PARASITE: PAssword Recovery Attack against Srp Implementations in ThE wild

Daniel De Almeida Braga
Pierre-Alain Fouque
Mohamed Sabt

EDUC Seminar - November, 25th 2021

Me, Myself and I

Cryptography in the Wild: The Security of Cryptographic Implementations and Standards

What I Have Been Doing

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- Recent interest in DRM systems
- Formally verified implementations and constant-time verification tools

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Context and Motivations

A Few Words About PAKEs

What to expect from a PAKE, starting from a password:

- Authentication
- End up with strong key
- Resist to (offline) dictionary attack

Lot's of different PAKEs (two main families: balanced - asymmetric).

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Case study: Secure Remote Password (SRP)

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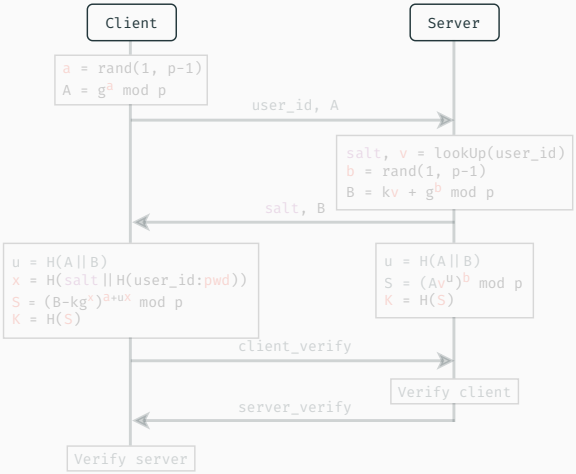
- Recent work on SRP at ACNS[4]

[4] A.Russon *Threat for the Secure Remote Password Protocol and a Leak in Apple's Cryptographic Library.* In ACNS. 2021

SRP Protocol Overview



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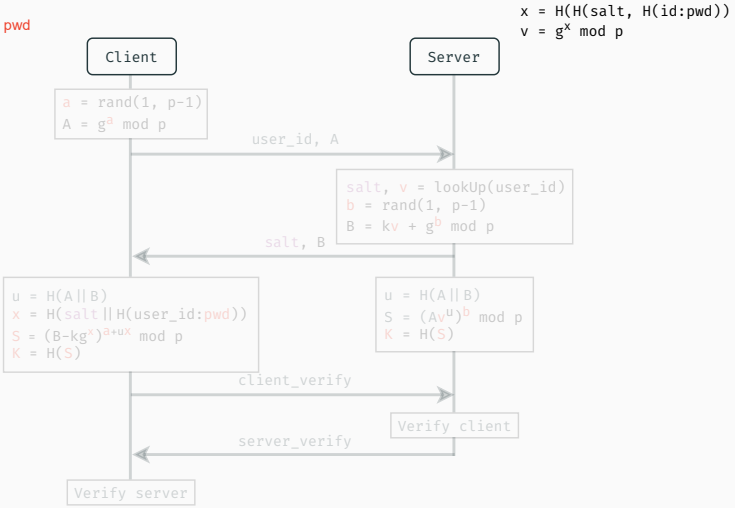

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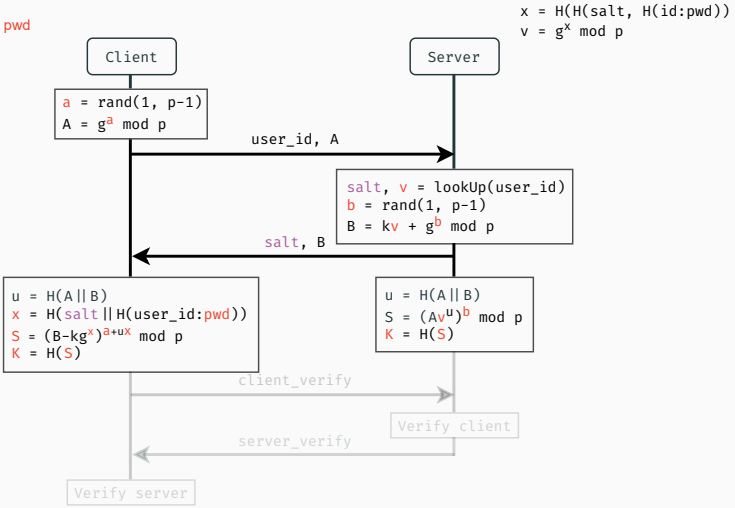

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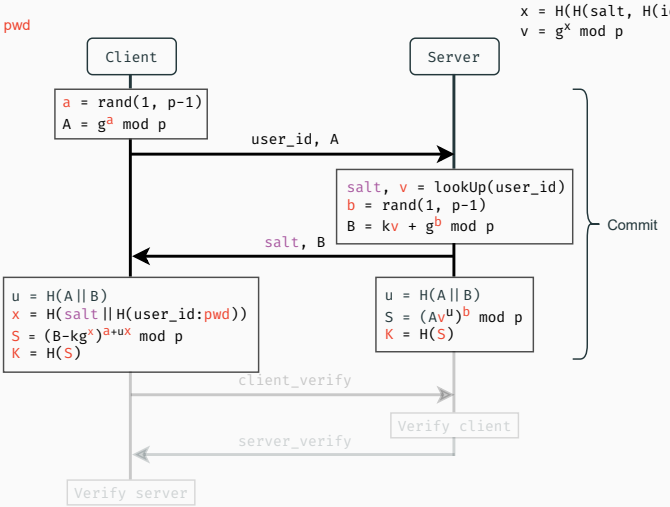

