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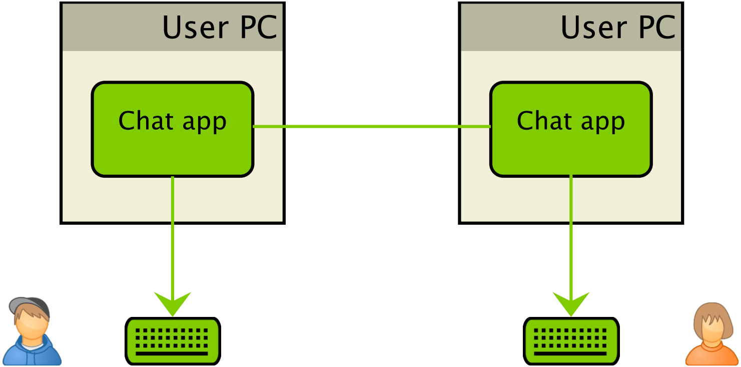
SGXIO: Generic Trusted I/O Path for Intel SGX

Samuel Weiser, Mario Werner,
Graz University of Technology - IAIK

March 23rd, 2017

Application Scenario



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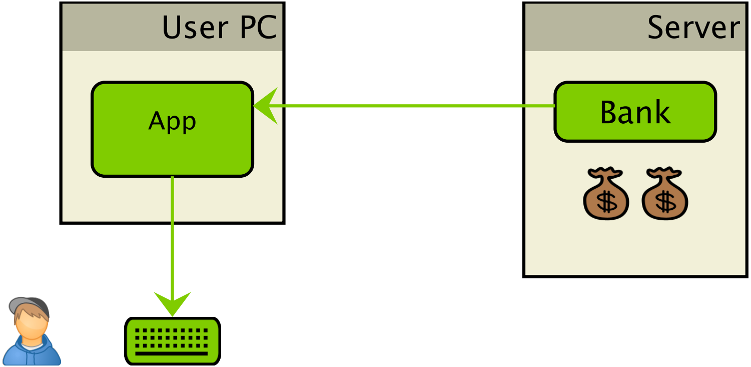
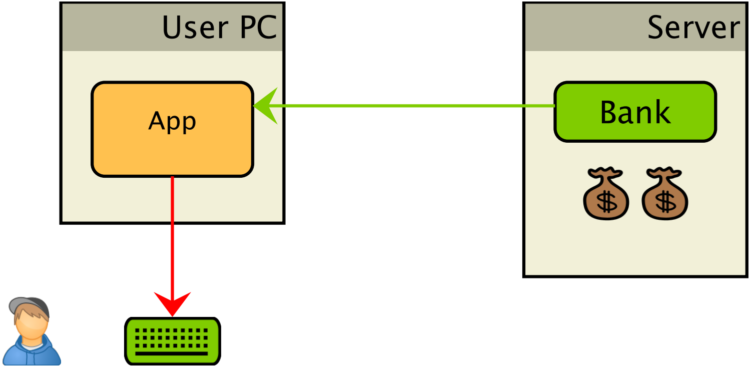
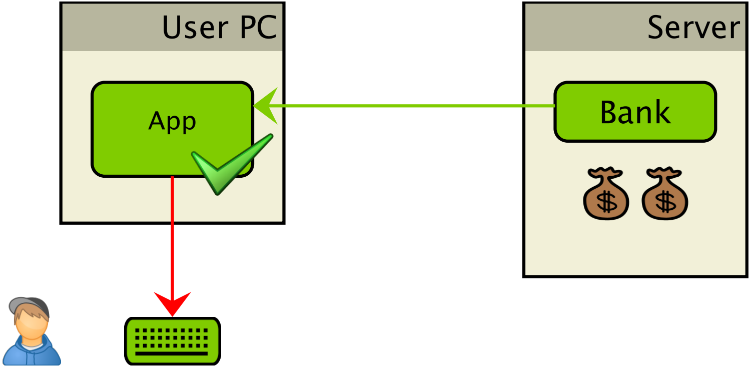


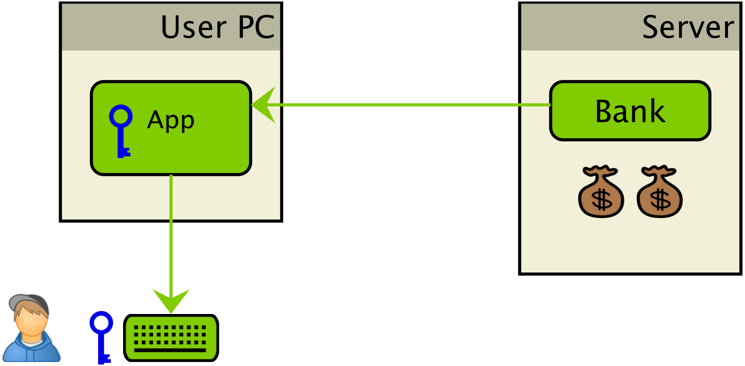
Current Situation



Intel SGX enhances app security



Trusted I/O path requires crypto



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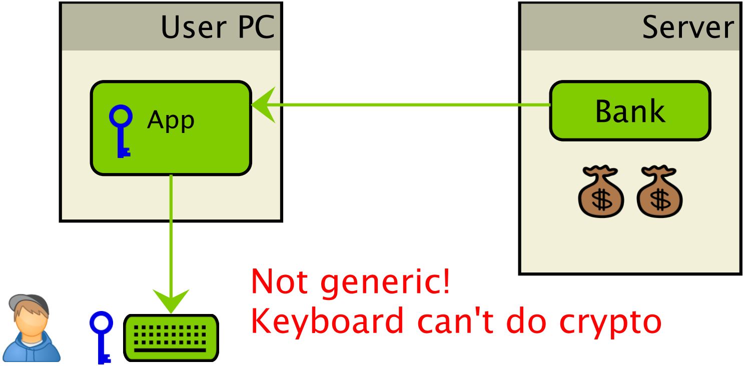

Not generic!
Keyboard can't do crypto

SGX does NOT support
Generic Trusted I/O Path!

SGXIO: Generic Trusted I/O Path for Intel SGX

SGXIO Architecture

- Conceptual work

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  - Use **SGX** to protect user app

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  - Use **hypervisor** for trusted path [3]

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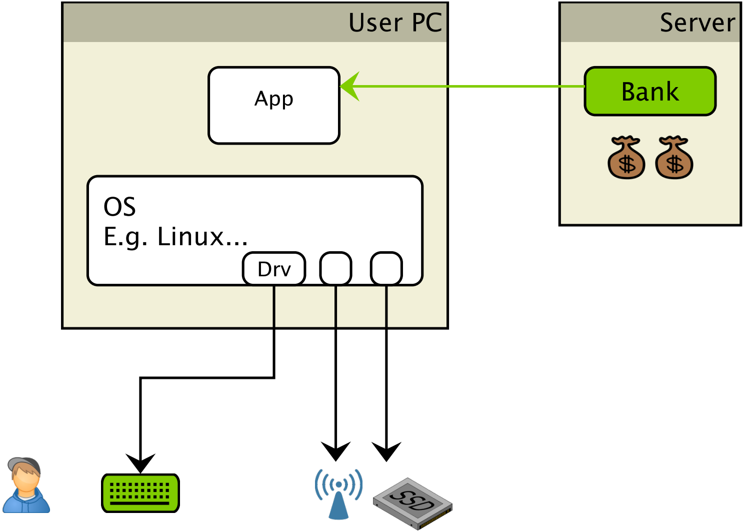
→ Achieve trusted path for SGX

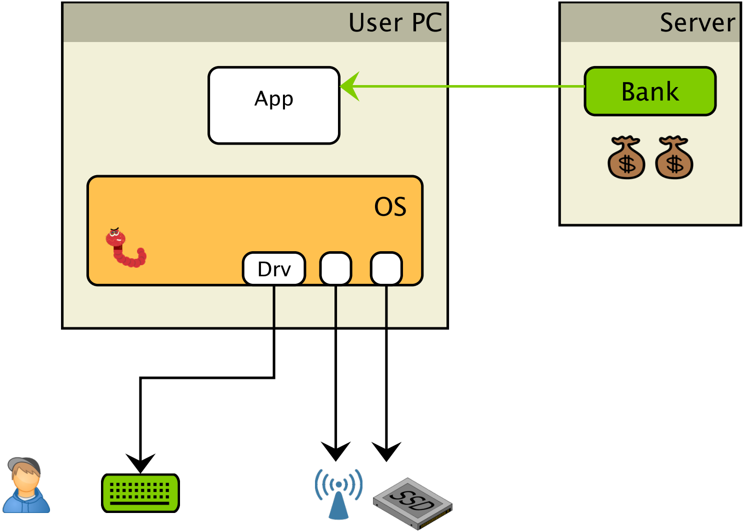
→ Support verification of the trusted path

Why do we need SGX?

