PARASITE: PAssword Recovery Attack against Srp Implementations in ThE wild

Daniel De Almeida Braga
Pierre-Alain Fouque
Mohamed Sabt

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

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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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Lesson to learn: Small leakage can be devastating

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Case study: Secure Remote Password (SRP)

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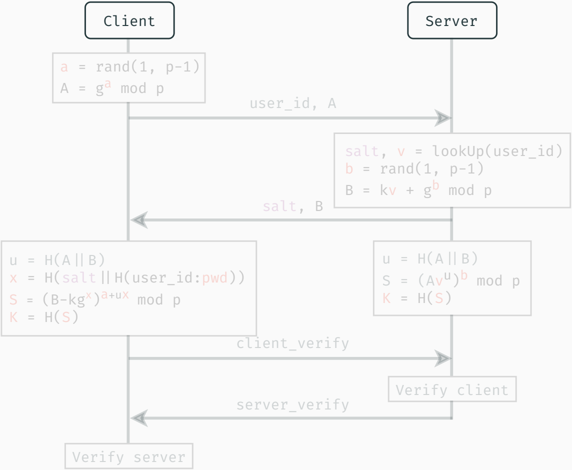
What about SRP implementations in the wild?

- Still widely deployed and used
- Not much recent work on it
- Recent work on SRP at ACNS[4]

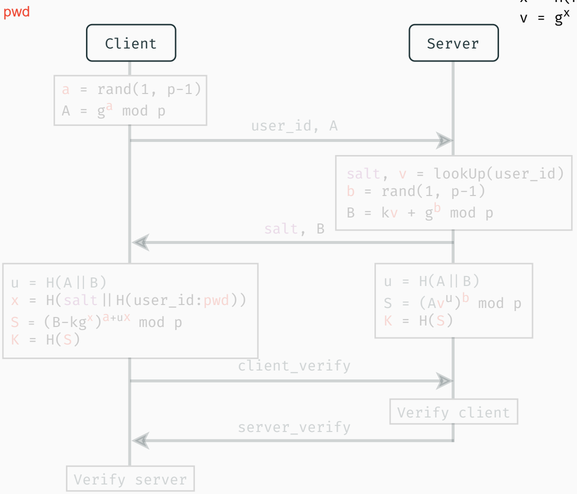
[4] A.Russon *Threat for the Secure Remote Password Protocol and a Leak in Apple's Cryptographic Library.* In ACNS. 2021

SRP Protocol Overview



SRP Protocol Overview

$x = H(H(salt, H(id:pwd))$
$v = g^x \bmod p$



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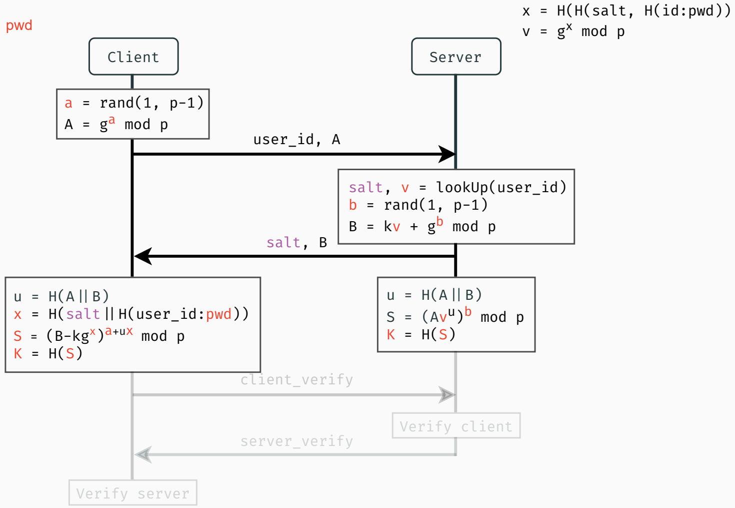

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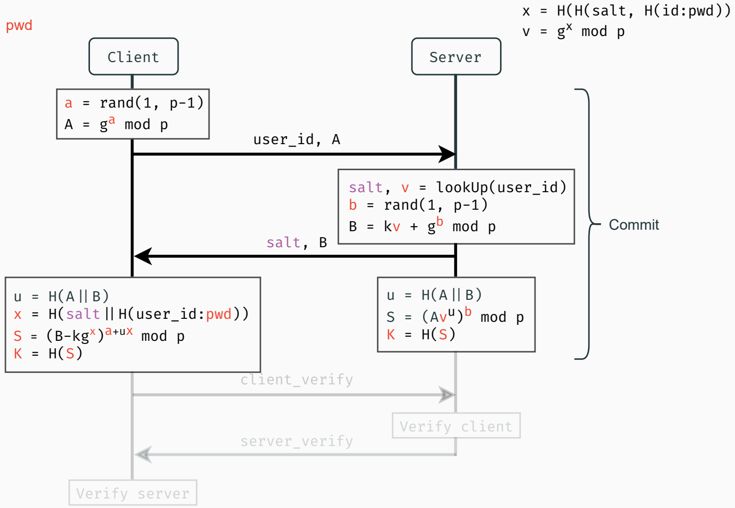

