TPMs and the Linux Kernel

Unlocking a better path to hardware security

Ignat Korchagin
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$ whoami

- Linux team at Cloudflare
- Systems security and performance
- Low-level programming

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What is a TPM?

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What is a TPM?

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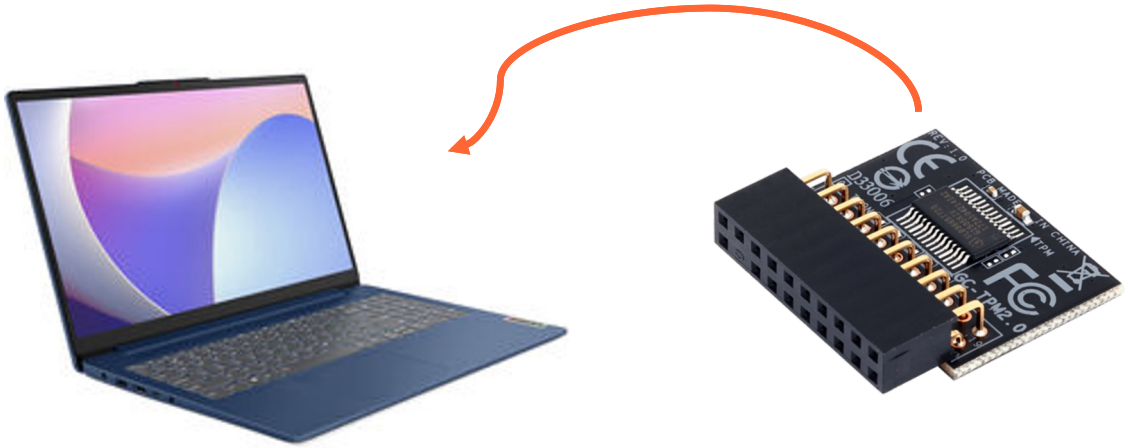
What is a TPM?



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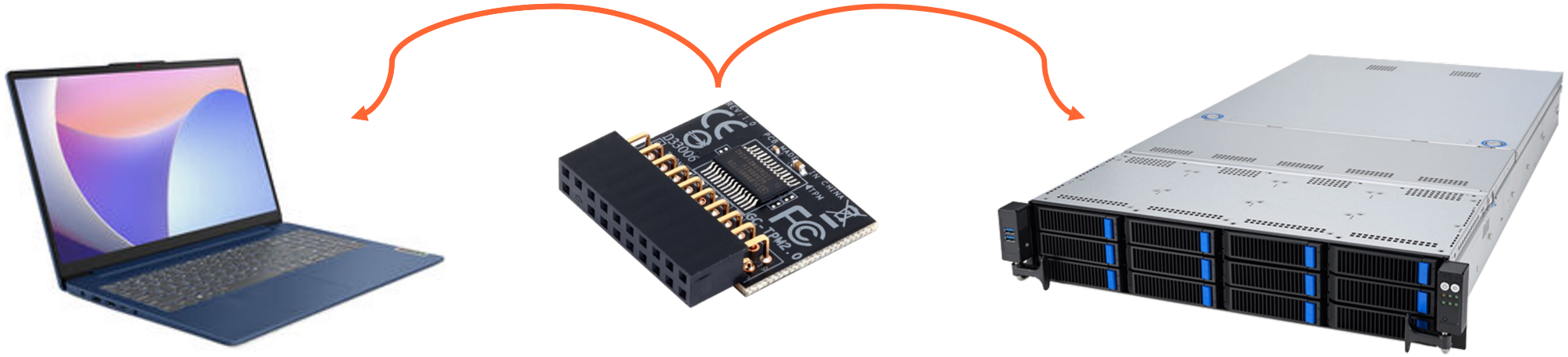
What is a TPM?



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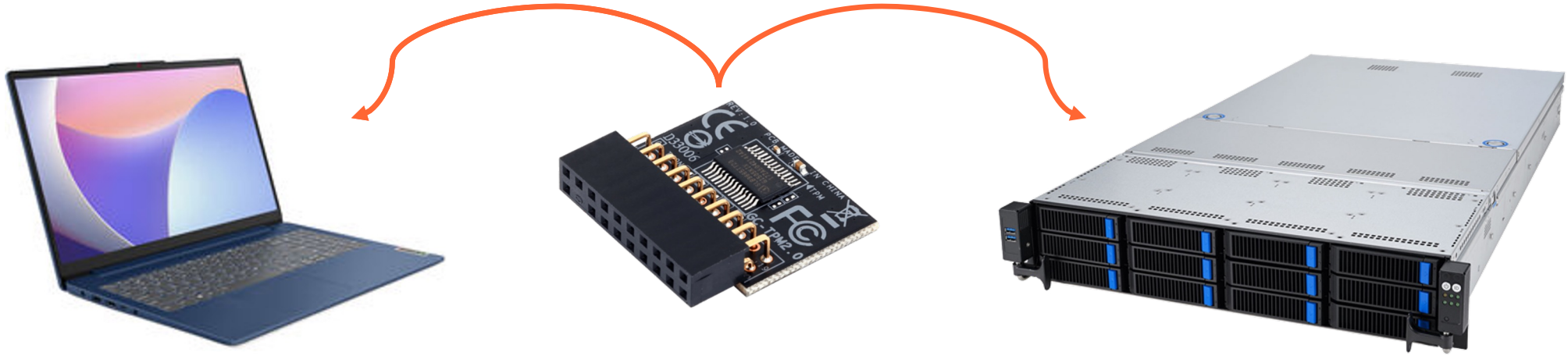
What is a TPM?



- A discrete security chip on modern laptops and servers
- Passive, non-intrusive: only responds to commands and performs cryptographic operations
- Foundation for platform integrity, authentication and remote attestation
- Can handle cryptographic keys

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This talk is not about system integrity or attestation

Can I store my keys in the TPM?

And use them without exposing the key material to the main memory?

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Application keys in the TPM

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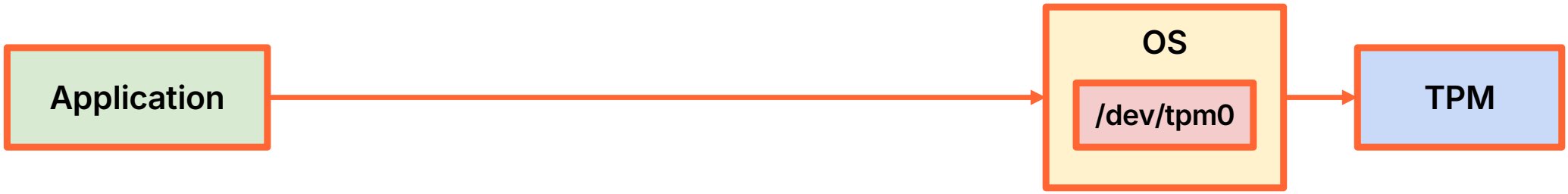

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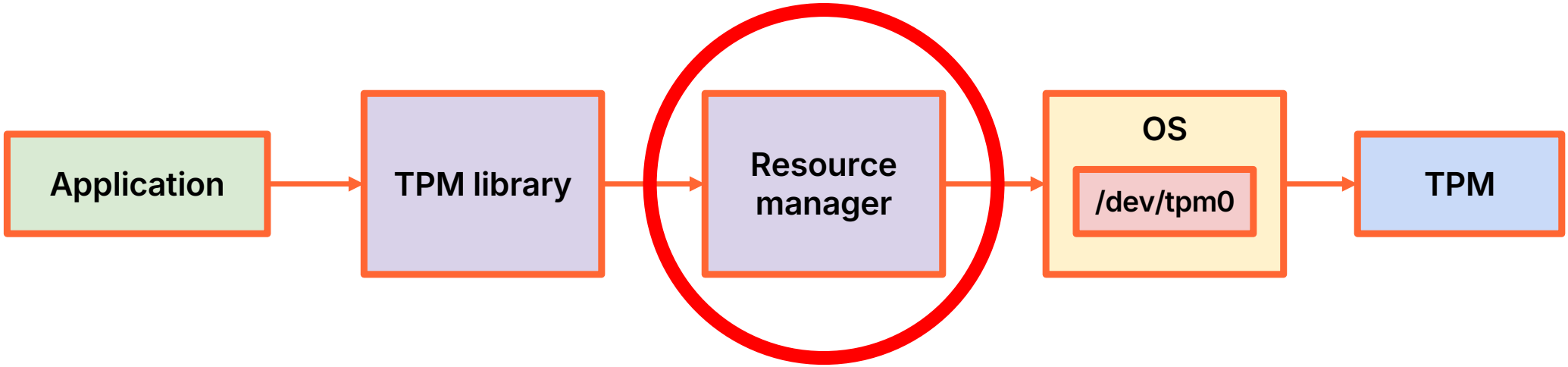

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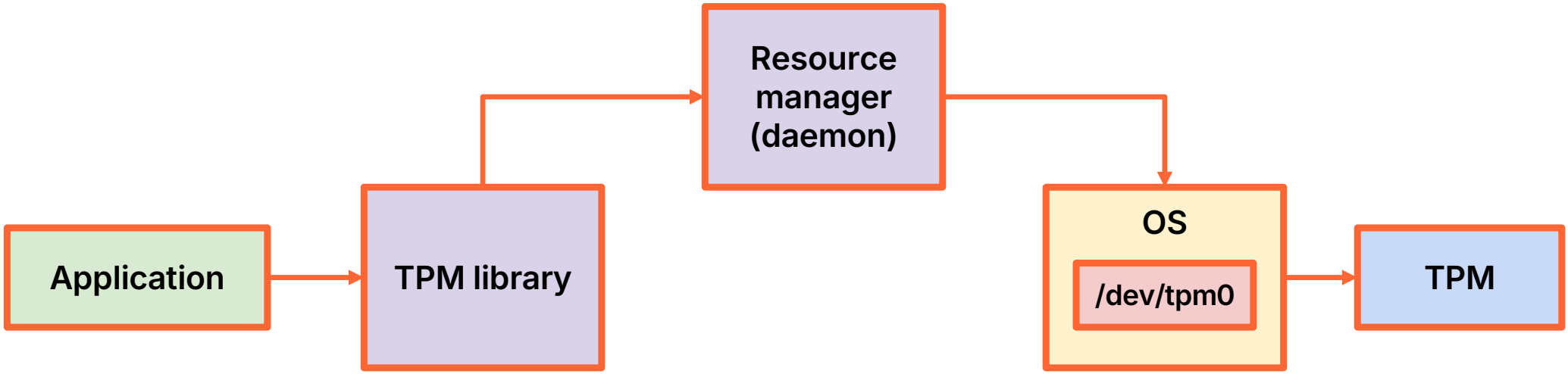

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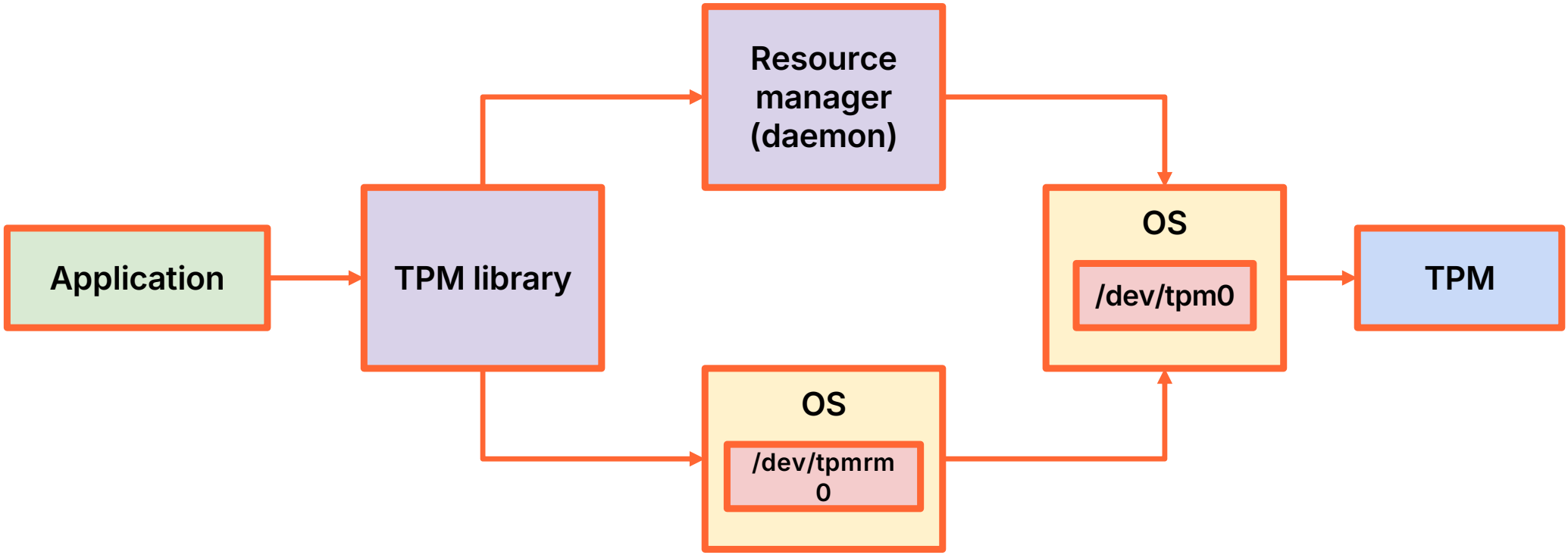

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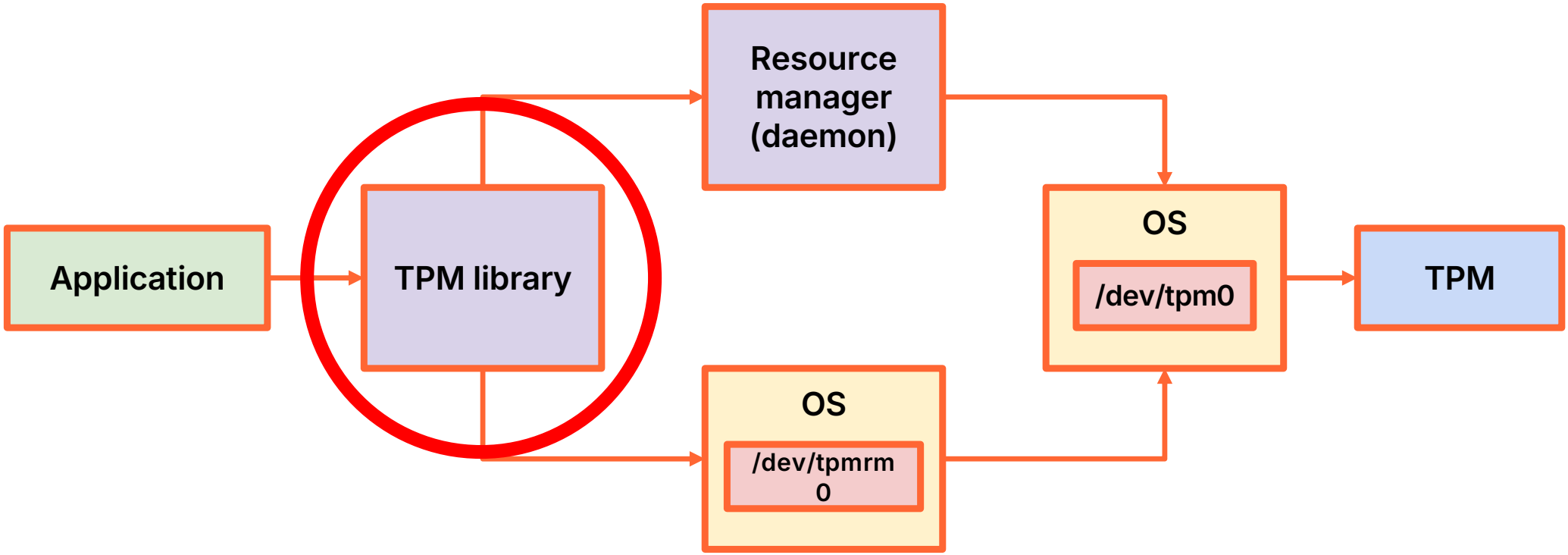

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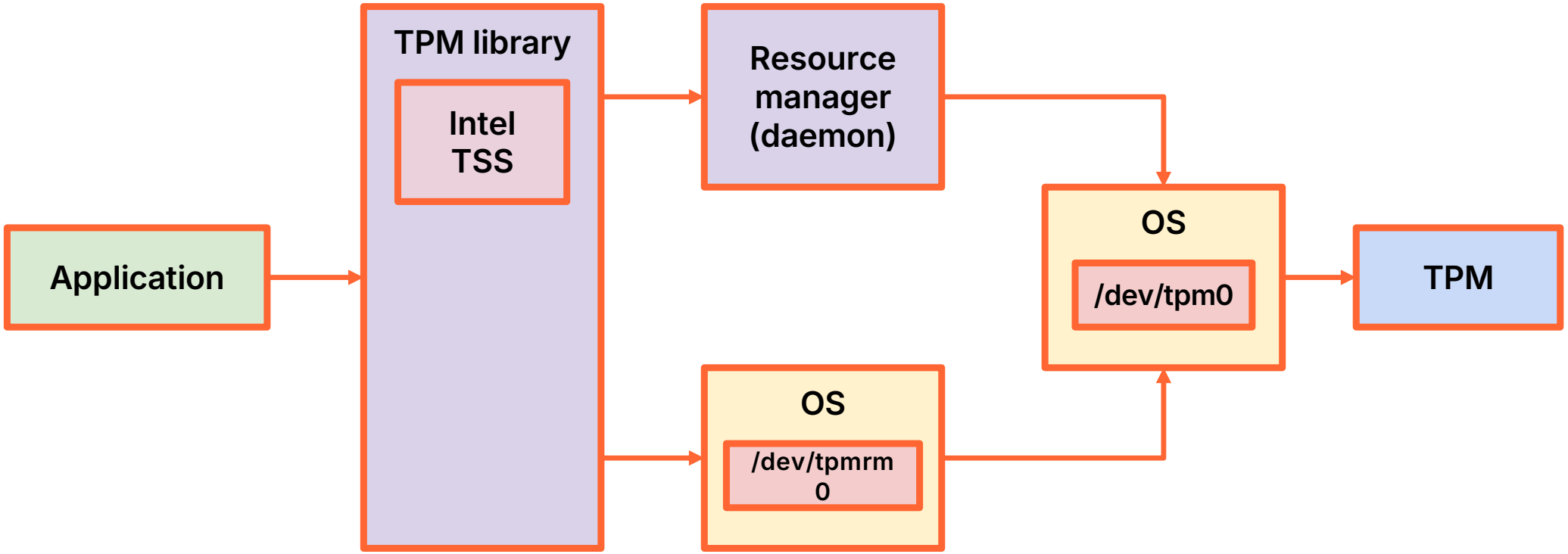

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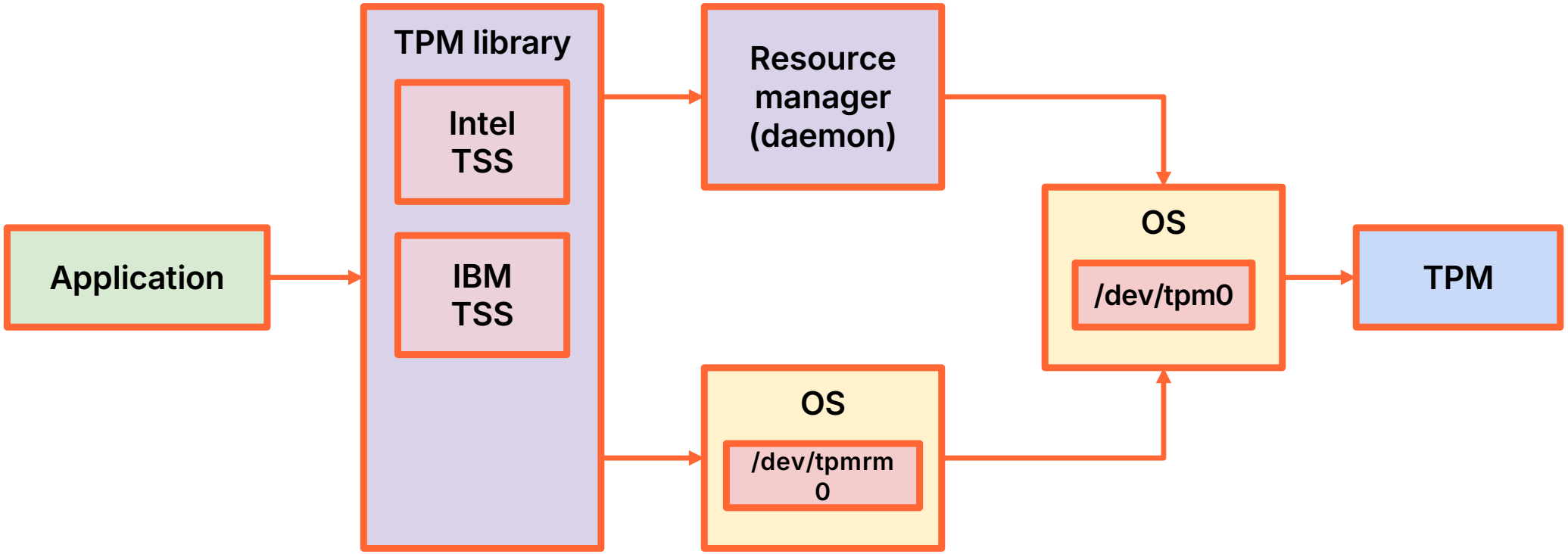

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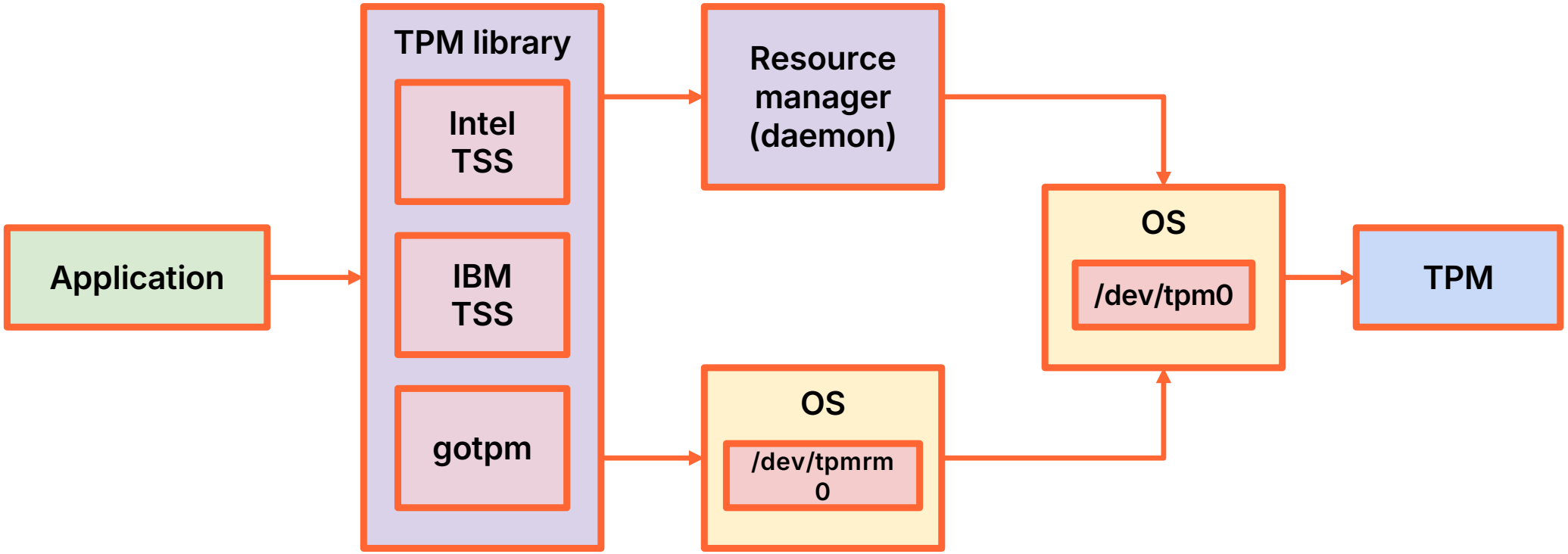

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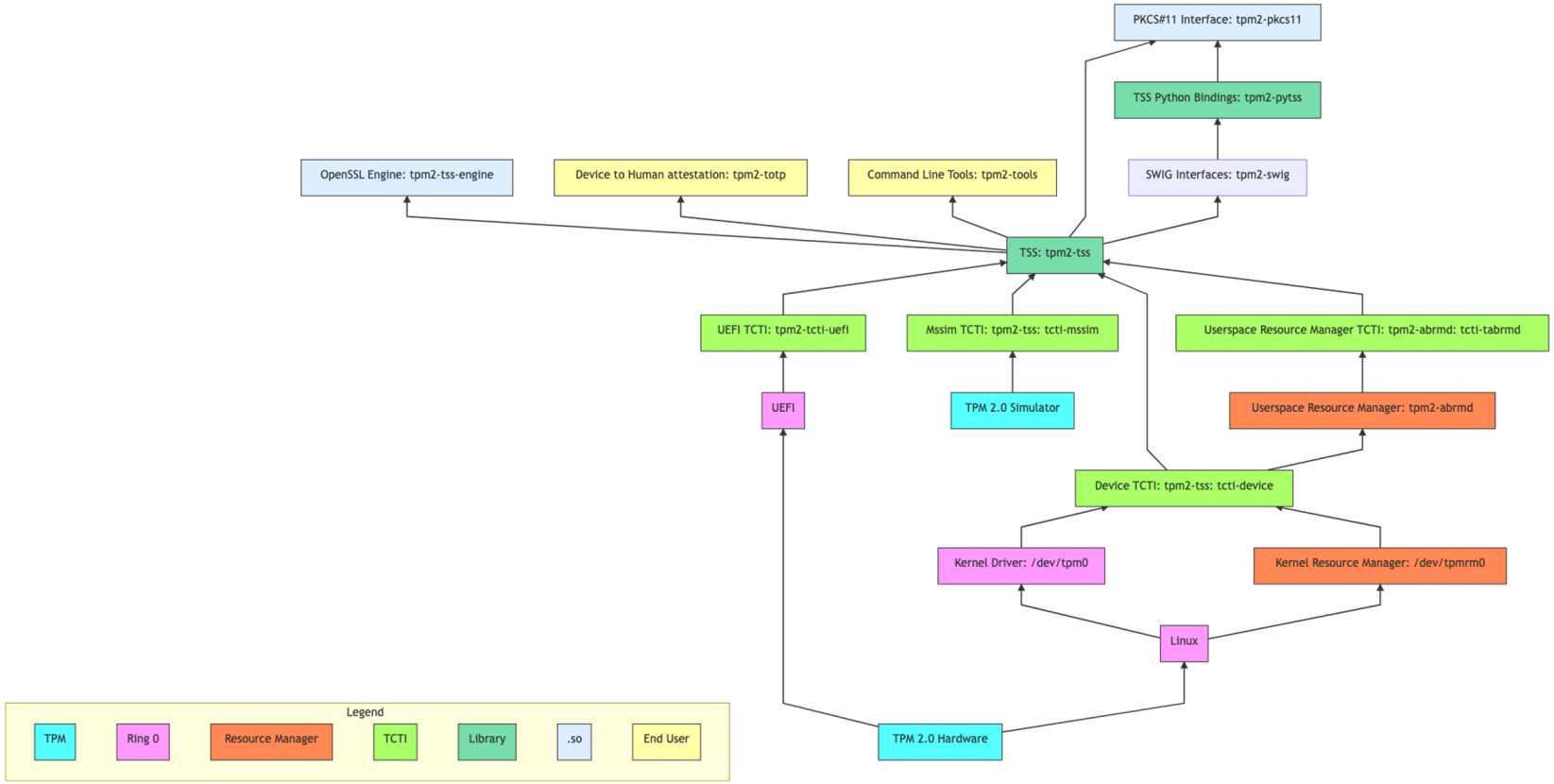
TPM2 software stack



