Preliminary Study of Trusted Execution Environments on Heterogeneous Edge Platforms

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Outline

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- Introduction
- Trusted Execution Environment (TEE)
  - Intel Software Guard eXtension (SGX)
  - ARM TrustZone Technology
  - AMD Secure Encrypted Virtualization Technology
- Edge Computing with TEE
- Conclusion and Future Work

Outline

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Why moving to Edge from Cloud?

Edge Computing

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- Reduced network latency for time-sensitive tasks.
  E.g. *Real-time monitoring for transportation [1]*.

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- Increased efficiency for performance-sensitive tasks.
  E.g. *Video analytics for public safety [2]*.

Edge Computing

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- Reduced network latency for time-sensitive tasks.
  E.g. *Real-time monitoring for transportation [1]*.
- Increased efficiency for performance-sensitive tasks.
  E.g. *Video analytics for public safety [2]*.
- Increased privacy for sensitive data.
  E.g. *Data of home security cameras [3]*.

What about the security?

Edge Computing

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What about the security?

- Close to end-user
  $\Rightarrow$ Close to manipulation
- Distributed deployment
  $\Rightarrow$ Lacking centralized protection

Solution?

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Trusted Execution Environment (TEE)

- An isolated execution environment that remains secure even when the system software is compromised.
- Using hardware-assisted protection to guarantee the security.
- Different hardware vendors use different protection mechanisms.

Intel Software Guard eXtension (SGX)

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Intel Software Guard eXtension (SGX) is proposed via three research papers in 2013 [4, 5, 6].

- The user-level application creates an *enclave* to act as a TEE.
- The memory inside an *enclave* is encrypted by a hardware memory encryption engine.
- Memory access from the outside to the *enclave* is prohibited.

Intel Software Guard eXtension (SGX)

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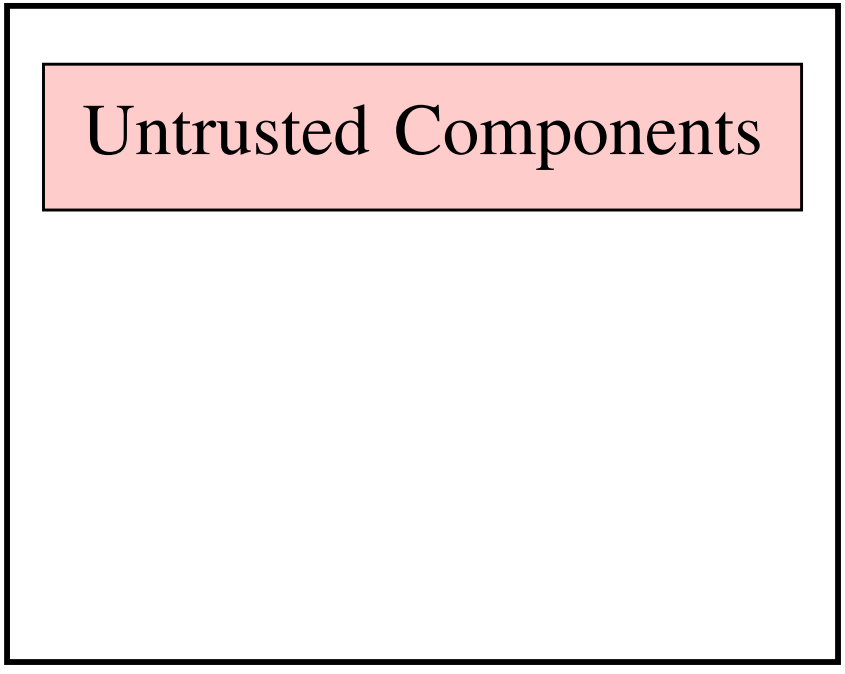
Securing Application in Untrusted OS



