From Dragondoom to Dragonstar: Side-channel Attacks and Formally Verified Implementation of WPA3 Dragonfly Handshake

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Mozilla[2]
INRIA, Paris[3]

Toward Secure Wi-Fi Protocols...

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Offline dictionary attack

Nom du réseau Wi – Fi (SSID): **Bbox –** [redacted]

Mot de passe Wi – Fi (Clé de sécurité WPA, à saisir sans espace):

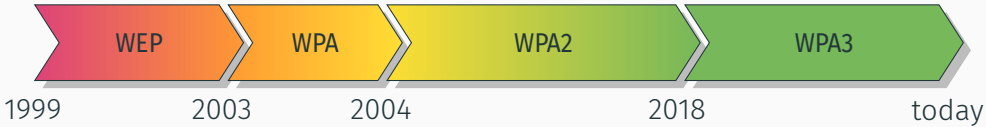
e376 10e4 3c75 a37d 8a8c 3806 98b7 bc

Toward Secure Wi-Fi Protocols...

Offline dictionary attack

KRACK attack

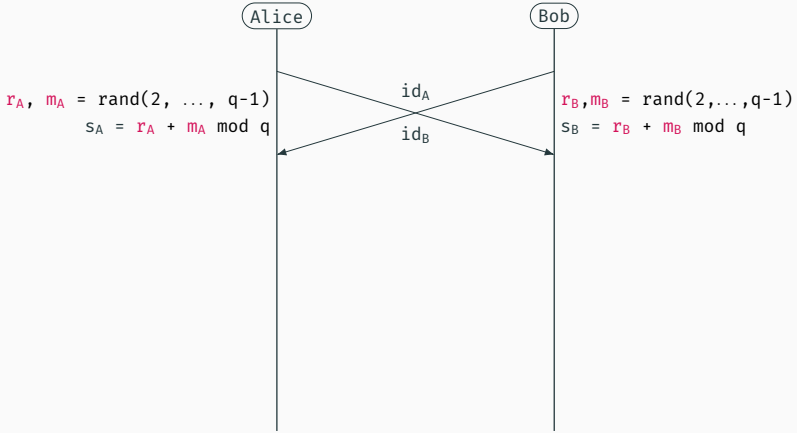
Toward Secure Wi-Fi Protocols...



+ More secure
+ Based on a PAKE (Dragonfly[1])

[1] D. Harkins. *Dragonfly Key Exchange.* RFC 7664. 2015

Dragonfly / SAE - A Balanced PAKE



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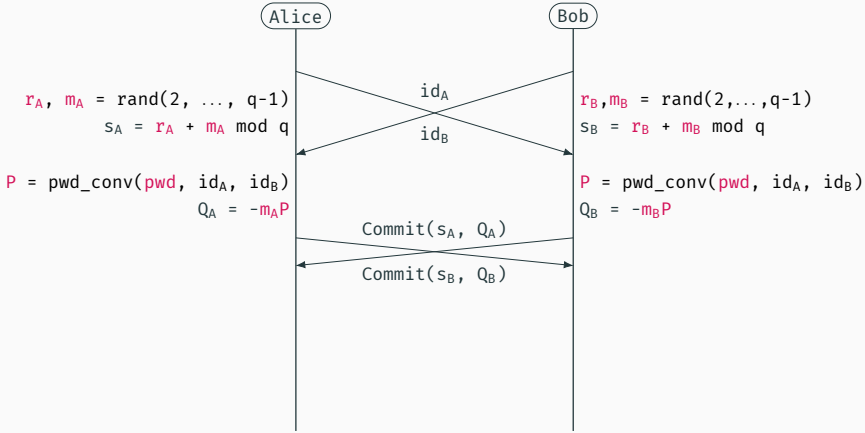