https://tpm2-software.github.io/

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Application keys in the TPM

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Access permissions for the TPM

```
ignat@dev:~$ echo hello > /dev/tpmrm0
-bash: /dev/tpmrm0: Permission denied
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ignat@dev:~$ ls -l /dev/tpm0
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```

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Linux Kernel key retention service

AKA keyrings or keystore

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Linux Kernel key retention service

Application

Application

Application

https://www.kernel.org/doc/html/latest/security/keys/core.html

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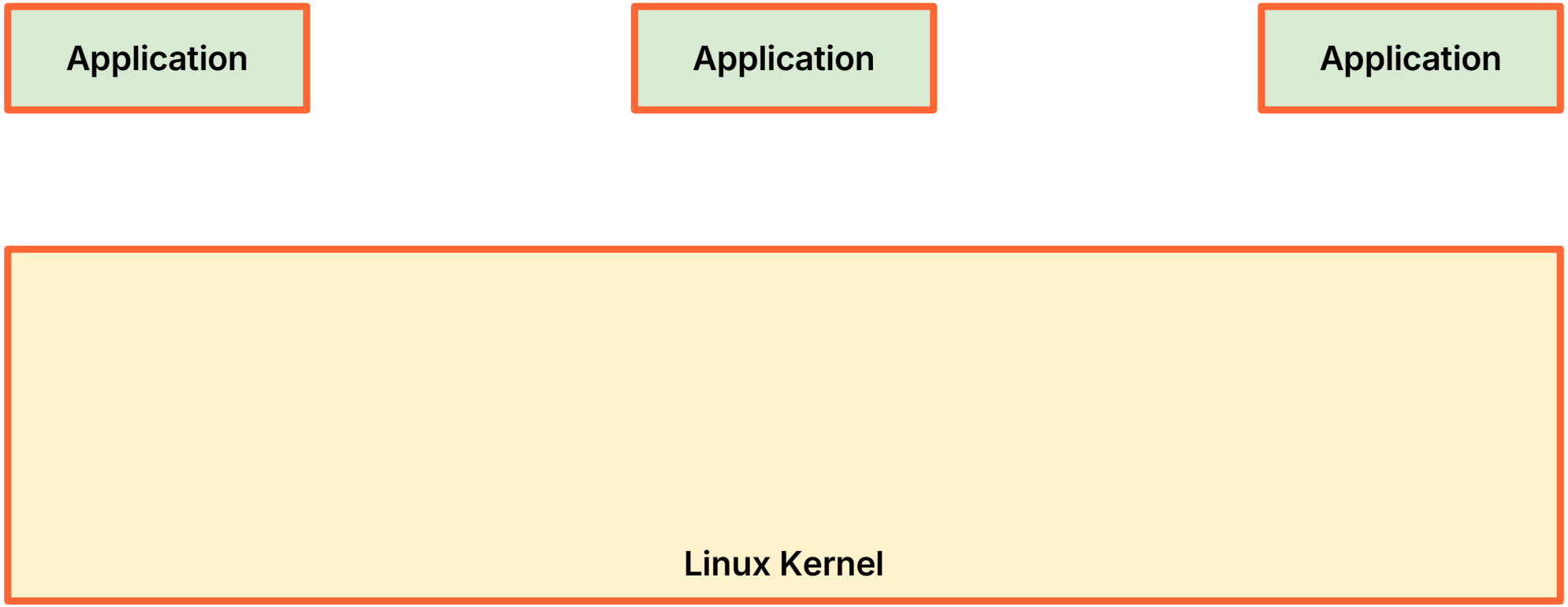
Linux Kernel key retention service



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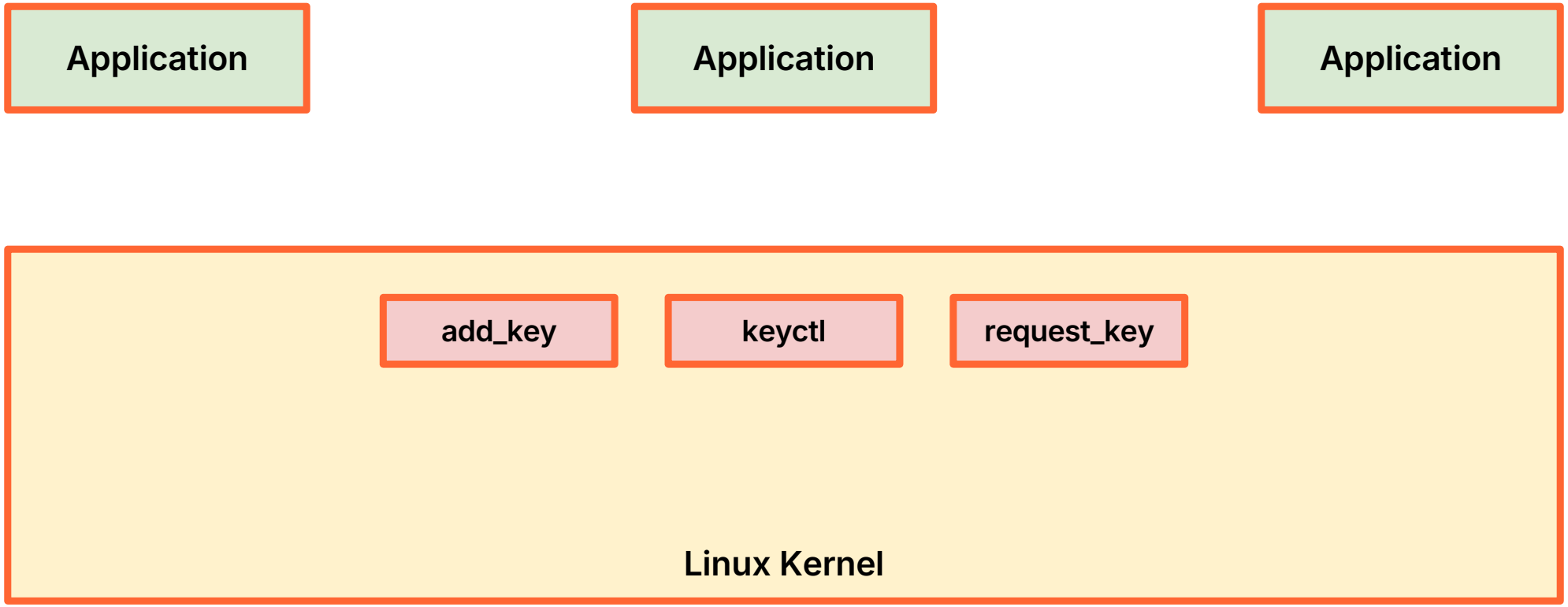

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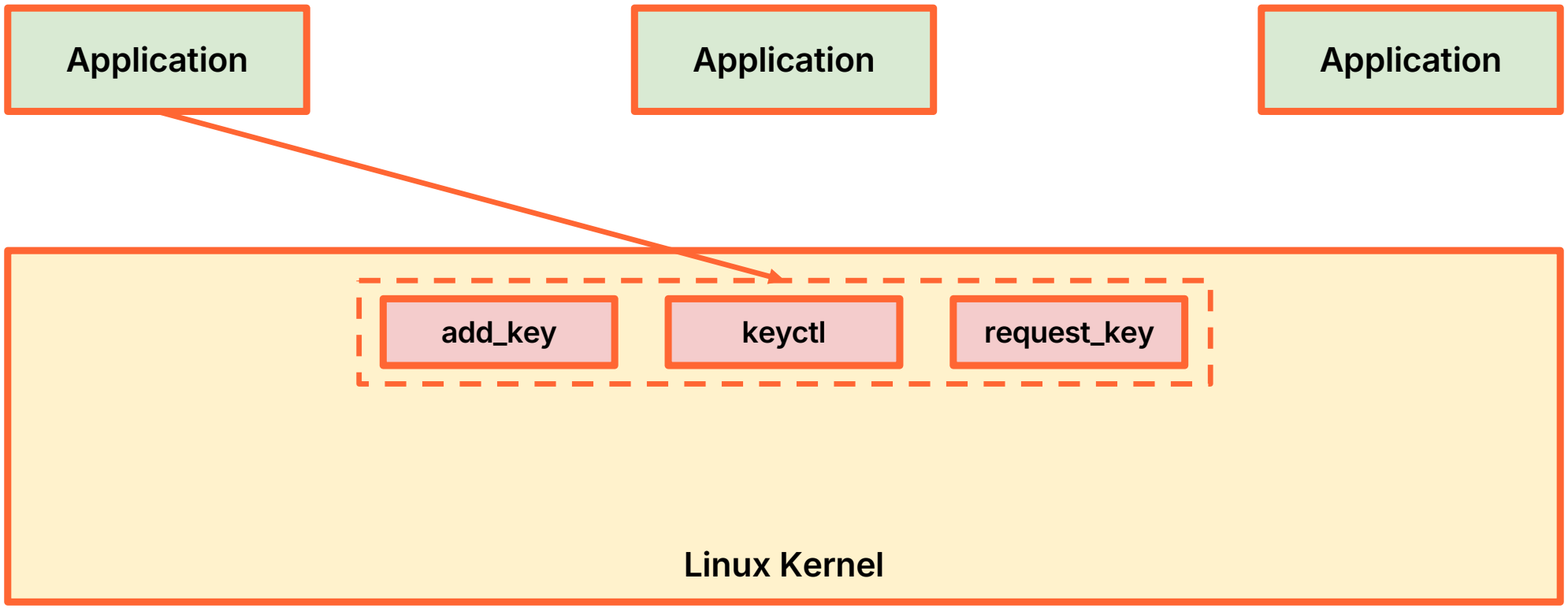

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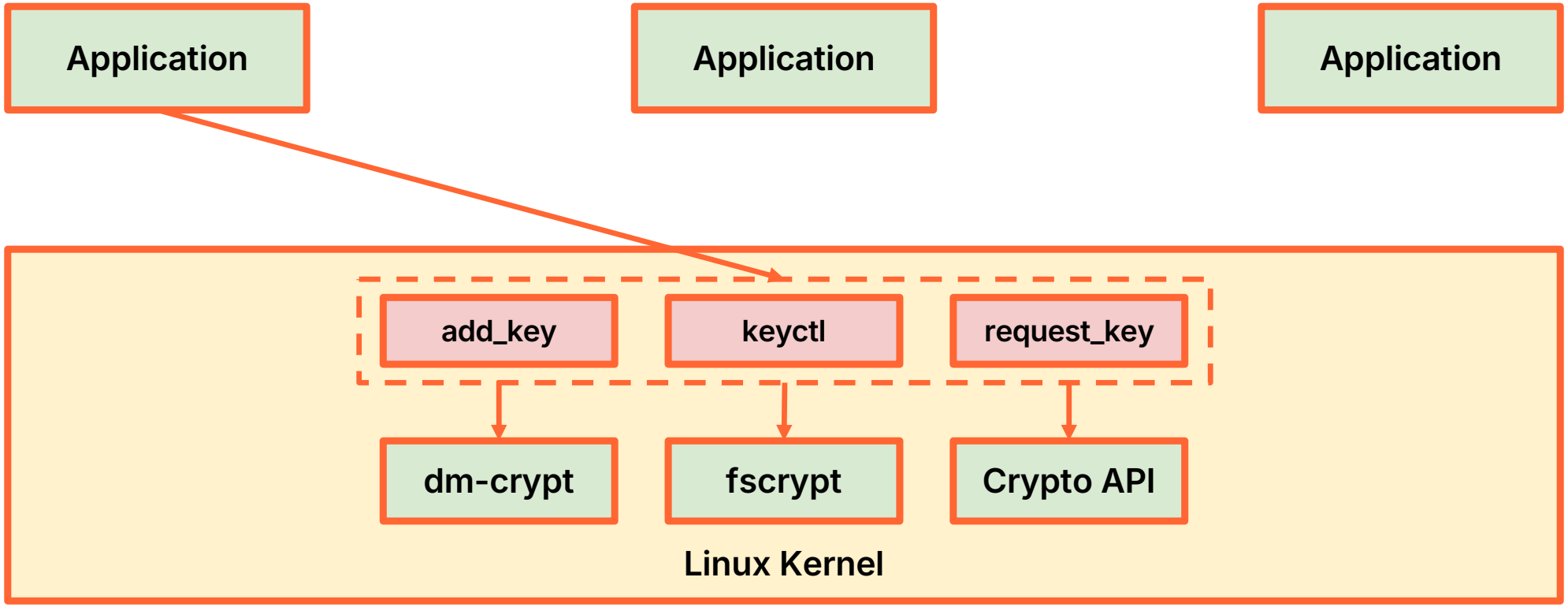

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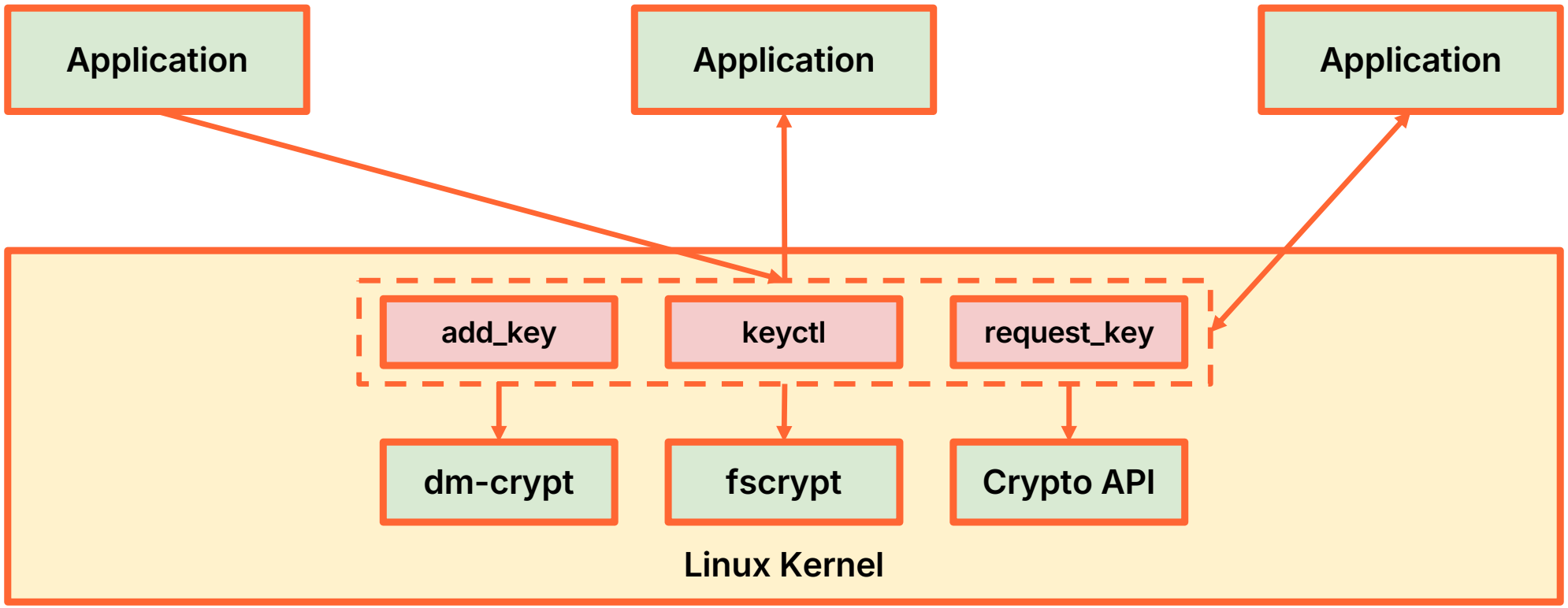

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Keys and keyrings

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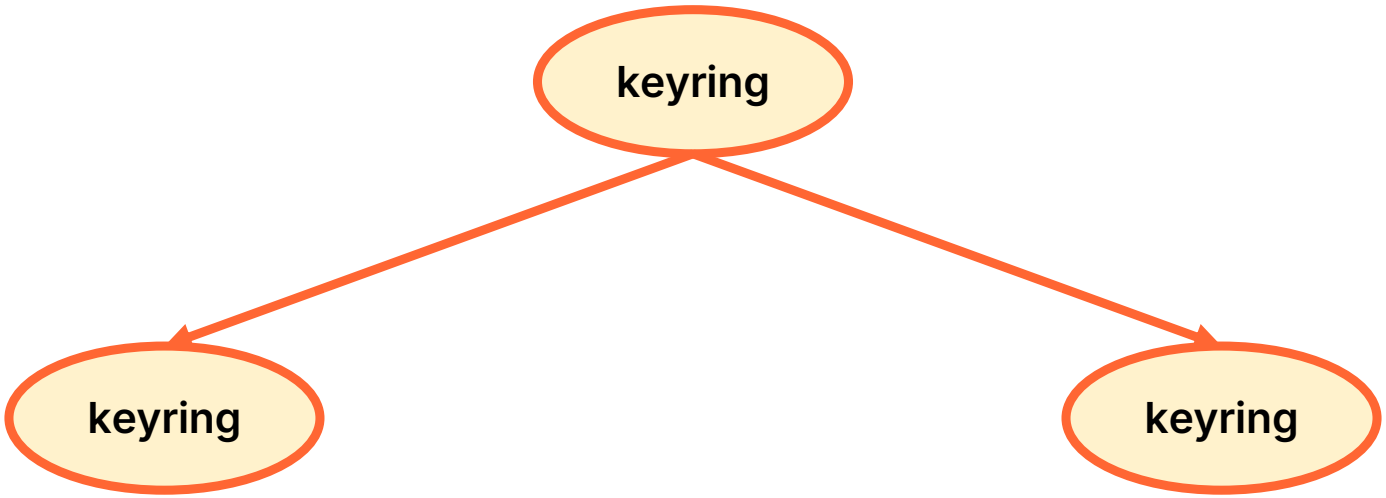
Keys and keyrings



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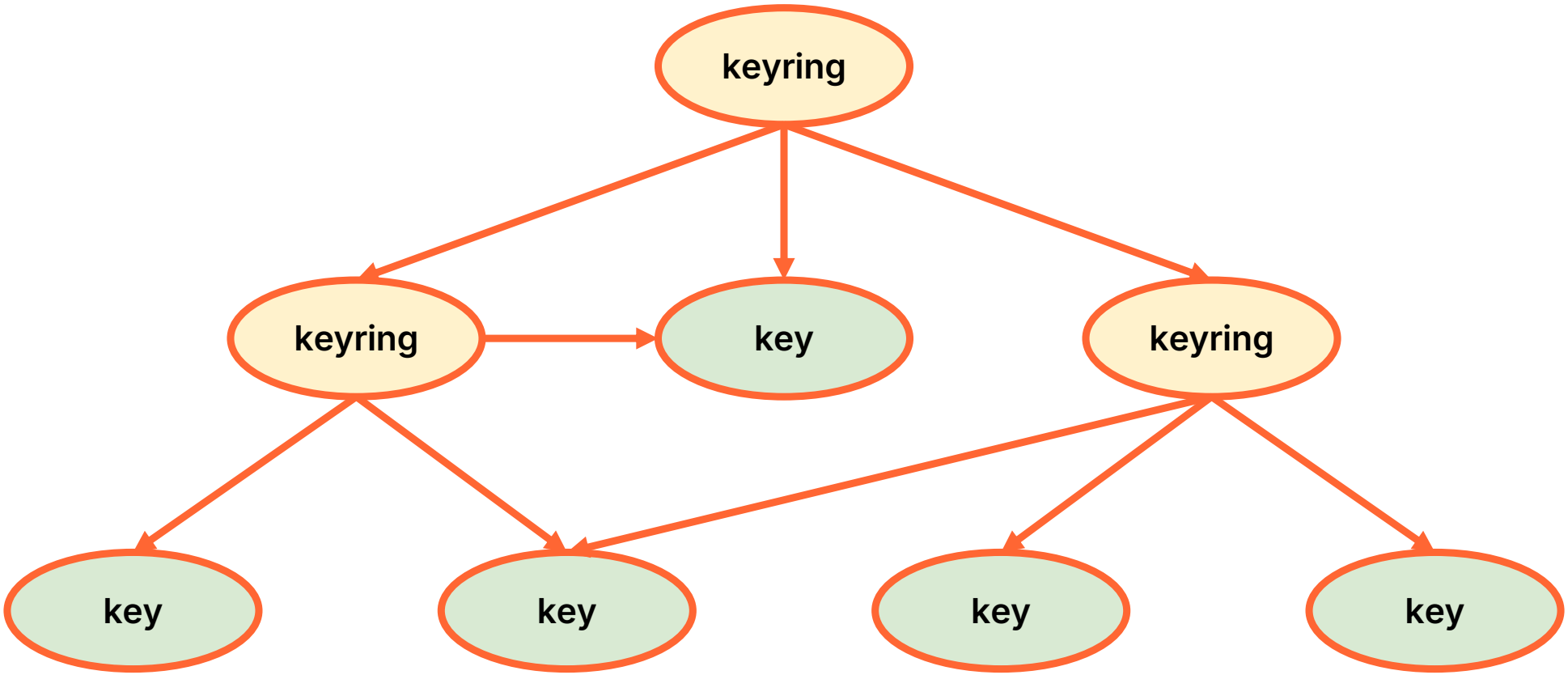
Keys and keyrings



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Example: secret sharing

```
alice@dev:~$ id
uid=1001(alice) gid=1001(alice)
groups=1001(alice)
```

```
bob@dev:~$ id
uid=1002(bob) gid=1002(bob)
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```

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Example: secret sharing

```
alice@dev:~$ id
uid=1001(alice) gid=1001(alice)
groups=1001(alice)
alice@dev:~$ keyctl add user secret
hunter2 @u
791615806
```