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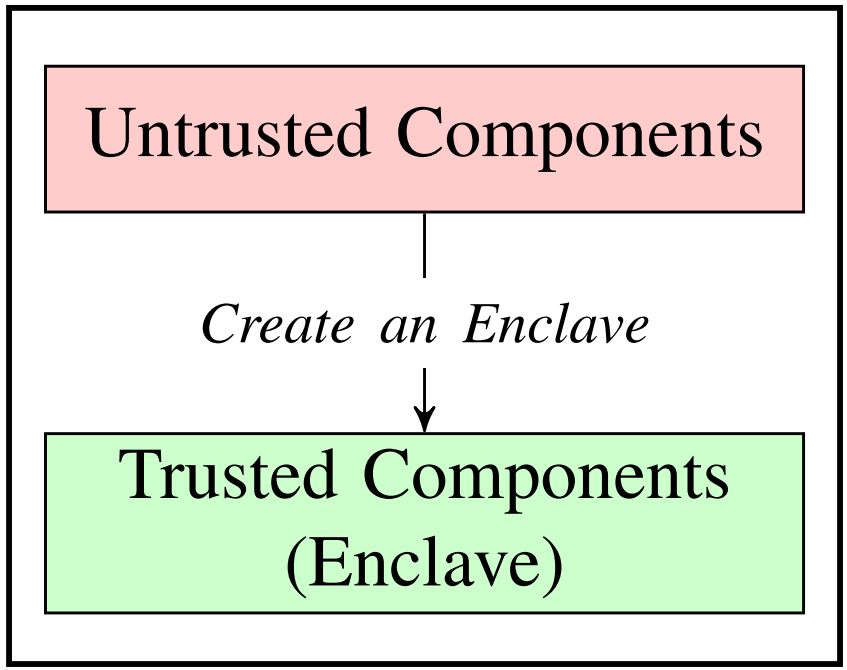

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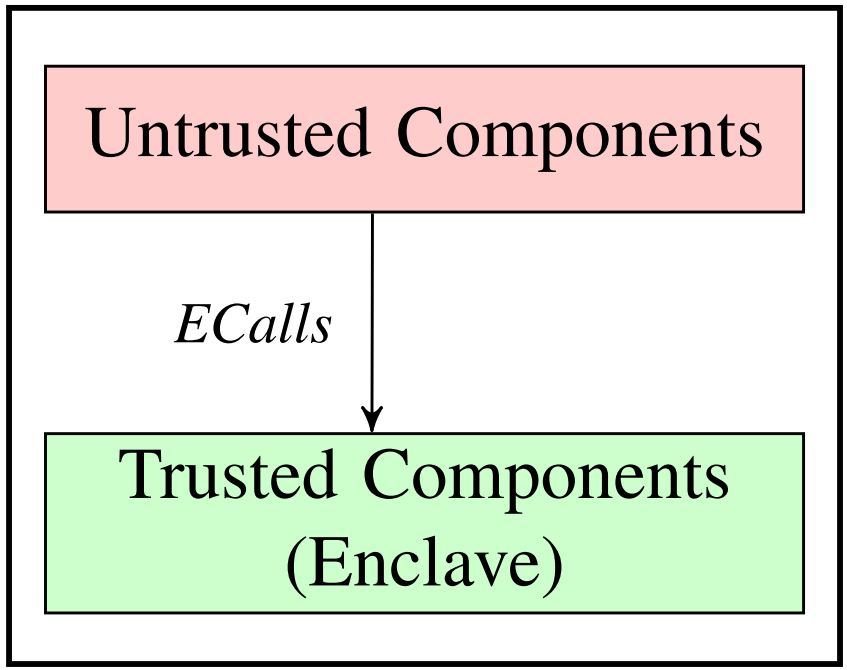

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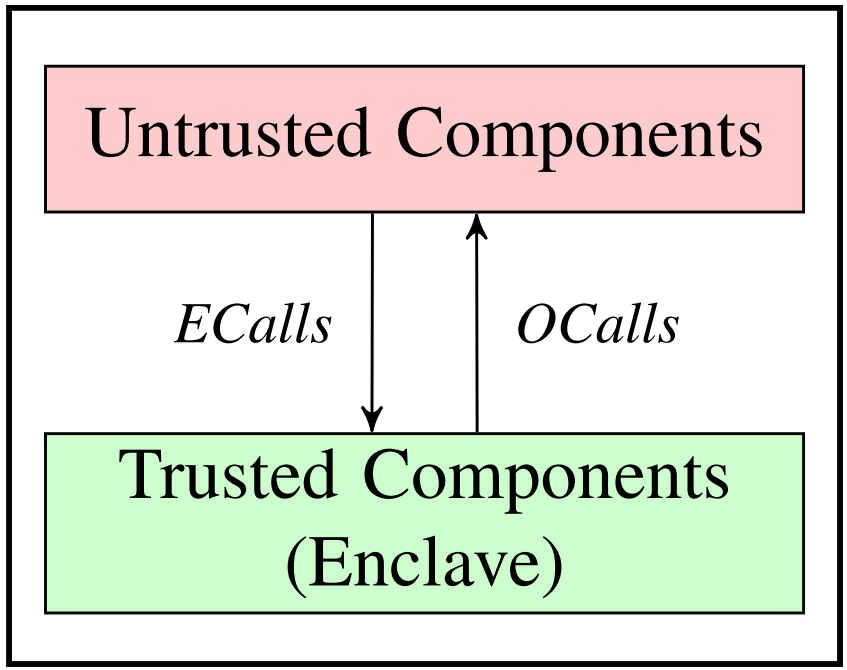