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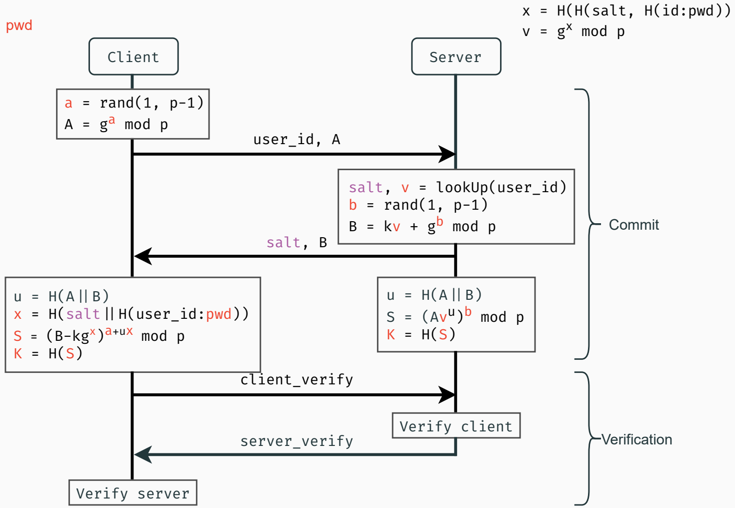

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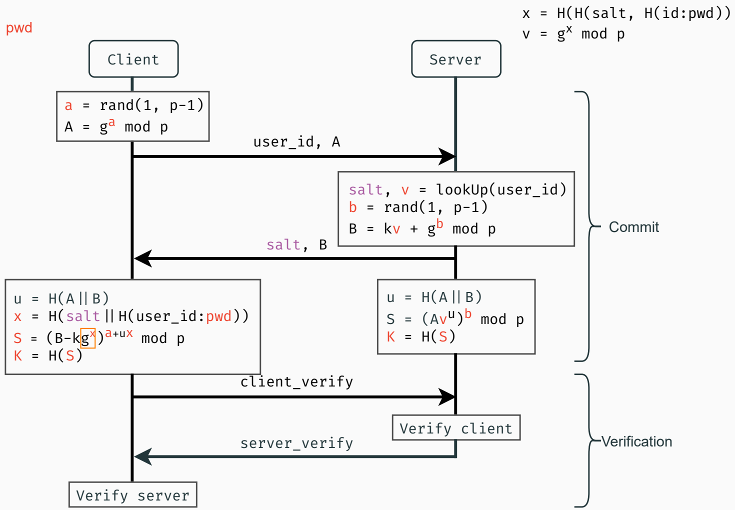

Contributions

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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`

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Side Channel Attacks

```python
def processPassword(pwd):
    if "a" in pwd:
        res = long_processing(pwd)
    else:
        res = short_processing(pwd)
    return res
```

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Gain information through timing:

0.5 seconds $\Rightarrow$ no a

10 seconds $\Rightarrow$ a

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def processPassword2(pwd):
    if "a" in pwd:
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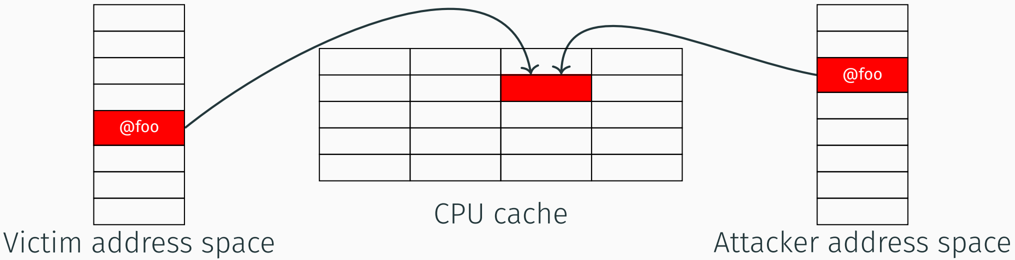
Gain information execution flow:

- Execute `long_processing` ⇒ *a*
- Else, no *a* in pwd

FLUSH+RELOAD[1]



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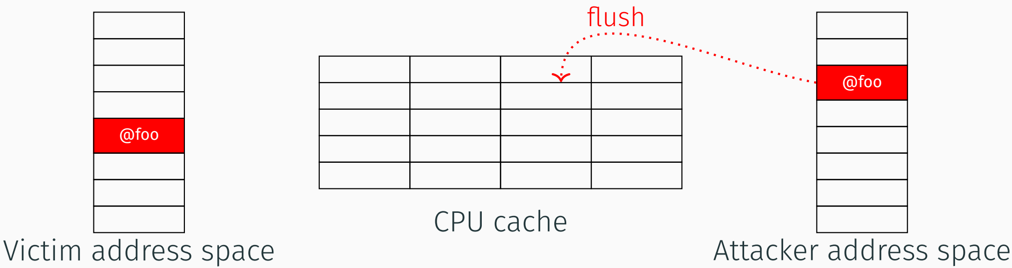