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bob@dev:~$ id
uid=1002(bob) gid=1002(bob)
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bob@dev:~$ keyctl newring from-others @u
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bob@dev:~$ keyctl show @u
Keyring
 812825228 --alswrv    1002 65534
keyring: _uid.1002
 966722684 --alswrv    1002  1002    \_
keyring: from-others
 791615806 --alswrv    1001  1001
\_ user: secret
```

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Example: secret sharing

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alice@dev:~$ id
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@u 966722684
alice@dev:~$ keyctl show
Session Keyring
 931561702 --alswrv   1001  1001
keyring: _ses
 107607516 --alswrv   1001 65534   \_
keyring: _uid.1001
```

```
bob@dev:~$ id
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```

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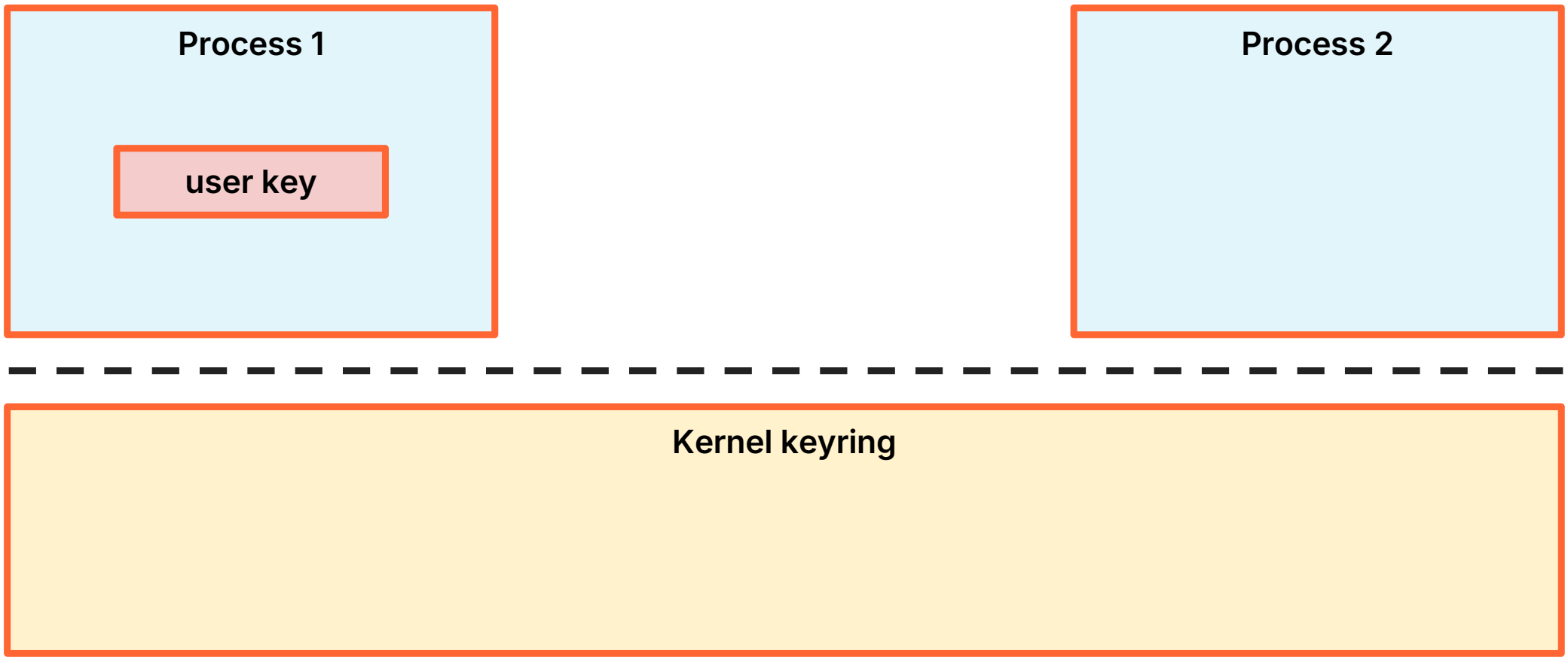
User keys



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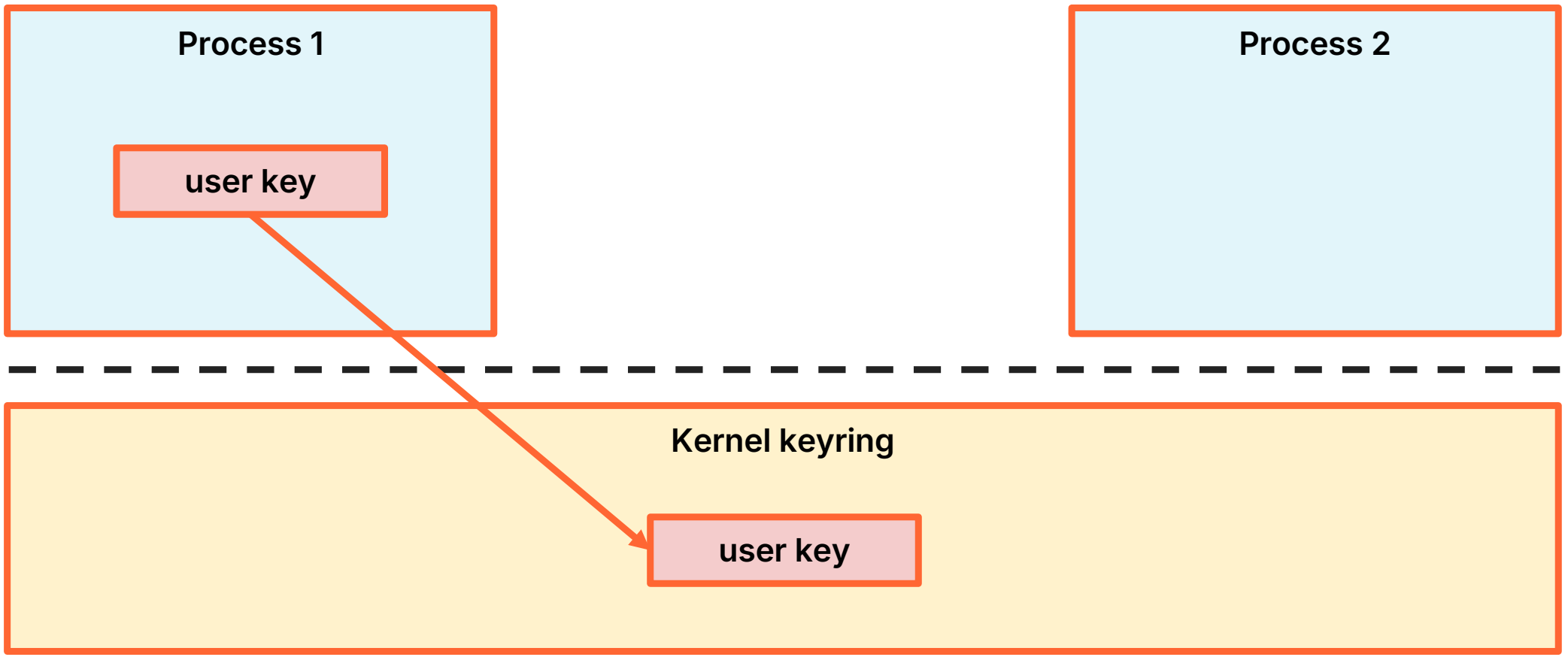

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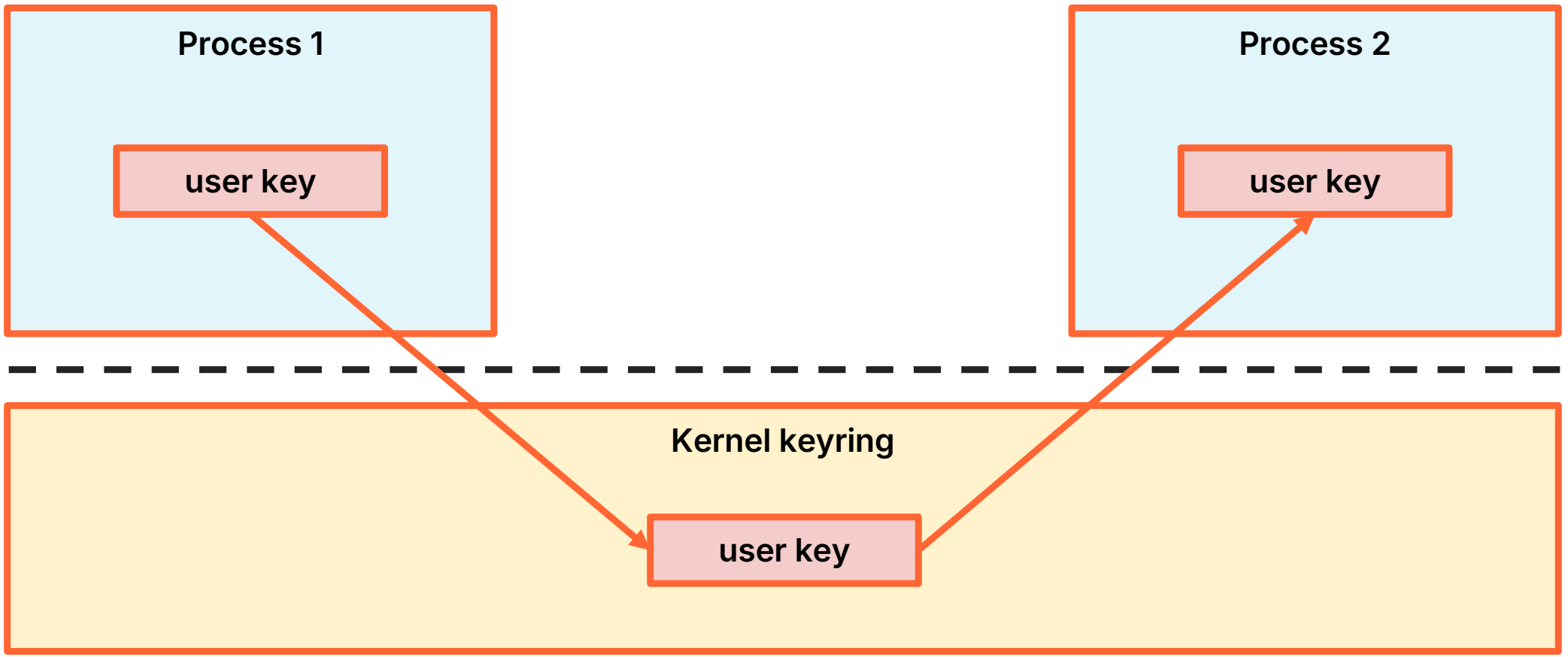

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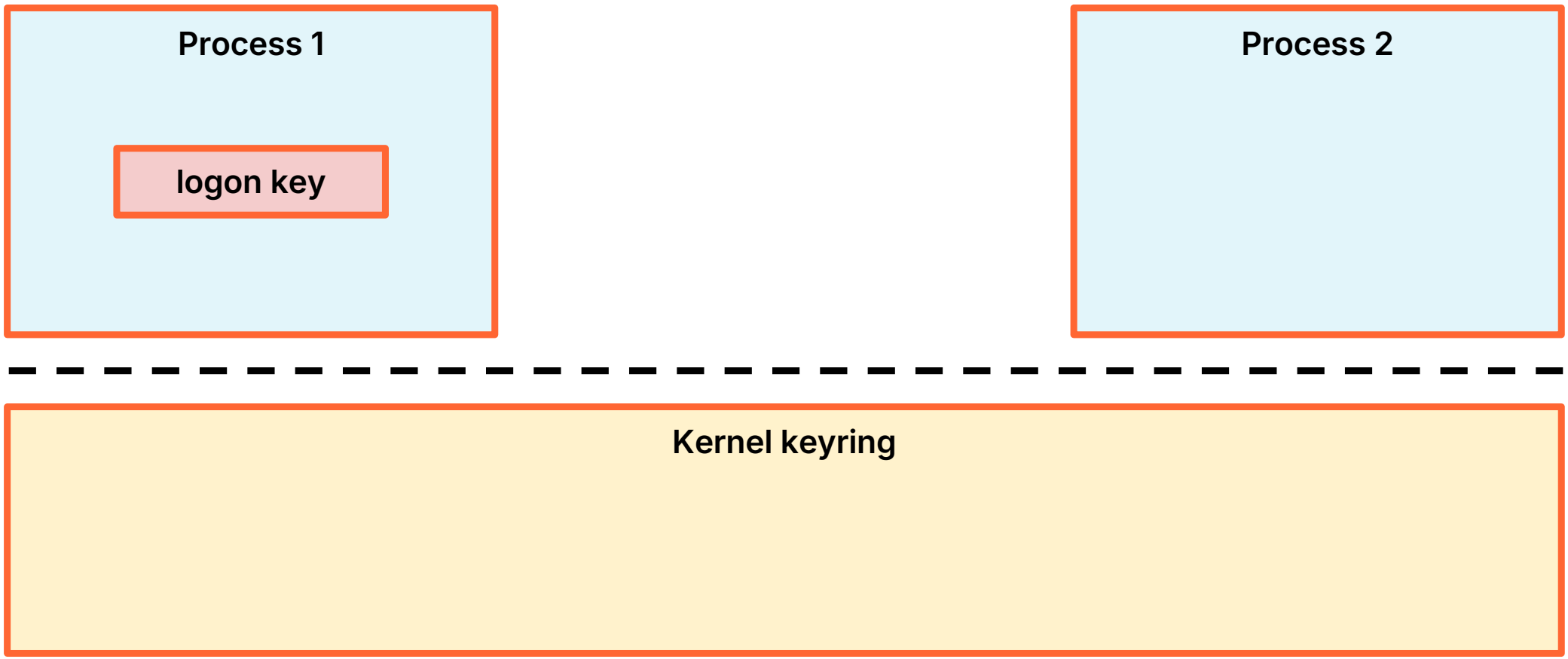
Logon keys



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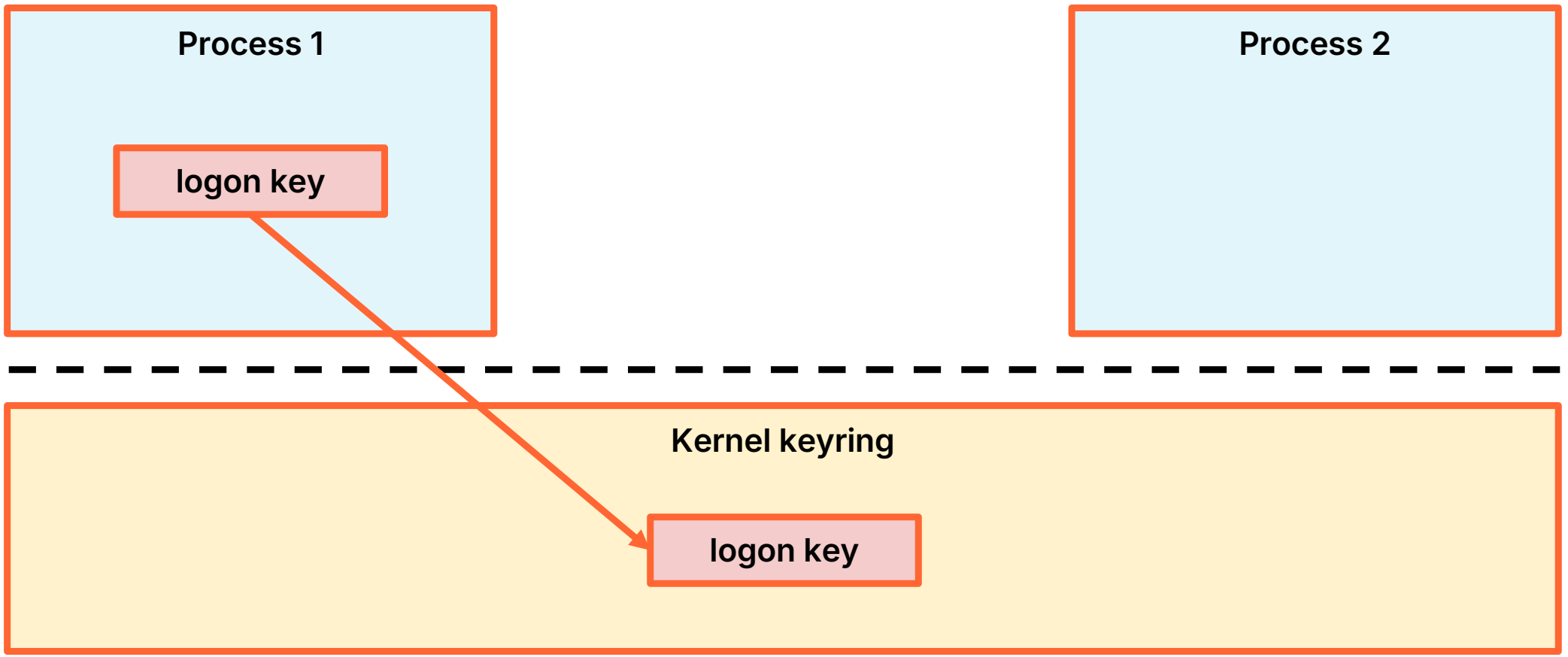
Logon keys



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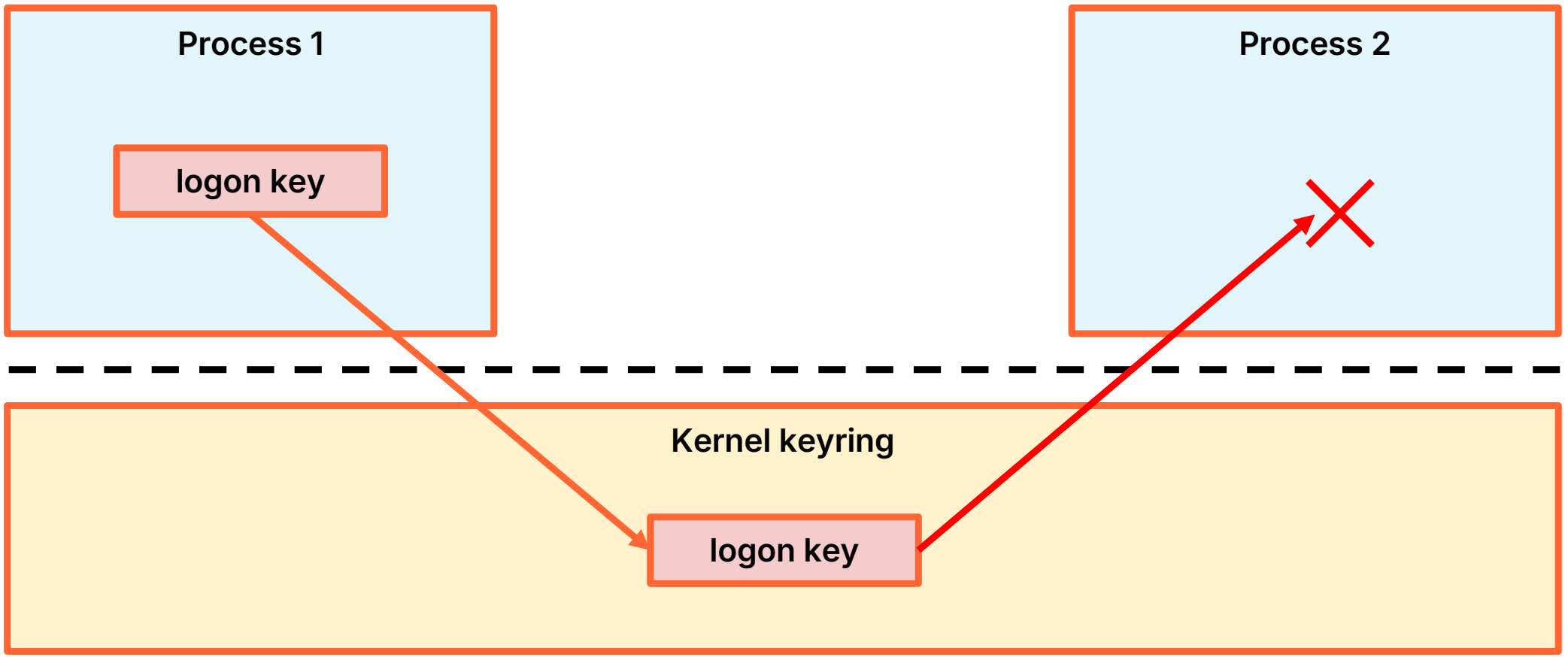

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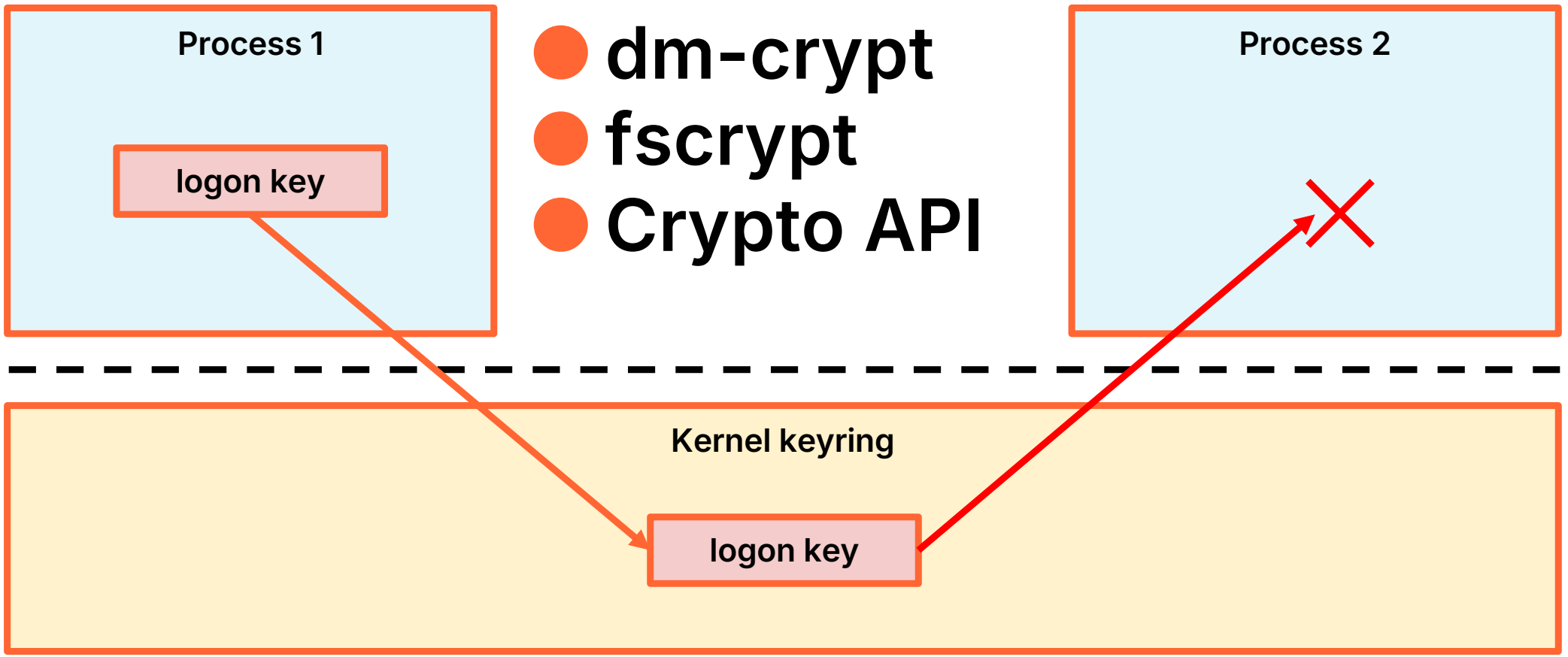

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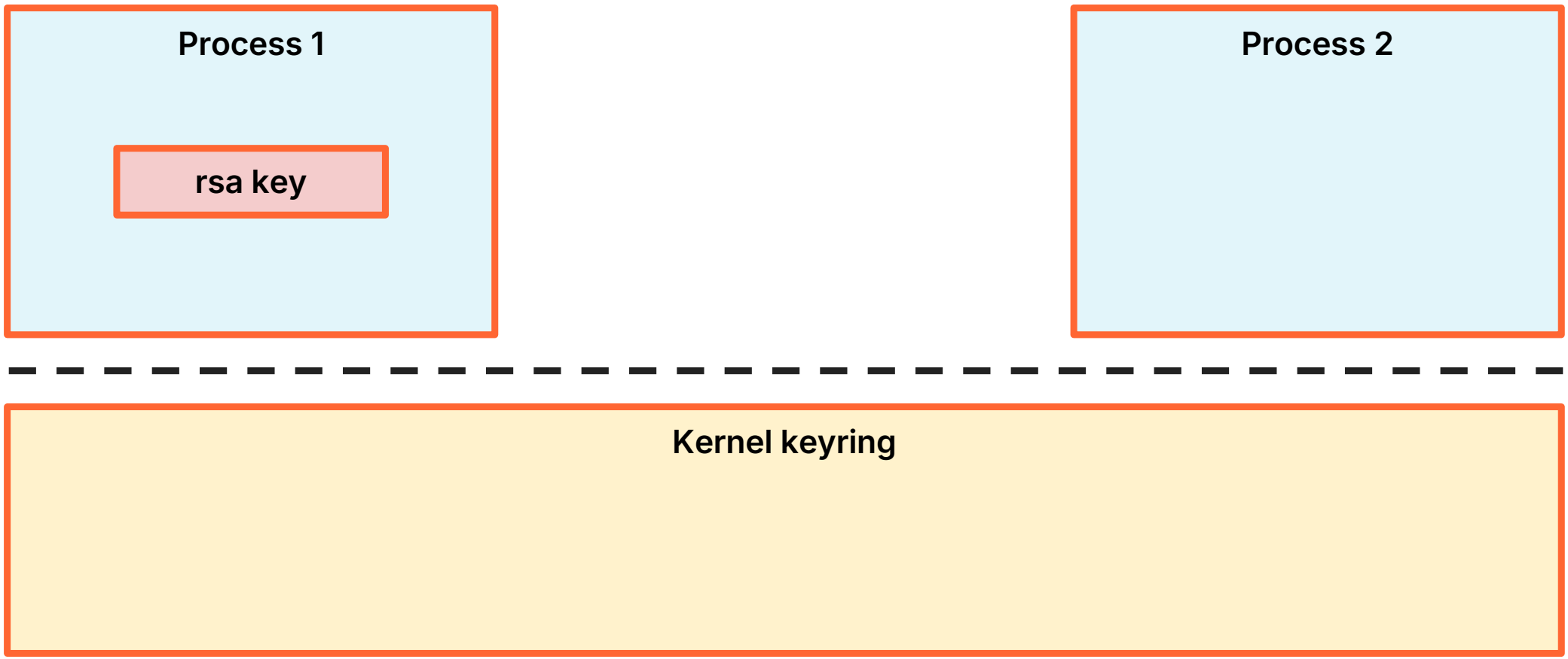
