Elasticlave:
An Efficient Memory Model for Enclaves

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NUS National University of Singapore

ETH zürich

Spatial Isolation in Intel SGX

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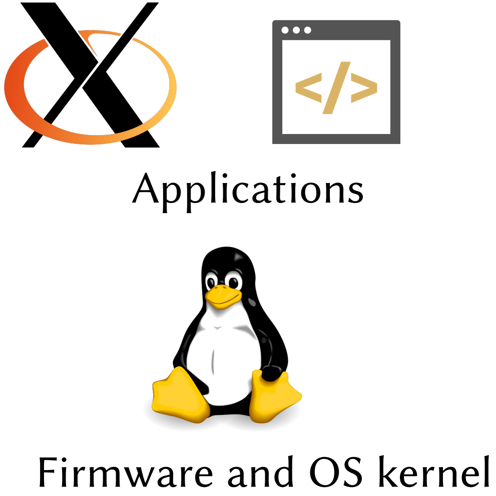
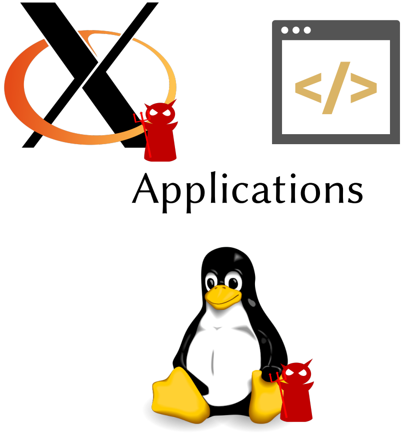


Applications

Firmware and OS kernel

Spatial Isolation in Intel SGX



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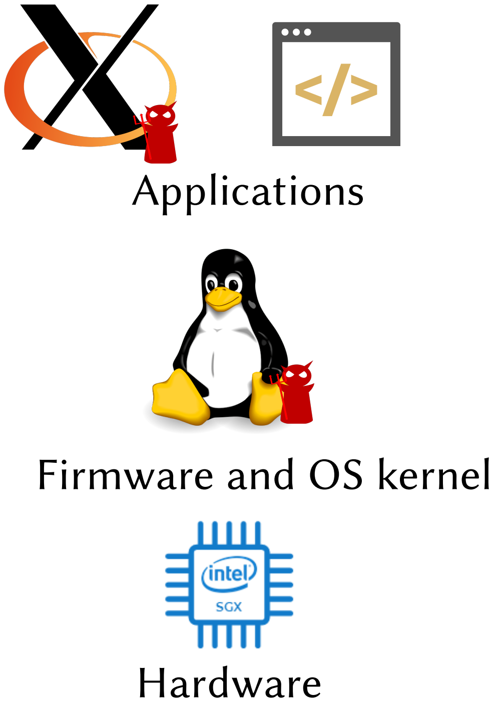

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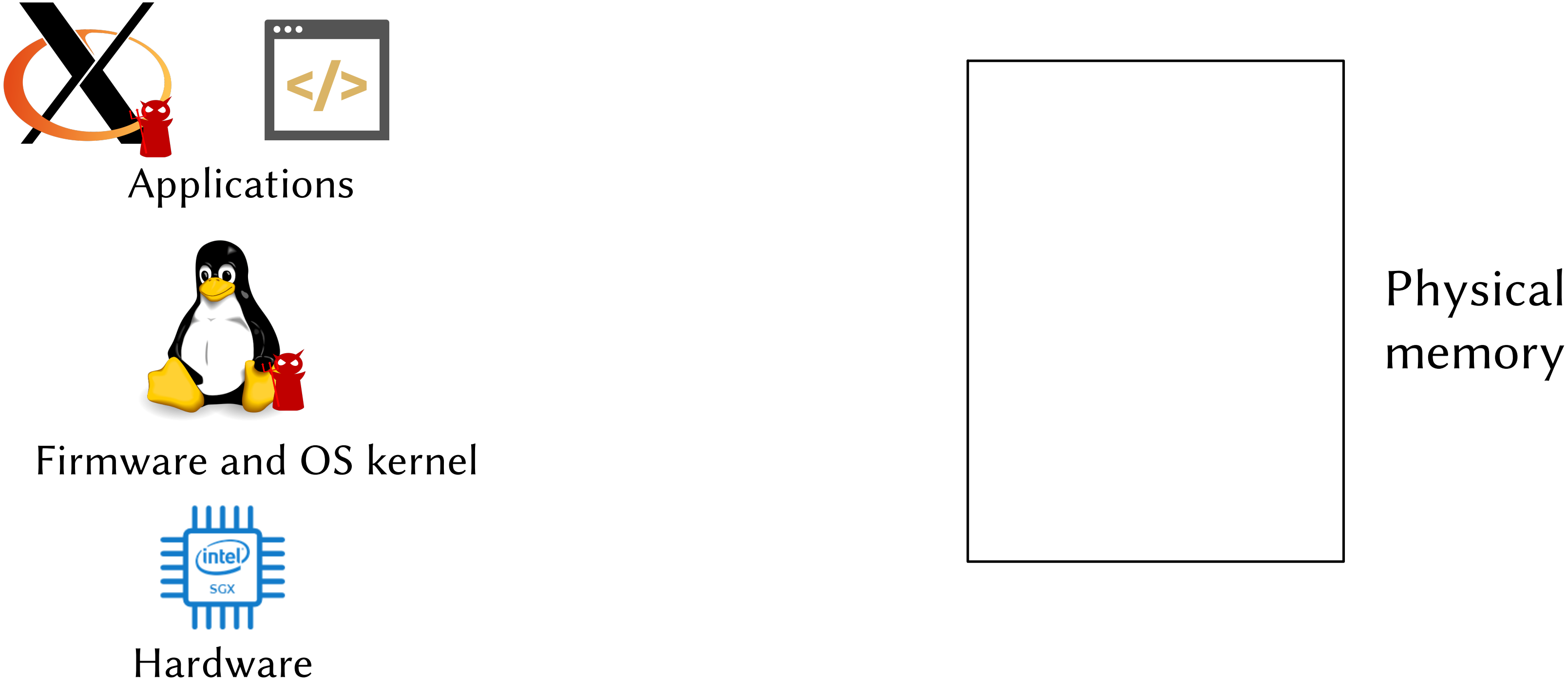

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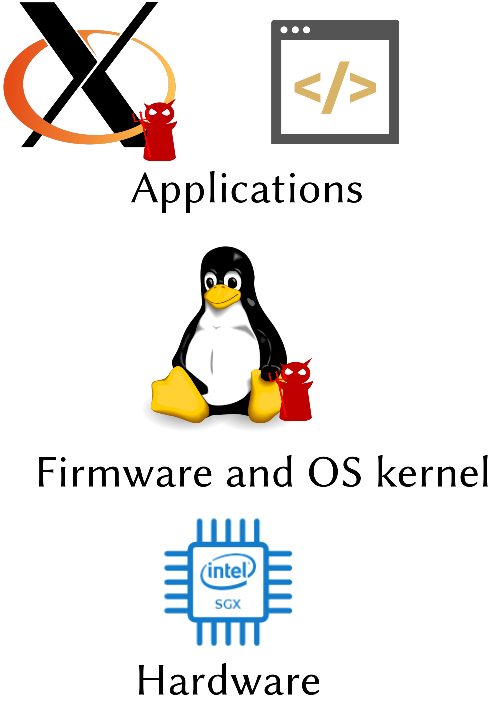

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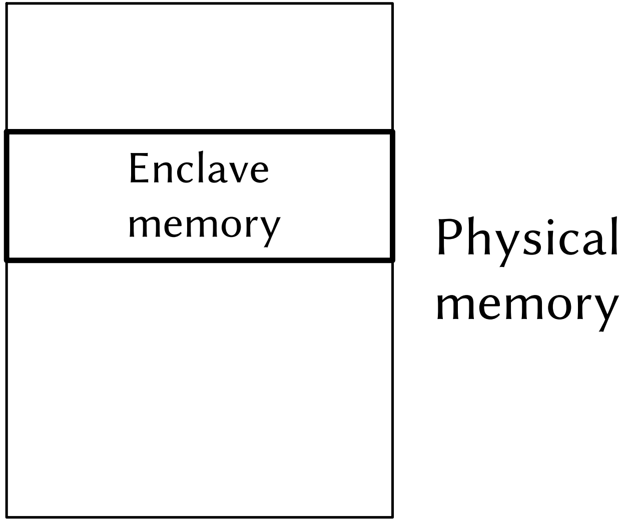
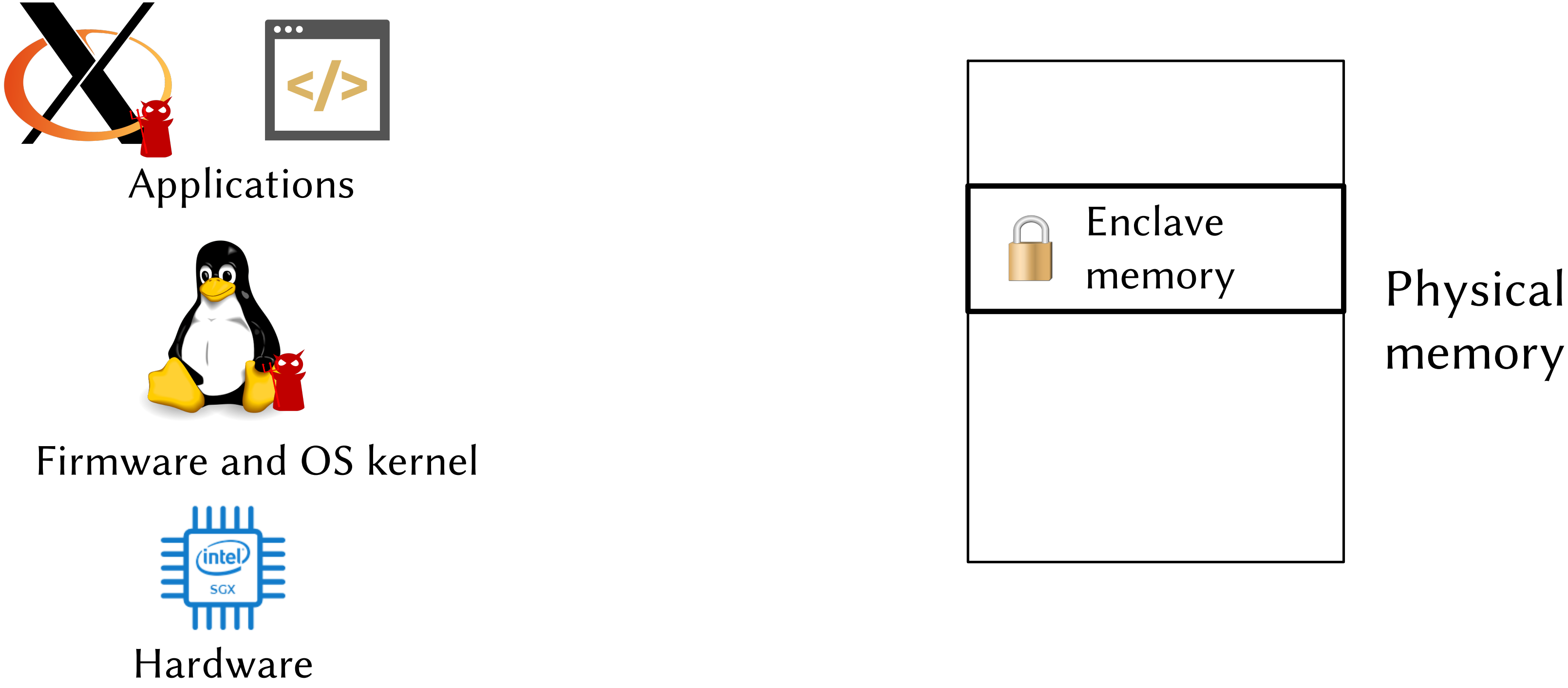


Enclave memory

Physical memory

Spatial Isolation in Intel SGX



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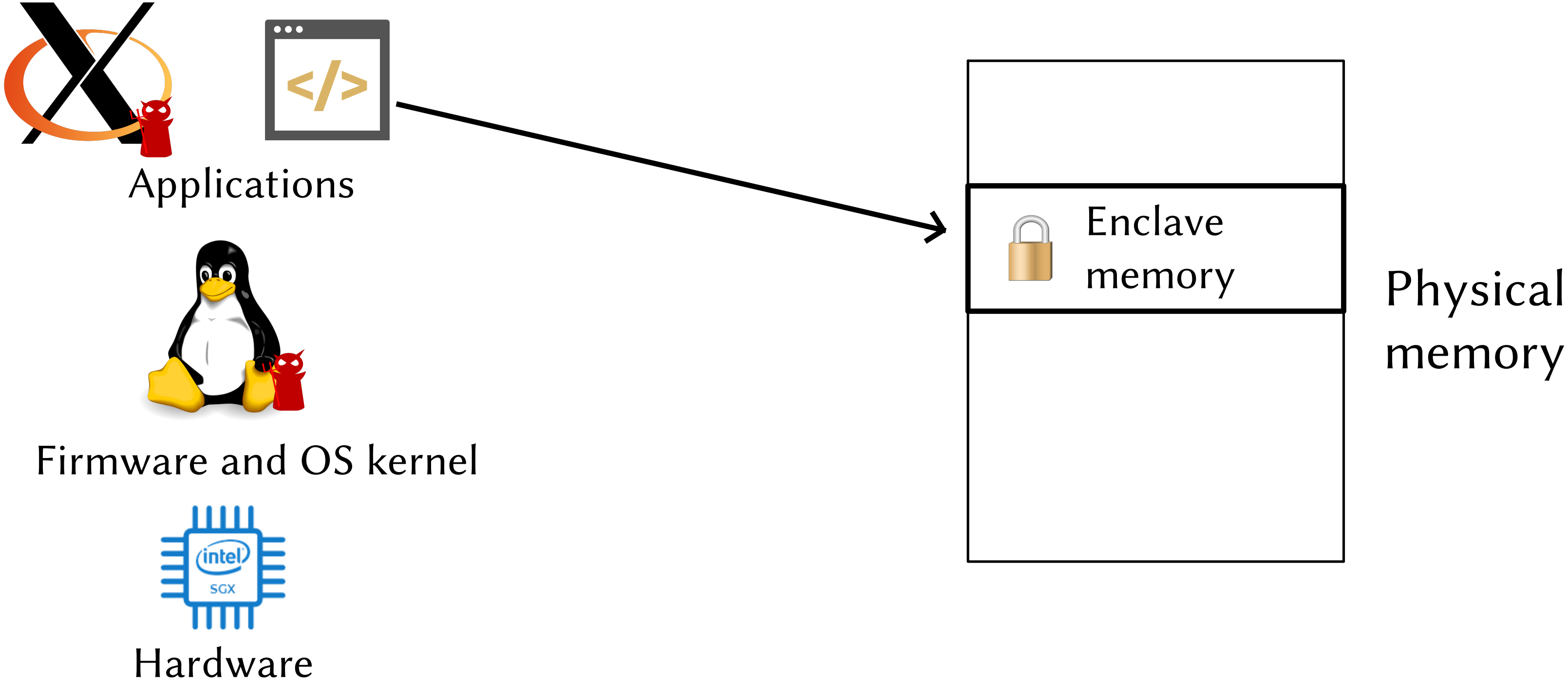

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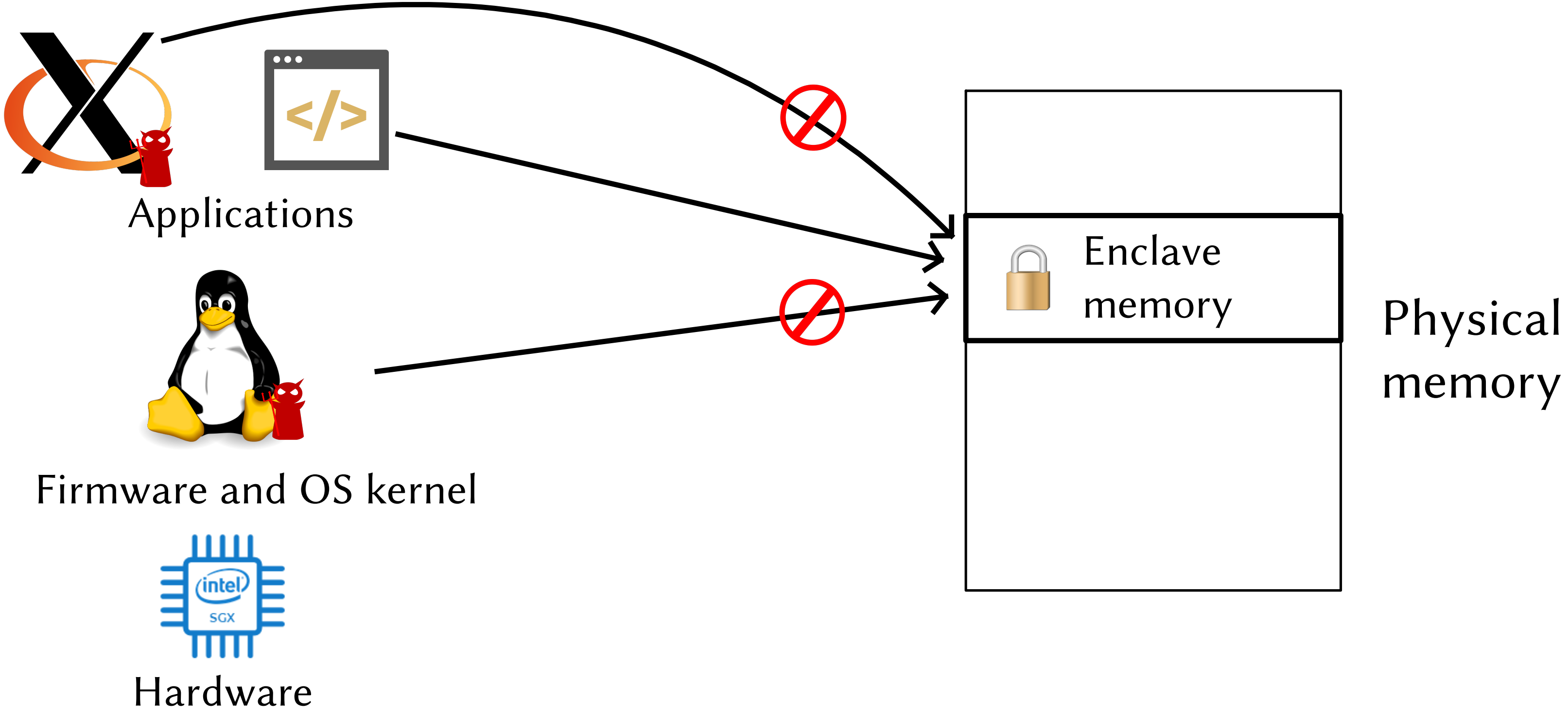