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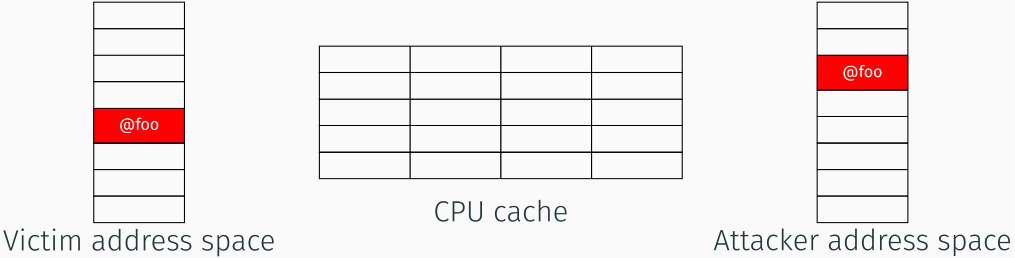

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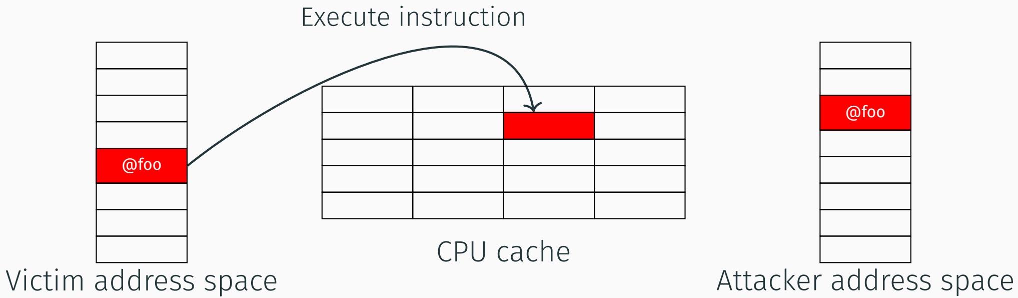

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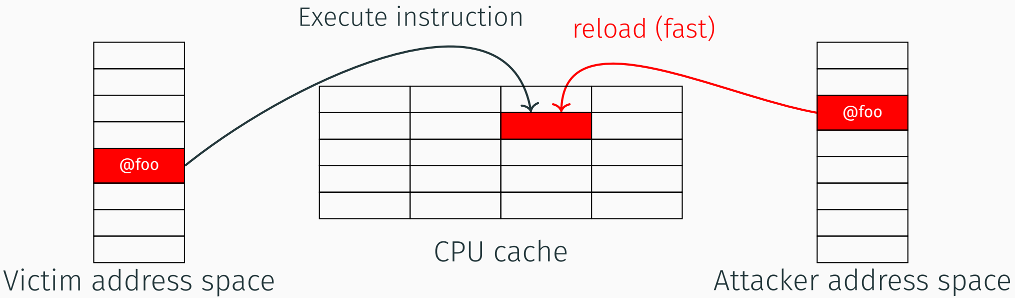

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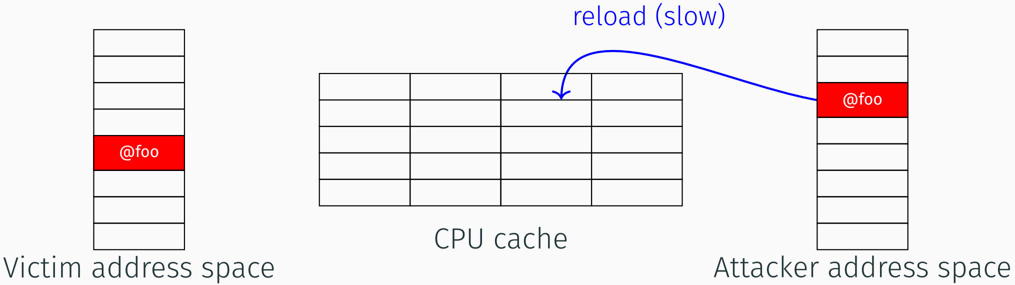

1. Maps the victim's address space
2. Flush the instruction we monitor
3. See how much time it takes to reload
   - Fast ⇒ the victim already executed
   - Slow ⇒ the victim did not

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Passive offline attack

No error and lots of information

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The Vulnerability

Modular exponentiation in OpenSSL

`BN_mod_exp`

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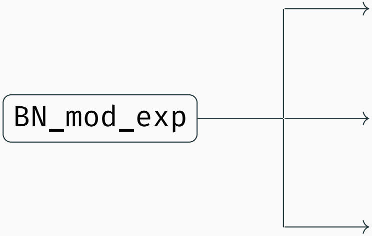

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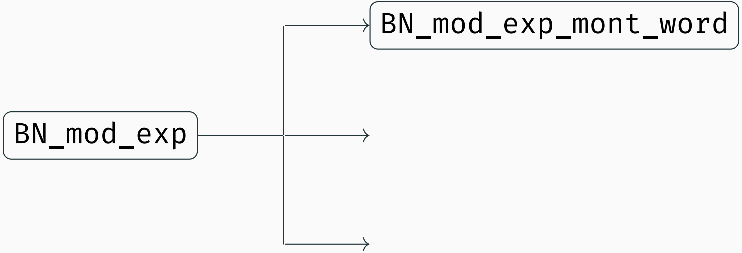

