PARASITE: PAssword Recovery Attack against Srp Implementations in ThE wild

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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

Lots of different PAKEs (two main families: balanced - asymmetric).

Why Looking at PAKEs?

Recent interest:

- Wide Deployment of Dragonfly in WPA3
- CFRG competition for new standard (OPAQUE and CPace)

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Practical security considerations

- Dragonfly and WPA3: Dragonblood[1] and attack refinement[2]
- Partitioning Oracle Attack[3] applied to some OPAQUE implementations

Case study: Secure Remote Password

[1] M.Vanhoef and E.Ronen *Dragonblood: Analyzing the Dragonfly Handshake of WPA3 and EAP-pwd*. In IEEE S&P. 2020

[2] D.Braga et al. *Dragonblood Is Still Leaking: Practical Cache-based Side-Channel in the Wild*. In ACSAC. 2020

[3] J.Len et al. *Partitioning Oracle Attack*. In USENIX Security. 2021

What about SRP?

Available for a long time => de facto standard for more than 20 years

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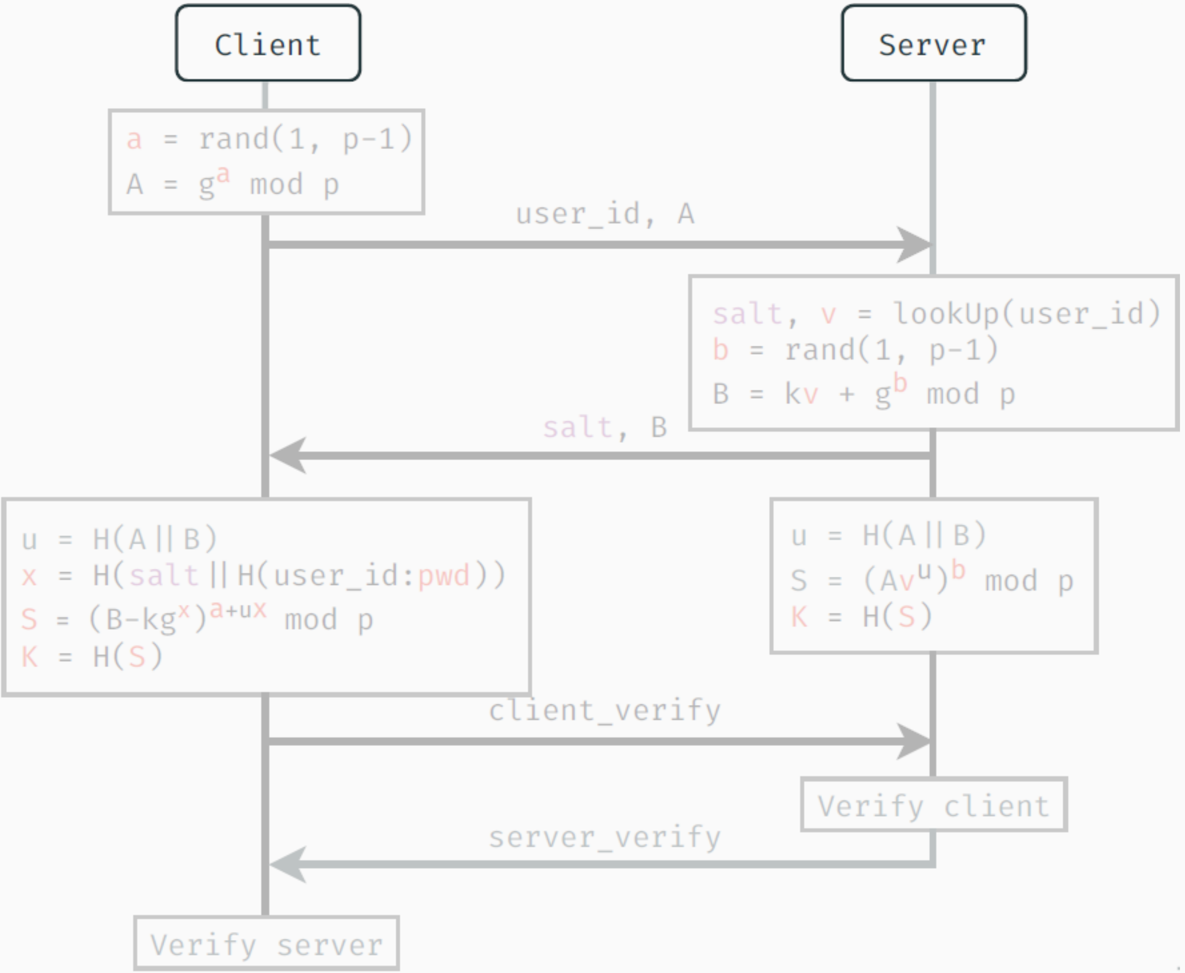
- Recent work on SRP at ACNS[1]

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

SRP Protocol Overview



Client

Server

a = rand(1, p-1)
$A = g^{a} \bmod p$

user_id, A

salt, v = lookUp(user_id)
b = rand(1, p-1)
$B = kv + g^{b} \bmod p$

salt, B

$u = H(A \| B)$
$x = H(salt \| H(user\_id:pwd))$
$S = (B - kg^{x})^{a+ux} \bmod p$
$K = H(S)$

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Verify client

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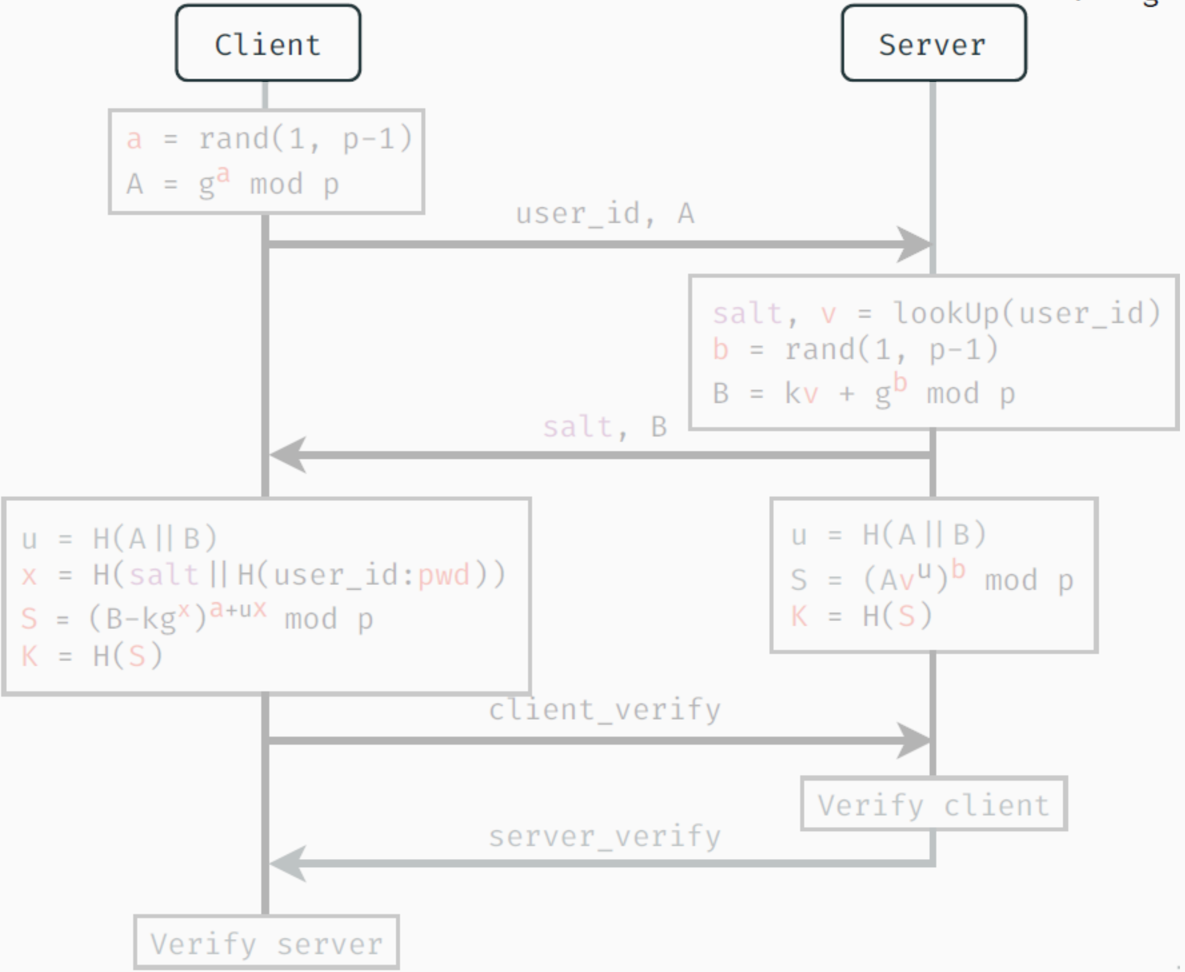

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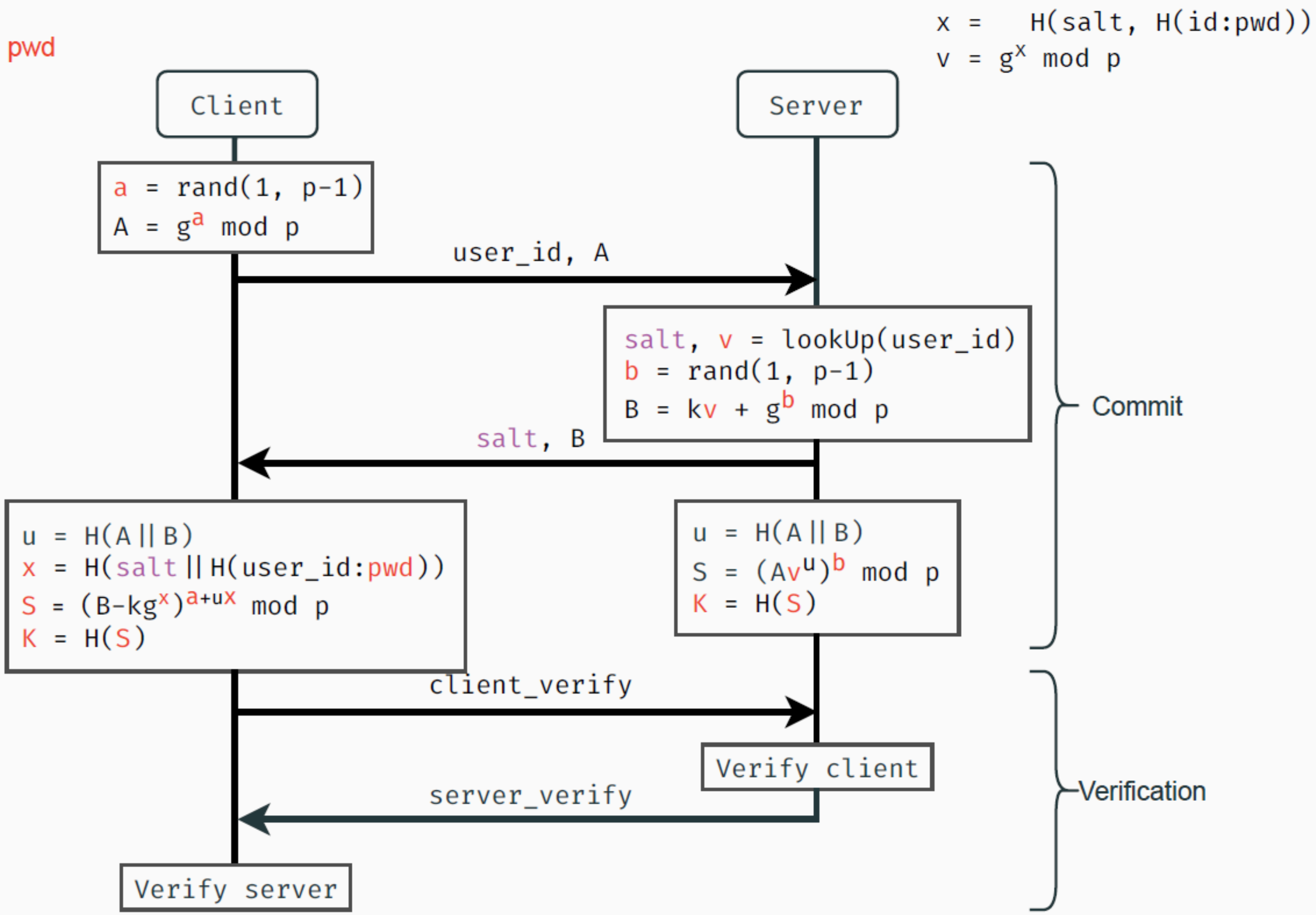