Asymmetric keys



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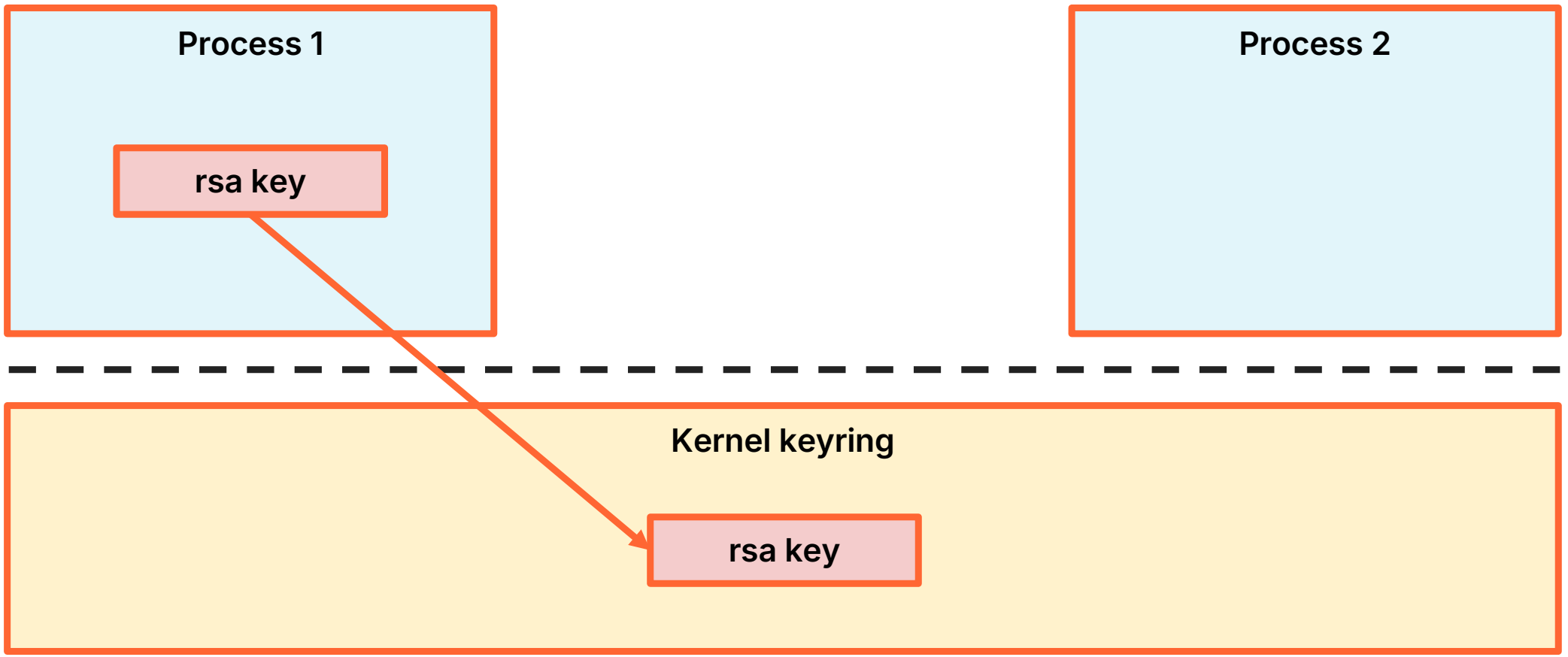
Asymmetric keys



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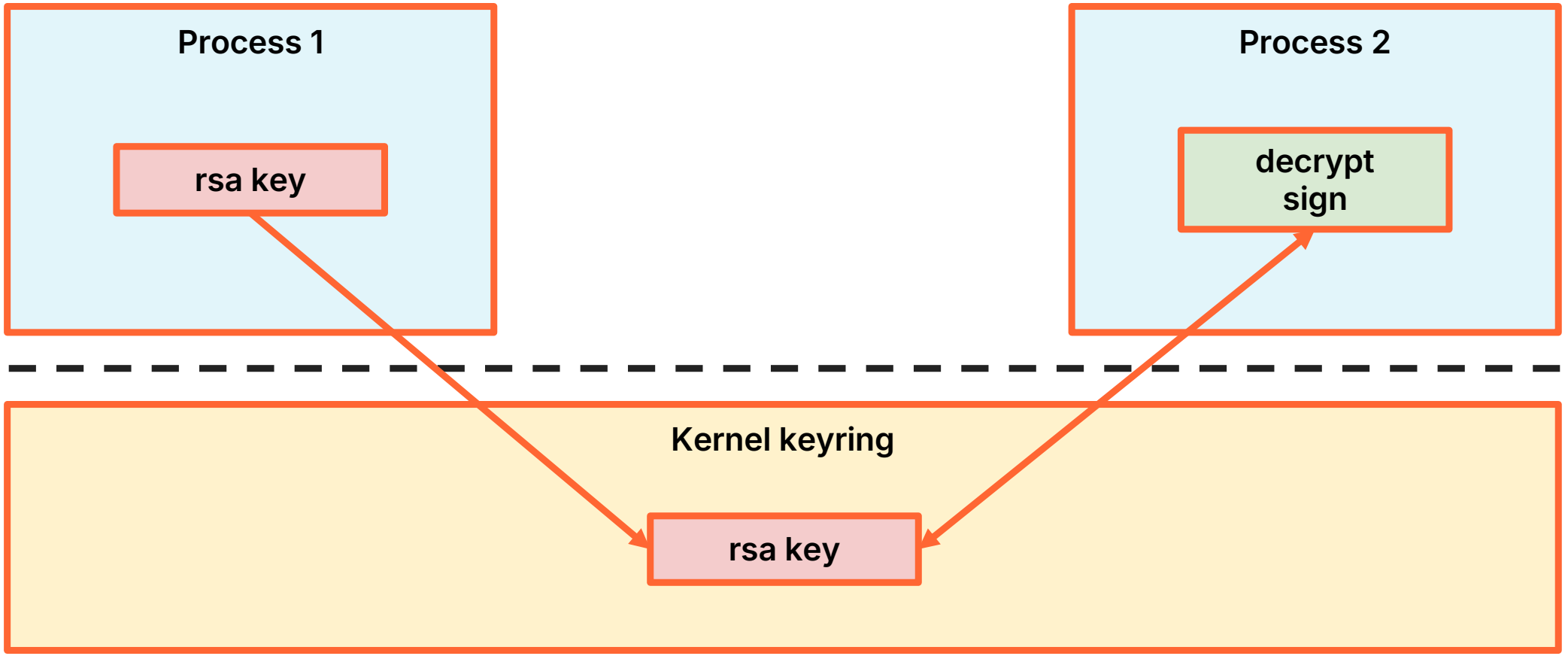
Asymmetric keys



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Linux keystore and TPMs

Better together?

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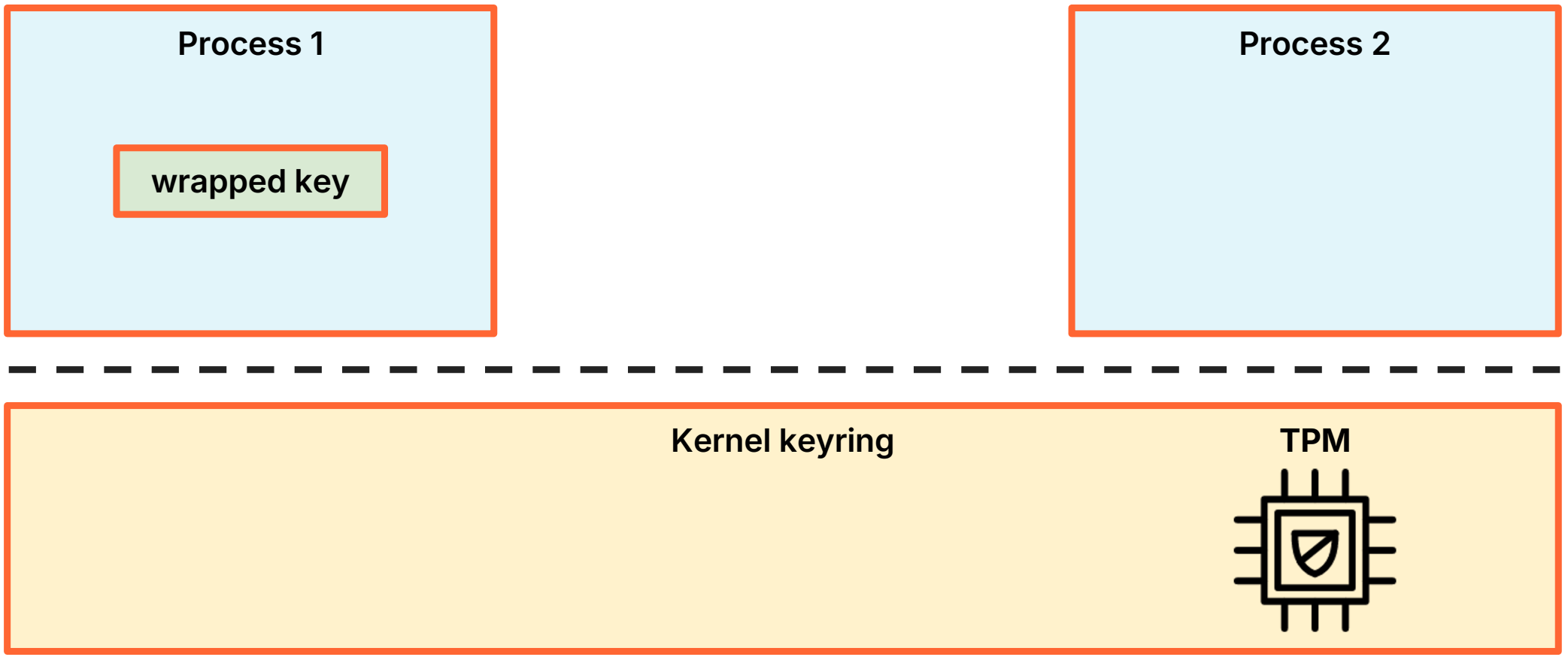
Trusted keys



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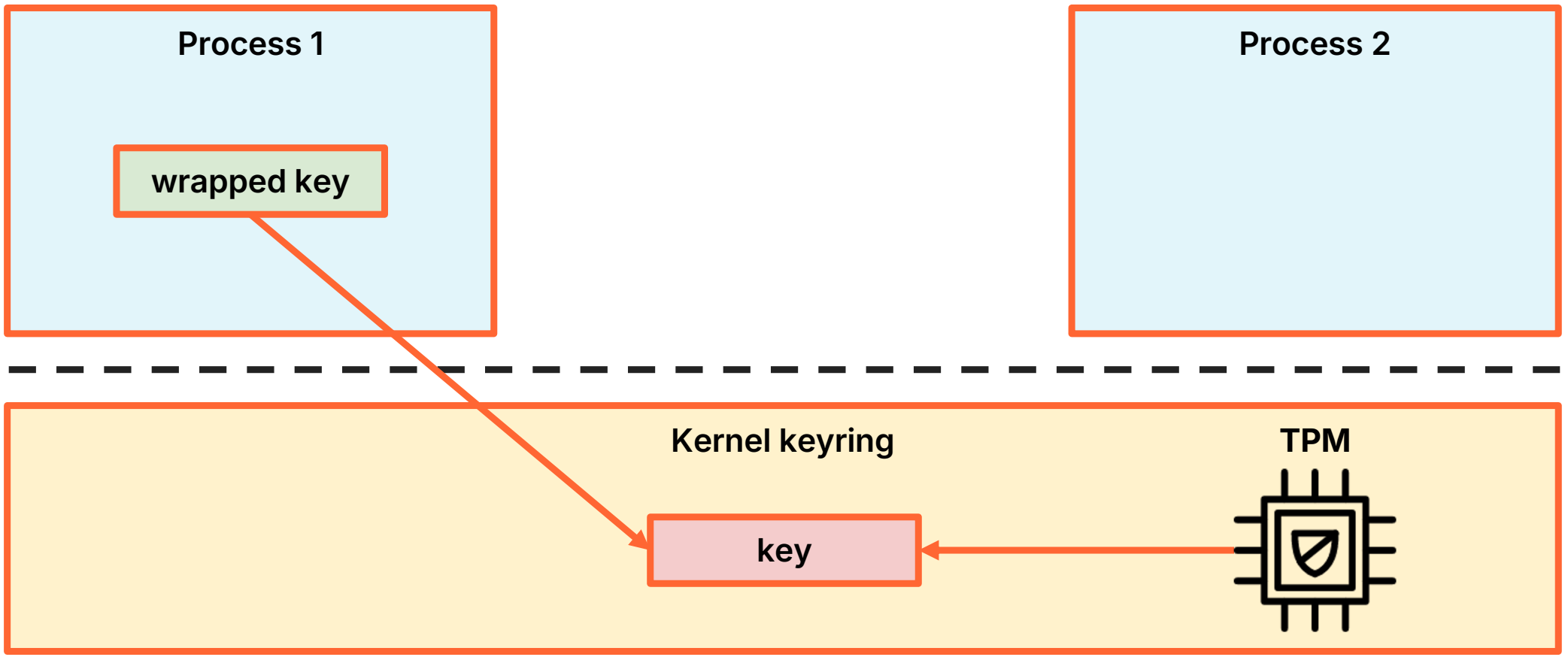
Trusted keys



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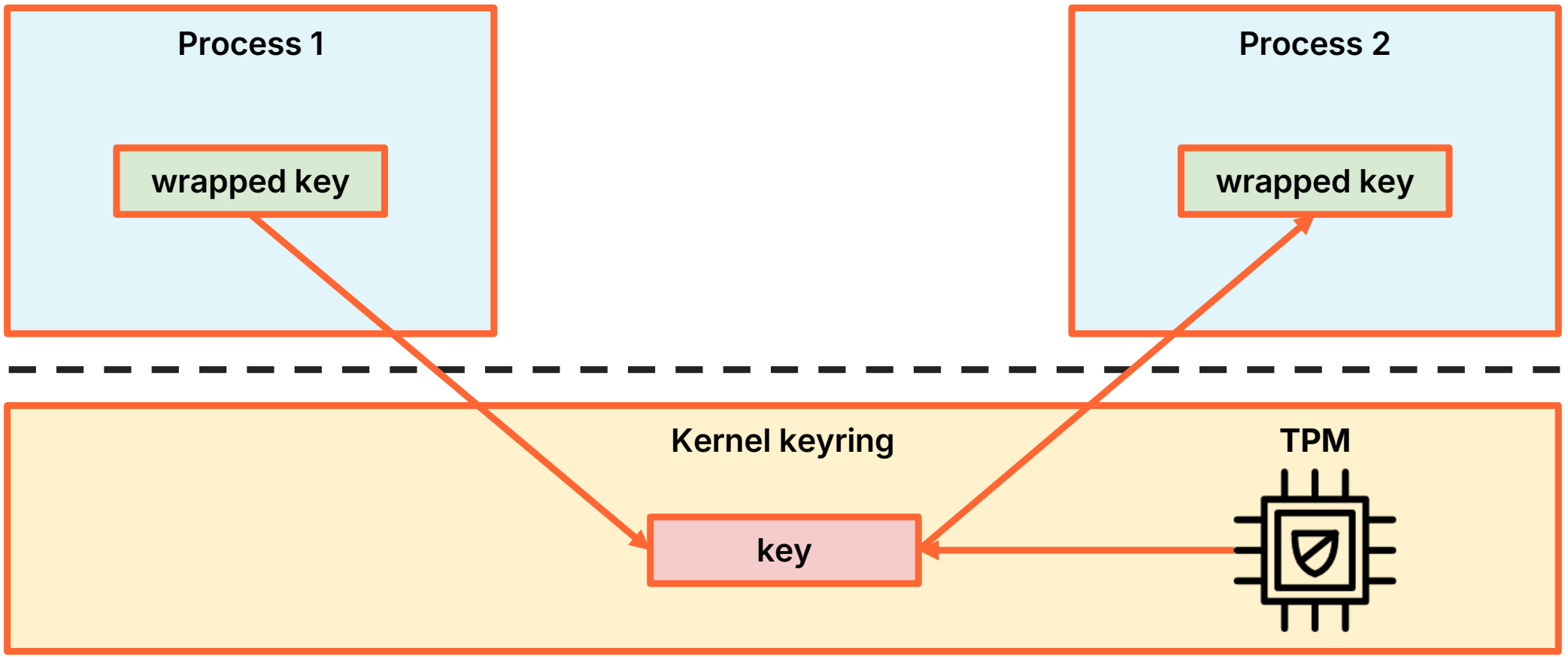

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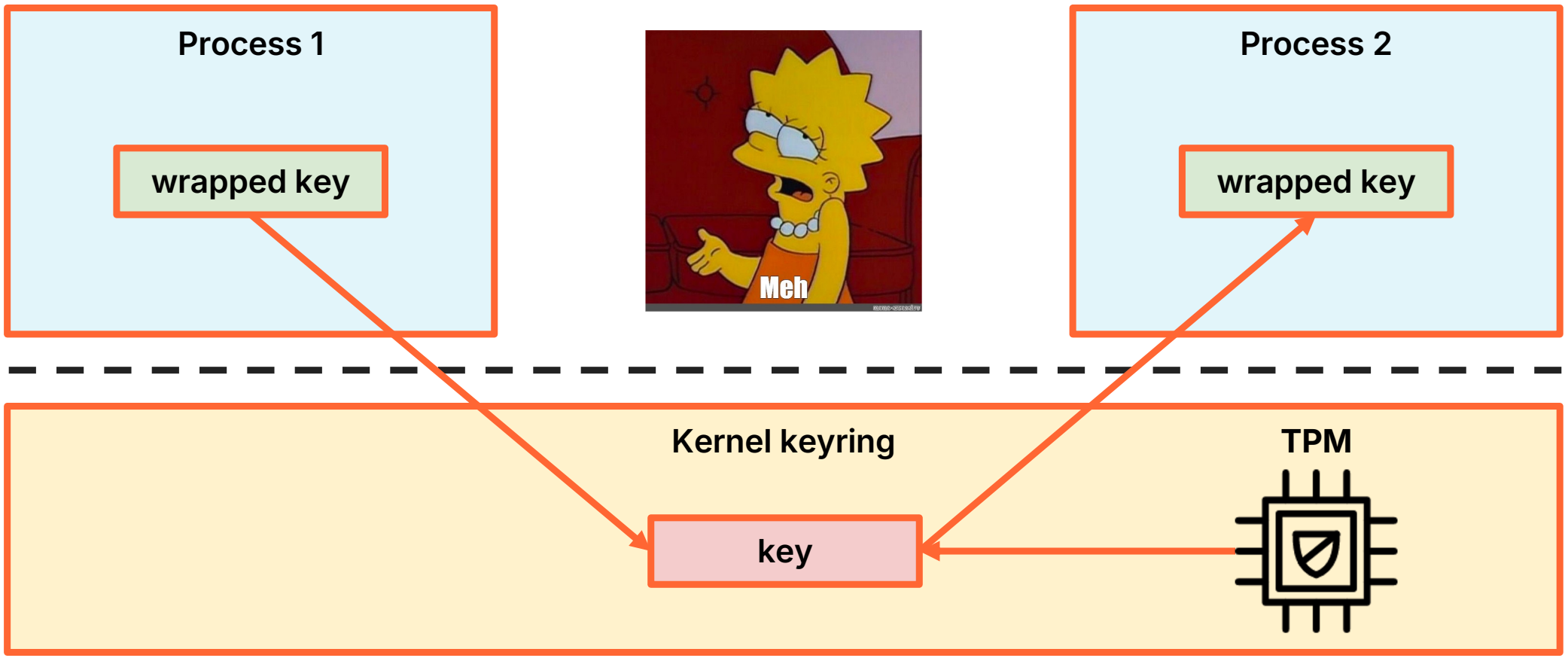

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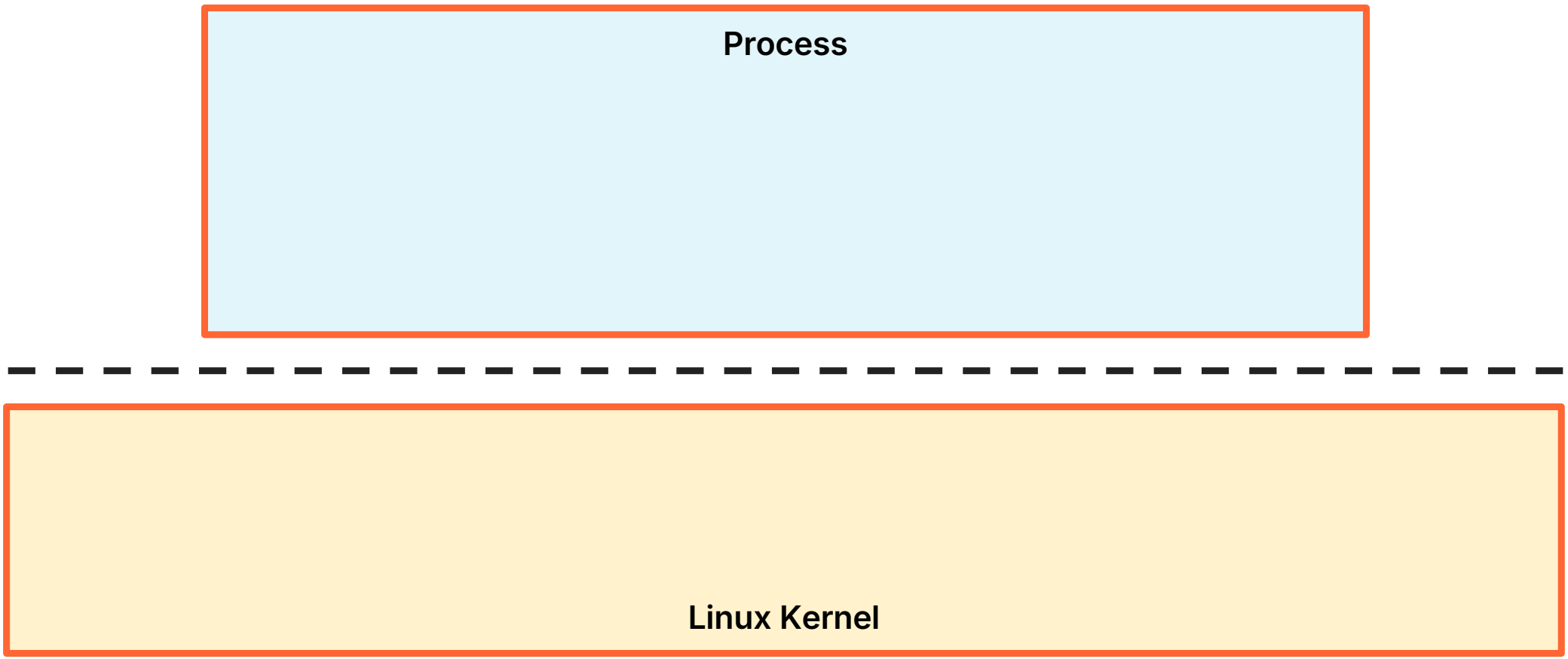
Linux Crypto API



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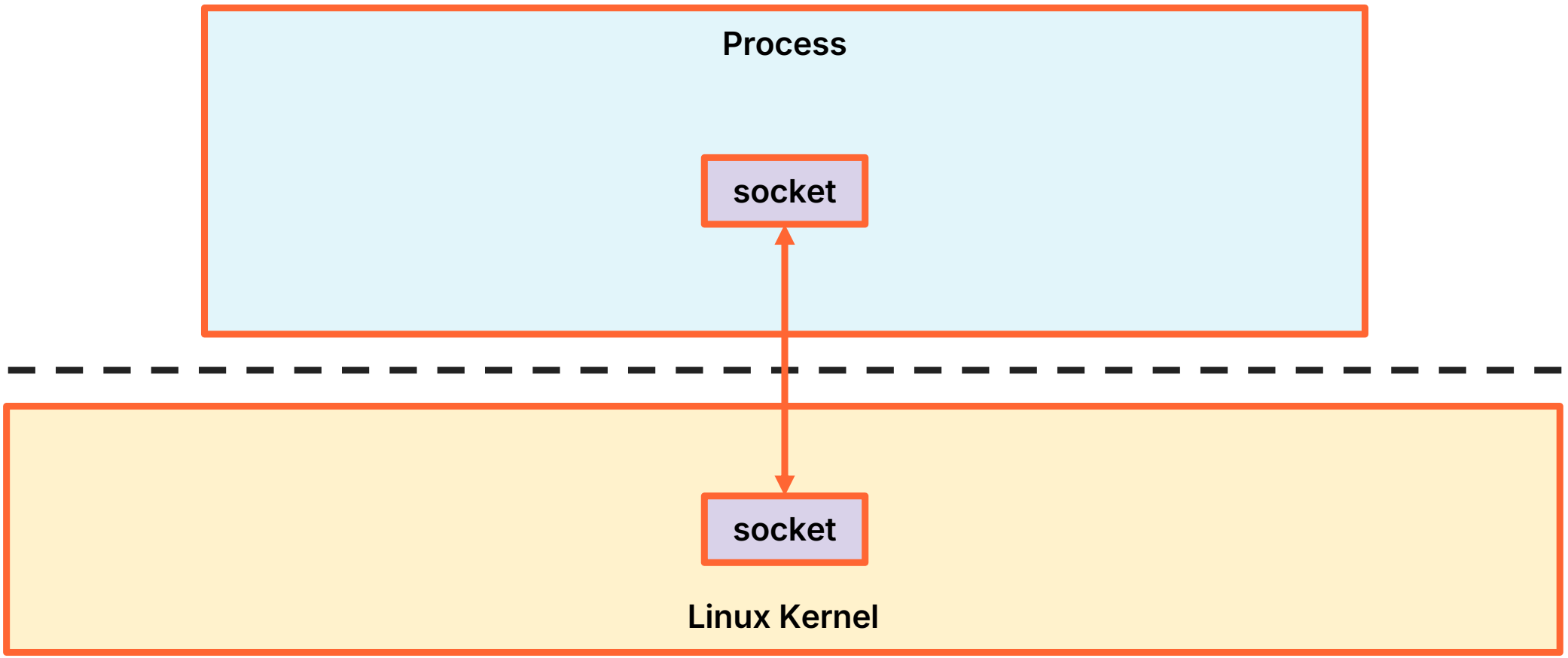
CLOUDFLARE

Linux Crypto API



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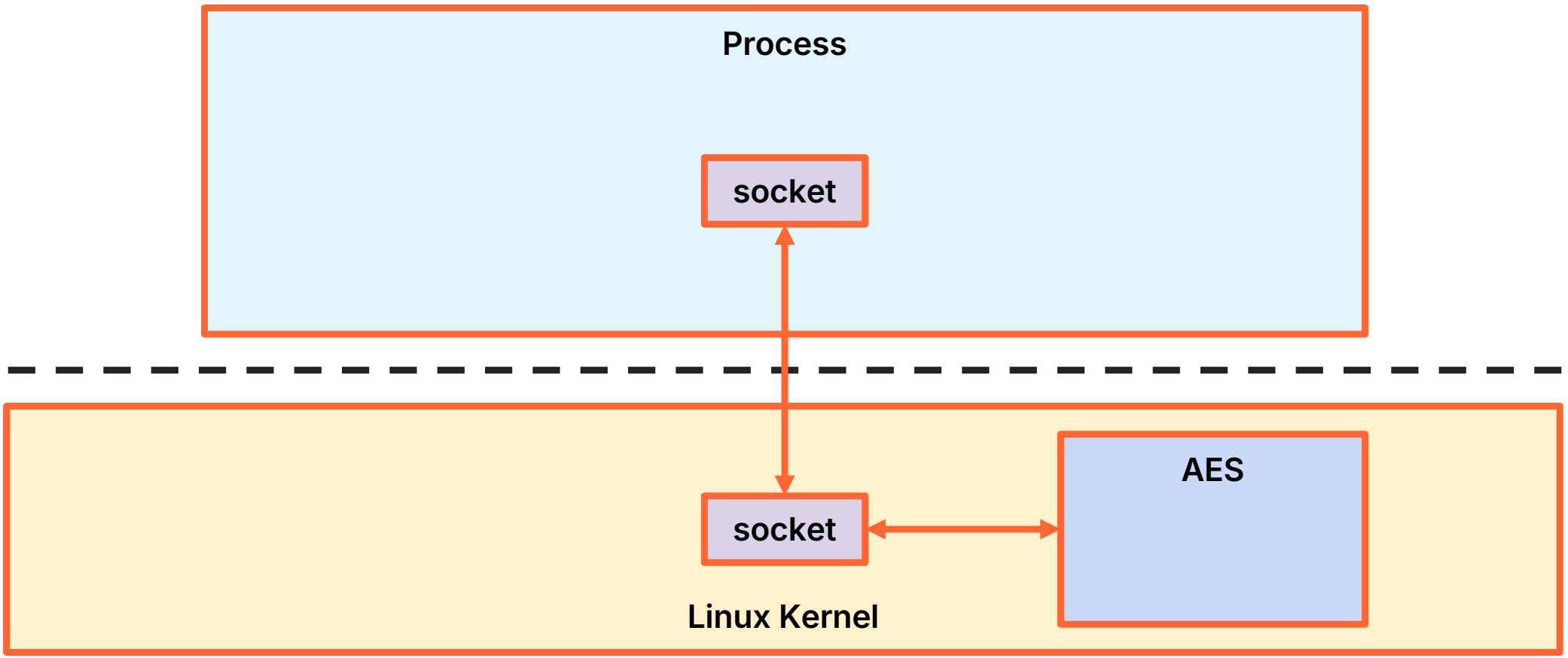
CLOUDFLARE

Linux Crypto API



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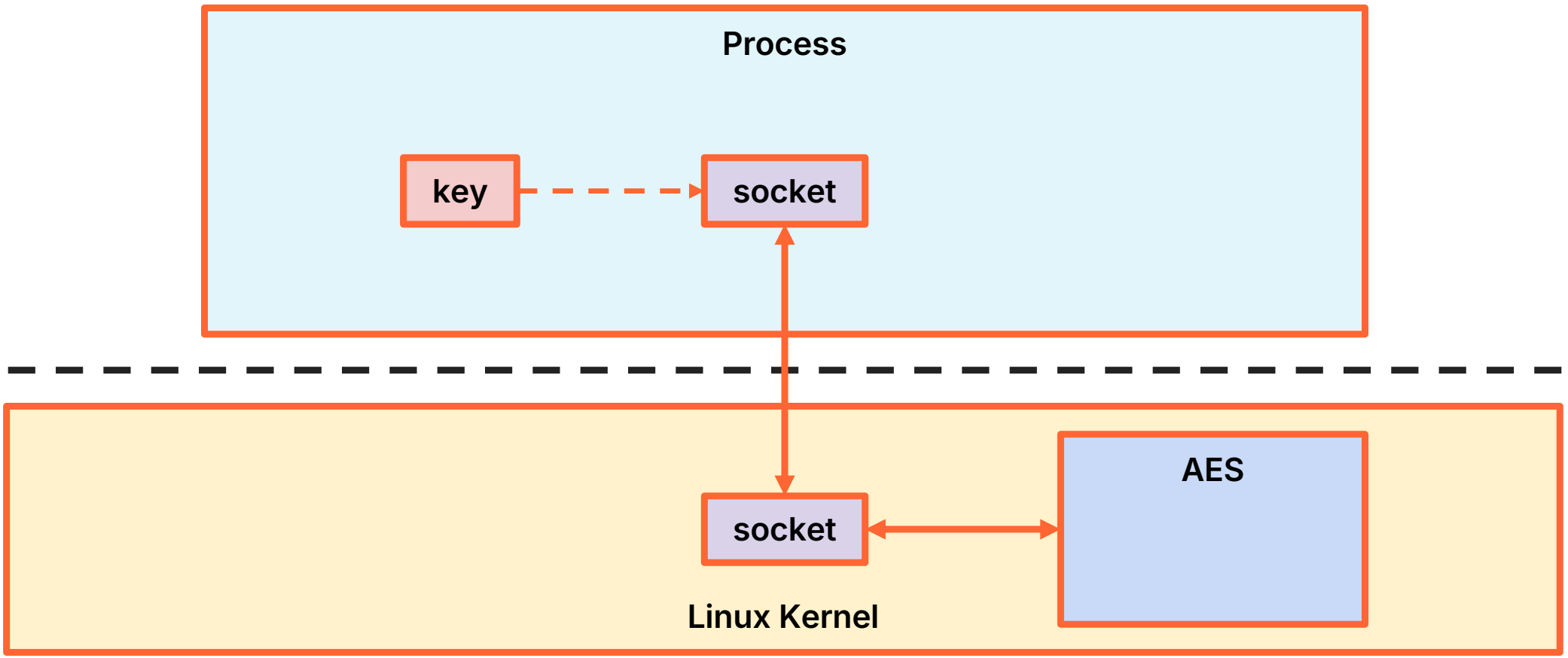
CLOUDFLARE

Linux Crypto API



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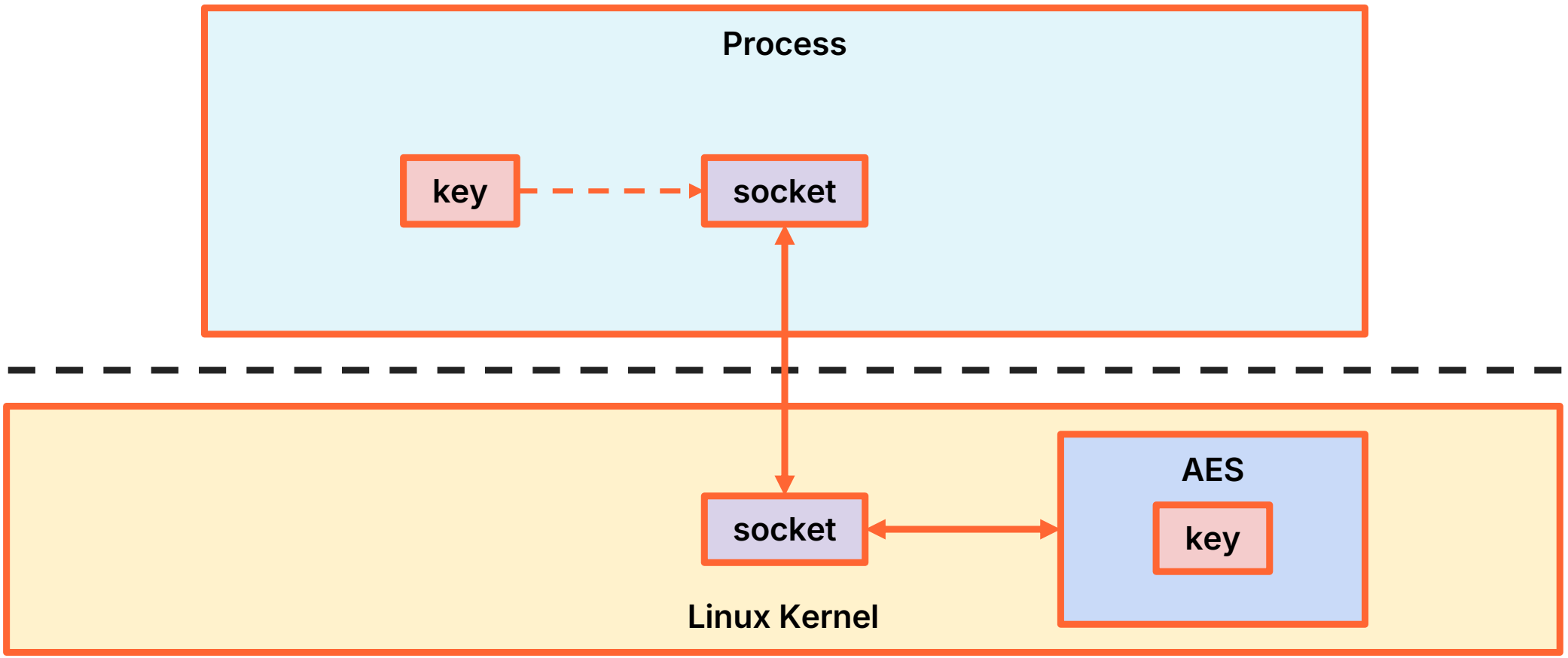
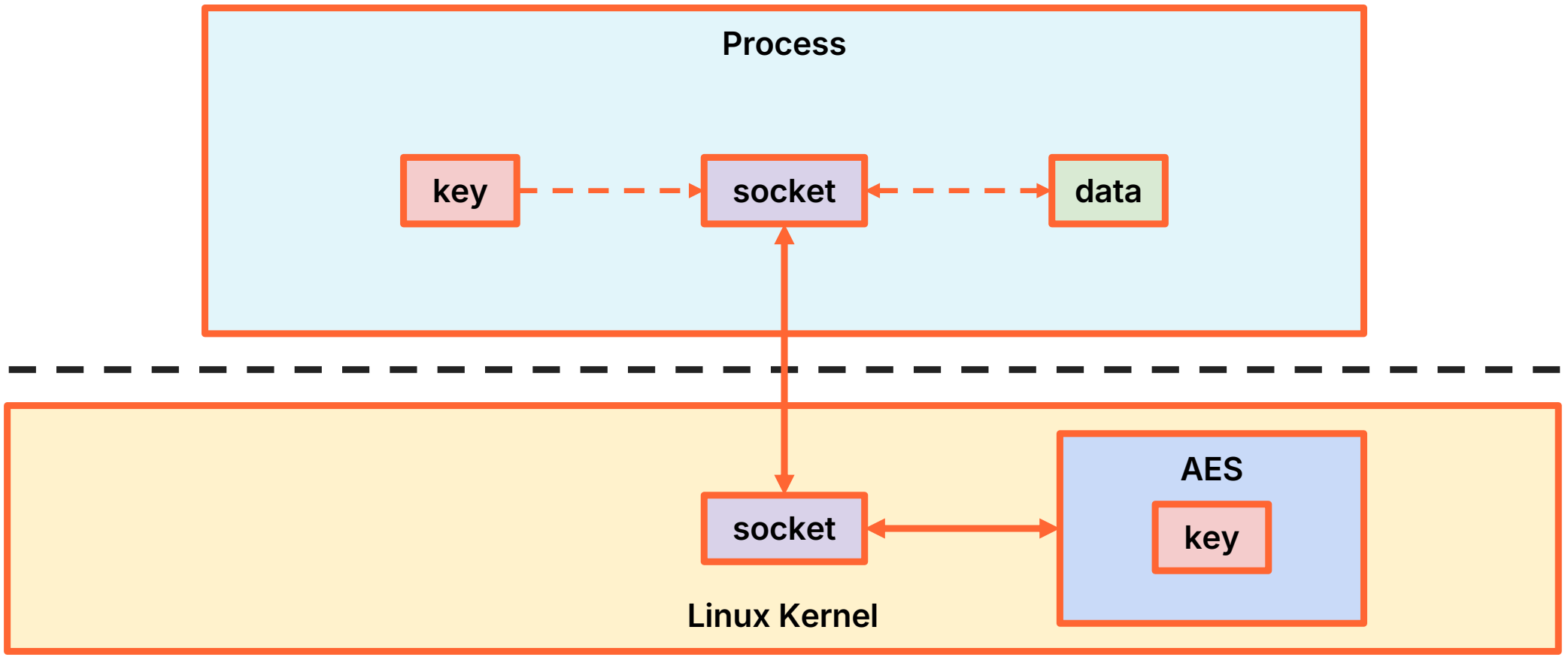
CLOUDFLARE

Linux Crypto API



CLOUDFLARE

Linux Crypto API



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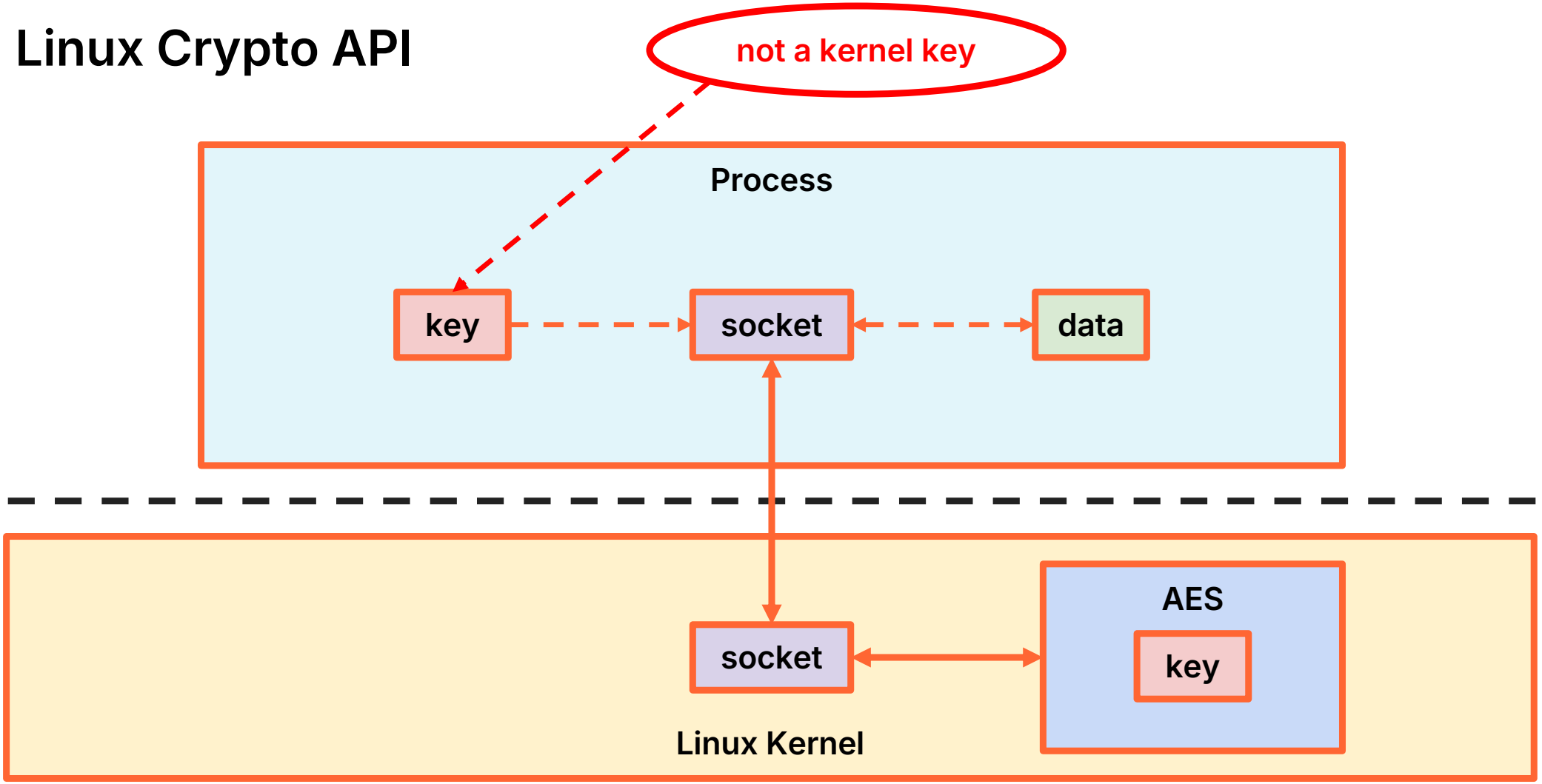
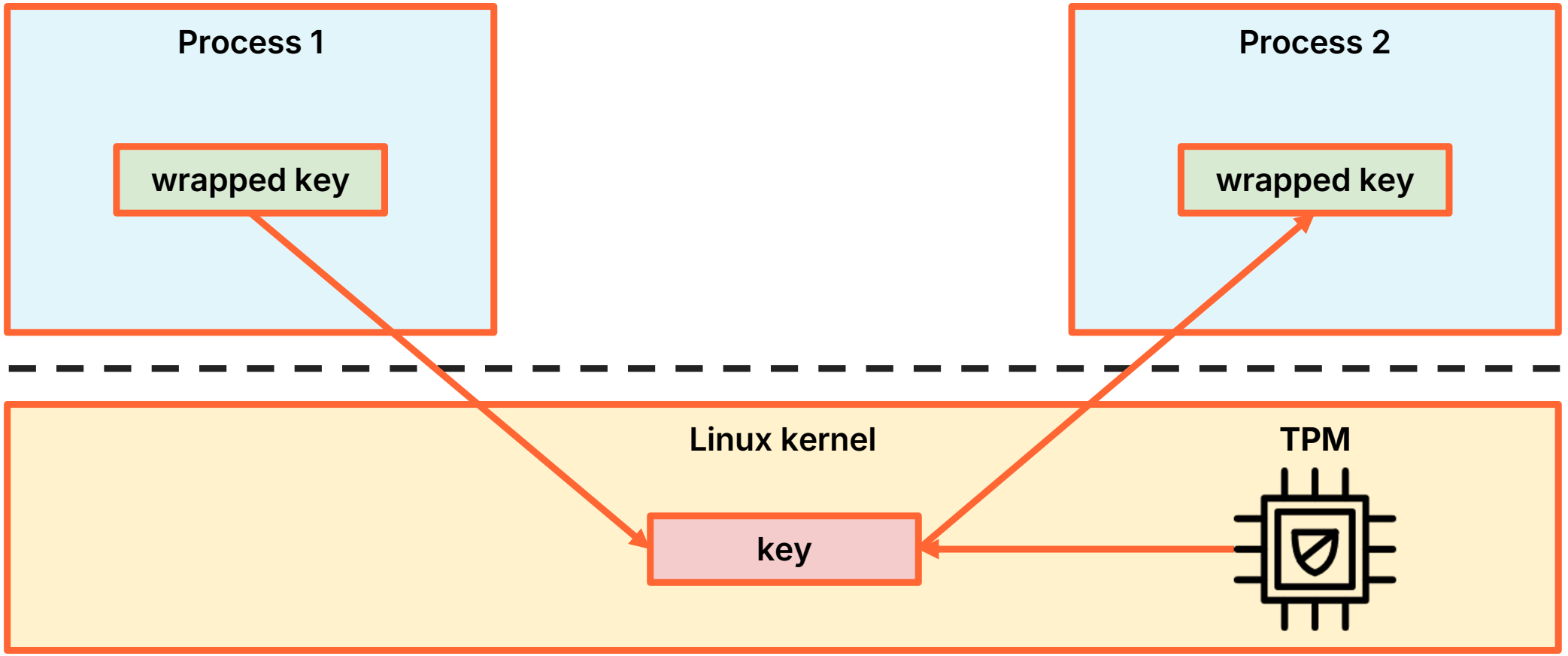
CLOUDFLARE

Linux Crypto API



CLOUDFLARE

Key usage from applications



