CURE: A Security Architecture with Customizable and Resilient Enclaves

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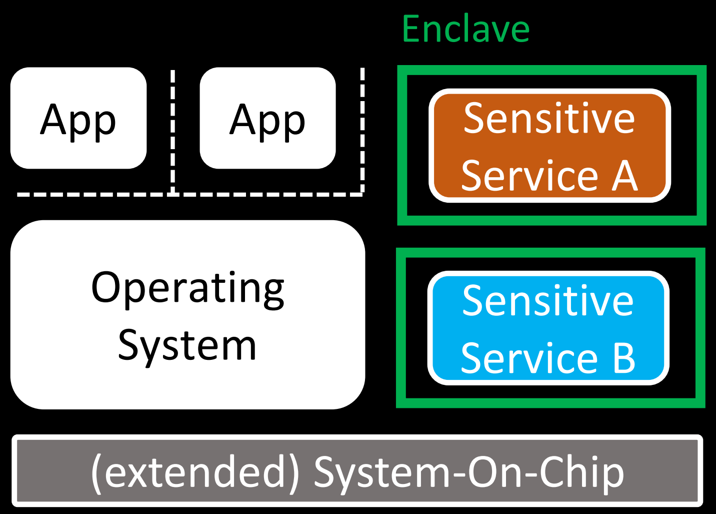
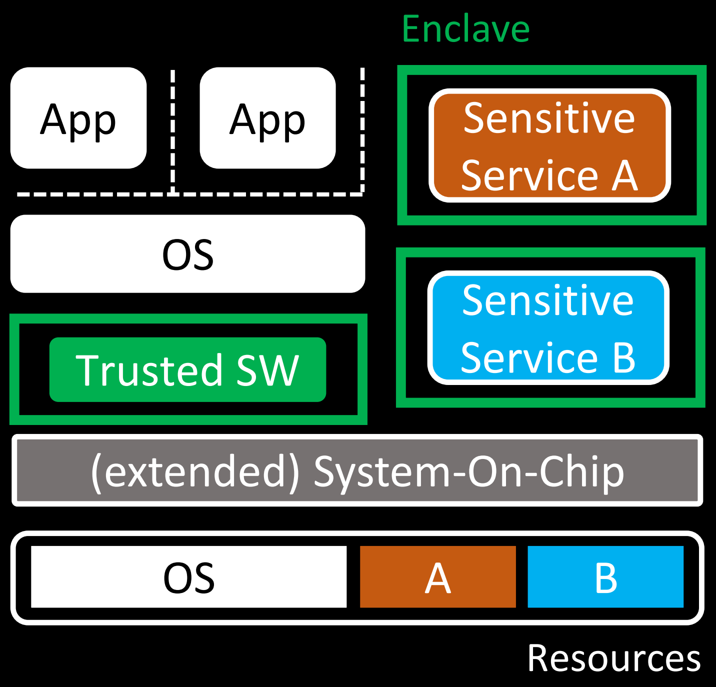
Enclave Security Architectures

- Enclaves prominent approach for protecting sensitive services
- OS assumed to be potentially compromised
- Isolated execution environment, backed by hardware-assisted security mechanisms



Enclave Security Architectures

- Enclaves prominent approach for protecting sensitive services
- OS assumed to be potentially compromised
- Isolated execution environment, backed by hardware-assisted security mechanisms
- Trusted SW configures security mechanisms
- Trusted SW assigns system resources to enclaves (memory, cores, caches)

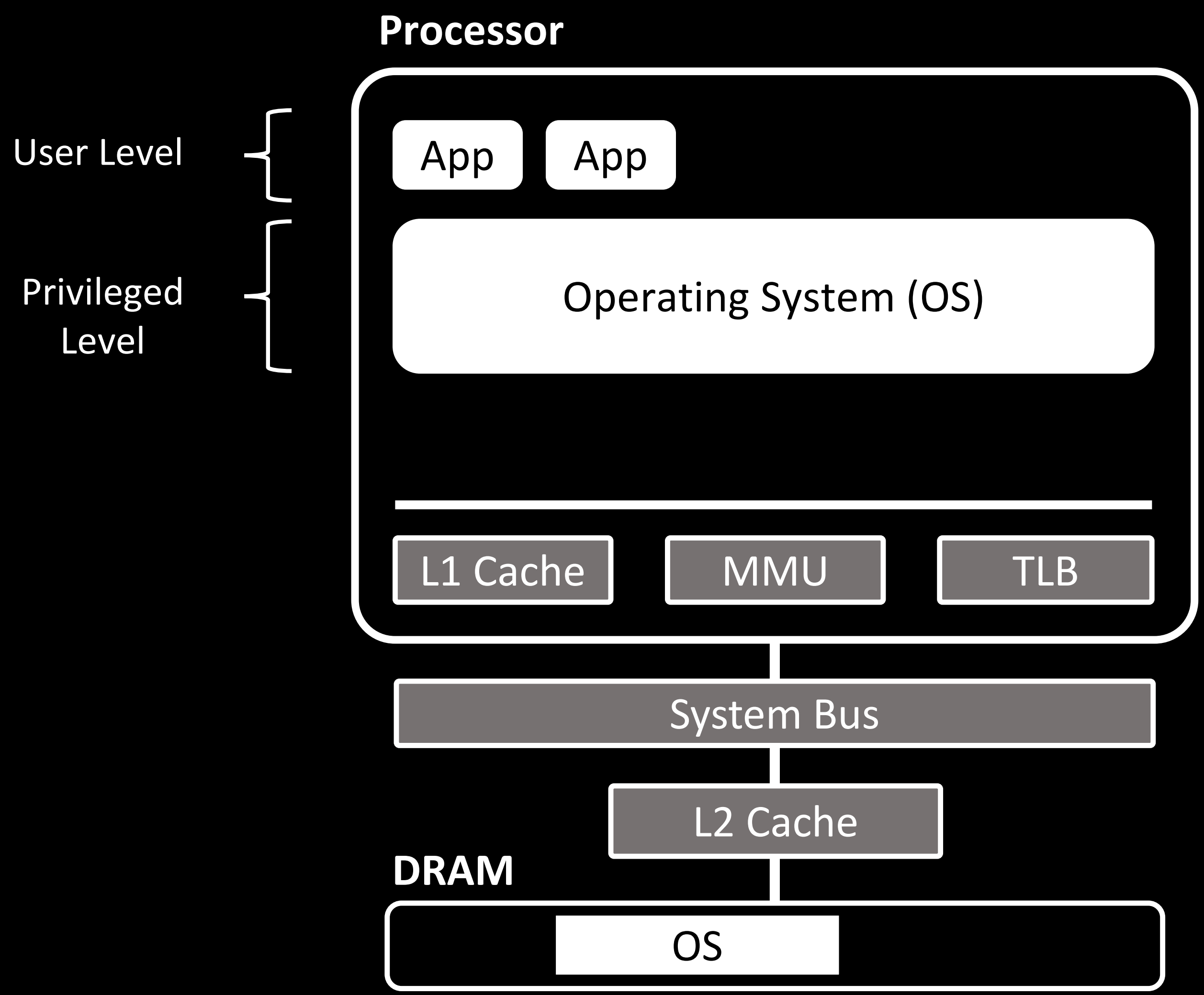


Challenges of Enclave Computing

- Security:
  - Side-channels attacks not considered in industry solutions
  - Cache side channels and controlled side channels (page table, interrupt handlers)
- Functionality:
  - Missing functionality regarding secure I/O, secure Direct Memory Access (DMA)
  - Secure binding of enclaves to peripherals
- Configurability:
  - Enclaves cannot be adapted to security and functionality requirements
  - Existing proposals follow *one-size-fits-all* approach