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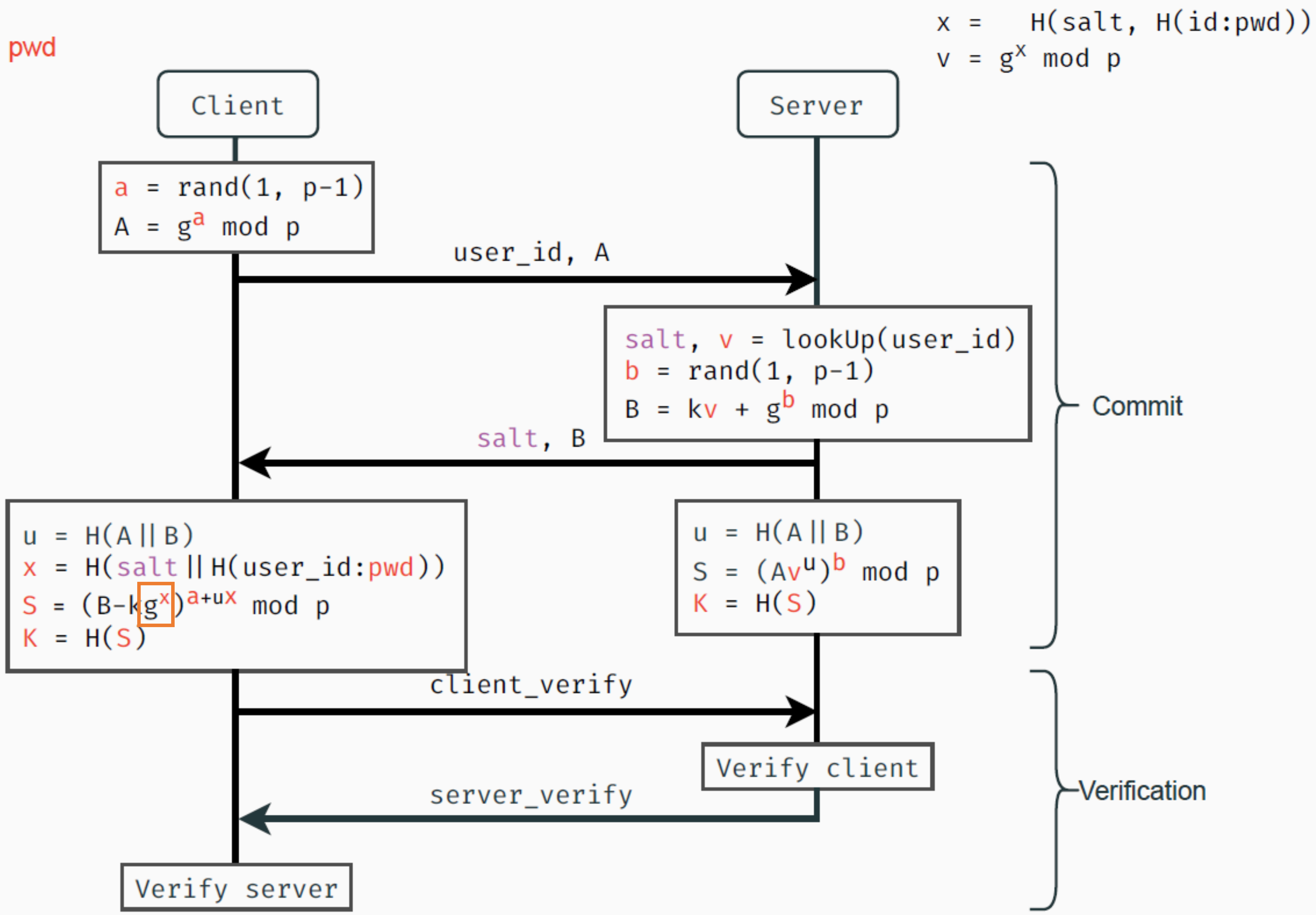

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Contributions

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

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A cache-attack that lets us extract information

during OpenSSL the modular exponentiation

allowing to recover the password in a single measure.

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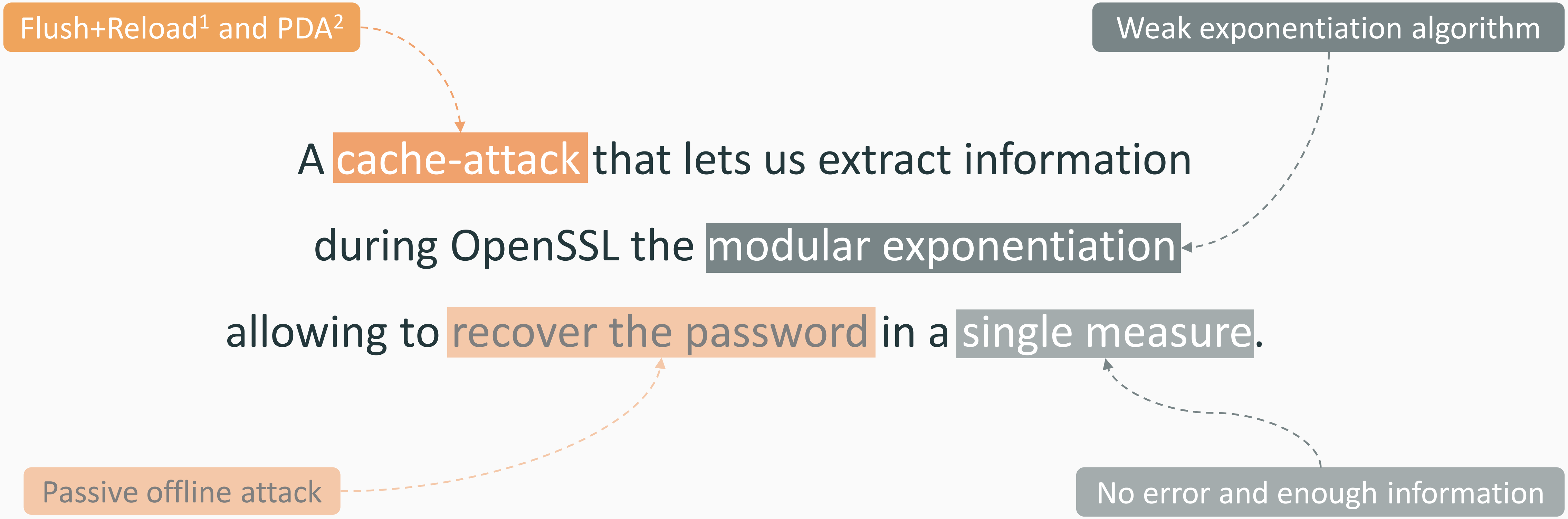

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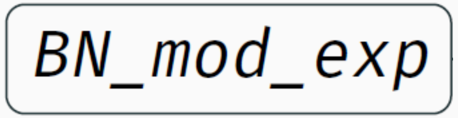
The Vulnerability

Modular exponentiation in OpenSSL



BN_mod_exp

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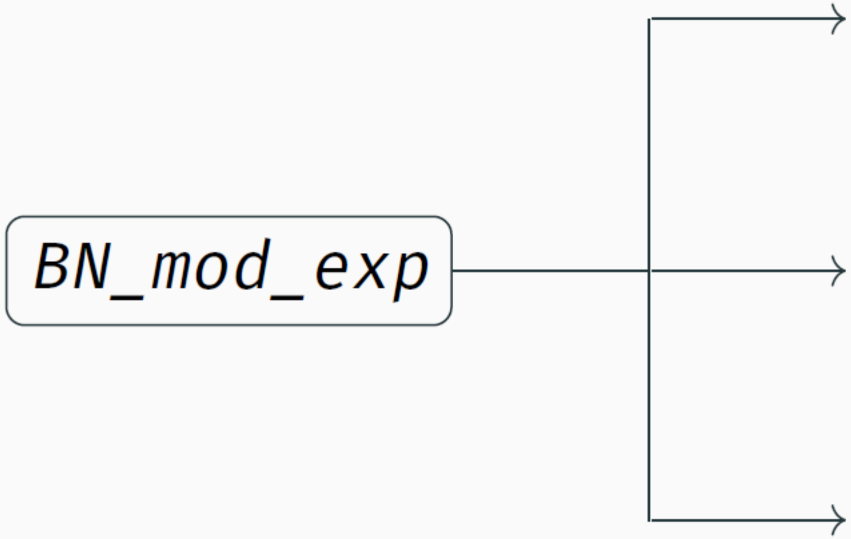

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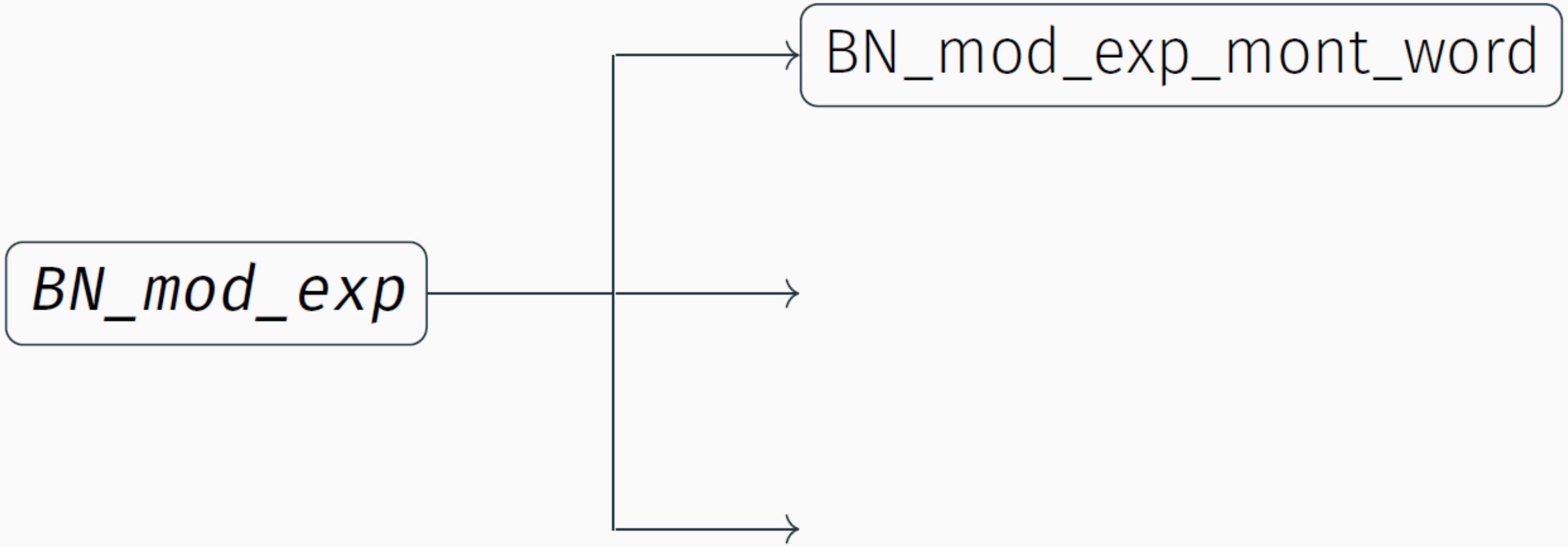

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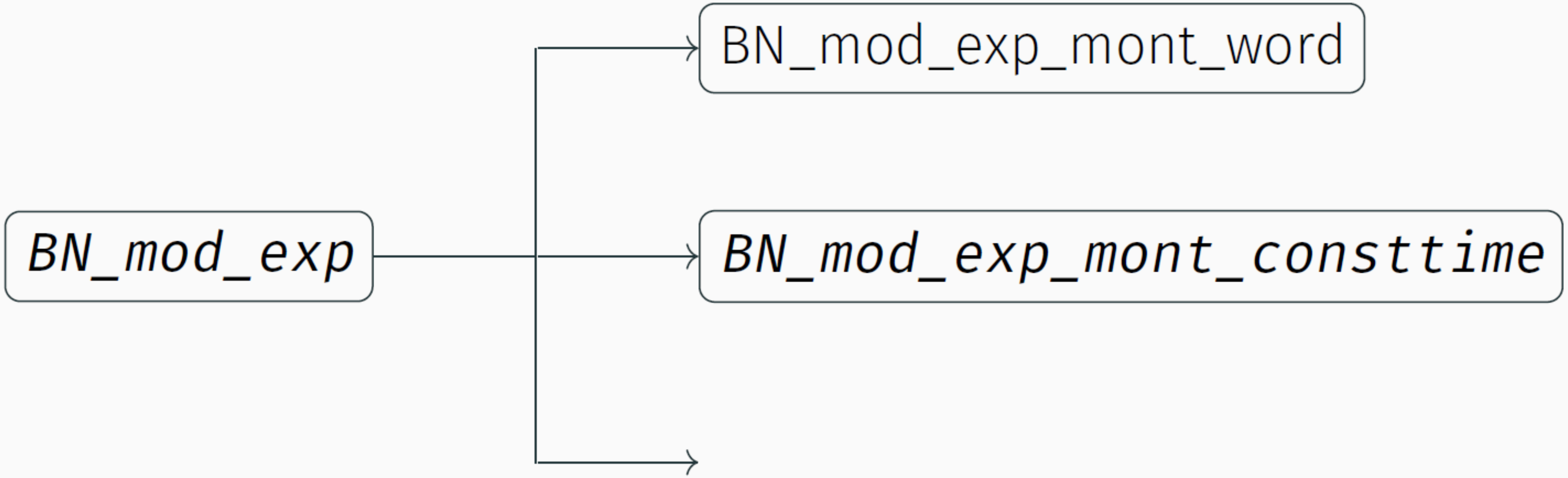

