Privacy-Preserving Systems (a.k.a., Private Systems)

CU Graduate Seminar

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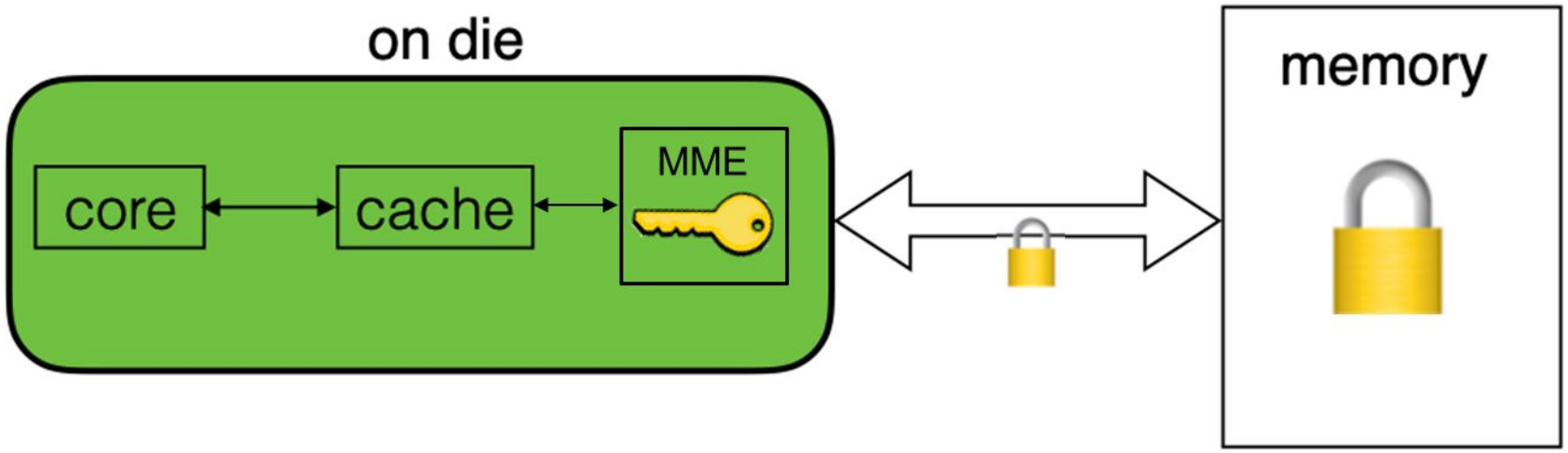
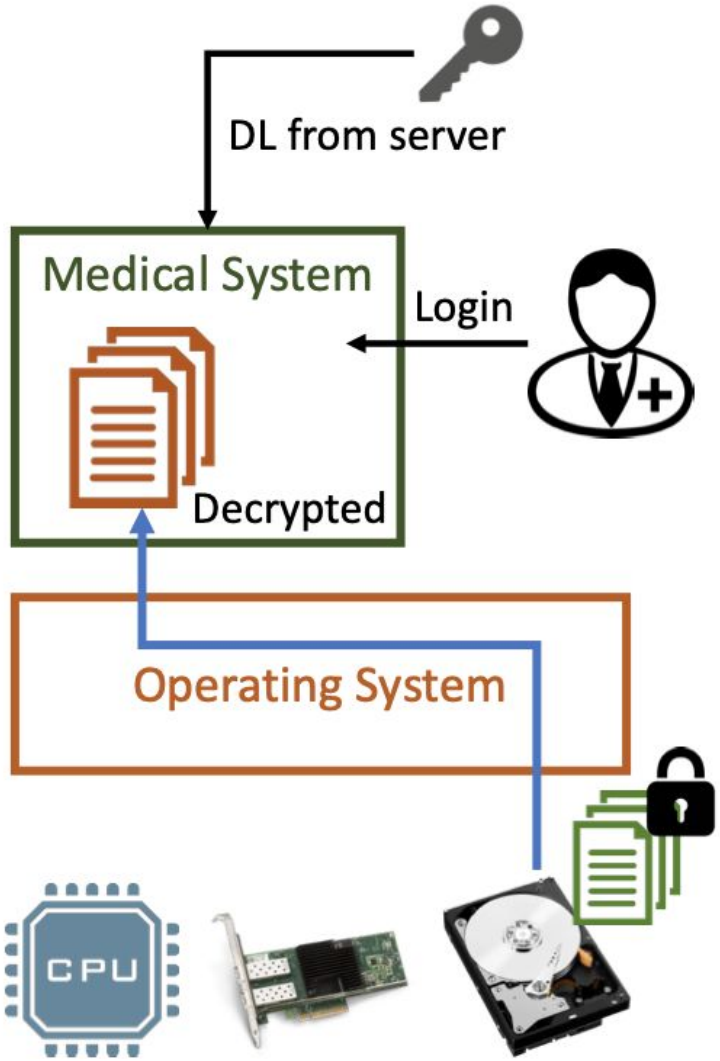
Hardware Enclaves