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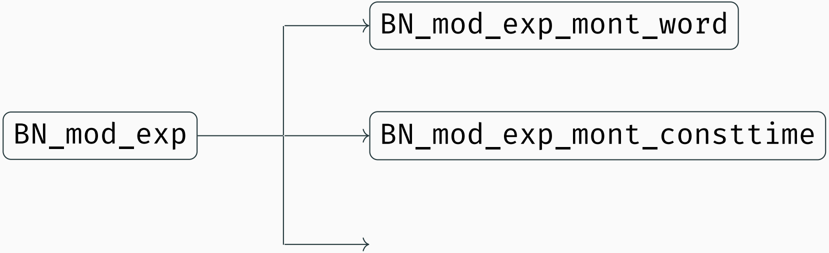

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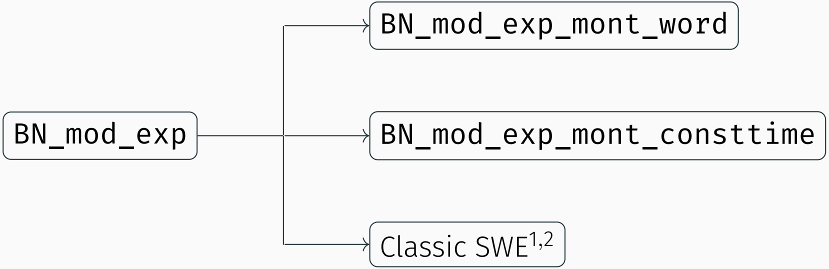

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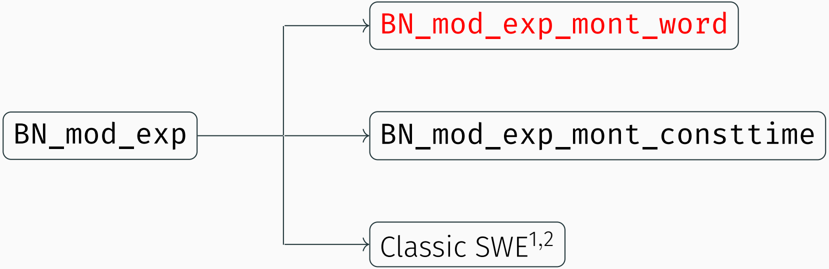

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Optimized Square-and-Multiply

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bin(x) =  1 1 0 1 0 ...
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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
  res = BN_to_mont_word(w)        # bignum
  for b in range(bitlen-2, 0, -1):
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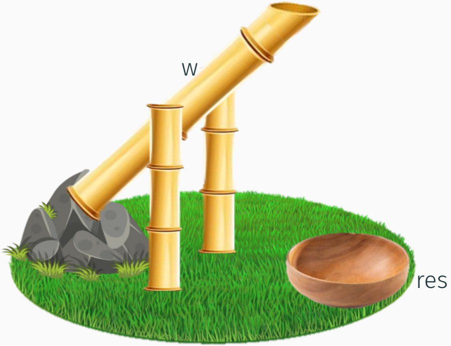


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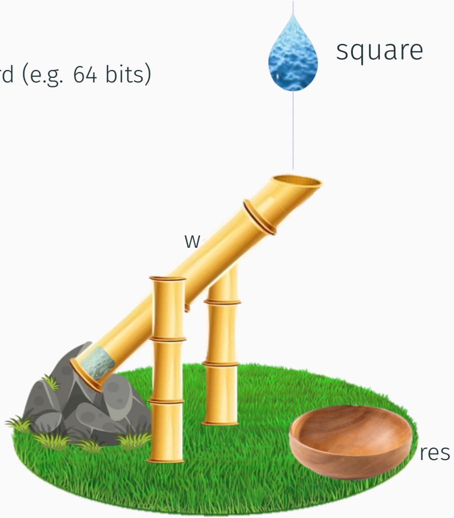


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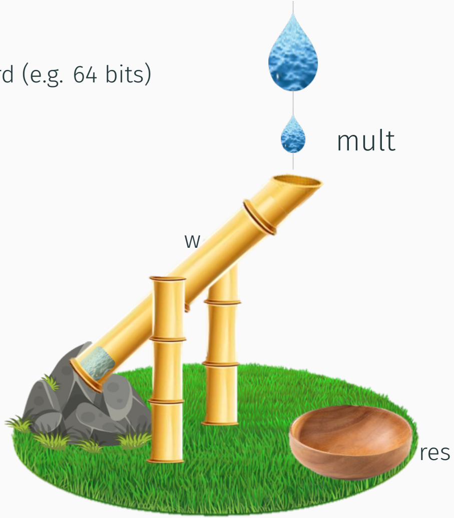


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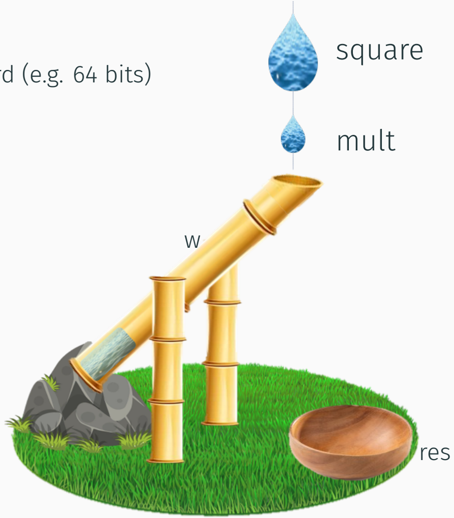