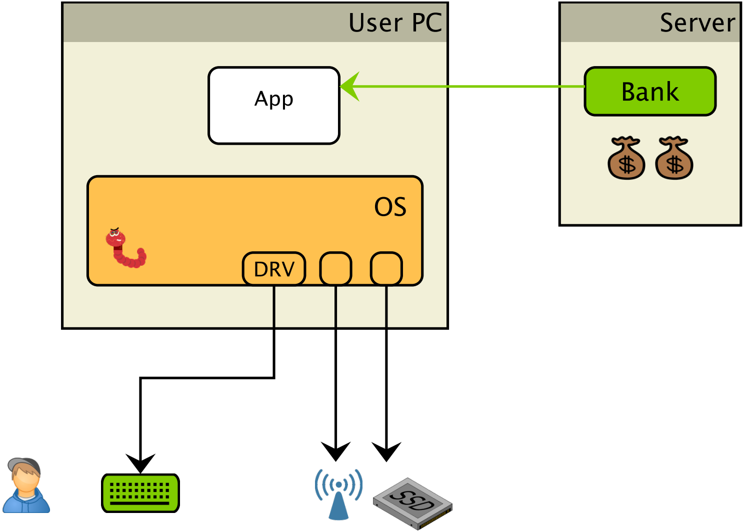
Setup: Commodity Operating System (OS)



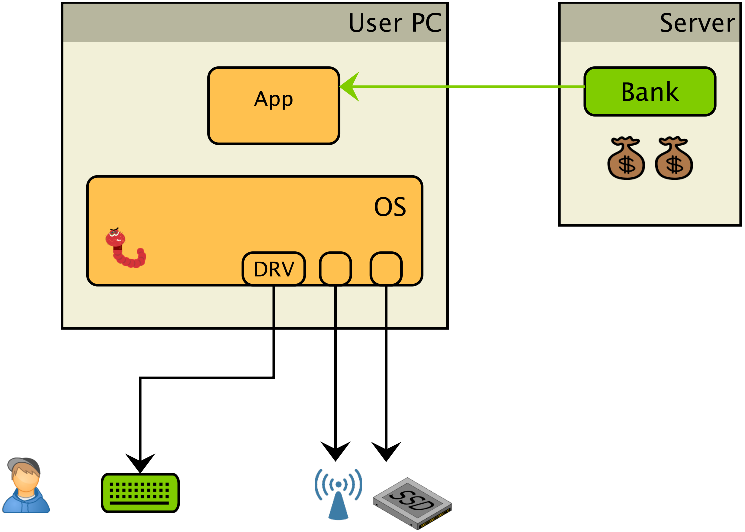
OS is untrusted



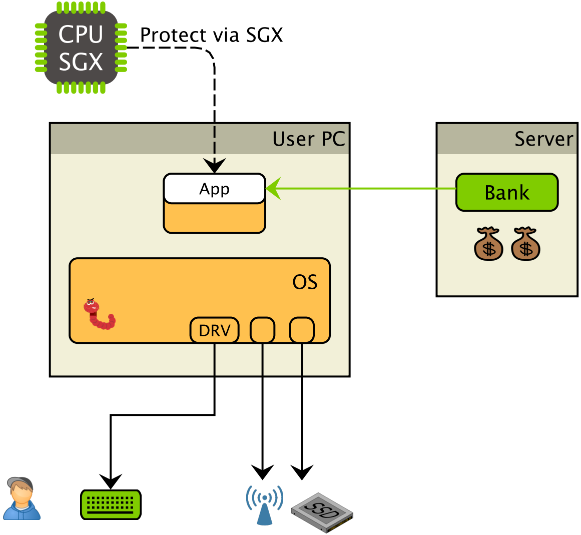
Driver is untrusted



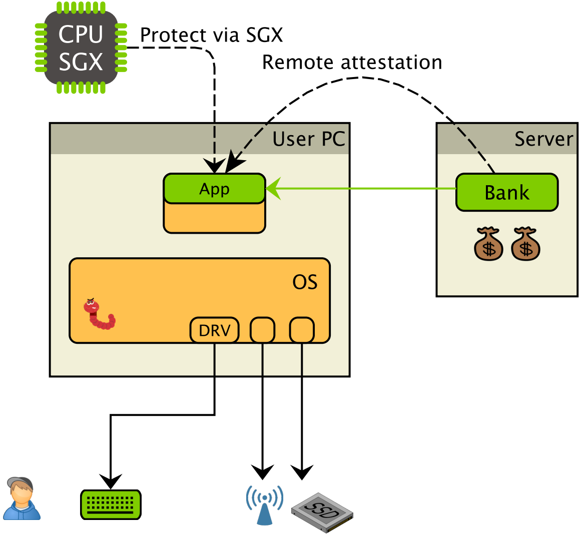
App is untrusted



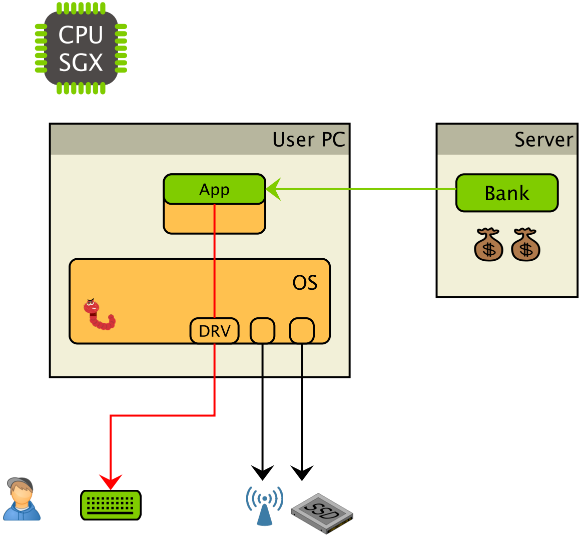
Protect app with SGX



Verify app with SGX

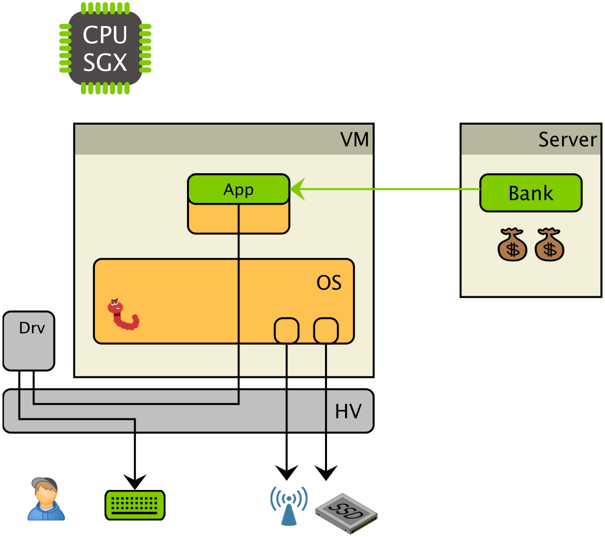


We want trusted path to user

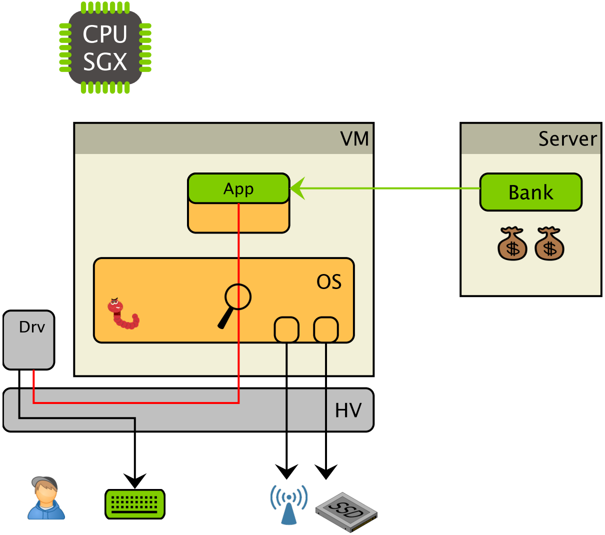


SGXIO

Isolate driver with hypervisor



OS can intercept trusted path



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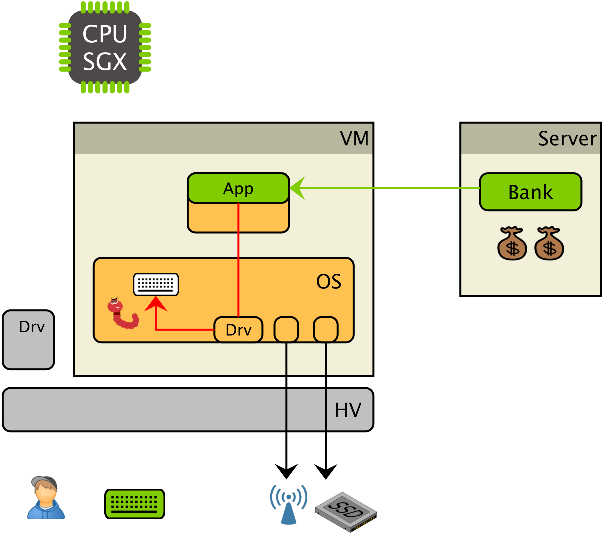
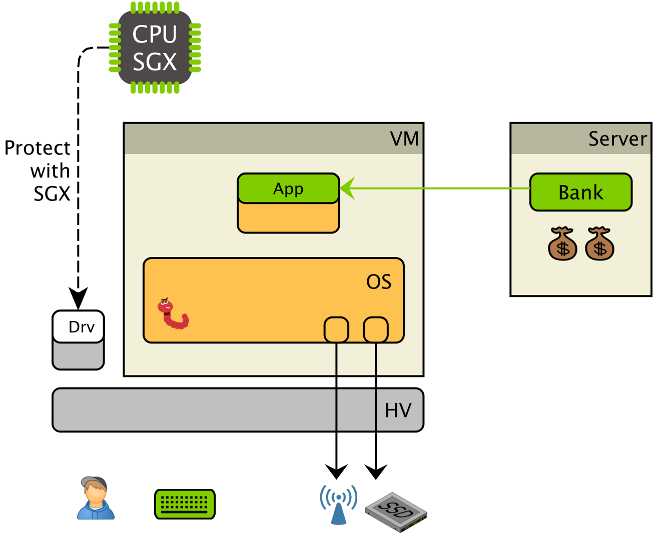