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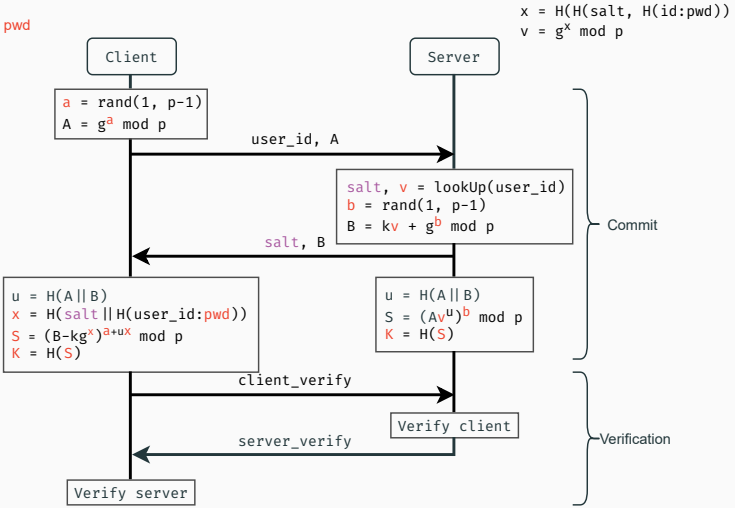

Contributions

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1. Study various SRP implementations
2. Highlight a leakage in the root library used for big number arithmetic (OpenSSL)
3. Design PoCs[1] of an offline dictionary attack recovering the password on impacted projects
4. Outline the importance of SCA, especially for PAKEs

[1] `https://gitlab.inria.fr/ddealmei/poc-openssl-srp`

Our Main Result

A cache-attack that let us extract information

during OpenSSL modular exponentiation

allowing to recover the password in a single measure

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Weak exponentiation algorithm

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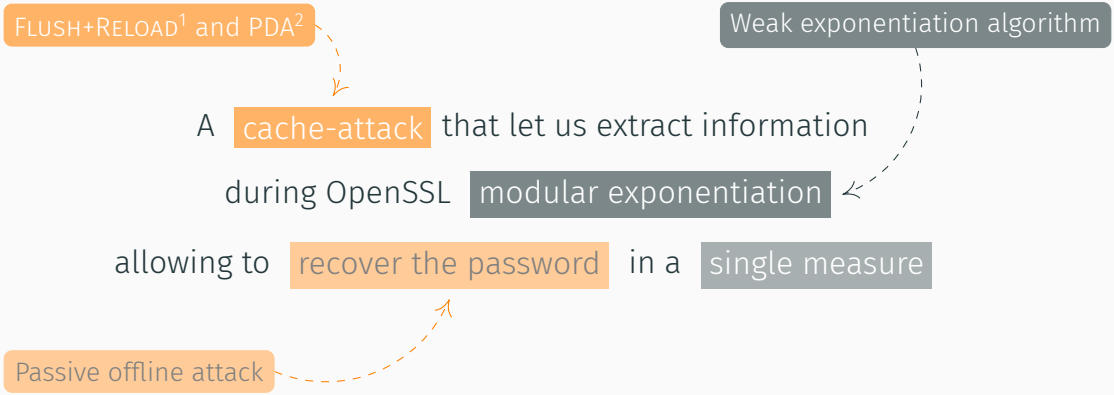

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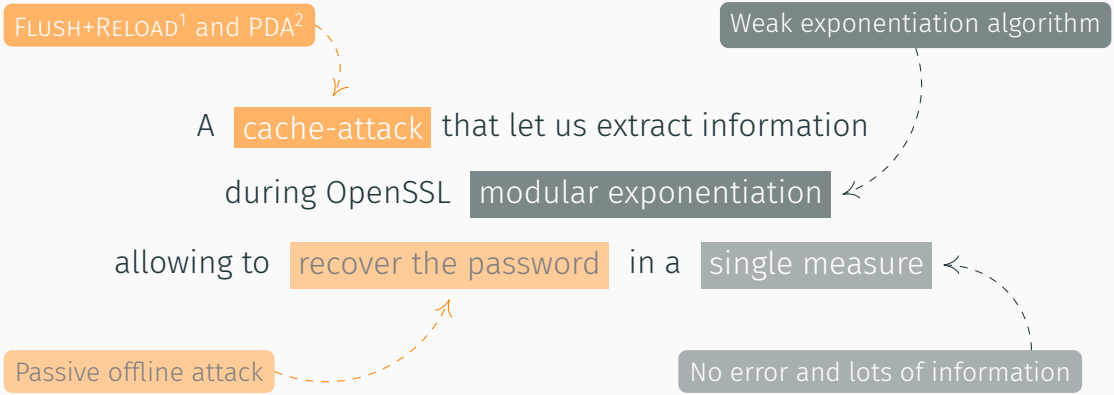

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The Vulnerability

Modular exponentiation in OpenSSL

`BN_mod_exp`

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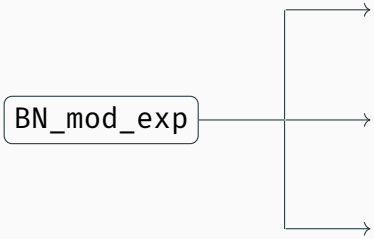

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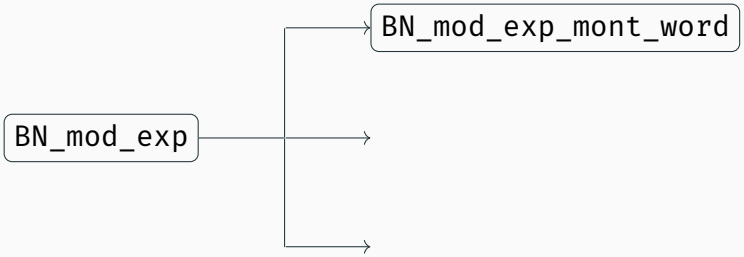