Hardware Enclaves (e.g., Intel SGX)

- Hardware-enforced isolated execution environment
- Data decrypted only on the processor
- Protect against an attacker who has root access or compromised OS
- Cloud offerings: Azure Confidential Computing, Google Asylo, …

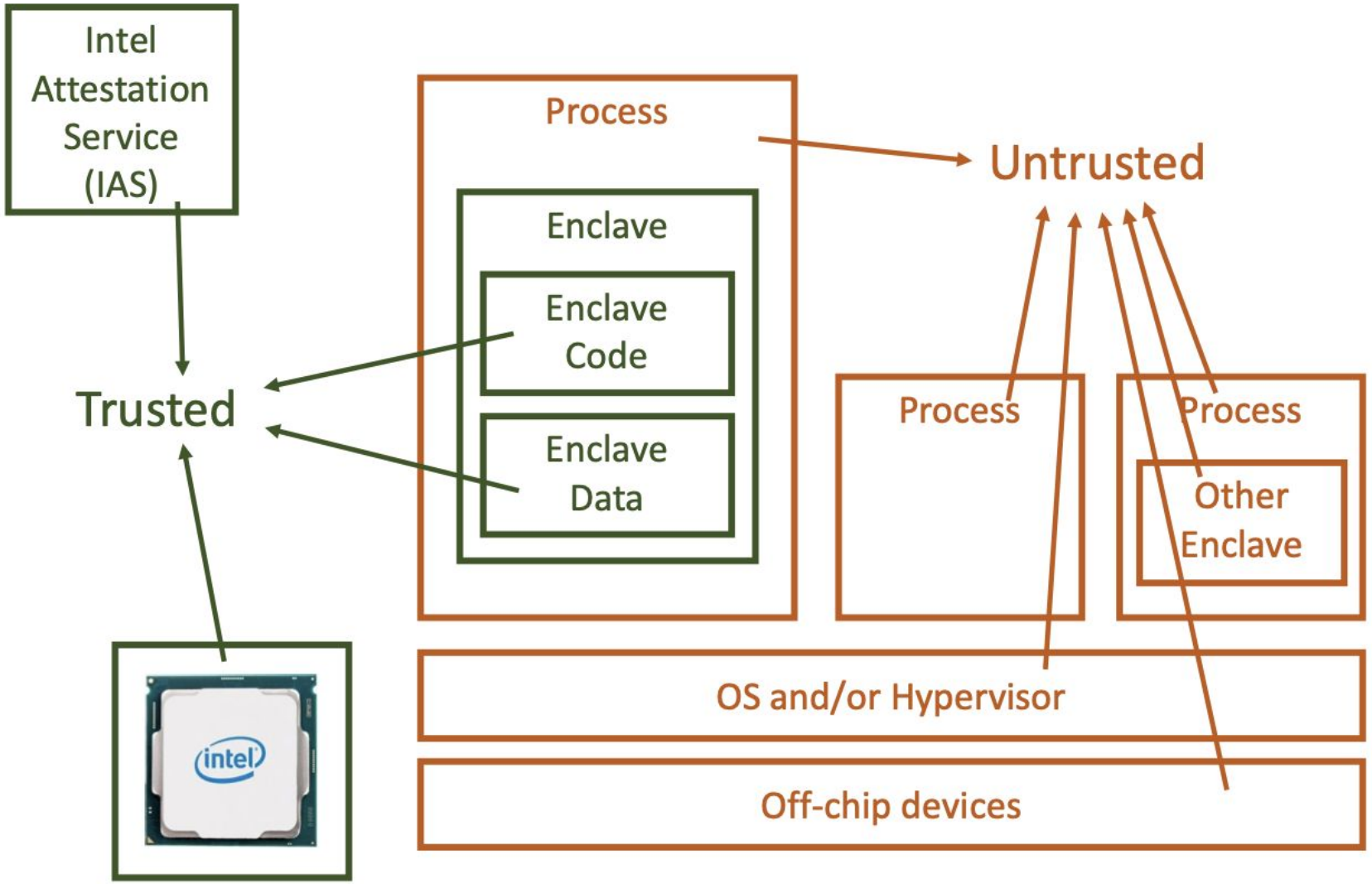


System Threats to Trusted Execution



- What can go wrong?
  - Side channels
    - out of scope for Intel SGX
  - Counterfeit software
  - Inject rootkits into OS
  - Privilege escalation
  - Install malicious kernel
  - Compromised HW devices
  - Cold-boot attacks