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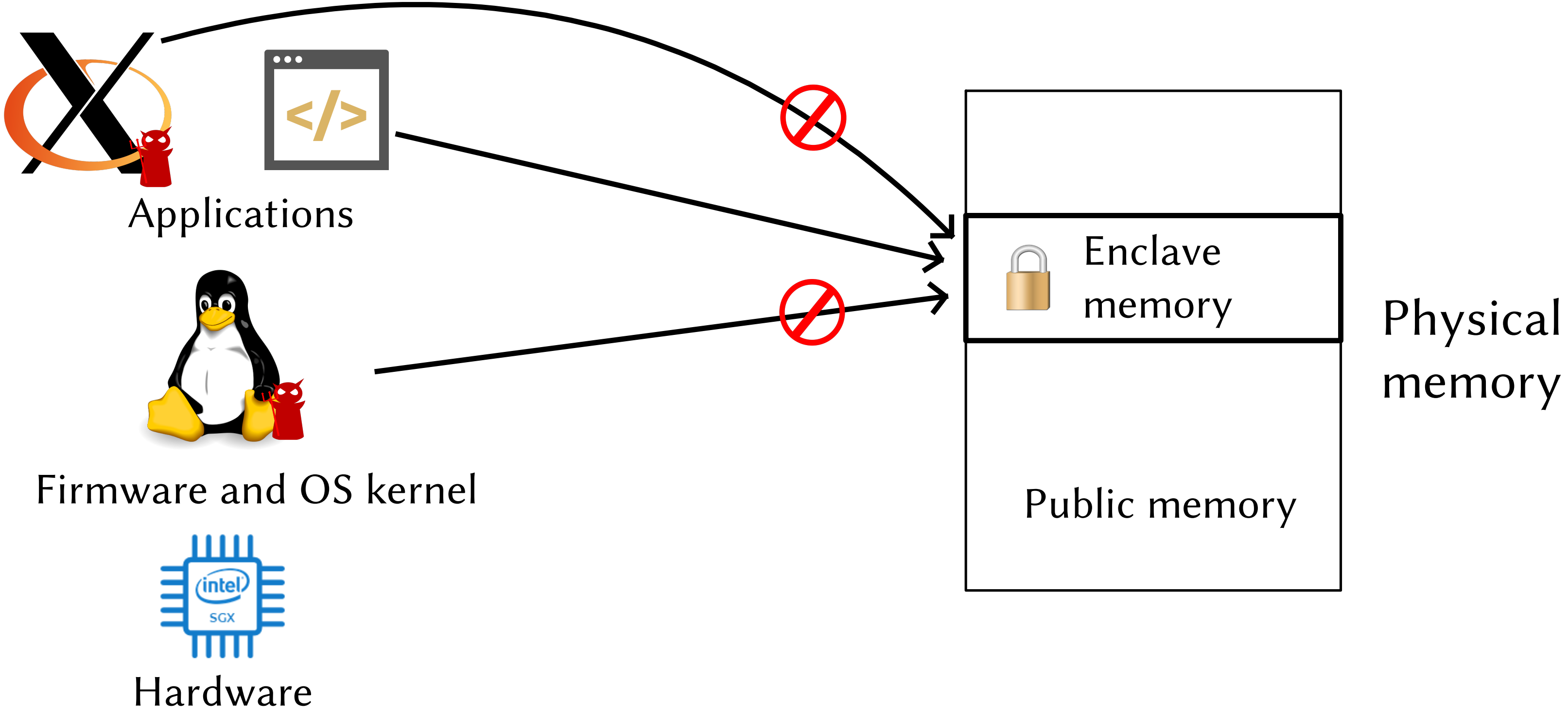

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Firmware and OS kernel

Hardware

Enclave memory

Public memory

Physical memory

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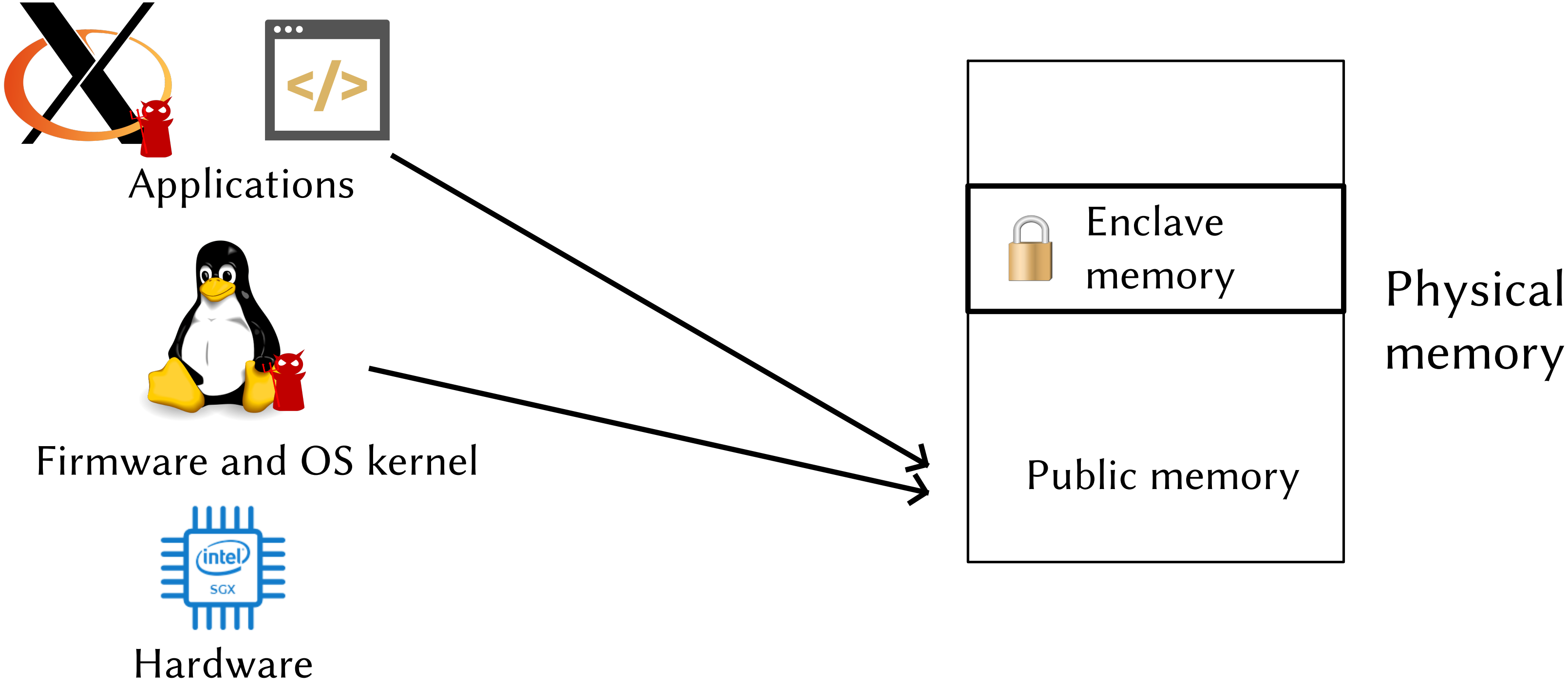

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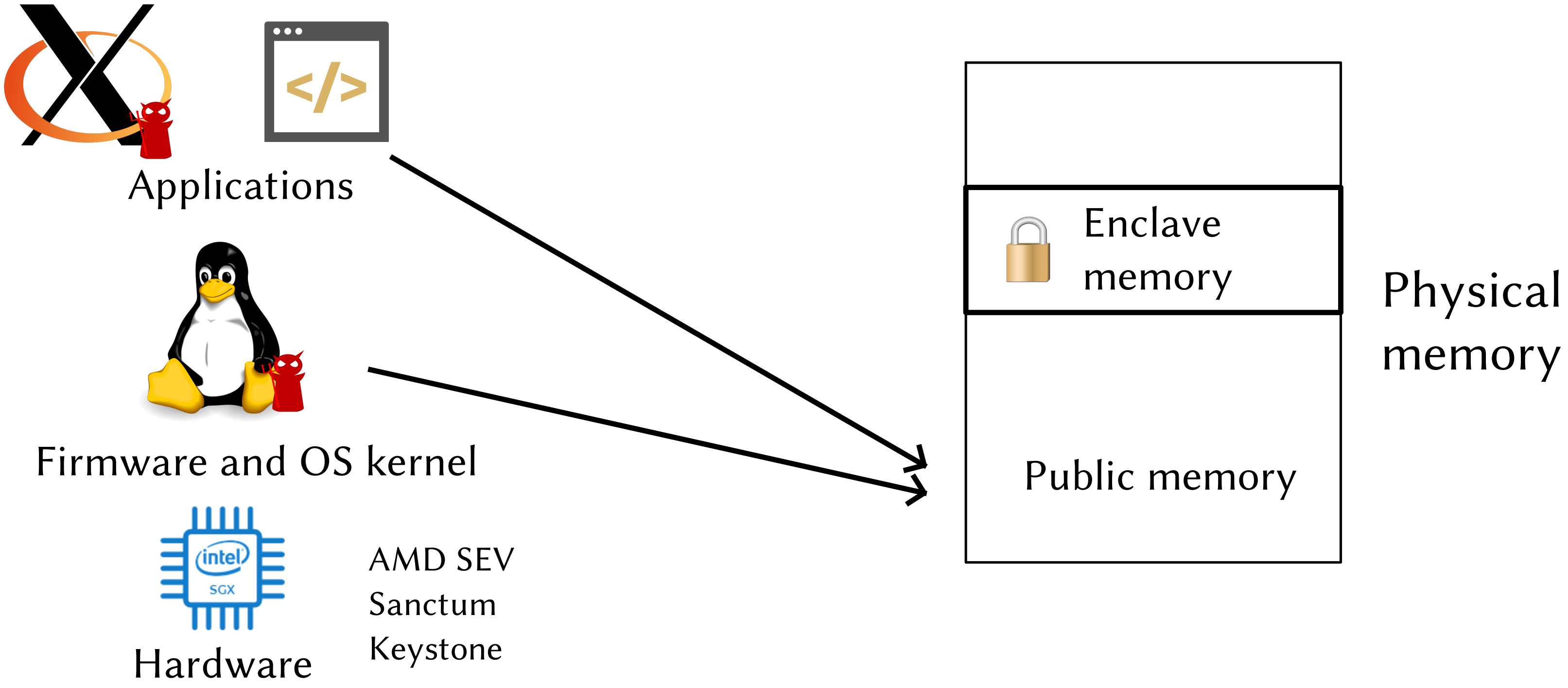

Applications

Firmware and OS kernel

Hardware

AMD SEV
Sanctum
Keystone

Enclave memory

Public memory

Physical memory

Problems due to Spatial Isolation

Limited in data sharing expressiveness

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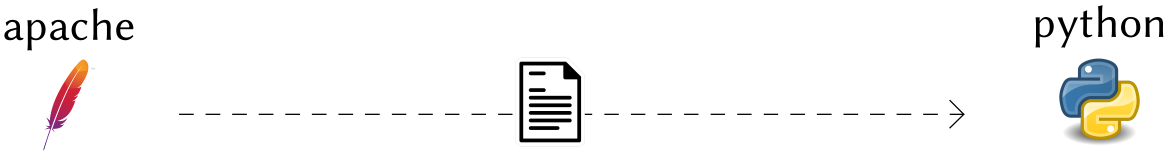

apache

python

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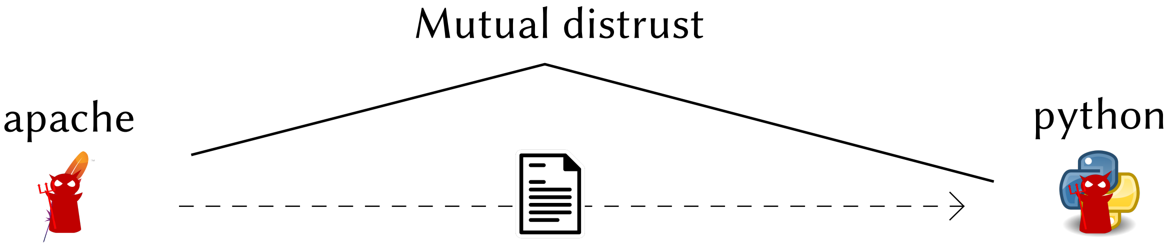

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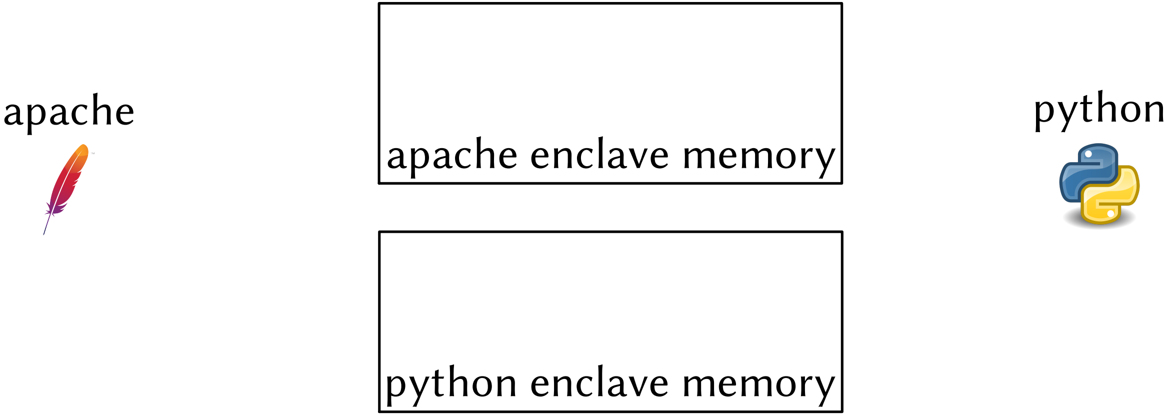

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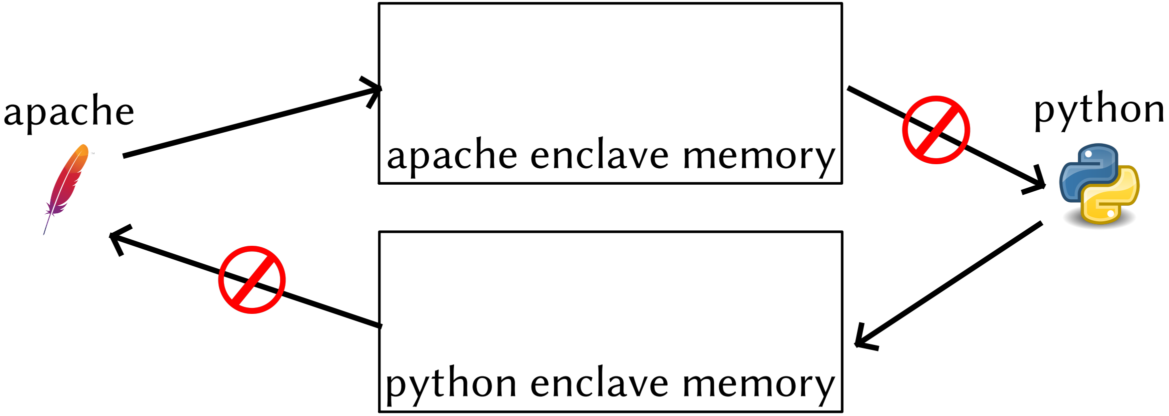