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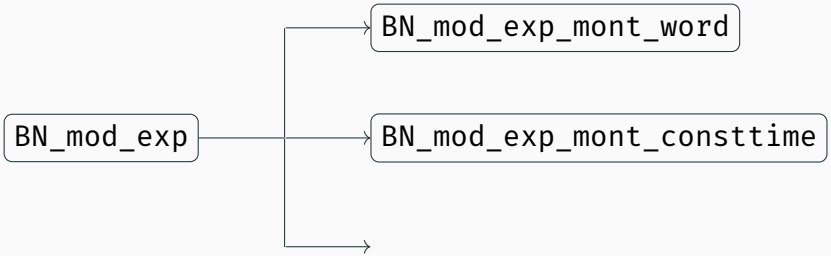

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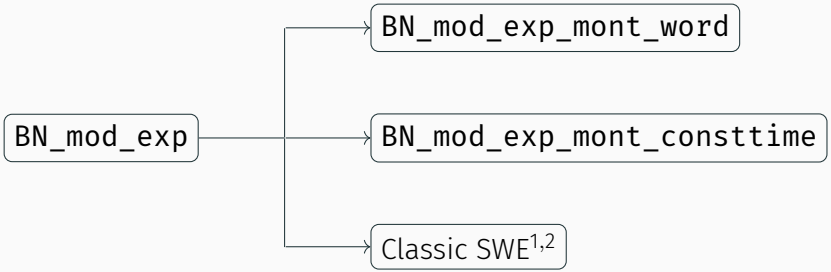

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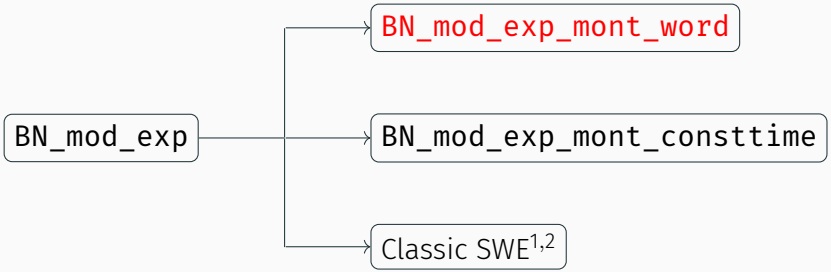

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Optimized Square-and-Multiply

bin(x) = 1 1 0 1 0 ...

res$= g^x \bmod p$

w processor word (e.g. 64 bits)

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def BN_mod_exp_mont_word(g, x, p):
  w = g                        # uint64_t
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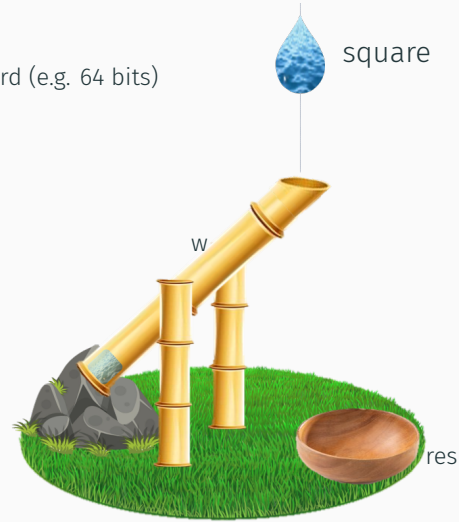


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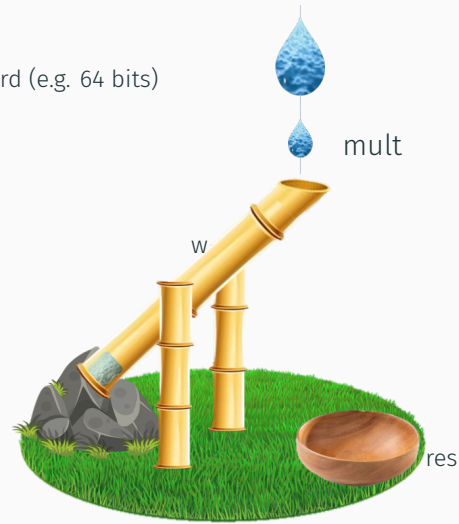


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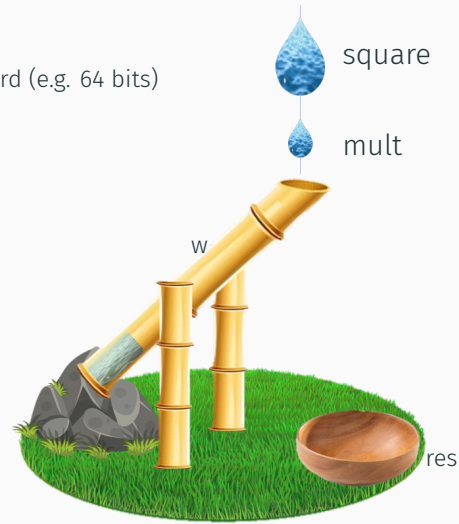


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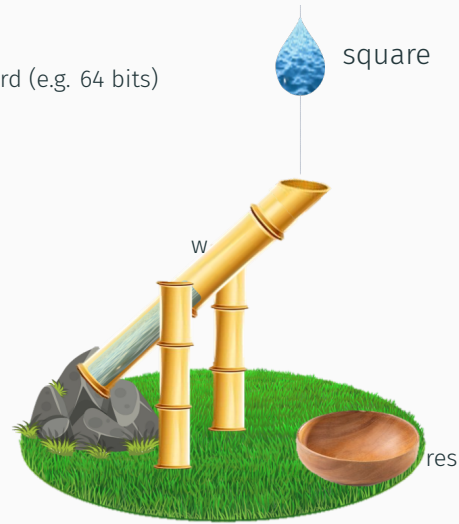


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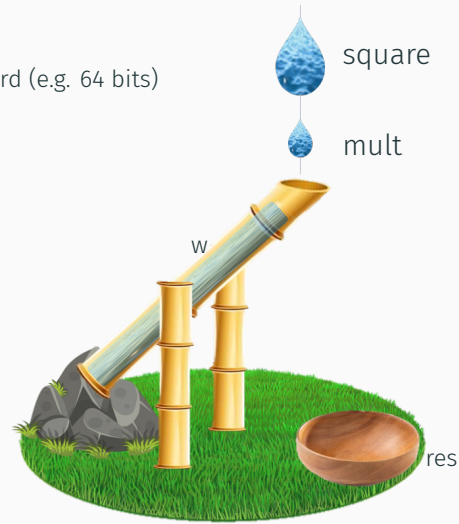