Run driver in SGX enclave



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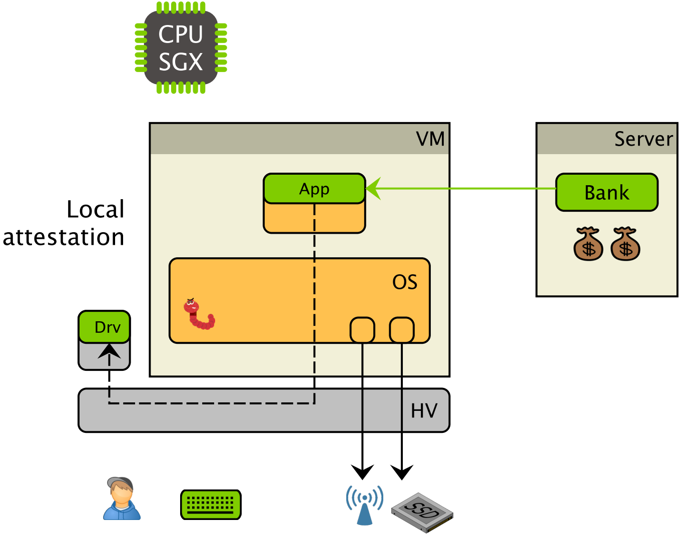
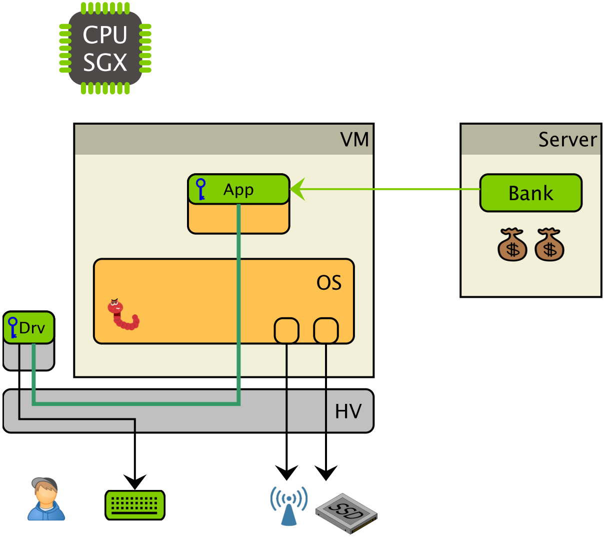
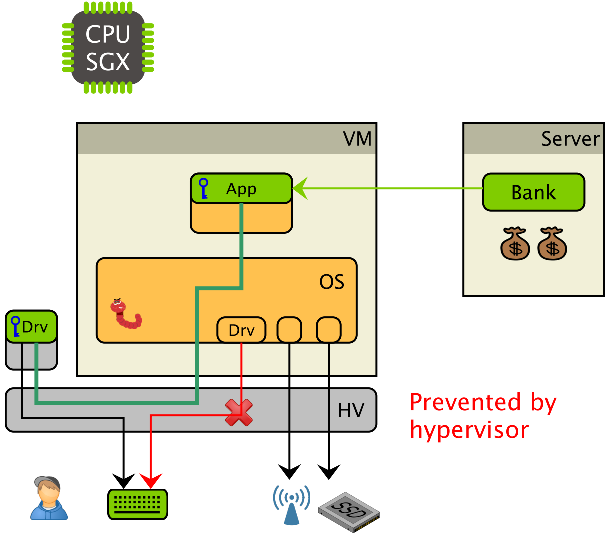


Encrypt trusted path



Isolate user device with Hypervisor (HV)



Prevented by hypervisor

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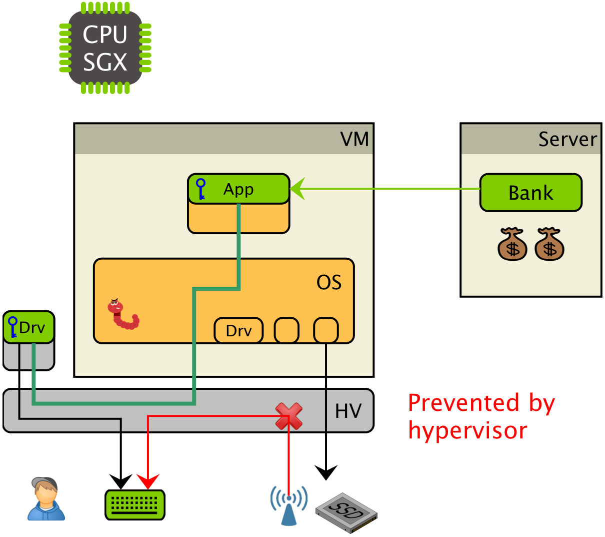
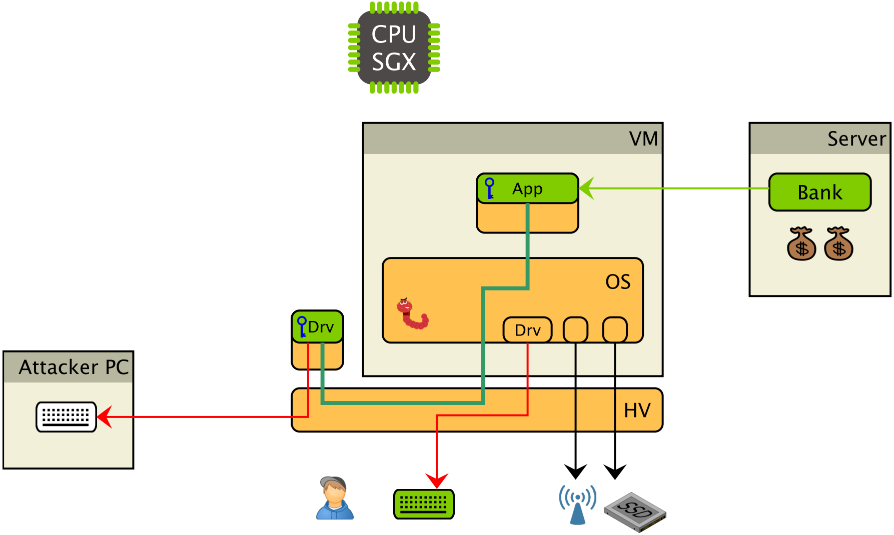
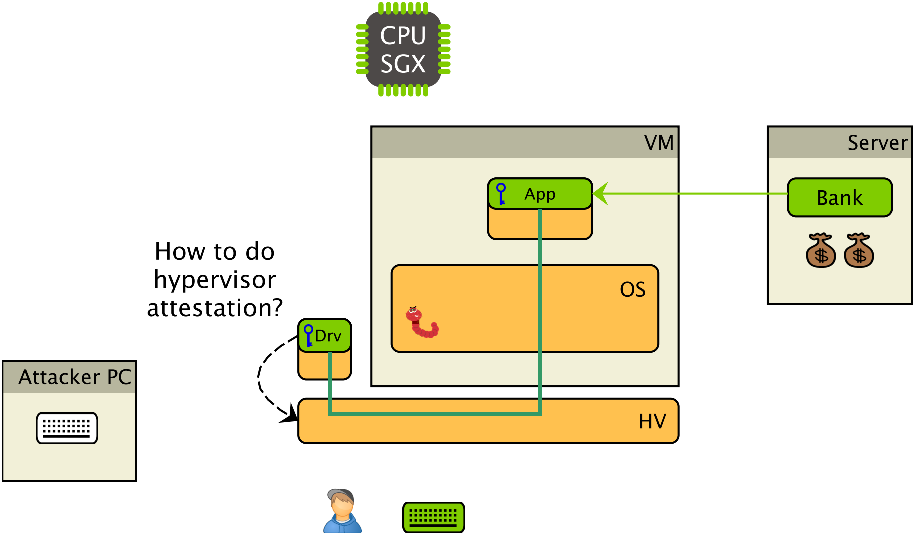


Prevented by hypervisor

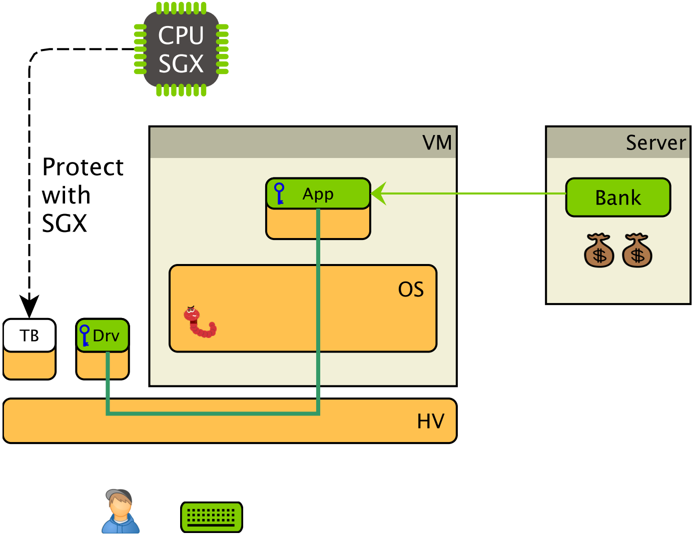
Compromised HV can intercept trusted path



