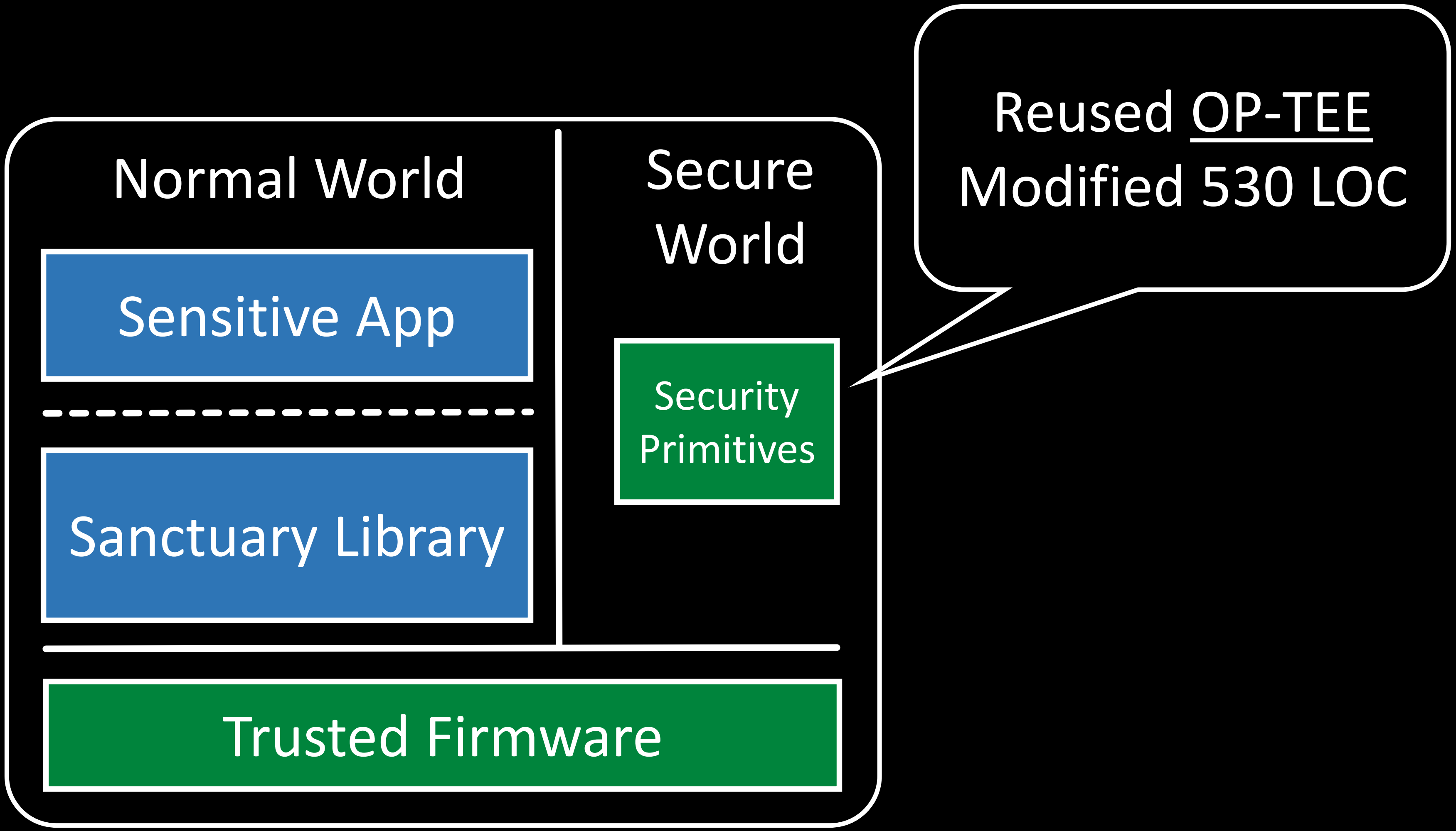
<u>Display OTP:</u>
600 ms (w/o shared cache)