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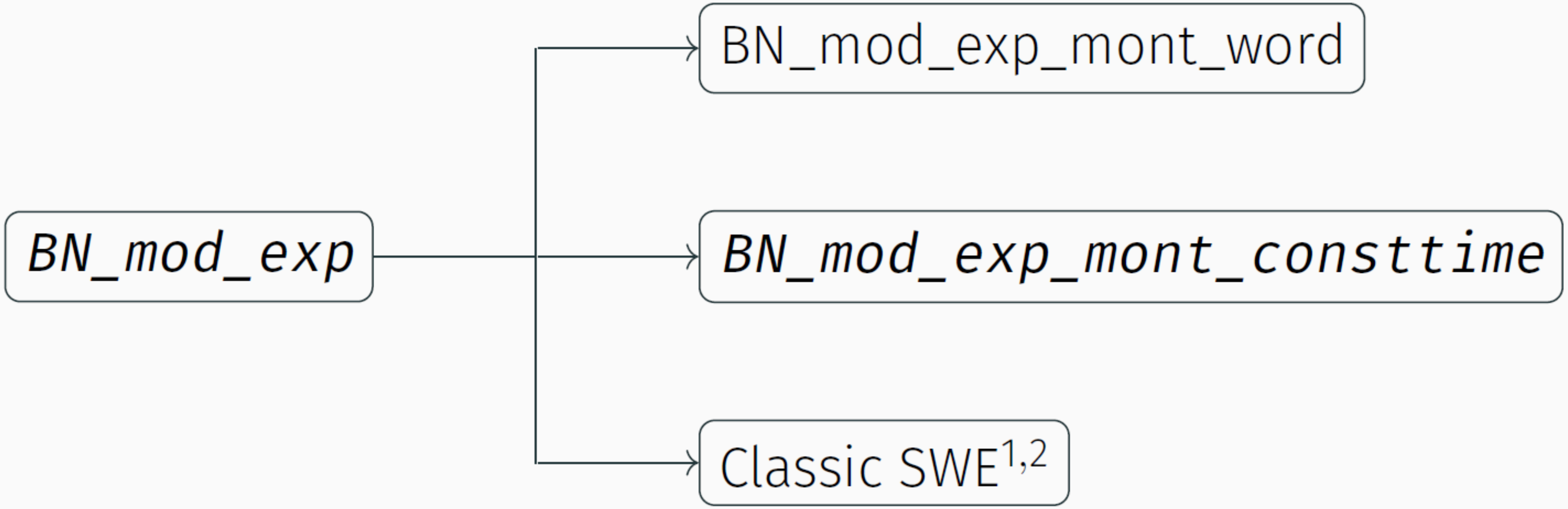

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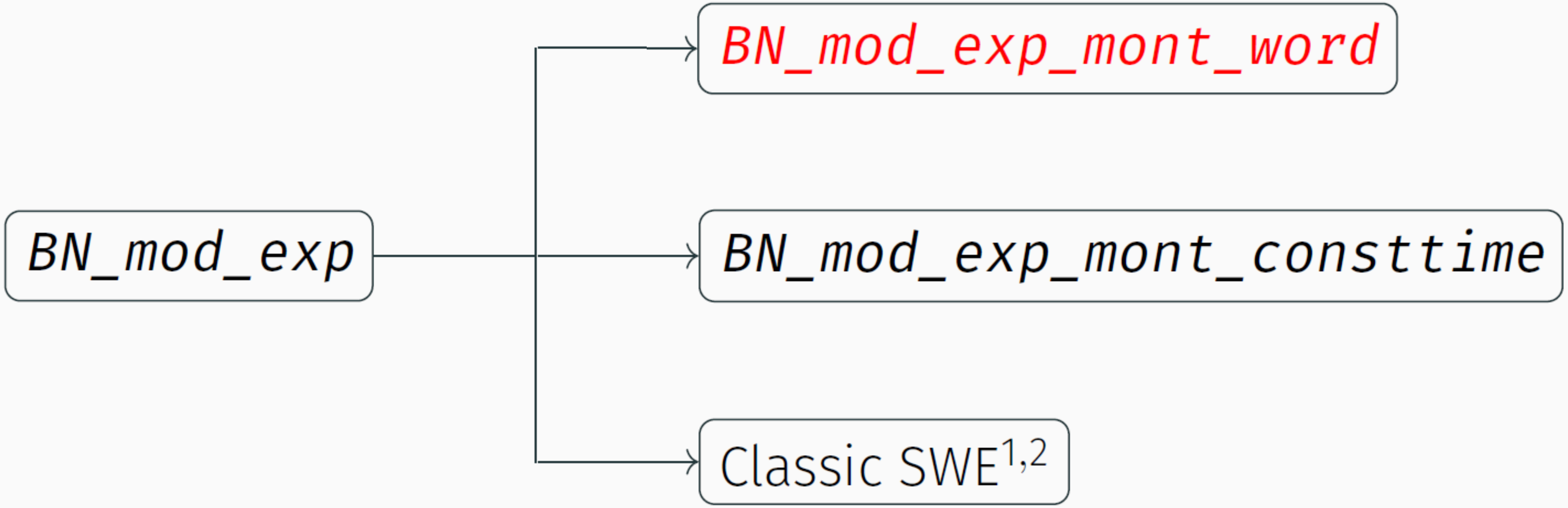

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Optimized Square-and-Multiply

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$res = g^e mod\ p$

w is a processor word (e.g. 64 bits)

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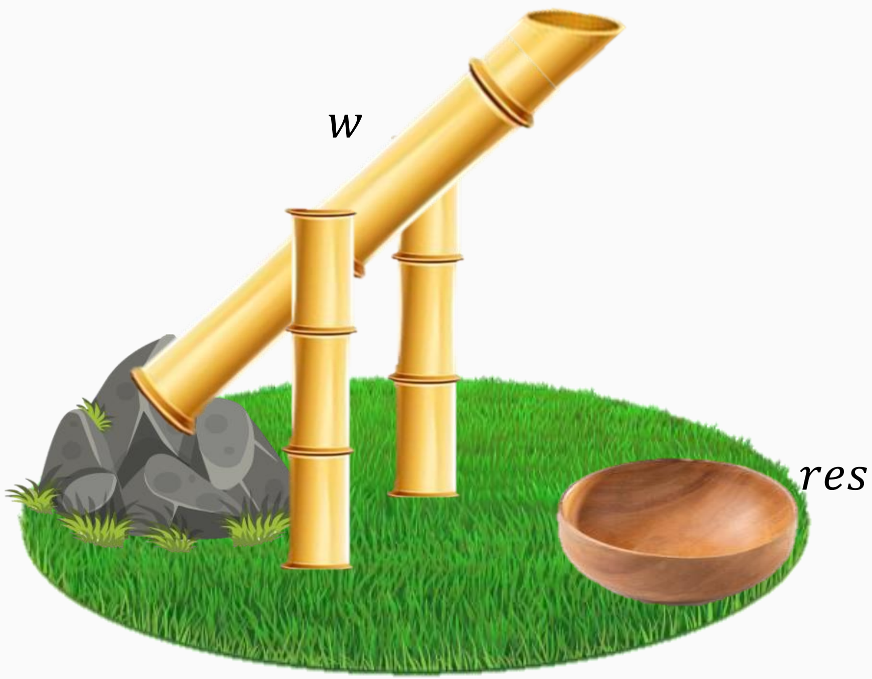

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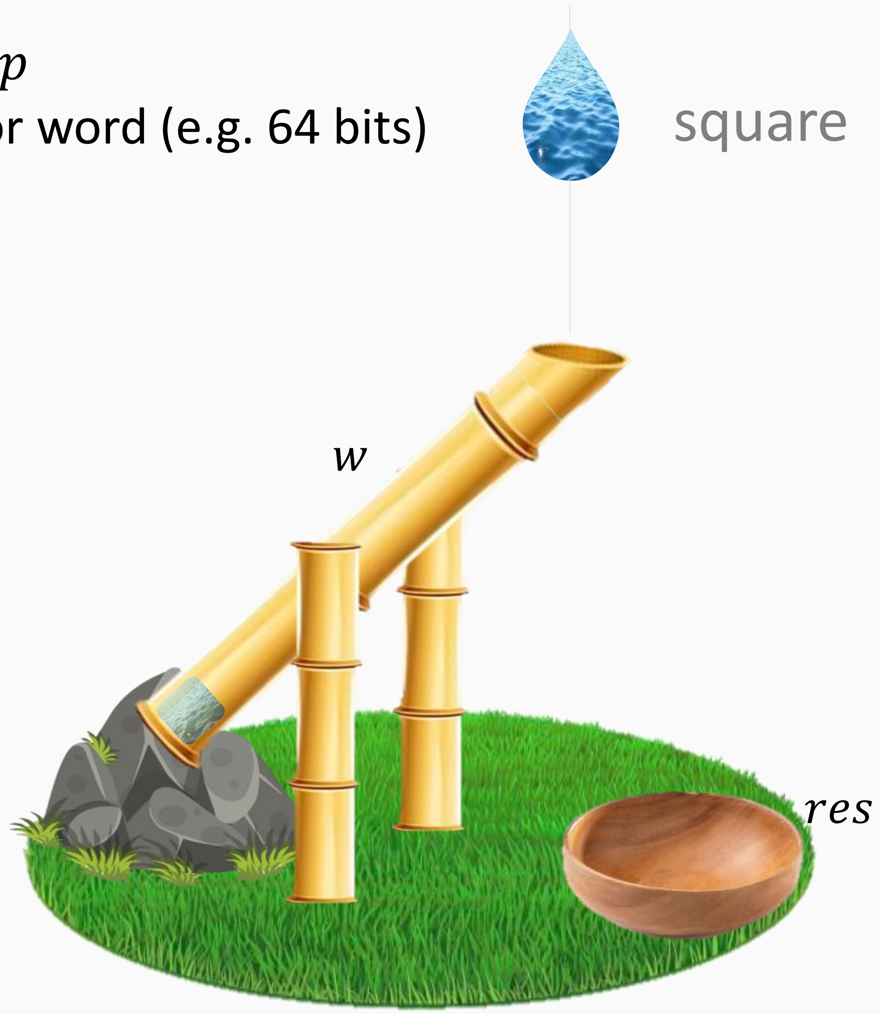

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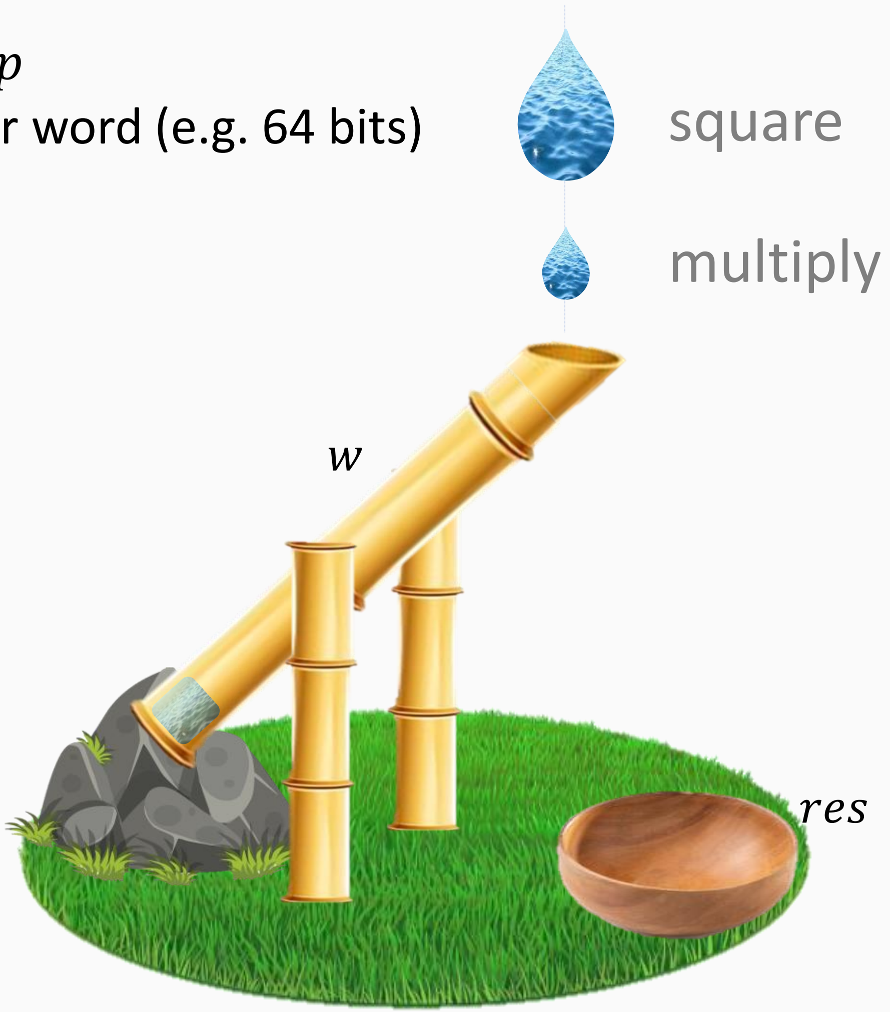