Hypervisor attestation required



Trusted Boot (TB) Enclave



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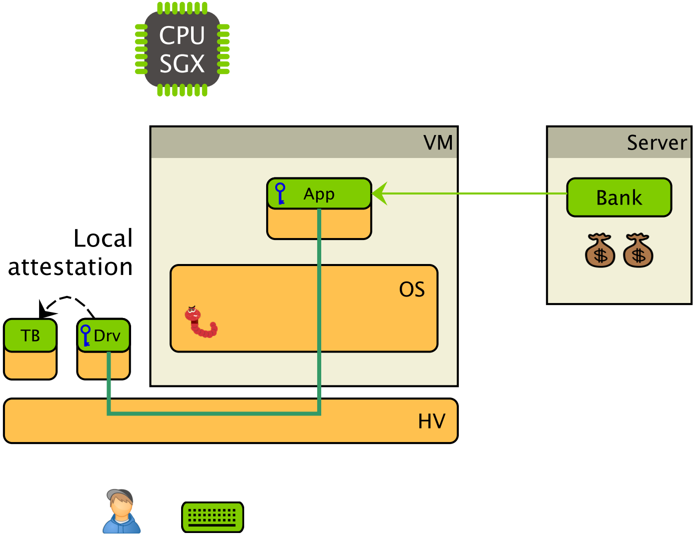
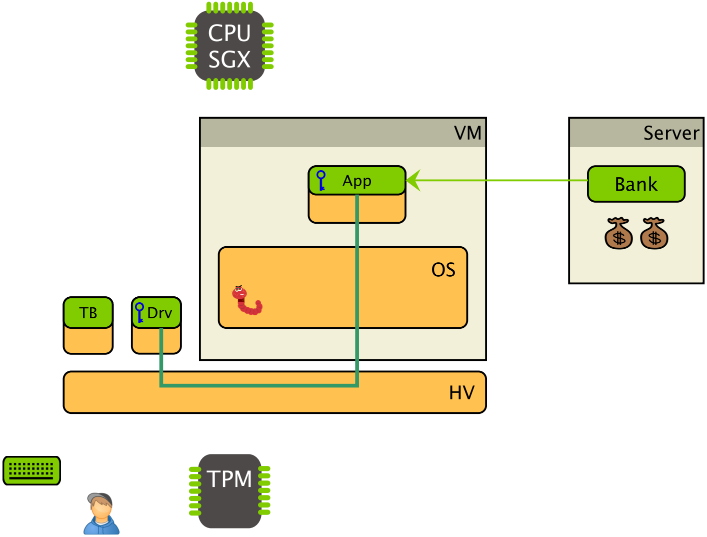
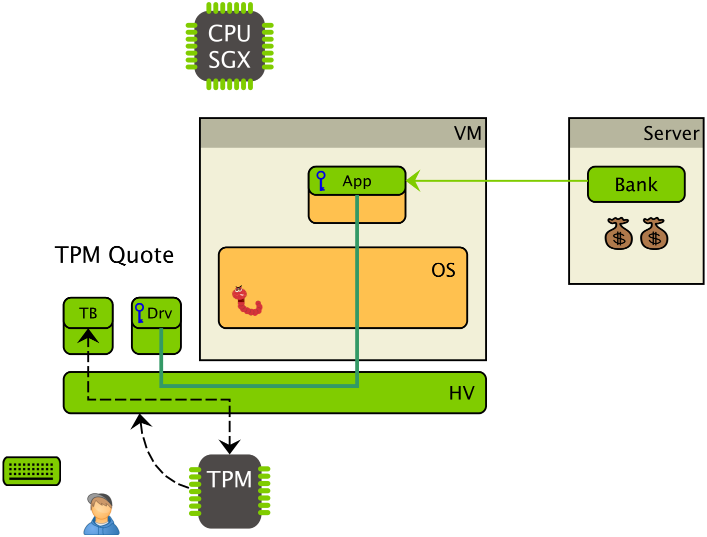


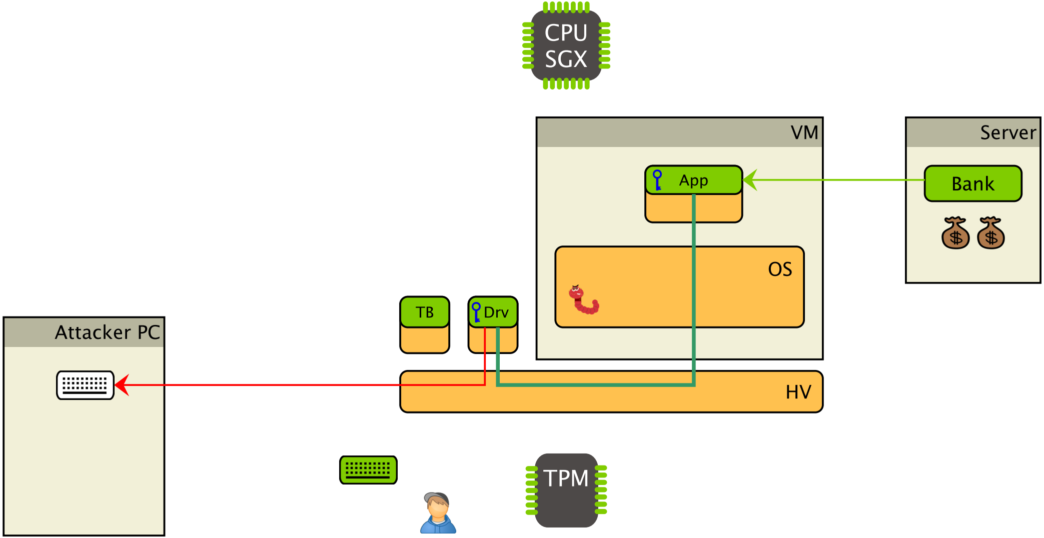
Trusted Platform Module (TPM)



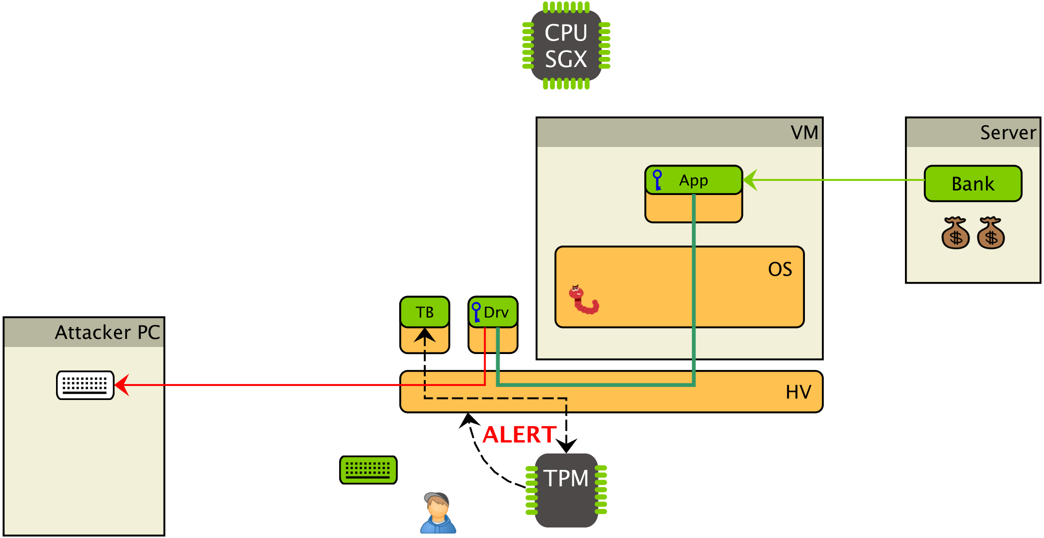
Trusted Boot



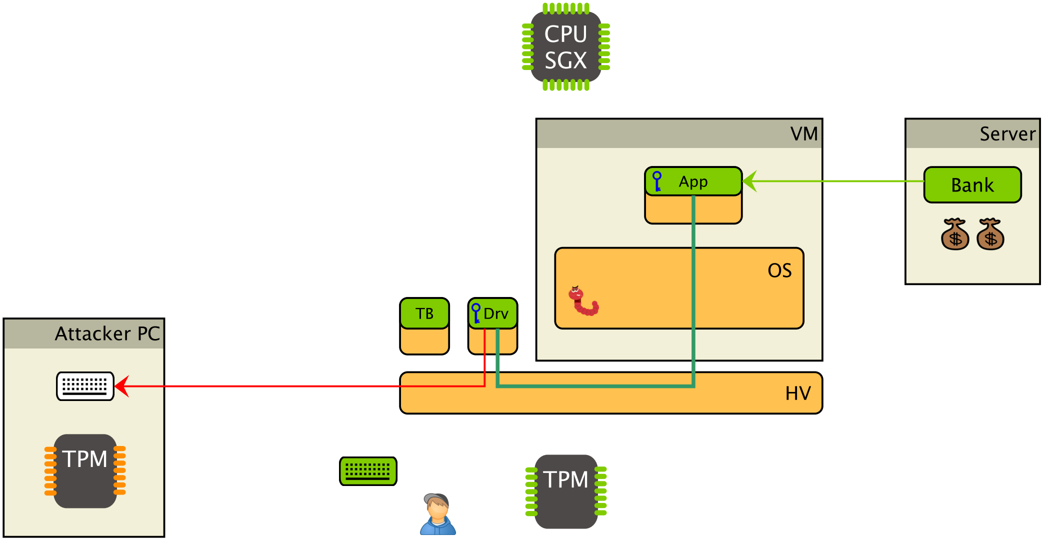
Can HV compromise be detected?