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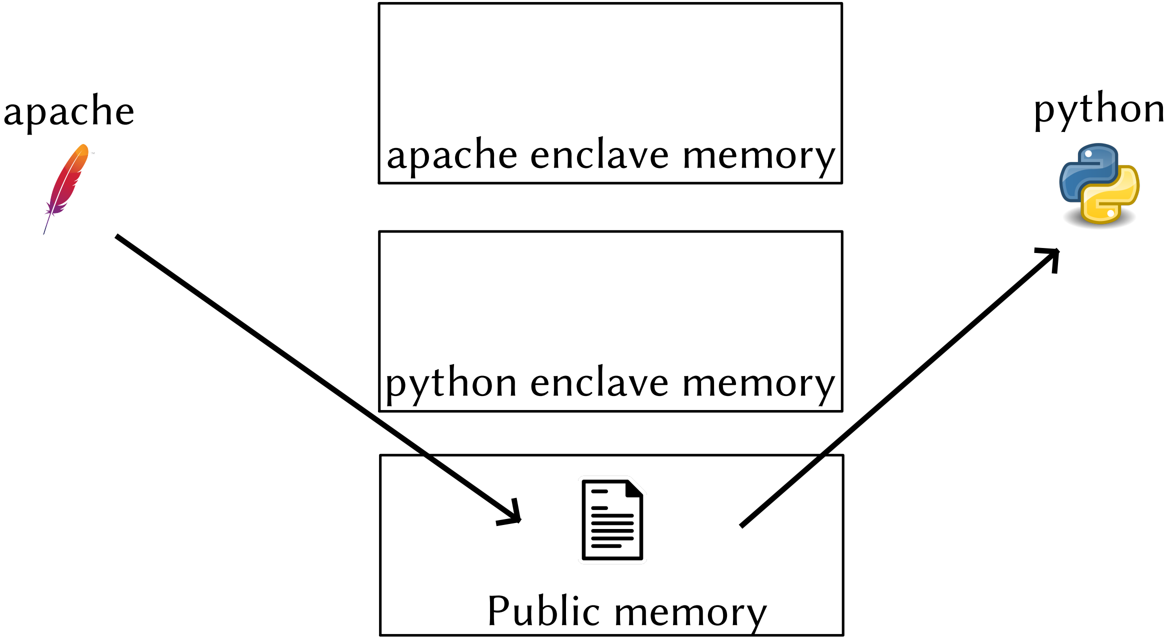

apache

apache enclave memory

python enclave memory

Public memory

python

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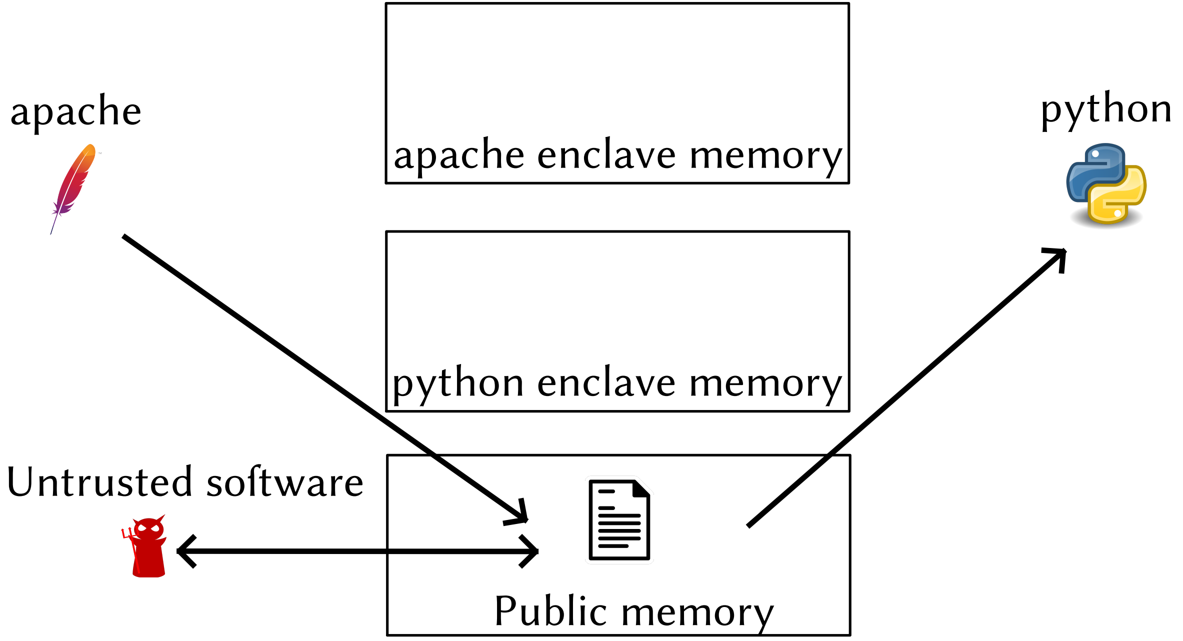

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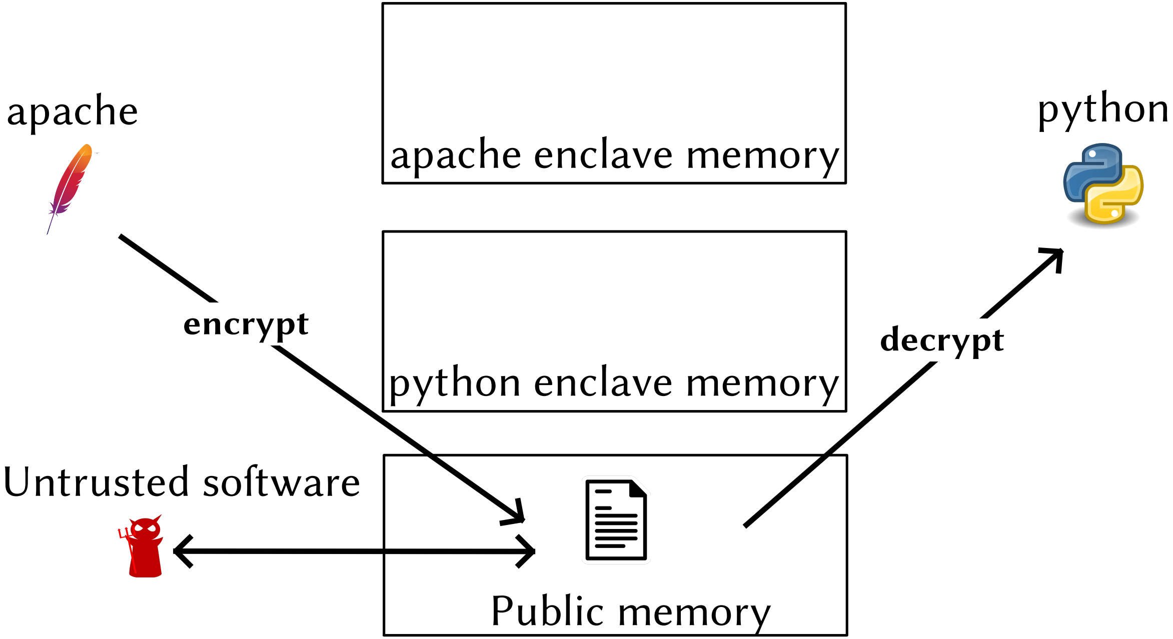

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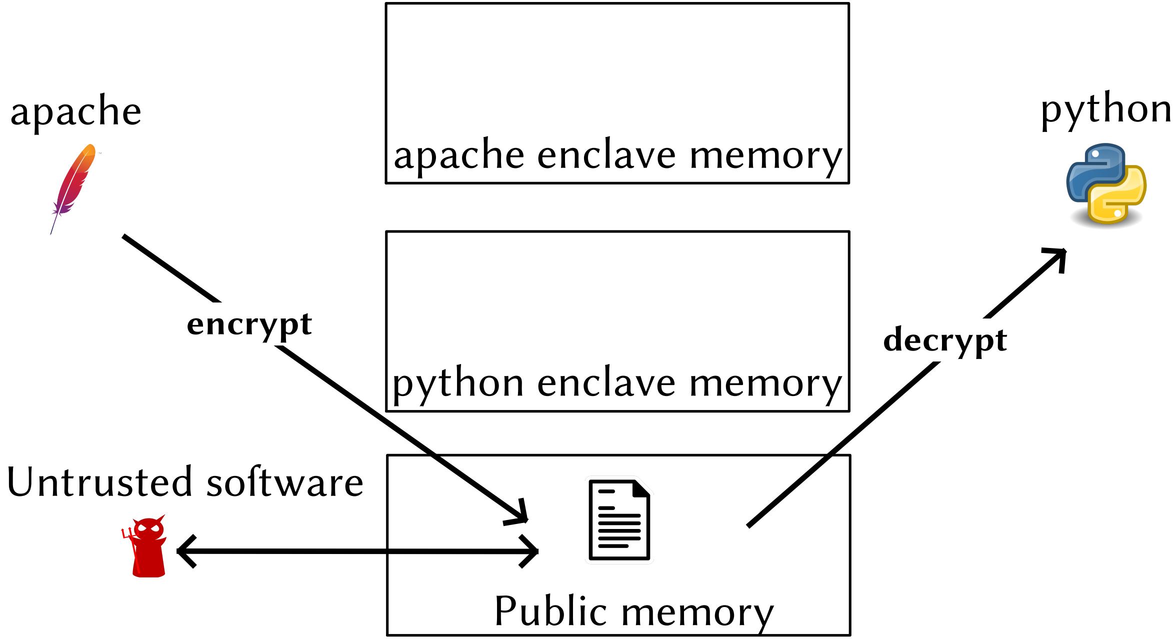

2 extra copies + encryption/decryption

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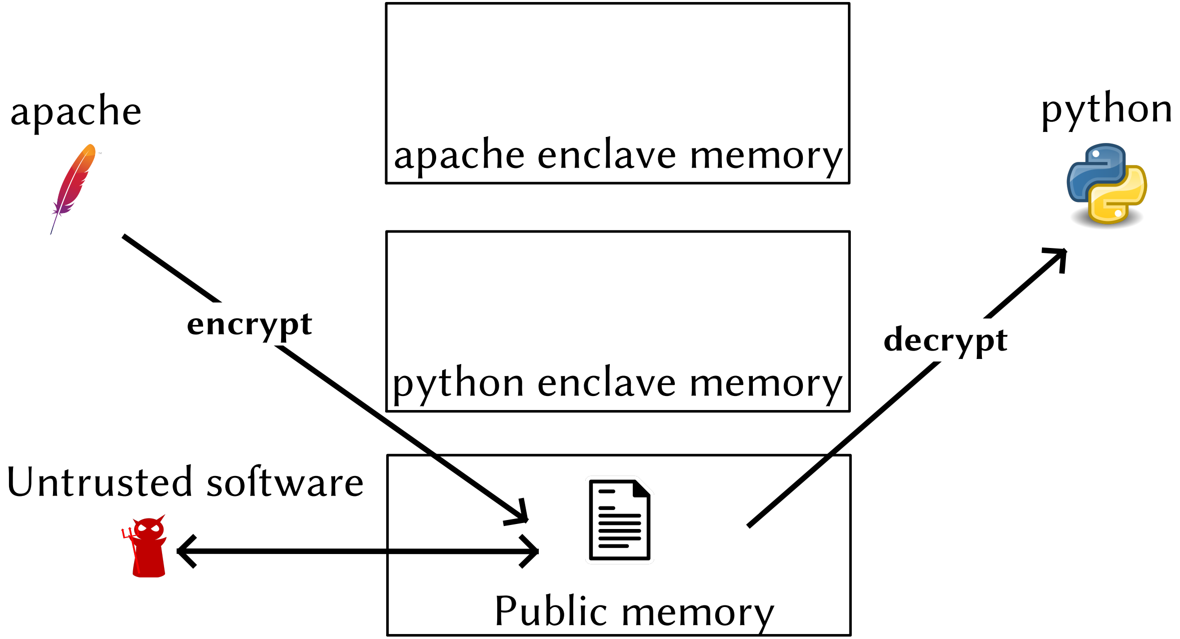


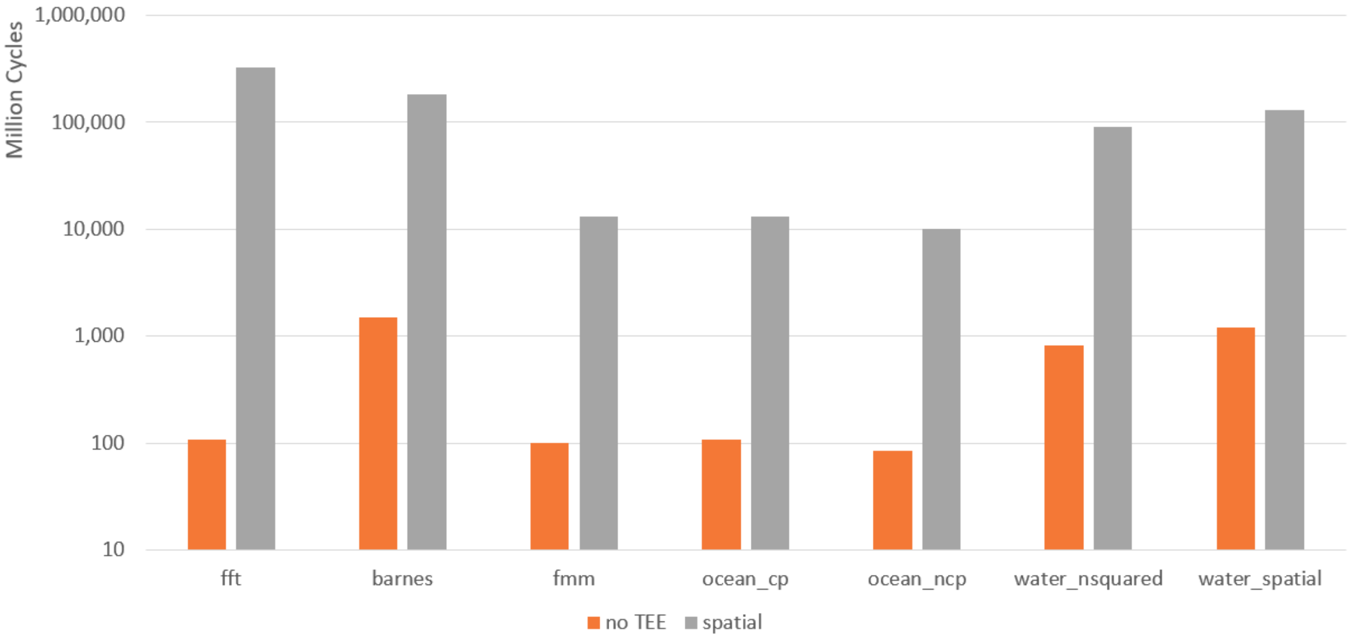
Client-server

2 extra copies + encryption/decryption

Similar in other patterns:

- Producer-consumer
- Proxy

Huge Overhead of Spatial Isolation



Contributions

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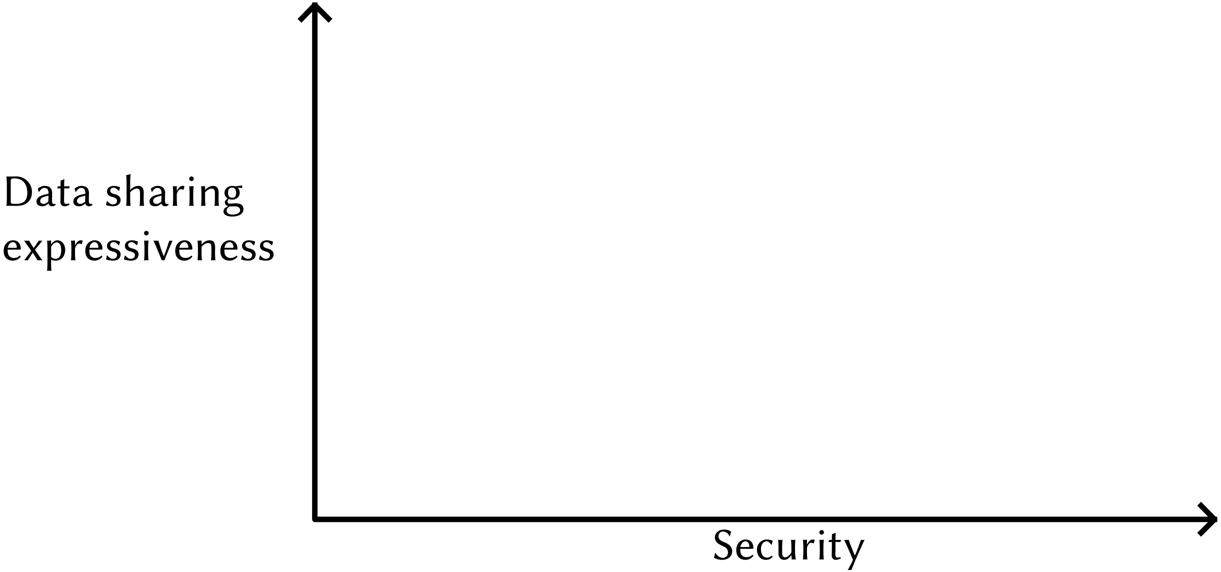