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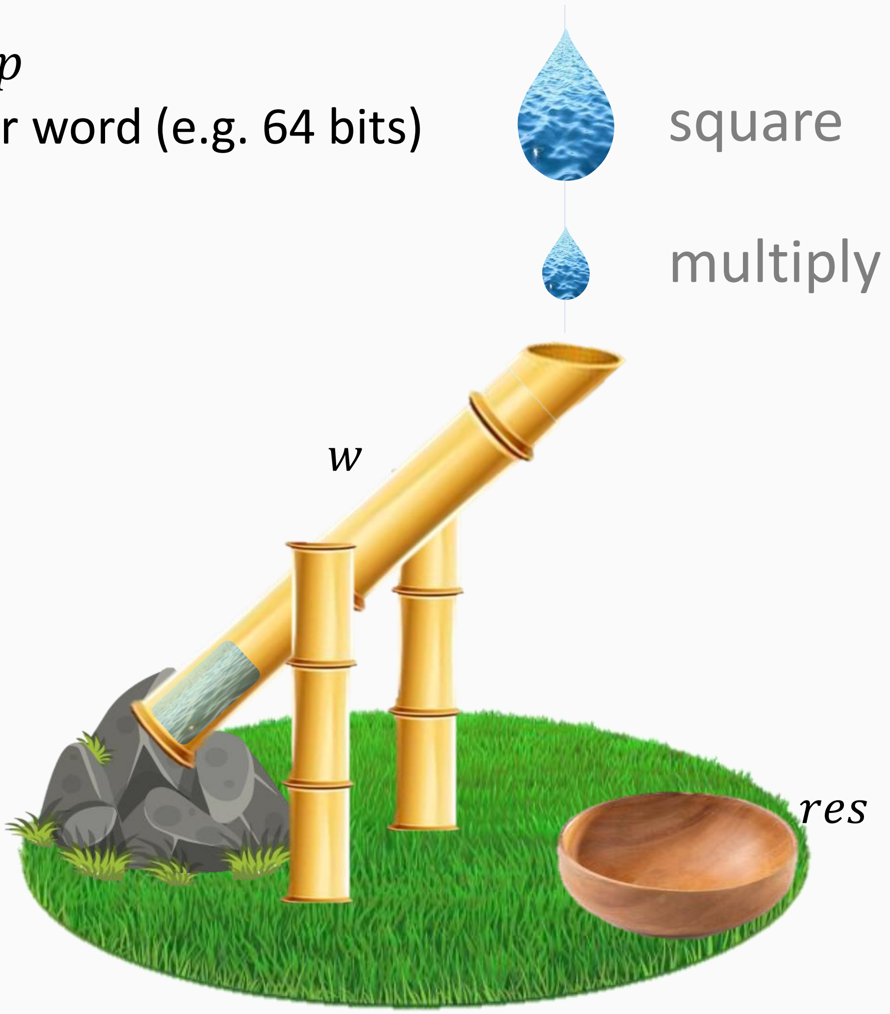

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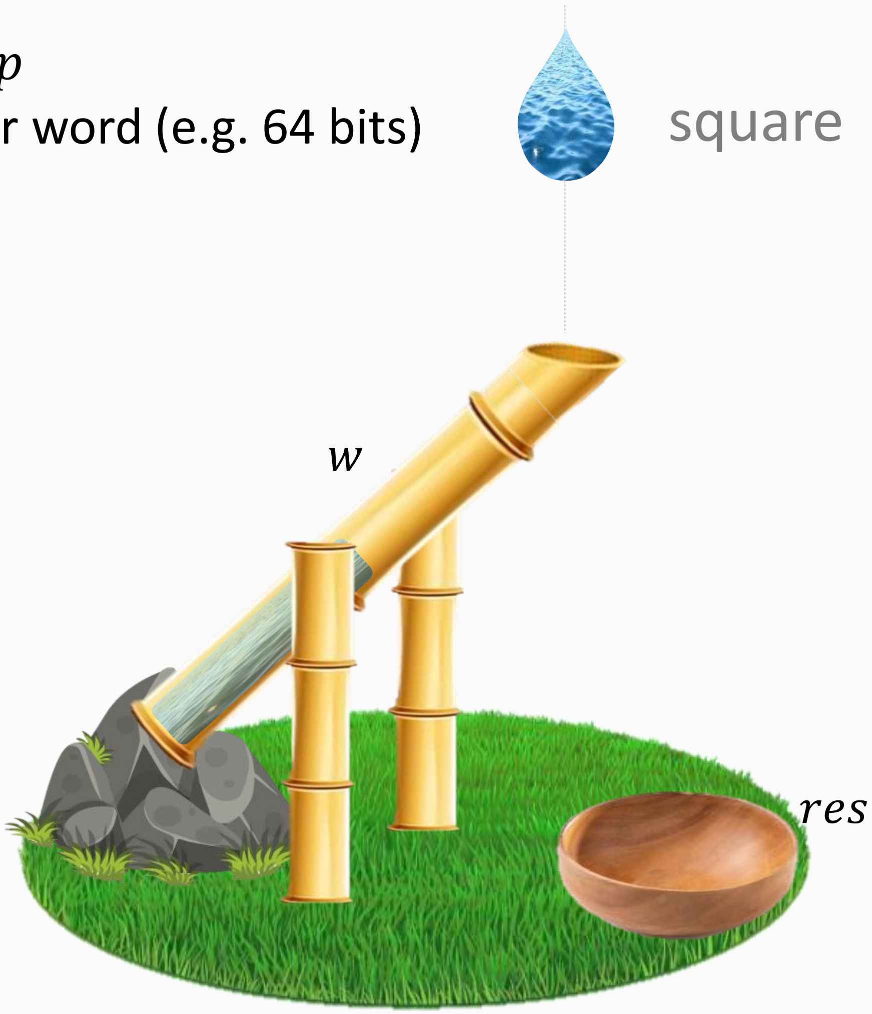

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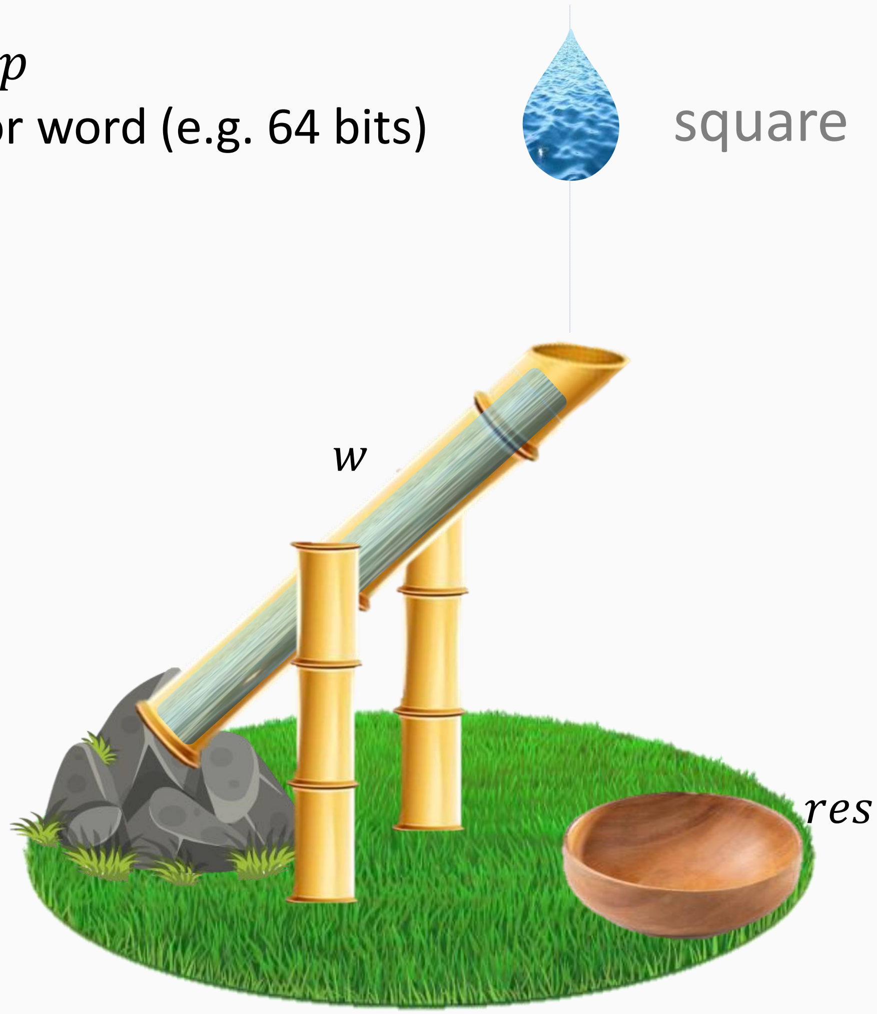

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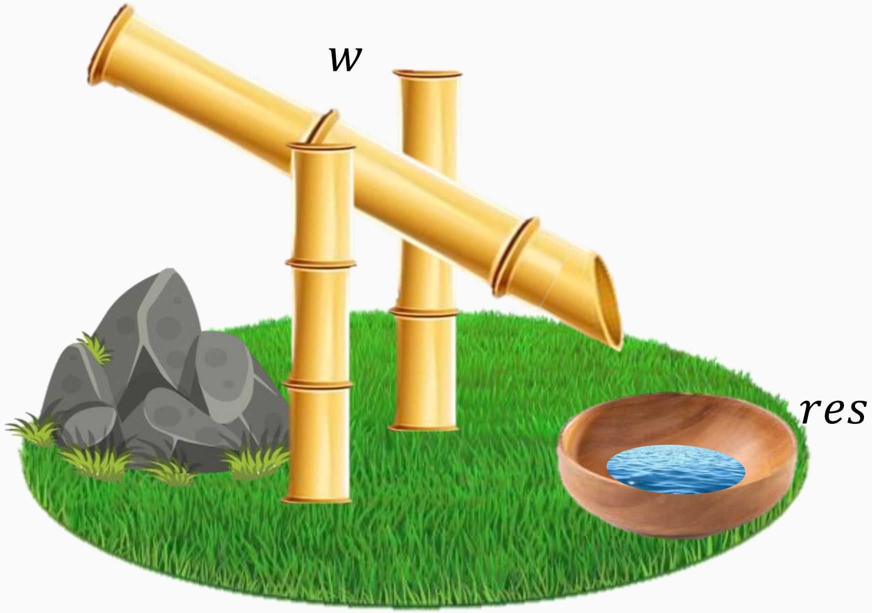

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Exploiting the Leakage

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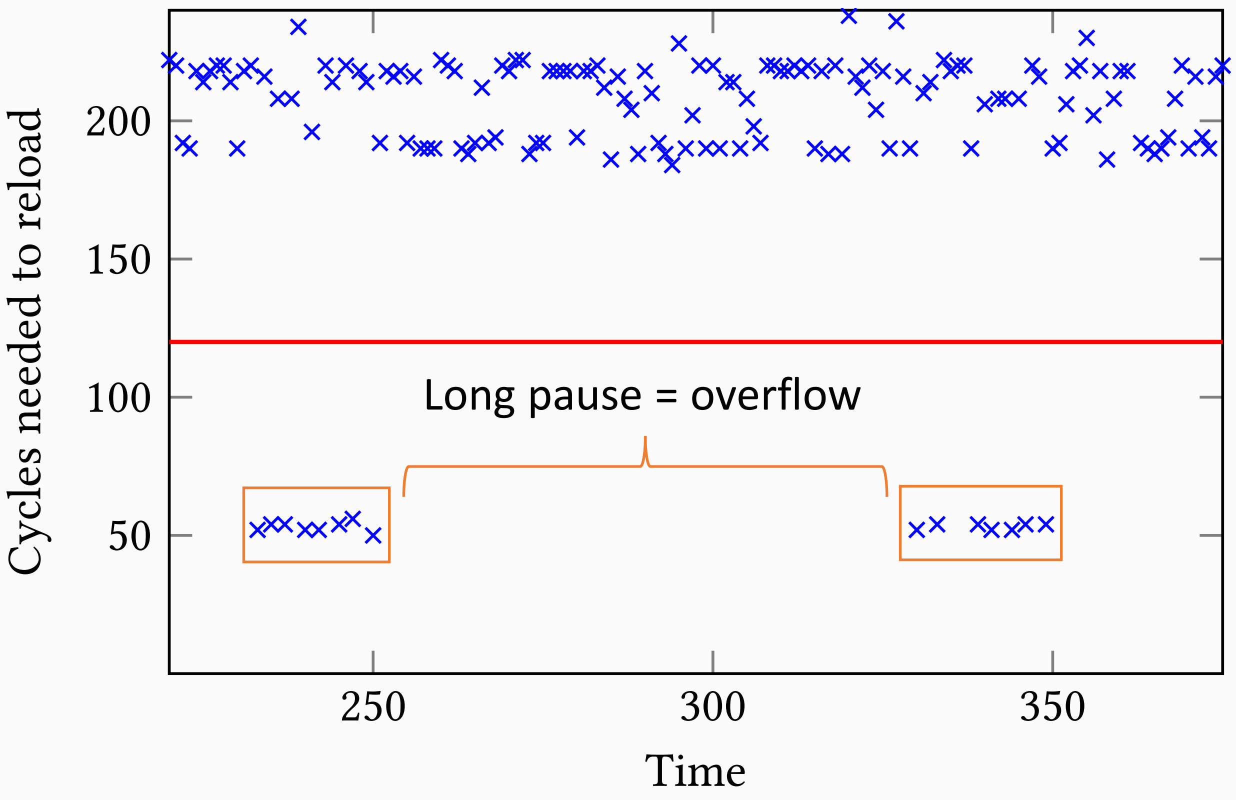
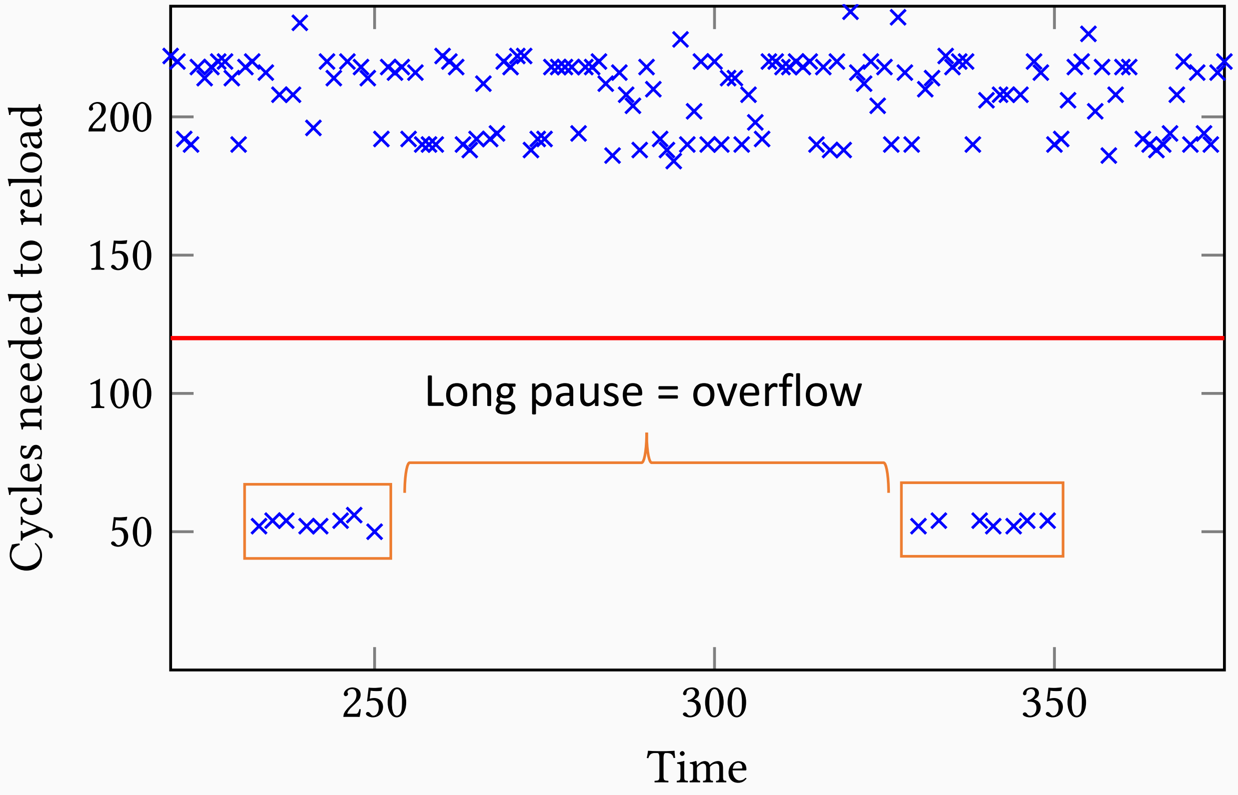