Can HV compromise be detected? Yes



Wait! Remote TPM attack (cuckoo attack)



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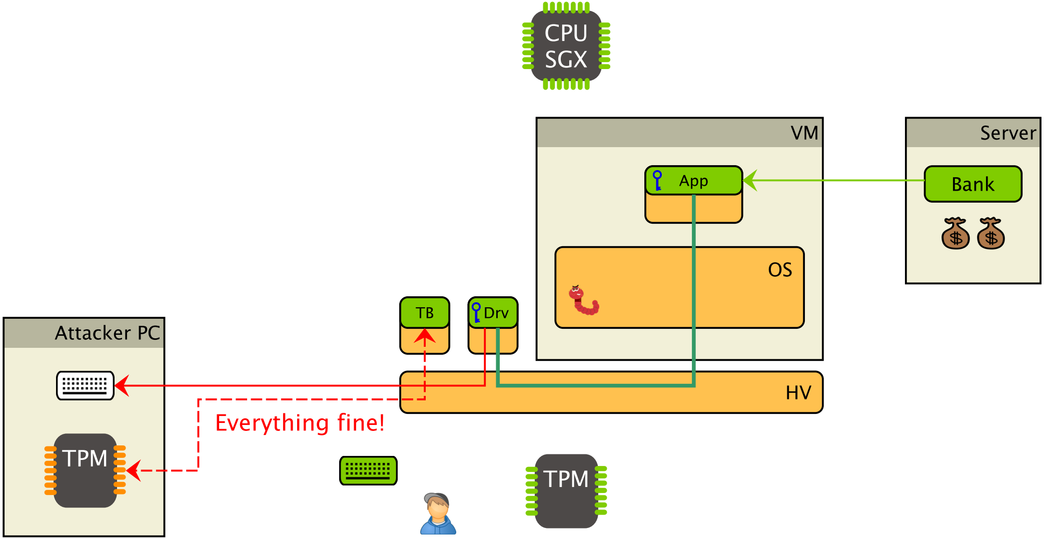
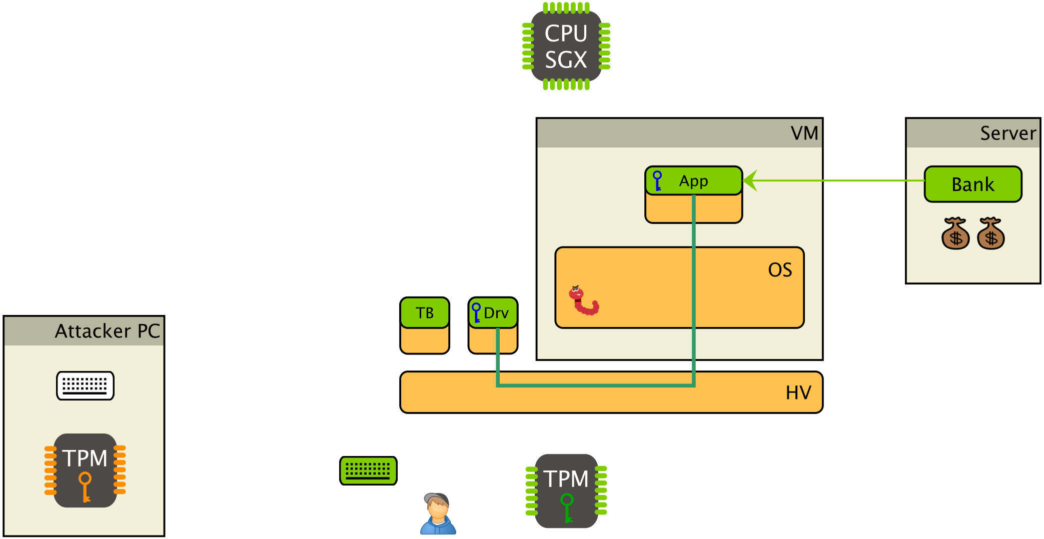


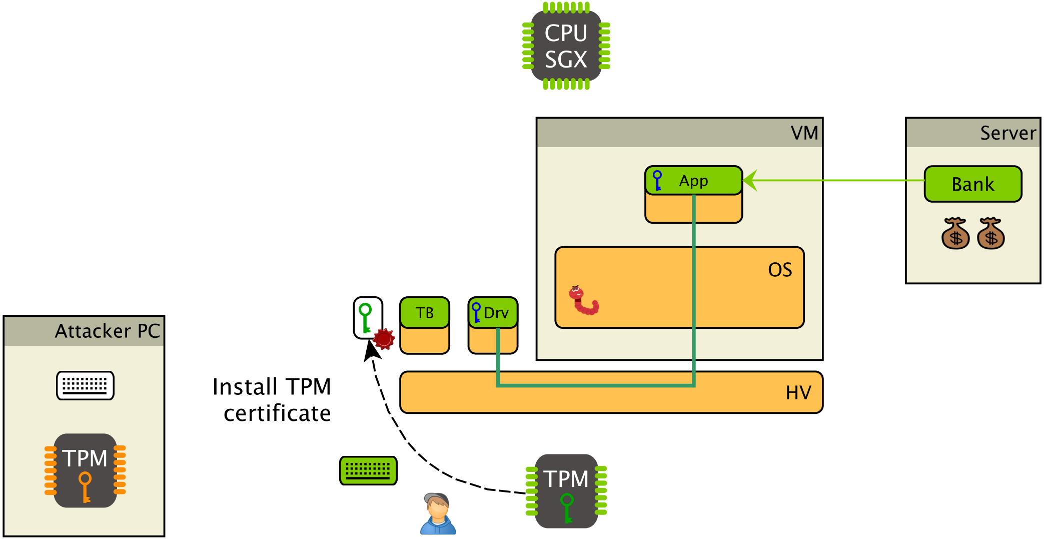
TB enclave needs to know correct TPM!

We need a domain binding between SGX and the TPM

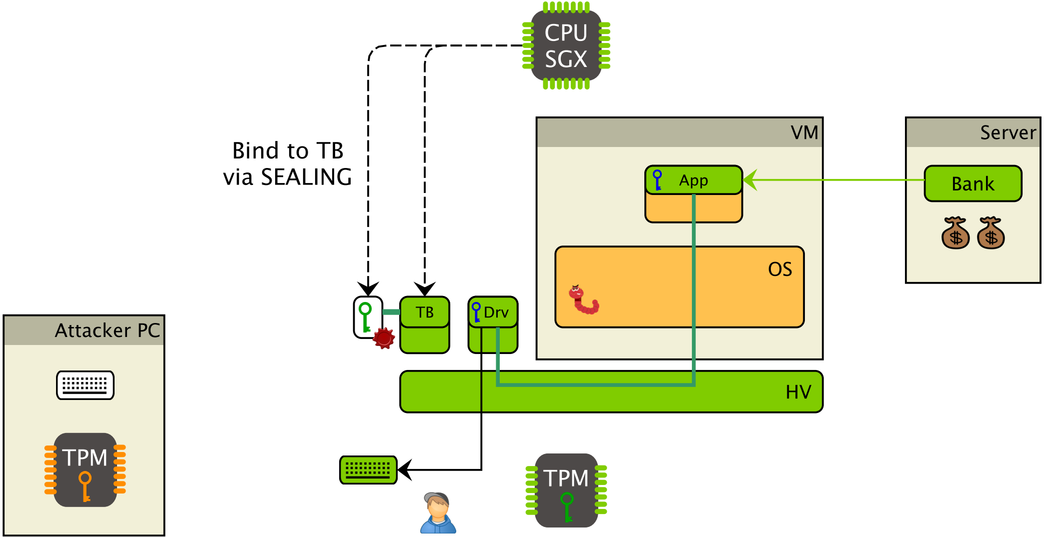
TPM Attestation Key



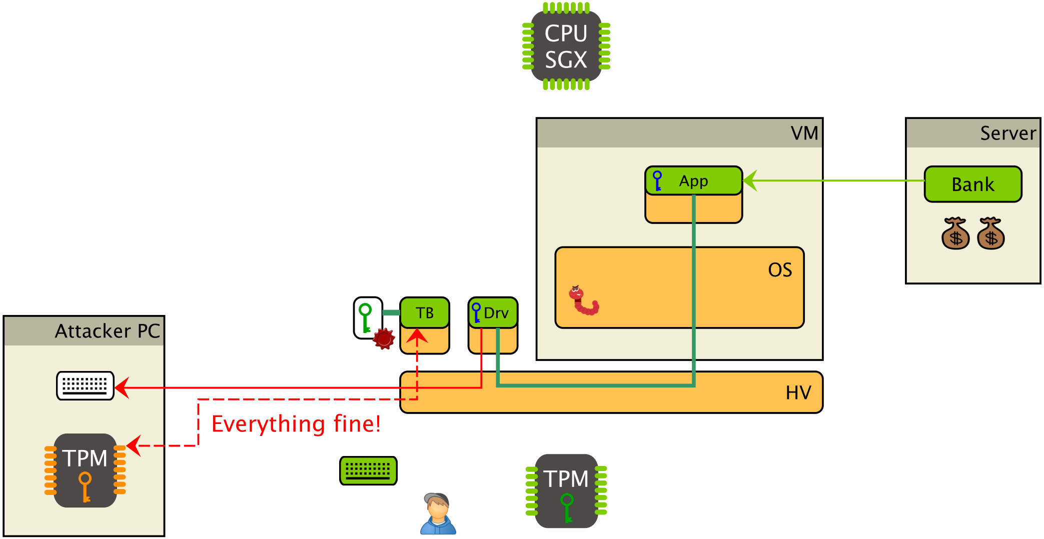
Install TPM certificate



Seal TPM certificate



Are remote TPM attacks thwarted?