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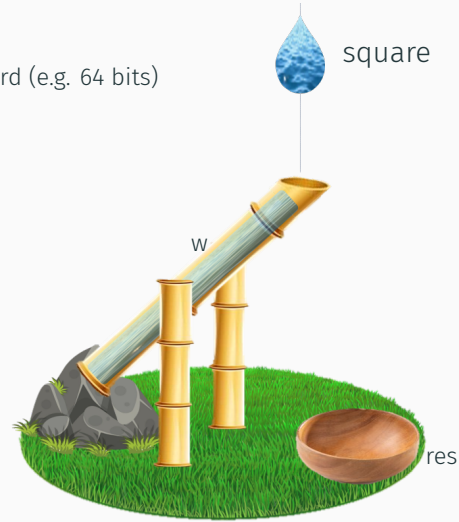


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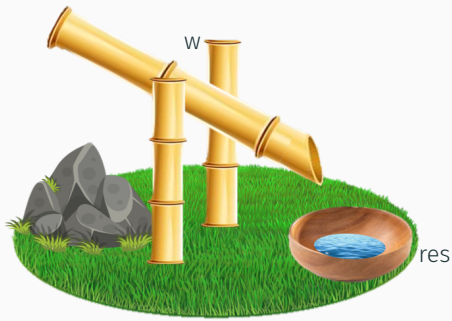


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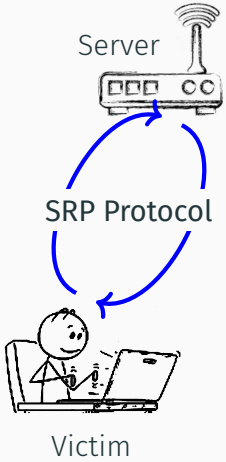
Exploiting the Leakage

Attacker Model

- Unprivileged spyware on the victim station
- Victim tries to connect
- MitM can help to gather more information (optional)

Attack Workflow



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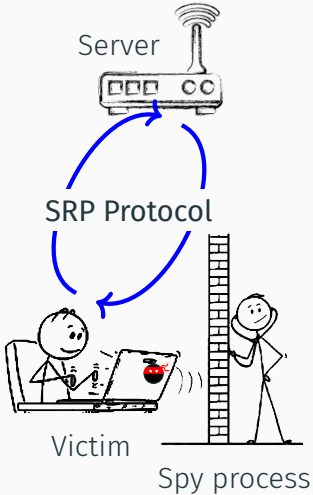

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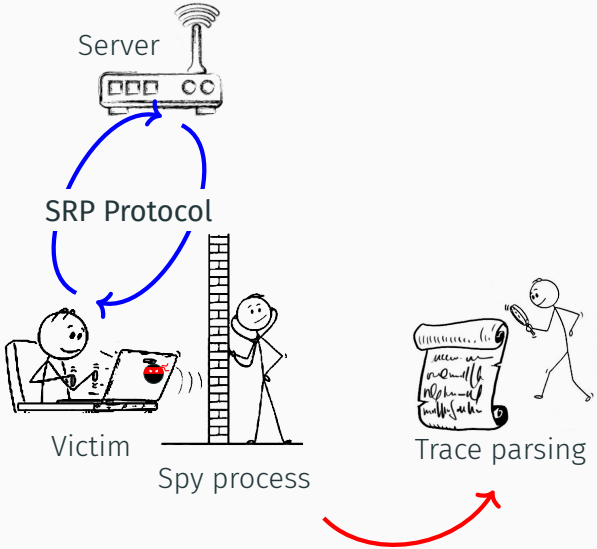

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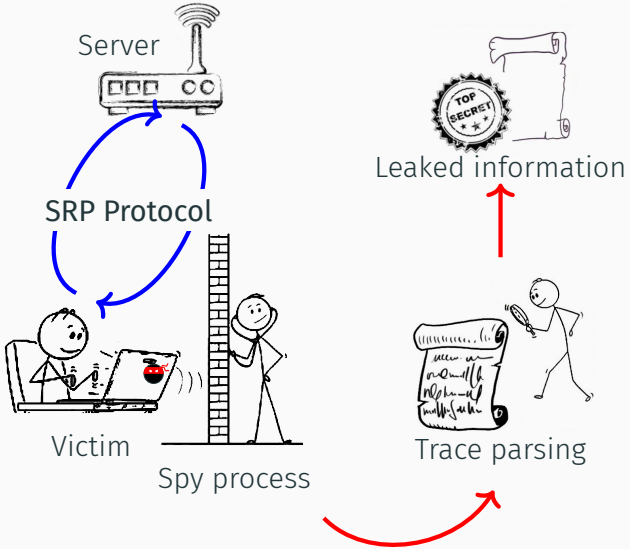