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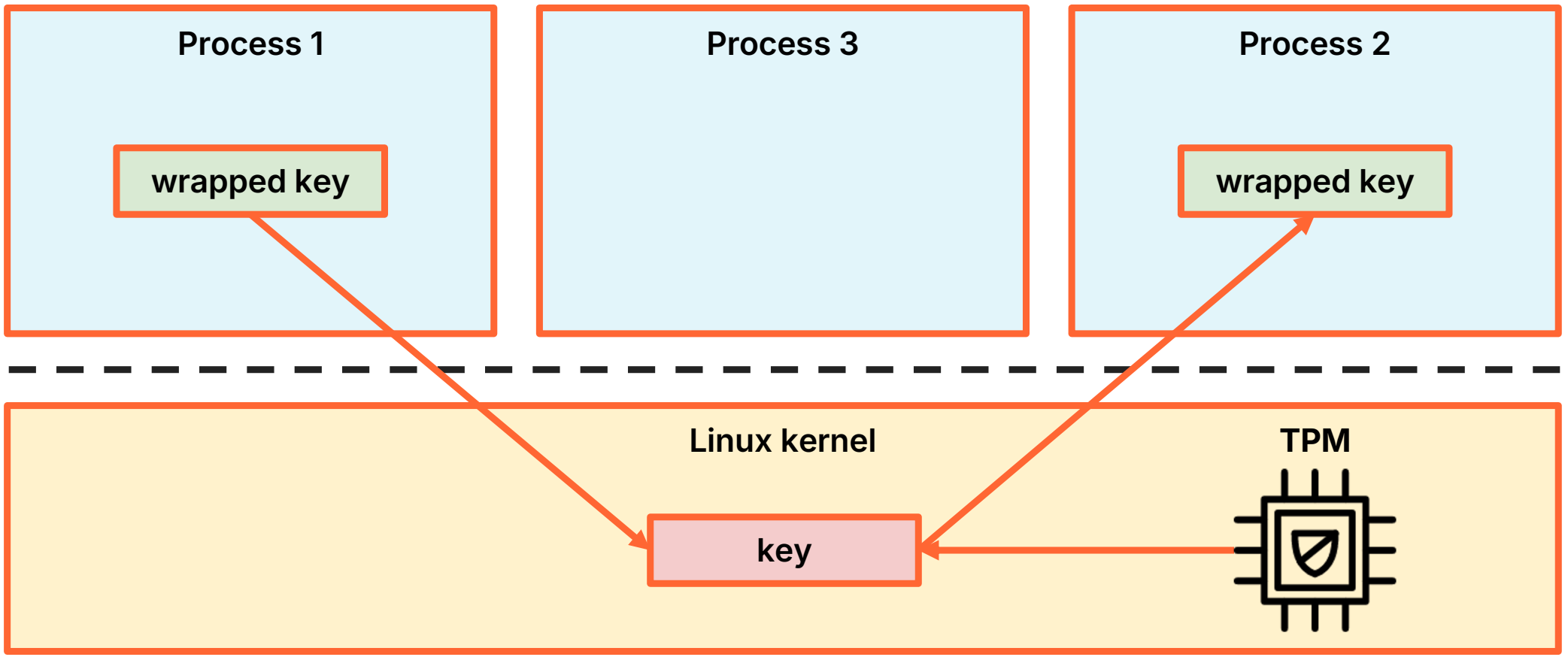

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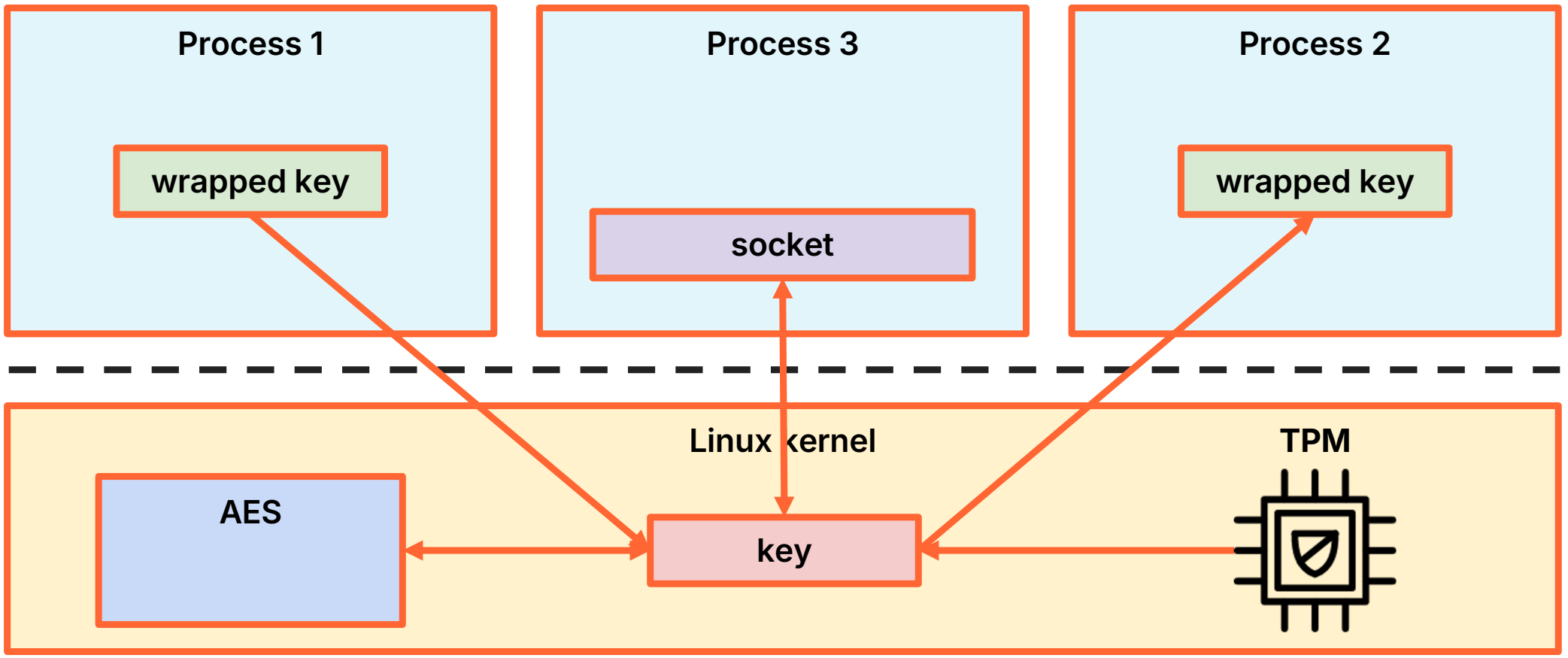

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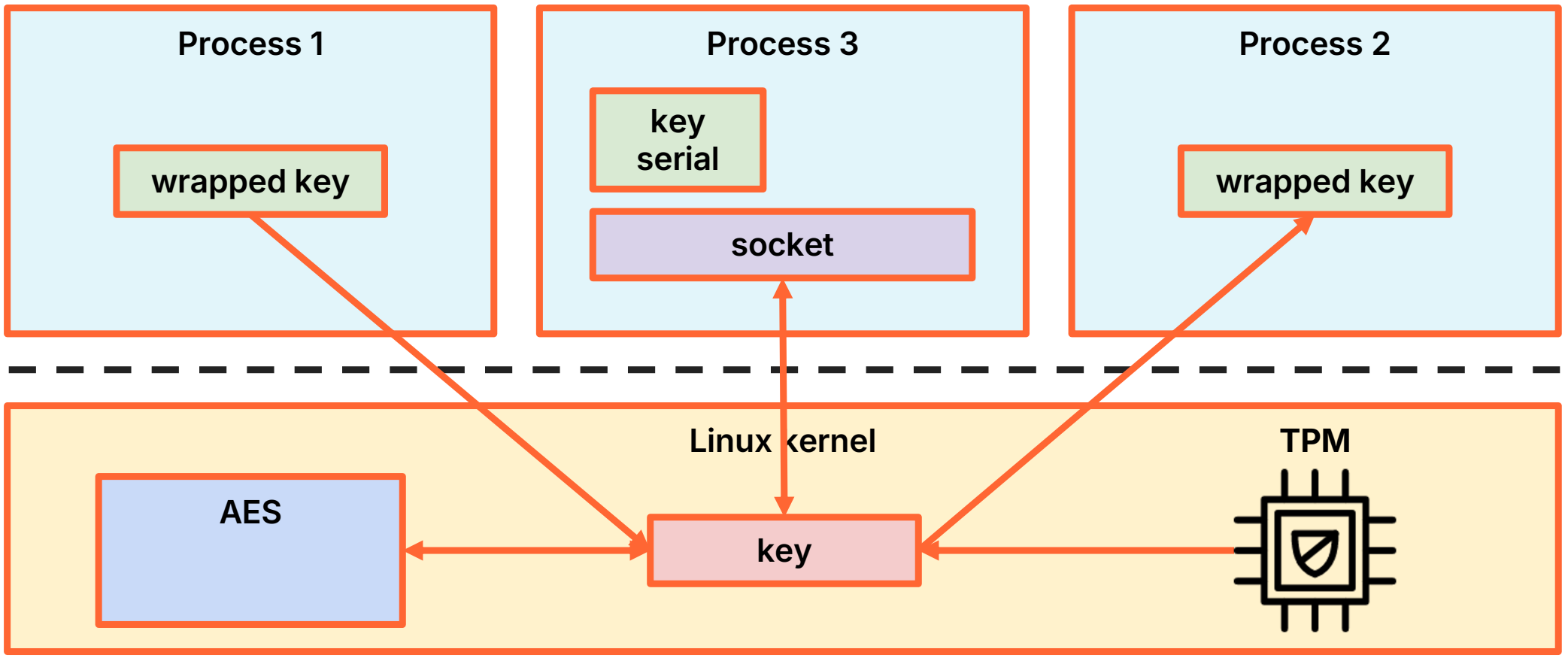

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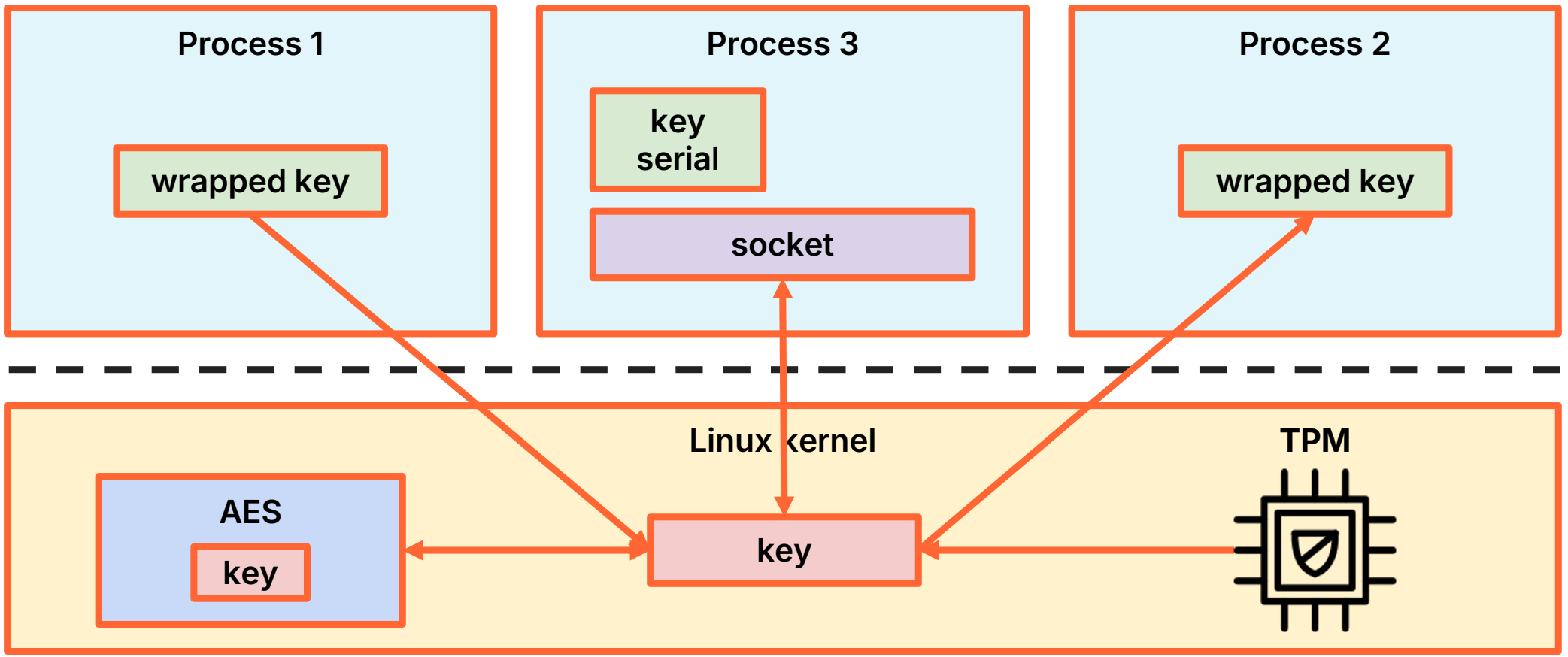

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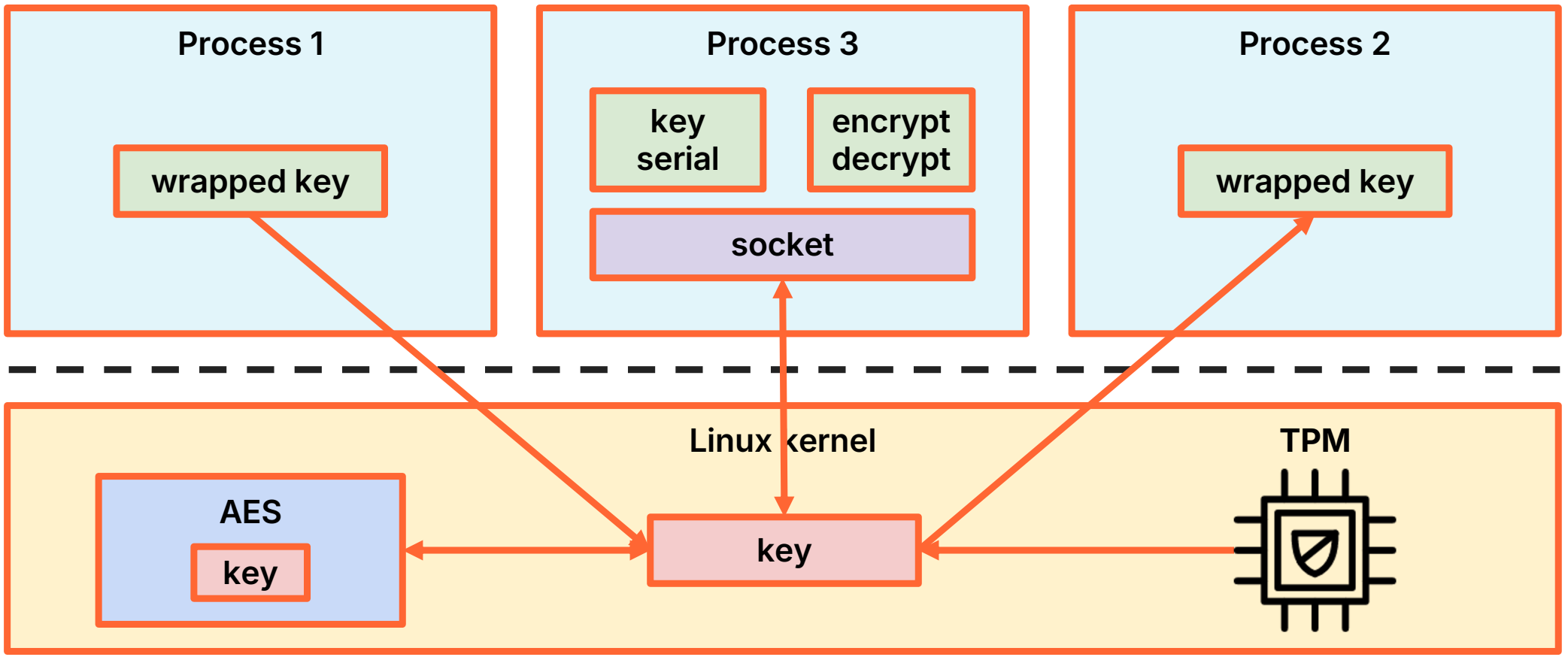

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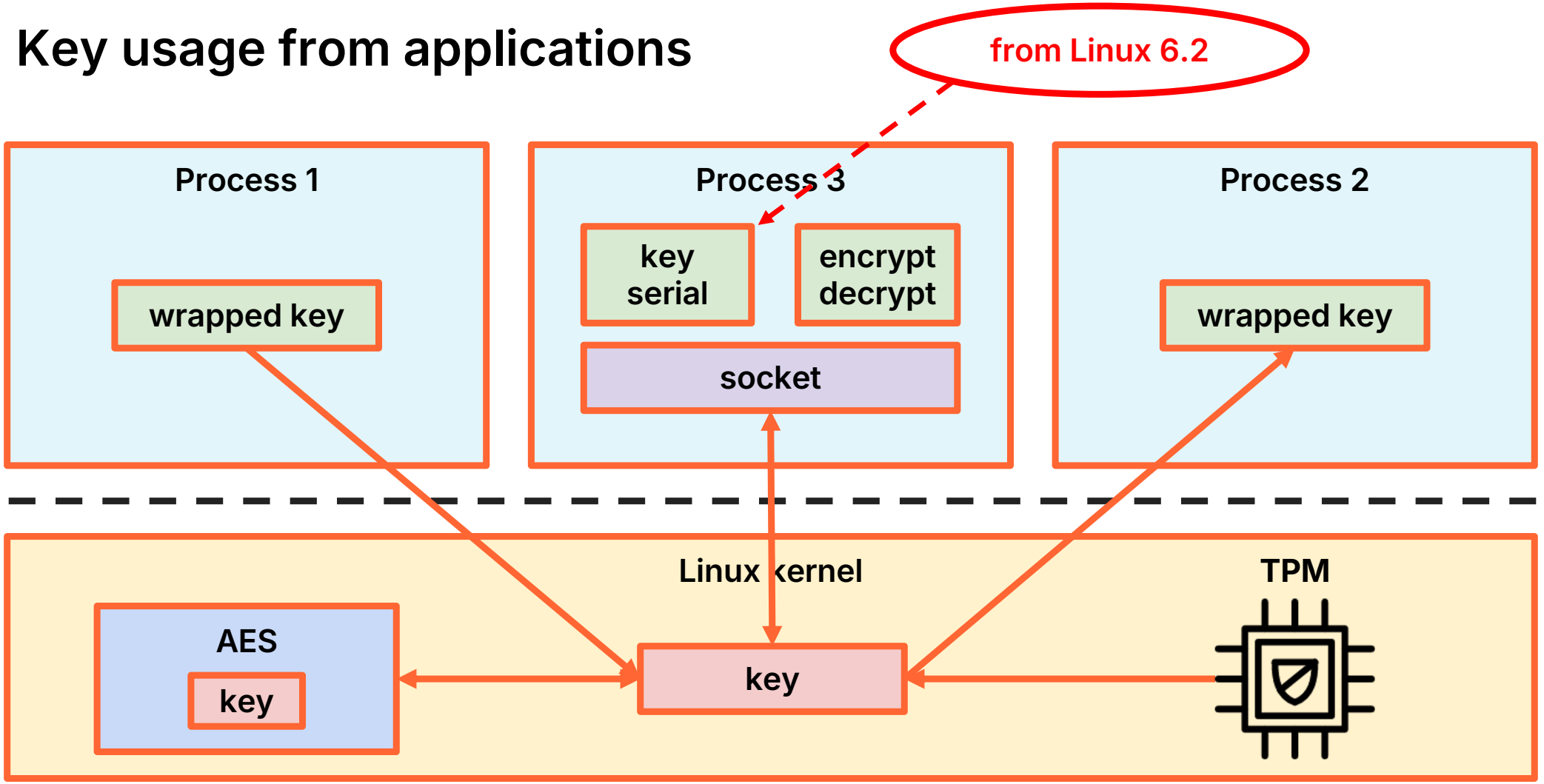

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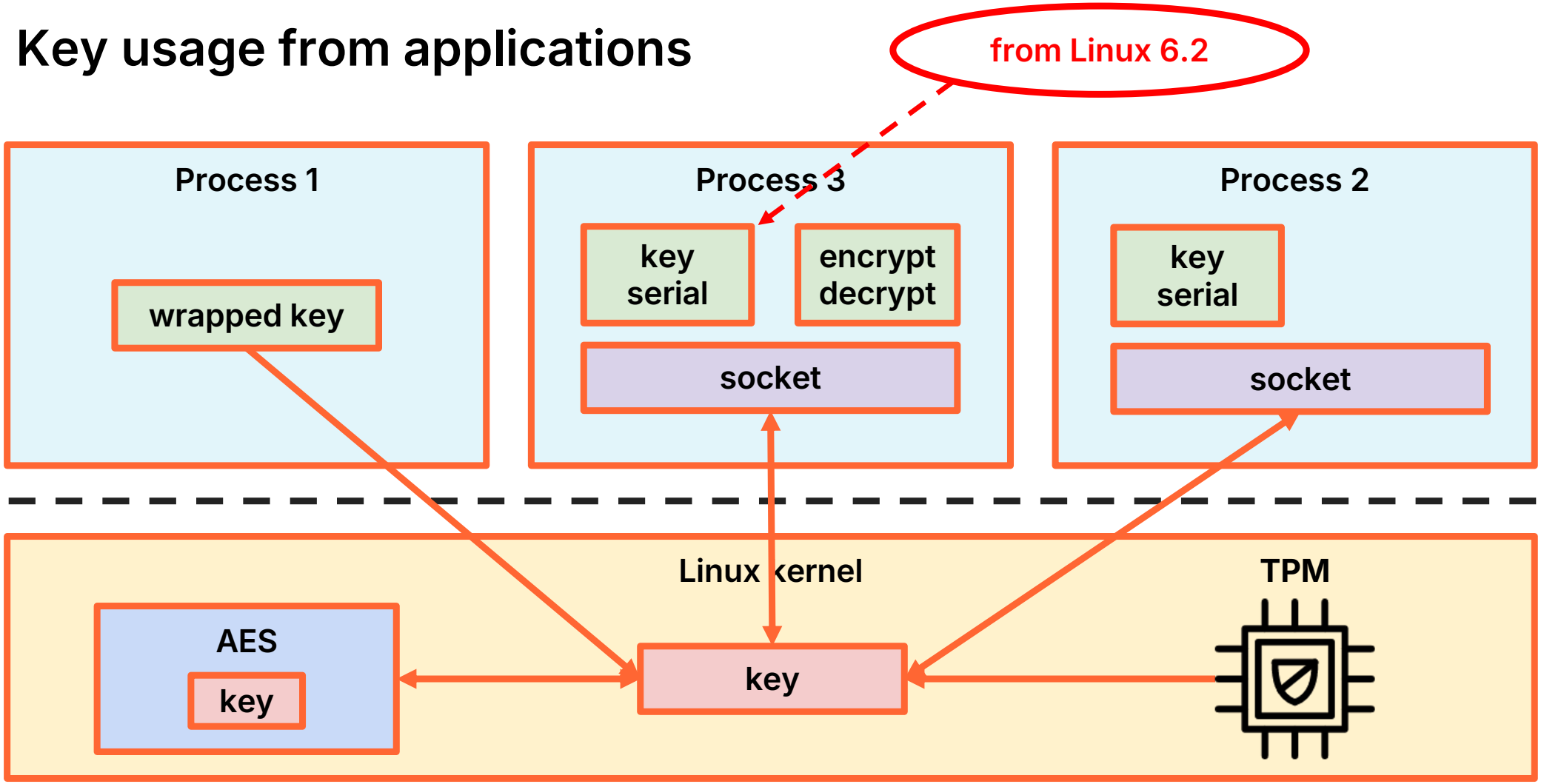

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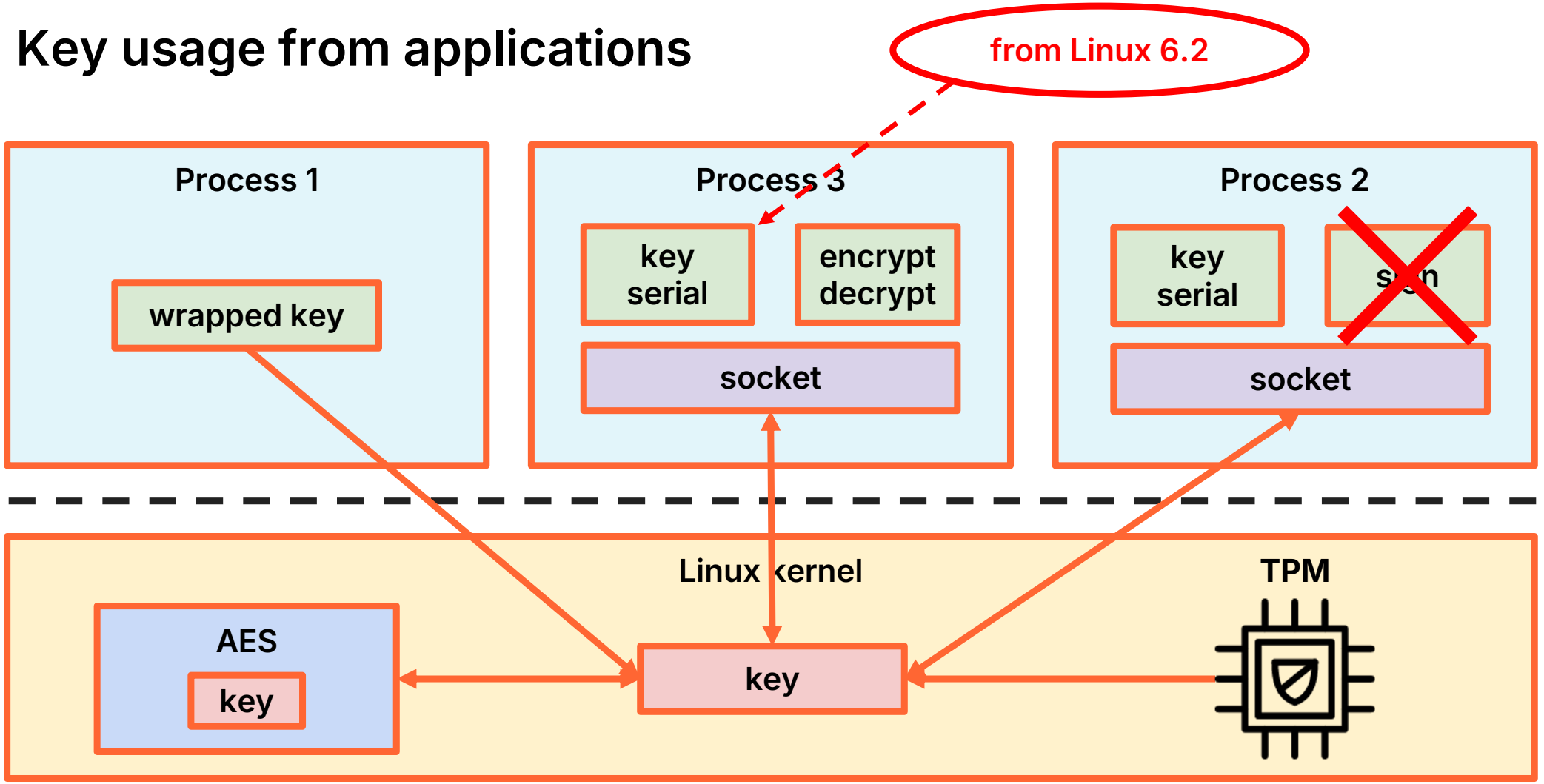


CLOUDFLARE

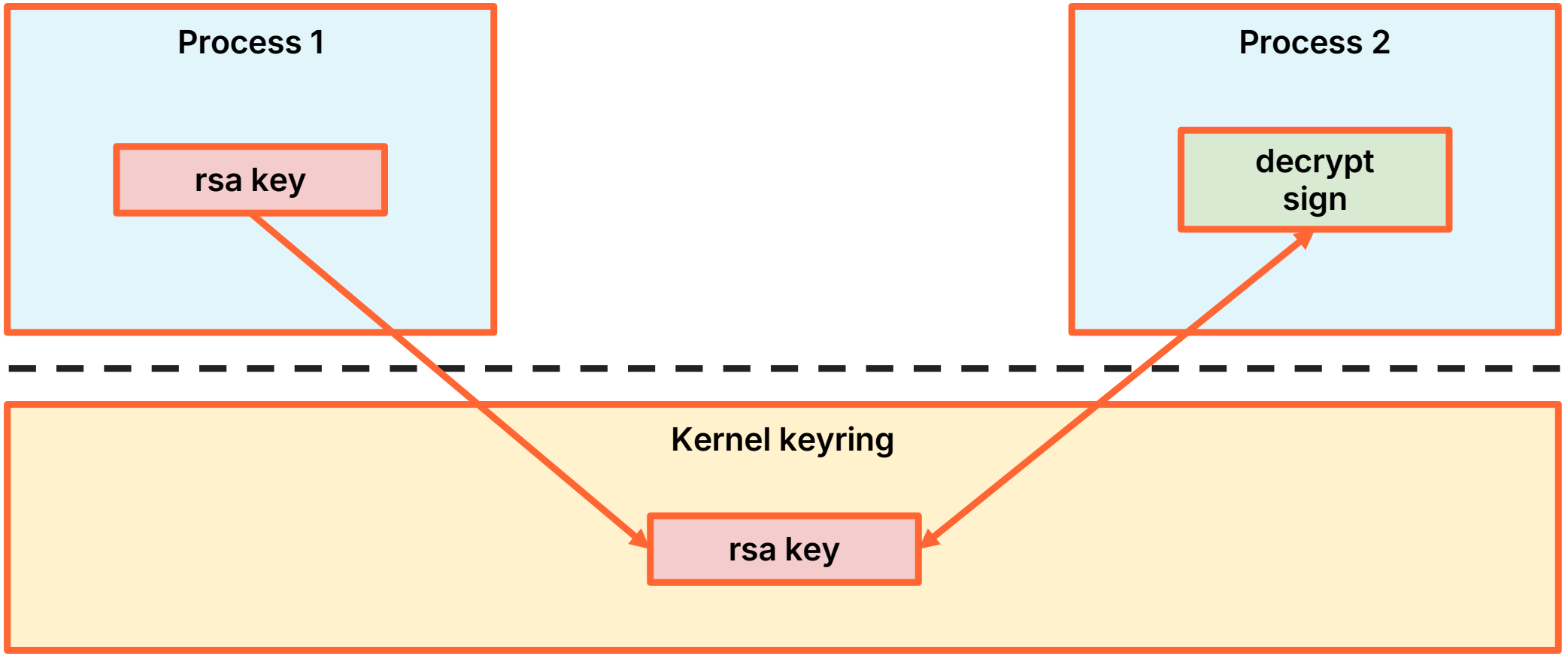
Asymmetric TPM keys

https://lore.kernel.org/lkml/20240528210823.28798-2-jarkko@kernel.org/T/

@ignatkn

CLOUDFLARE

Asymmetric TPM keys



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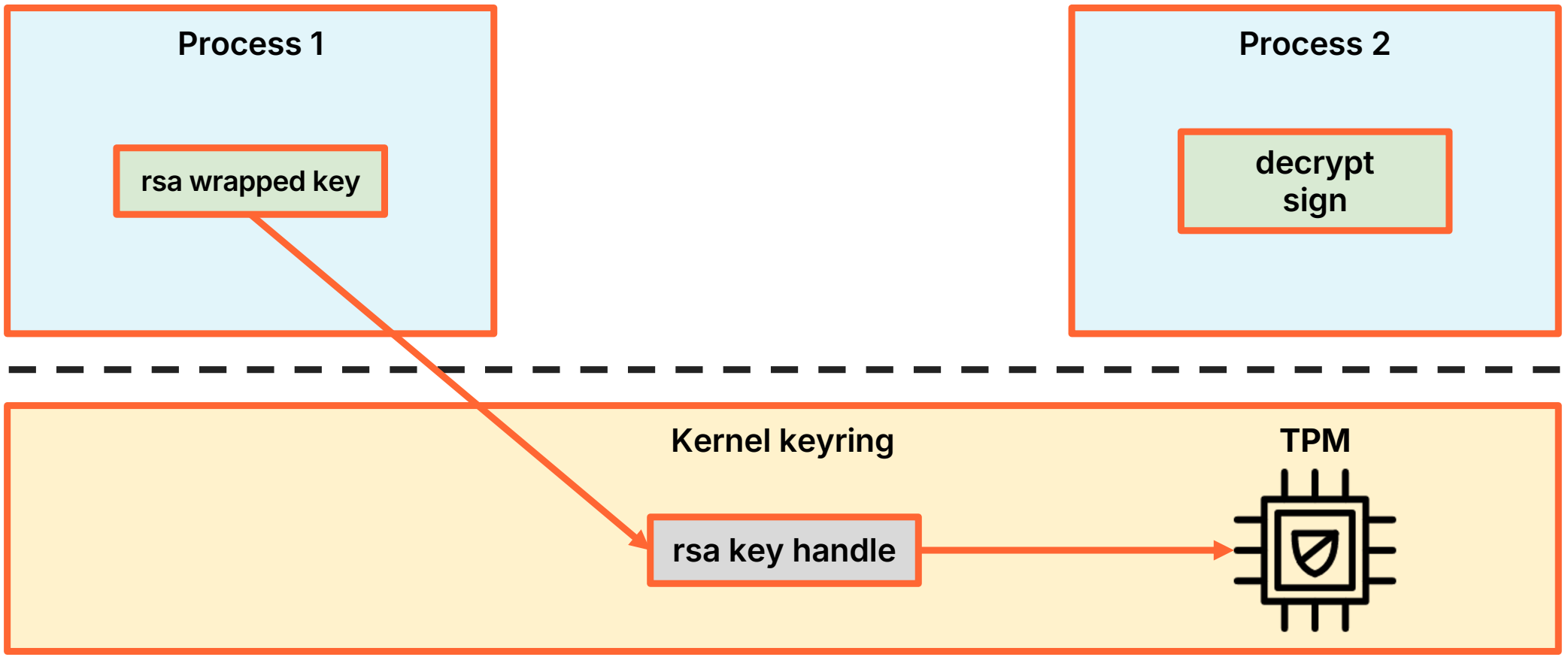
CLOUDFLARE

Asymmetric TPM keys



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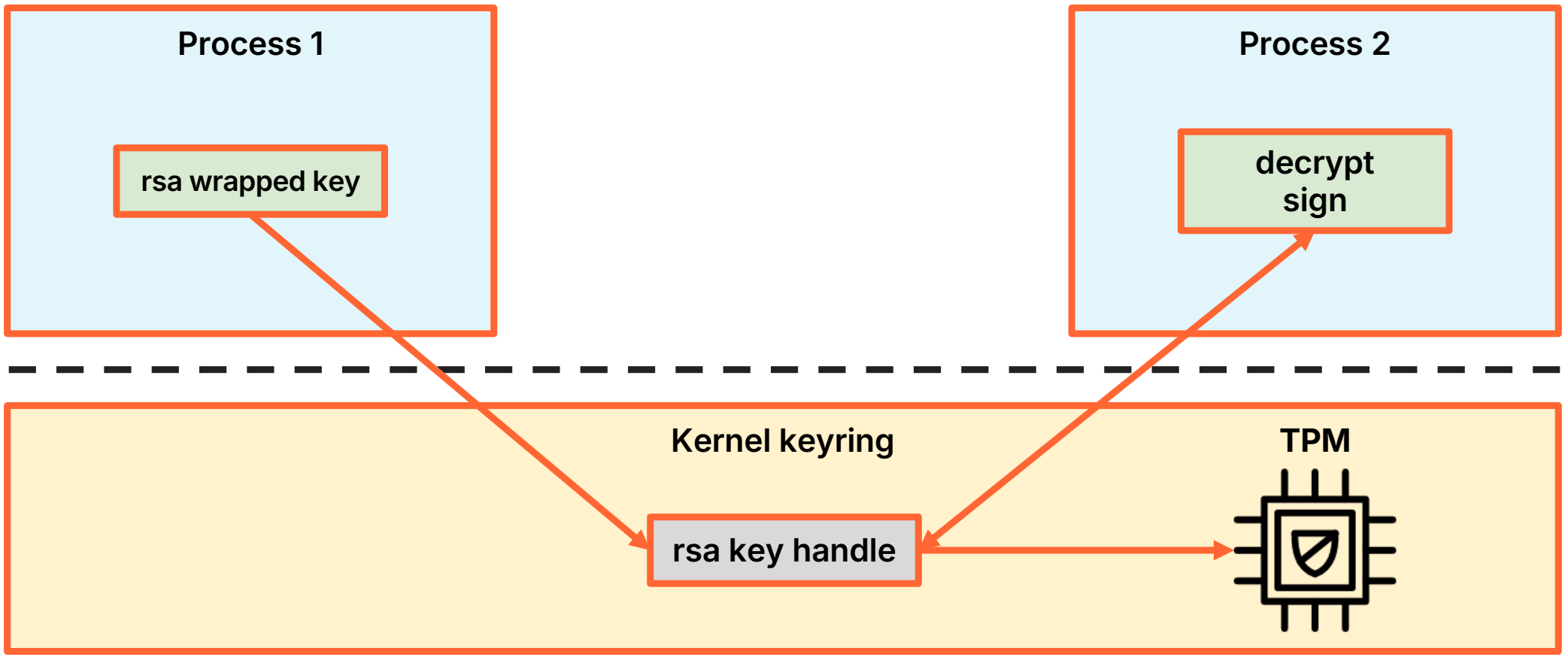
Asymmetric TPM keys

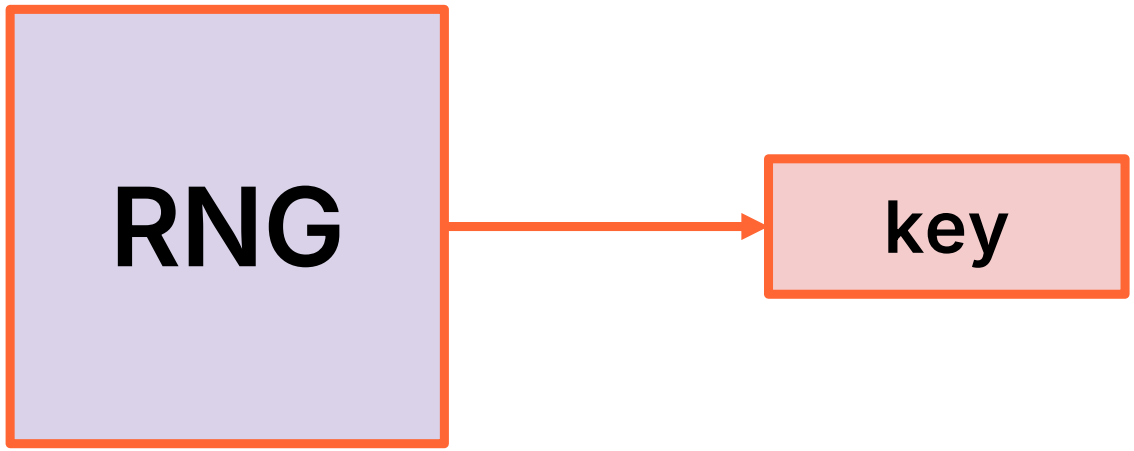


CLOUDFLARE

Wrapped keys

CLOUDFLARE

Wrapped keys



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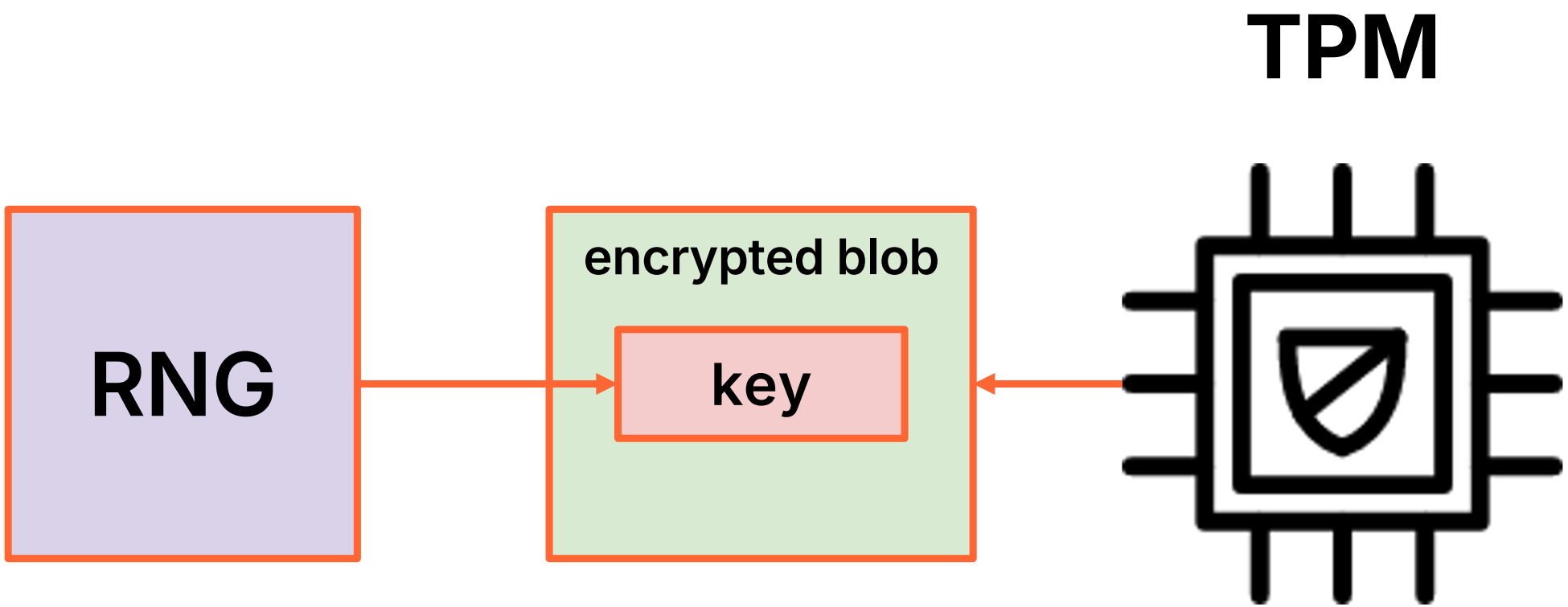

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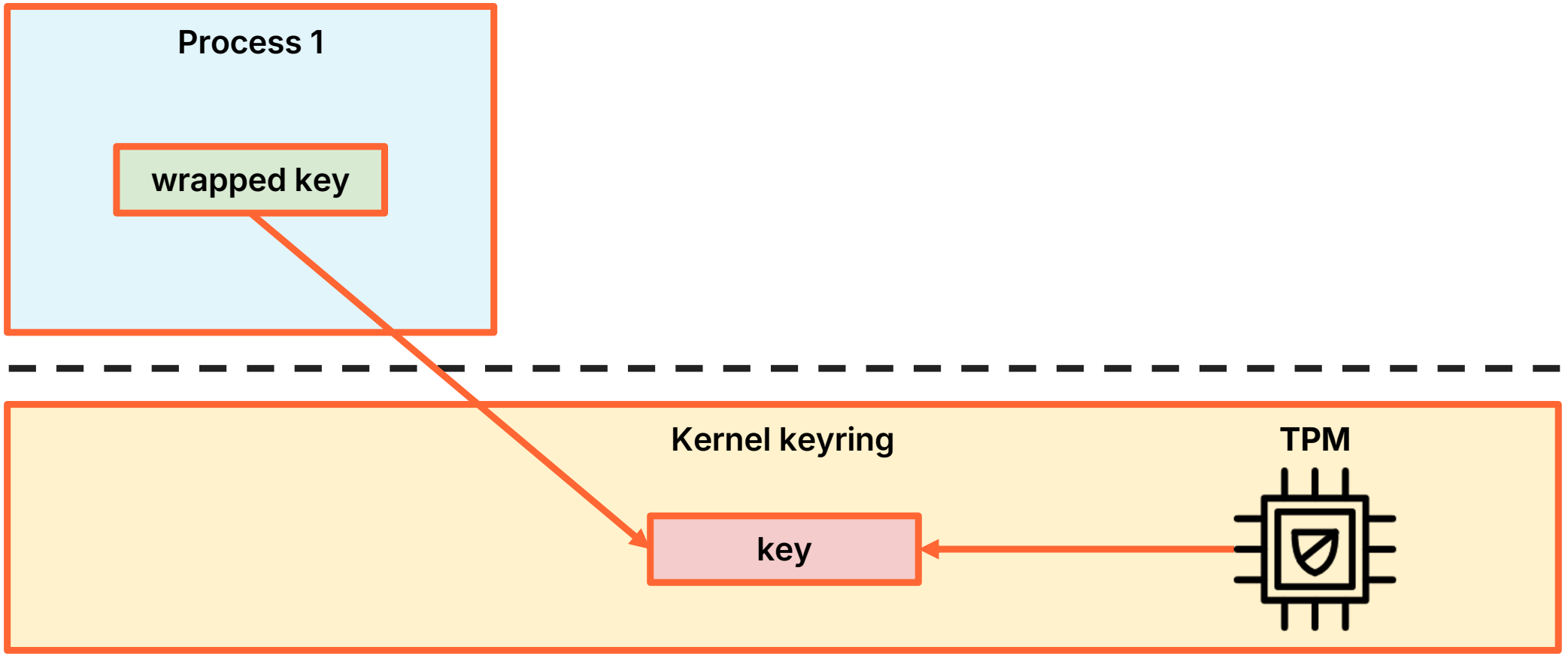
CLOUDFLARE

Trusted key management



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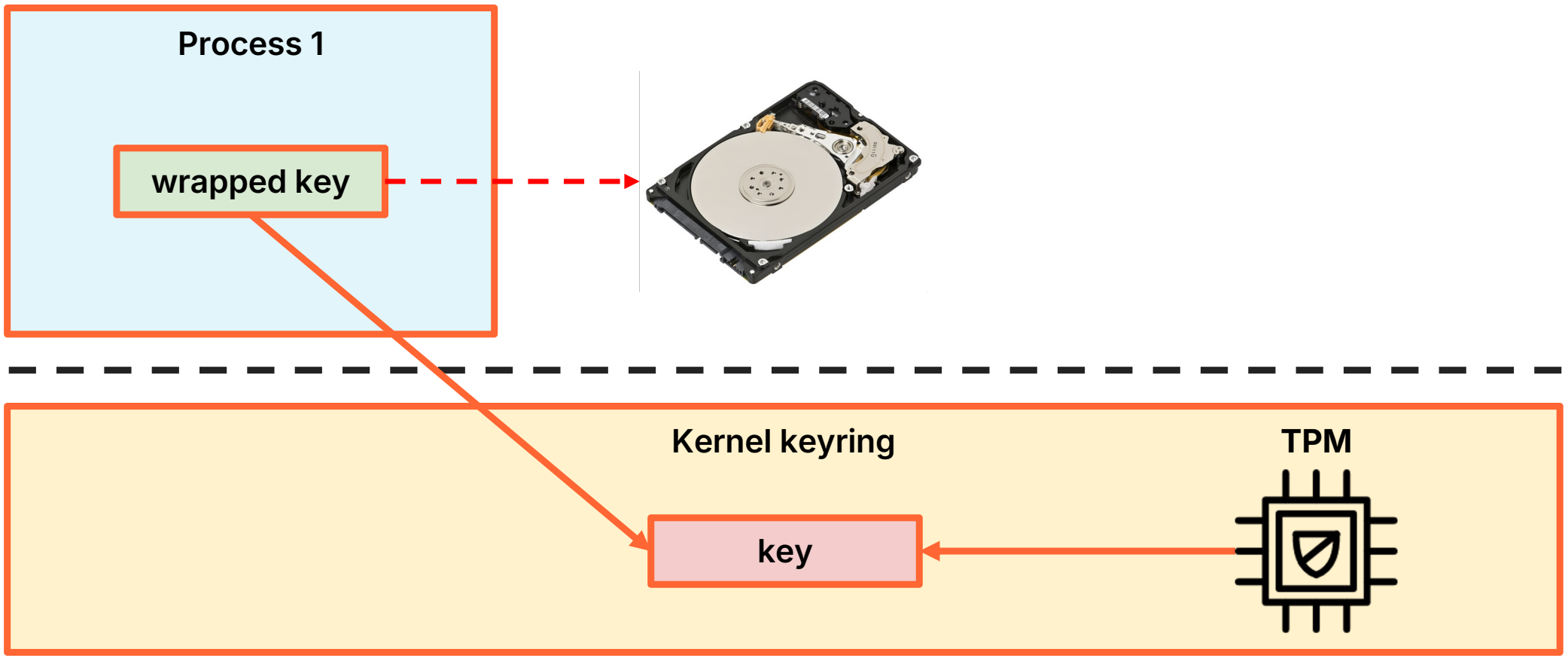
Trusted key management



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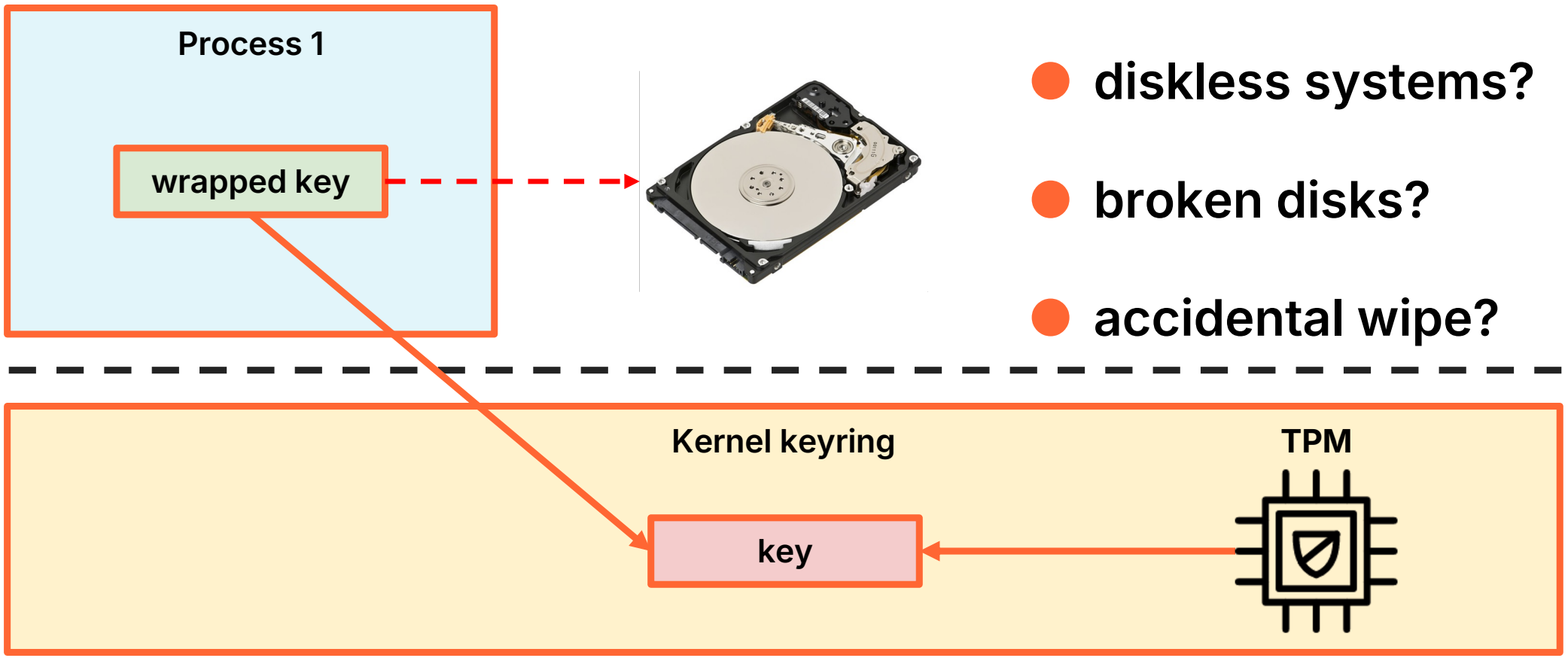