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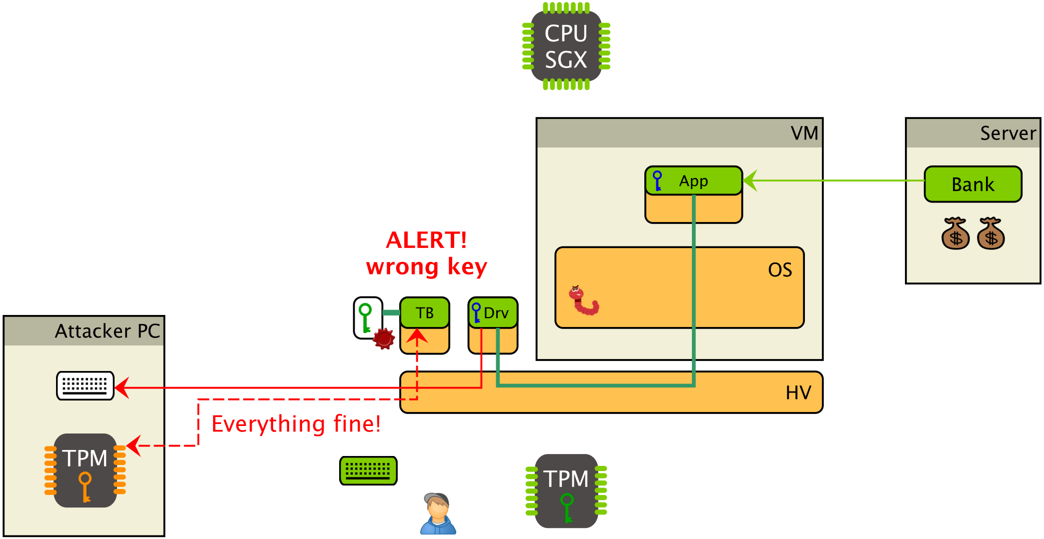
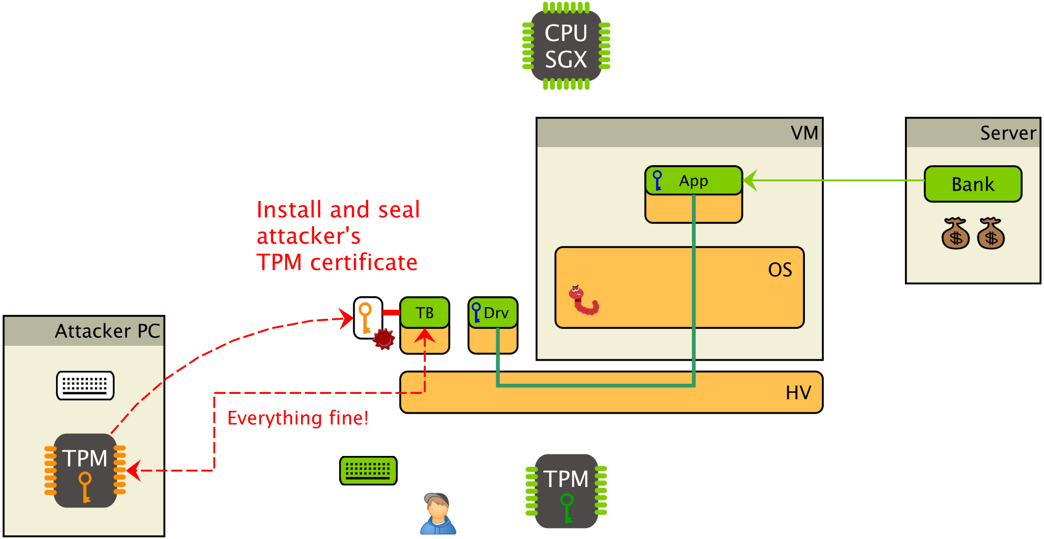


Wait! Just install attacker's TPM certificate



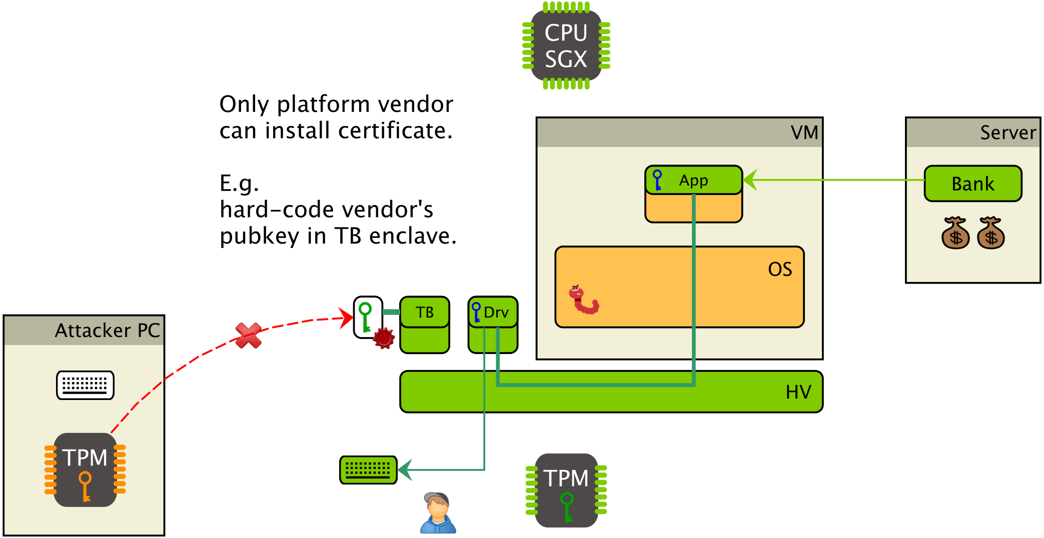
Install and seal attacker's TPM certificate

Everything fine!

Certificate installation policy required

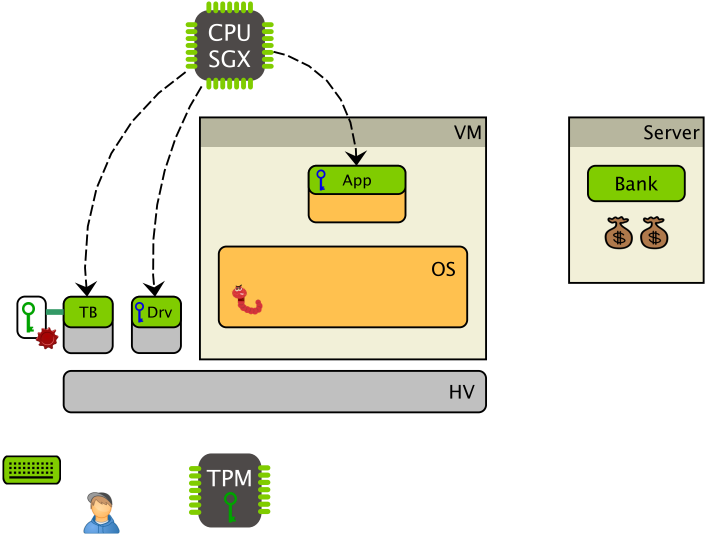
Only platform vendor can install certificate.

E.g.
hard-code vendor's pubkey in TB enclave.

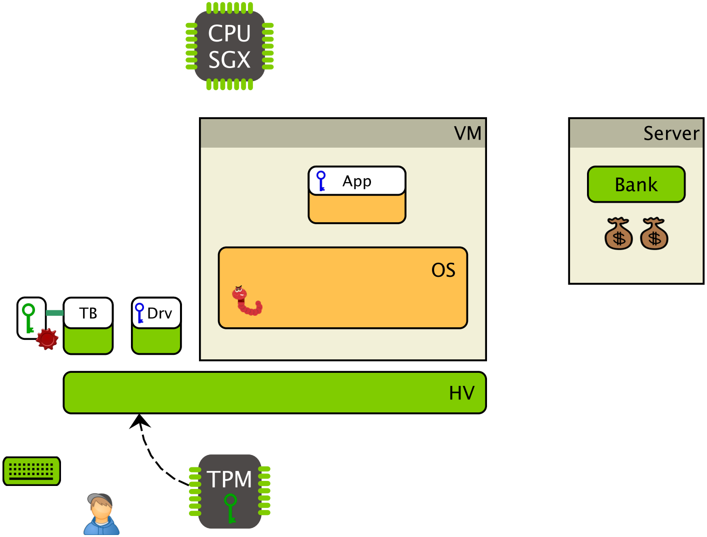


What did we achieve so far?