Return core to OS

Code Modifications



Code Modifications



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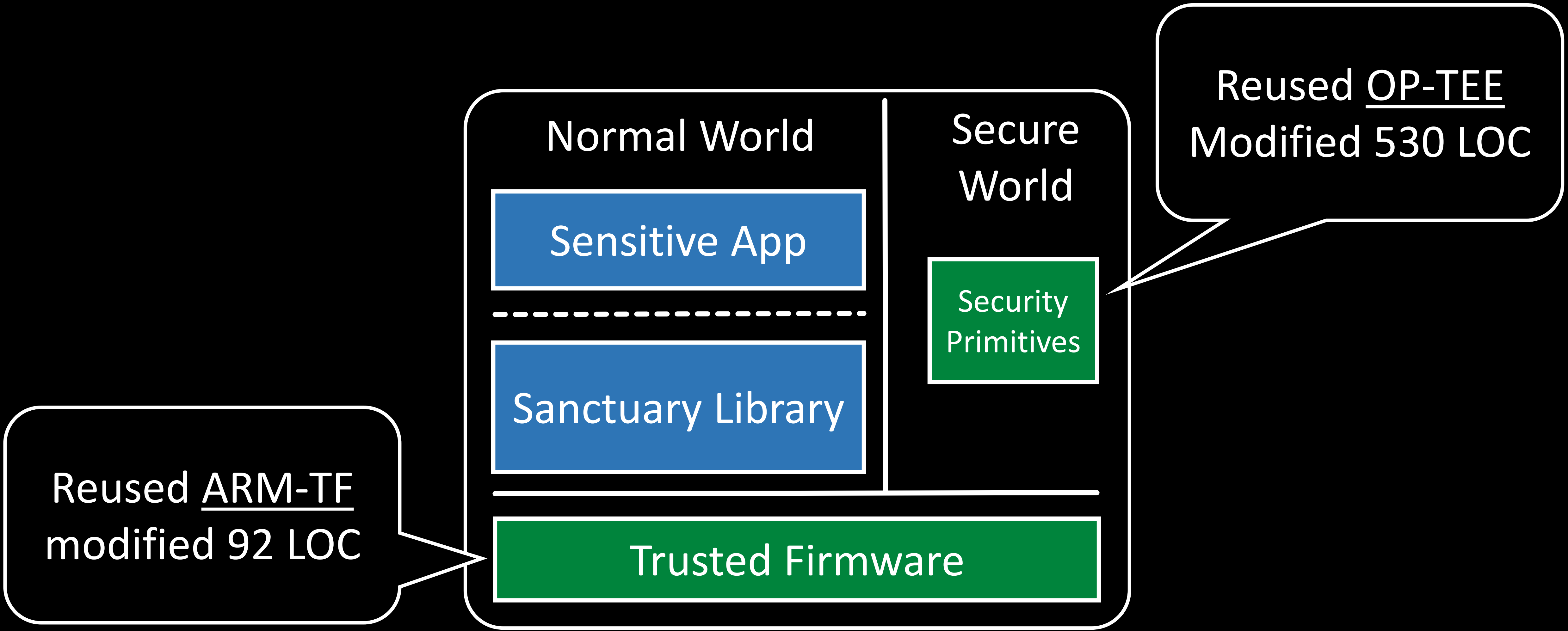

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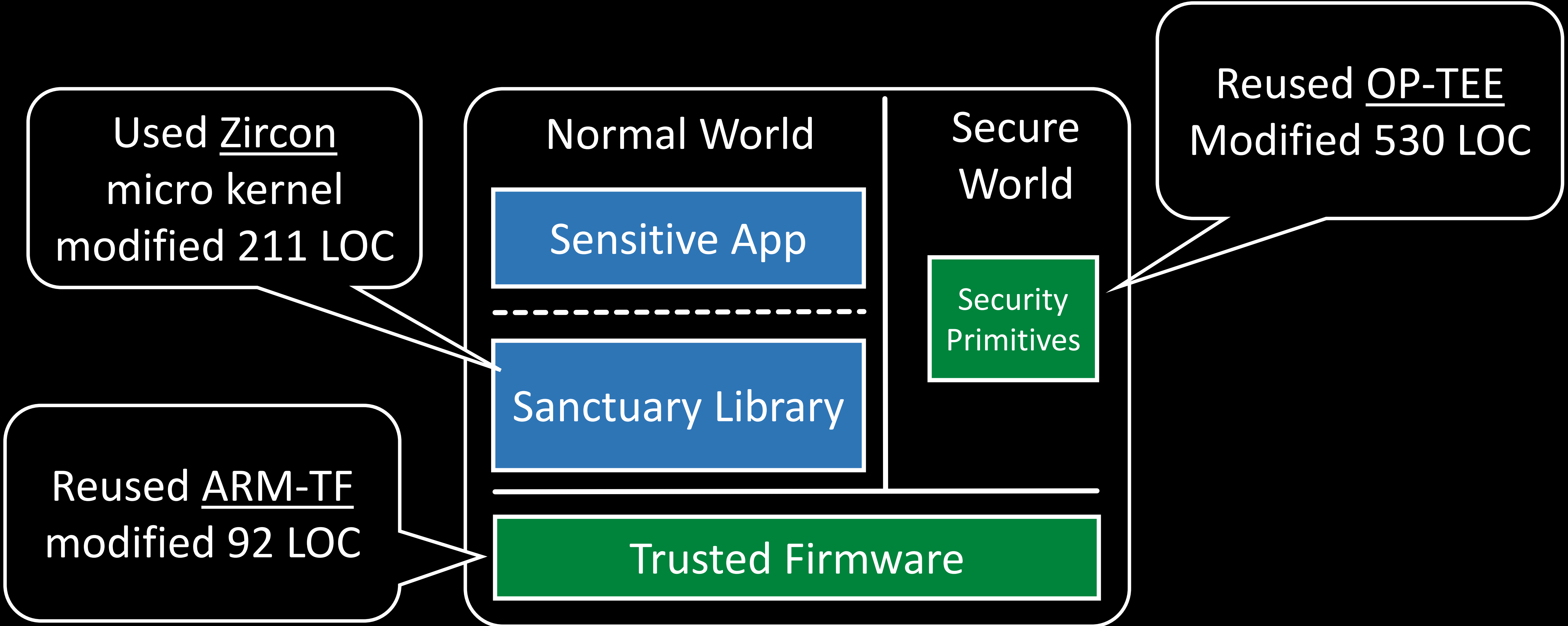

Conclusion

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- Current Work
  - ➢ Implement further use cases (IP protection of ML algorithms, digital car key)
  - ➢ Sanctuary for RISC-V

Questions ?

emmanuel.stapf@trust.tu-darmstadt.de