CLOUDFLARE

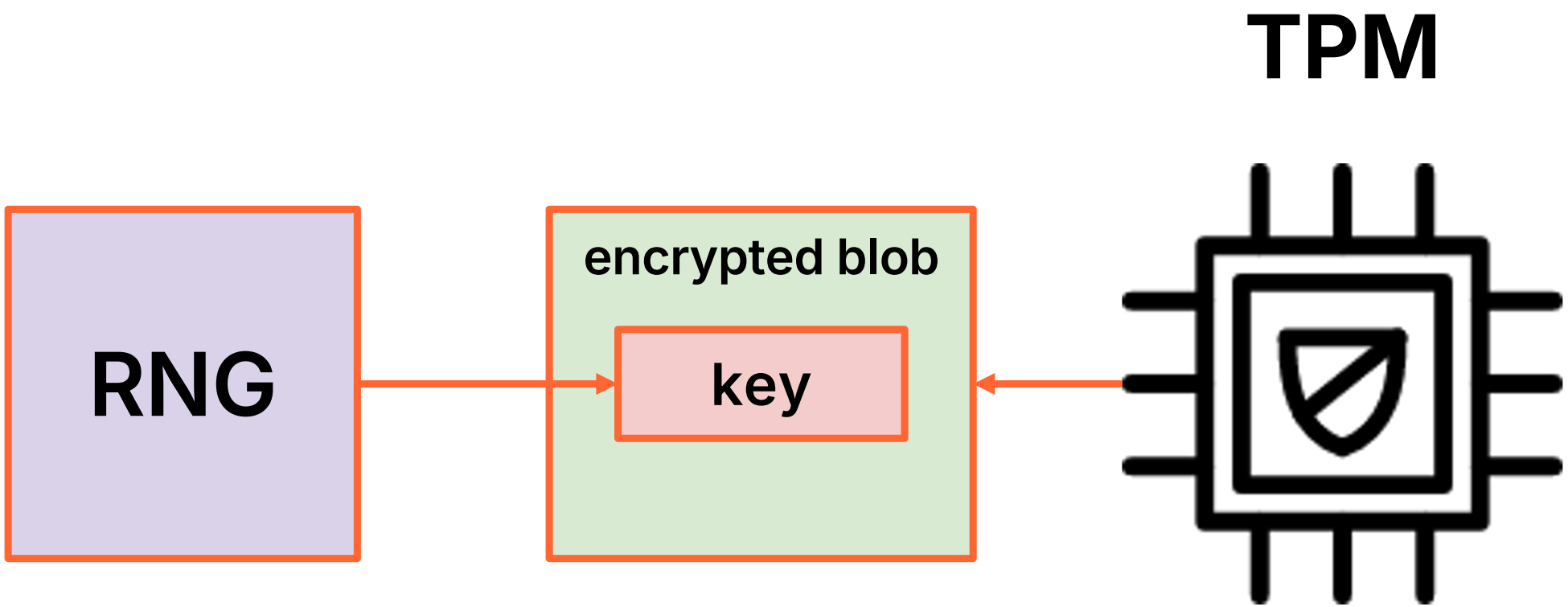
Trusted key management



- diskless systems?
- broken disks?
- accidental wipe?

CLOUDFLARE

Wrapped keys



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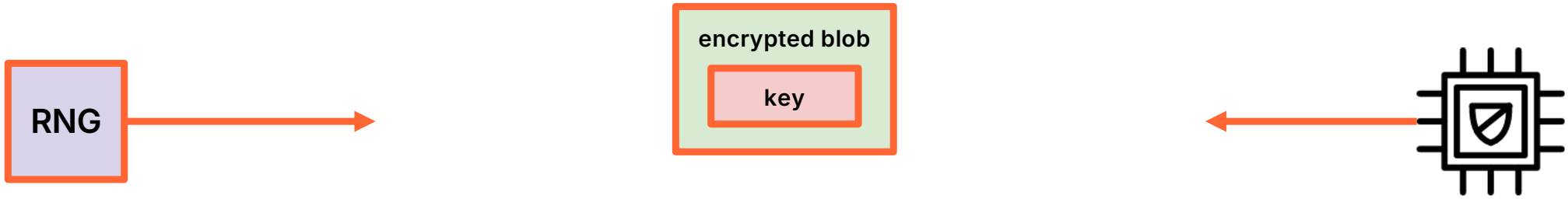
Wrapped keys



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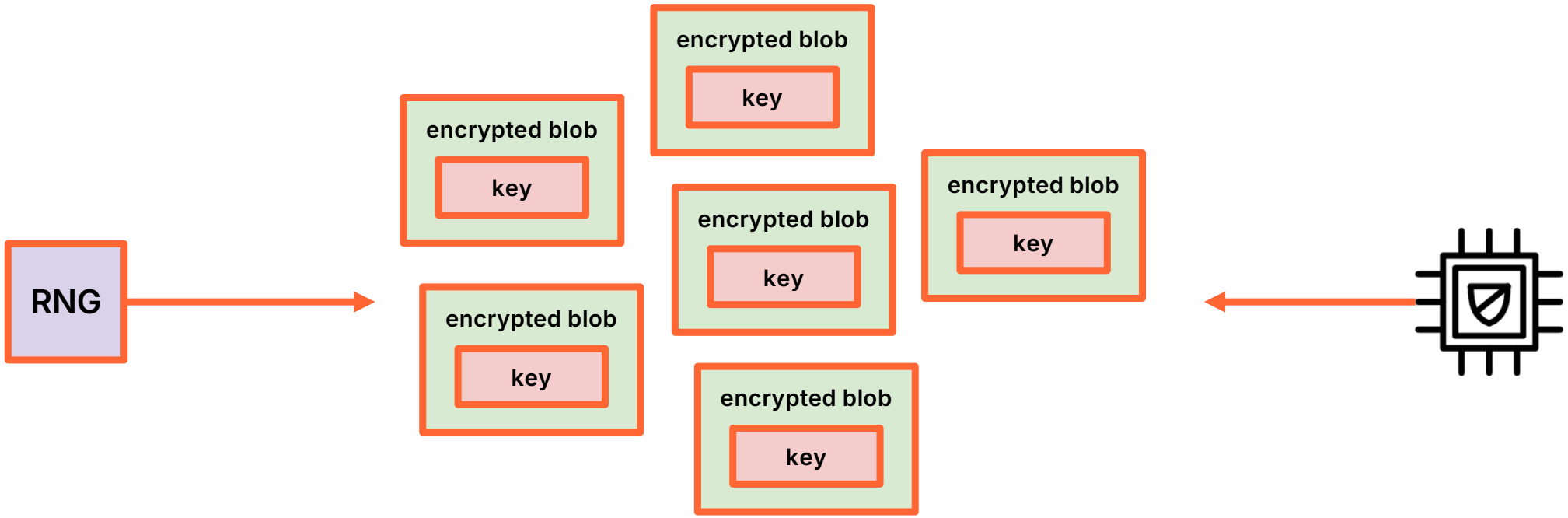

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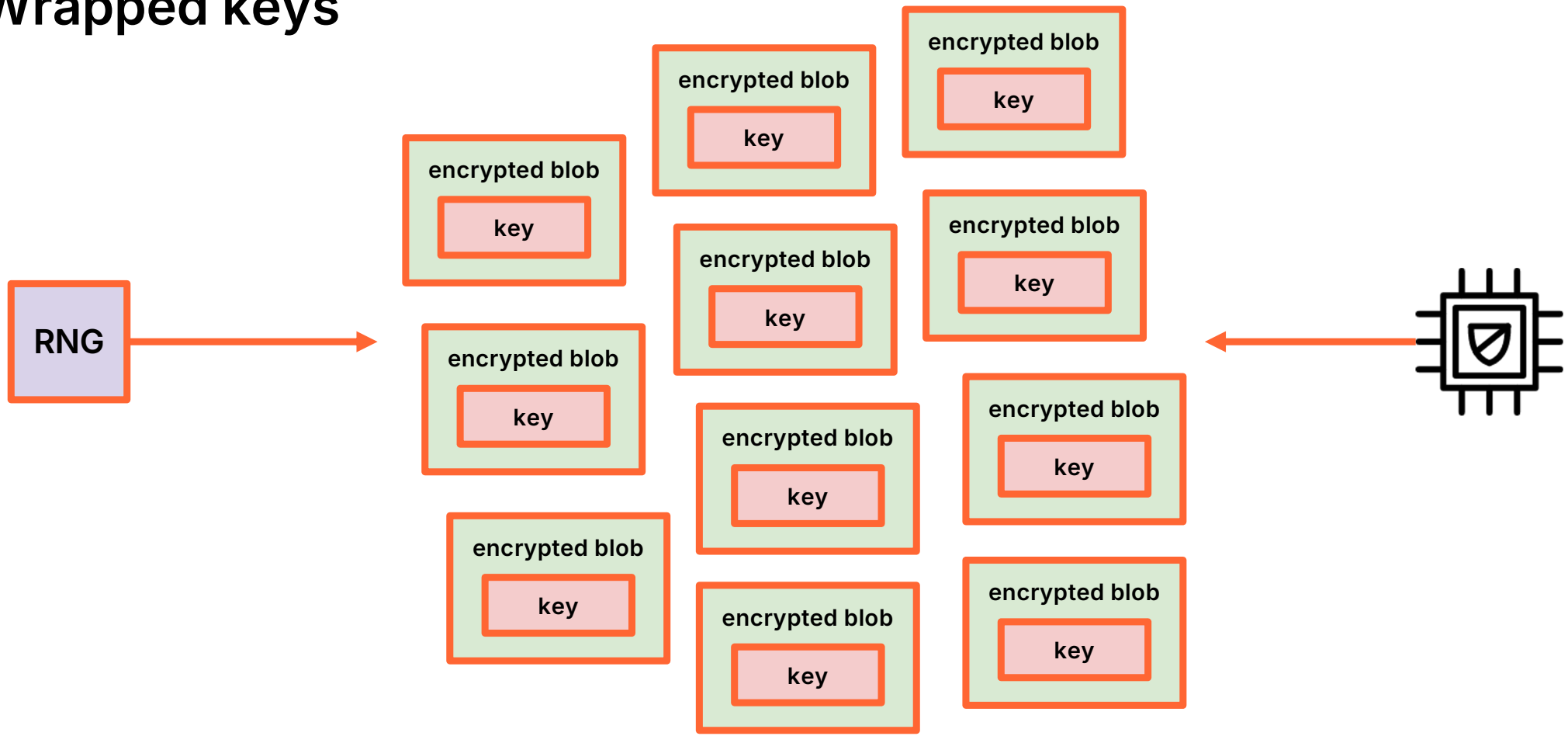

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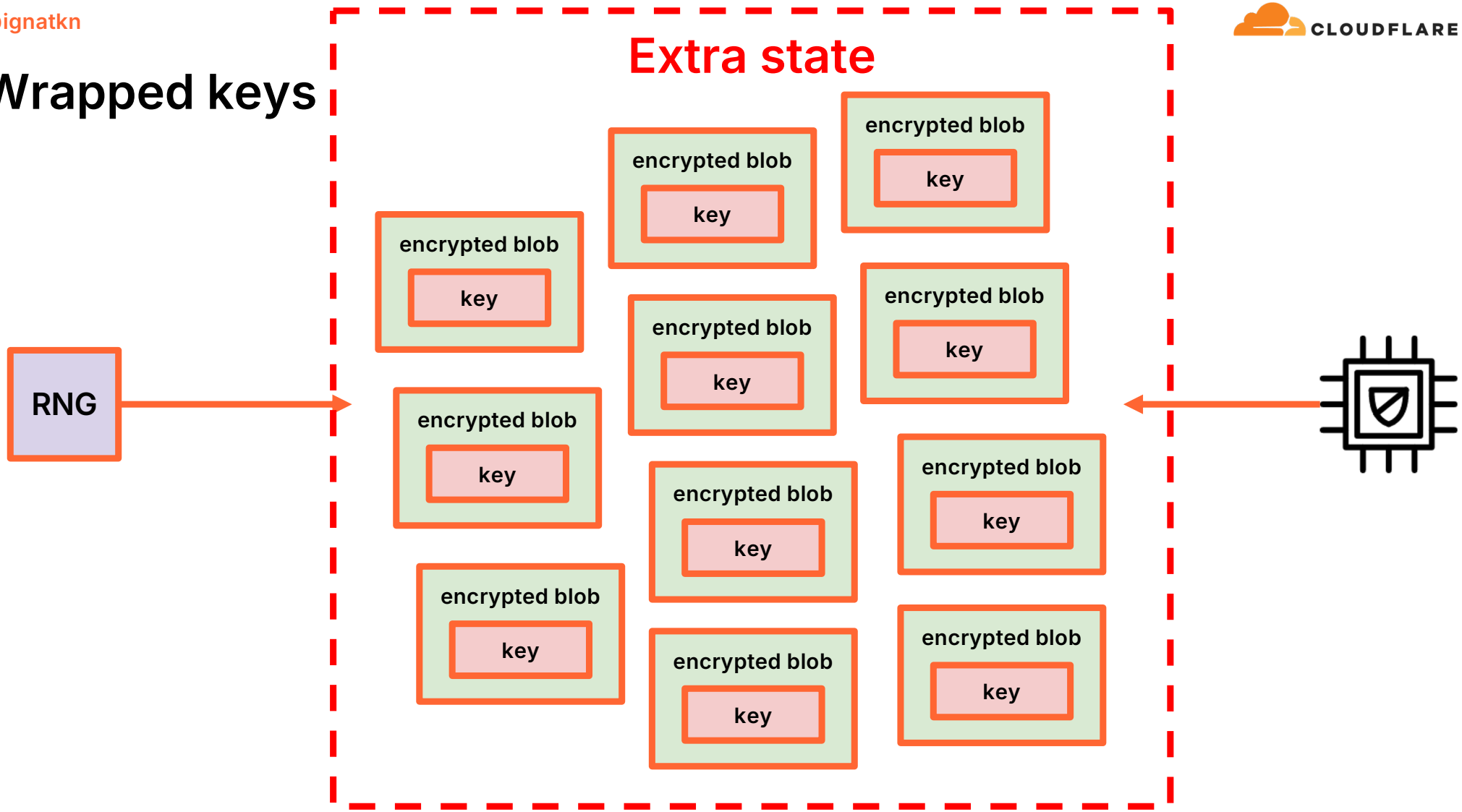

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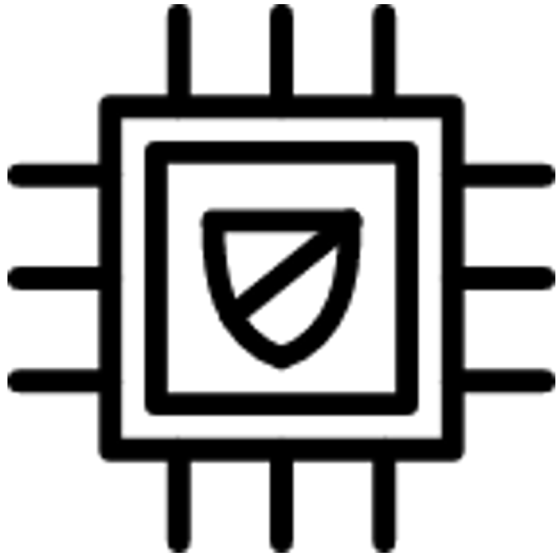
CLOUDFLARE

Derived keys

TPM



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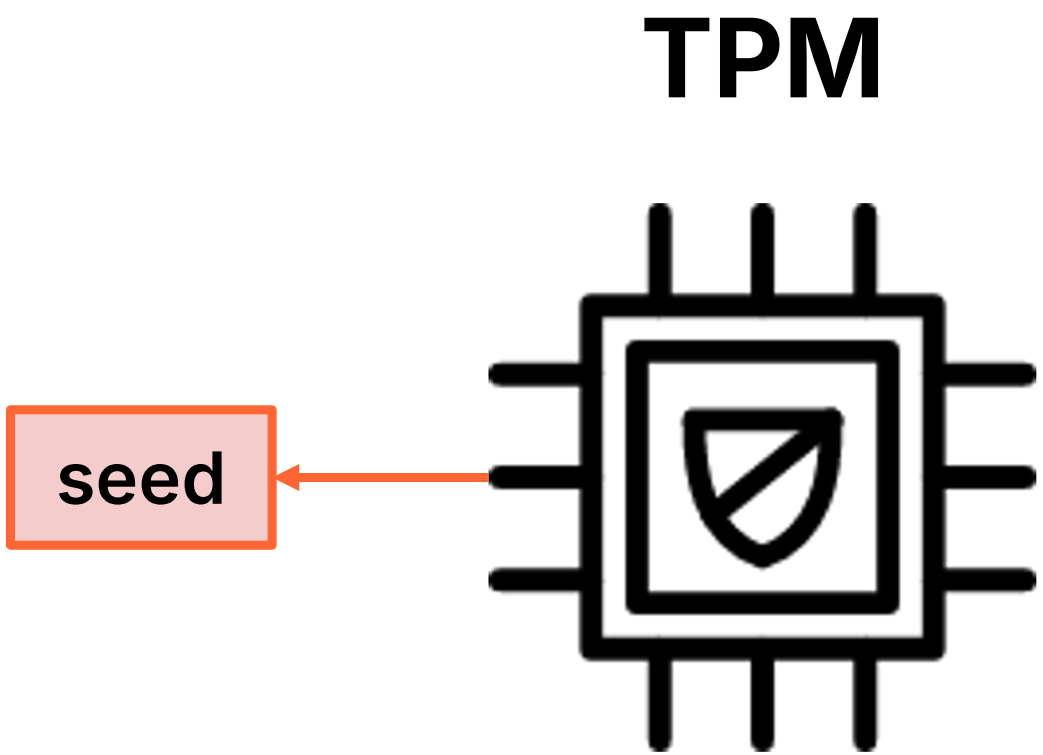

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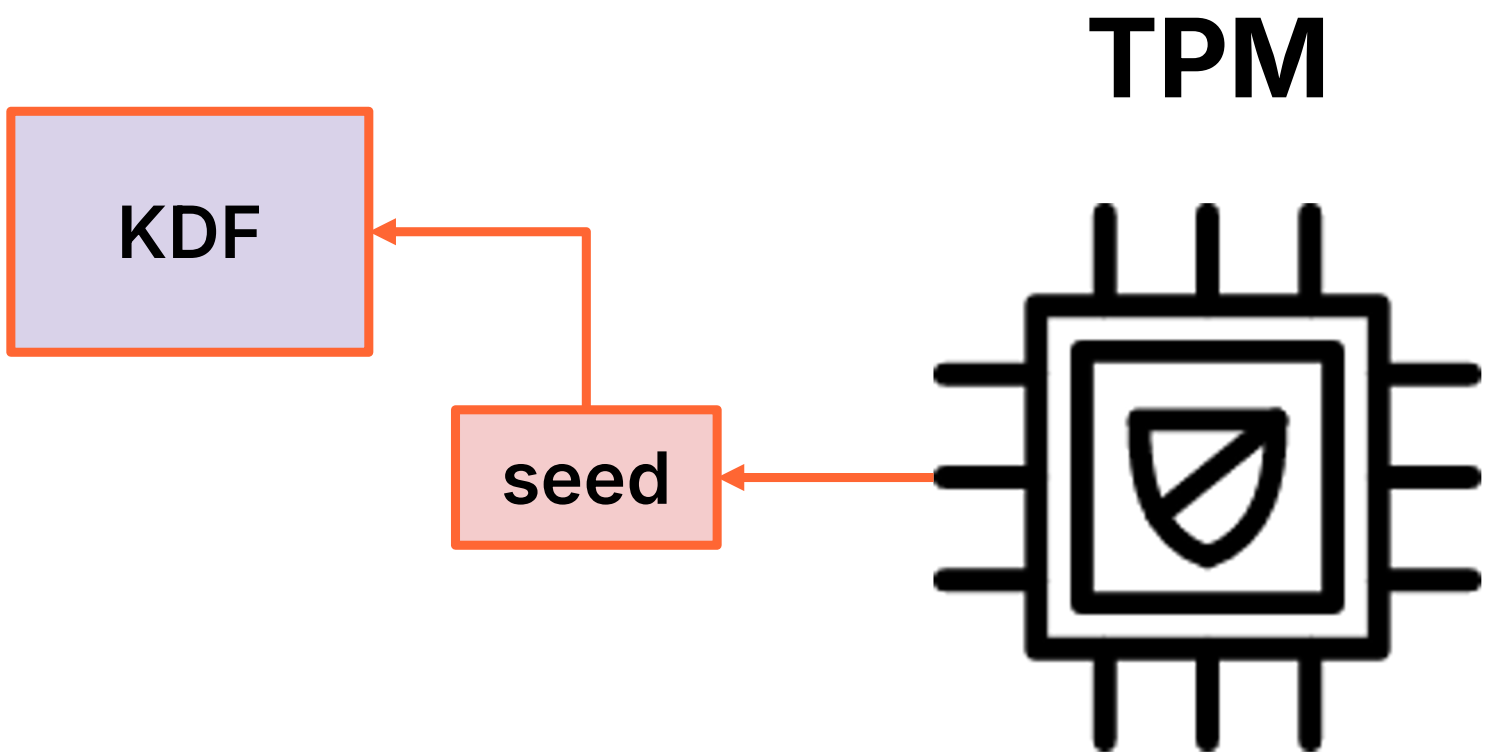

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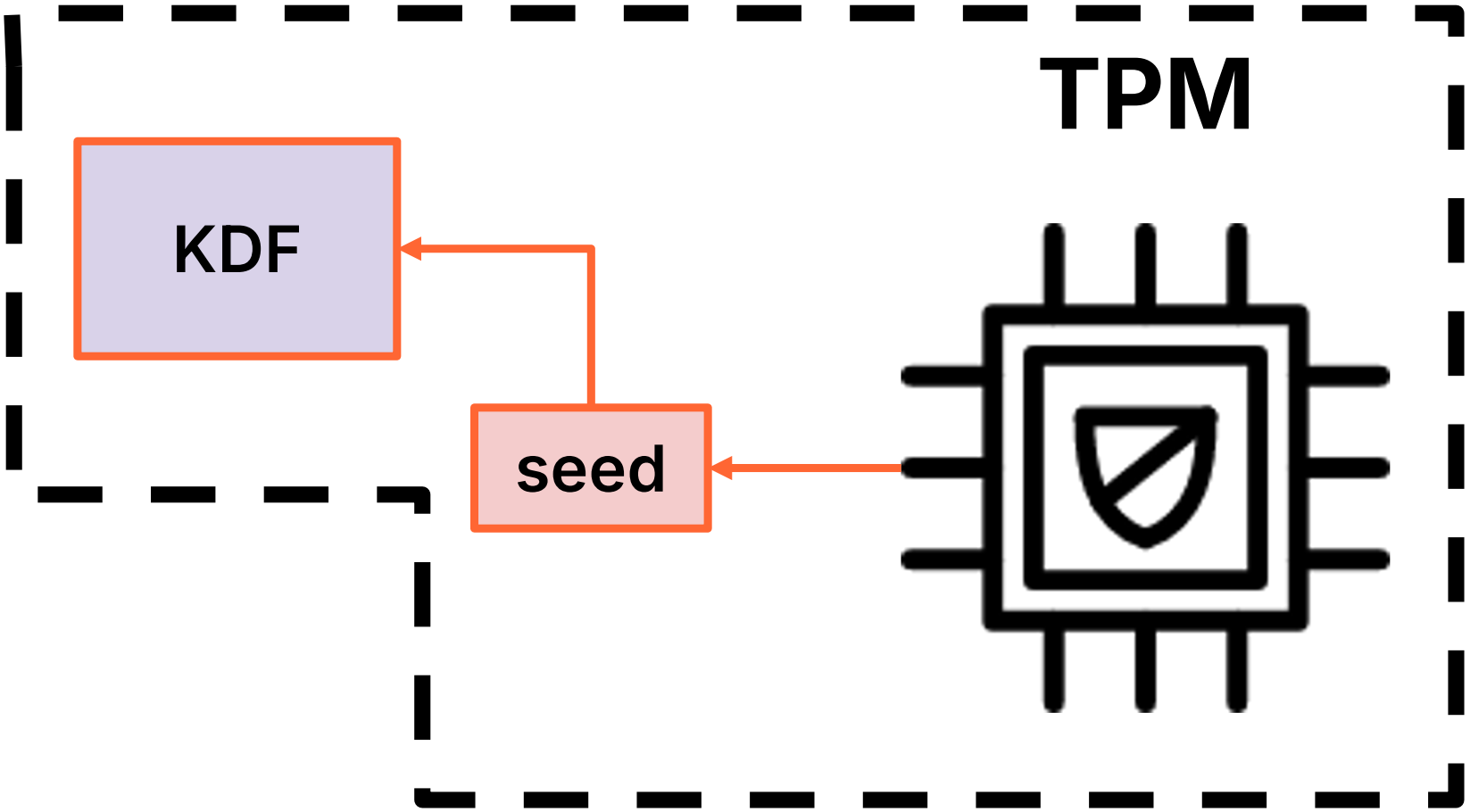

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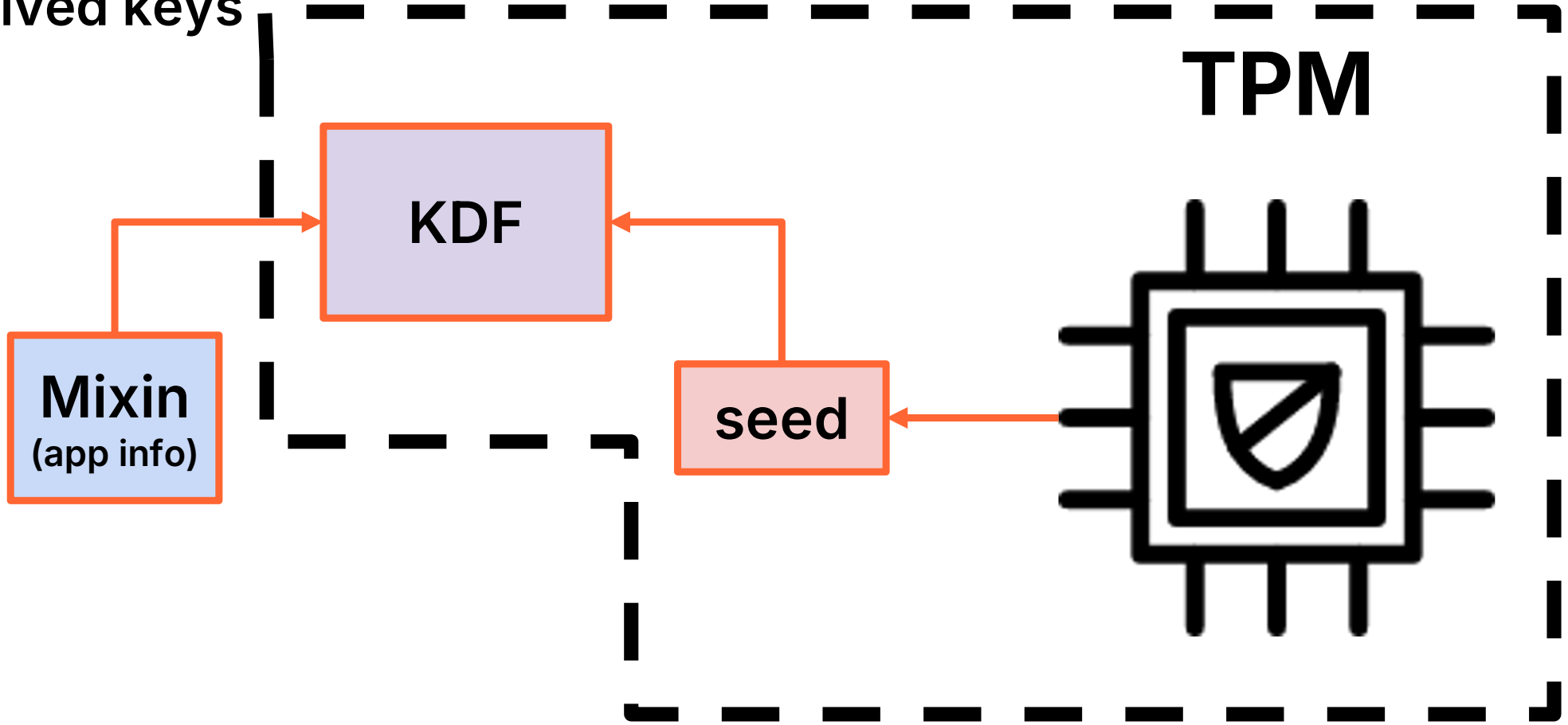

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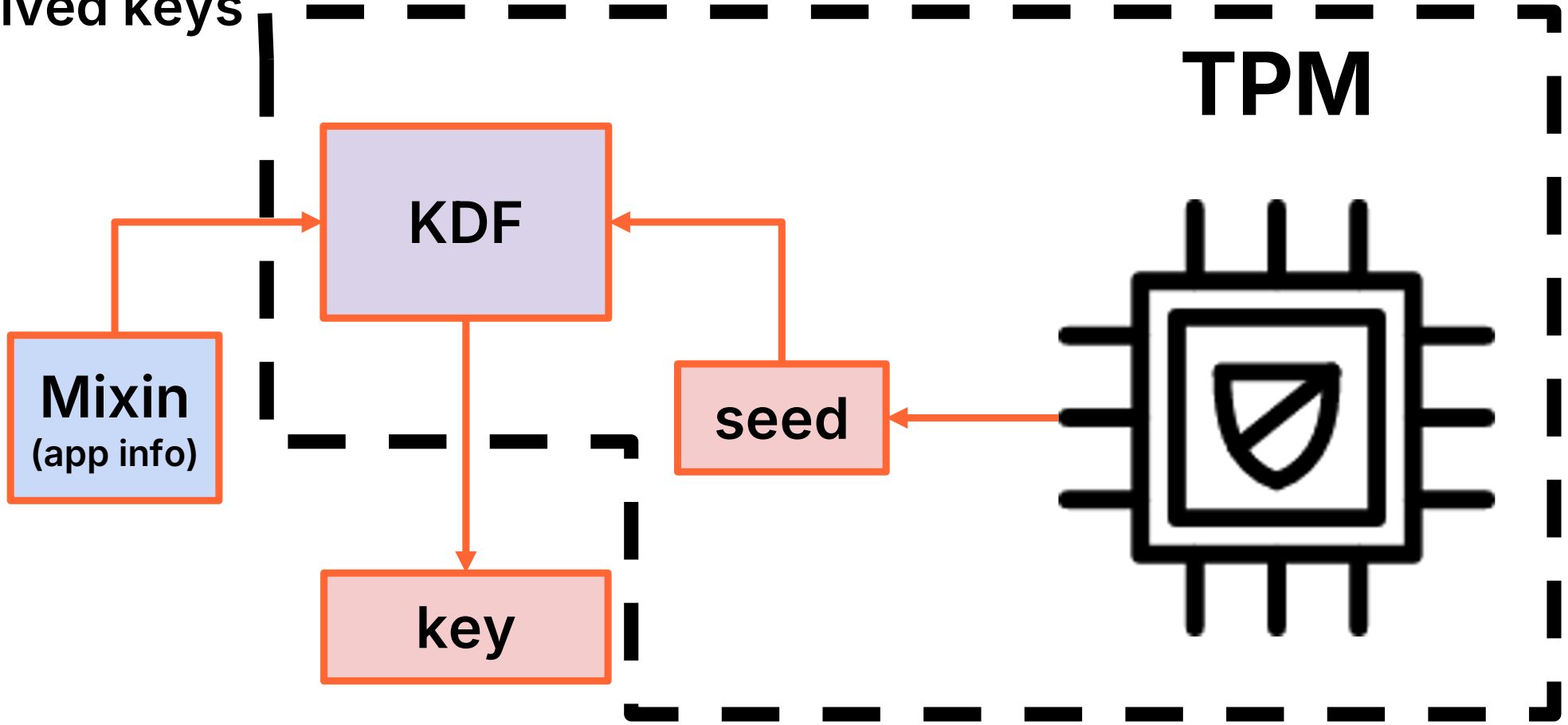

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CLOUDFLARE

Derived keys

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CLOUDFLARE

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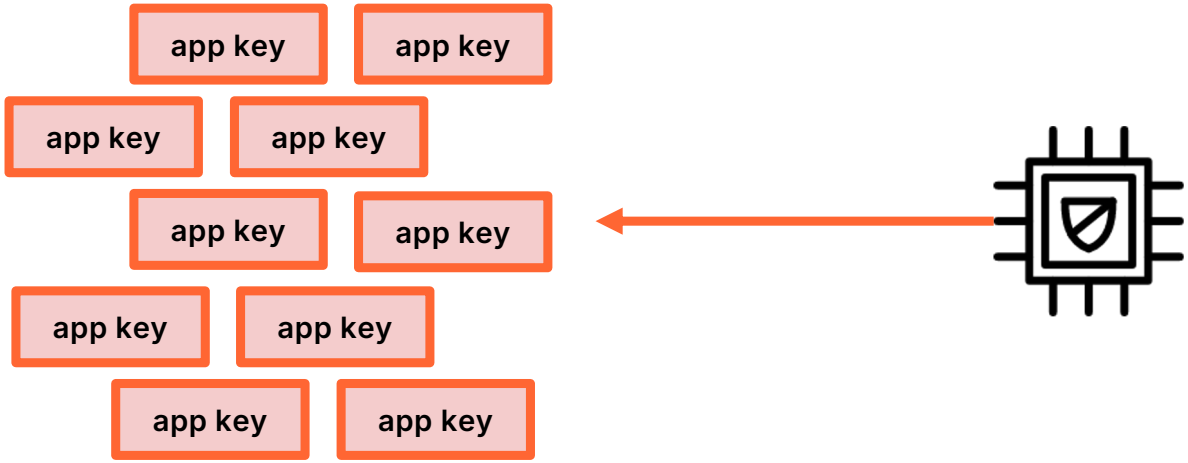

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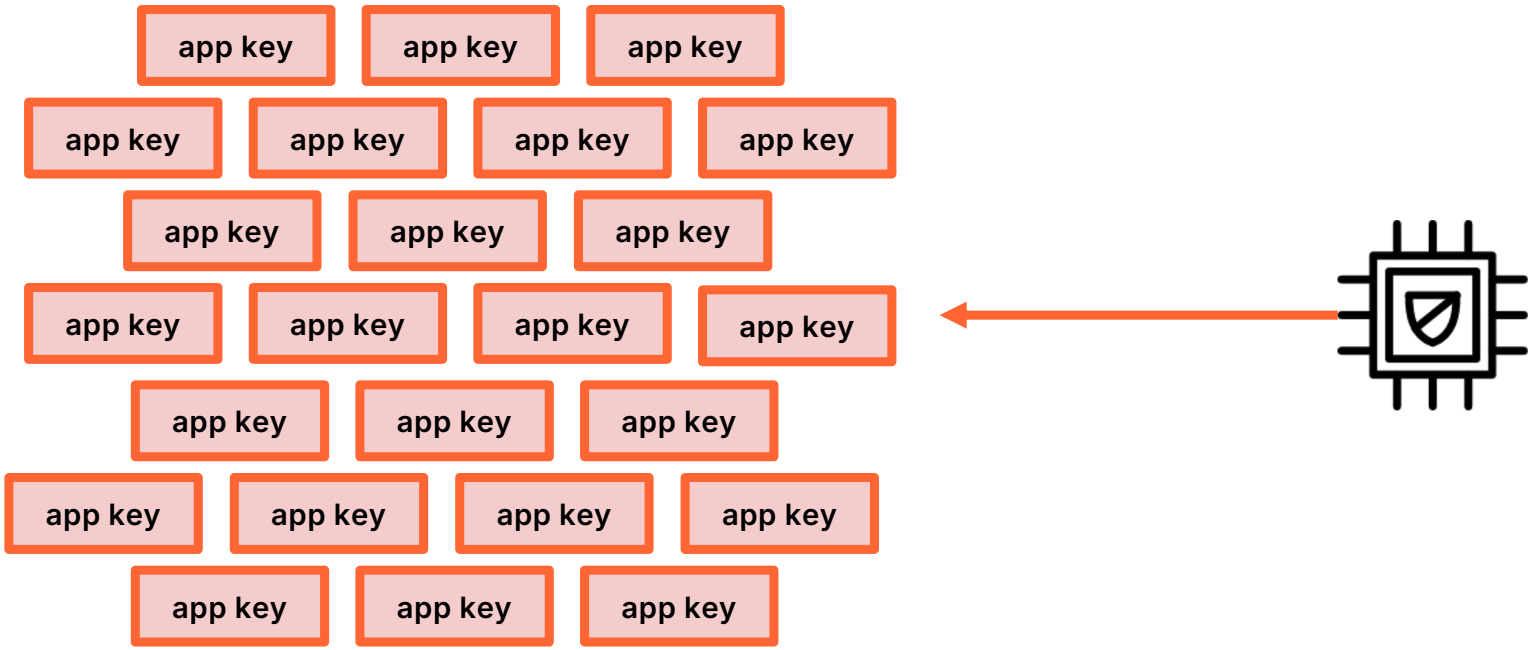

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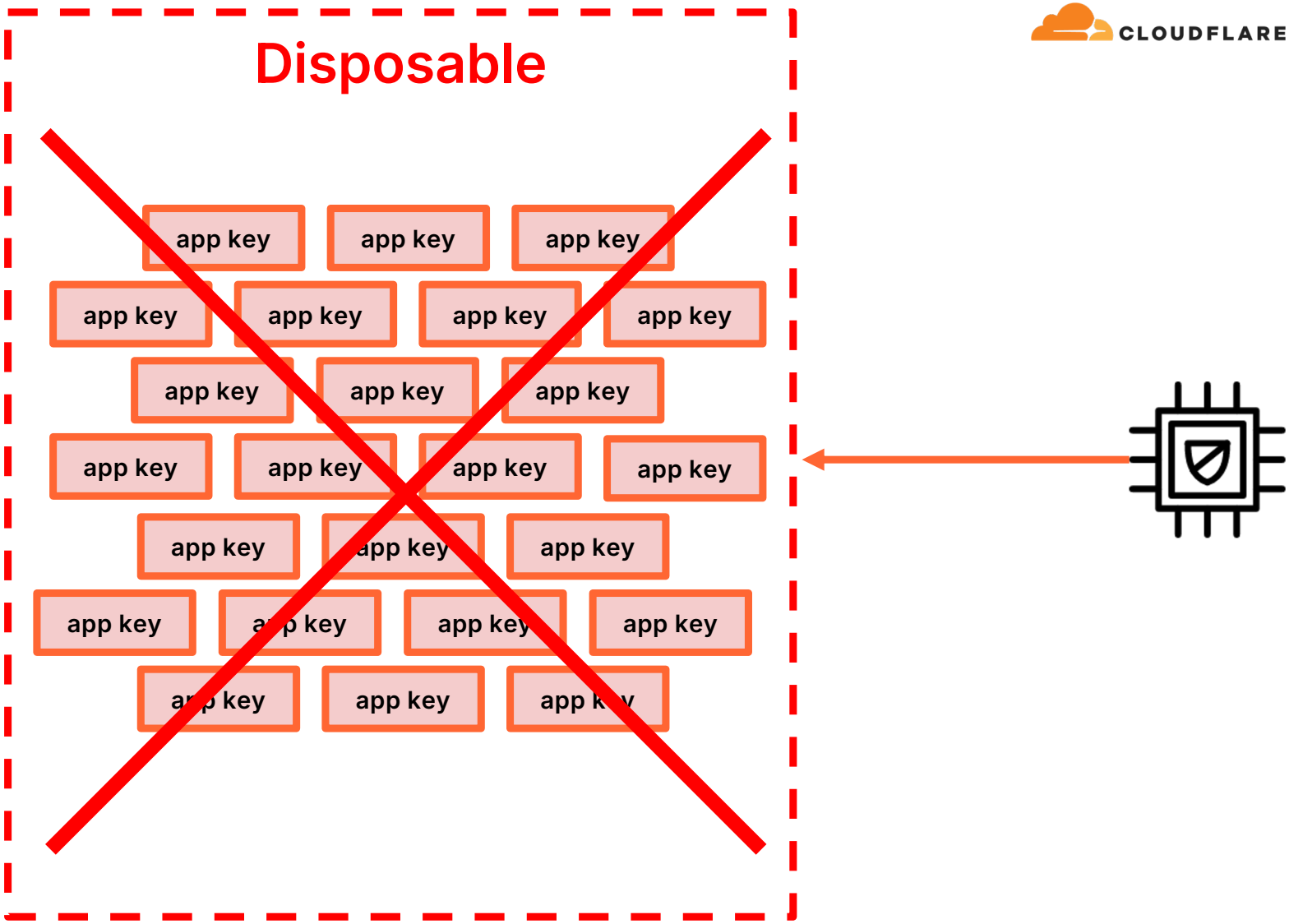
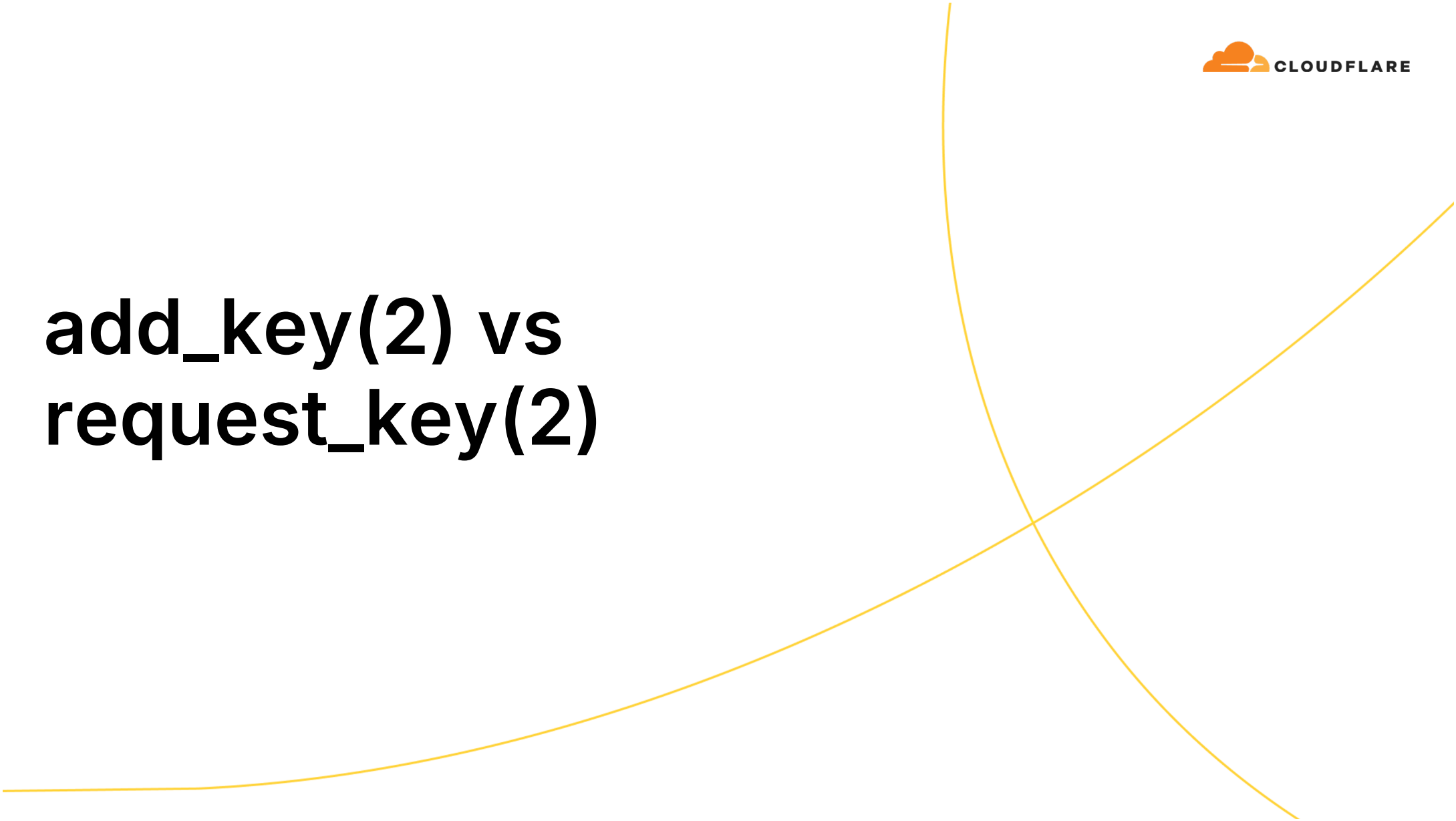