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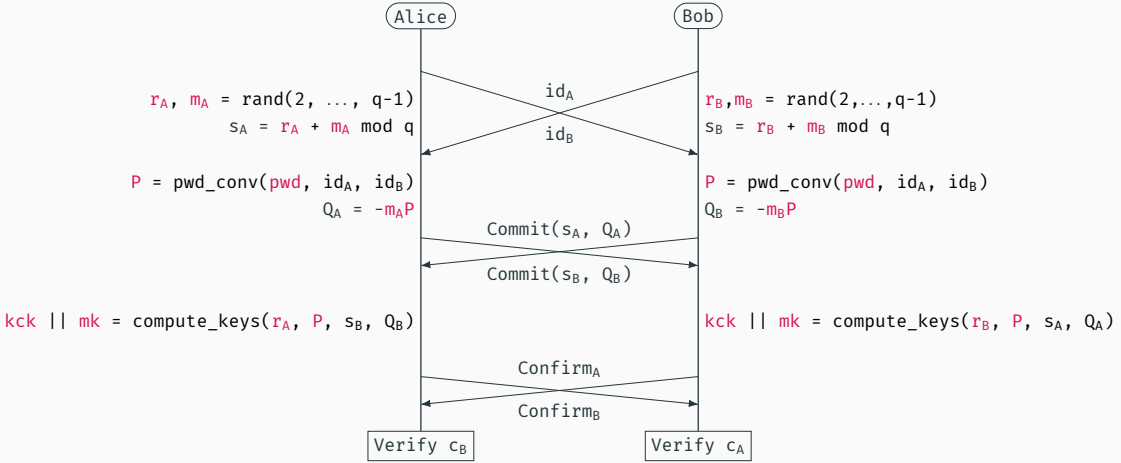

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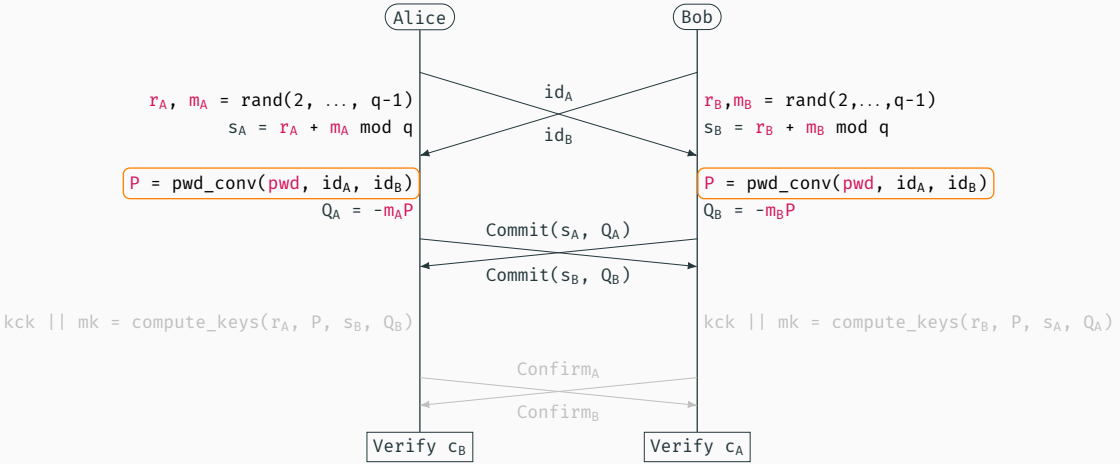

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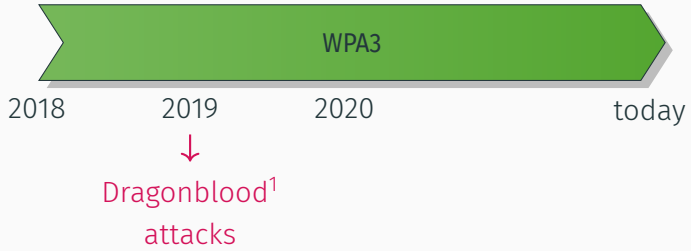

- Weird choice of password conversion method
  - Probabilistic
  - Difficult to implement securely
- Concerned were raised… and confirmed

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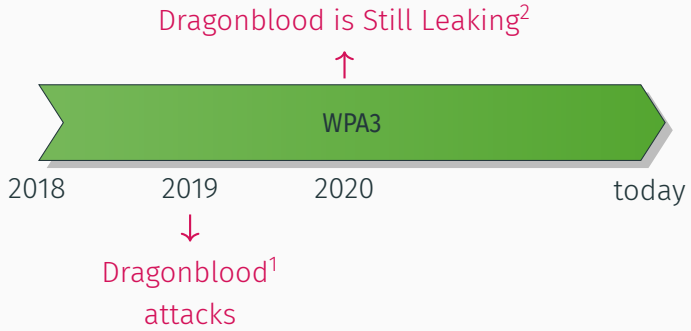