Long pause = overflow

Trace Interpretation



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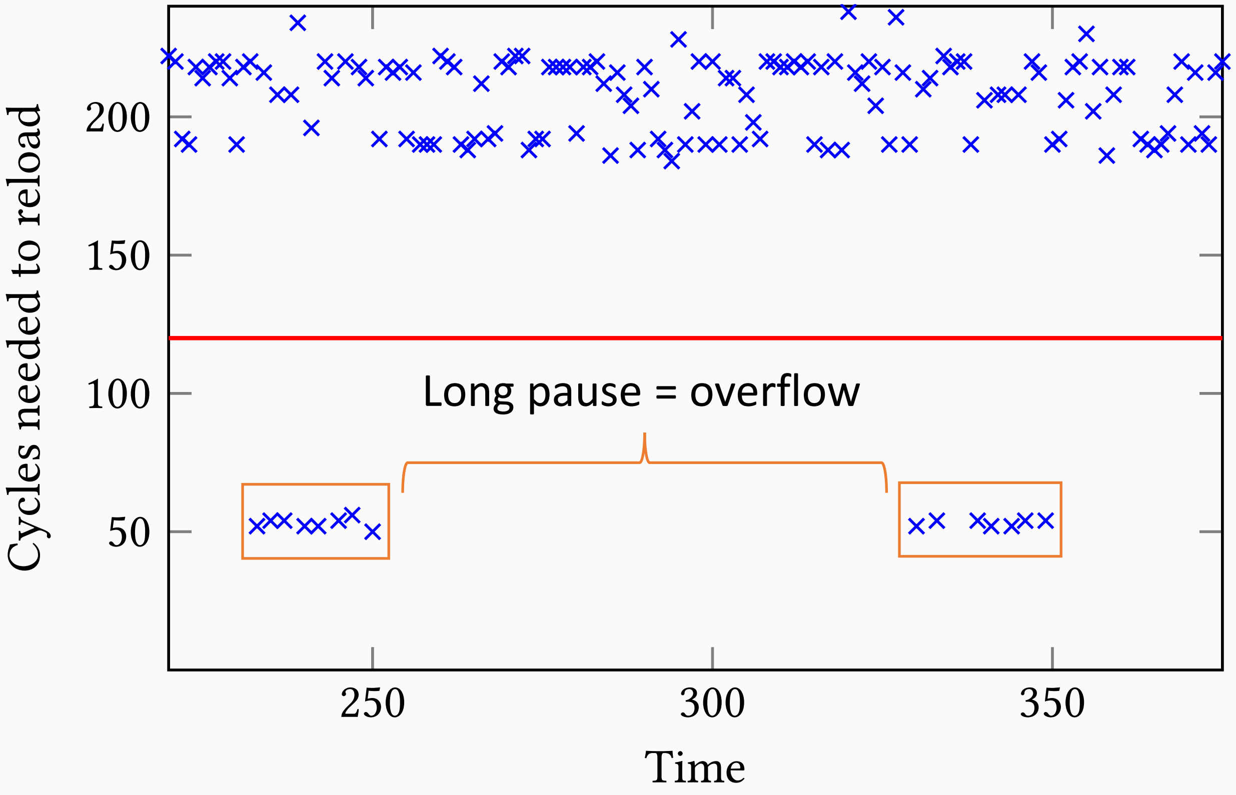

Rules ($b \in \{0,1\}$):

Vvvv -> $111b$

Vvvvv -> $yyyyb$, $yyyy \in \{110b, 10bb, 0111\}$

Vv.....v -> $0 \dots 0yyyyb$

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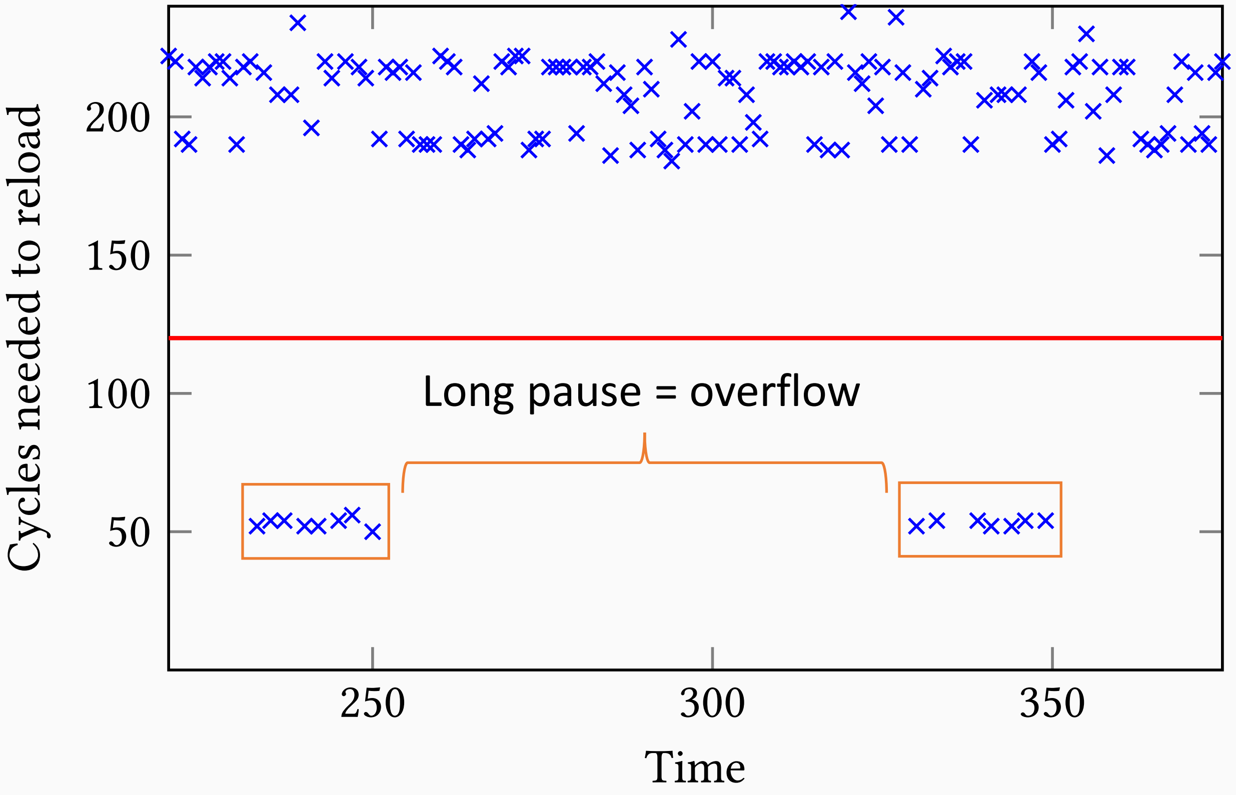

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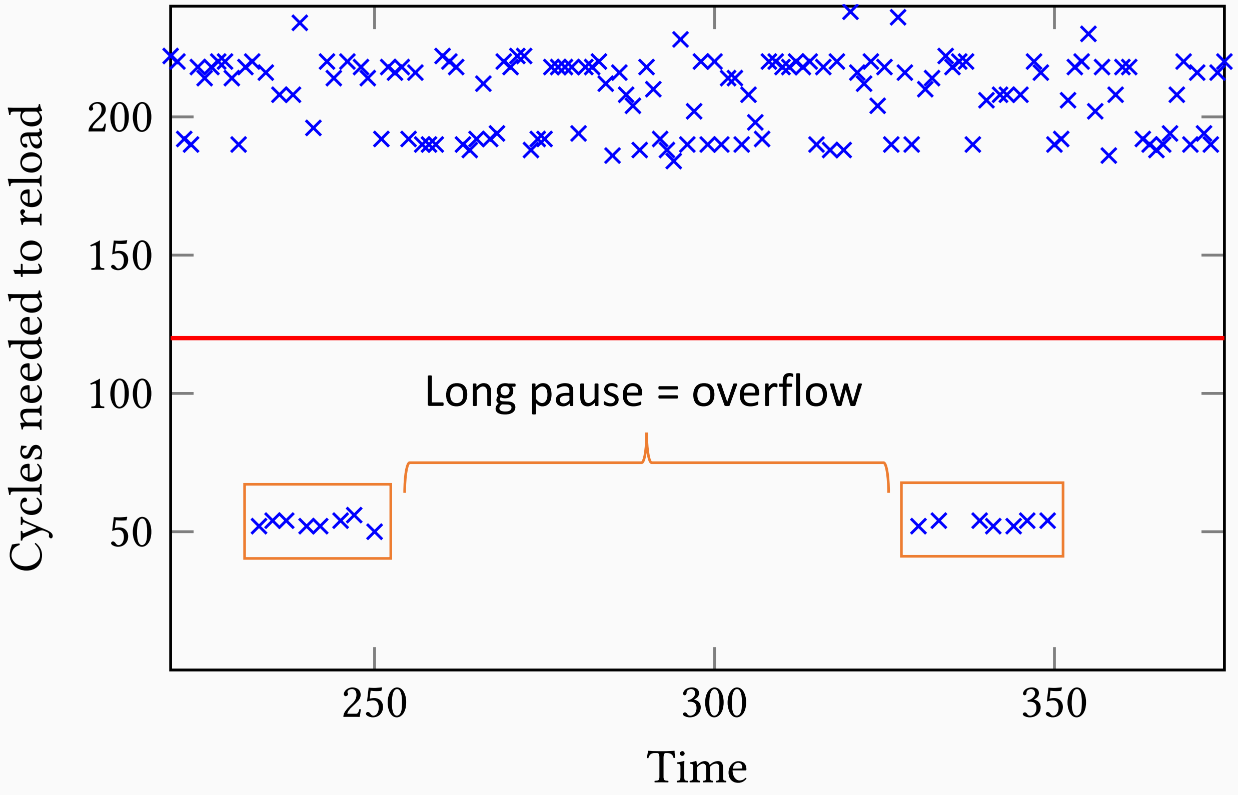