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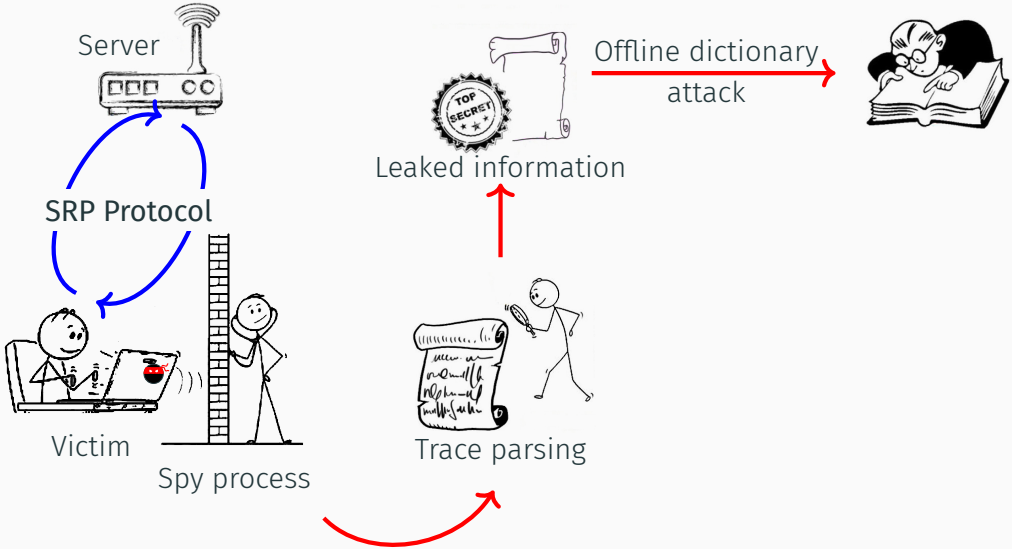

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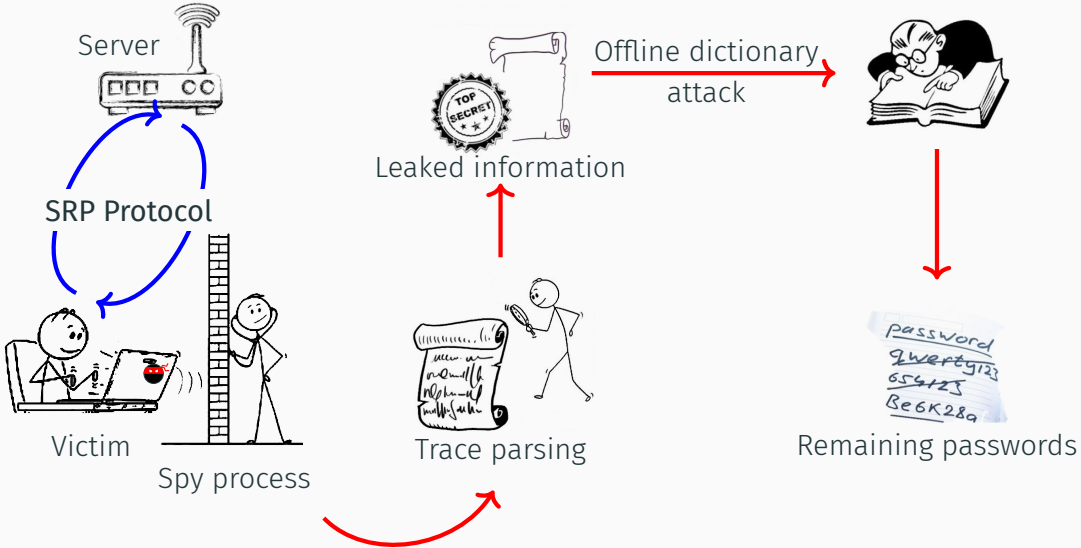

Trace Acquisition

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    next_w = w × w
    if (next_w / w) != w:
      res = BN_mod_mul(res, w, p)
      next_w = 1
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    res = BN_mod_sqr(res, res, p)

    if BN_is_bit_set(x, b):
      next_w = w × g;
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```