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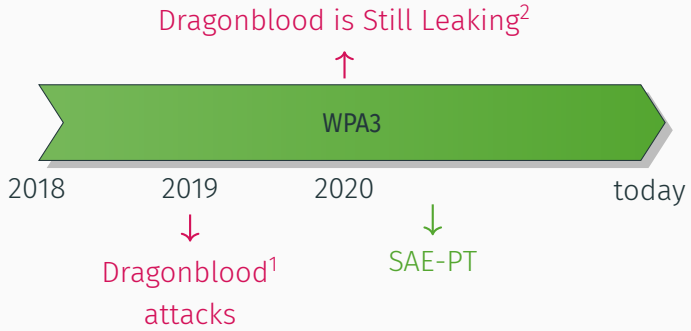

- Better password conversion (SSWU)
  - Deterministic
  - Straightforward constant-time implementation
- ⚠ **Not** backward compatible

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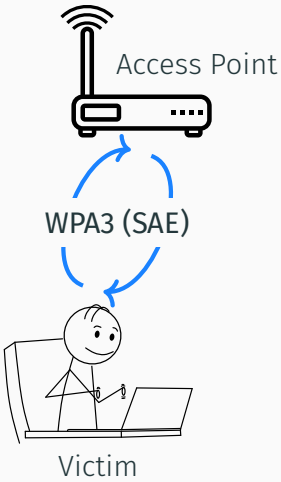

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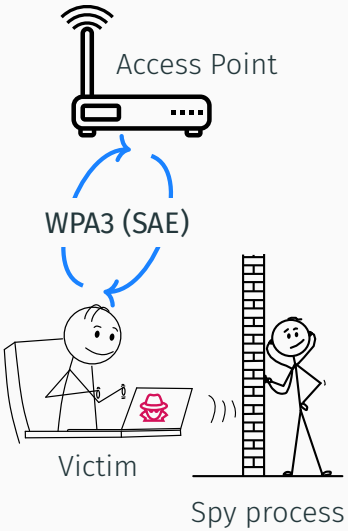

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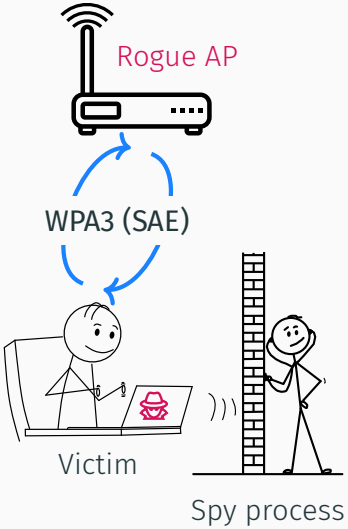
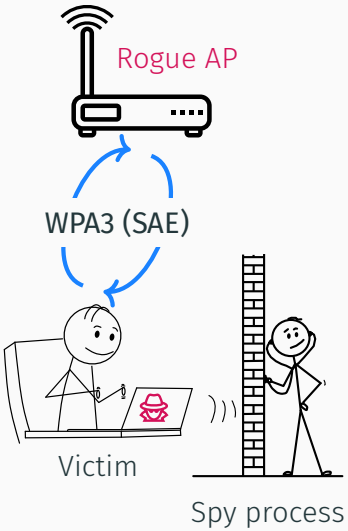




Spying/Data Acquisition

- Implementation specific
- Usually noisy measurement

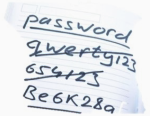
Comparison metric: Signal to Noise ratio

Attack Workflow

Leaked information

Trace parsing

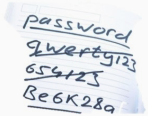
Offline Dictionary Attack



Remaining passwords

Offline Dictionary Attack

`H(secret) = 10...`



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x	H(x)
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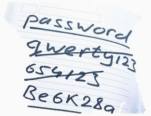
pwd_1	
pwd_2	
pwd_3	
...	
pwd_n	



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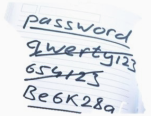