Threat Model for Hardware Enclaves

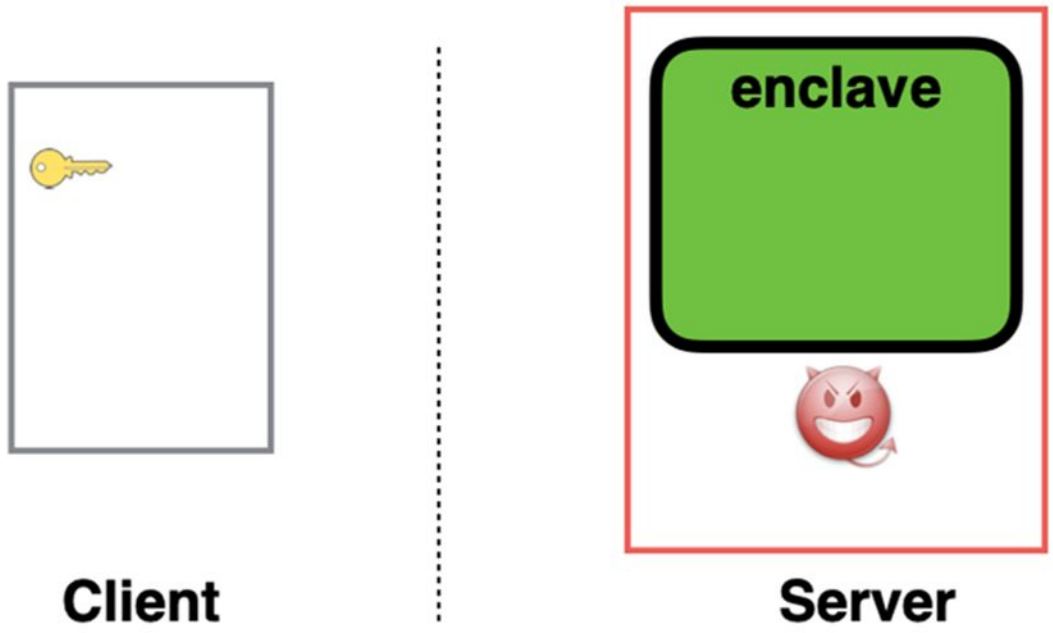


Elements of Secure Enclaves

- Secure boot: HW-verified measurement + first instruction
- On-chip program isolation
- Cryptographically protected external memory
- Execution integrity; no interference from attackers
- Remote attestation
- Secret sealing

Remote Attestation

Enables verifying which code runs in the enclave and performing key exchange. With this, you can bootstrap end-to-end encryption between your clients and the authenticated (trusted) code of your application.