add_key(2) vs request_key(2)



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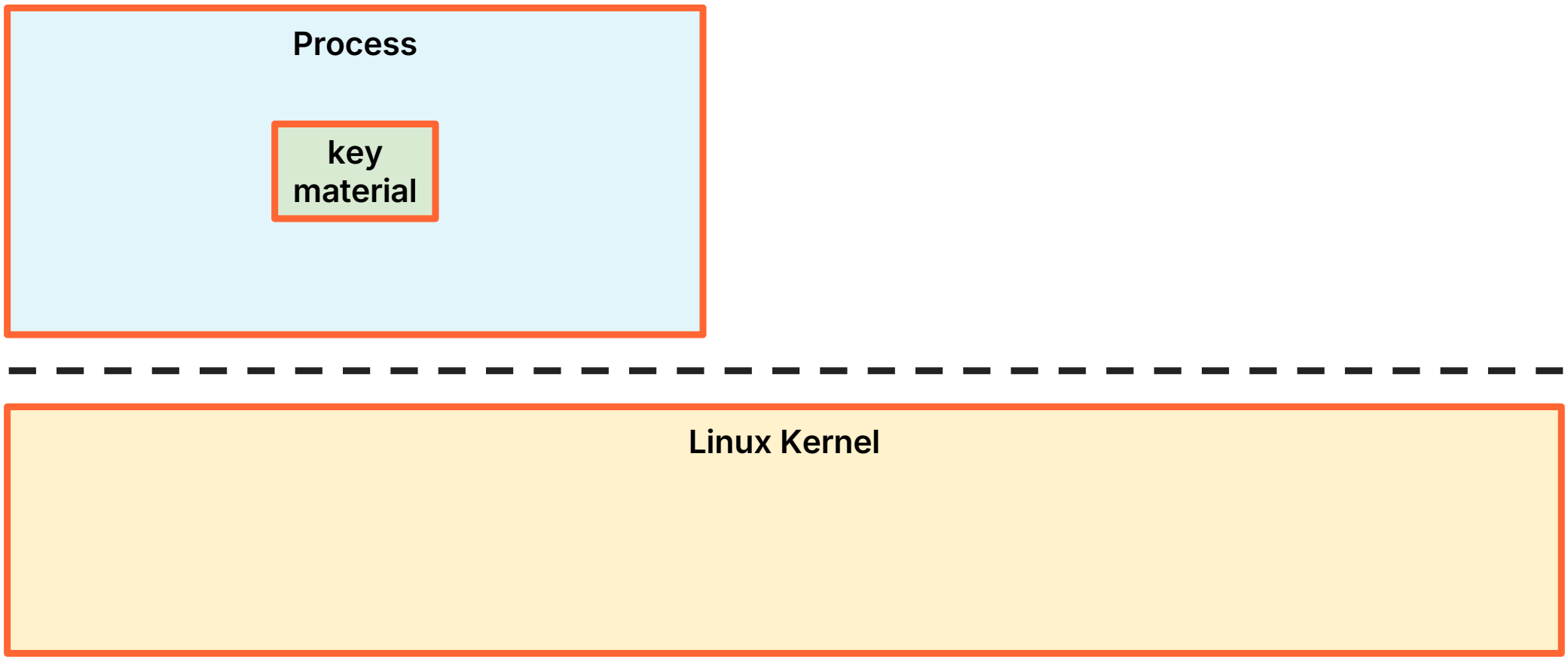

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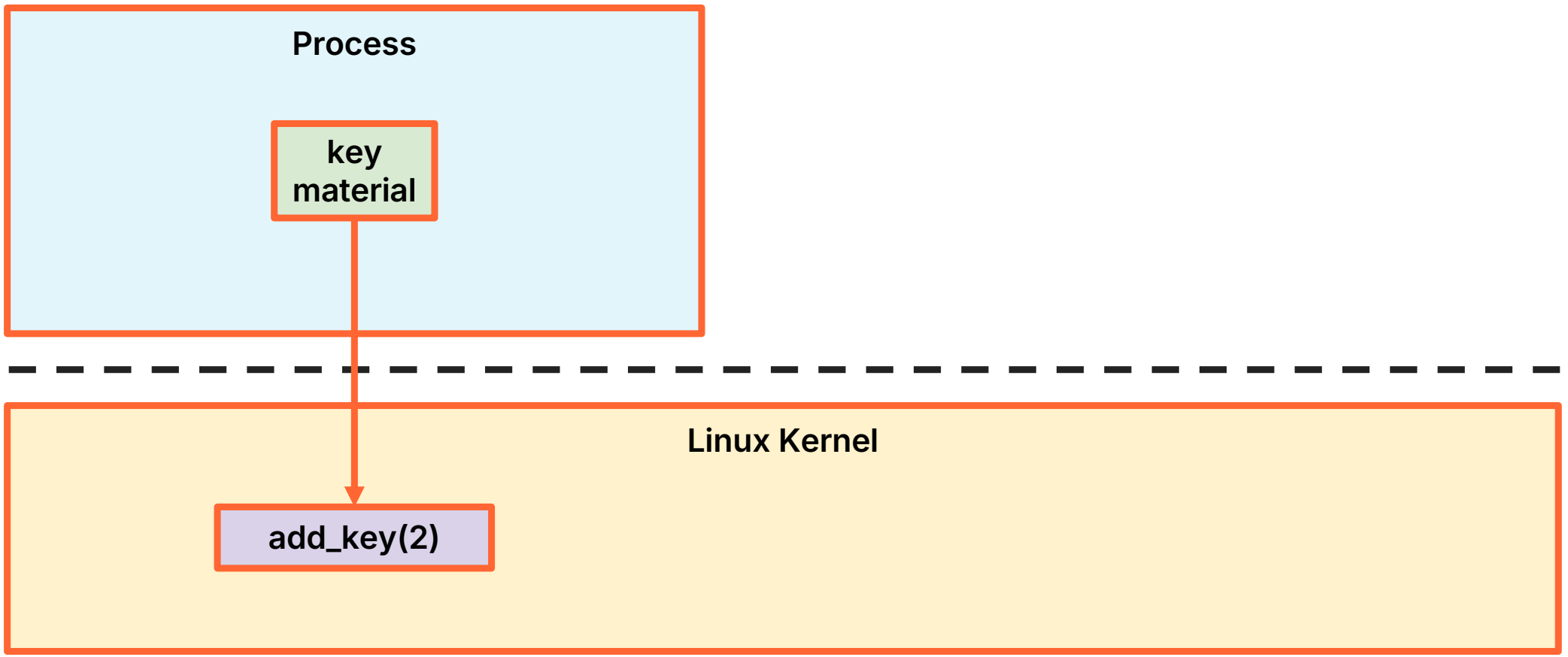

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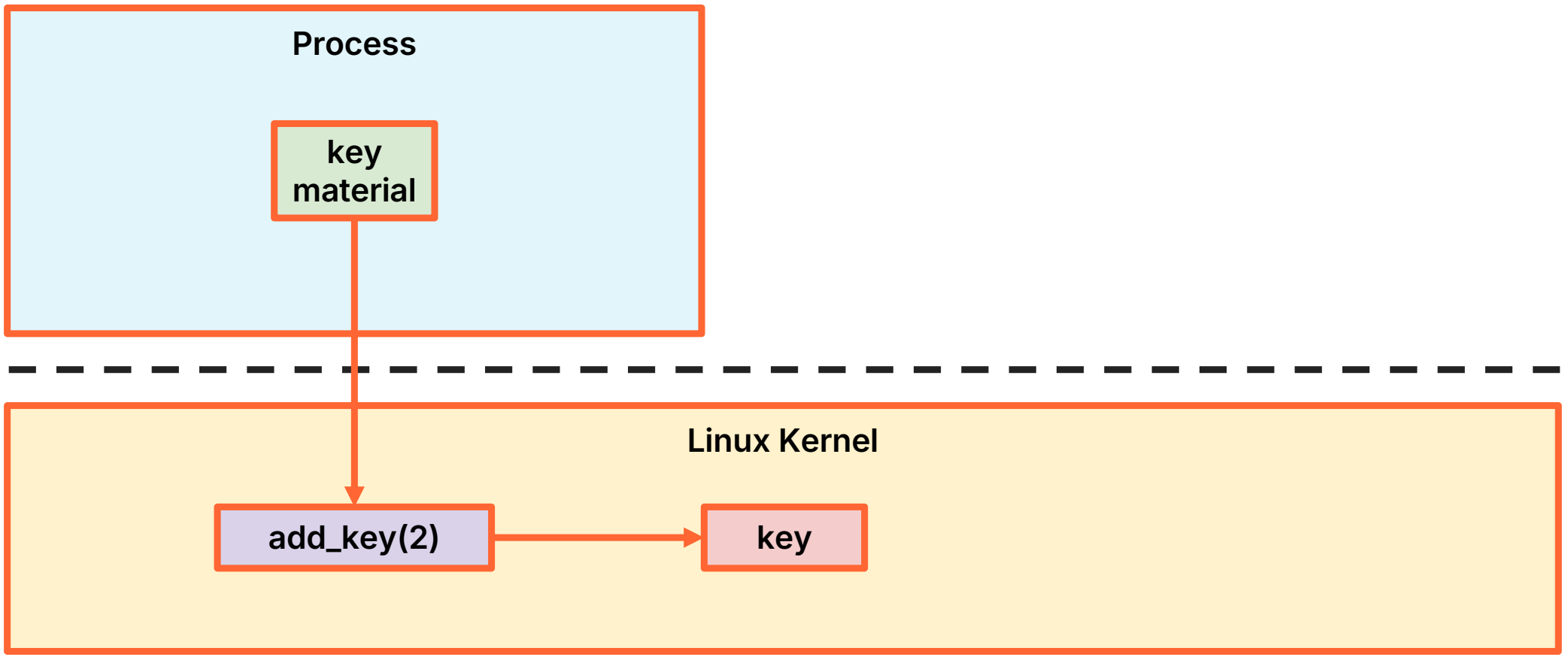

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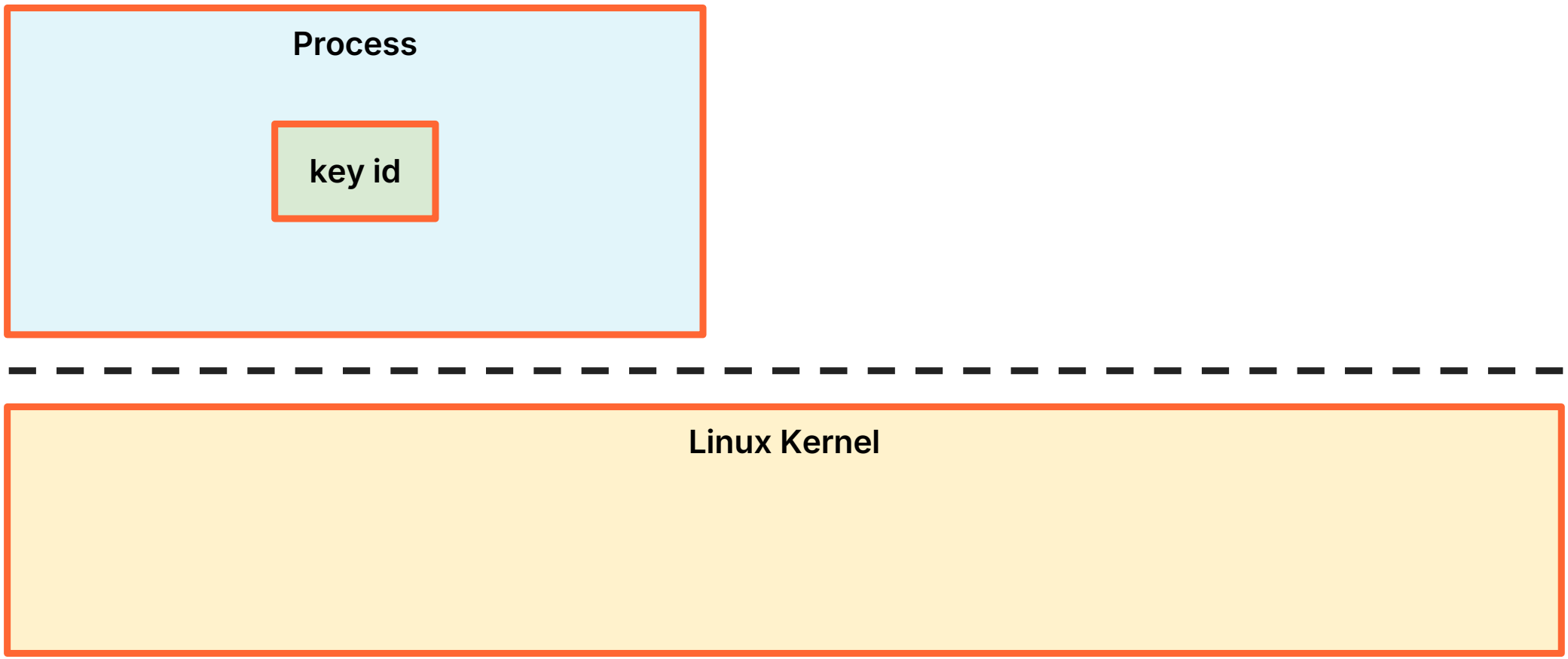

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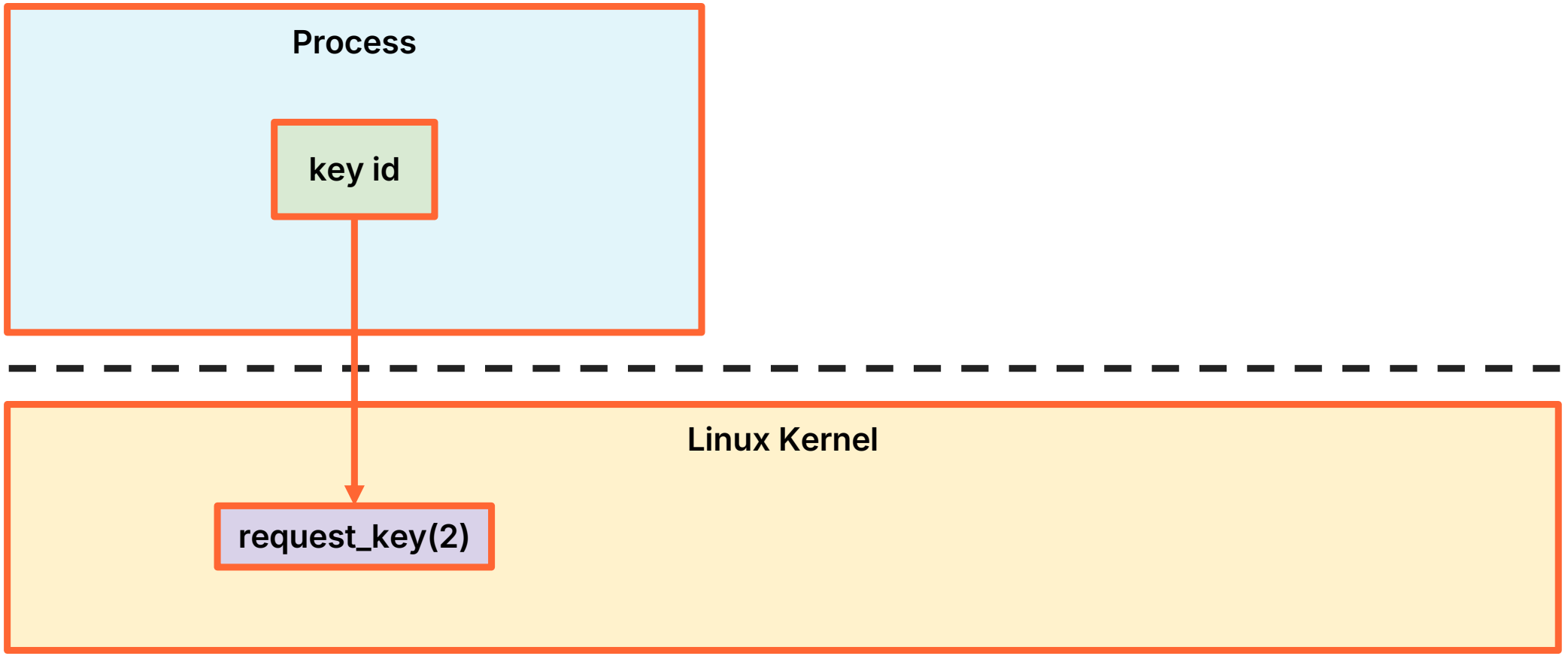

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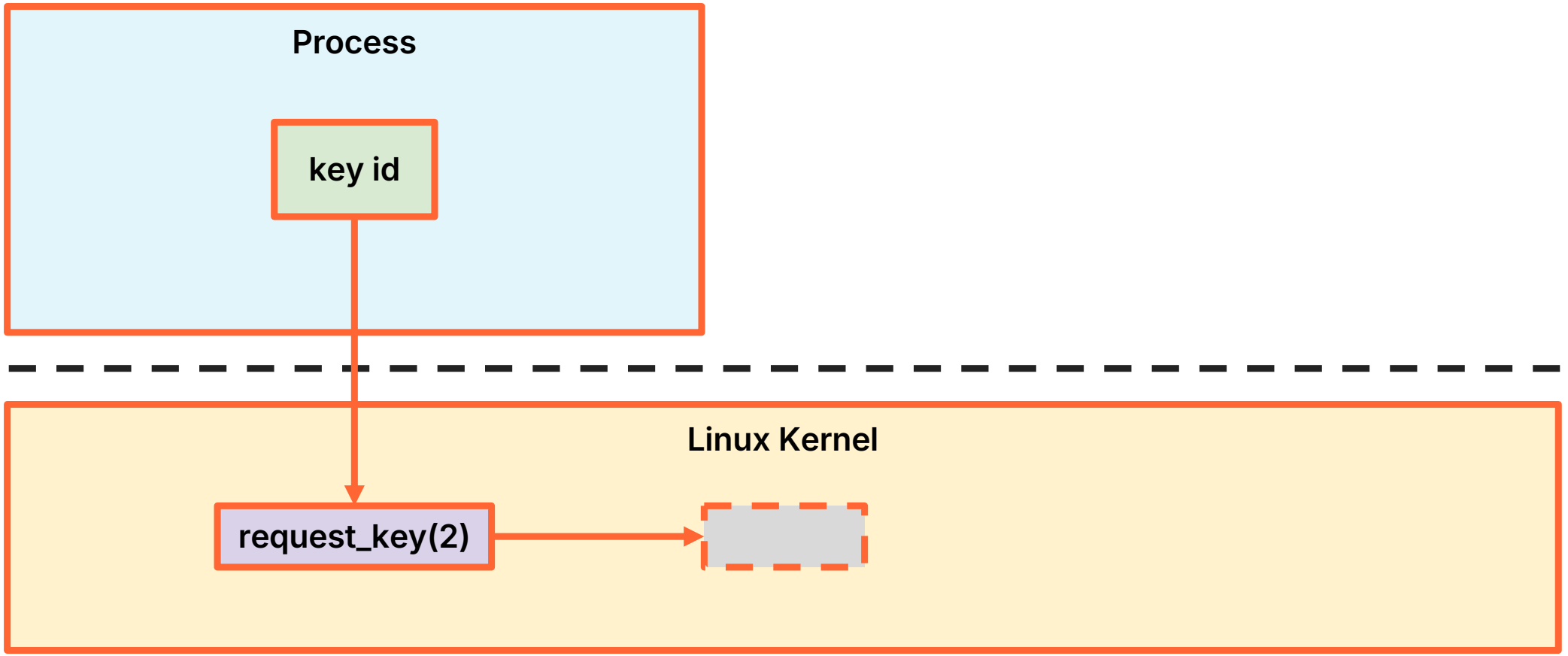

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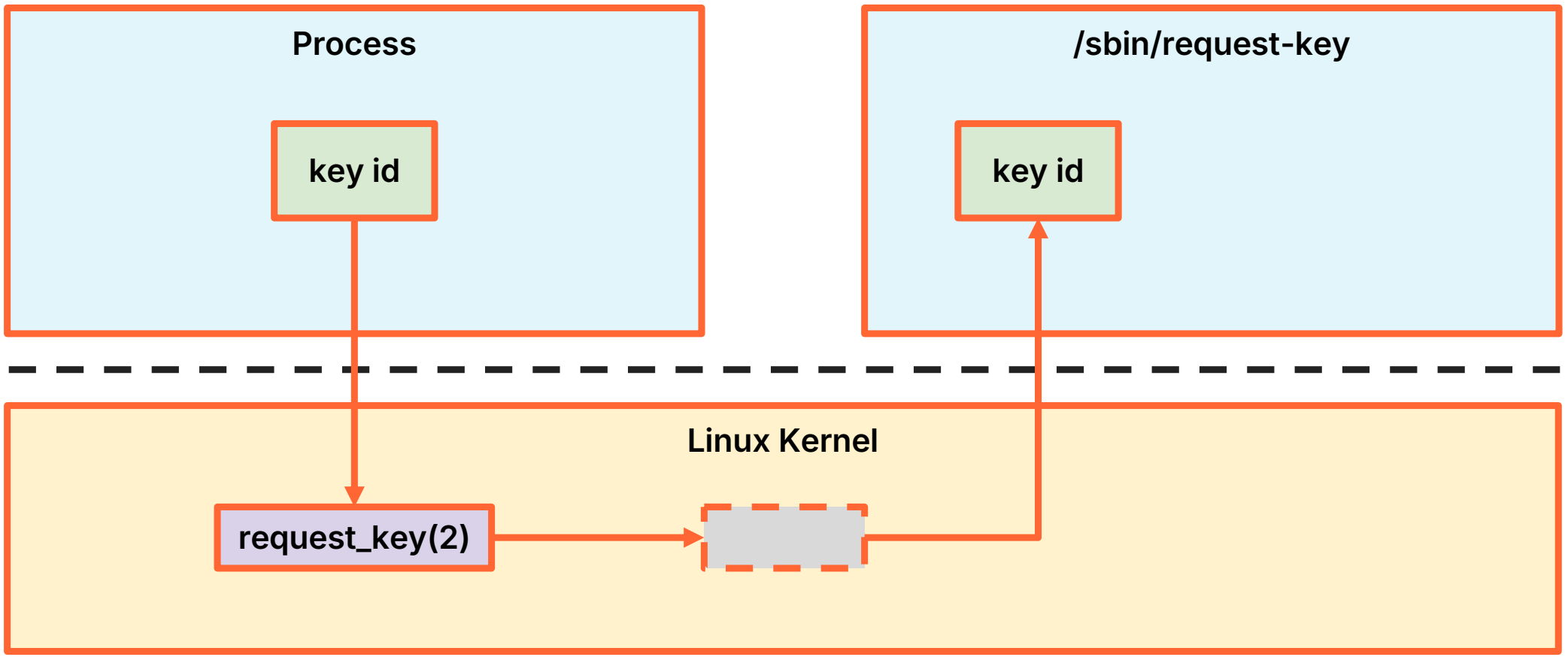

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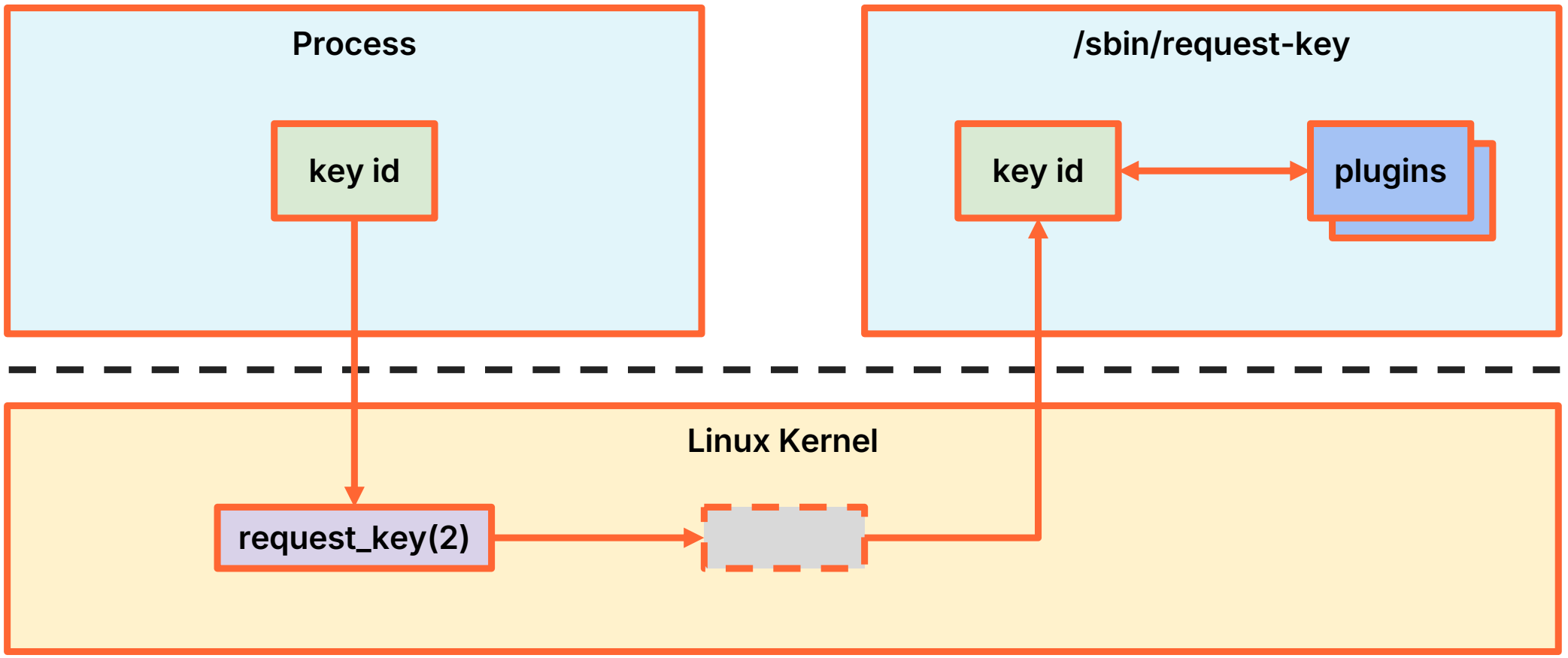

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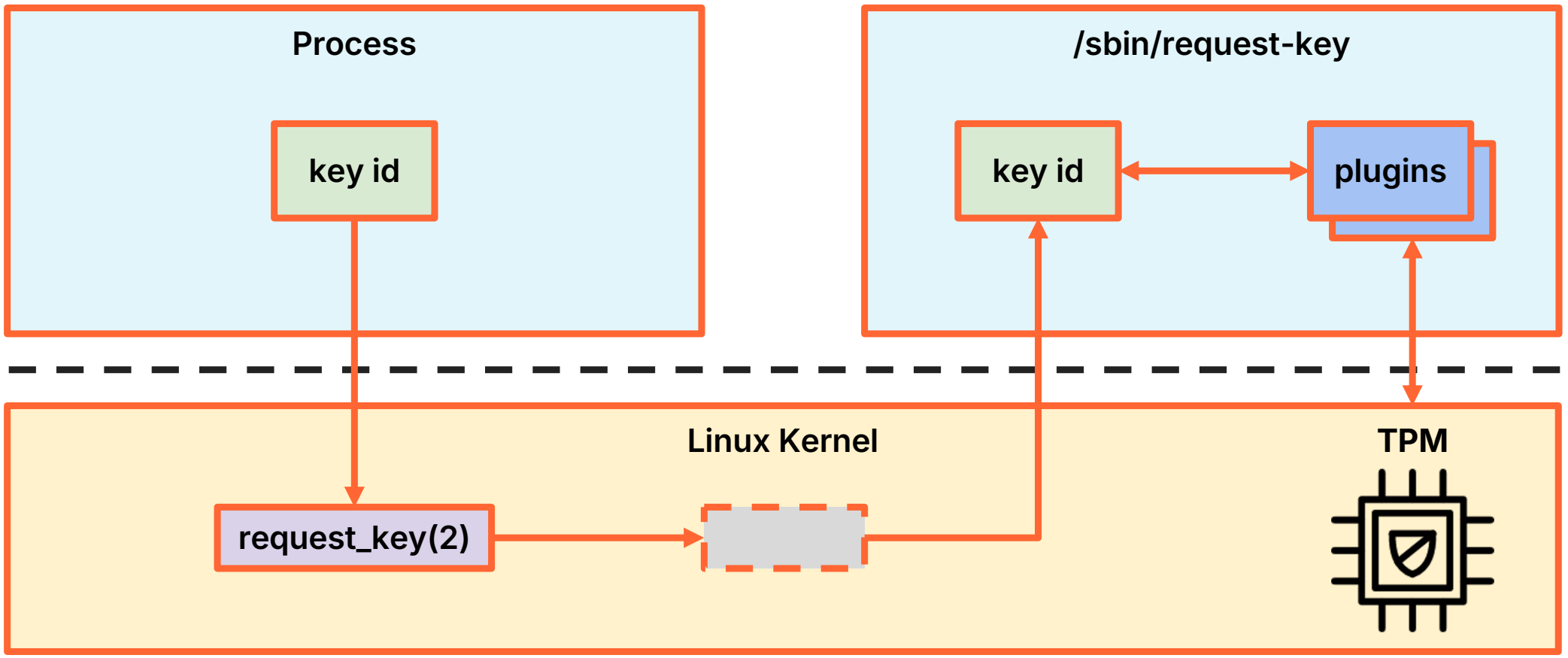

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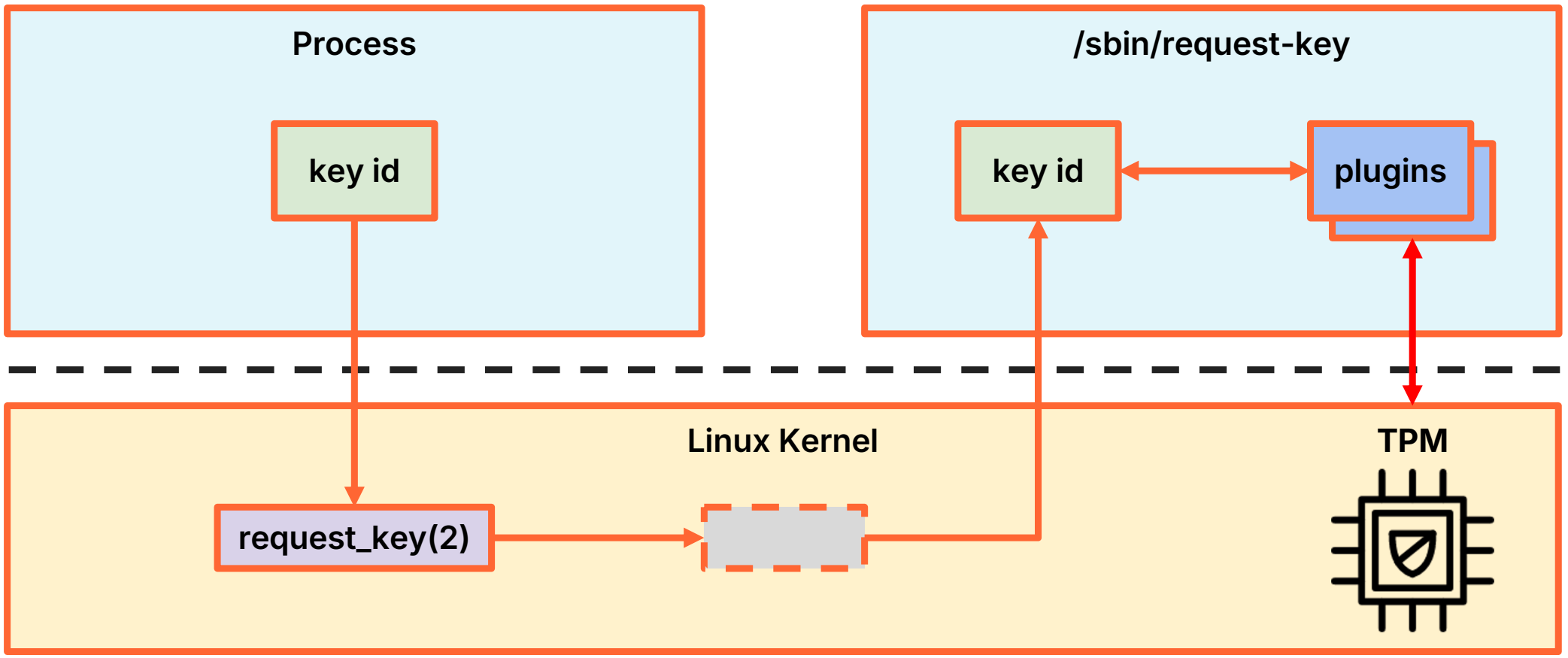

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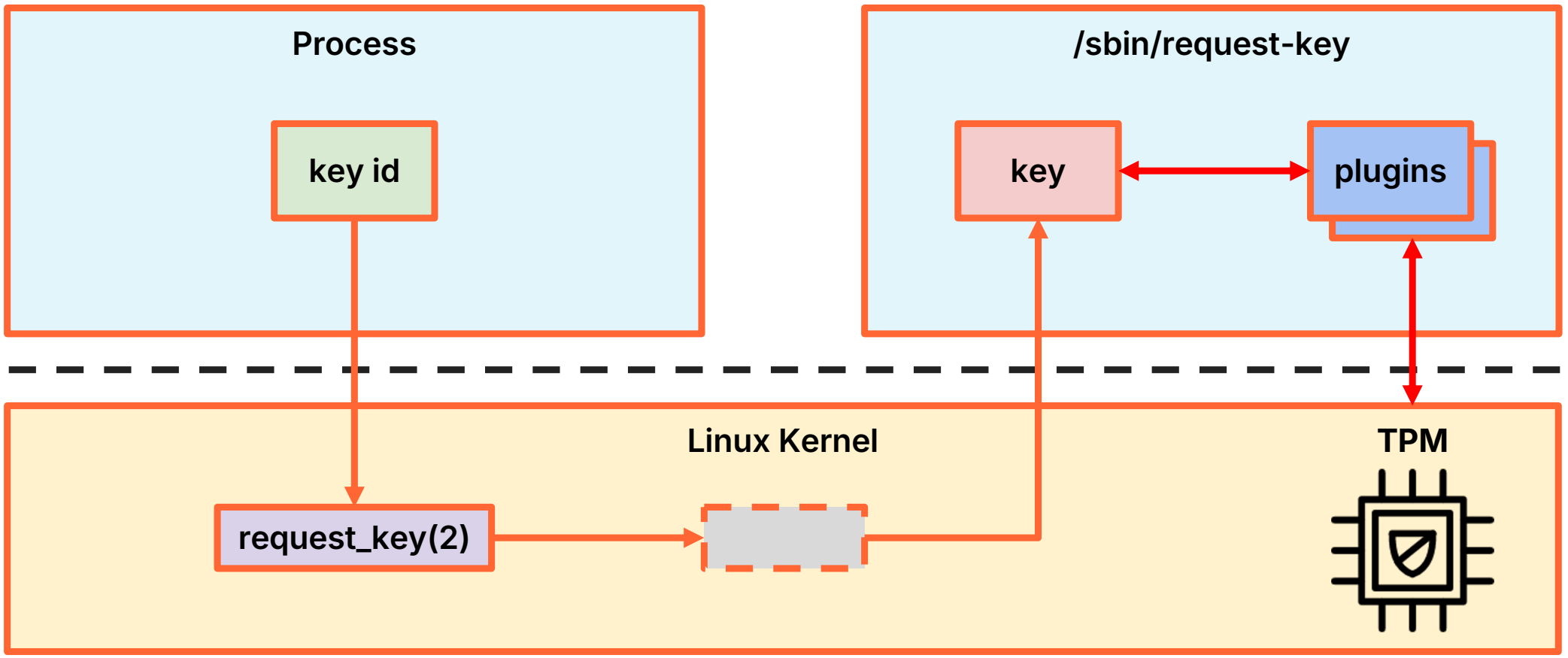

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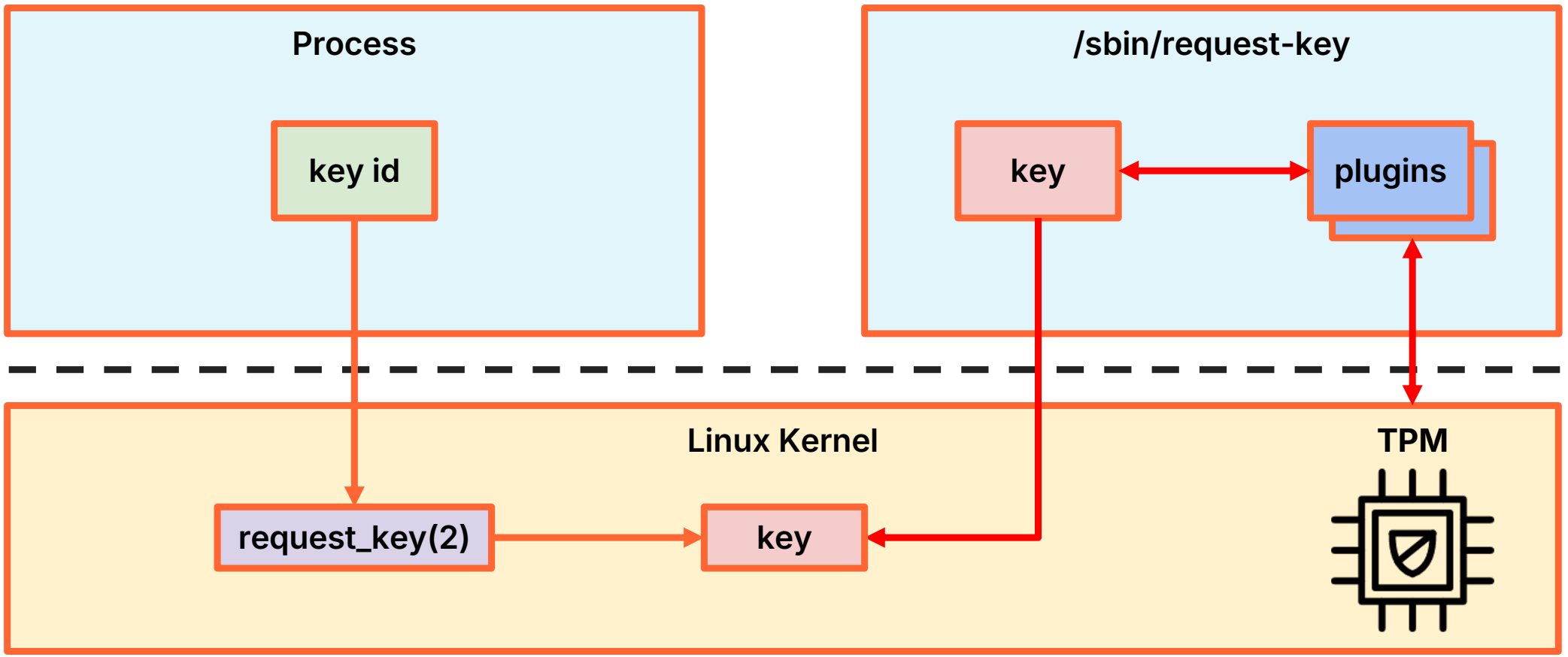

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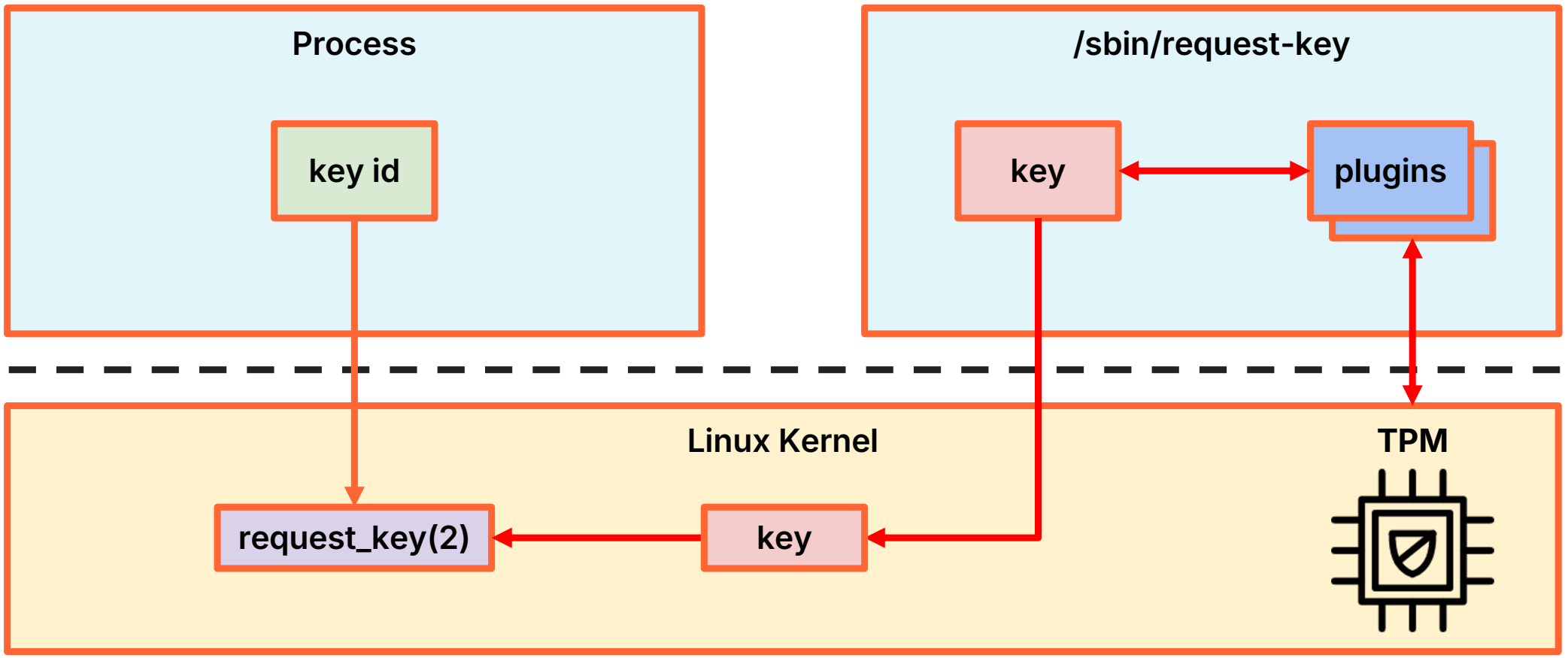

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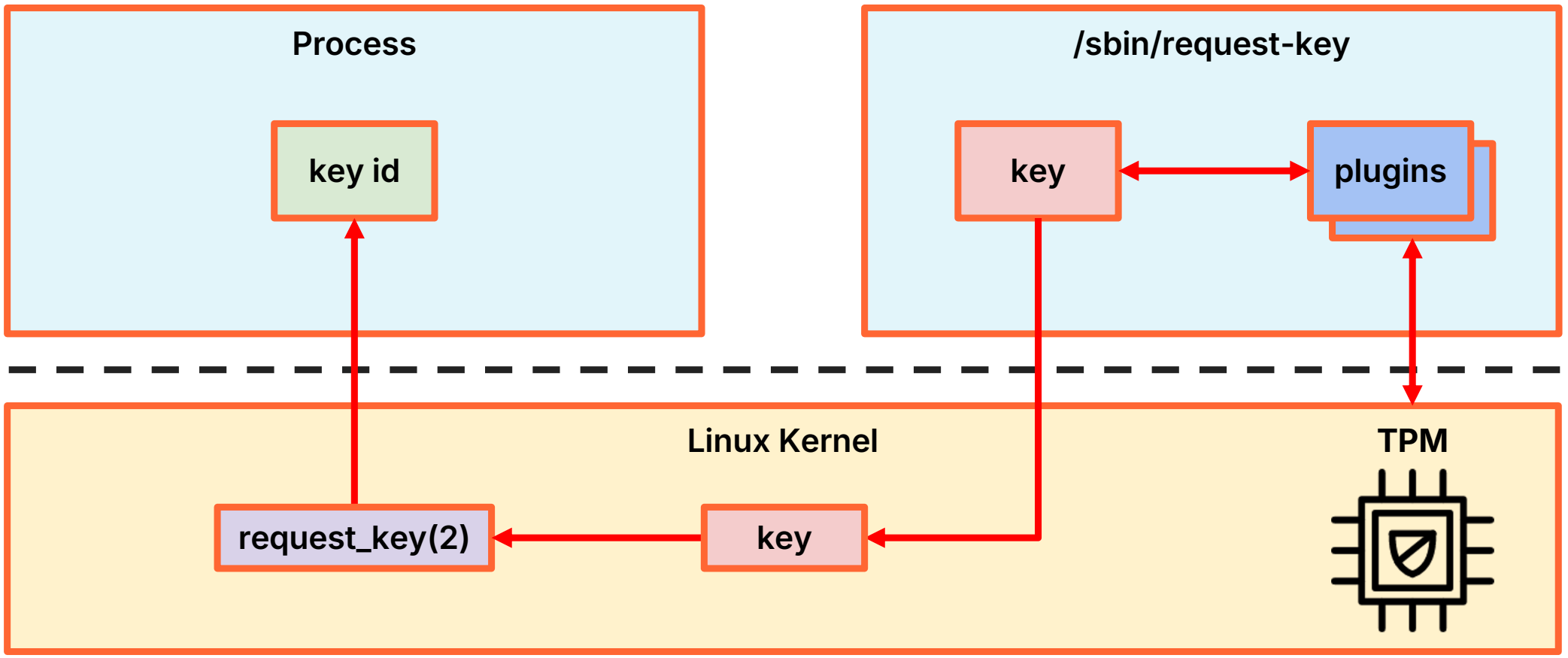

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CLOUDFLARE

TPM derived keys request_key(2) plugin

https://t.ly/0J6L-

@ignatkn

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ cat /etc/request-key.d/derived.conf
create * tpm2:derived:* * |/home/ignat/git/tpm-derived-keys/derived.py %t %d
%c %u %g
```