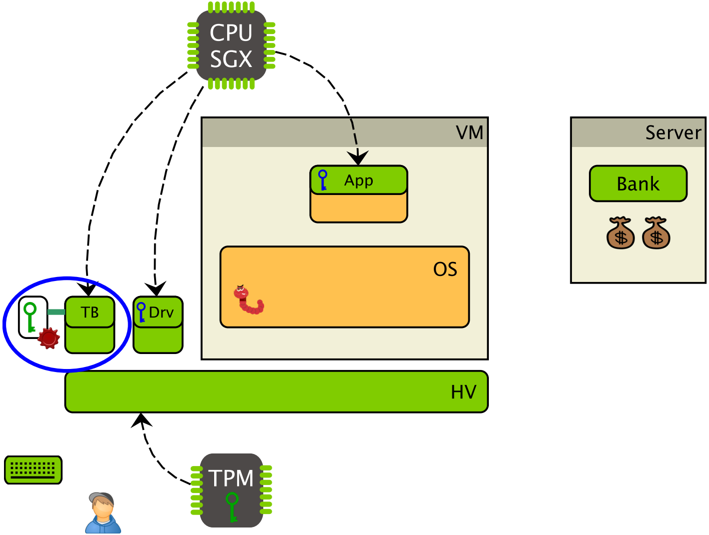
Recap: SGX protects enclaves



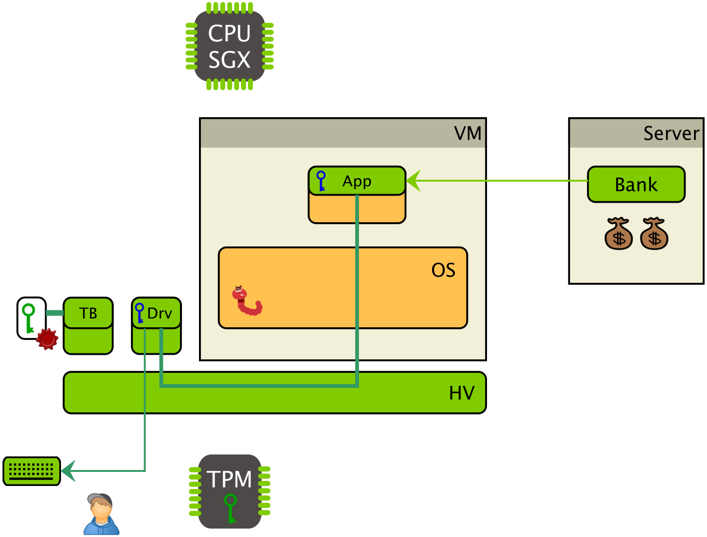
Recap: TPM attests hypervisor



We achieved Domain Binding: SGX — TPM



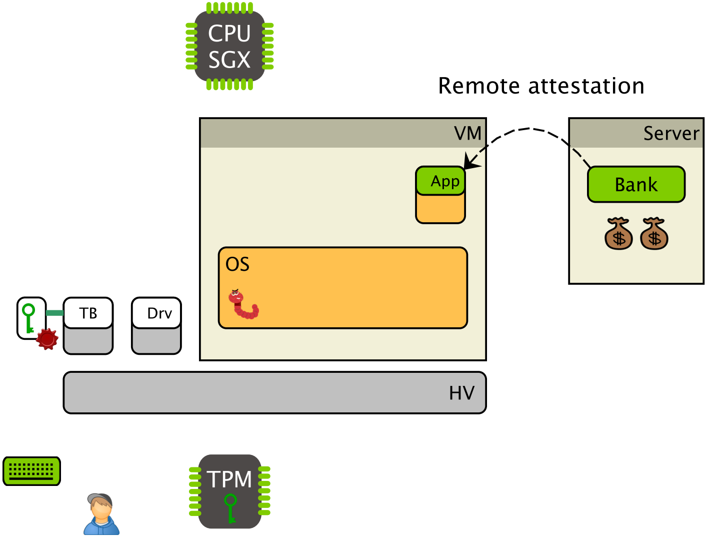
We achieved attestable trusted path



Well, almost...

Enclave Virtualization Attacks

Driver Enclave Virtualization Attack



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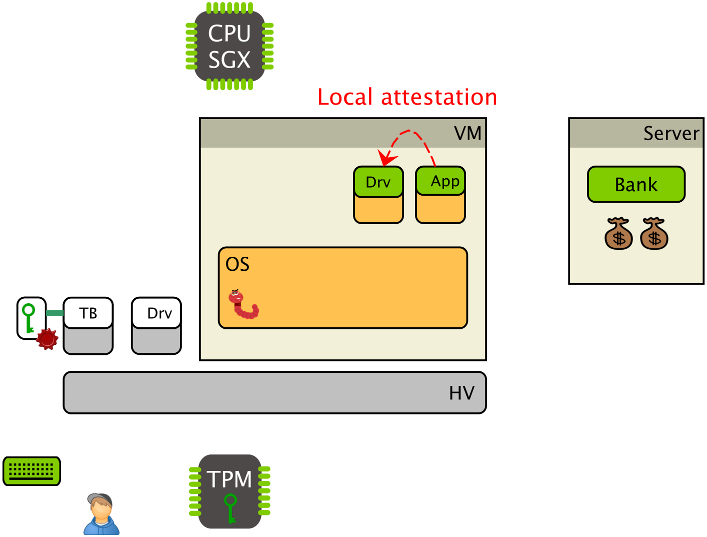

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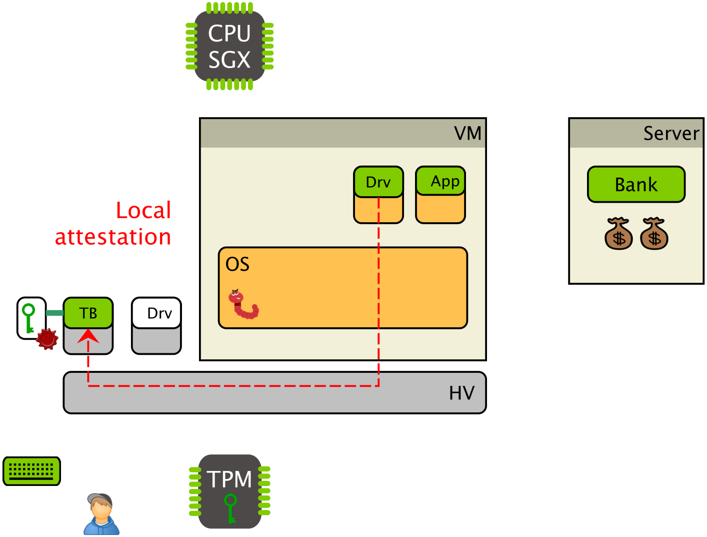

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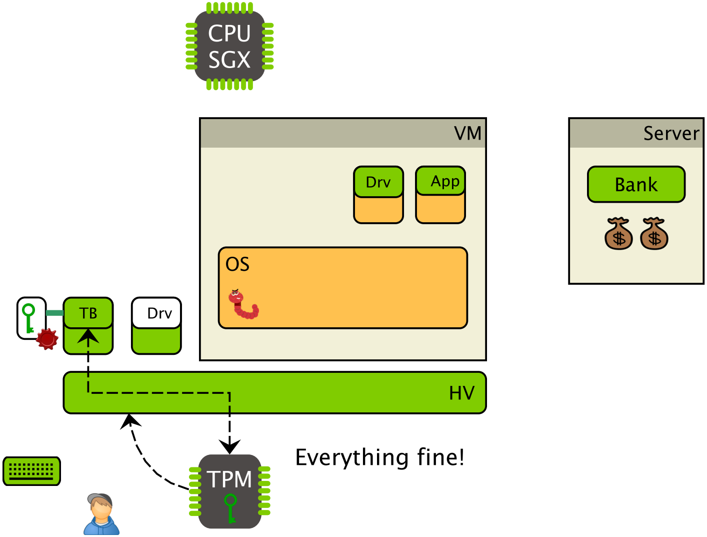

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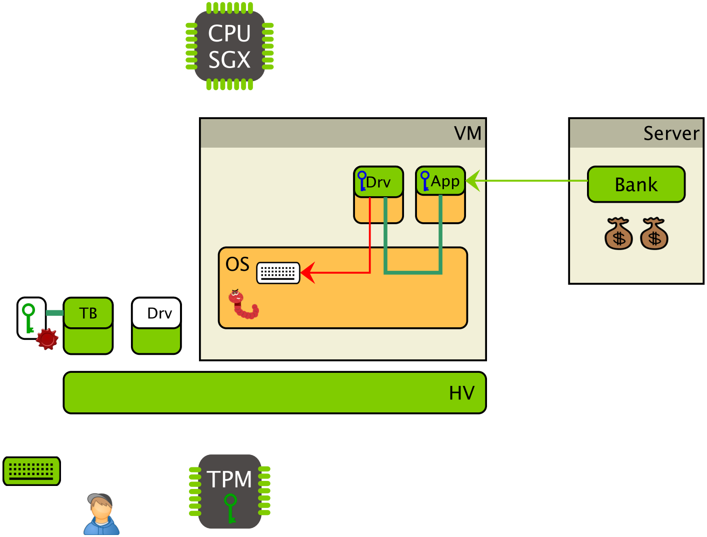
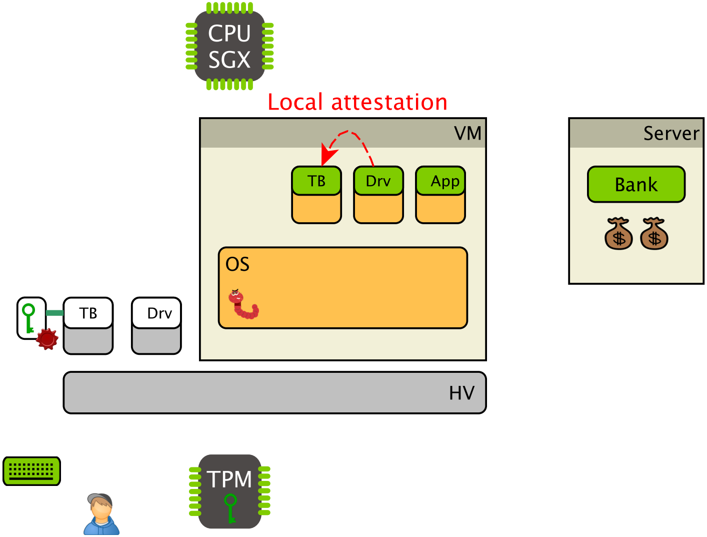