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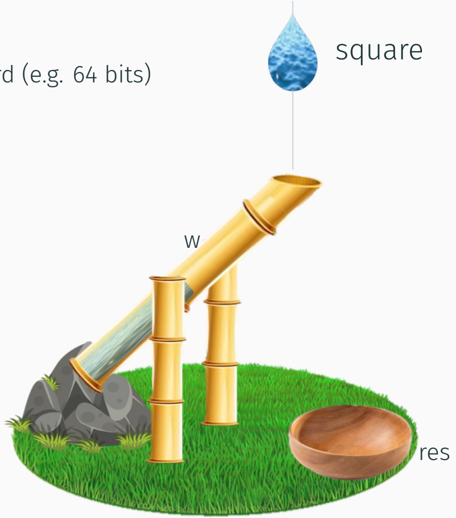


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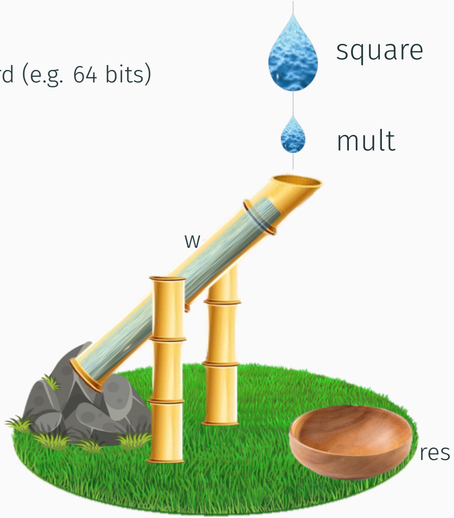


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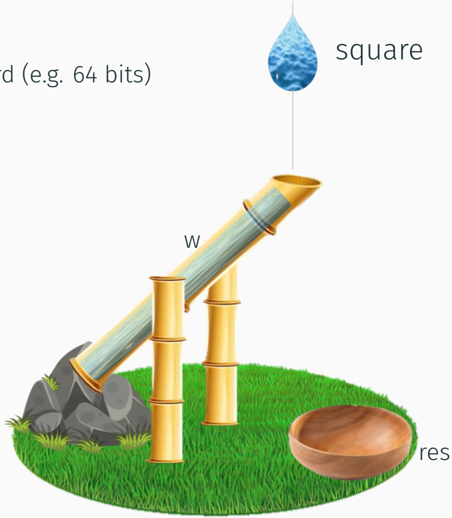


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```

Optimized Square-and-Multiply

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

res= $g^x \mod p$

w processor word (e.g. 64 bits)


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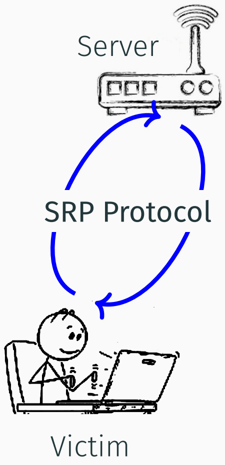
Exploiting the Leakage

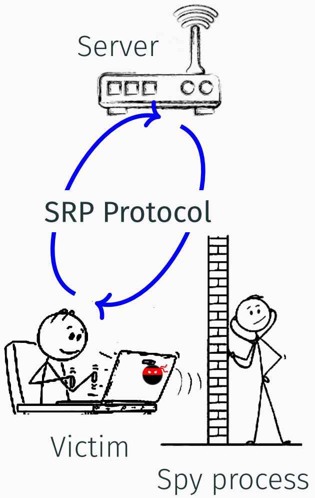
Attacker Model

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

Attack Workflow



Attack Workflow



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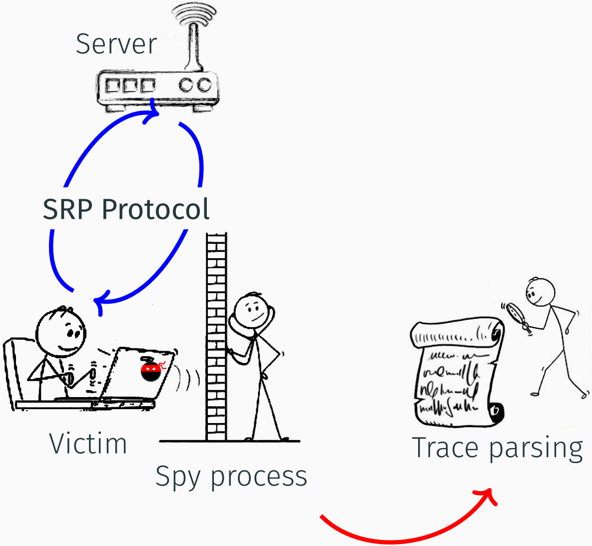