@ignatkn

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ cat /etc/request-key.d/derived.conf
create * tpm2:derived:* * |/home/ignat/git/tpm-derived-keys/derived.py %t %d
%c %u %g
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
655215536
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ cat /etc/request-key.d/derived.conf
create * tpm2:derived:* * |/home/ignat/git/tpm-derived-keys/derived.py %t %d
%c %u %g
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
655215536
ignat@dev:~$ keyctl print 655215536
:hex:72b7392c62c9279806983 04f20b9d0d01d0b7fee3e54bba0c180086c940df023
```

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TPM derived keys via request_key(2)

```
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655215536
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ignat@dev:~$ keyctl unlink 655215536
1 links removed
```

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:hex:72b7392c62c9279806983 04f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 655215536
1 links removed
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ cat /etc/request-key.d/derived.conf
create * tpm2:derived:* * |/home/ignat/git/tpm-derived-keys/derived.py %t %d
%c %u %g
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655215536
ignat@dev:~$ keyctl print 655215536
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 655215536
1 links removed
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
```

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TPM derived keys via request_key(2)

```
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%c %u %g
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655215536
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:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
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1 links removed
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ignat@dev:~$ keyctl print 806632423
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ignat@dev:~$ keyctl unlink 806632423
1 links removed
```

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TPM derived keys via request_key(2)

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806632423
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:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
```

CLOUDFLARE

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806632423
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:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 path" @s
302248702
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 path" @s
302248702
ignat@dev:~$ keyctl print 302248702
:hex:21e346d301e9a3be6053505bd753cf68515fd152b5665ead6a4ec253371d2716
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 path" @s
302248702
ignat@dev:~$ keyctl print 302248702
:hex:21e346d301e9a3be6053505bd753cf68515fd152b5665ead6a4ec253371d2716
ignat@dev:~$ keyctl unlink 302248702
1 links removed
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 path" @s
302248702
ignat@dev:~$ keyctl print 302248702
:hex:21e346d301e9a3be6053505bd753cf68515fd152b5665ead6a4ec253371d2716
ignat@dev:~$ keyctl unlink 302248702
1 links removed
ignat@dev:~$ sudo ./keyctl request2 user tpm2:derived:test "32 path" @s
1037265117
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ /usr/bin/keyctl request2 user tpm2:derived:test "32 path" @s
806632423
ignat@dev:~$ keyctl print 806632423
:hex:72b7392c62c927980698304f20b9d0d01d0b7fee3e54bba0c180086c940df023
ignat@dev:~$ keyctl unlink 806632423
1 links removed
ignat@dev:~$ cp /usr/bin/keyctl ./
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 path" @s
302248702
ignat@dev:~$ keyctl print 302248702
:hex:21e346d301e9a3be6053505bd753cf68515fd152b5665ead6a4ec253371d2716
ignat@dev:~$ keyctl unlink 302248702
1 links removed
ignat@dev:~$ sudo ./keyctl request2 user tpm2:derived:test "32 path" @s
1037265117
ignat@dev:~$ keyctl print 1037265117
:hex:93130b4be4bc1a8fbc1d9fec3374ad5dc5698419982119352fd3c2e4ee22e577
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
ignat@dev:~$ keyctl unlink 807021204
1 links removed
```

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807021204
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:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
ignat@dev:~$ keyctl unlink 807021204
1 links removed
ignat@dev:~$ cp ./keyctl ./keyctl2
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
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:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
ignat@dev:~$ keyctl unlink 807021204
1 links removed
ignat@dev:~$ cp ./keyctl ./keyctl2
ignat@dev:~$ ./keyctl2 request2 user tpm2:derived:test "32 csum" @s
776827534
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
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1 links removed
ignat@dev:~$ cp ./keyctl ./keyctl2
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776827534
ignat@dev:~$ keyctl print 776827534
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
```

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```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
ignat@dev:~$ keyctl unlink 807021204
1 links removed
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776827534
ignat@dev:~$ keyctl print 776827534
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
ignat@dev:~$ keyctl unlink 776827534
1 links removed
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
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ignat@dev:~$ keyctl unlink 776827534
1 links removed
ignat@dev:~$ sed -i 's/Bad message/Bad massage/' ./keyctl2
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
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:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
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ignat@dev:~$ keyctl unlink 776827534
1 links removed
ignat@dev:~$ sed -i 's/Bad message/Bad massage/' ./keyctl2
ignat@dev:~$ ./keyctl2 request2 user tpm2:derived:test "32 csum" @s
732784450
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ ./keyctl request2 user tpm2:derived:test "32 csum" @s
807021204
ignat@dev:~$ keyctl print 807021204
:hex:f638e269b0ebf1830faef47e0b4ba898220b5f8b77ae44a2fab0c2e41d13ba28
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1 links removed
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776827534
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732784450
ignat@dev:~$ keyctl print 732784450
:hex:15257529326a3b5874d2e4165245a2c4a758b3e6c549e876e3b808fe8a748c80
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
700095445
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
700095445
ignat@dev:~$ echo abc | openssl sha256 -binary > abc.sha256
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
700095445
ignat@dev:~$ echo abc | openssl sha256 -binary > abc.sha256
ignat@dev:~$ keyctl pkey_sign 700095445 0 abc.sha256 enc=pkcs1 hash=sha256 |
openssl sha256
SHA2-256(stdin)=
bb82fda82a8cbfd2ff96d52258234c9eb565b807784fbb79ac422a0caa2b48c4
```

CLOUDFLARE

TPM derived keys via request_key(2)

```
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
700095445
ignat@dev:~$ echo abc | openssl sha256 -binary > abc.sha256
ignat@dev:~$ keyctl pkey_sign 700095445 0 abc.sha256 enc=pkcs1 hash=sha256 |
openssl sha256
SHA2-256(stdin)=
bb82fda82a8cbfd2ff96d52258234c9eb565b807784fbb79ac422a0caa2b48c4
ignat@dev:~$ keyctl unlink 700095445
1 links removed
```

CLOUDFLARE

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ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
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SHA2-256(stdin)=
bb82fda82a8cbfd2ff96d52258234c9eb565b807784fbb79ac422a0caa2b48c4
ignat@dev:~$ keyctl unlink 700095445
1 links removed
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
734509723
```

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TPM derived keys via request_key(2)

```
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
700095445
ignat@dev:~$ echo abc | openssl sha256 -binary > abc.sha256
ignat@dev:~$ keyctl pkey_sign 700095445 0 abc.sha256 enc=pkcs1 hash=sha256 |
openssl sha256
SHA2-256(stdin)=
bb82fda82a8cbfd2ff96d52258234c9eb565b807784fbb79ac422a0caa2b48c4
ignat@dev:~$ keyctl unlink 700095445
1 links removed
ignat@dev:~$ keyctl request2 asymmetric tpm2:derived:test "32 csum" @s
734509723
ignat@dev:~$ keyctl pkey_sign 734509723 0 abc.sha256 enc=pkcs1 hash=sha256 |
openssl sha256
SHA2-256(stdin)=
bb82fda82a8cbfd2ff96d52258234c9eb565b807784fbb79ac422a0caa2b48c4
```

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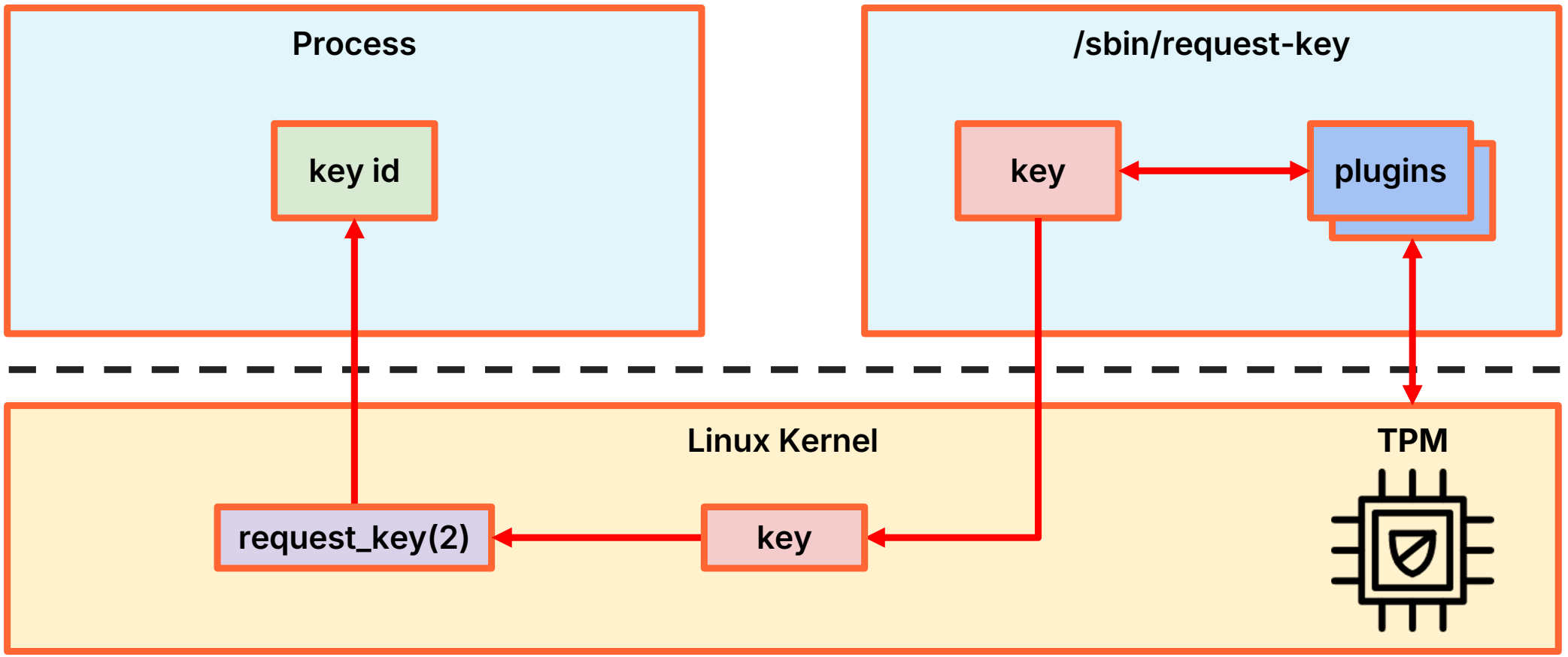
TPM derived keys via request_key(2) drawbacks



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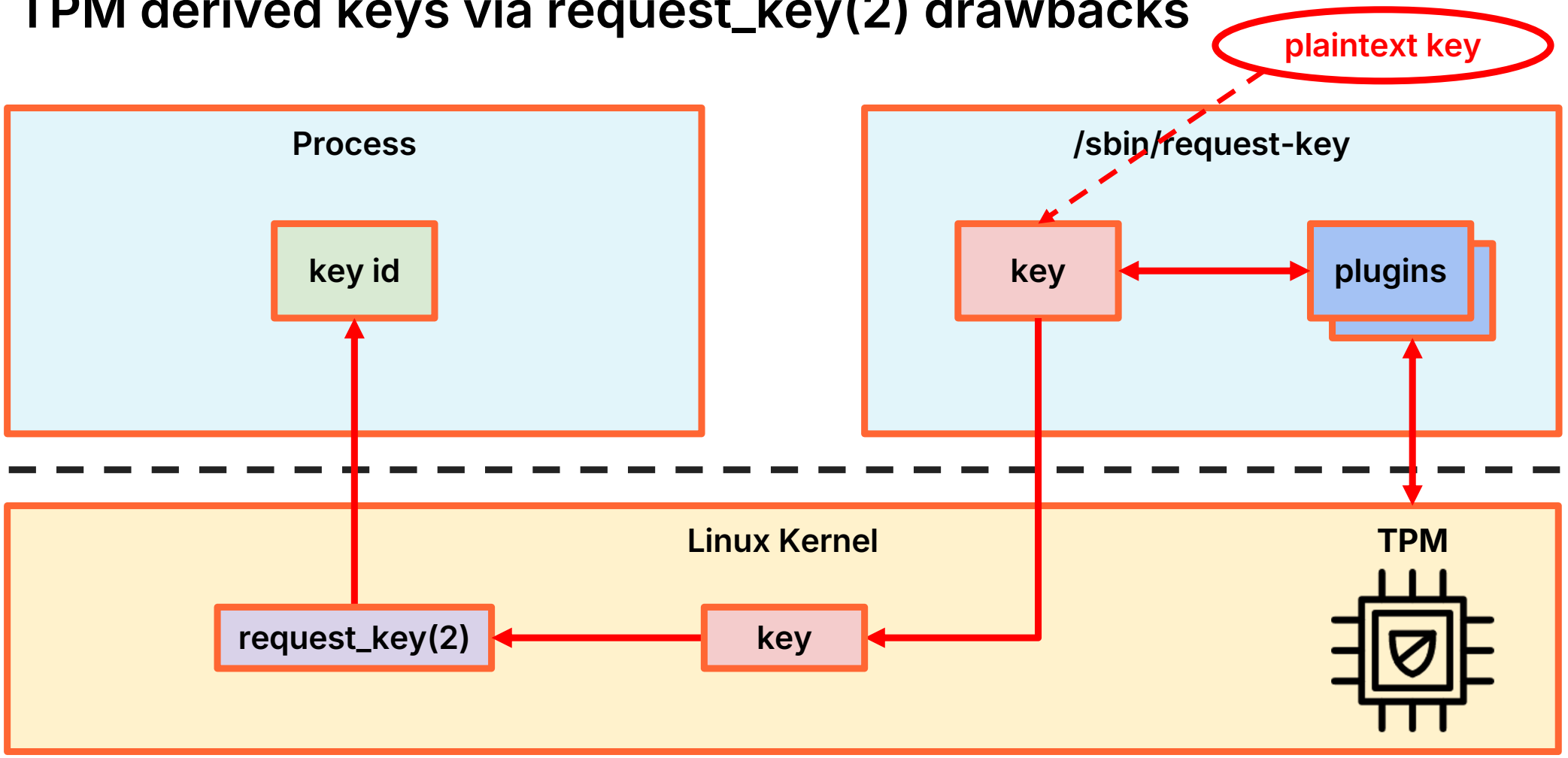
CLOUDFLARE

TPM derived keys via request_key(2) drawbacks



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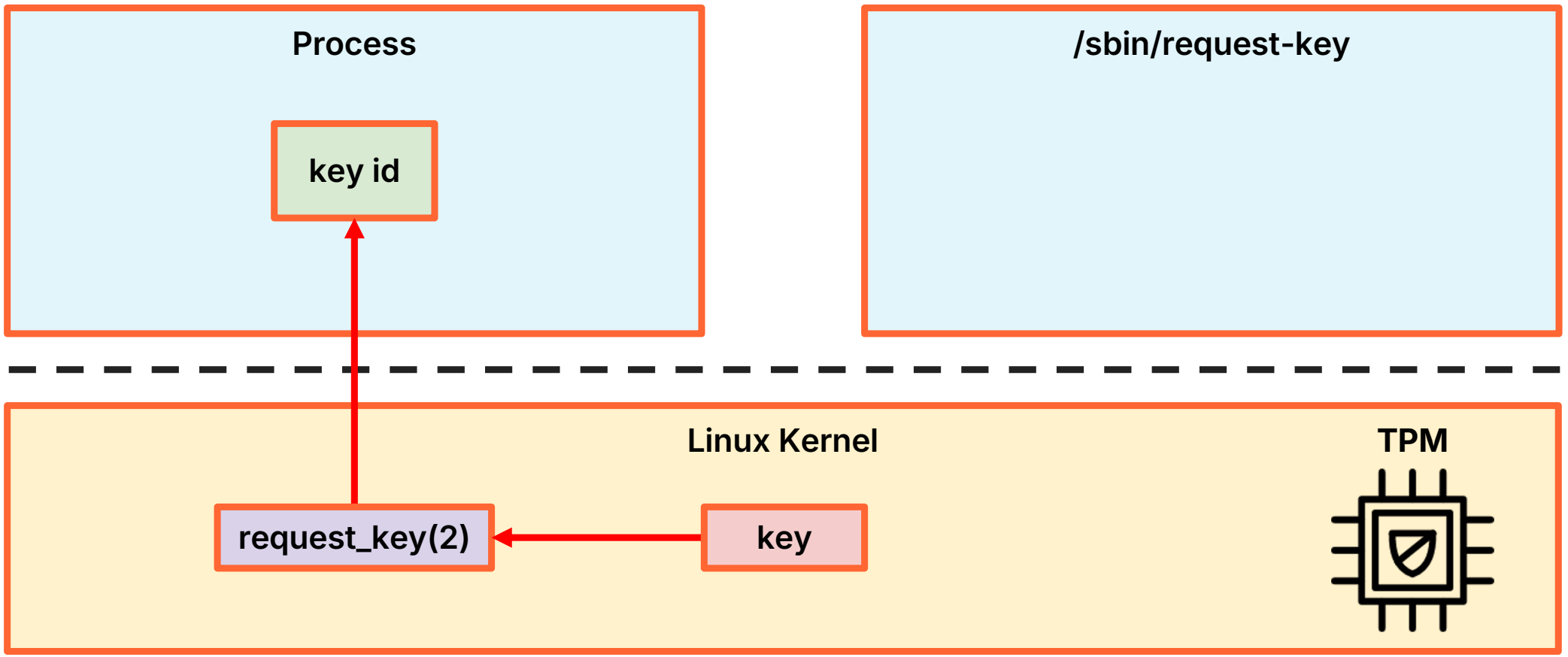
TPM derived keys directly in the kernel



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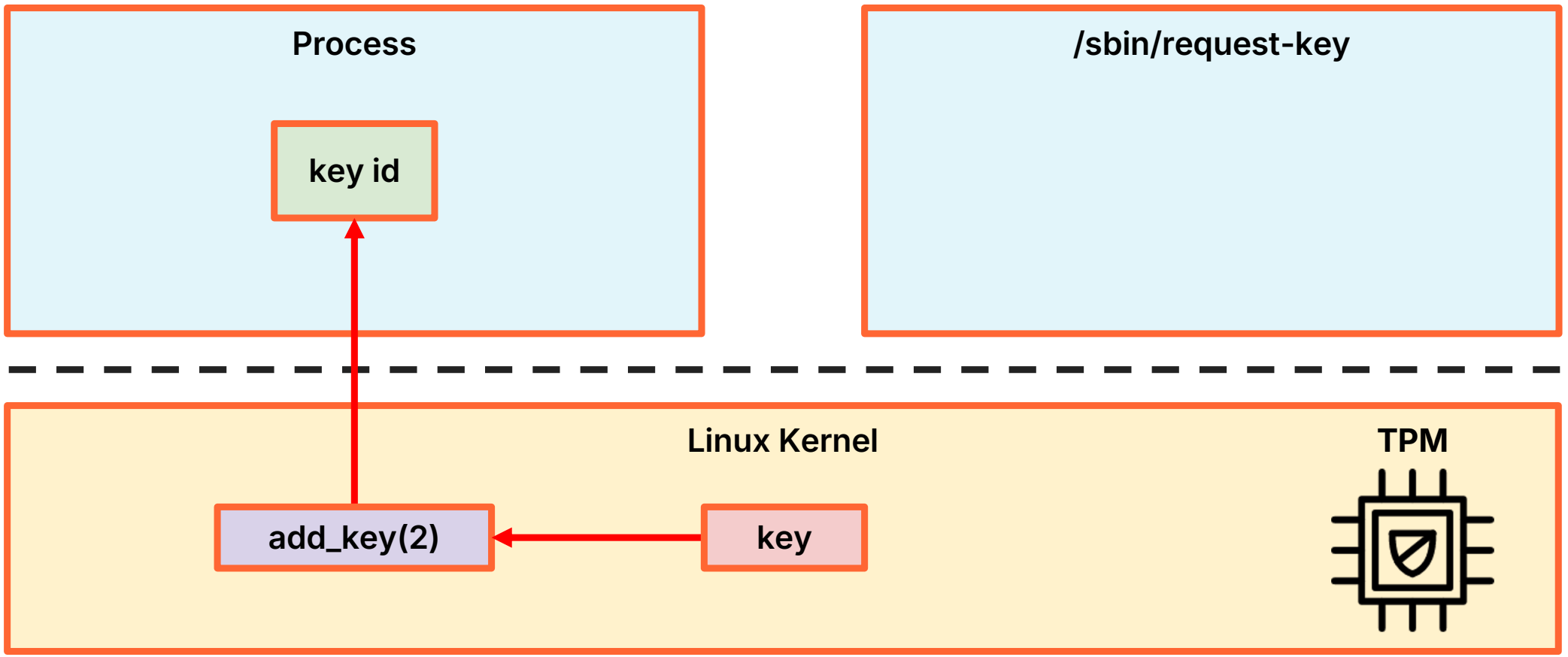
CLOUDFLARE

TPM derived keys directly in the kernel



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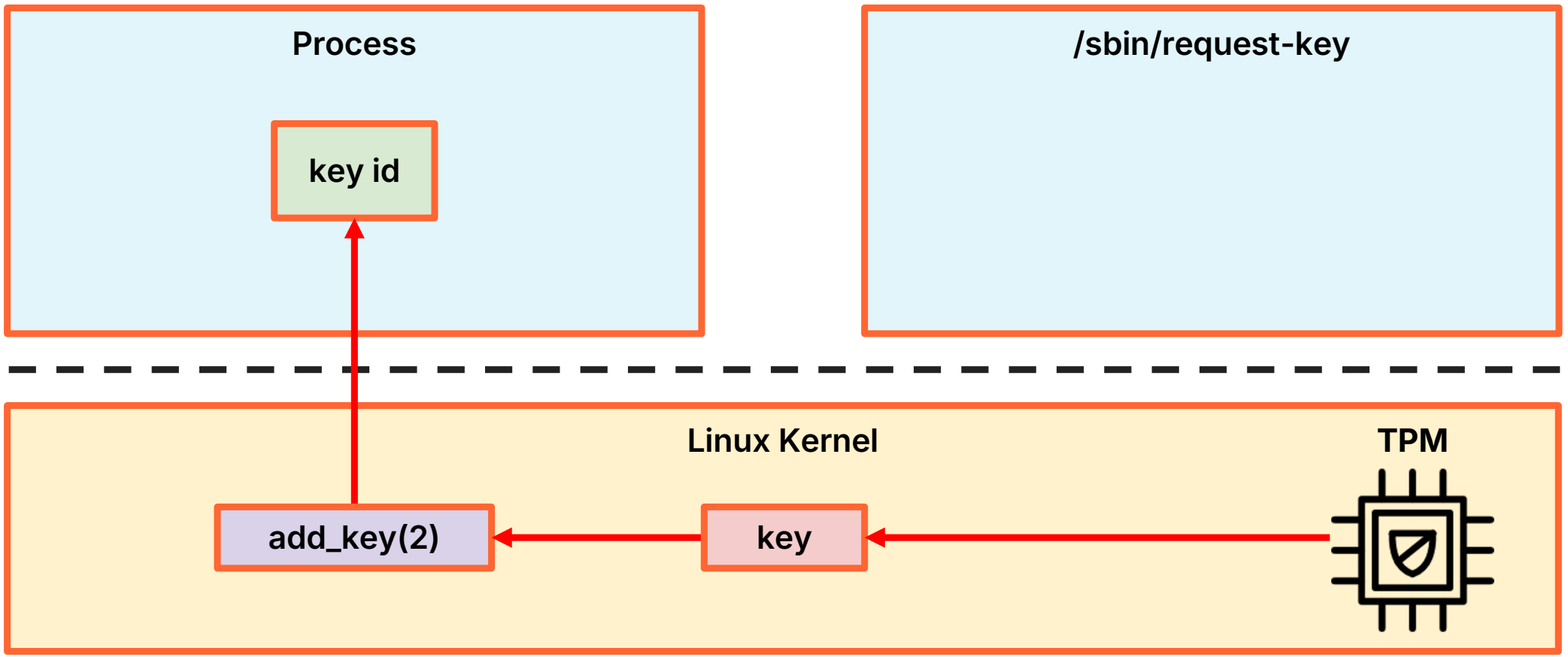
CLOUDFLARE

TPM derived keys directly in the kernel



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TPM derived keys request_key(2) plugin

https://lore.kernel.org/linux-kernel/20240503221634.44274-2-ignat@cloudflare.com/T/

“I don't honestly believe that this will ever be a solution for any possible problem that exist in this planet”

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Conclusions

- Interfacing with TPMs is hard, so applications avoid them altogether

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- Interfacing with TPMs is hard, so applications avoid them altogether
- Linux Kernel key retention service (keystore) can be a good layer to abstract away the TPM interaction complexity for applications
  - but some additional development might be needed

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Conclusions

- Interfacing with TPMs is hard, so applications avoid them altogether
- Linux Kernel key retention service (keystore) can be a good layer to abstract away the TPM interaction complexity for applications
  - but some additional development might be needed
- TPM derived keys is a good alternative to TPM wrapped keys providing similar hardware-backed security with potentially easier key management
  - can be implemented via a request_key(2) plugin for current kernels
  - in-kernel version is needed to avoid exposing the plaintext key material to userspace

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Conclusions

- Interfacing with TPMs is hard, so applications avoid them altogether
- Linux Kernel key retention service (keystore) can be a good layer to abstract away the TPM interaction complexity for applications
  - but some additional development might be needed
- TPM derived keys is a good alternative to TPM wrapped keys providing similar hardware-backed security with potentially easier key management
  - can be implemented via a request_key(2) plugin for current kernels
  - in-kernel version is needed to avoid exposing the plaintext key material to userspace
- Exposing TPMs through Linux Kernel keystore can provide applications with a straightforward path to adopting hardware security without too much exposure to TPM internals
  - probably true for other security chips

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Links

- https://www.kernel.org/doc/html/latest/security/keys/core.html
- https://www.kernel.org/doc/html/latest/security/keys/trusted-encrypted.html
- https://lore.kernel.org/lkml/20240528210823.28798-2-jarkko@kernel.org/T/
- https://gist.github.com/ignatk/9038d139e983ca355136aec7ec2d9bfc
- https://lore.kernel.org/linux-kernel/20240503221634.44274-2-ignat@cloudflare.com/T/

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Thank you!

Questions?