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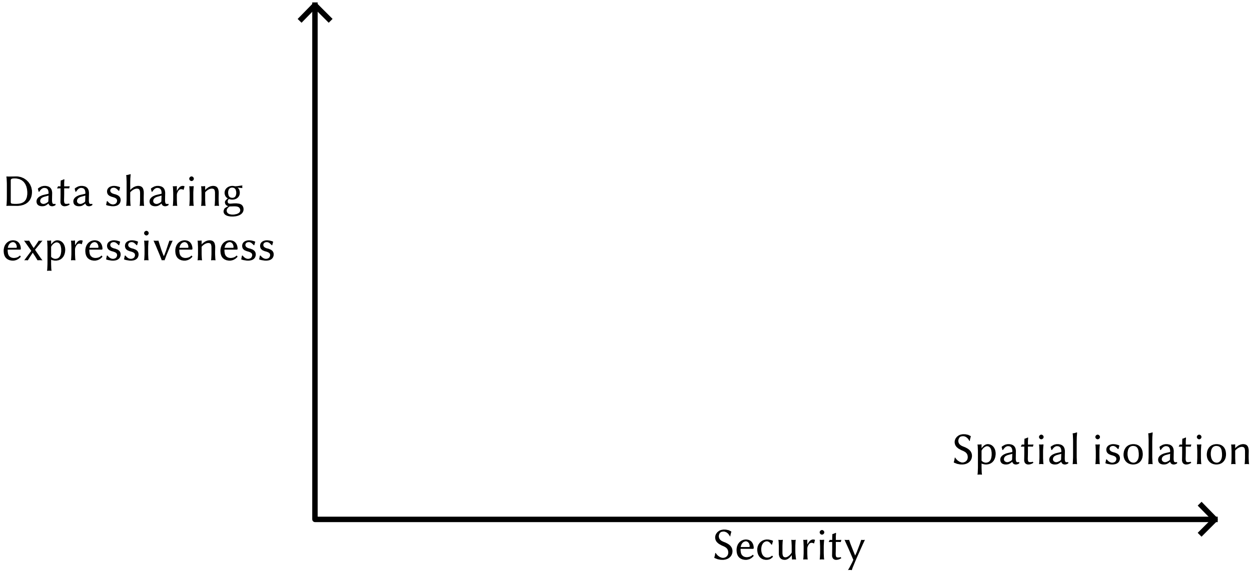

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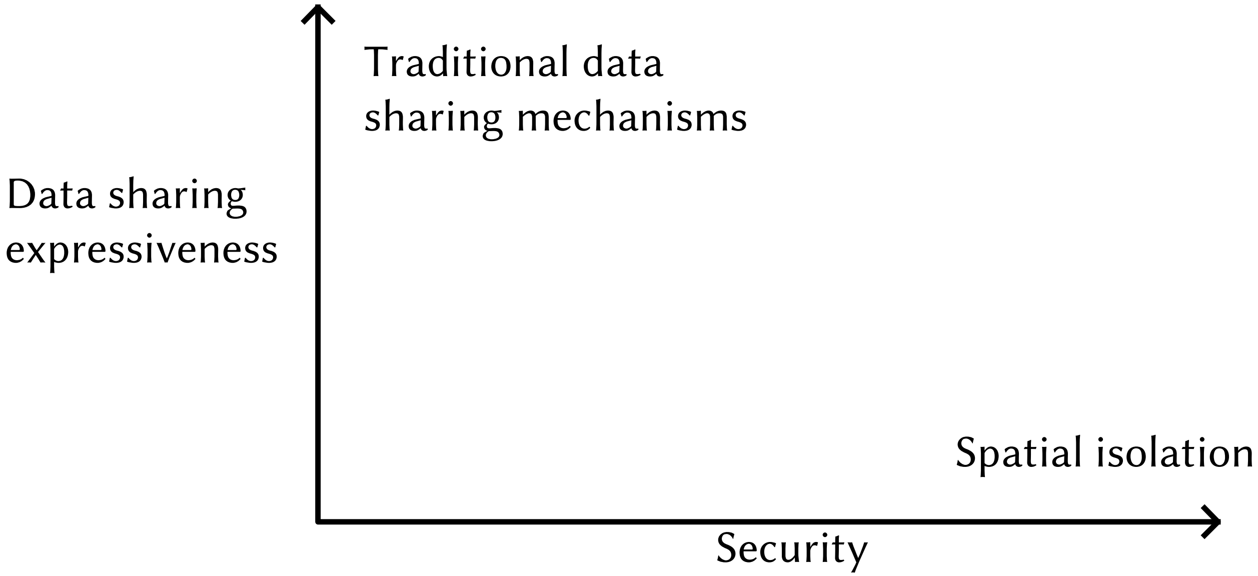


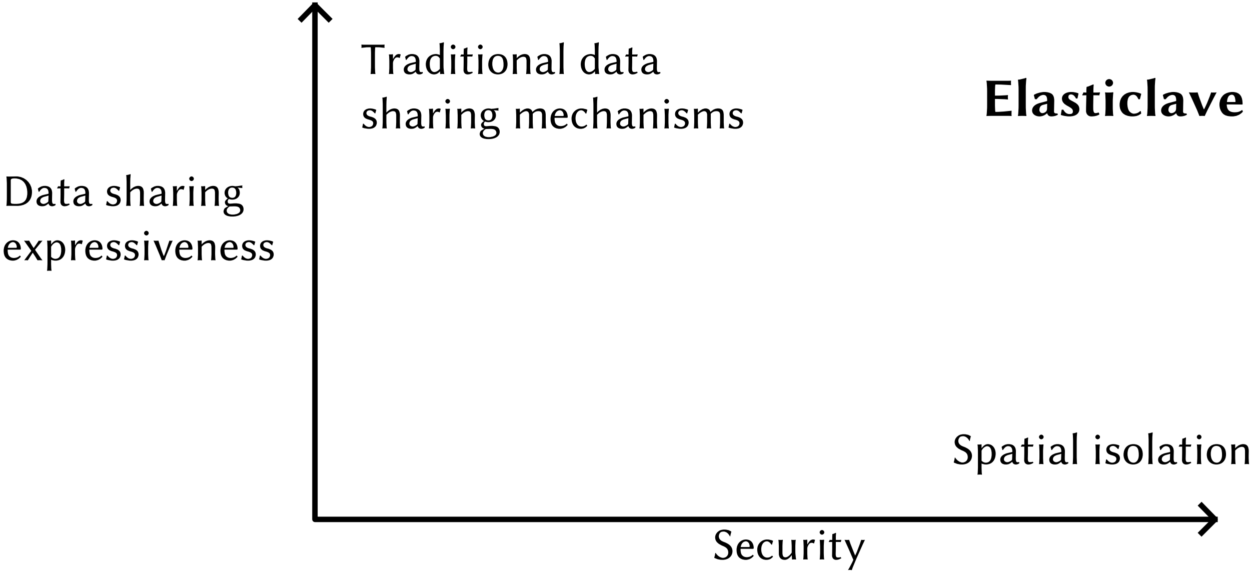
Traditional data sharing mechanisms

Data sharing expressiveness

Spatial isolation

Security

Contributions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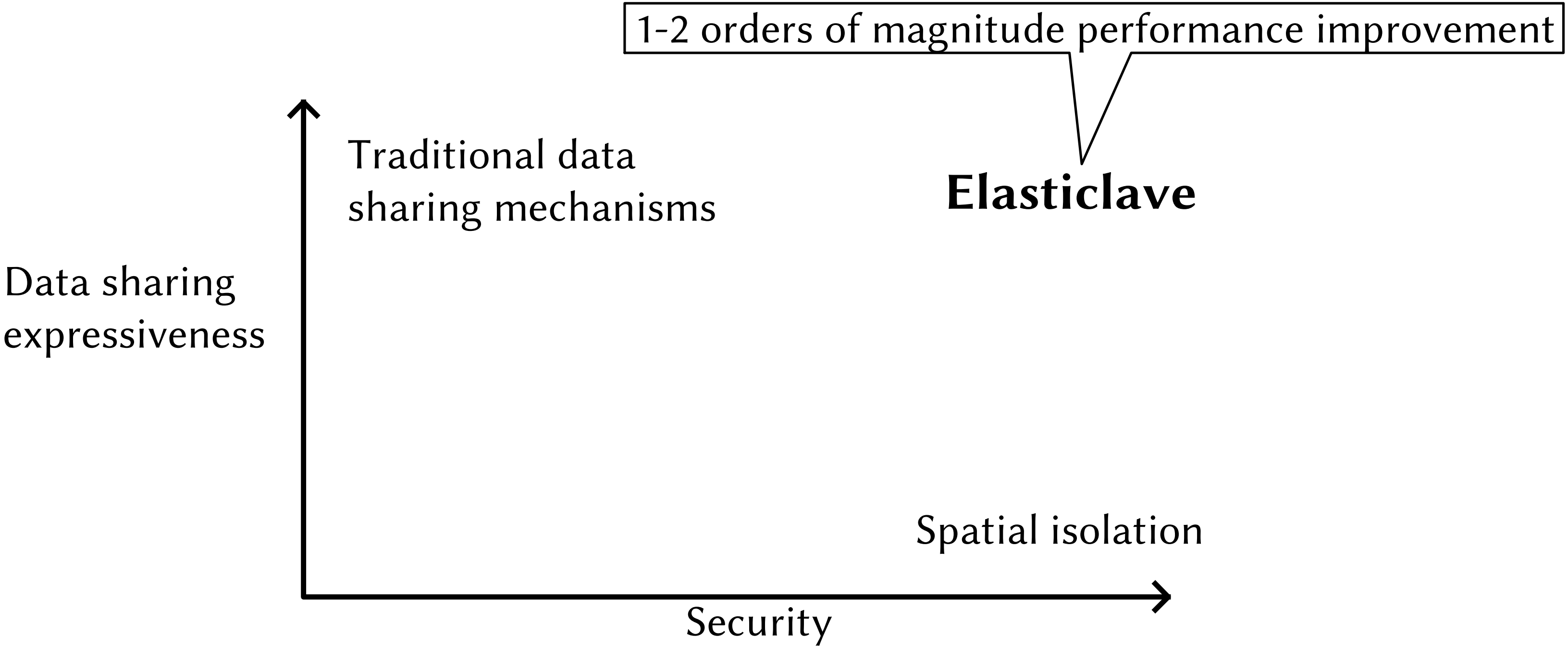

1-2 orders of magnitude performance improvement

Traditional data sharing mechanisms

Elasticlave

Data sharing expressiveness

Spatial isolation

Security

Threat Model

- Malicious OS

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- Mutually distrusting applications (compromised during runtime)

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- Malicious OS
- Mutually distrusting applications (compromised during runtime)
- DoS attacks are out of scope

Idea: Temporal Isolation

Spatial isolation: memory region is either always private or always public

Temporal isolation: different enclaves may access memory region at different times

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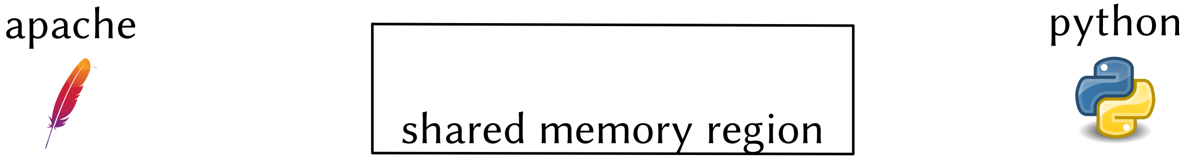

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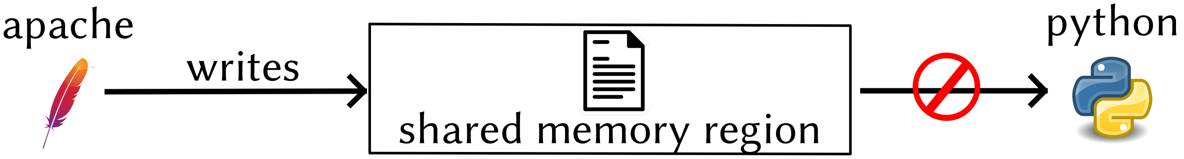

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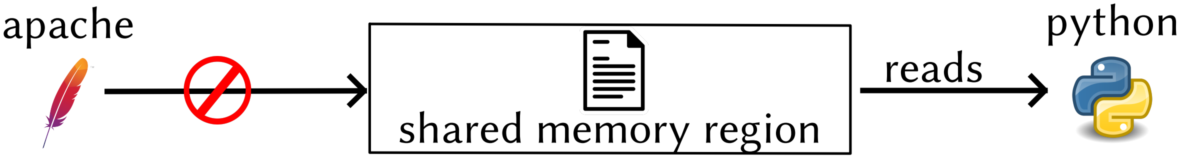

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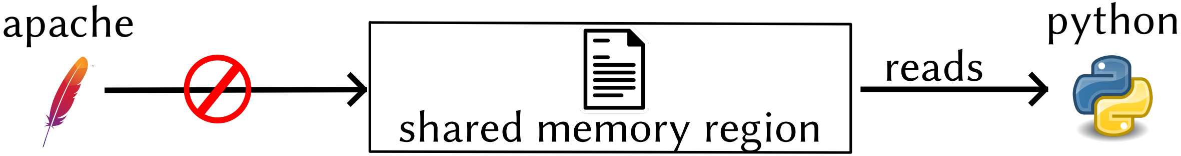

No extra copies or encryption/decryption

Temporal Isolation Challenge I

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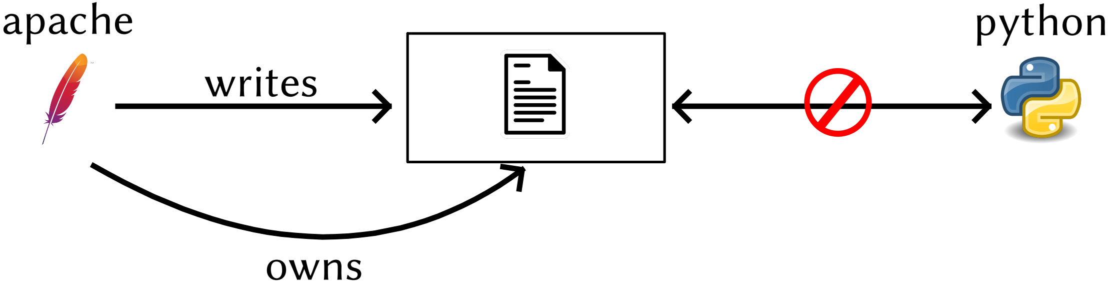

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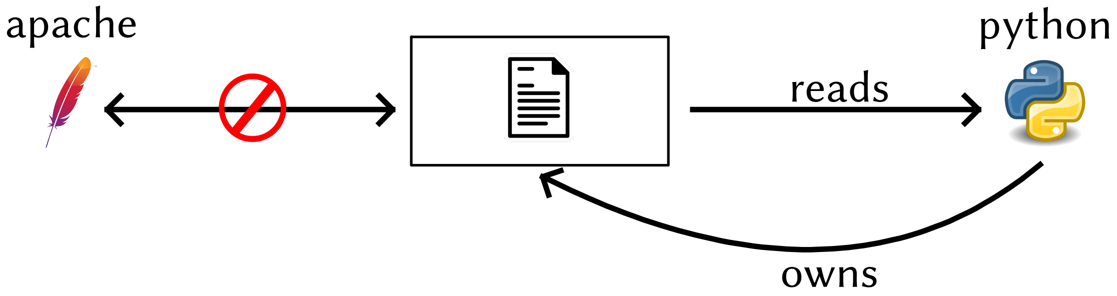

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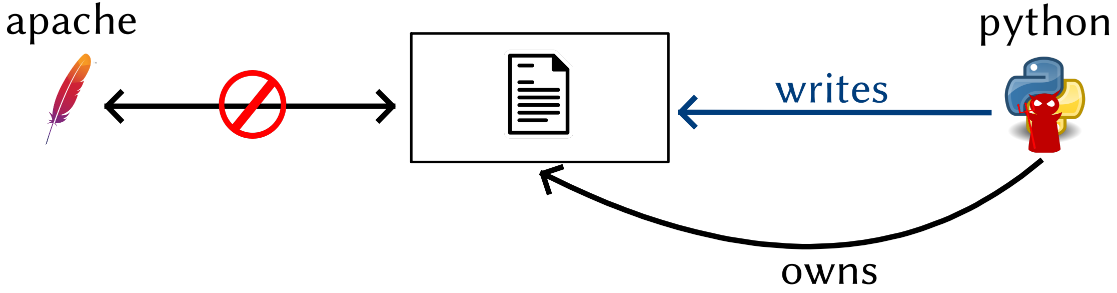

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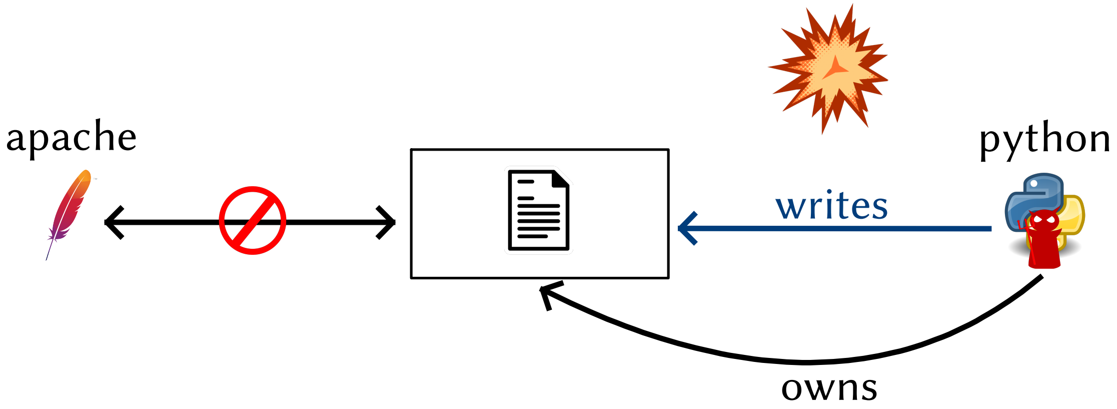

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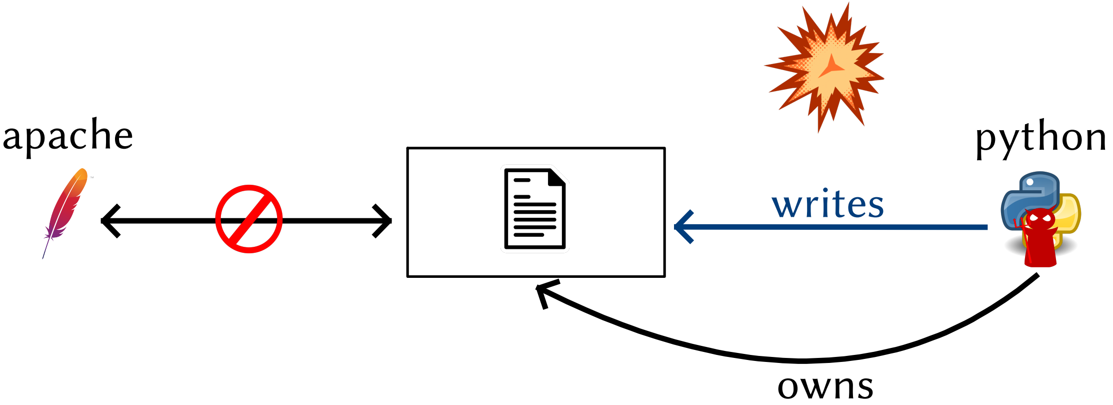

Problem: Sharer has no control over how data is accessed after sharing

How does Elasticlave solve this?