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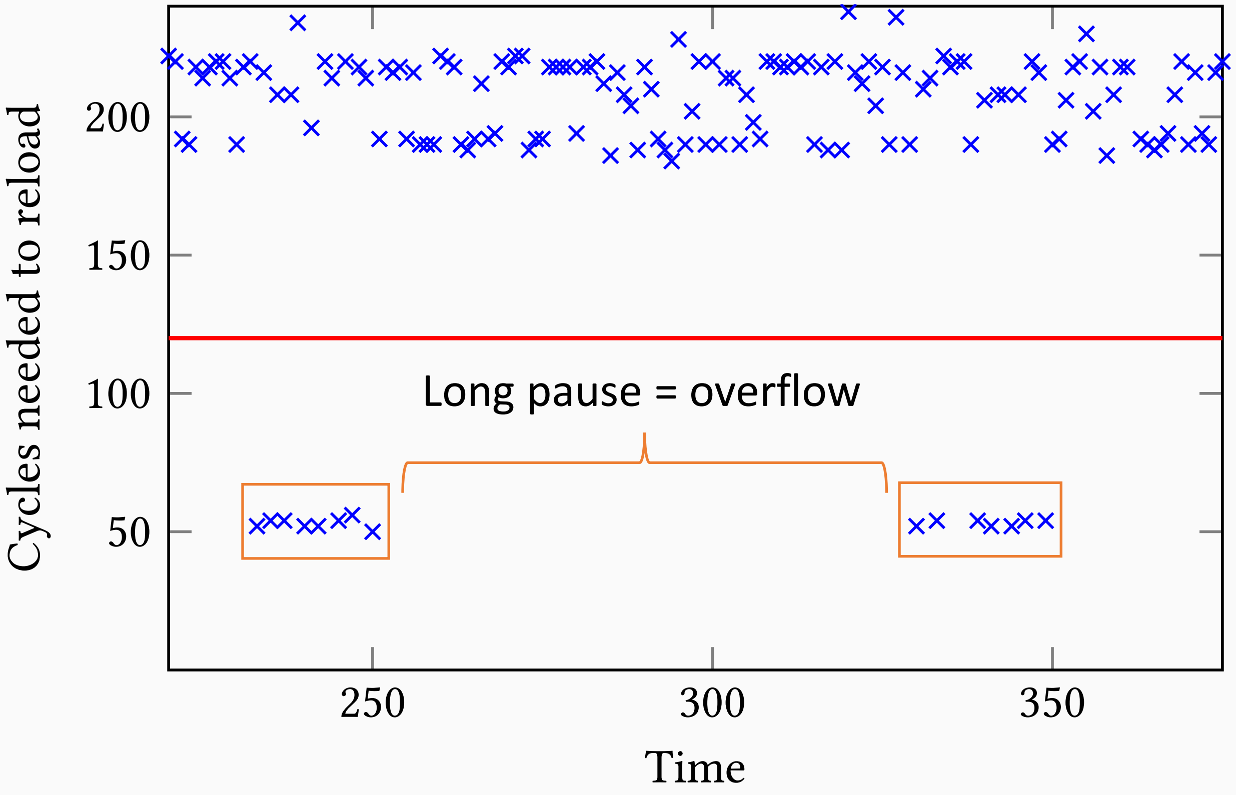

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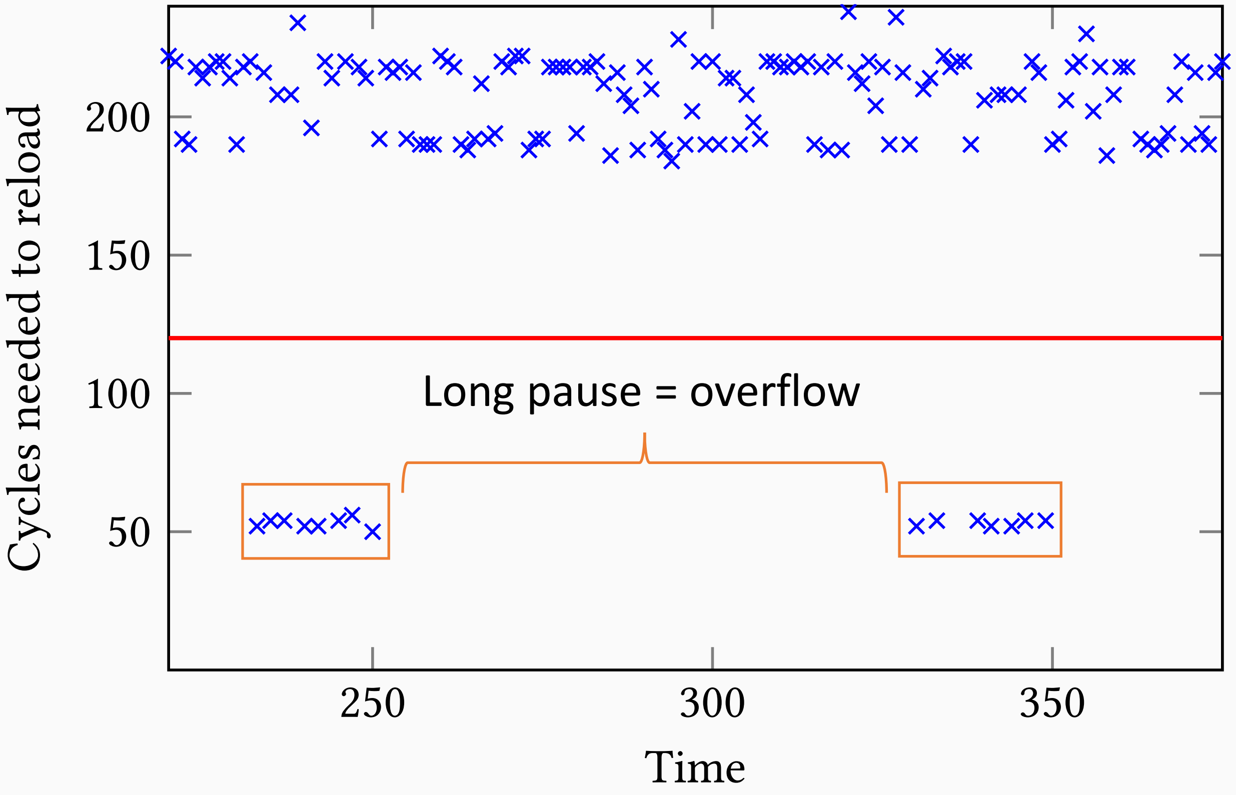

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Dictionary Attack

Client : $x = H(salt \mid\mid H(user\_id:password))$
$v = g^x \bmod p$

Dictionary Attack

Client : x = H(salt || H(user_id:password))
v = g^x mod p

$b \in \{0,1\}$
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Recovered: `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`

Dictionary Attack

Client : x = H(salt || H(user_id:password))
v = g^x mod p

$b \in \{0,1\}$
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```
Recovered:      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**

Dictionary Attack

Client : x = H(salt || H(user_id:password))
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```
Recovered:      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
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   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
   …
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Recovered:	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**

Dictionary Attack

Client : x = H(salt || H(user_id:password))
v = g^x mod p

$b \in \{0,1\}$
$yyyy \in \{110b, 10bb, 0111\}$

Password	X value	Diff score
Recovered:	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

Single Measurement Attack

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

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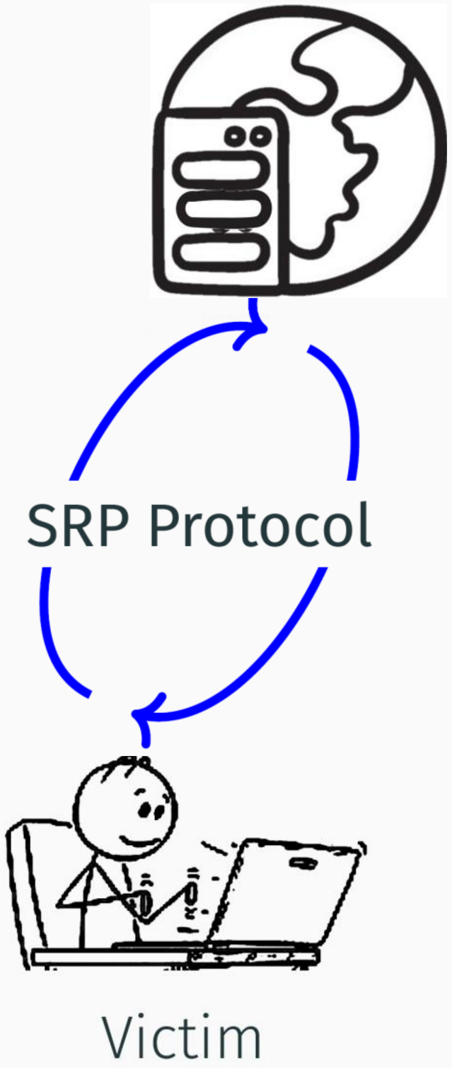
SHA-1: 66 bits of information

SHA-256: 104 bits of information

Attacker Model

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

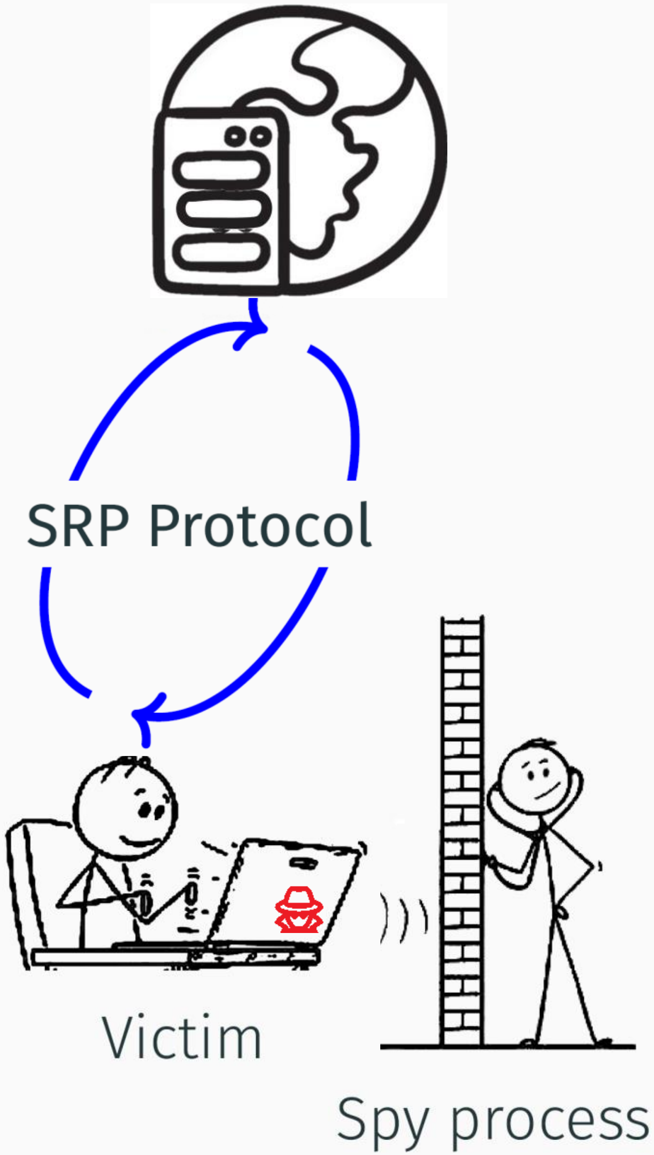
Classical Workflow



SRP Protocol

Victim

Classical Workflow



SRP Protocol

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Spy process

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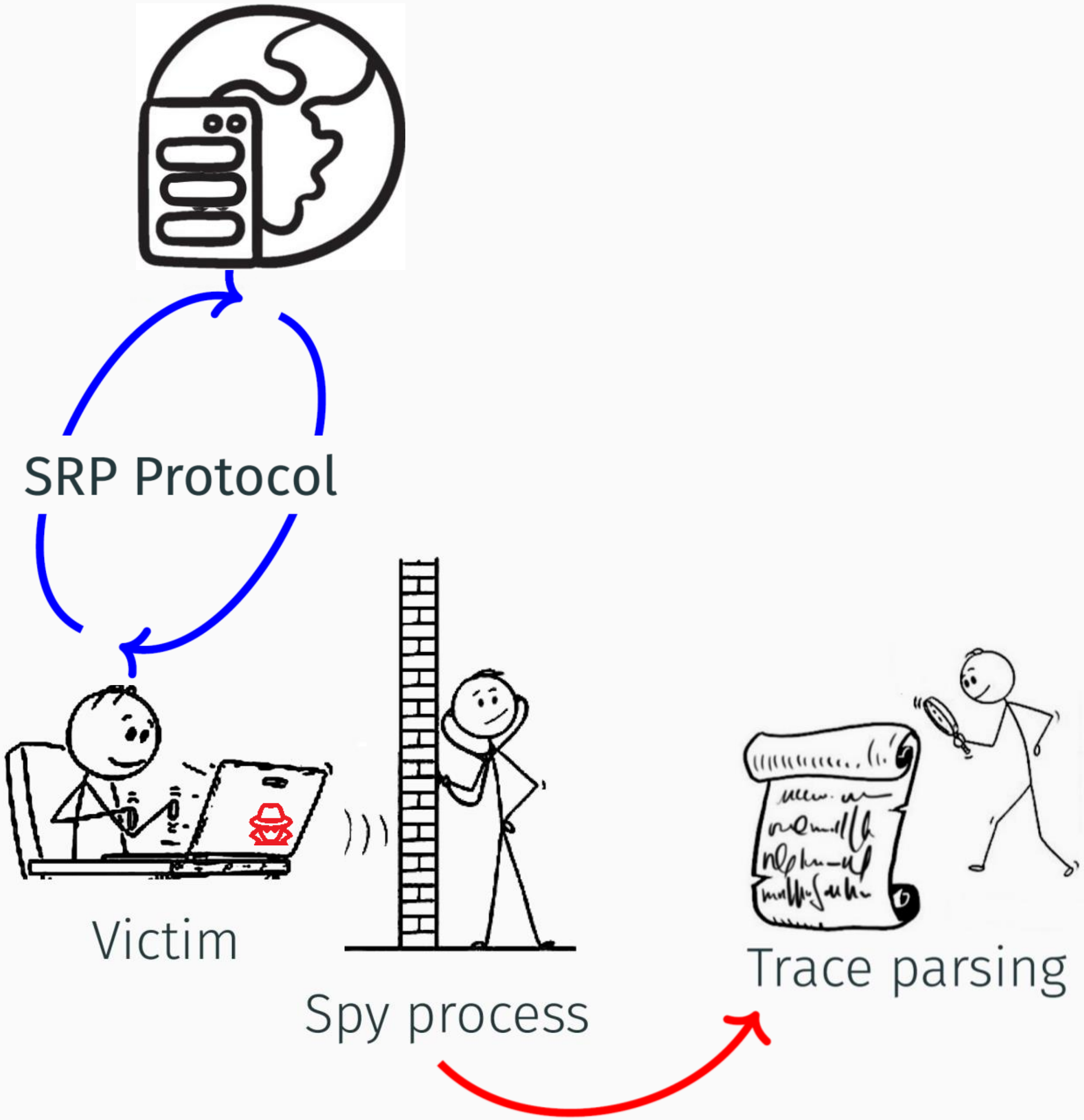