ARM TrustZone Technology

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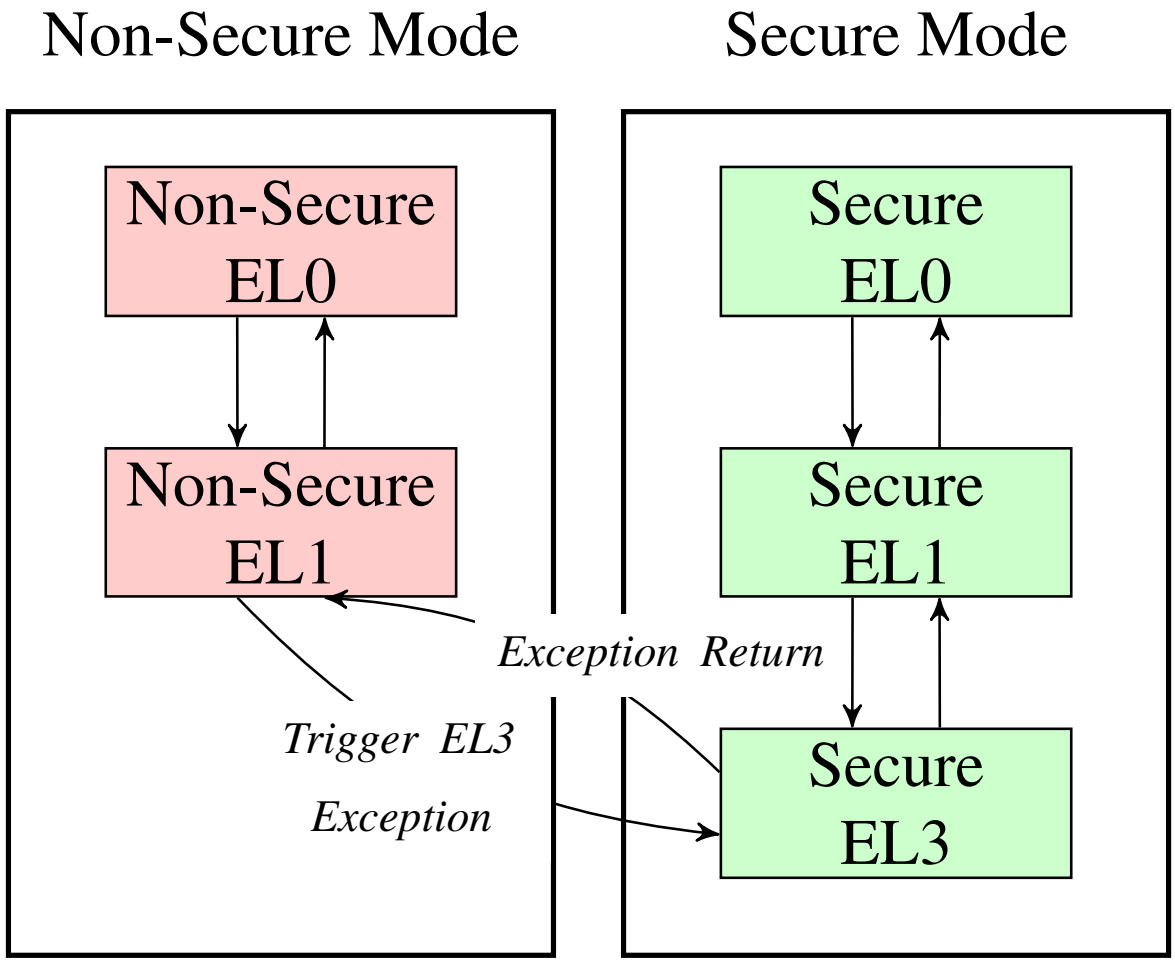
ARM proposed the TrustZone Technology [7] since ARMv6 around 2002.