Elasticlave Design: Maximum Permissions

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~~Transferring ownership~~ fixed owner

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Owner sets *maximum permissions* for other enclaves

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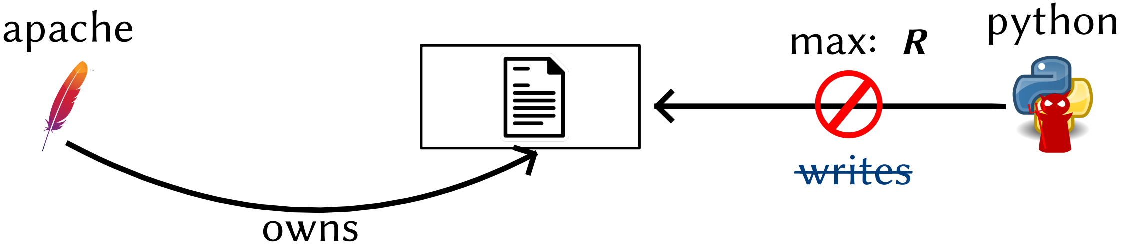

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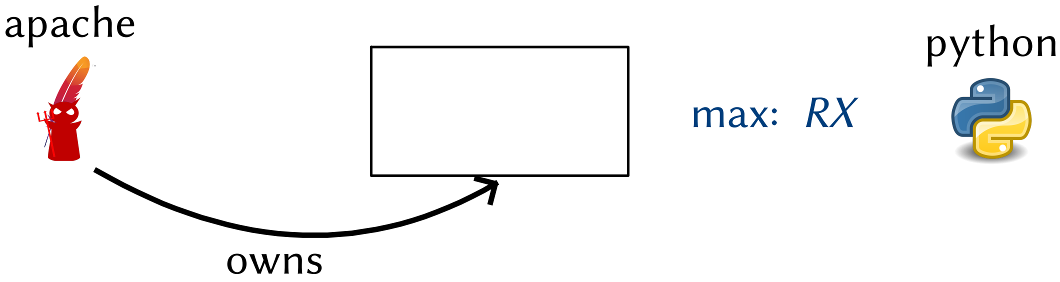


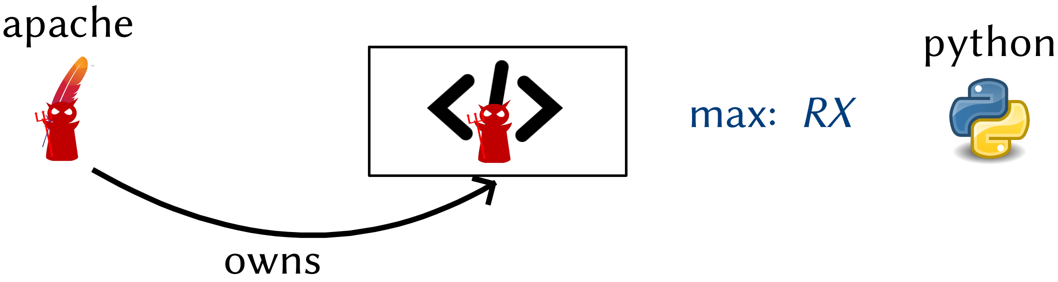
apache

owns

max: *RX*

python

Temporal Isolation Challenge II



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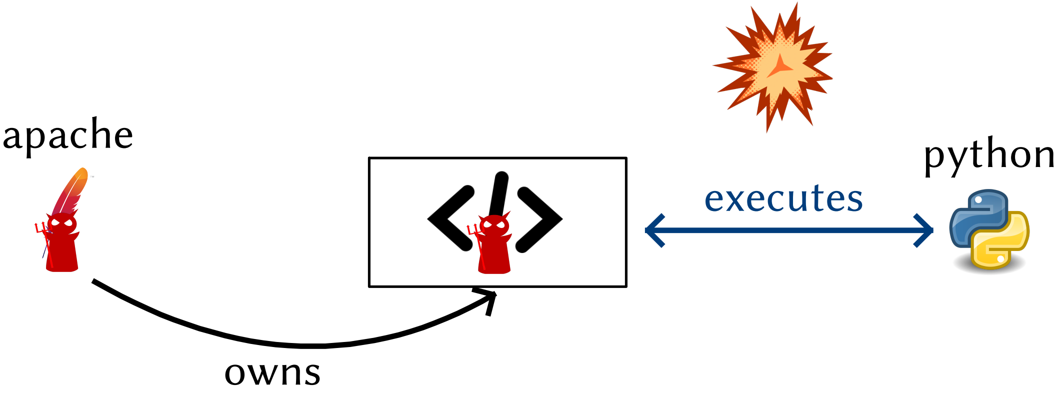

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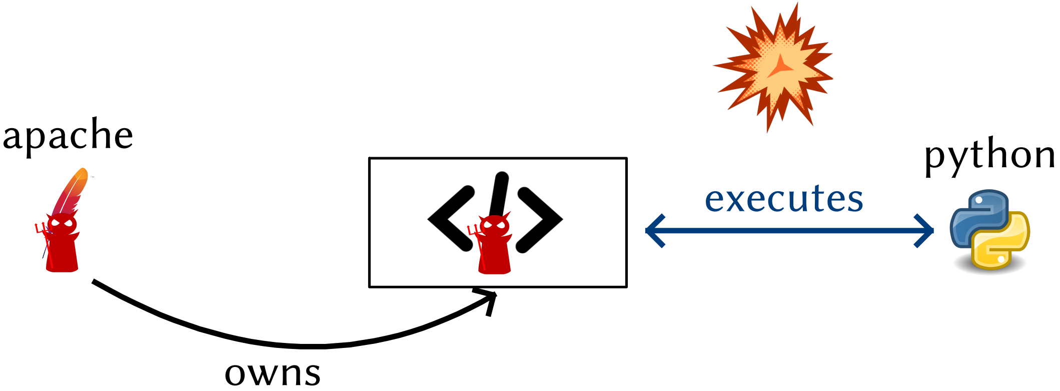

Problem: Accessors cannot enforce their own memory protection permissions

Elasticlave Design: Effective Permissions

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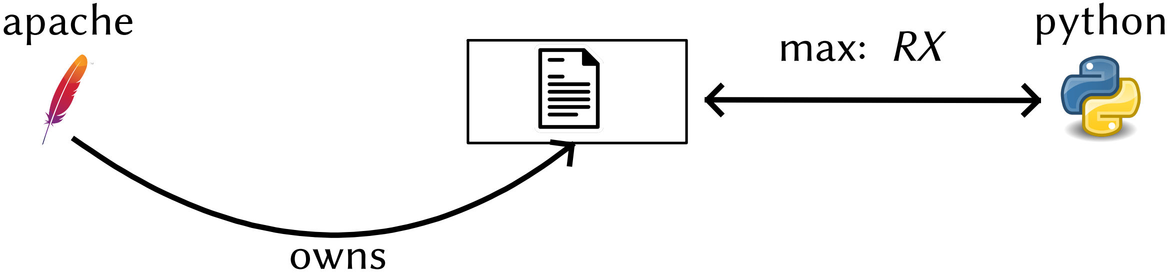

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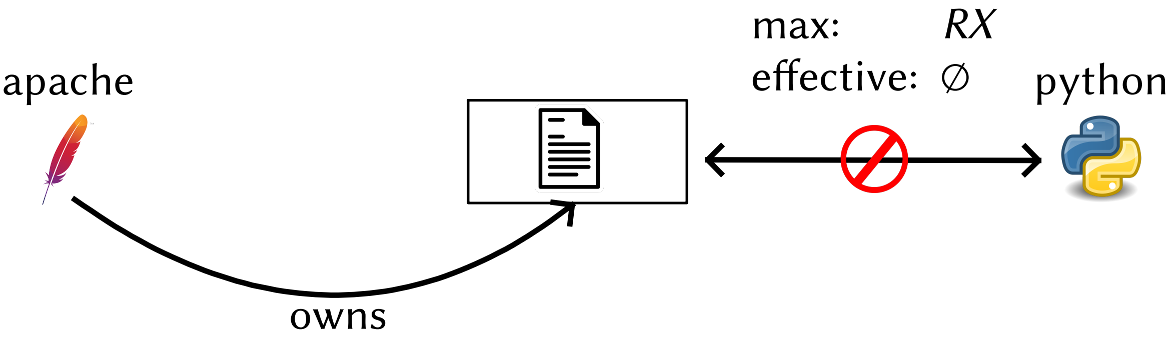
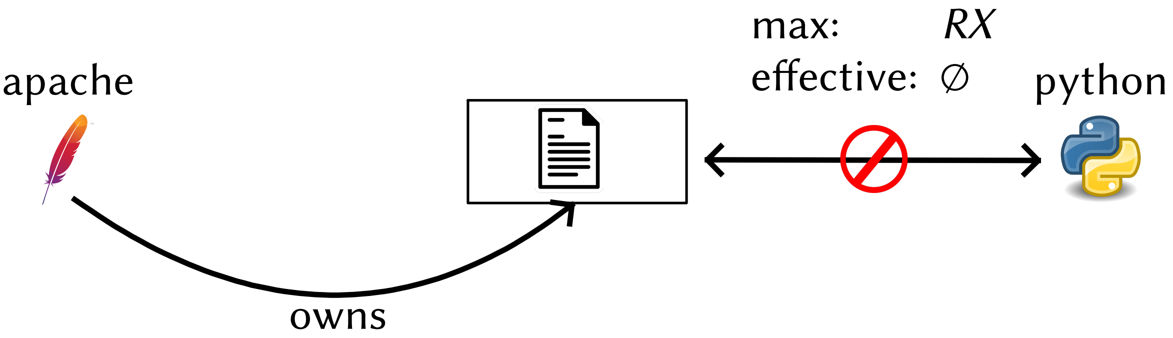


Elasticlave Design: Effective Permissions

Each enclave can request hardware to change *its own* effective permissions dynamically



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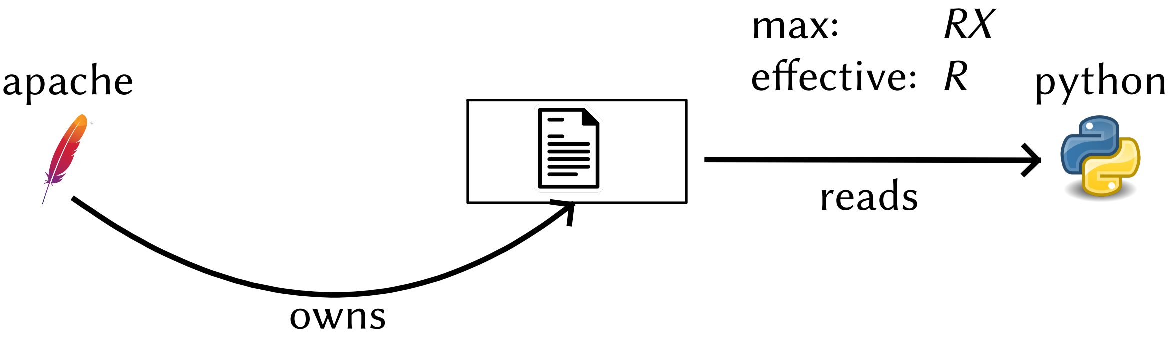

Connecting Maximum and Effective Permissions

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For any (enclave, memory region) pair,
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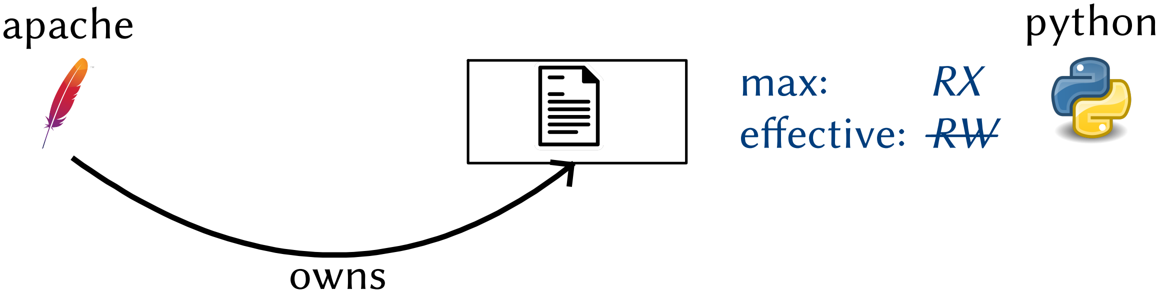

apache

python

max: *RX*

effective: ~~*RW*~~

owns

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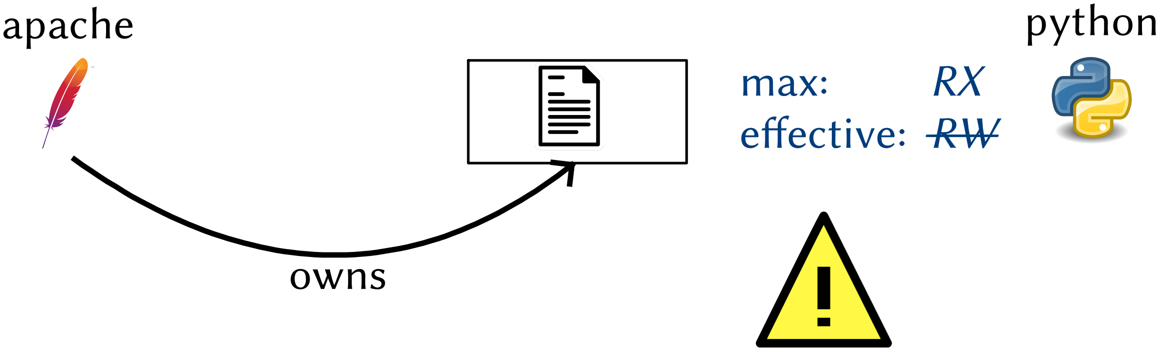

apache

owns

max: *RX*

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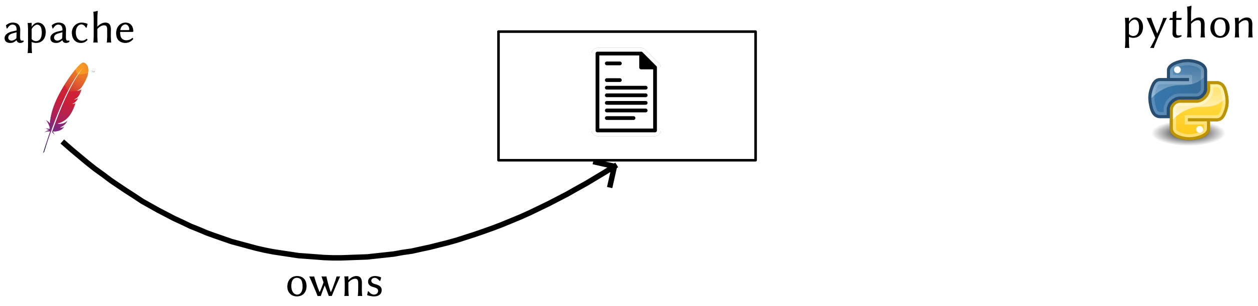
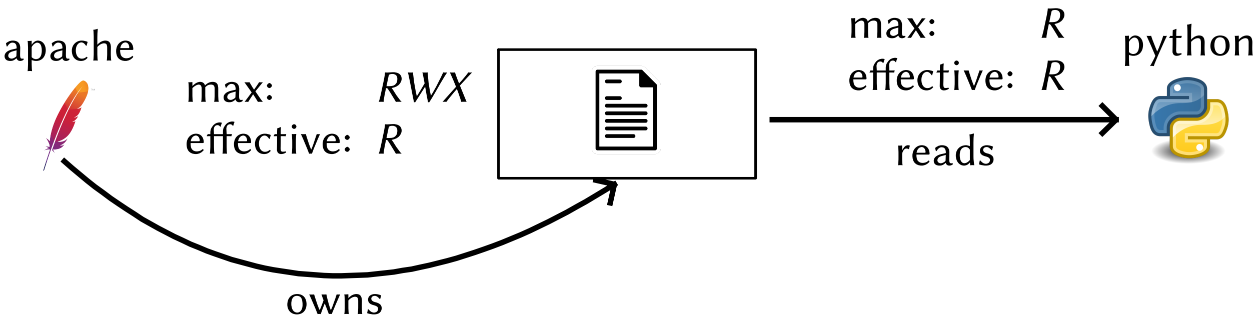
Exception