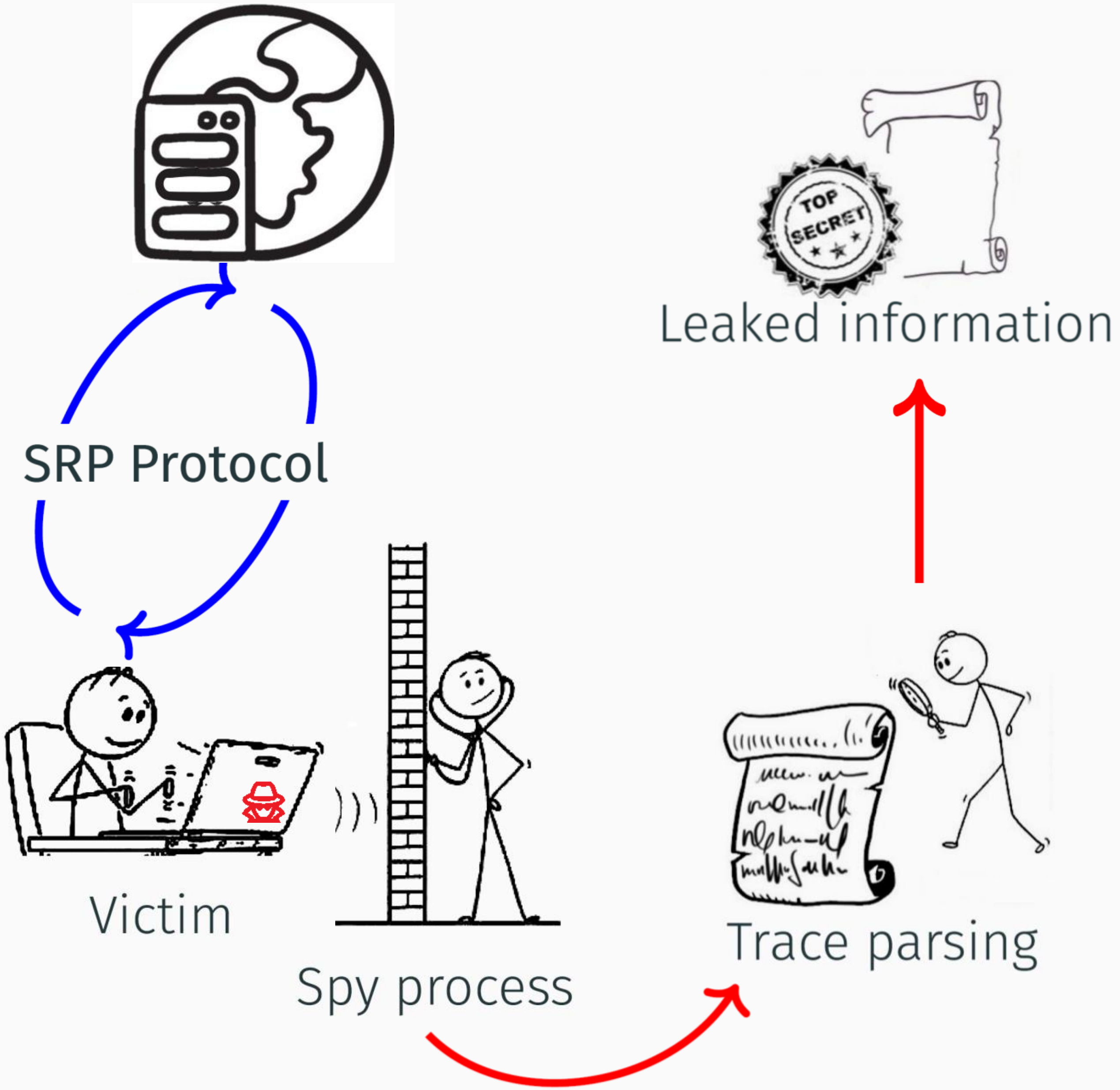
SRP Protocol

Victim

Spy process

Trace parsing

Classical Workflow



Leaked information

SRP Protocol

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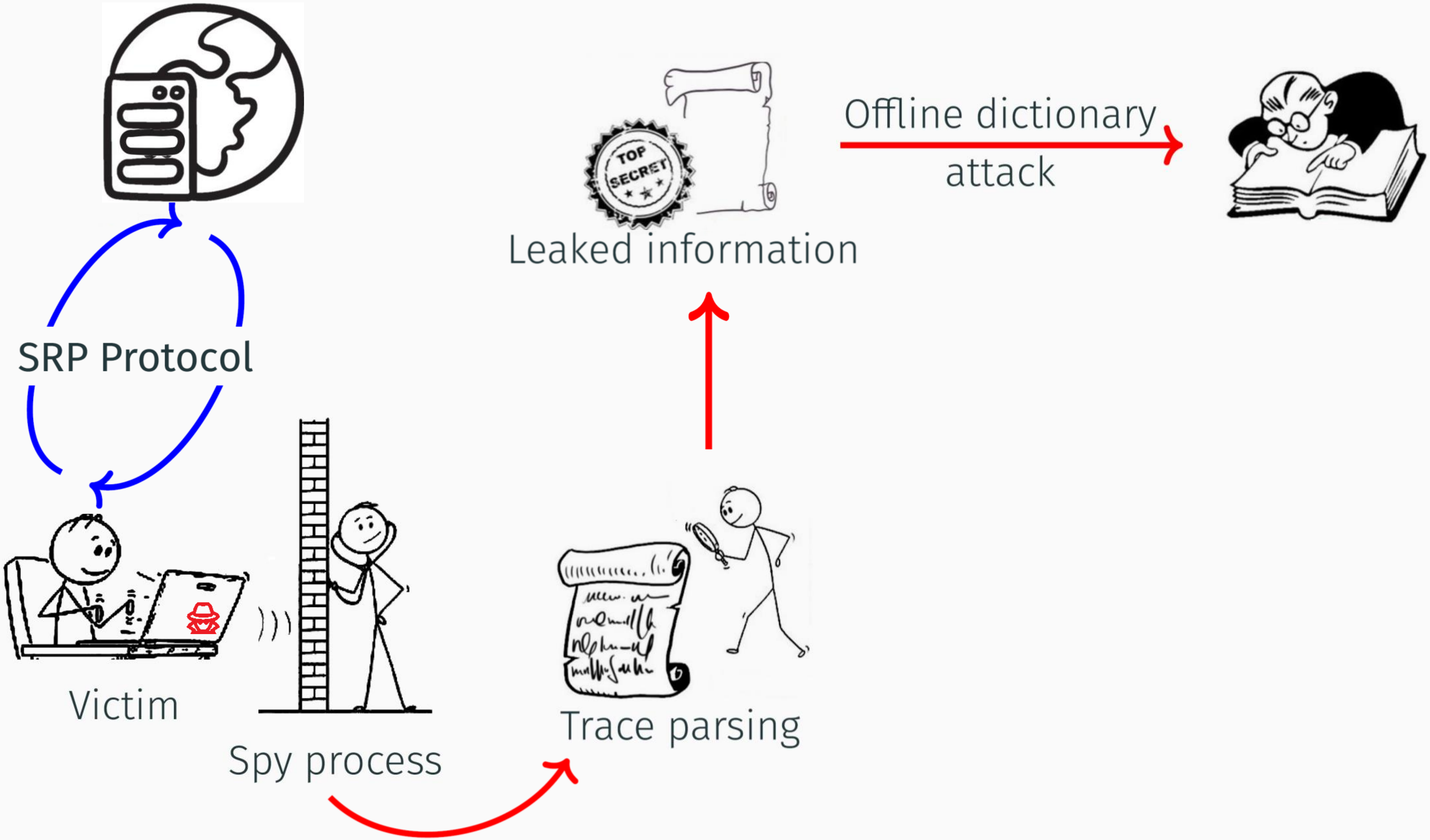
Spy process

Trace parsing

Classical Workflow



SRP Protocol

Victim

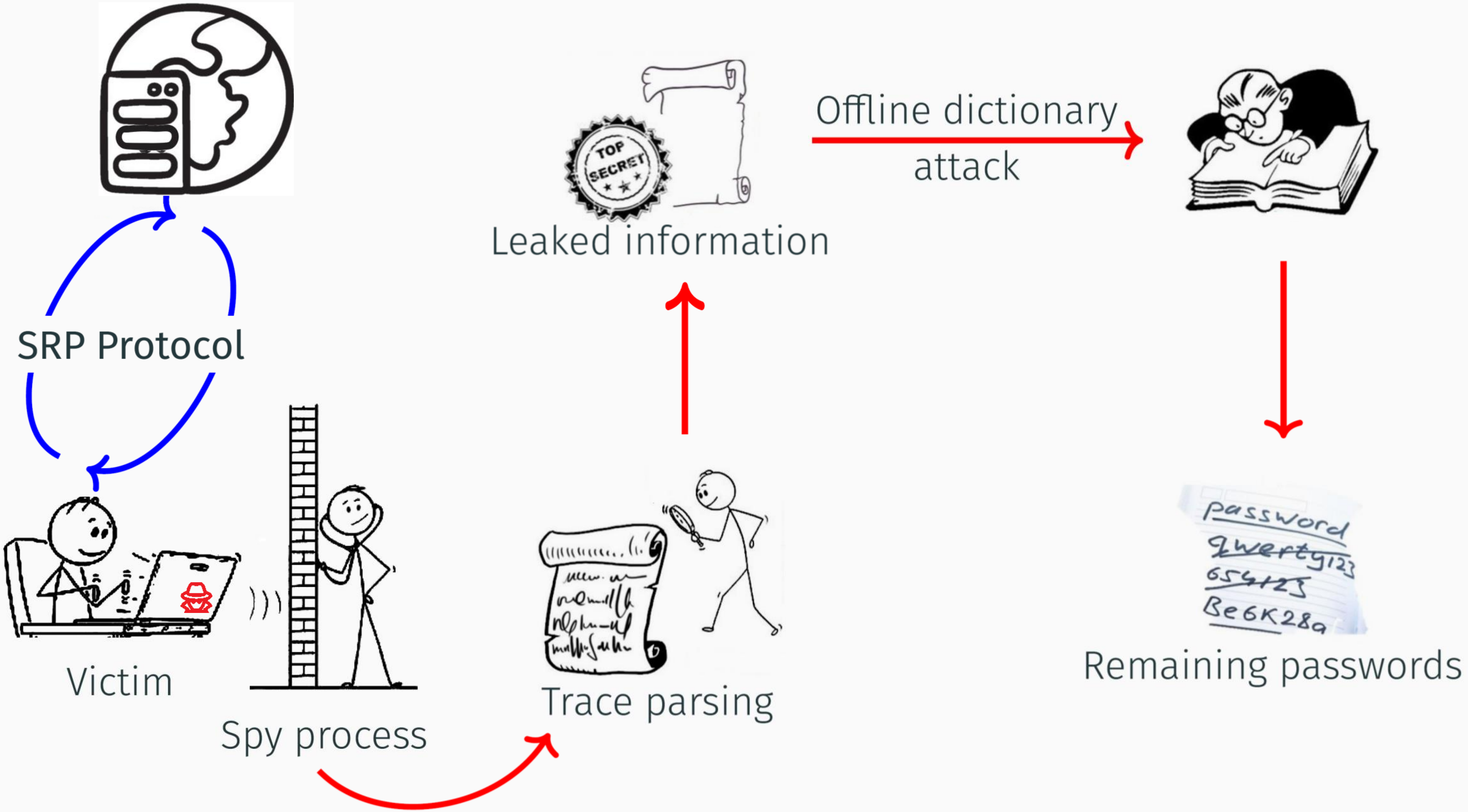
Spy process

Trace parsing

Leaked information

Offline dictionary attack

Classical Workflow



SRP Protocol

Victim

Spy process

Trace parsing

Leaked information

Offline dictionary attack

Remaining passwords

Practical Impact

Impacted Projects

- Lots of project using OpenSSL are impacted, including
  - OpenSSL TLS-SRP
  - Apple HomeKit ADK
  - PySRP (used in ProtonMail python client)
  - …

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

Impacted Languages

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

All SRP implementations using these packages / libraries would be affected!