Enclave Types
in Existing Enclave Security Architectures

User-space Enclaves



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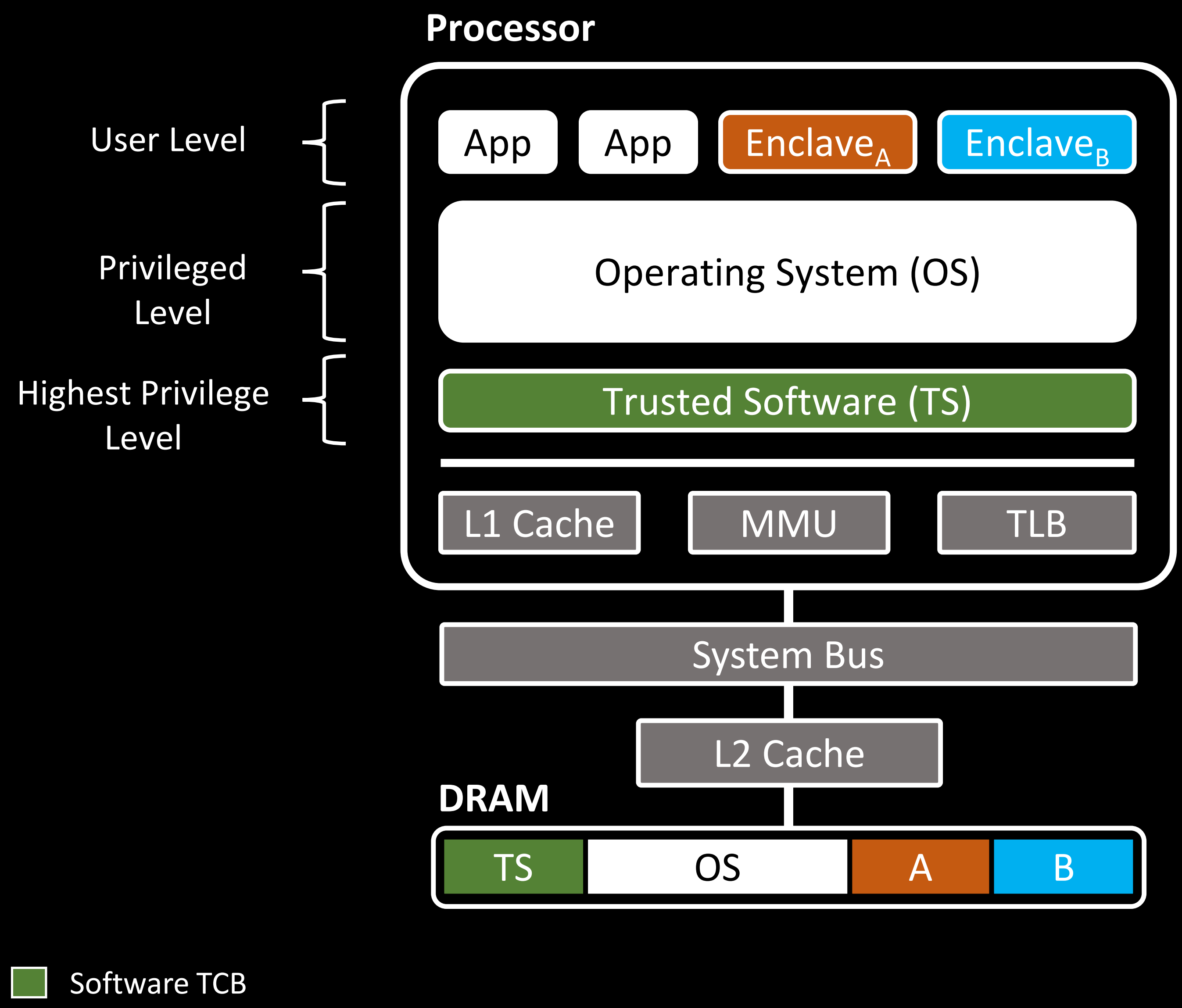

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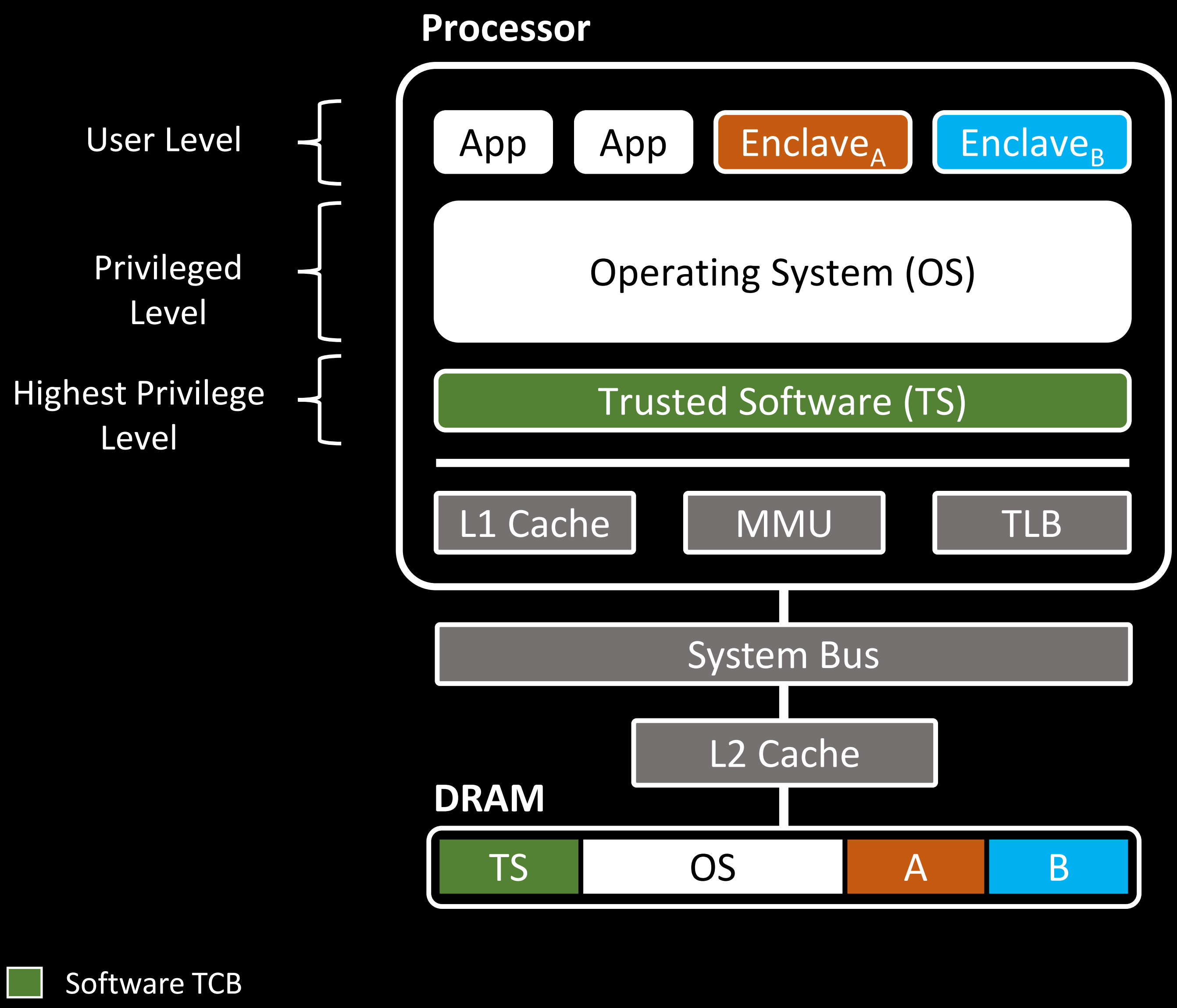


Pros:

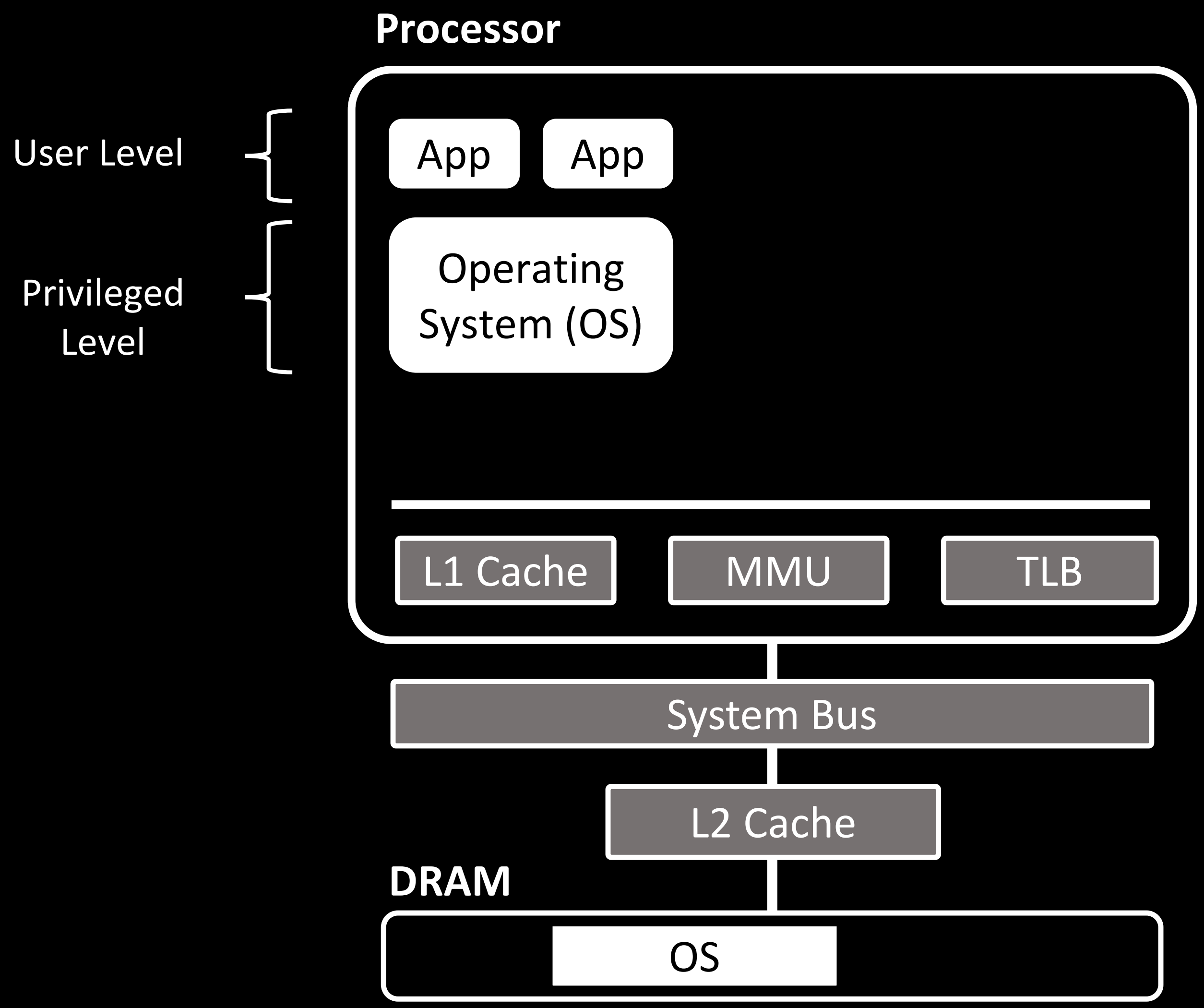
- Reuse of OS functionalities
- Low system resource consumption
- *Easy* to develop

Cons:

- No privileged code in enclave (I/O)
- Increased performance overhead for context switches
- Protection from controlled side-channel attacks challenging

• Provided by Sanctum [1], SGX [2] and various extensions [3-8]