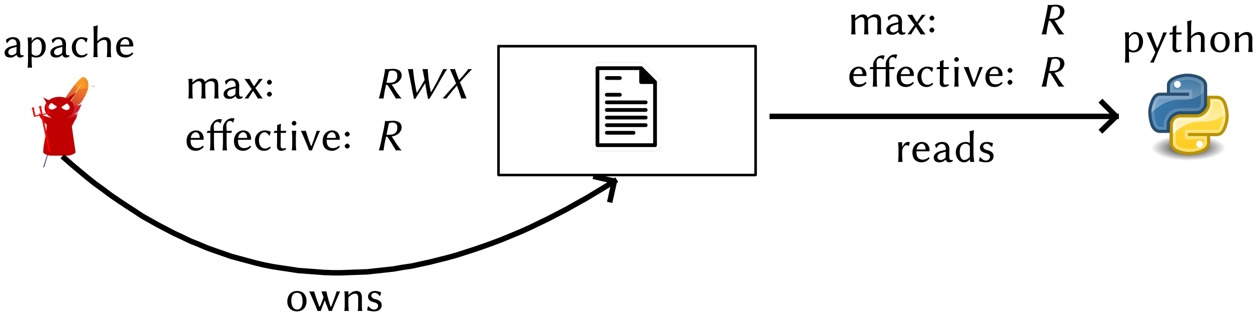
Temporal Isolation Challenge III



Temporal Isolation Challenge III



Temporal Isolation Challenge III



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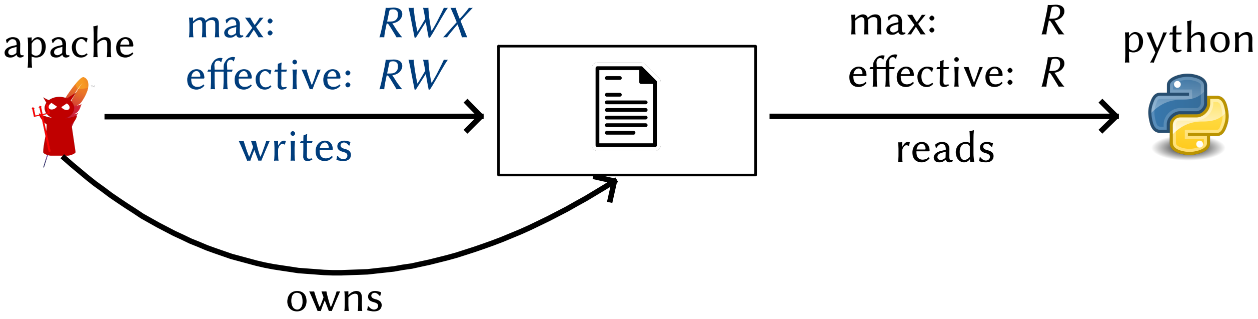

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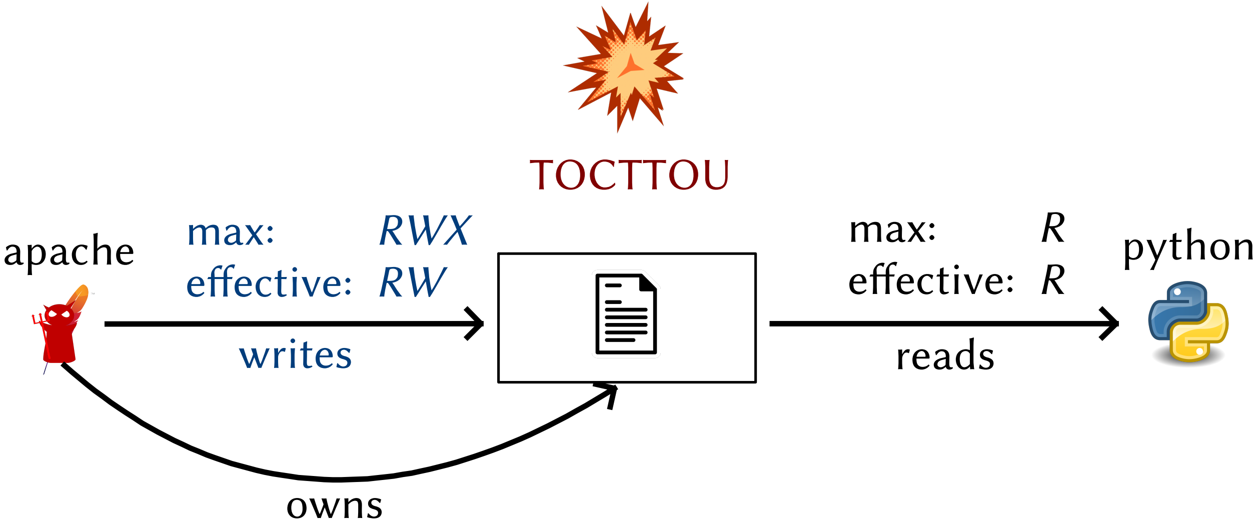


TOCTTOU

apache

max: *RWX*

effective: *RW*

writes

owns

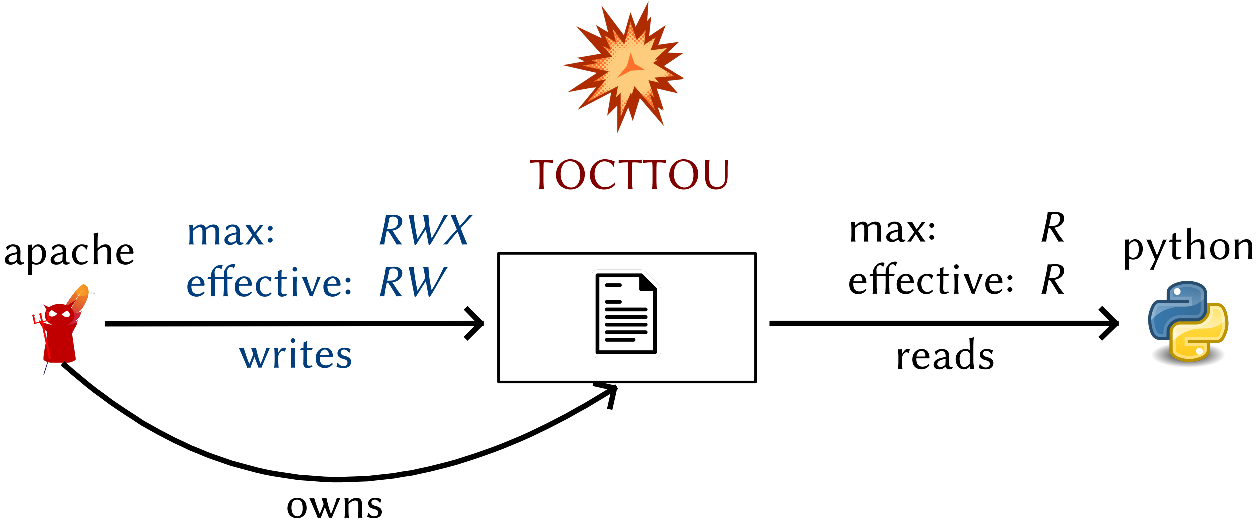
max: *R*

effective: *R*

reads

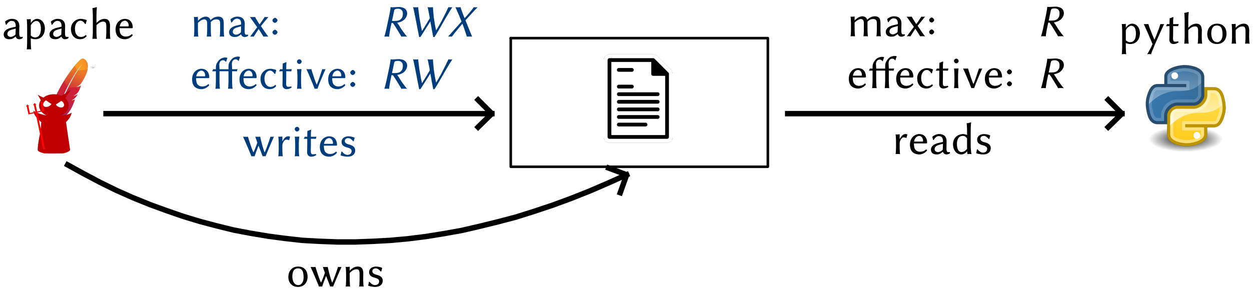
python

Temporal Isolation Challenge III



Problem: No mechanism for synchronization

Elasticlave: Lock Bit



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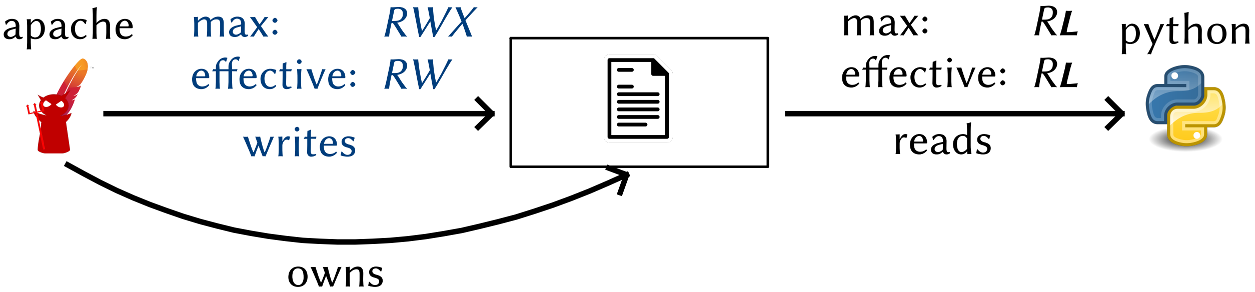


apache

max: *RWX*

effective: *RW*

writes

owns

max: *R***L**

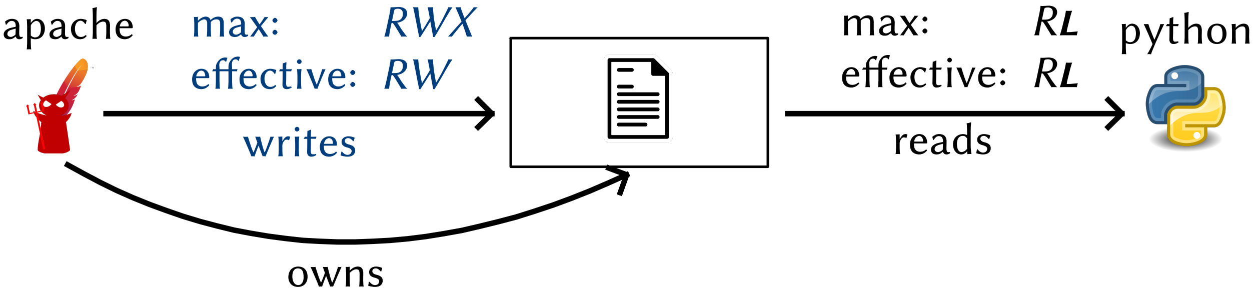
effective: *R***L**

reads

python

Elasticlave: Lock Bit

When held in effective permissions:
exclusive access guaranteed



apache

max: *RWX*
effective: *RW*

writes

owns

max: *R***L**
effective: *R***L**

reads

python

Elasticlave: Lock Bit

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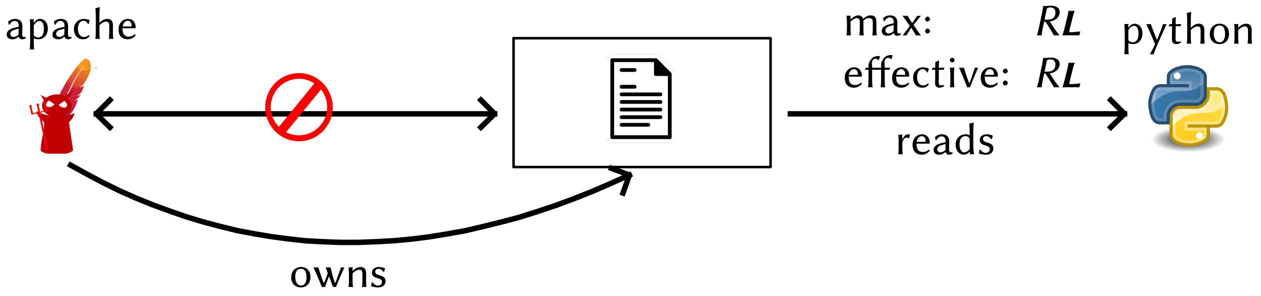


Elasticlave Summary

Three elements:

- Maximum permissions

Elasticlave Summary

Three elements:

- Maximum permissions
- Effective permissions (≤ maximum permissions)

Elasticlave Summary

Three elements:

- Maximum permissions
- Effective permissions (≤ maximum permissions)
- Synchronization: lock bit