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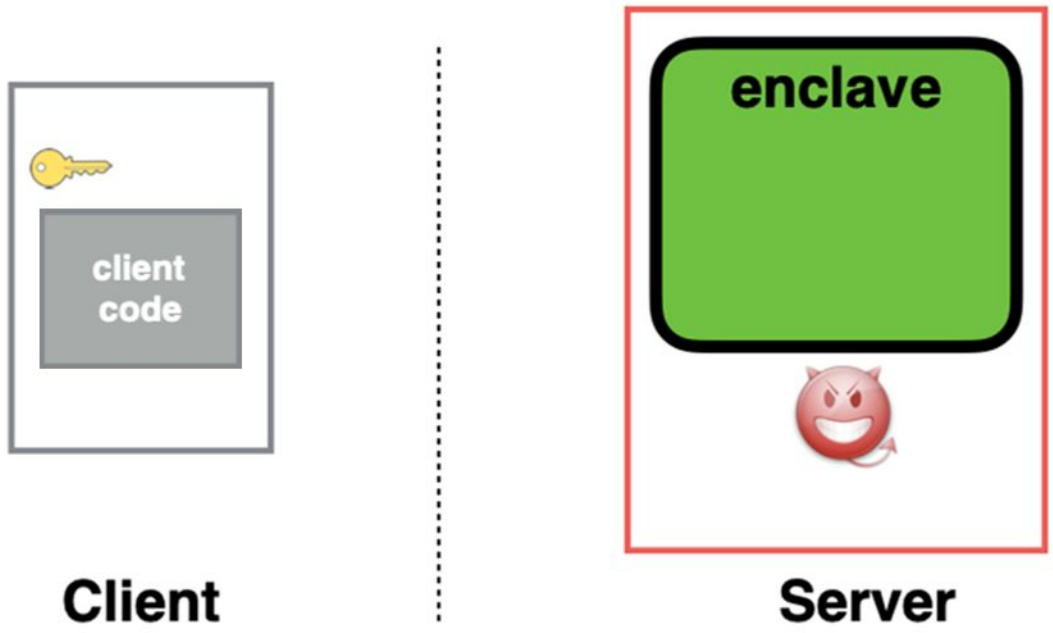

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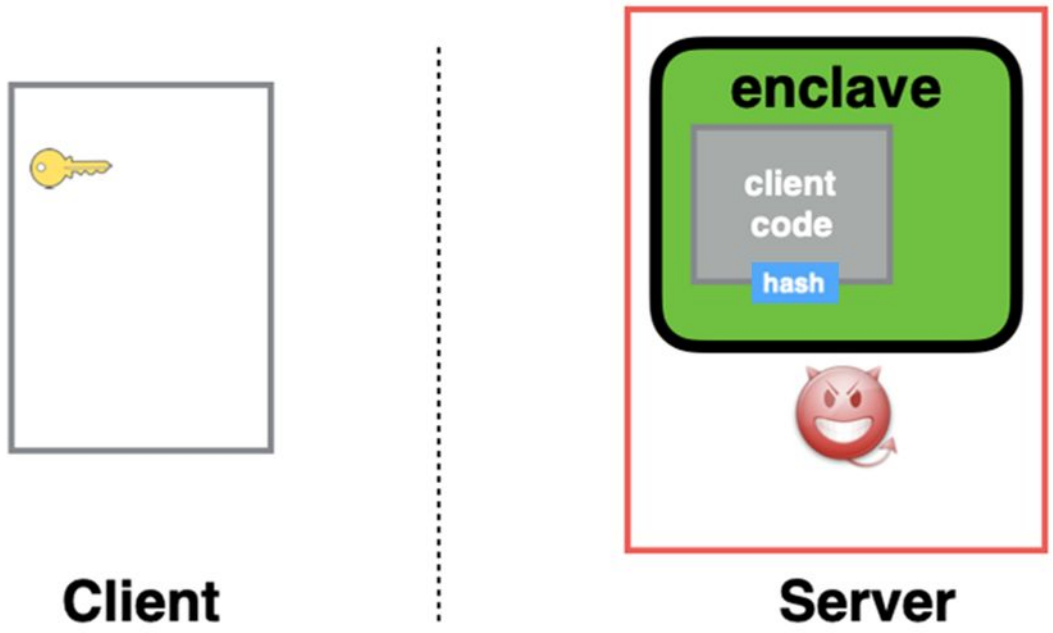