- The CPU has secure and non-secure states.
- The RAM is partitioned to secure and non-secure regions.
- The interrupts are assigned into the secure or non-secure group.
- Hardware peripherals can be configured as secure access only.

ARM TrustZone Technology



AMD Secure Encrypted Virtualization Technology

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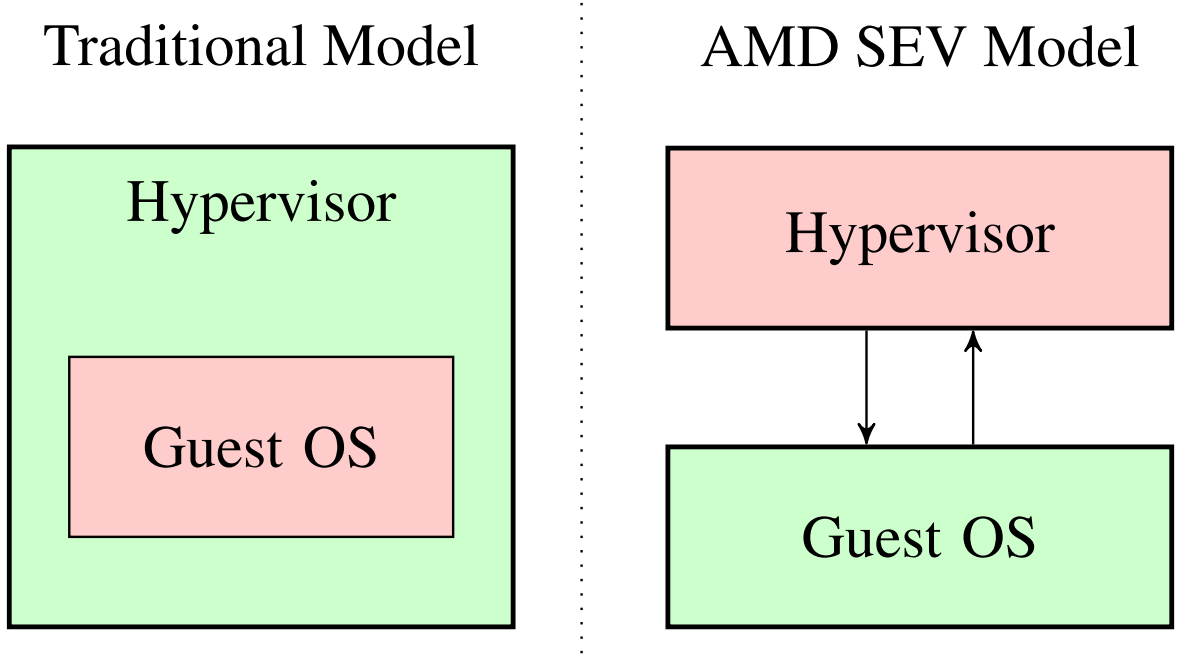
AMD Secure Encrypted Virtualization (SEV) [8, 9] Technology is released with AMD Secure Memory Encryption (SME) in 2016.

- Protecting the VM memory space from the hypervisor.
- Based on AMD Memory Encryption Technology and AMD Secure Processor.
  - Memory Encryption: An AES 128 encryption engine inside the SoC.
  - Secure Processor: A 32-bit ARM Cortex-A5 with TrustZone technology.
- Modification to the application is NOT required.

AMD Secure Encrypted Virtualization Technology



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How to secure the Edge nodes?

Securing the Edge Computing

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How to secure the Edge nodes?

- Secure the data and computation
  $\Rightarrow$ Using existing TEEs

- Accommodate to heterogeneous Edge nodes
  $\Rightarrow$ Adopting heterogeneous TEEs on different platforms

Performance Concerns

- The switch between the trusted and untrusted components should be efficient.
- The computing power inside the trusted component should be high.
- Introducing the trusted component should not affect the performance of the untrusted components.

Edge Computing with Intel SGX

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- Testbed Specification
  - Intel Fog Node, which is designed specifically for Fog Computing.
  - Hardware: An octa-core Intel Xeon E3-1275 processor.
  - Software: Tianocore BIOS and 64-bit Ubuntu 16.04.

Experiment Setup

- Context Switch: Use `RDTSC` instruction to record the time consumption of a pair of `ECall` and `OCall` with different parameter sizes.
- Secure Computation: Calculate MD5 of a pre-generated random string with 1024 characters inside the enclave, and record the time consumption.
- Overall Performance: Trigger a secure computation every one second, and use GeekBench [10] to measure the performance score.