Kernel-space Enclave



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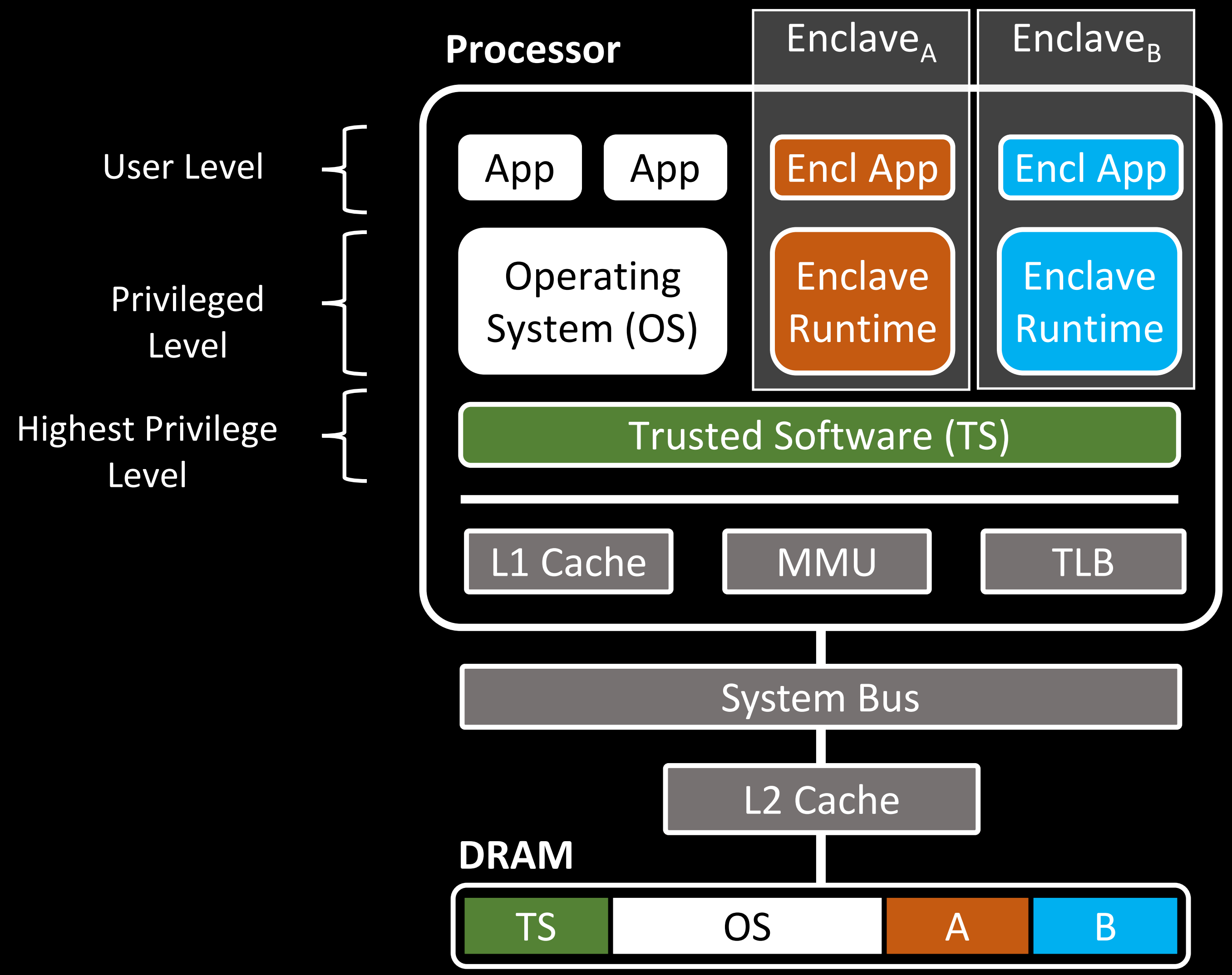
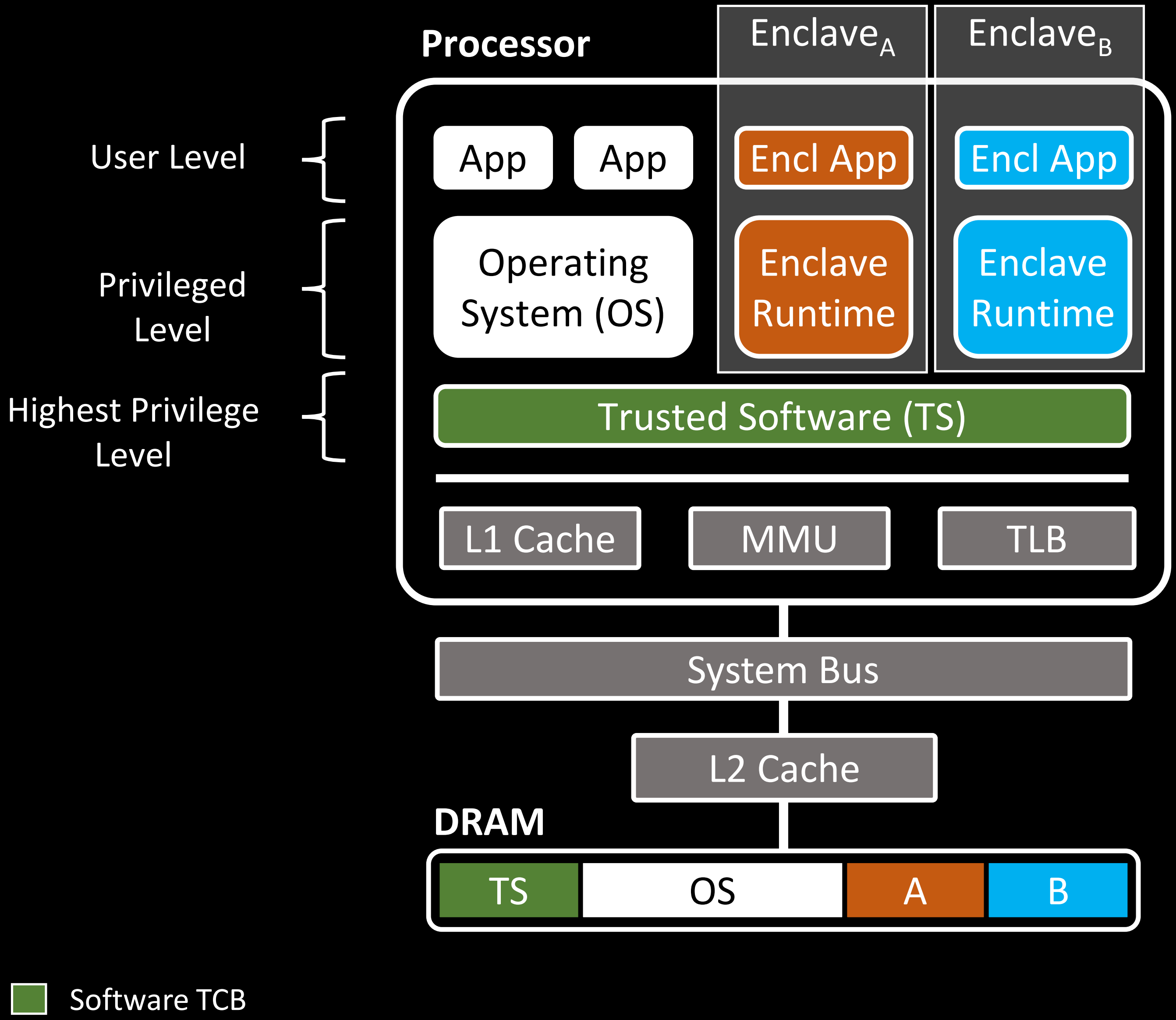


Software TCB

Kernel-space Enclave



Pros:

- Privilege code in enclave
- No overhead on context switches
- Easier to prevent controlled side-channel attacks

Cons:

- Increased resource consumption
- Increased overhead for enclave setup
- Need to develop runtime

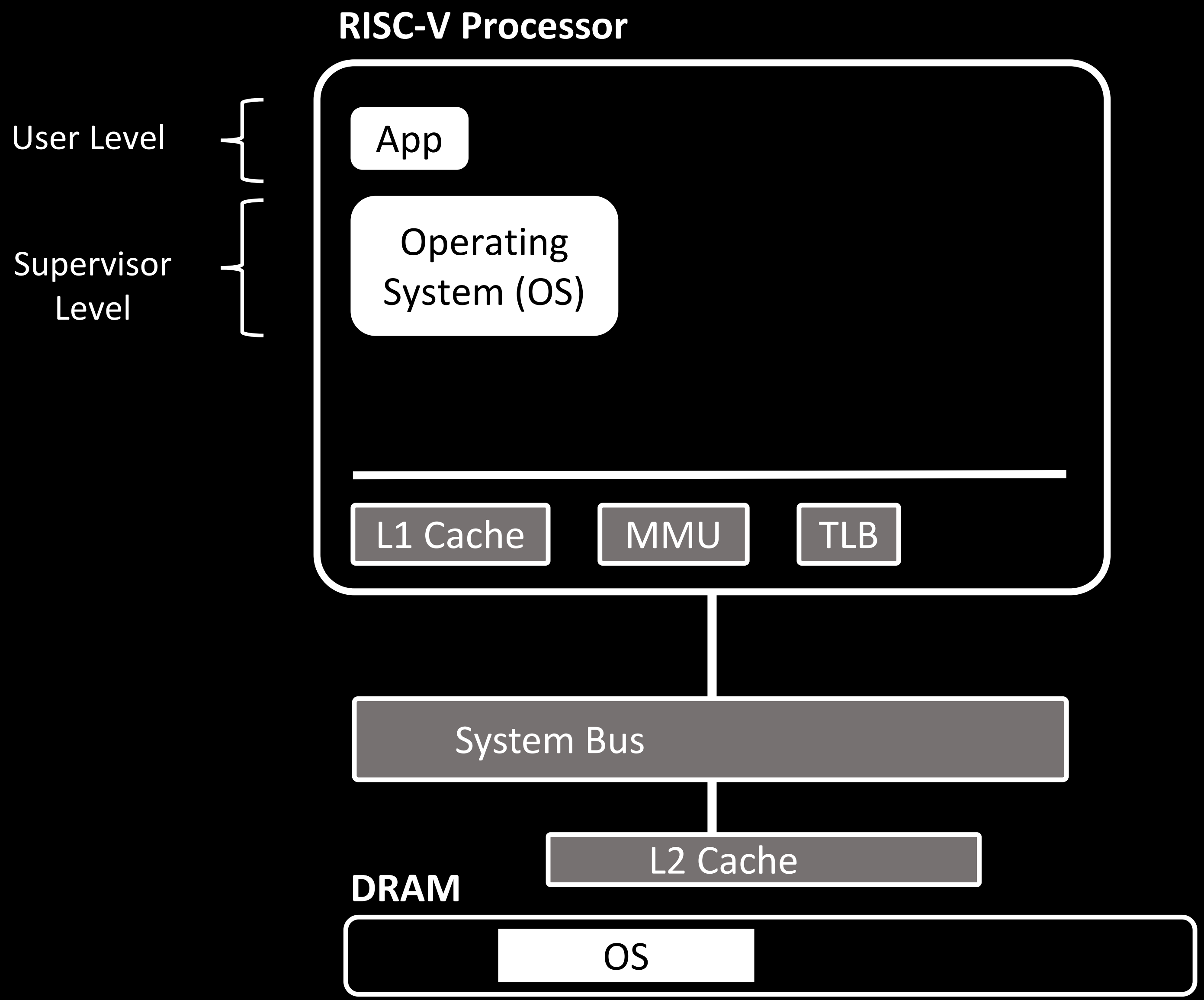
- Provided by TrustZone [9], Sanctuary [10] or Keystone [11]