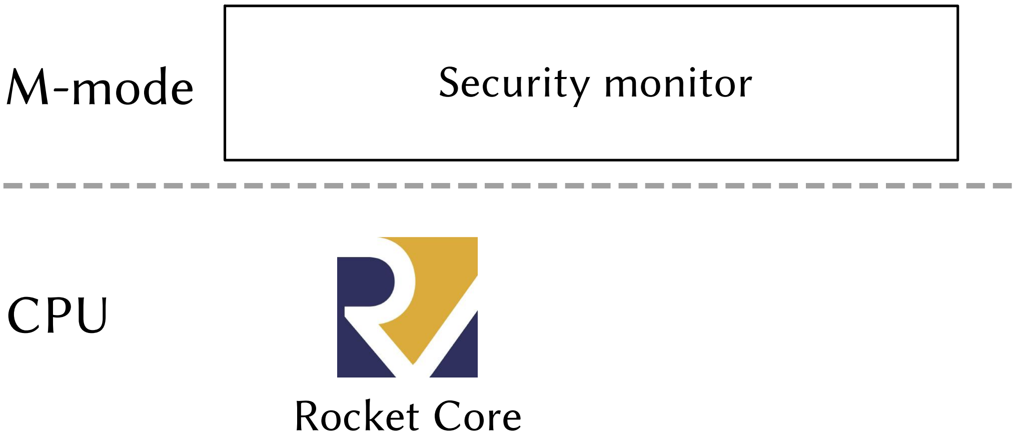
Implementation

Implementation

CPU

Rocket Core

Implementation



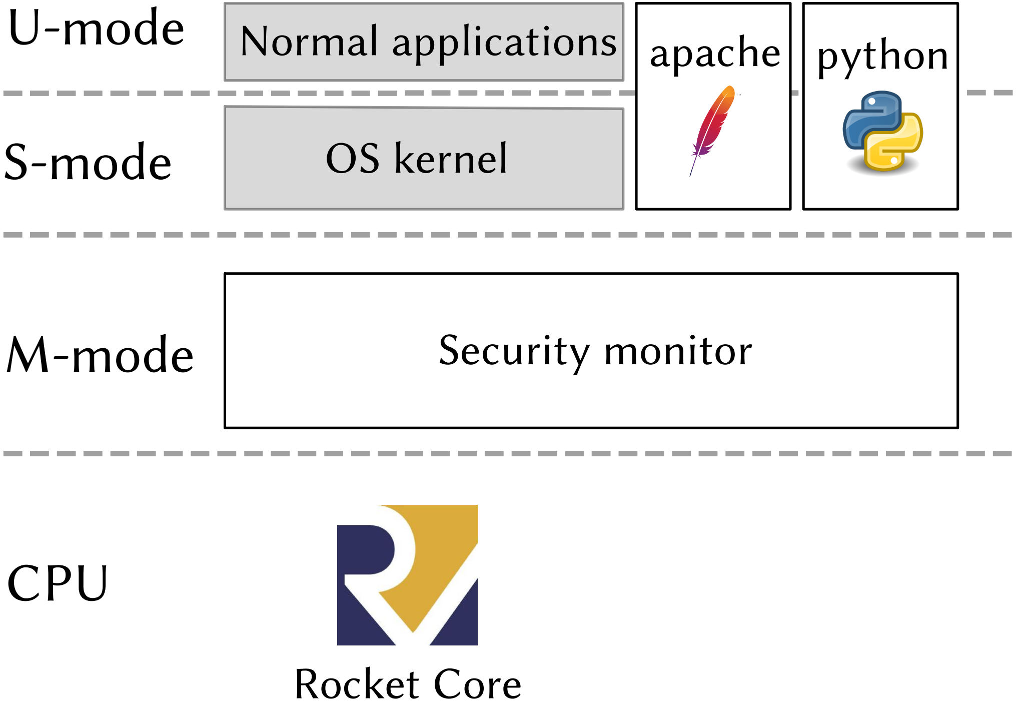
M-mode

Security monitor

CPU

Rocket Core

Implementation



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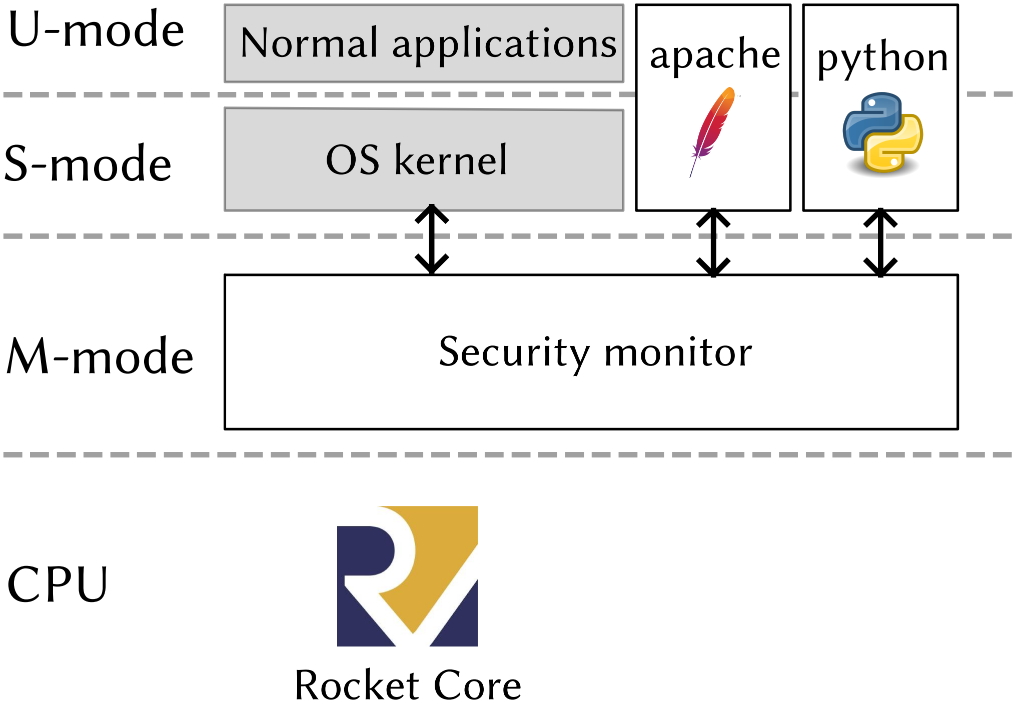

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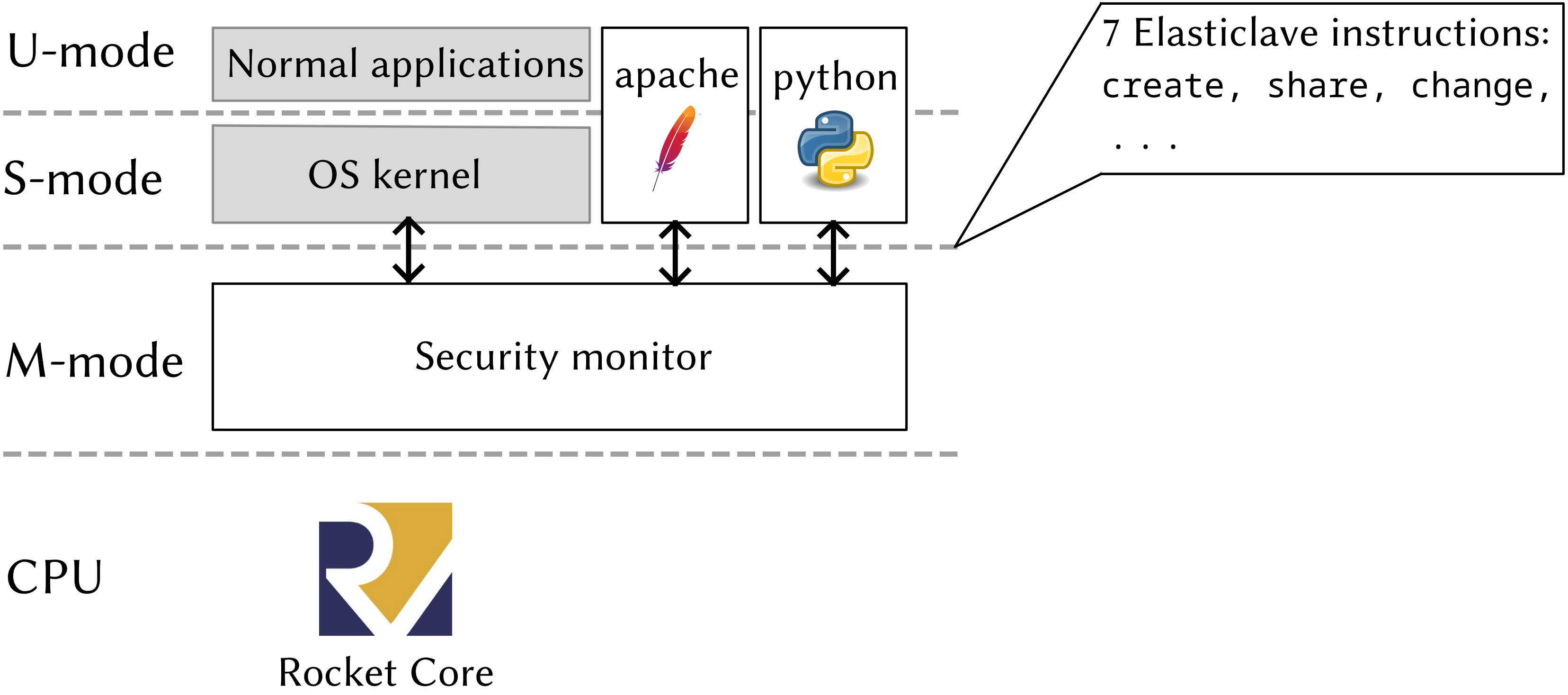

7 Elasticlave instructions: `create, share, change, ...`

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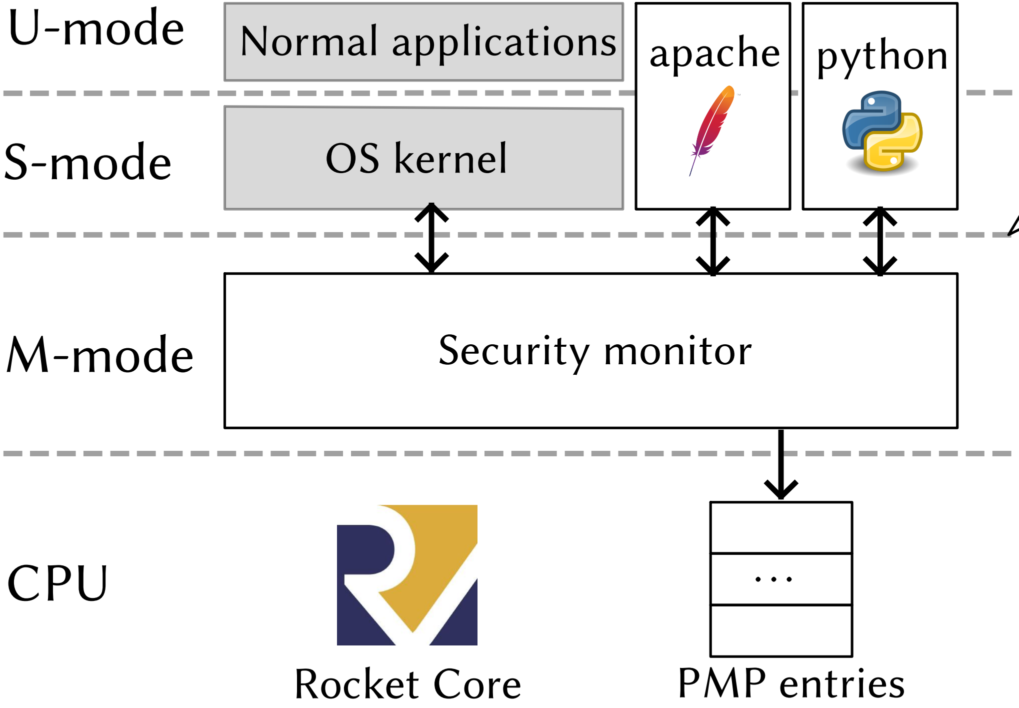

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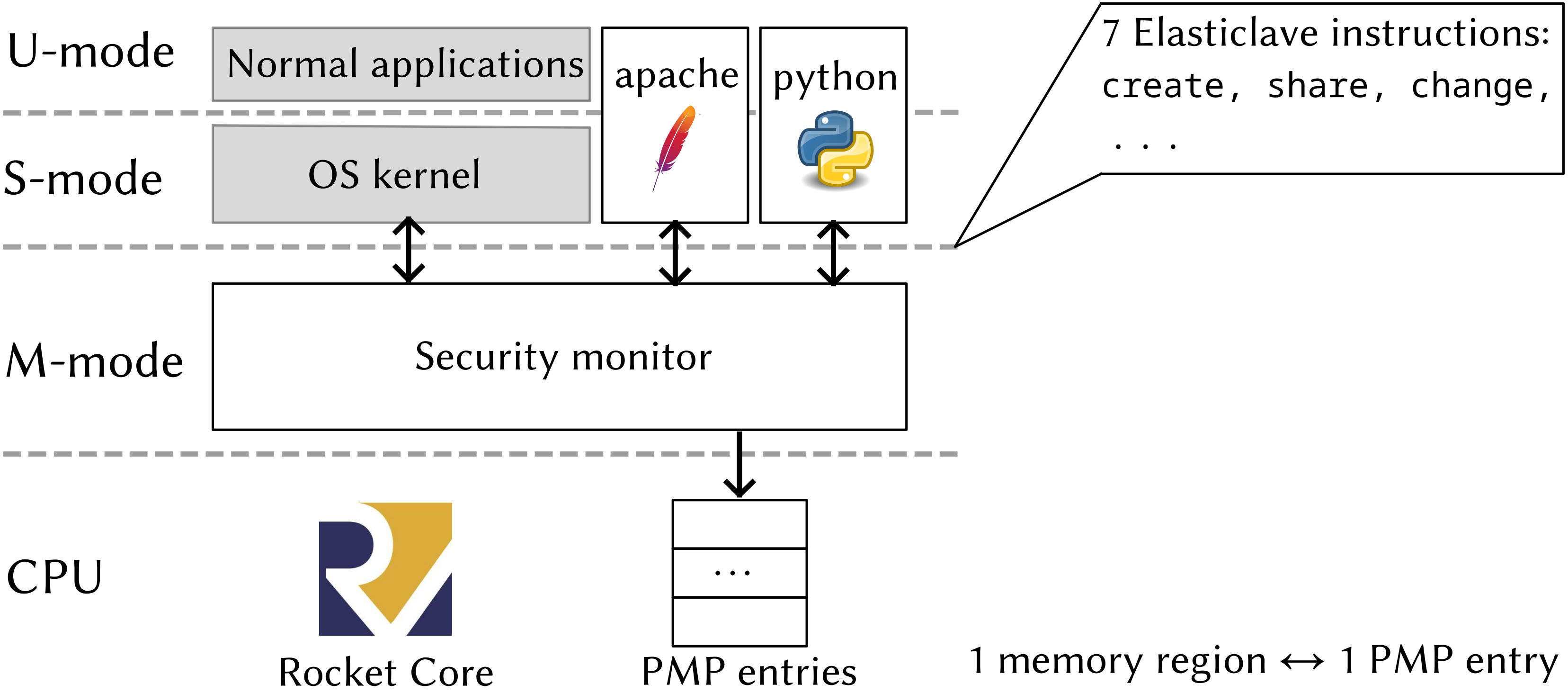


U-mode

Normal applications

apache

python

S-mode

OS kernel

M-mode

Security monitor

CPU

Rocket Core

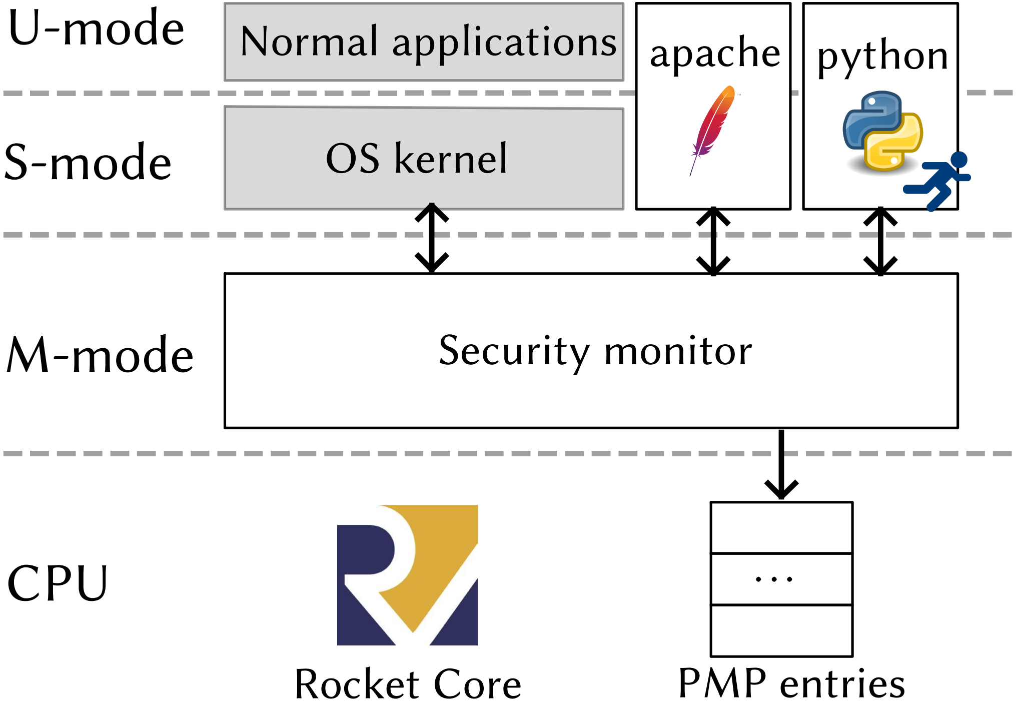
PMP entries

. . .