Table: Context Switching Time of Intel SGX on the Fog Node (μs).

Buffer Size	Mean	STD	95% CI
0 KB	2.039	0.066	[2.035, 2.044]
1 KB	2.109	0.032	[2.107, 2.111]
4 KB	2.251	0.059	[2.247, 2.254]
8 KB	2.362	0.055	[2.359, 2.366]
16 KB	2.714	0.036	[2.712, 2.716]

Table: Time Consumption of MD5 (μs).

CPU Mode	Mean	STD	95% CI
Normal	4.734	0.095	[4.728, 4.740]
Enclave	6.737	0.081	[6.732, 6.742]

Table: Performance Score by GeekBench.

Sensitive Computation	Mean	STD	95% CI
No	4327.33	17.124	[4323.974, 4330.686]
Yes	4306.46	14.850	[4303.550, 4309.371]

- Testbed Specification
  - ARM Juno v1 development board, which represents ARM's official design purpose.
  - Hardware: A dual-core 800 MHZ Cortex-A57 cluster and a quad-core 700 MHZ Cortex-A53 cluster.
  - Software: ARM Trusted Firmware (ATF) [11] v1.1 and Android 5.1.1.

Experiment Setup

- Context Switch: Use Performance Monitor Unit (PMU) to record the time consumption of the context switch caused by `SMC` instruction.
- Secure Computation: Calculate MD5 of a pre-generated random string with 1024 characters in secure mode, and record the time consumption.
- Overall Performance: Trigger a secure computation every one second, and use GeekBench to measure the performance score.

Table: Context Switching Time of ARM TrustZone (μs).

Step	Mean	STD	95% CI
Non-secure to Secure	0.135	0.001	[0.135, 0.135]
Secure to Non-secure	0.082	0.003	[0.082, 0.083]
Overall	0.218	0.005	[0.218, 0.219]

Table: Time Consumption of MD5 (μs).

CPU Mode	Mean	STD	95% CI
Non-secure	8.229	0.231	[8.215, 8.244]
Secure	9.670	0.171	[9.660, 9.681]

Table: Performance Score by GeekBench.

Sensitive Computation	Mean	STD	95% CI
No	984.70	1.878	[984.332, 985.068]
Yes	983.44	3.273	[982.799, 984.082]

Edge Computing with AMD SEV

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- Testbed Specification
  - A customized machine with AMD EPYC-7251 CPU.
  - Hardware: 8 physical cores and 16 logic threads.
  - Software: Ubuntu 16.04.5 with SEV-enabled Linux kernel 4.15.10 and KVM 2.5.0.

Experiment Setup

- Context Switch: Use `RDTSC` instruction to record the time consumption of the context switch caused by `VMMCALL` instruction.
- Secure Computation: Calculate MD5 of a pre-generated random string with 1024 characters inside the guest, and record the time consumption.
- Overall Performance: Trigger a secure computation every one second, and use GeekBench to measure the performance score.

Edge Computing with AMD SEV

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- Context switch in AMD SEV takes about 3.09 μs.

Table: Time Consumption of MD5 (μs).

CPU Mode	Mean	STD	95% CI
Guest OS	3.66	0.126	[3.602, 3.720]
Host OS	0.70	0.005	[0.697, 0.702]

Table: Performance Score by GeekBench.

Sensitive Computation	Mean	STD	95% CI
No	3425.05	41.016	[3417.011, 3433.089]
Yes	3283.15	32.772	[3276.727, 3289.573]

Edge Computing with TEE

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- The context switch in all tested TEEs is efficient.
- The computing power in the TEEs provided by ARM TrustZone is lower than that out of the TEEs.
- The overall performance overhead of involving Intel SGX, ARM TrustZone, and AMD SEV in Edge Computing is 0.48%, 0.13%, and 4.14%, respectively.

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Conclusion and Future Work

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- The hardware-assisted TEEs provided by different hardware vendors make it possible to fit the security requirement of heterogeneous Edge nodes.
- Deploying of these TEEs can efficiently improve the security of the Edge nodes with a low performance overhead.
- In the future, we will use Asylo project from Google, an open framework for enclave applications, as a base to further develop a generic framework for TEEs on Edge platforms.

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Thank you!

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Questions?

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