CURE: A Security Architecture with Customizable and Resilient Enclaves

Goals of the CURE Security Architecture

- Tackle the aforementioned challenges
- Security:
  - Protect against controlled side-channel attacks (page table, interrupt handlers)
  - Protect against cache side-channels attacks
- Functionality:
  - Provide a secure binding from peripherals to enclaves
- Configurability:
  - Provides different types of enclave, selected depending on sensitive service & usage scenario

CURE: Customizable and Resilient Enclaves



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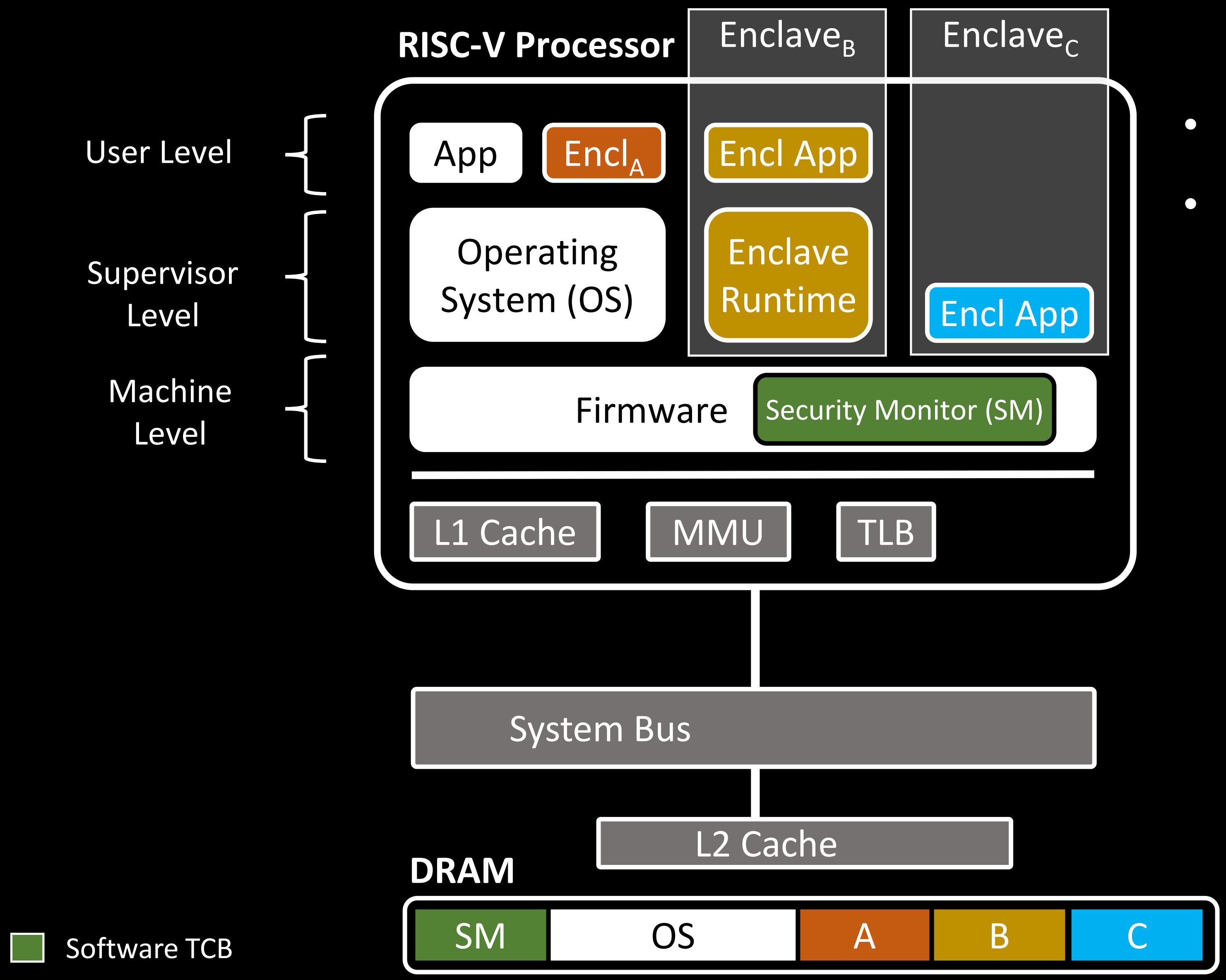

- Multiple *types* of enclaves
- SM responsible for all security-critical tasks and services (e.g., remote attestation)

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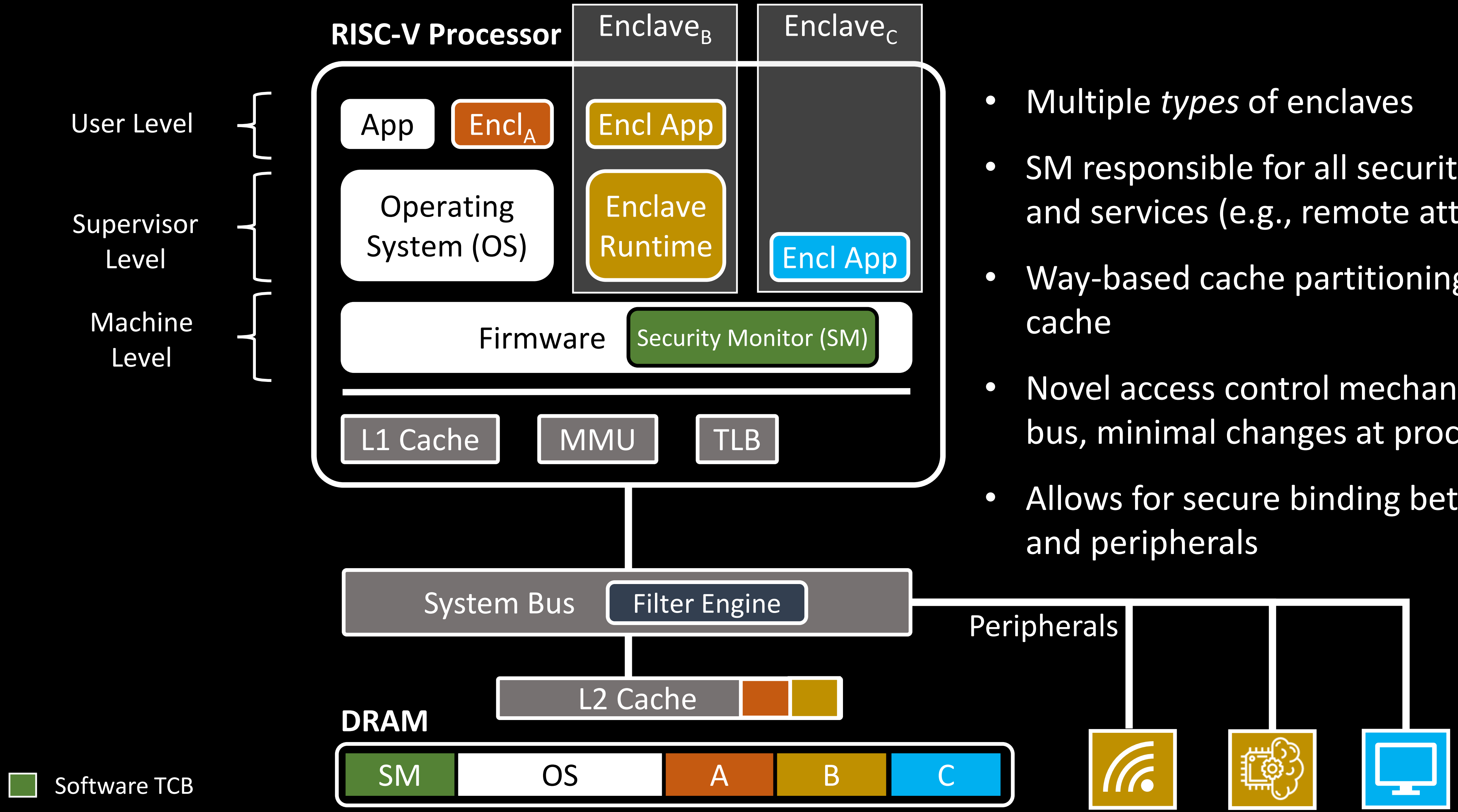

