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CYBER SECURITY IN THE AGE OF LARGE-SCALE ADVERSARIES

Forking Attacks on SGX Applications are Real

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RUHR UNIVERSITÄT BOCHUM RUB

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HORST GÖRTZ INSTITUT

TALK OUTLINE

CYBER SECURITY IN THE AGE OF LARGE-SCALE ADVERSARIES

1. Introduction
2. Forking Attacks & Mitigations
3. Study
4. Discussion
5. Summary & Outlook

ABOUT ME

- Annika Wilde

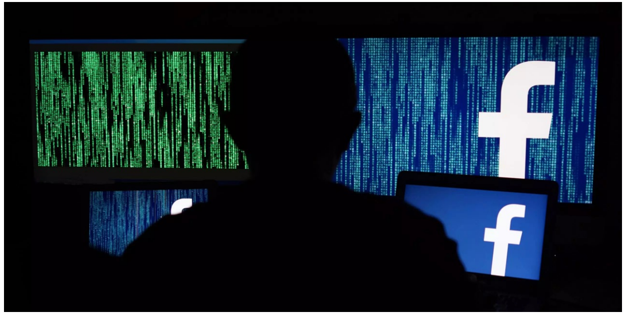
- Chair for Information Security at Ruhr-University Bochum
- PhD student since October 2022

- Research:
  - Platform Security
  - Trusted Execution Environments (SGX, Keystone)

CLOUD COMPUTING

Facebook hack April 2021 [1]

- Database exposed in plain
- 530 million users affected



➔ Trusted Execution Environments (TEE)

- ARM TrustZone (Samsung, Huawei, …)
- Intel SGX (Signal, …)

[1] https://about.fb.com/news/2021/04/facts-on-news-reports-about-facebook-data/

INTEL SECURE GUARD EXTENSION (SGX)

- Extension of the x86 ISA
- Hardware-based isolation for trusted code – *enclaves*
- Trusted runtime memory
- Sealing: persist enclave state across enclave restarts
    - Encrypt data with a platform-specific key
- Attestation: verifiable certificate of enclave code + platform

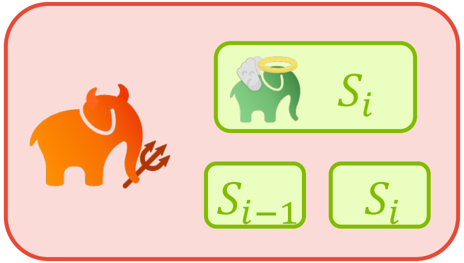
Forking Attacks & Mitigations

FORKING ATTACKS

Rollback

Problem:

Enclaves ensure the **confidentiality and integrity** of sealed data, BUT enclaves cannot verify **freshness**



FORKING ATTACKS

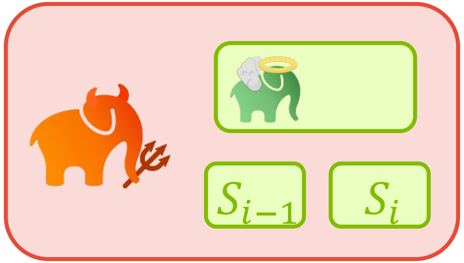
Rollback

Problem:

Enclaves ensure the **confidentiality and integrity** of sealed data, BUT enclaves cannot verify **freshness**

Attack:

1. The attacker terminates the enclave



FORKING ATTACKS

Rollback

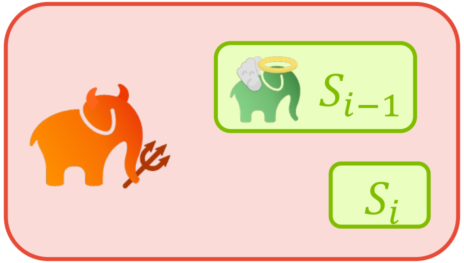
Problem:

Enclaves ensure the **confidentiality and integrity** of sealed data, BUT enclave cannot verify **freshness**

Attack:

1. The attacker terminates the enclave
2. The attacker provides a stale state

➔ The enclave initializes to a stale state



FORKING ATTACKS

Cloning

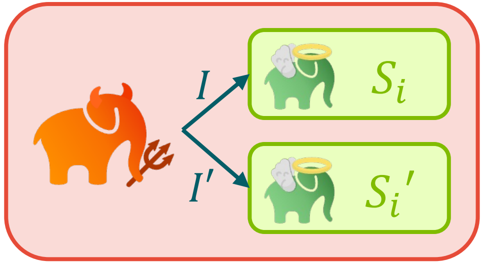
Problem:

Enclaves cannot determine the **number of instances** running on a machine

Attack:

1. The attacker launches n instances of the enclave
2. The enclaves have the same ID
3. The attacker provides different inputs

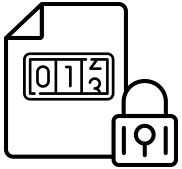
➔ Diverging enclave states



FORKING MITIGATIONS

Monotonic Counters

- Counter strictly increasing



Rollback:
- Sealing: increase MC + seal it
- Unsealing: verify sealed MC

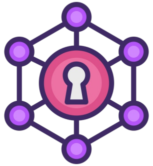
Cloning:
- Increase MC on enclave start
- Periodically check MC value

Trusted Third Party

- External party tracking the enclave state

Distributed Systems

- Distributed system tracking state
- Components secure each other's state
- Fault tolerance mechanisms



FORKING MITIGATIONS

CloneBuster [2]

- Use cache as a covert channel
- Enclaves self-detect if they are cloned

- No rollback protection
- Cloning protection without TTP

➔ Secure enclaves that do not seal state

[2] No Forking Way: Detecting Cloning Attacks on Intel SGX Applications, Briongos *et al.*, 2023

FORKING MITIGATIONS

CloneBuster [2]

19%
SGX-based applications are vulnerable to cloning attacks

[2] No Forking Way: Detecting Cloning Attacks on Intel SGX Applications, Briongos *et al.*, 2023

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Study

Impact of Cloning Attacks

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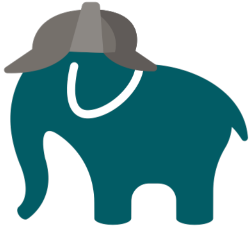
Research question:

How big is the impact of cloning attacks?



COLLECTION OF APPLICATIONS

- sgx-papers [3]
- Awesome SGX Open Source Projects [4]

Excluding:
- Libraries
- Runtime frameworks
- Projects without design documentation

[3] https://github.com/vschiavoni/sgx-papers
[4] https://github.com/Maxul/Awesome-SGX-Open-Source

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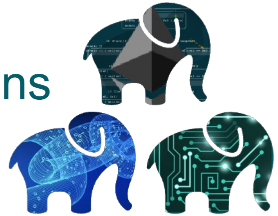
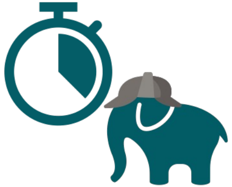
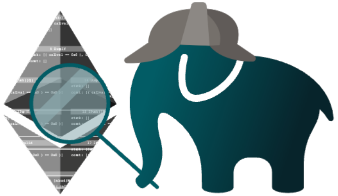
APPLICATION ANALYSIS

72 applications



~ 2 hours per application





Manual investigation

150 hours in total

APPLICATION ANALYSIS

Example

Application:

- Aria [5]
- IEEE ICDE 2021
- In-memory KVS
- Encrypted storage
- Enclave manages encryption keys

Analysis:

1. Is source code available? → No
2. Is the application vulnerable to rollback attacks? → No
3. Is the application susceptible to cloning attacks? → Yes

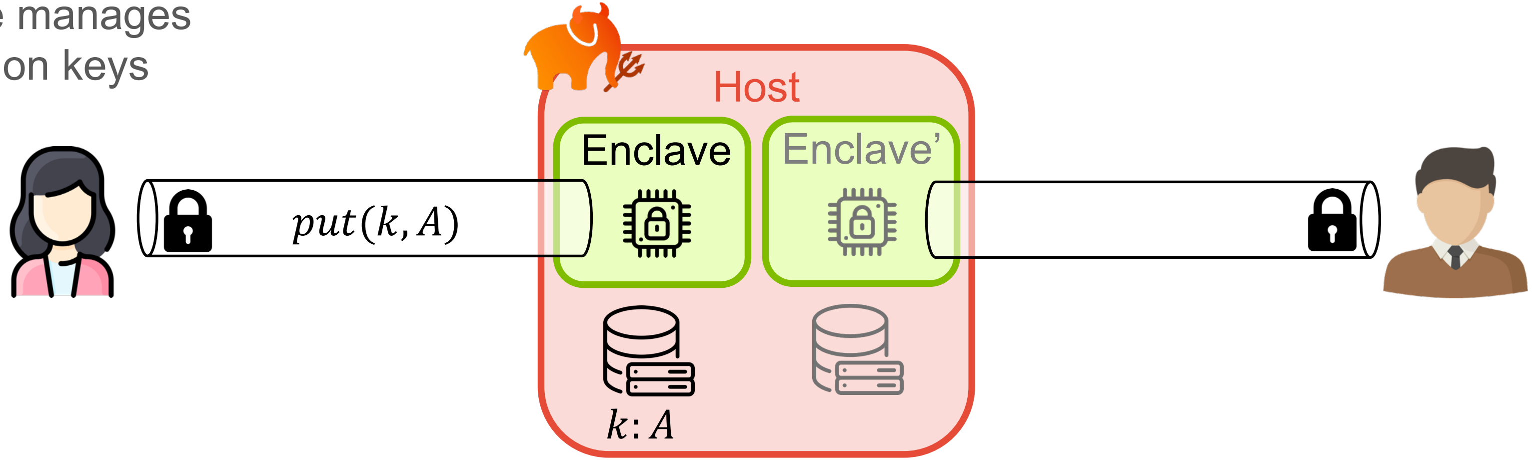
[5] Aria: Tolerating Skewed Workloads in Secure In-memory Key-value Stores, Yang *et al.*, 2021