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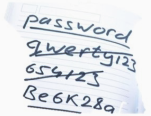

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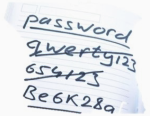

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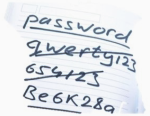

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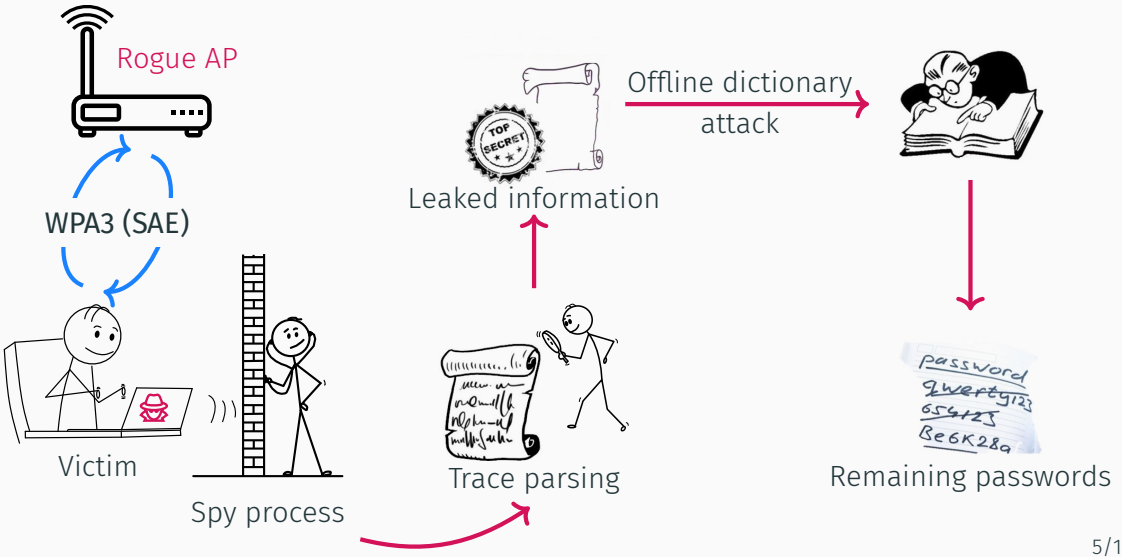

Looking Under the Hood

We mostly analyzed Wi-Fi daemons...

... what about their dependencies, like crypto libraries?