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- Way-based cache partitioning on shared L2 cache
- Novel access control mechanism on system bus, minimal changes at processor
- Allows for secure binding between enclaves and peripherals

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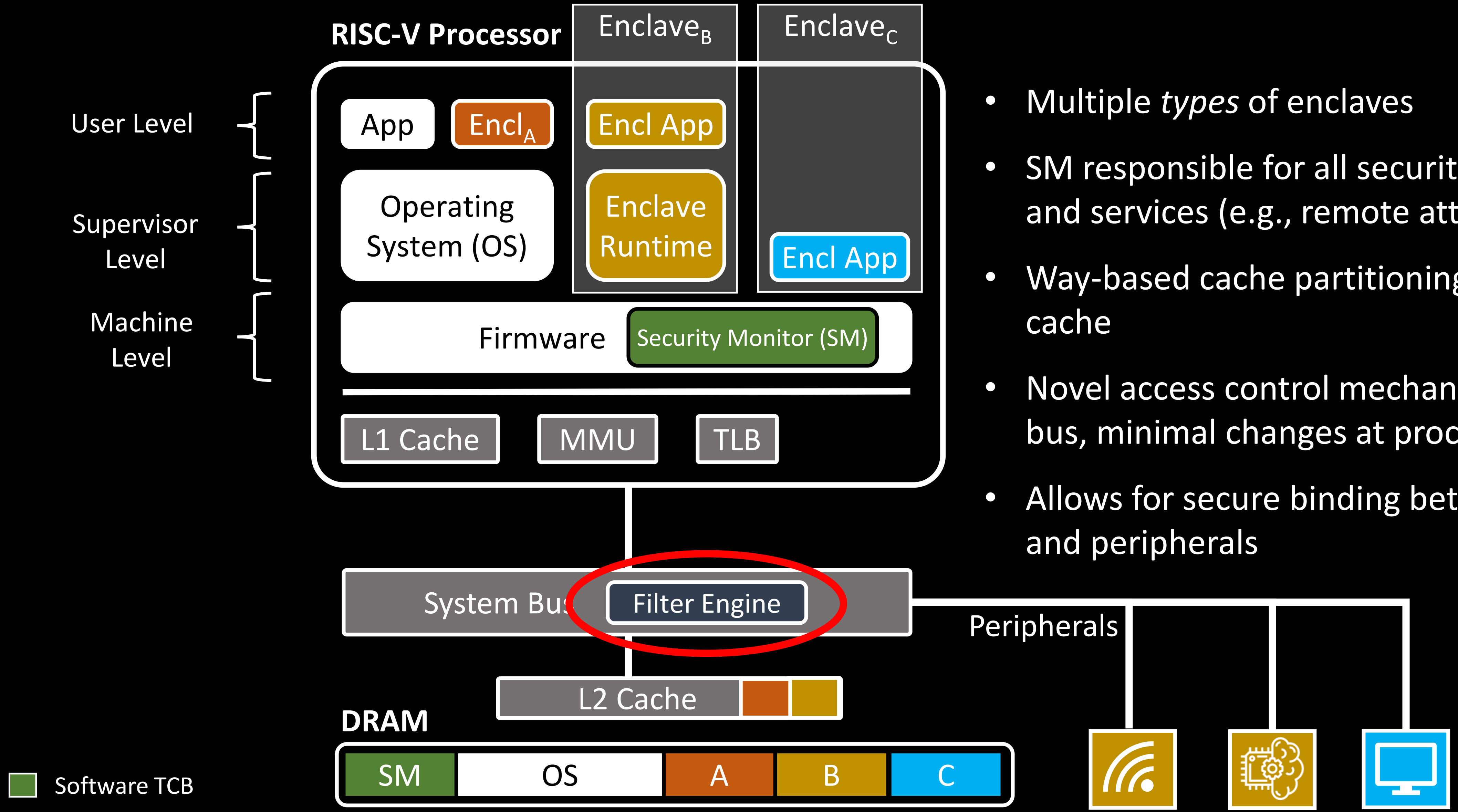

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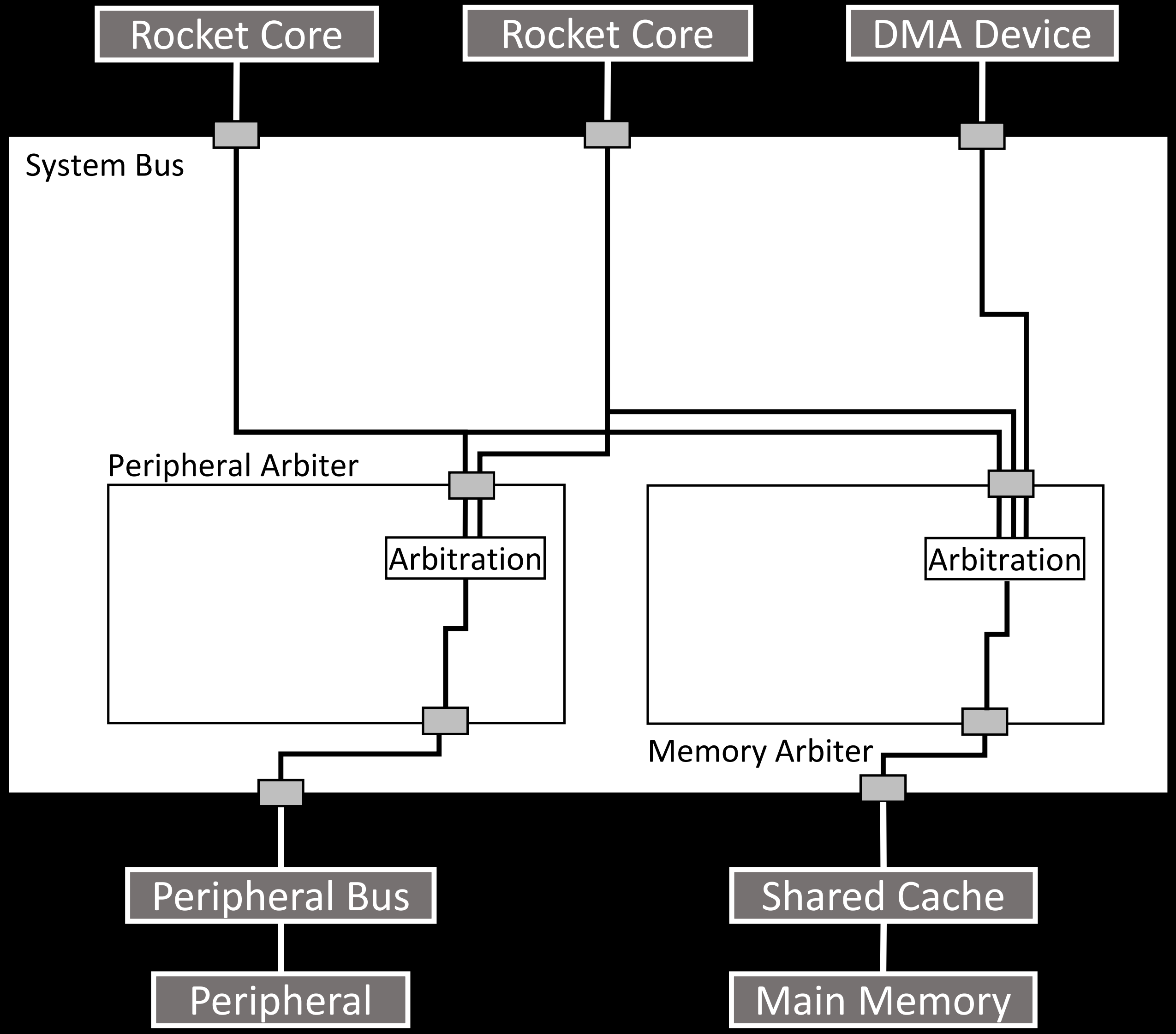
Details on System Bus Access Control