APPLICATION ANALYSIS

Exemplary Attack

Aria [5]

- In-memory KVS
- Encrypted storage
- Enclave manages encryption keys



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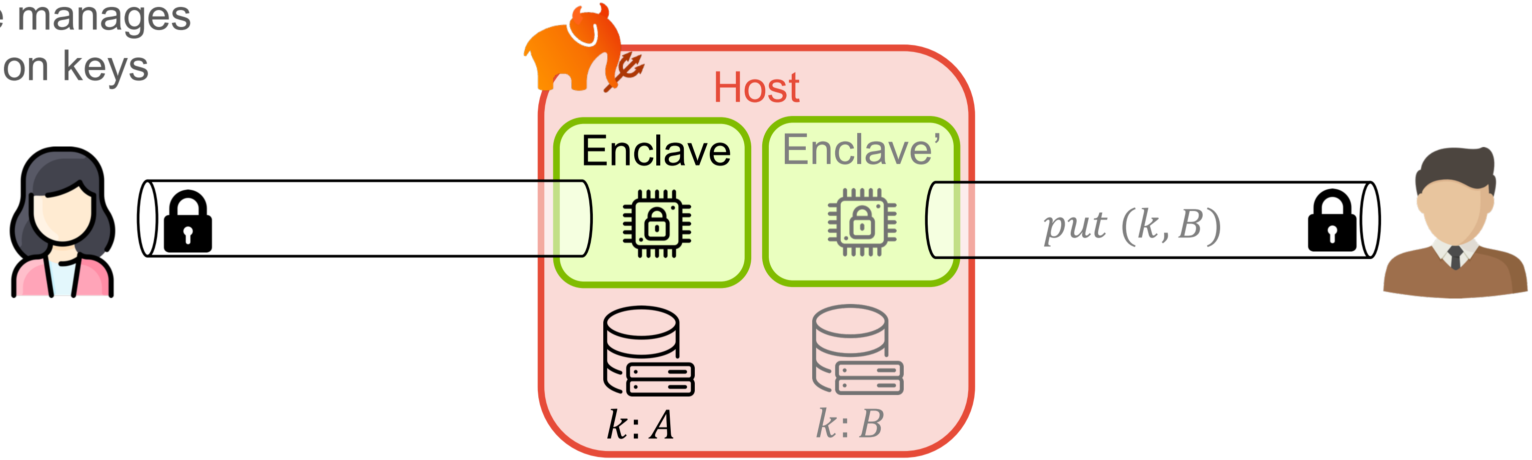