TB Enclave Virtualization Attack



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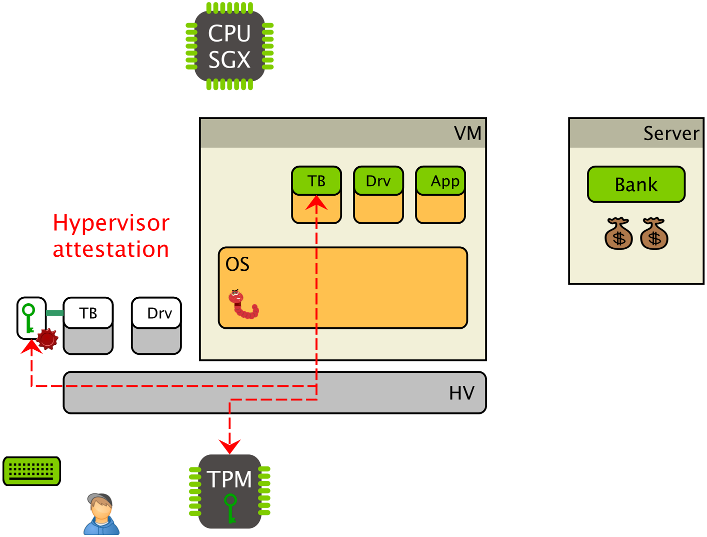

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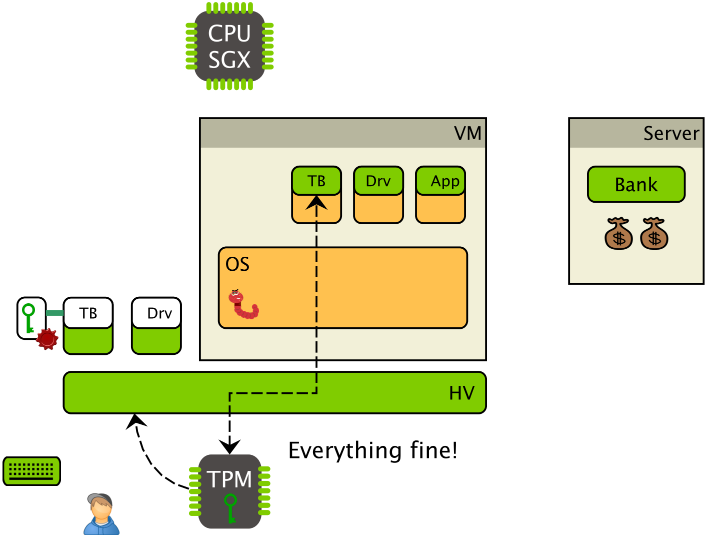

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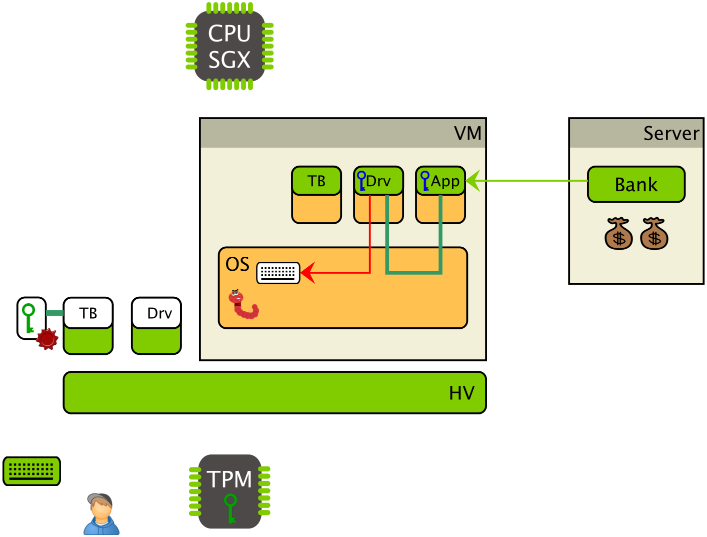

Making enclaves context-aware

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- Enclaves do not know their execution context
- Driver/TB Enclave cannot detect virtualization

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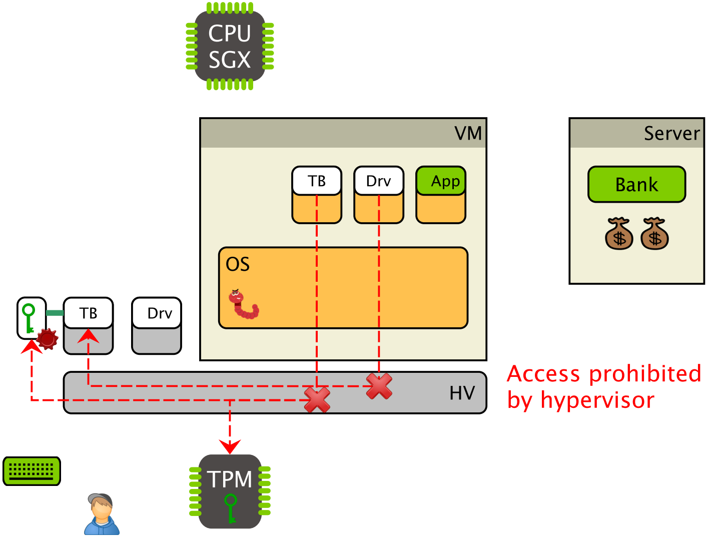
Solution:

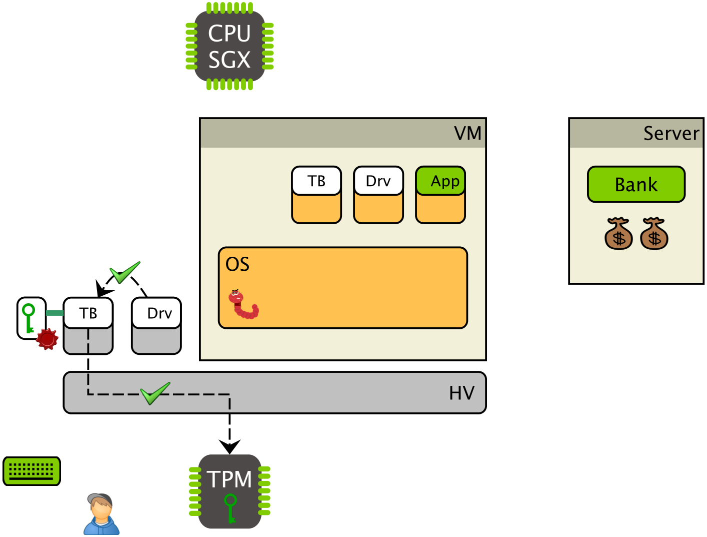
- Hypervisor knows enclave context
- Hypervisor isolates legitimate TB enclave and TPM from OS

Making enclaves context-aware



Access prohibited by hypervisor

Making enclaves context-aware



Summary: SGXIO Requirements

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Summary: SGXIO Requirements

- App and untrusted OS inside a VM
- Driver outside this VM
- Hypervisor isolating driver and user device from VM
- TPM for trusted boot
- Strong binding between TPM and TB Enclave
  - Certificate installation policy
- Hypervisor isolating TB enclave and TPM from VM

More Topics

- User verification
- Choice of hypervisor
- Driver and app design
- Intel PAVP, Intel Insider
- Fast & lightweight key exchange with SGX local attestation

→ See paper [1, 2]

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- PCI device isolation [3]
- Hardware I/O support for enclaves [4]

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arXiv:1701.01061, January 2017.

[2] Samuel Weiser and Mario Werner.
SGXIO: Generic Trusted I/O Path for Intel SGX.
In *CODASPY'17*, 2017.

[3] Z. Zhou, V. D. Gligor, J. Newsome, and J. M. McCune.
Building Verifiable Trusted Path on Commodity x86 Computers.
In *SP'12*, pages 616–630, May 2012.

[4] Samuel Weiser.
Secure I/O with Intel SGX.
Master's thesis, Graz University of Technology, 2016.
`https://pure.tugraz.at/portal/files/7516934/2016_Weiser_Thesis_SecureIO_SGX.pdf`.