Looking Under the Hood

```
def set_compressed_point(x, fmt, ec)
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- Branching on the compression format
- Affects SAE (legacy version)
- 1-bit leakage
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- Wide scope (targets utility function)

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Affected projects:

- hostap/wpa_supplicant with OpenSSL/WolfSSL
- iwd with ell
- FreeRadius with OpenSSL

”Obviously” Vulnerable, yet Difficult to Exploit

- Very few conditional instructions (one cache line or less)
- Many false positives with ”vanilla” Flush+Reload
- Using existing attack to create a new distinguisher

Abuse prefetching behaviors to create a new distinguisher!

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
      y = compute_y(x, ec)

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    [...]

    return P
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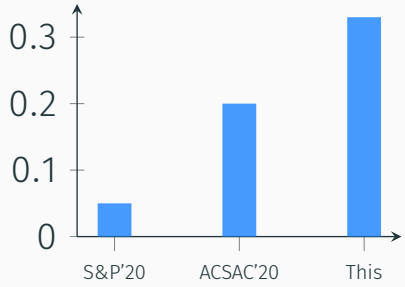
Very accurate distinguisher, with a better spatial resolution!



Sustainable patch for hostap

- Cryptographic libraries refused to patch
- Many other potential vulnerabilities (≈ 400)

Shall we replace them?

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HaCl*: A Formally Verified Cryptographic Library[1]

- Memory-safety
- Functional correctness
- Secret independence

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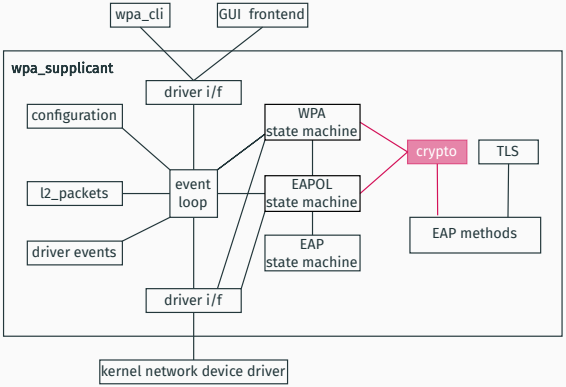
Fixing hostap[1]



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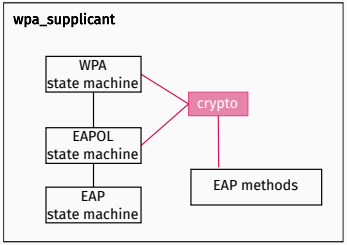

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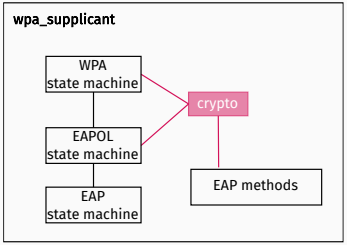


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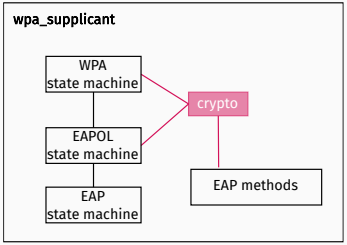


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Impact

A New Attack

- Dictionary attack (SAE/SAE-PT)
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  - First side-channel in SAE-PT (supposed to be ct by design)
- New generic gadget
  - Potential impact on many low-level arithmetic functions

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Material available at