7 Elasticlave instructions:
`create, share, change,`
`. . .`

1 memory region ↔ 1 PMP entry

Implementation



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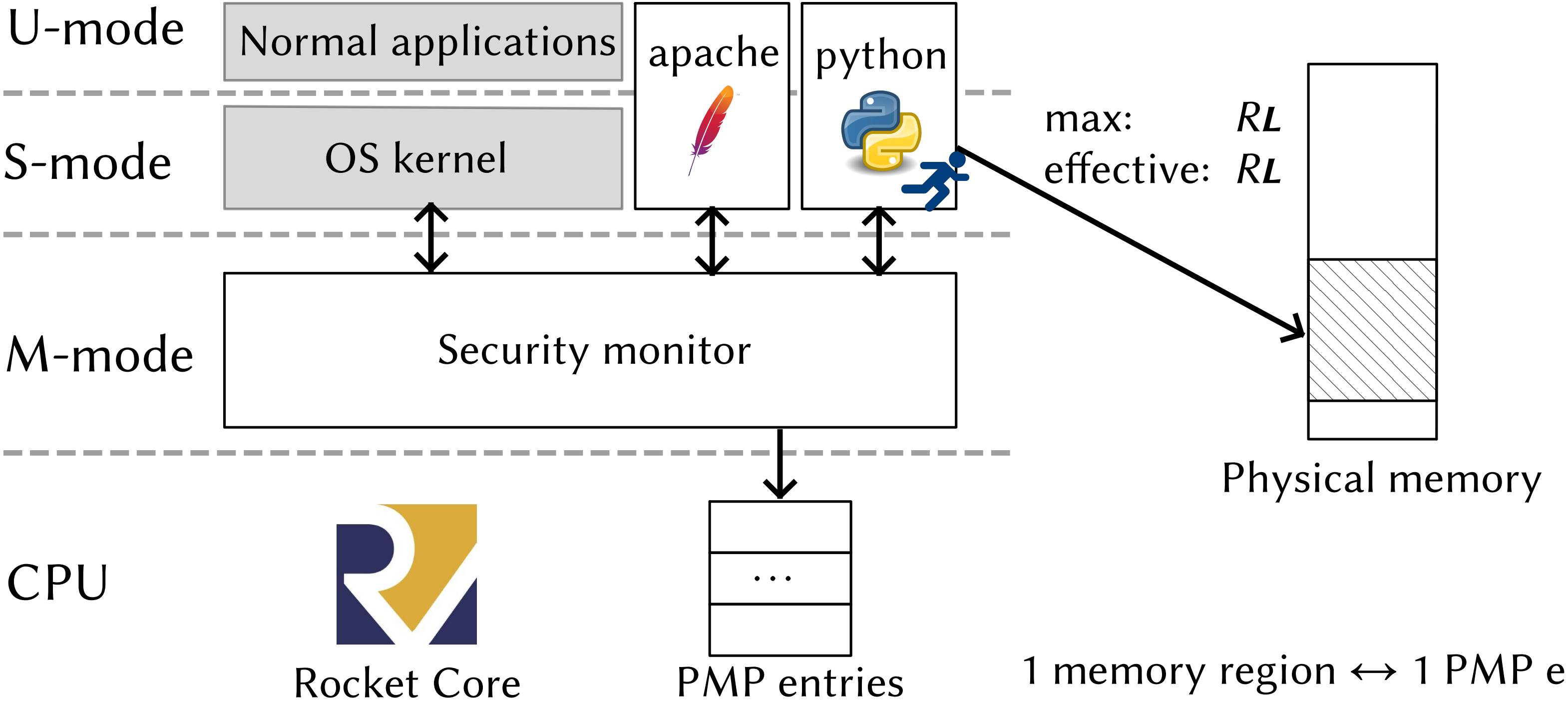

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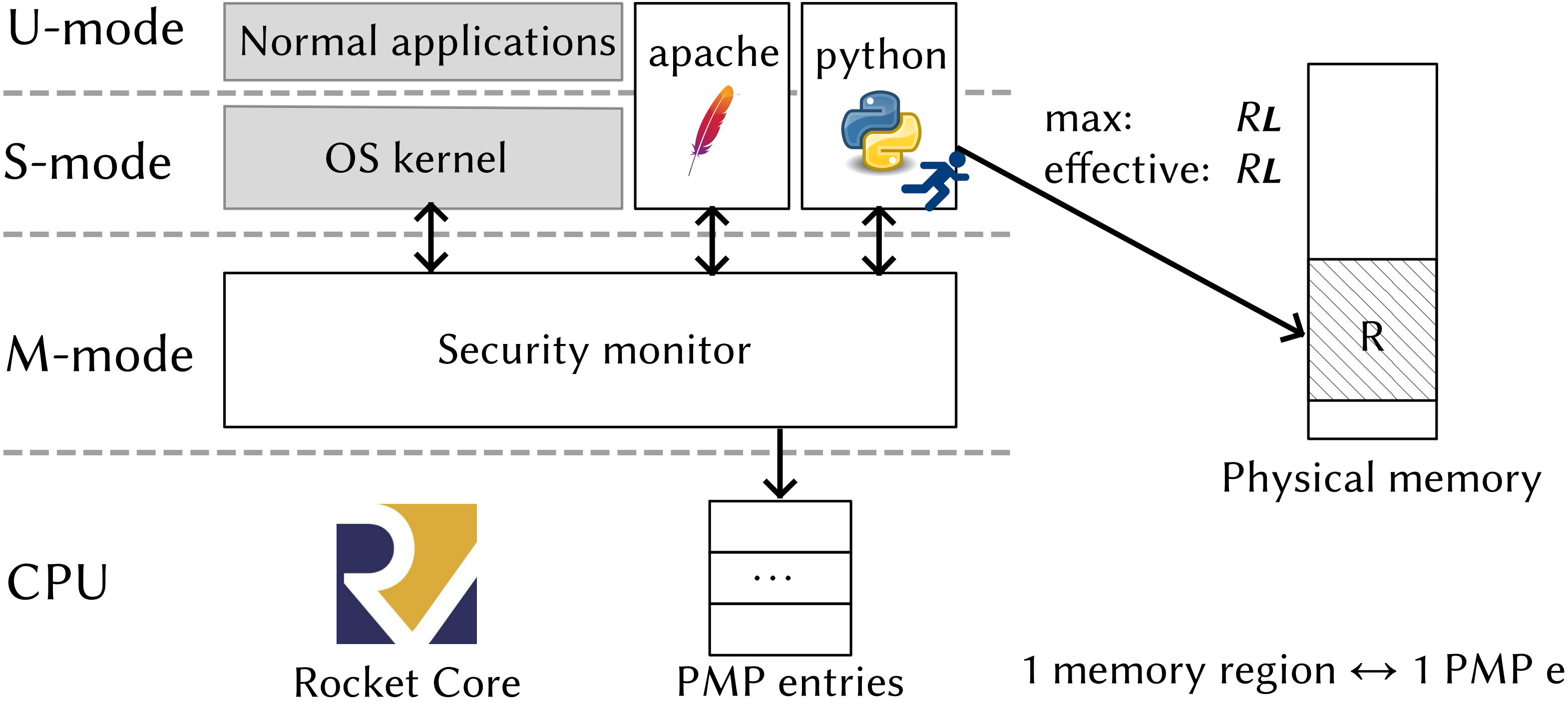

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Evaluations

Evaluation question: Performance of Elasticlave compared to spatial isolation

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Benchmarks:

Evaluations

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- Handcrafted microbenchmarks for data sharing patterns

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Run on cycle-accurate FPGA-accelerated simulator (FireSim)

SPLASH-2 (sharing-intensive)

Two enclaves performing parallel computation

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Elasticlave: memory region accessible to both enclaves

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Spatial isolation: passing data through extra copies and encryption/decryption

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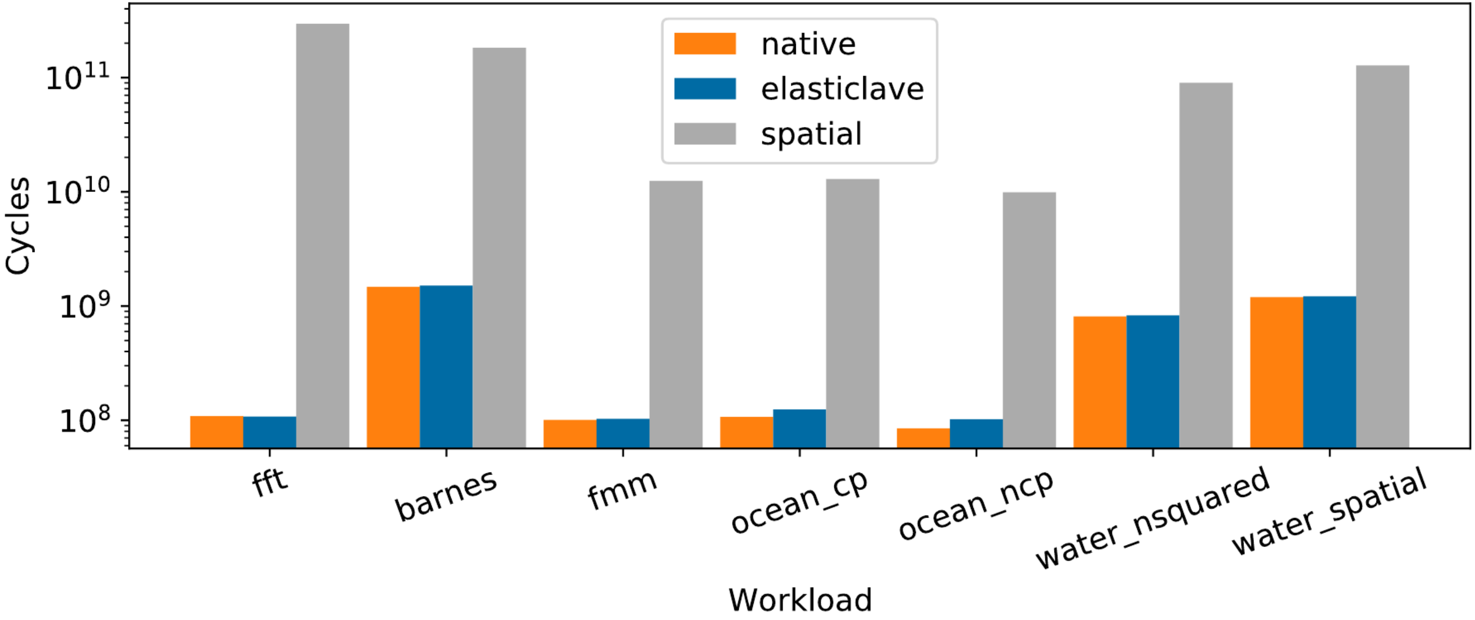
Two enclaves performing parallel computation

Elasticlave: memory region accessible to both enclaves

Spatial isolation: passing data through extra copies and encryption/decryption

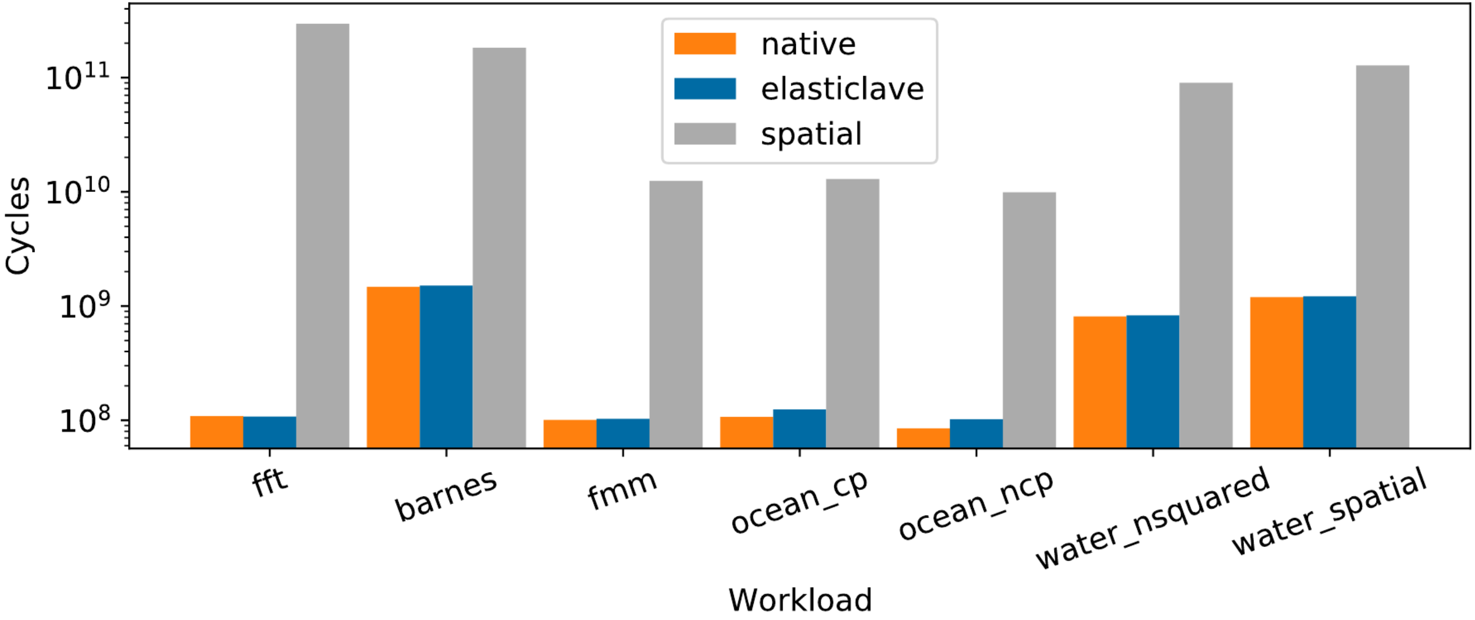
Native: two threads

Evaluation Results on SPLASH-2 (sharing-intensive)



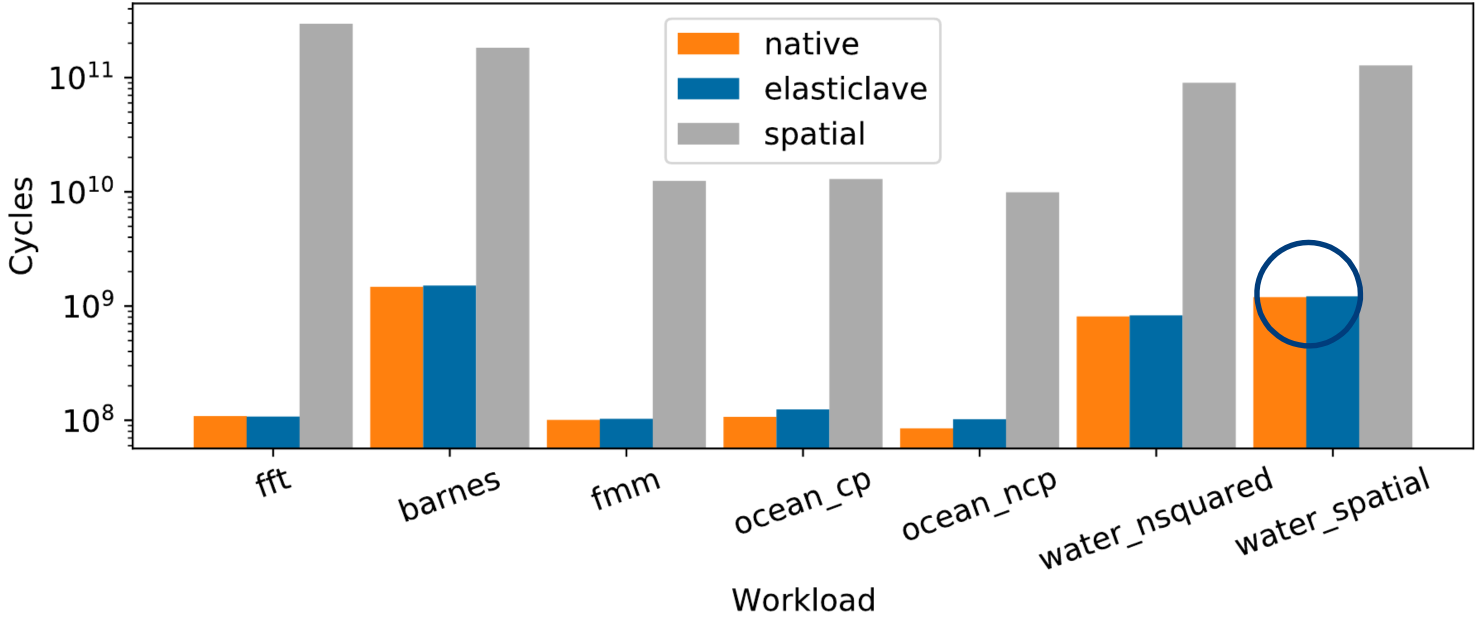
Evaluation Results on SPLASH-2 (sharing-intensive)

100x performance improvement

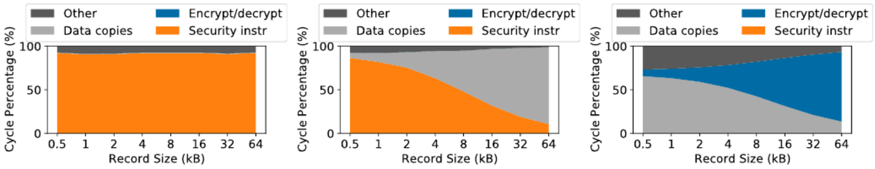


Evaluation Results on SPLASH-2 (sharing-intensive)

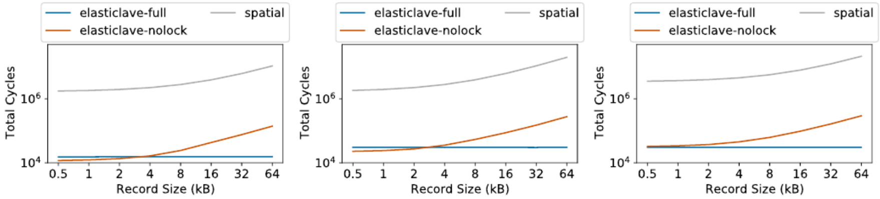
Comparable to native Linux



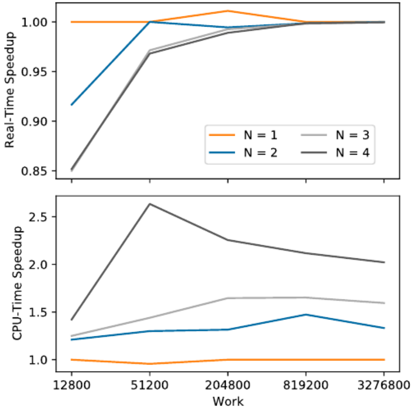
More in Paper

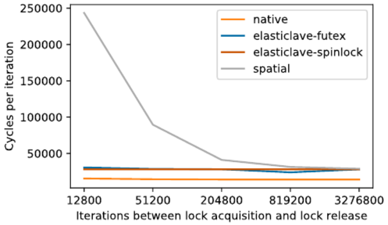


(a) ELASTICLAVE-full (b) ELASTICLAVE-nolock (c) spatial



(a) Producer-consumer (b) Client-server (c) Proxy





Conclusions

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Artifact available: `https://github.com/jasonyu1996/elasticlave`

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Thanks for listening!