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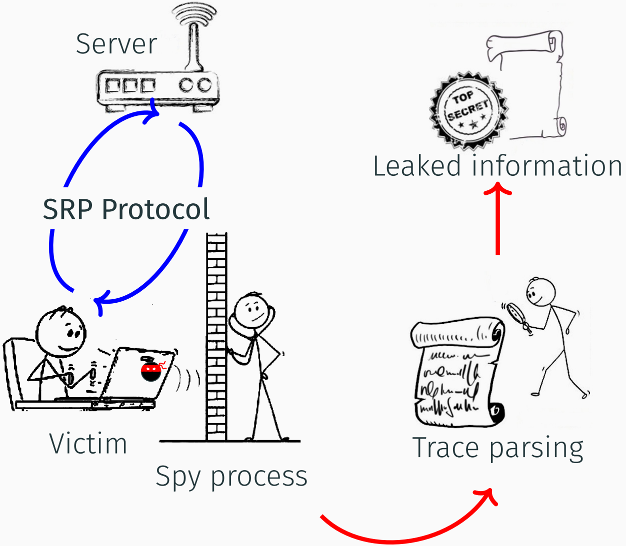

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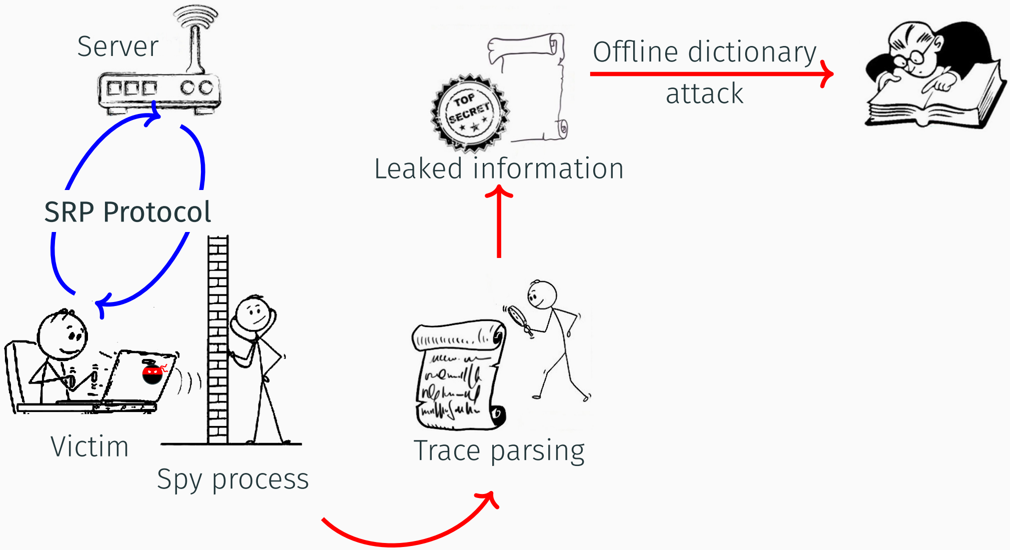

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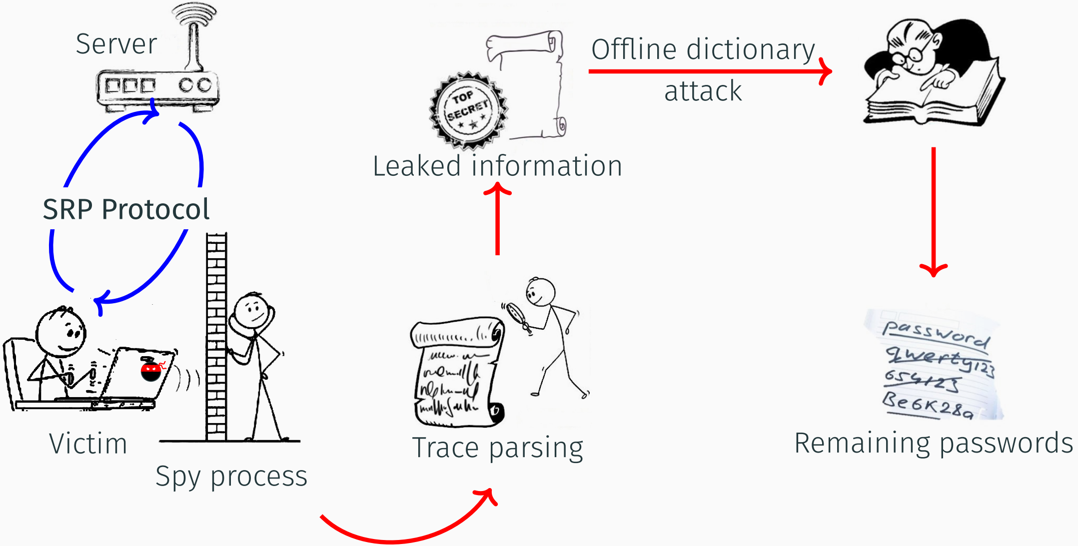