- `https://gitlab.inria.fr/ddealmei/artifact_dragondoom`
- `https://gitlab.inria.fr/ddealmei/artifact_dragonstar`

Appendix

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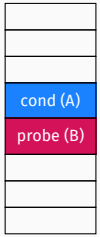

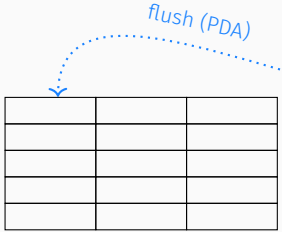

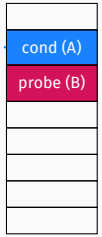

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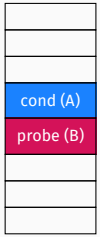

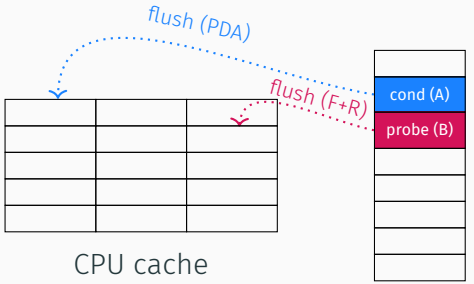

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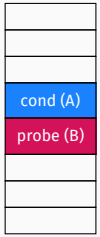

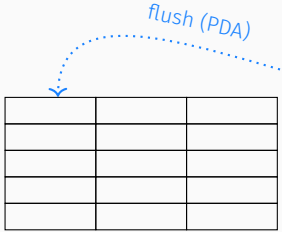

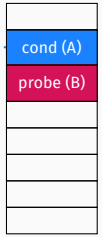

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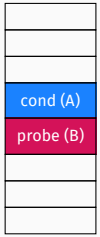

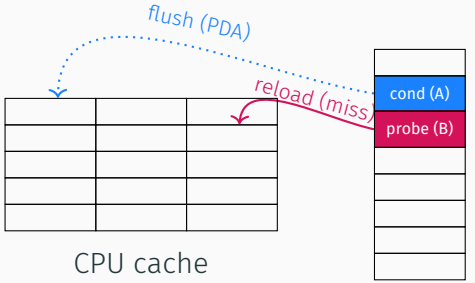

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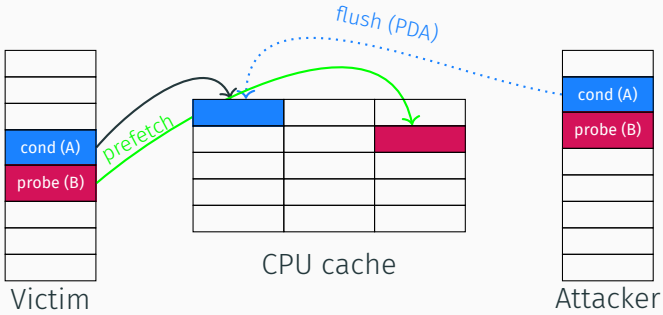

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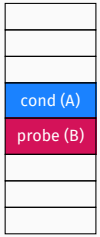
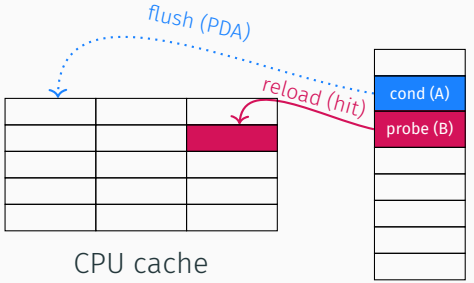
A

B





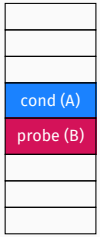
nb hits: 1

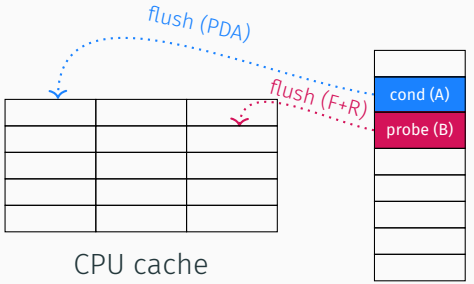
Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

→   if y = fmt mod 2:
        y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B





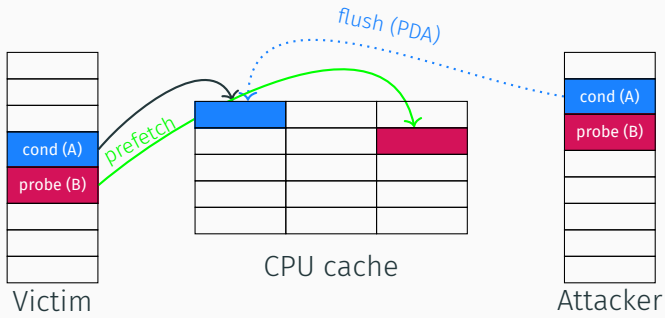
nb hits: 1

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B



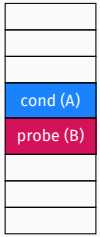
nb hits: 1

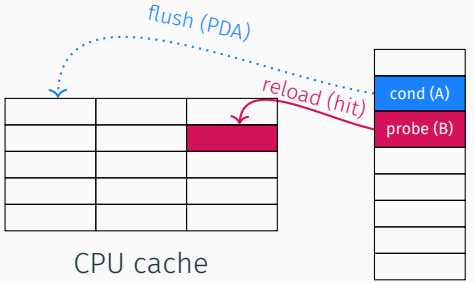
Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B





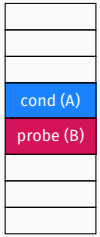
nb hits: 2

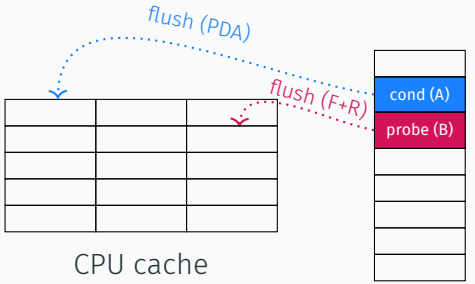
Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B





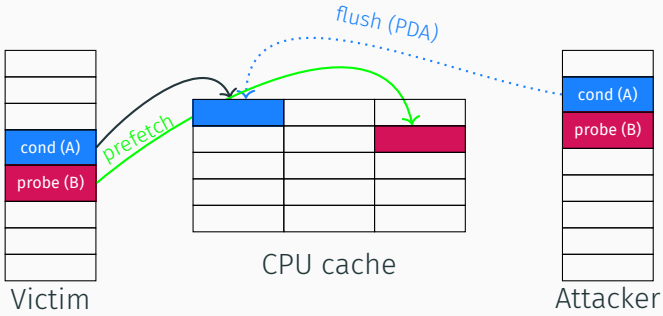
nb hits: 2

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B



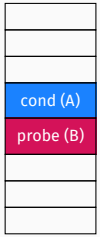
nb hits: 2

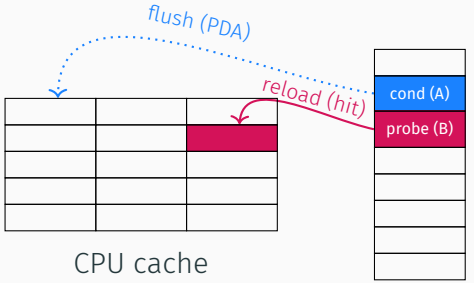
Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B





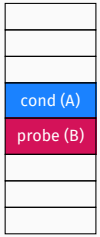
nb hits: 3

Prefetcher-based Side Channel

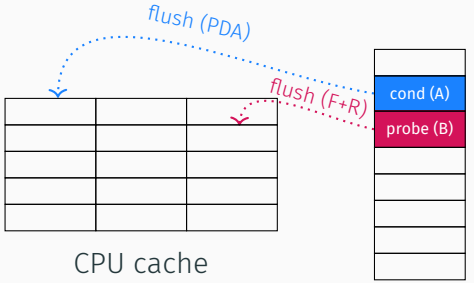
```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
→       y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