Trace Acquisition

```
def BN_mod_exp_mont_word(g, x, p):
  w = g                       # uint64_t
  res = BN_to_mont_word(w)  # bignum
  for b in range(bitlen-2, 0, -1):
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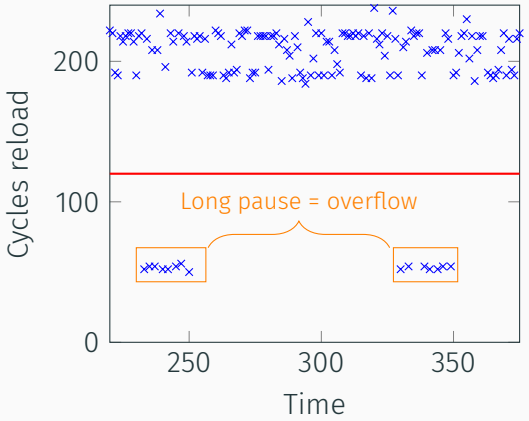
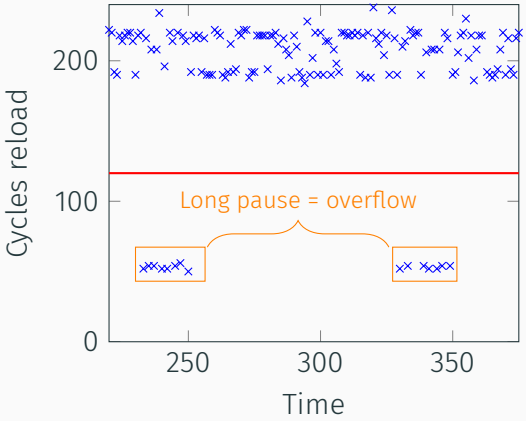


Trace Interpretation



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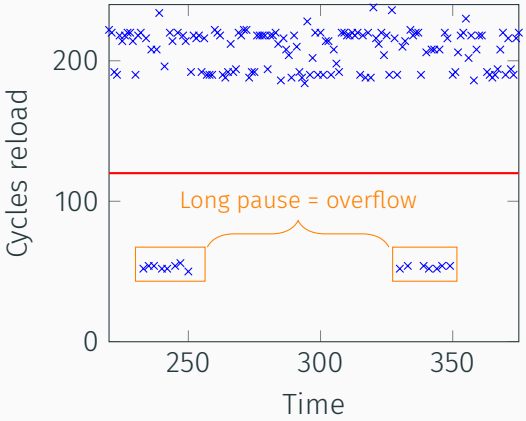

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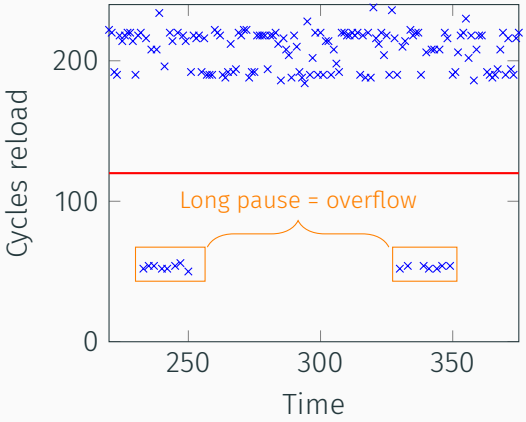

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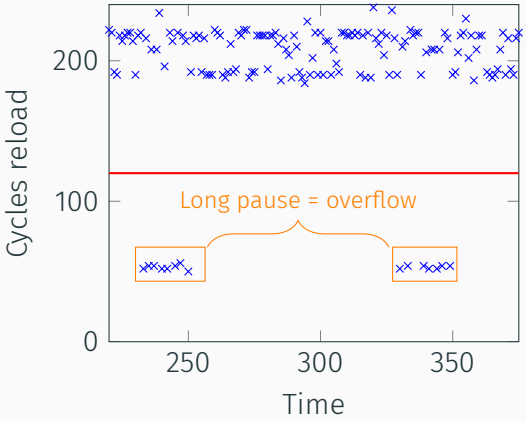

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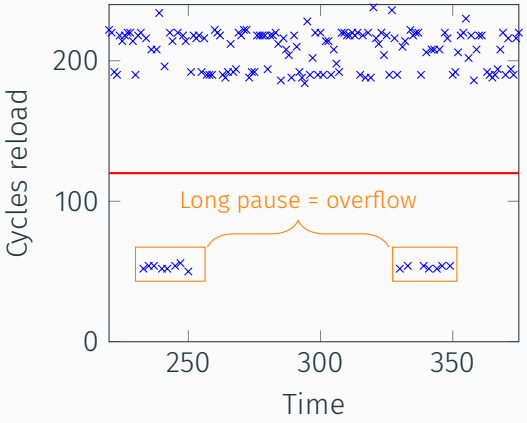
`Vvvv`	`Vvvvv`	`Vvvvvv`	`Vvvvv`	`Vvvvv`	`Vvvv`
4	5	6	5	5	4

Trace Interpretation



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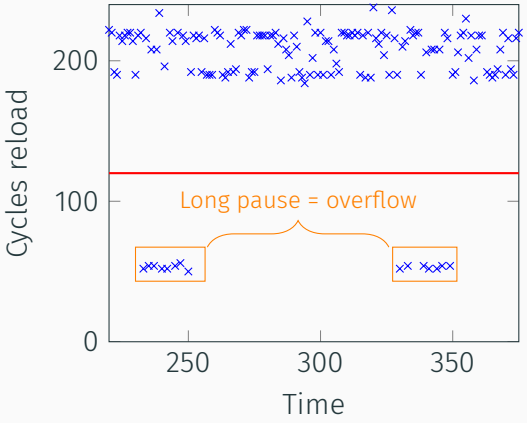
`Vvvv` `Vvvvv` `Vvvvvv` `Vvvvv` `Vvvvv` `Vvvv`
`4` `5` `6` `5` `5` `4`

⇓

`111b`

Trace Interpretation



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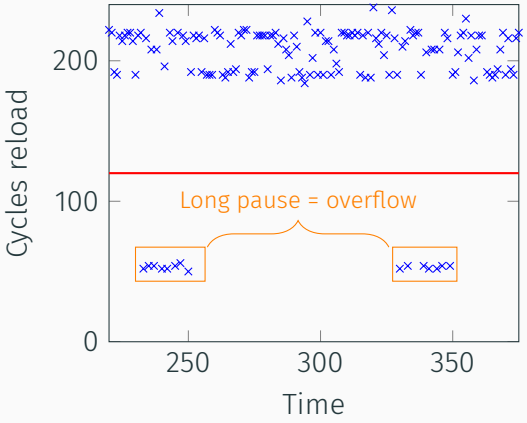
```
Vvvv  Vvvvv  Vvvvvv  Vvvvv  Vvvvv  Vvvv
  4     5       6      5      5      4
  ⇓     ⇓
111b  yyyyb
```

Trace Interpretation



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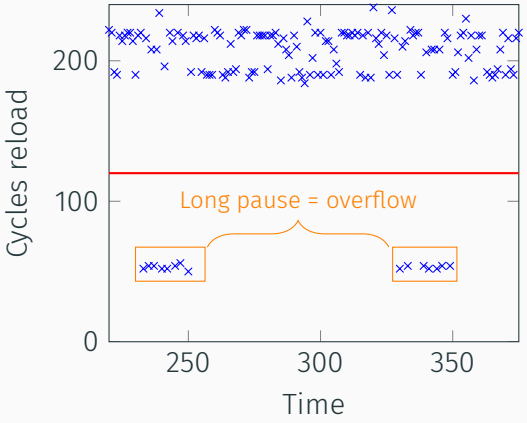

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⇓	⇓	⇓	⇓		
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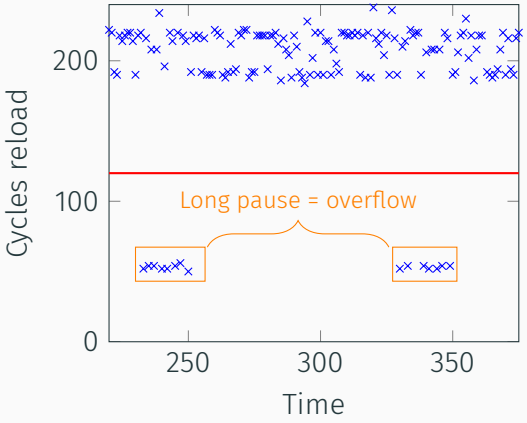

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⇓	⇓	⇓	⇓	⇓	
`111b`	`yyyyb`	`0yyyyb`	`yyyyb`	`yyyyb`	

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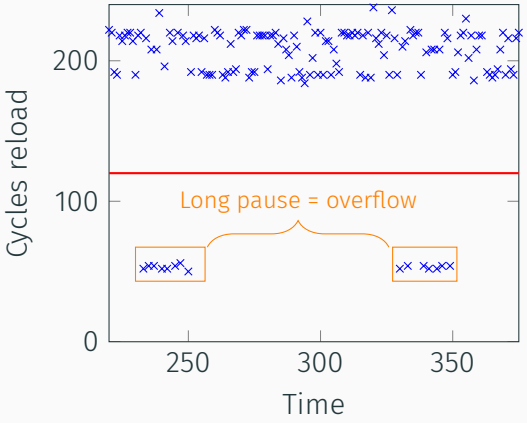

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⇓	⇓	⇓	⇓	⇓	⇓
`111b`	`yyyyb`	`0yyyyb`	`yyyyb`	`yyyyb`	`bbbb`

Practical Results

Client: $x = H(salt \,||\, H(user\_id : password))$

$$v = g^x \bmod p$$

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```
trace:    1 1 1 b y y y y b 0 y y y y b 1 1 1 b 0 y y y y b
```