- Adding *enclave ID* to TileLink protocol (A & C channels) propagated through system

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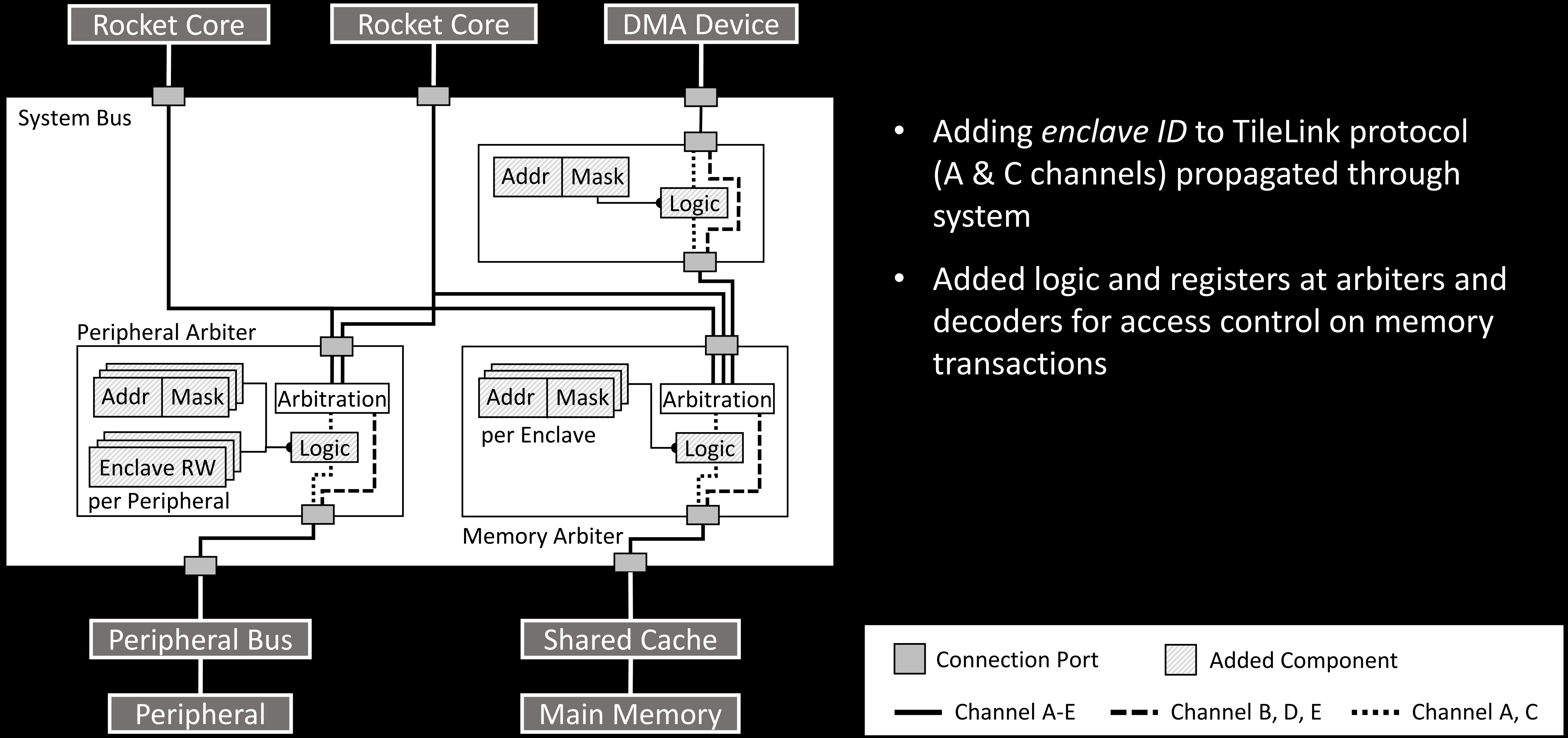

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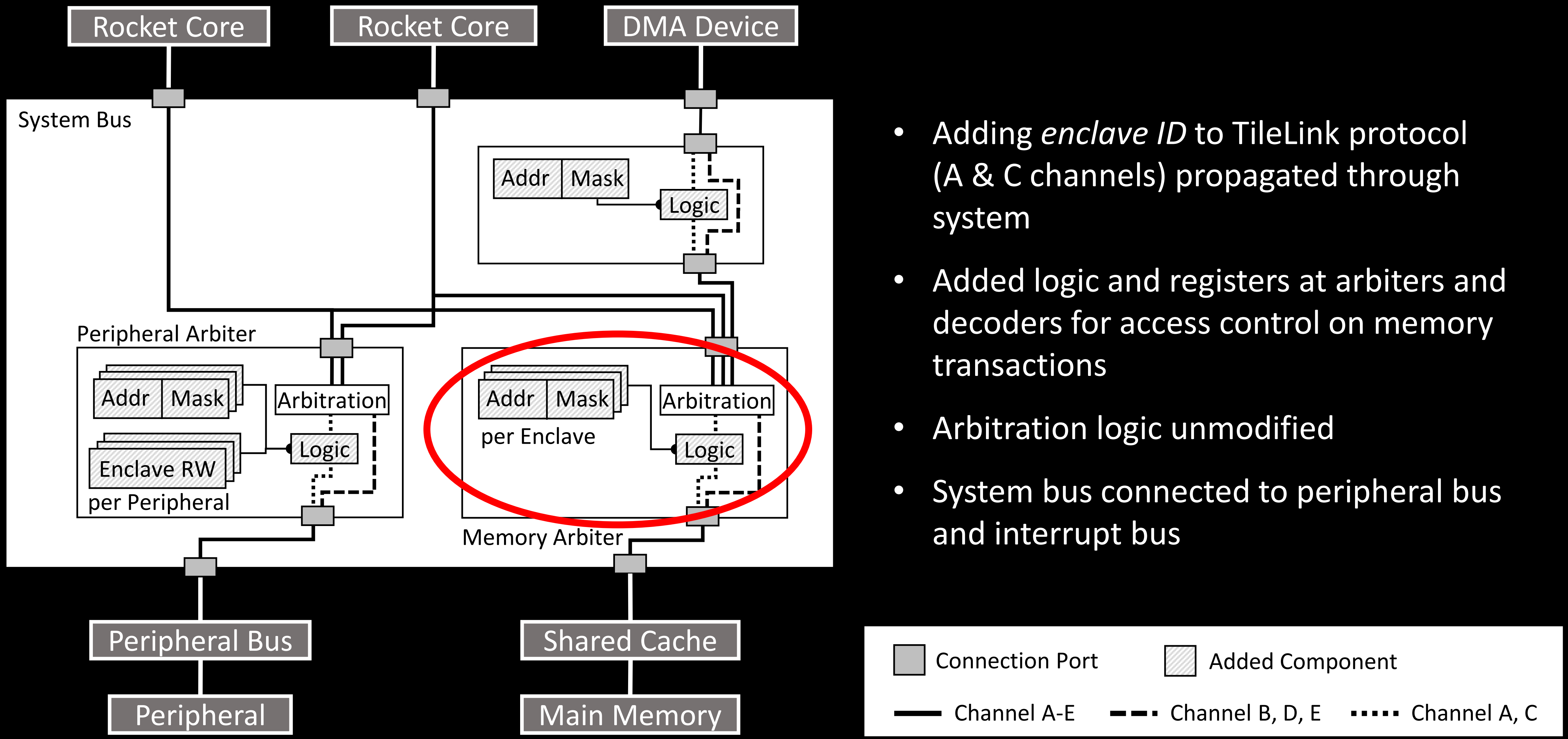
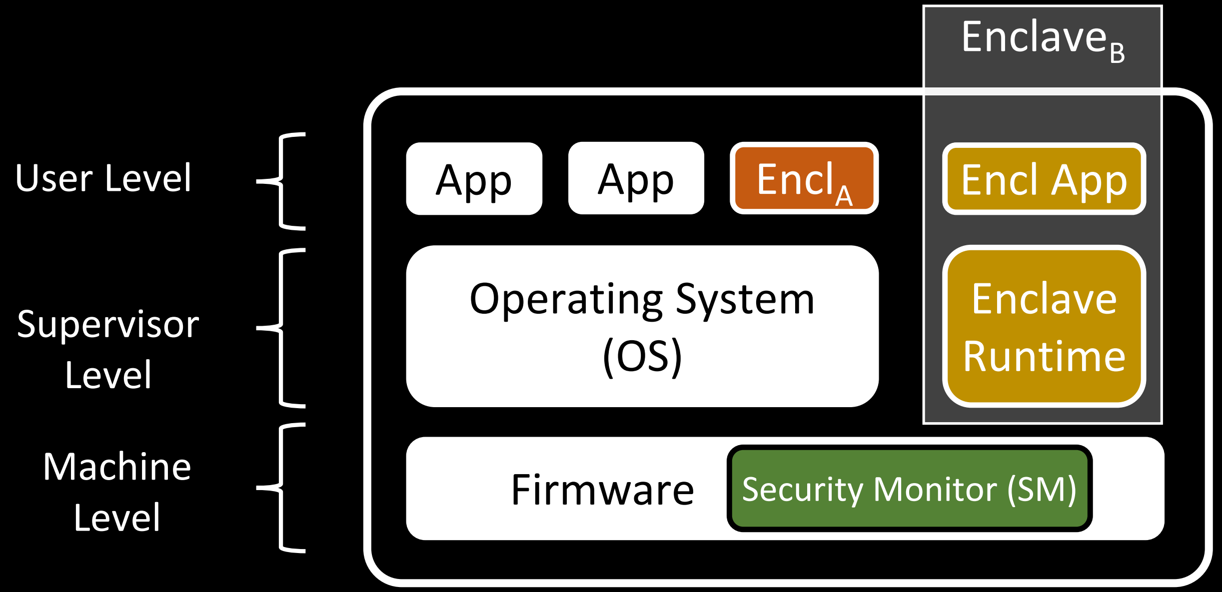