A

B



Victim



CPU cache

Attacker

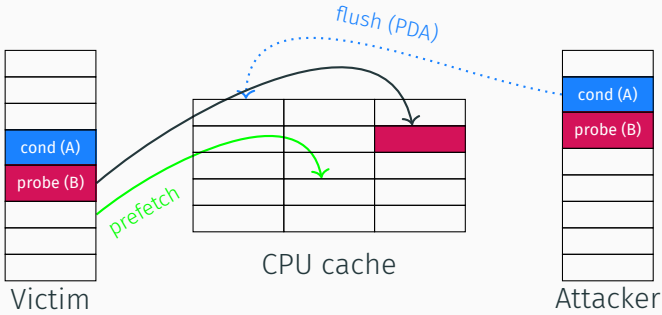
nb hits: 3

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
      y = ec.p - y

→   P = init_point(x, y, ec)
    [...]

    return P
```

A

B



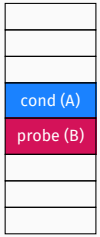
nb hits: 3

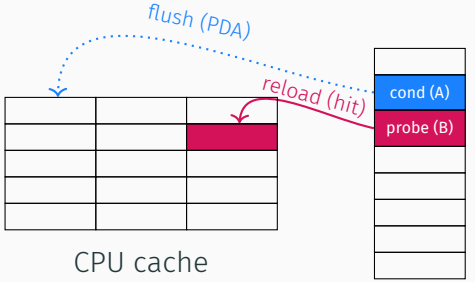
Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
    y = compute_y(x, ec)

    if y = fmt mod 2:
      y = ec.p - y

→   P = init_point(x, y, ec)
    [...]

    return P
```

A

B





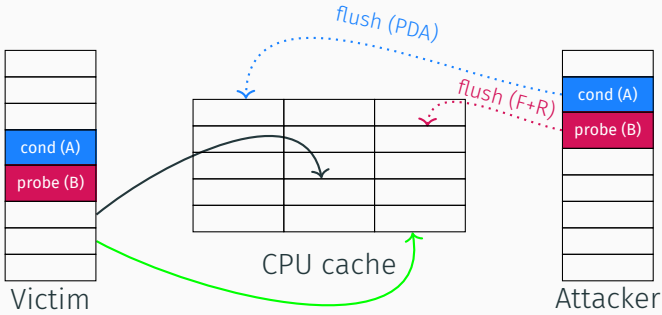
nb hits: 4

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
      y = compute_y(x, ec)

      if y = fmt mod 2:
        y = ec.p - y

      P = init_point(x, y, ec)
      [...]

→     return P
```

A

B



nb hits: 4

Prefetcher-based Side Channel

```
def set_compressed_point(x, fmt, ec):
     y = compute_y(x, ec)

    if y = fmt mod 2:
      y = ec.p - y

    P = init_point(x, y, ec)
    [...]

    return P
```

Very accurate distinguisher, with a better spatial resolution!