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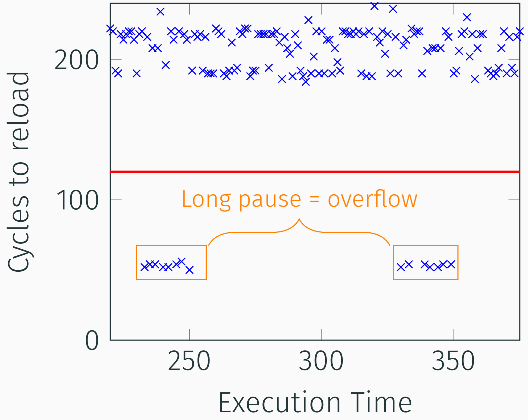

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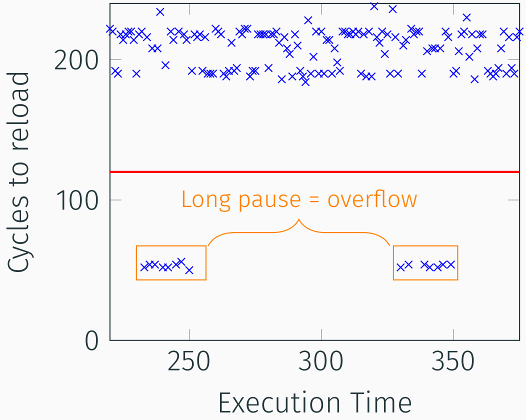

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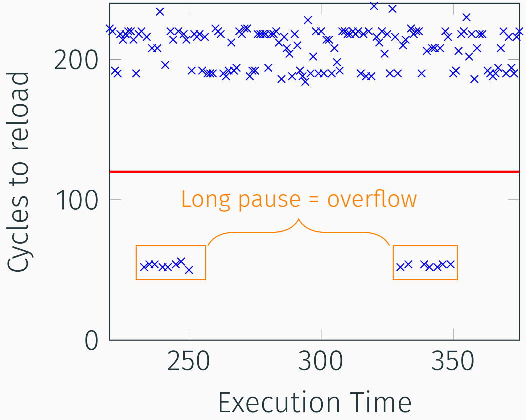

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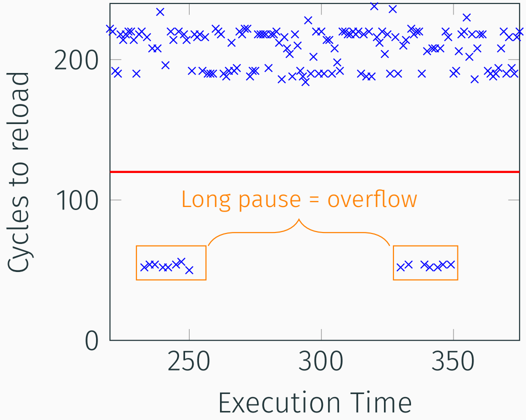

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bbbb	bbbbb	bbbbbb	bbbbb	bbbbb	bbbb
4	5	6	5	5	4

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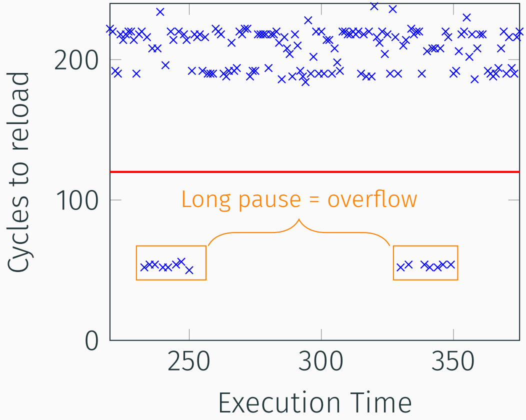

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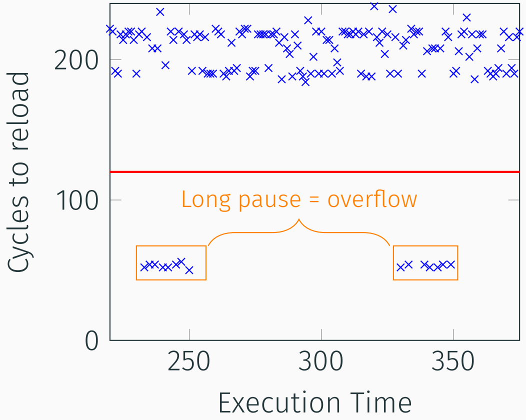
```
bbbb  bbbbb  bbbbbb  bbbbb  bbbbb  bbbb
 4      5      6       5      5     4
 ⇓
111b
```

Trace Interpretation



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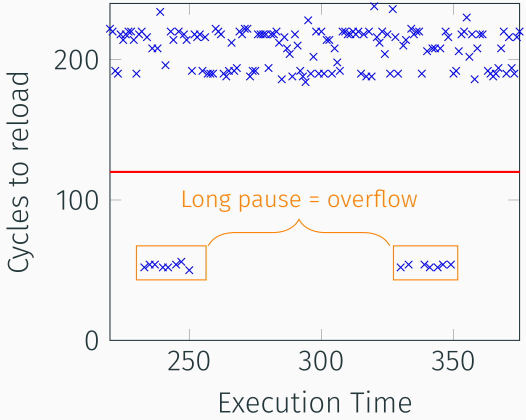