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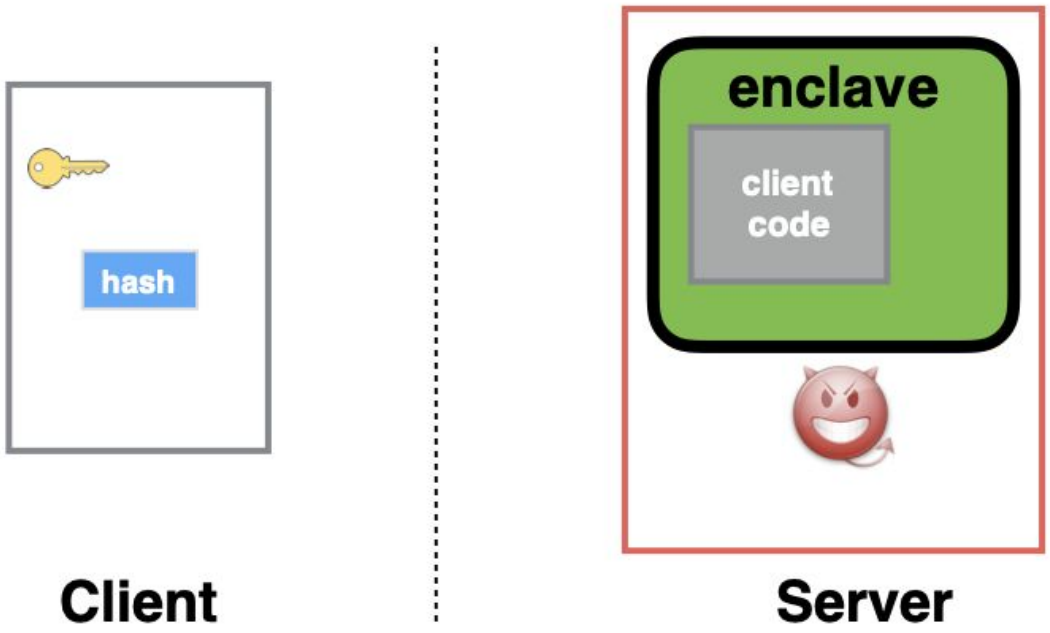

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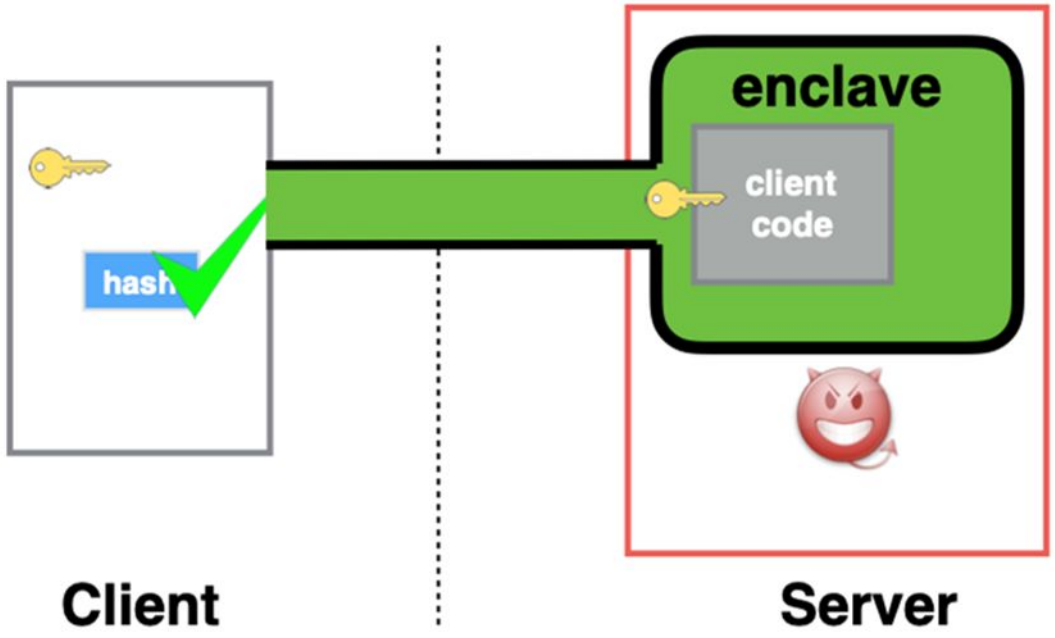