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$$v = g^x \bmod p$$

trace:	1	1	1	b	y	y	y	y	b	0	y	y	y	y	b	1	1	1	b	0	y	y	y	y	b
pwd_1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1
pwd_2	1	1	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	1	0	1
pwd_3	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
pwd_4	1	1	1	1	1	1	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	1	1	1	1
pwd_5	0	1	1	1	1	0	1	1	1	1	0	0	1	0	1	1	1	0	0	0	0	1	0	0	0
...																									
pwd_n	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1

Password	x value

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pwd_3	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
pwd_4	1	1	1	1	1	1	0	0	0	0	1	0	1	1	0	1	1	1	0	0	0	1	1	1	1
pwd_5	0	1	1	1	1	0	1	1	1	1	0	0	1	0	1	1	1	0	0	0	0	1	0	0	0
...																									
pwd_n	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1

Password **x value**

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pwd_1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1
pwd_2	1	1	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	1	0	1
pwd_3	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
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pwd_3	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	11
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...																										
pwd_n	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	12

Password	x value	Diff score

Practical Impact

Impacted Projects

- Lots of project using OpenSSL are impacted, including
  - OpenSSL TLS-SRP
  - Apple HomeKit ADK
  - Protonmail's python client
  - GoToAssist (?)

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  - OpenSSL TLS-SRP
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  - Protonmail's python client
  - GoToAssist (?)

Wait, how are big numbers managed in high level languages ?...

Impacted Langages

- Many reference libraries are based on OpenSSL to manage bignums
- They usually (never ?) manage the flag properly
  - Ruby/openssl
  - Javascript node-bignum
  - Erlang OTP
  - PySRP

All SRP implementations using these packages / libraries are affected!

Mitigations & Conclusion

Mitigations

Two choices:

- Patch OpenSSL TLS-SRP by adding the proper flag
  - Most projects use the bignum API, not the whole SRP
  - Difficult to propagate
  - Root cause of the issue remains

- Switch to a secure by default implementation (flag for insecure/optimized)
  - No flag $\Rightarrow$ secure implementation (potential performance loss)
  - All projects are patched at once

Mitigations

Two choices:

- Patch OpenSSL TLS-SRP by adding the proper flag ← OpenSSL's choice
  - Most projects use the bignum API, not the whole SRP
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Practical attack against SRP implementations

- Vulnerability inherited by lots of projects
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Practical attack against SRP implementations

- Vulnerability inherited by lots of projects
- Easy to exploit because we can use each recover bits independently

Long term lesson: be careful with SCA, especially in PAKE implementation

Leakage in a weak generic function

- Other protocols with small base may also use it
- Contact use if you think of one!

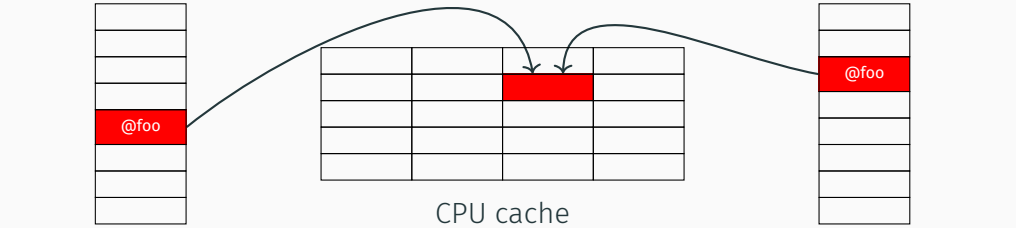
Thank you for your attention!

https://gitlab.inria.fr/ddealmei/poc-openssl-srp

@ daniel.de-almeida-braga@irisa.fr

Backup slides

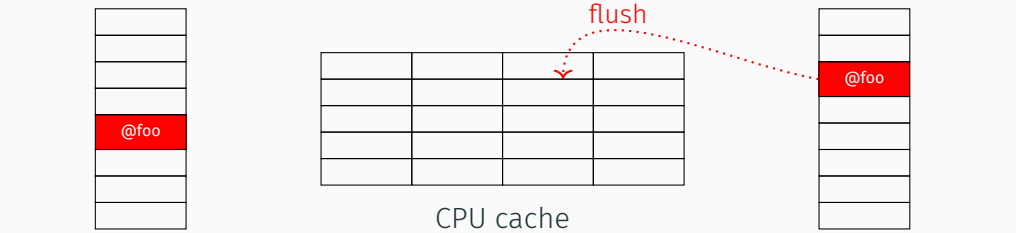
Flush+Reload[1]



1. Maps the victim's address space

[1] Y. Yarom et al. *Flush+Reload: a High Resolution, Low Noise, L3 Cache Side-Channel Attack.* In USENIX Security Symposium. 2014.