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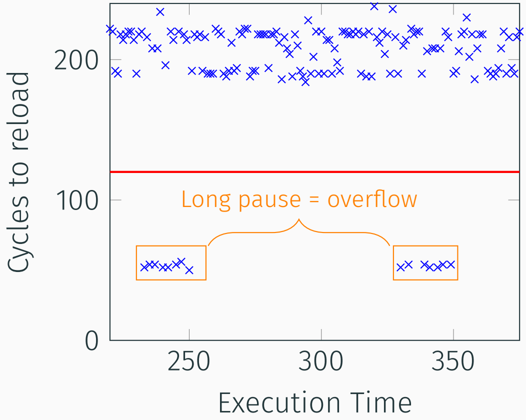

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⇓	⇓	⇓	⇓		
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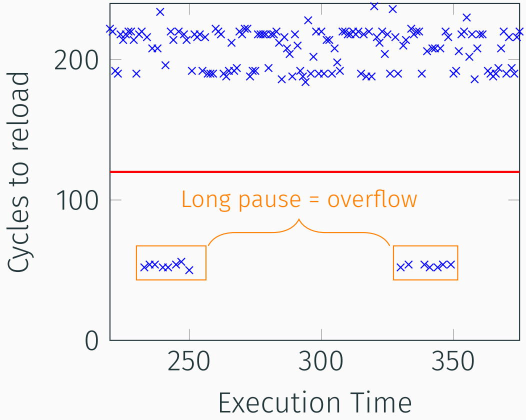

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bbbb	bbbbb	bbbbbb	bbbbb	bbbbb	bbbb
4	5	6	5	5	4
$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	
111b	yyyyb	0yyyyb	yyyyb	yyyyb	

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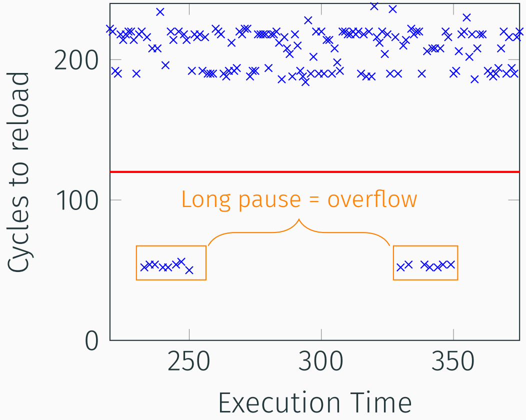

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bbbb  bbbbb  bbbbbb  bbbbb  bbbbb  bbbb
 4      5      6       5      5     4
 ⇓      ⇓      ⇓       ⇓      ⇓     ⇓
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Client: $x = H(salt \mid\mid H(user\_id : password))$

$v = g^x \bmod p$

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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
 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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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	15
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	14
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
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	0
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	11
...		
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**

Single Measurement Attack

- Very accurate measurement
- Each bit of information halves the number of possible passwords
  - k bits of information $\Rightarrow$ false positive/negative with probability of 2^{-k}

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For an n-bit exponent, we get $k = 0.4n + 2$ bits on average (verified empirically)

SHA-1: 66 bits of information

SHA-256: 104 bits of information

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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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

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Practical attack against SRP implementations

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

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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!

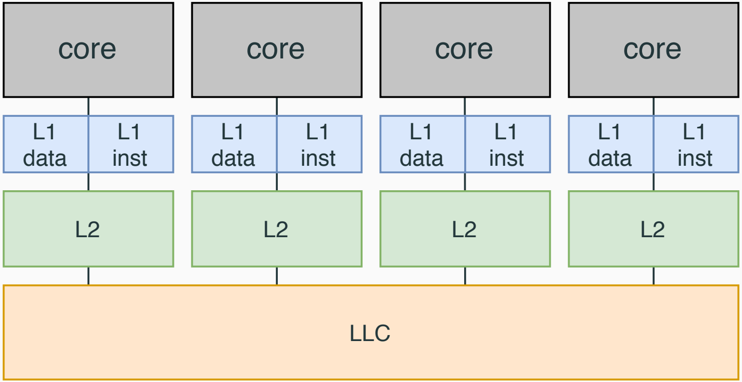
Thank you for your attention!

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

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

Backup slides

Intel CPU cache



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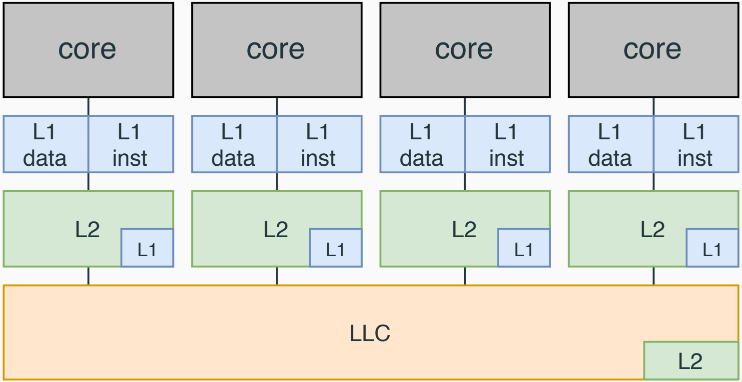

Inclusive cache