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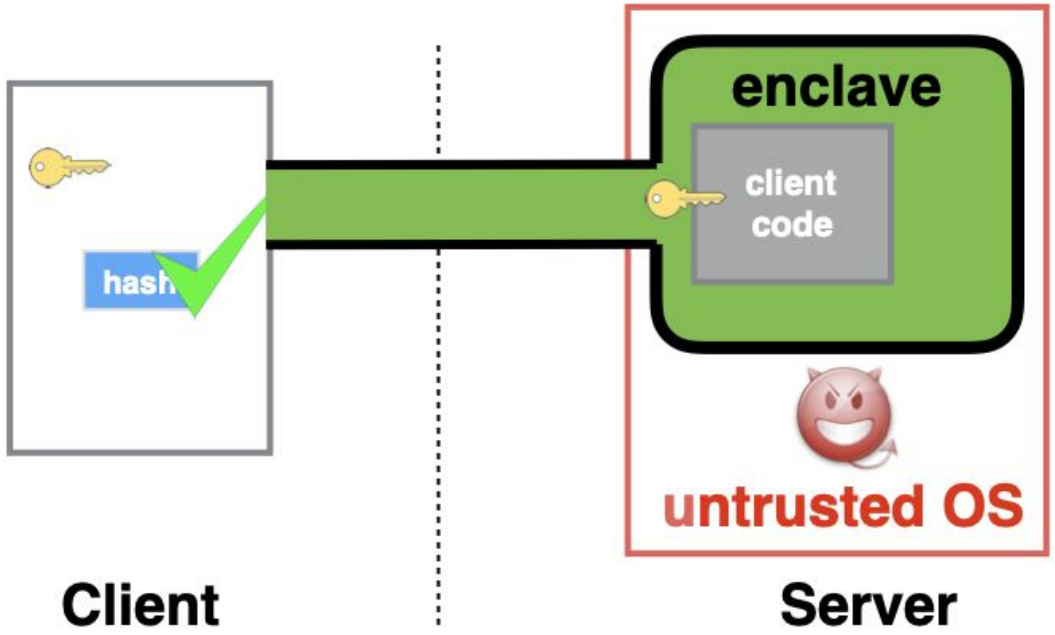