Mitigations & Conclusion

Mitigations

Two choices:

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

- Switch to a secure by default implementation (flag for insecure/optimized)
  - No flag = secure implementation (potential performance loss)
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Mitigations

Two choices:

- Patch this particular issue by adding the proper flag ← OpenSSL's choice
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Conclusion

- 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

Conclusion

- 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

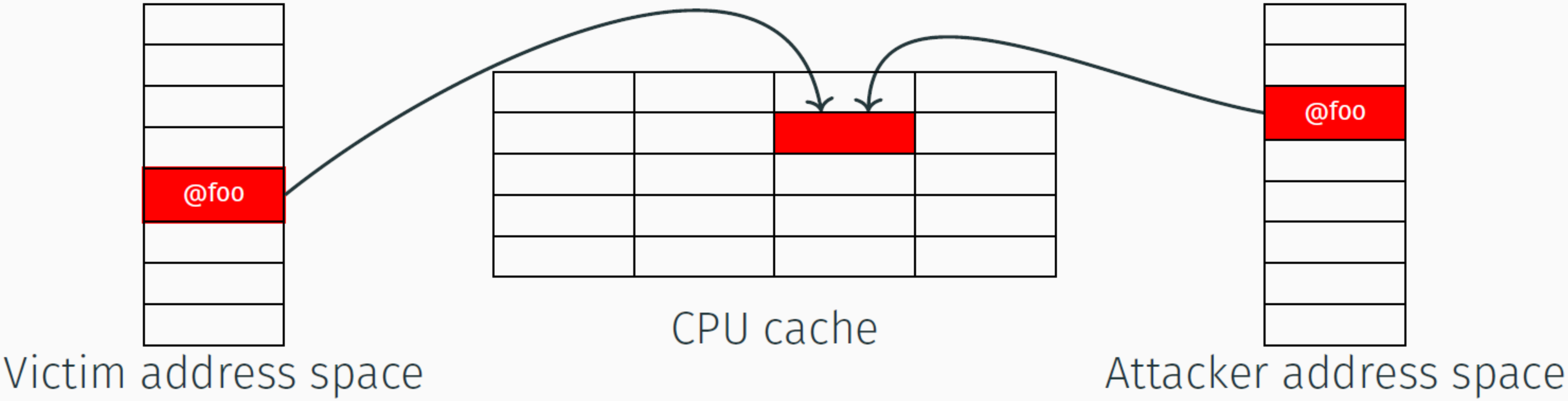
- Leakage in a weak generic function
  - Other protocols with small base may also use it
  - Contact use if you think of one!

Thank you for your attention!

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

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

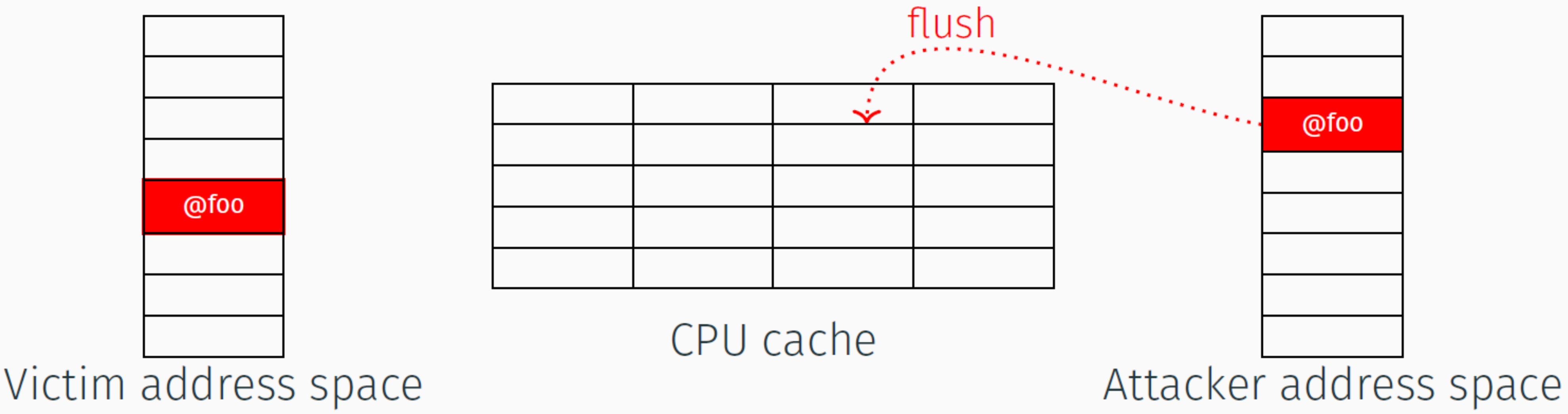
FLUSH+RELOAD[1]



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
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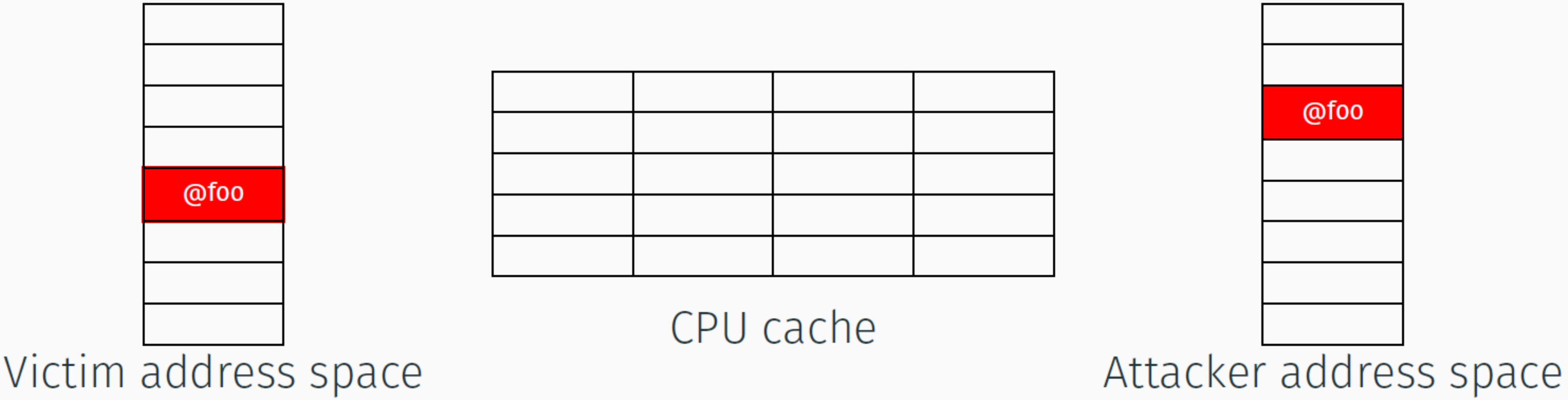

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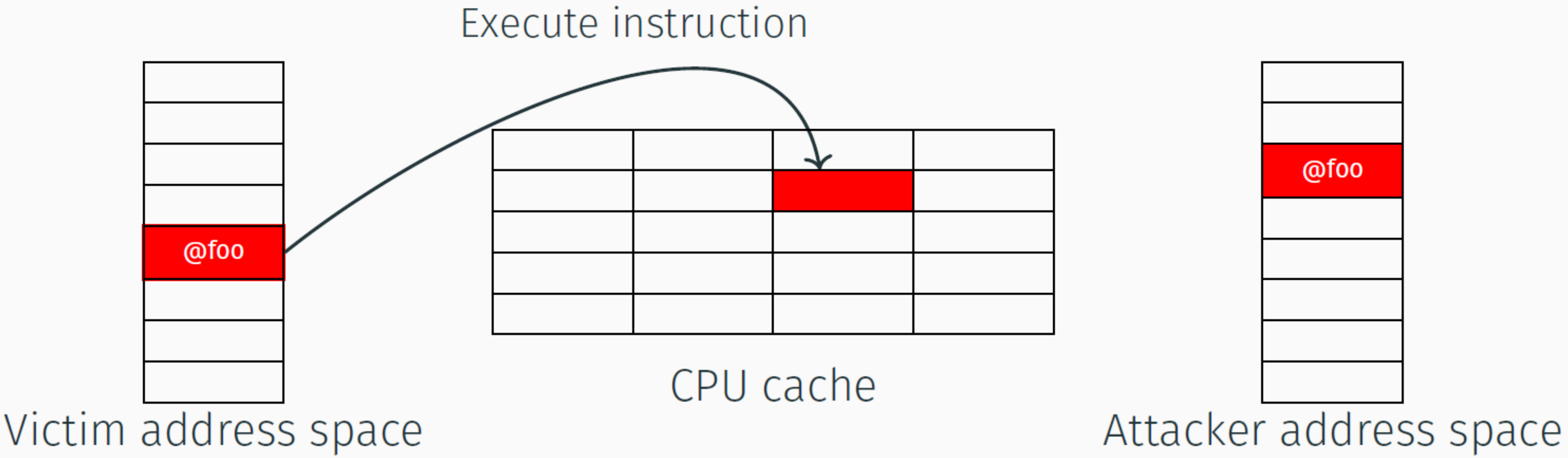

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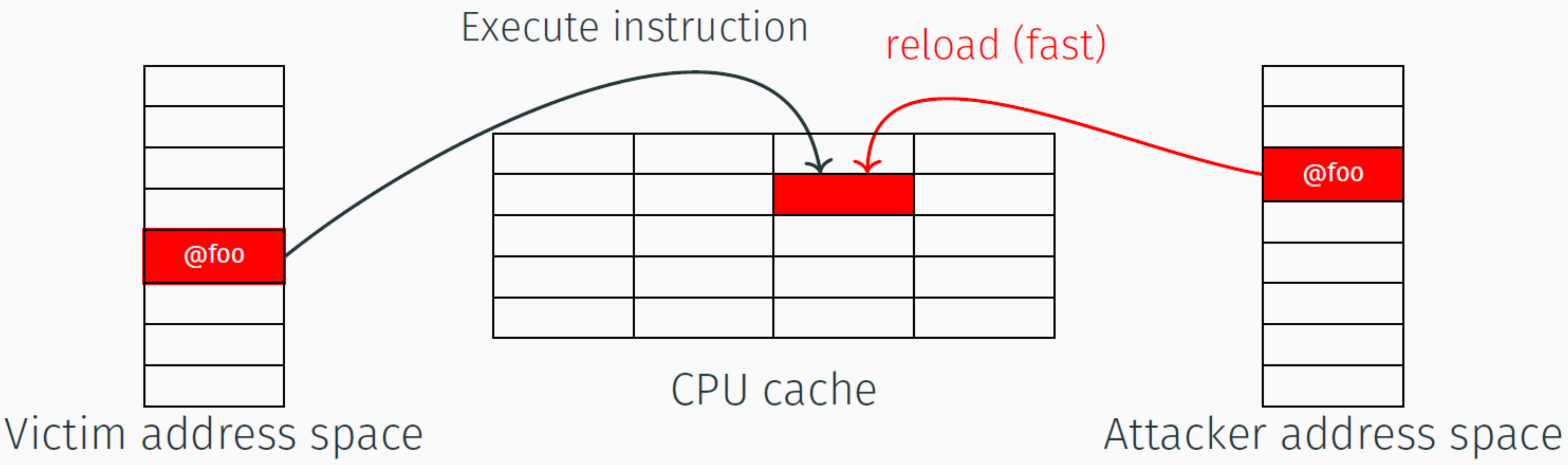

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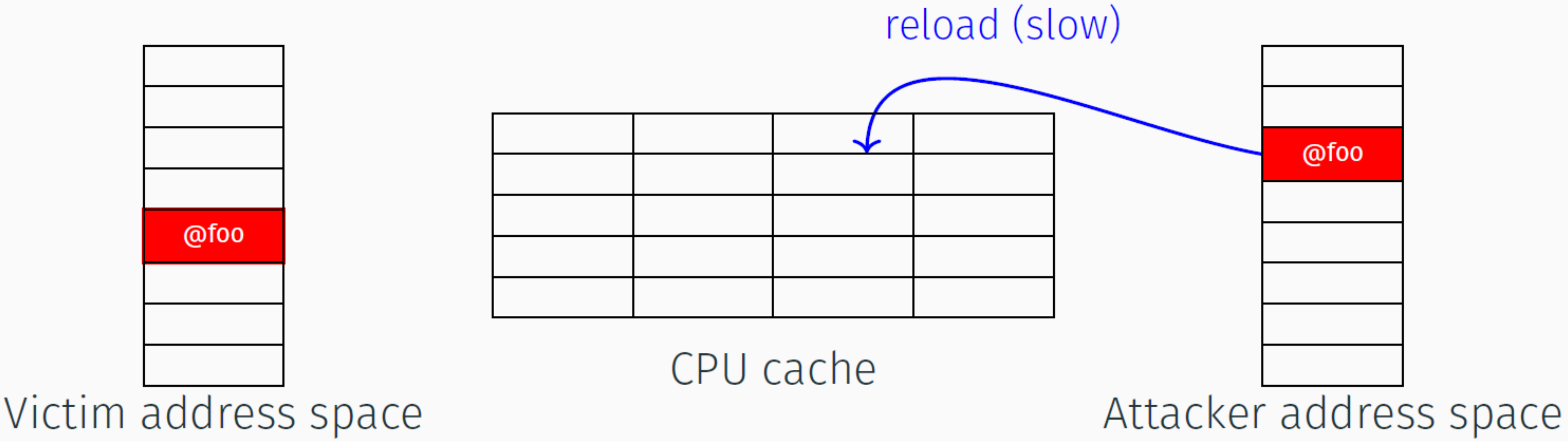

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[1] Y. Yarom et al. Flush+Reload: a High Resolution, Low Noise, L3 Cache Side-Channel Attack. In USENIX Security Symposium. 2014