Flush+Reload[1]



1. Maps the victim's address space
2. Flush the instruction we monitor

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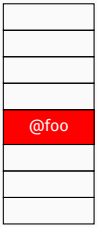
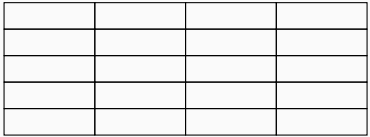
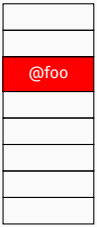


Victim address space



CPU cache



Attacker address space

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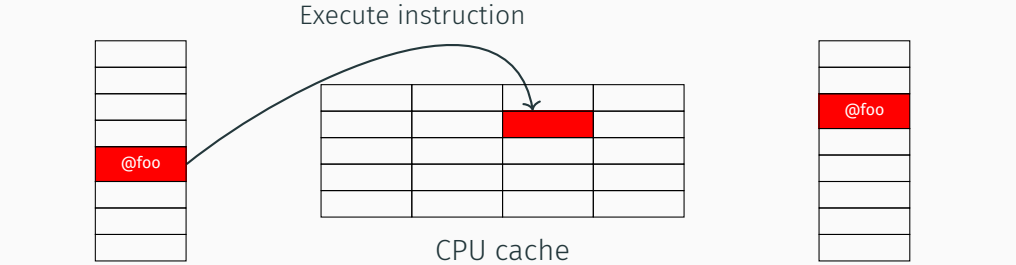
Flush+Reload[1]



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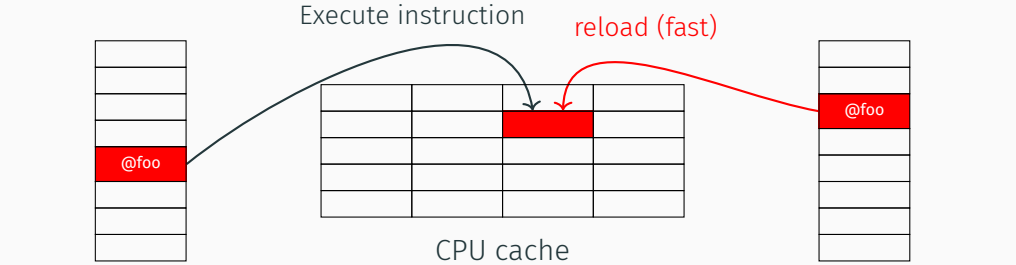

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   - Fast ⇒ the victim already executed

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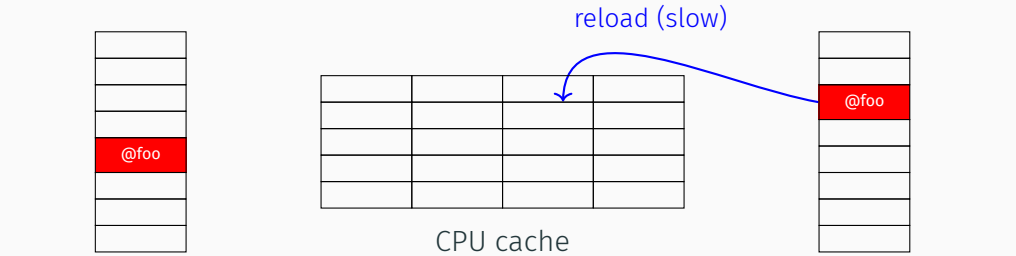

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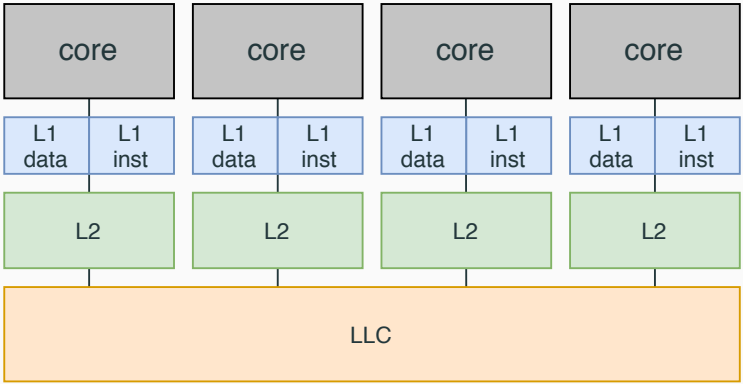
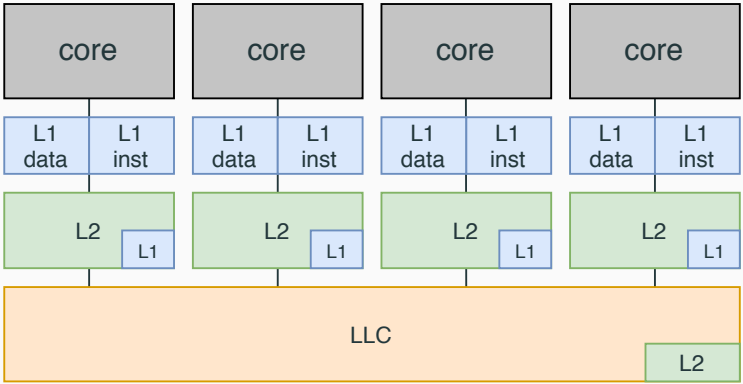
2. Flush the instruction we monitor
3. See how much time it takes to reload
   - Fast ⇒ the victim already executed
   - Slow ⇒ the victim did not

[1] Y. Yarom et al. *Flush+Reload: a High Resolution, Low Noise, L3 Cache Side-Channel Attack.* In USENIX Security Symposium. 2014.

Intel CPU cache



Intel CPU cache



Inclusive cache