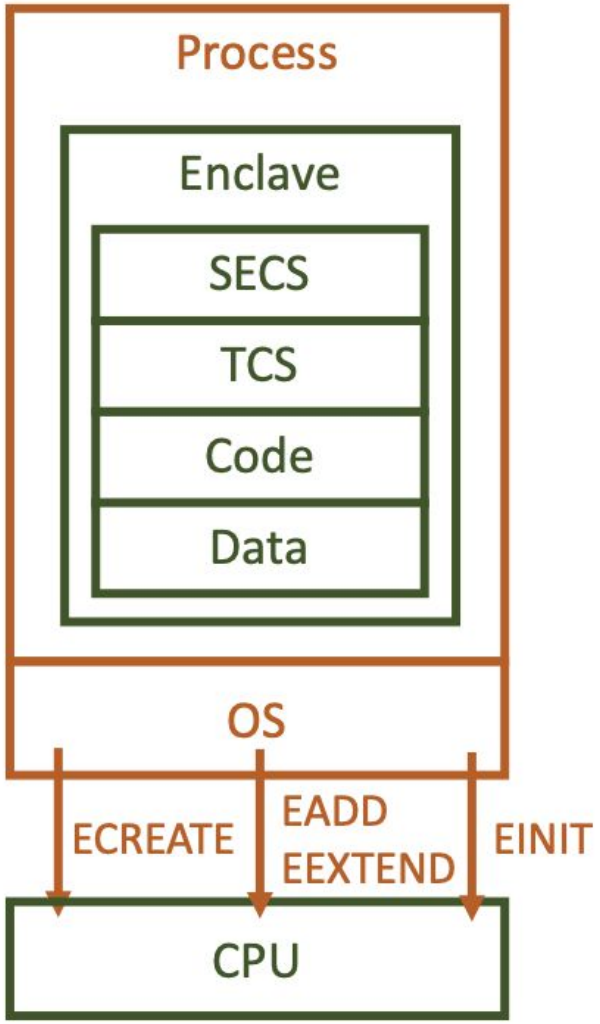
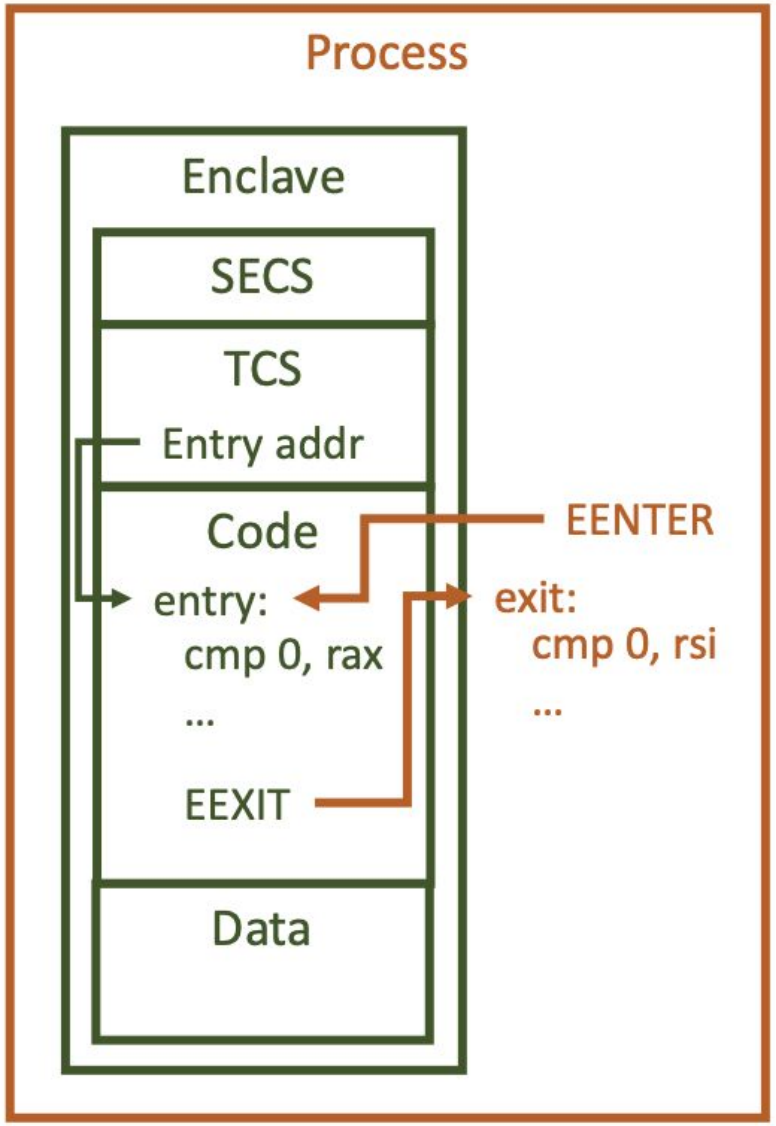