- Adding *enclave ID* to TileLink protocol (A & C channels) propagated through system
- Added logic and registers at arbiters and decoders for access control on memory transactions
- Arbitration logic unmodified
- System bus connected to peripheral bus and interrupt bus

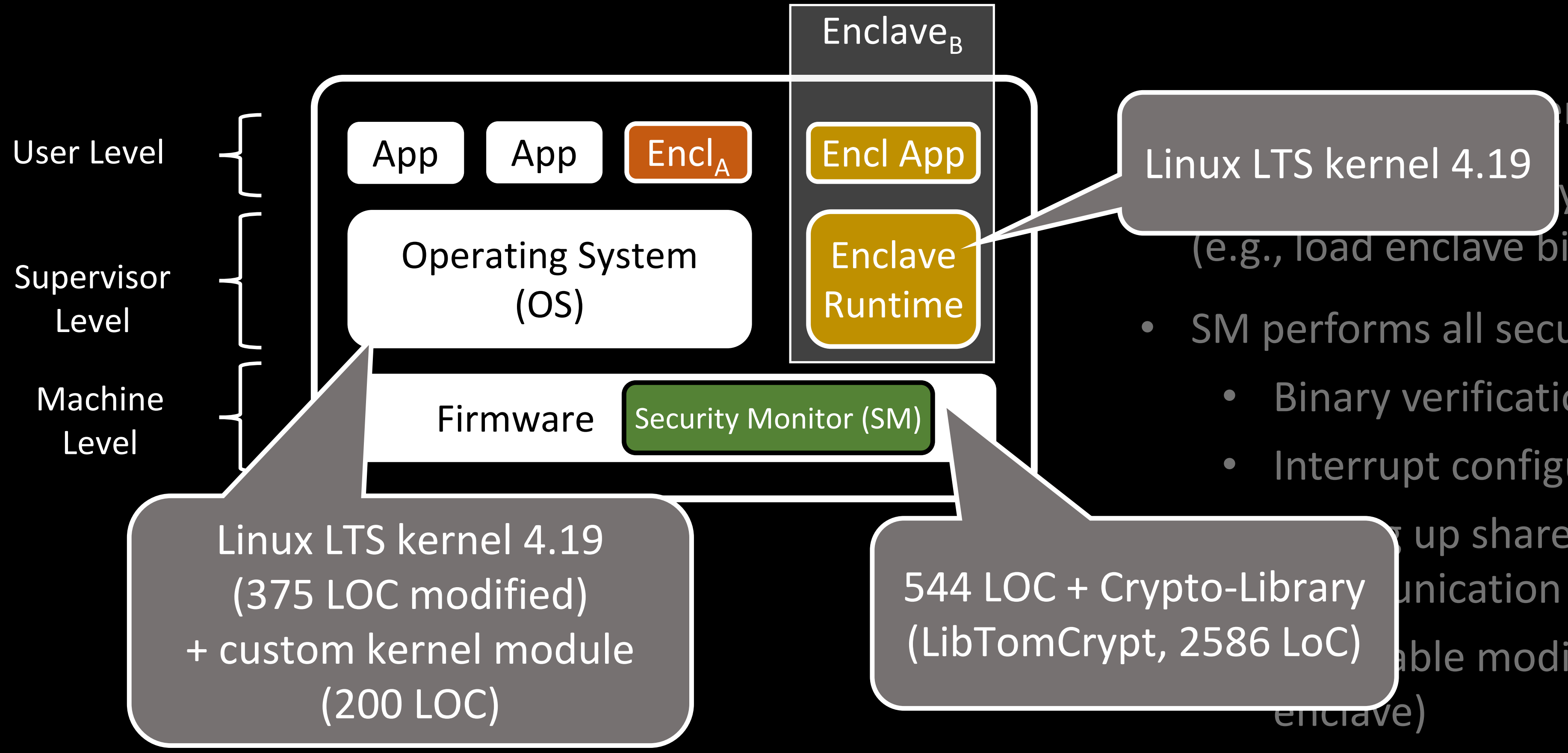
Details on Software Components



- Enclave setup triggered by OS
- OS performs security uncritical steps (e.g., load enclave binary)
- SM performs all security critical steps
  - Binary verification
  - Interrupt configuration
  - Setting up shared memory for communication
  - Page table modification (user-space enclave)

Software TCB

Details on Software Components



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■ Software TCB

Conclusion

- CURE successfully tackles identified challenges
- Security:
  - Keep all side-channel sensitive data structures inside enclave (page tables, interrupt handlers)
  - Dynamic way-based cache partitioning
- Functionality:
  - New access control mechanism on system bus enables enclave-to-peripheral binding
- Configurability:
  - Provides multiple types of enclaves
- CURE offers many possibilities for further development
  (e.g., VM enclaves, new side-channel resilient cache architectures)

Questions ?

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