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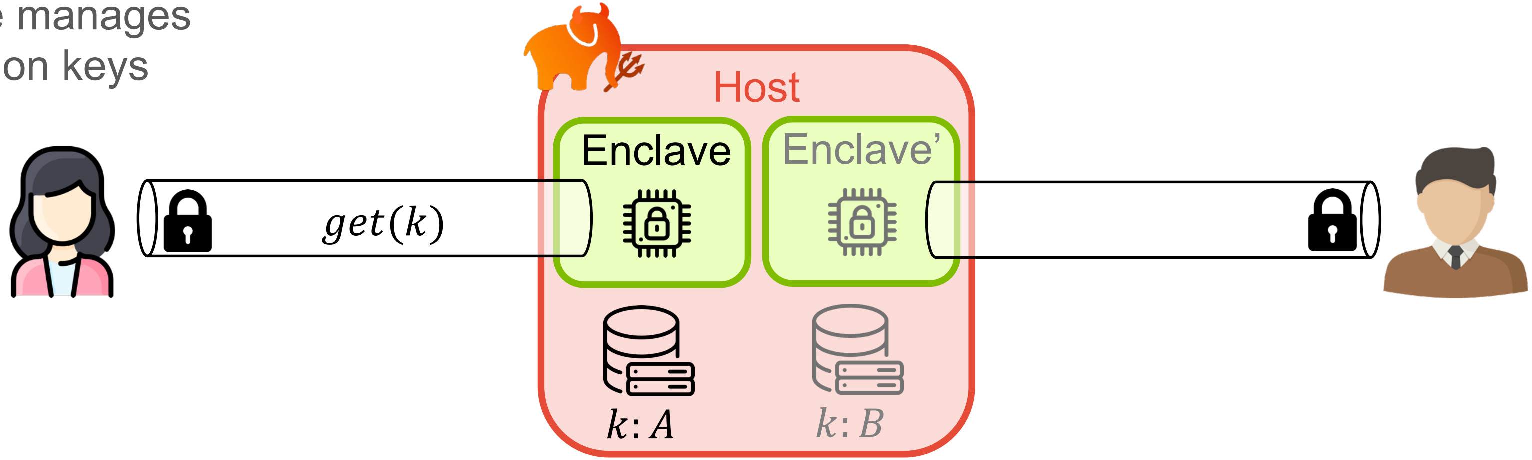

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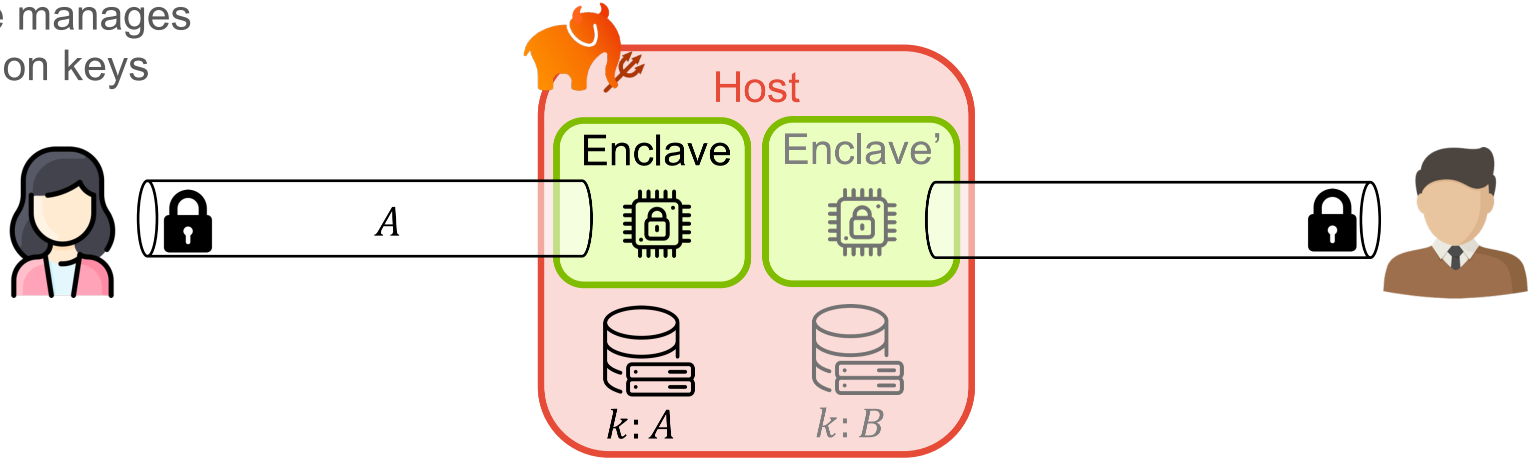

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CHALLENGES

- Ambiguous design documentation
  - How exactly are forking mitigations used?
  - How is the enclave interface defined?
  - …
- Missing implementation
- Incomplete implementation
- Blockchain applications
  - Can cloning attacks circumvent consensus?

KEY OBSERVATIONS

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Observation 1: 19% of the applications are vulnerable to cloning attacks.

Observation 2: All vulnerable applications can be assigned to one of 3 attack categories.

Observation 3: Database applications are particularly vulnerable.

Observation 4: 51% of the applications lack design documentation.

Observation 5: 25% of the applications provide no source code.

Observation 6: 33% of the applications provide incomplete implementations.

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Thank you :)

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