Enclave Creation with Intel SGX



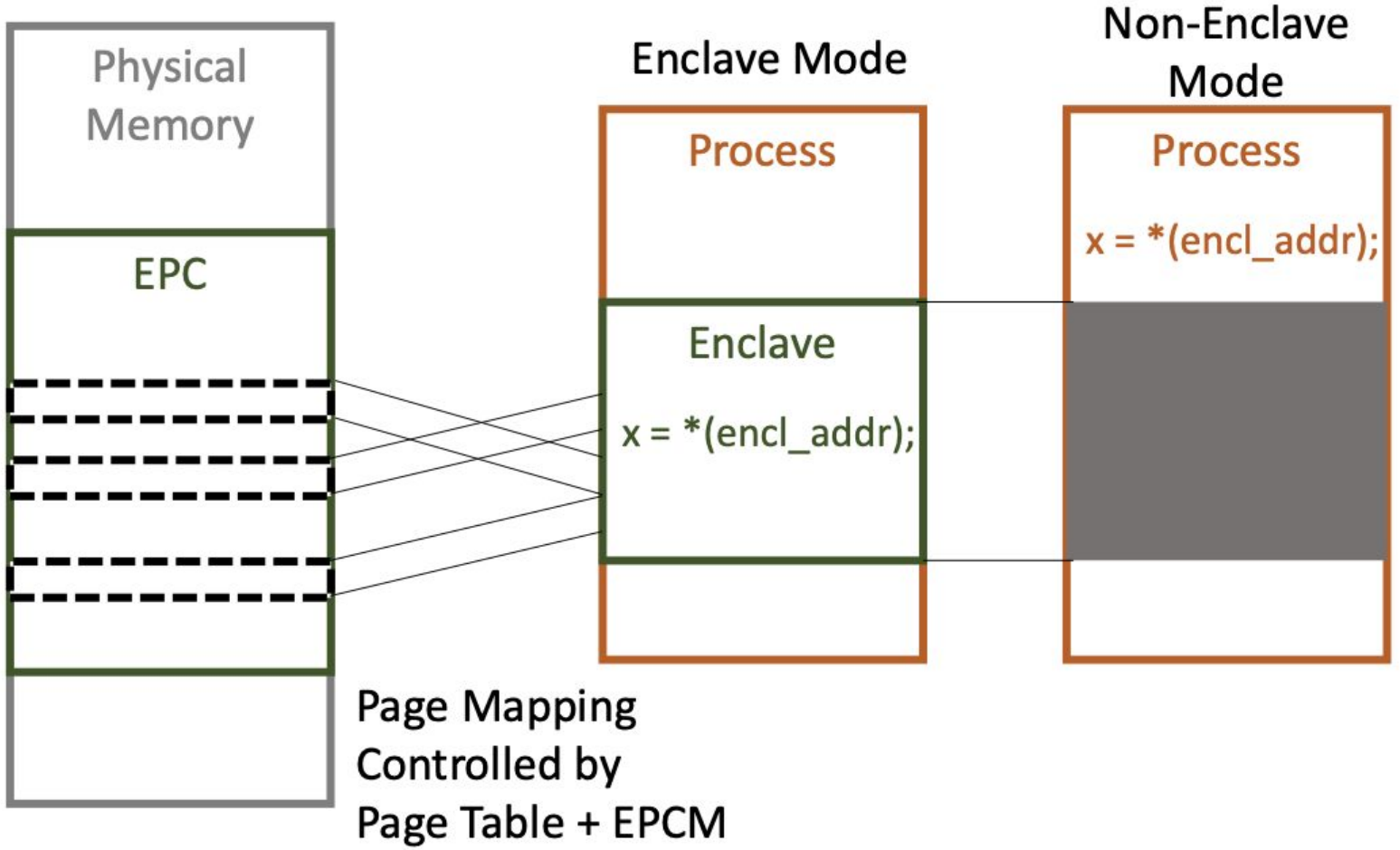
- ECREATE(SECS):
  create an enclave range
- EADD(SECS, addr, prot),
  EEXTEND(SECS, addr):
  add a page to enclave and measure the content
- EINIT(SECS, license):
  check & initialize an enclave

Enclave Enter & Exit



- EENTER(SECS, TCS):
  enter at a static enclave addr
- EEXIT(addr):
  exit enclave to any addr
- Enclave can accept parameters after the entry
- Attackers cannot interfere control flow unpredictably

Enclave Isolation



Abort page semantic:

EPC pages contains all 0s for execution outside the enclave

Existing Systems

Hardware enclaves are a very real technology that is available in multiple clouds, e.g.:

- Amazon: AWS EC2 Nitro Enclaves
- Microsoft: Azure SGX Enclaves
- Google: GCP Asylo

The End