Side-Channels Attacks on PAKE protocols

Daniel De Almeida Braga

CEA - October, 11th 2022

Me, Myself and I

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

What I Have Been Doing

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   - Why were the implementations vulnerable?
3. Are there sustainable ways to fix these vulnerabilities?

Context and Motivations

A Few Words About PAKEs

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

- Authentication
- End up with a strong key
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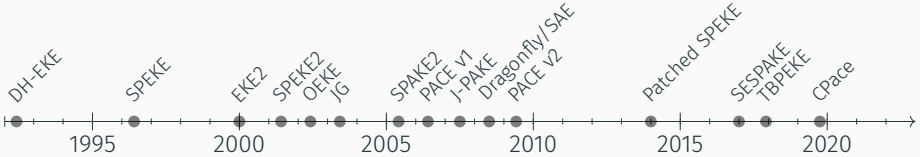

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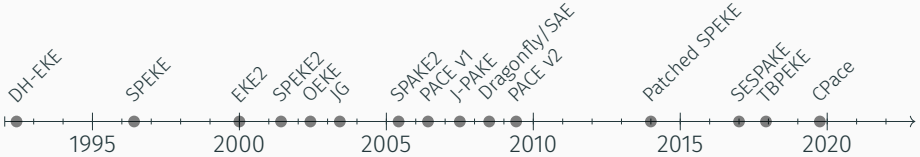

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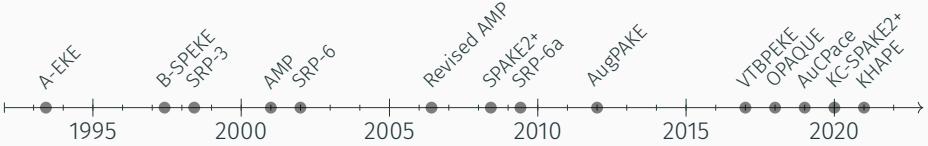

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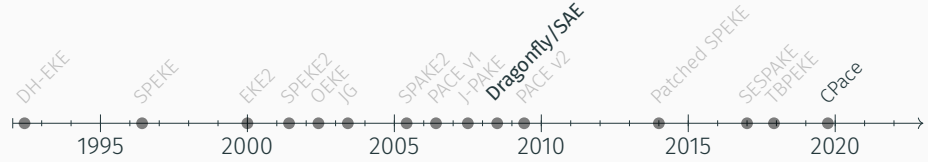

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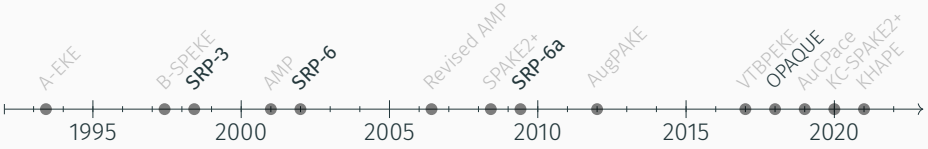

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Lesson to learn: Small leakage can be devastating

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Side Channel Attacks

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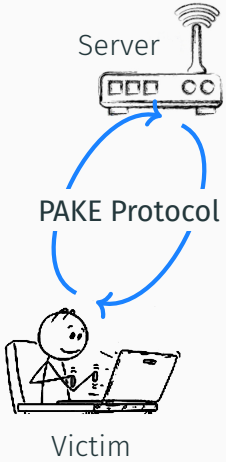
Gain information execution flow:

- Execute `long_processing` $\Rightarrow$ *a*
- Else, no *a* in pwd

Attack Workflow



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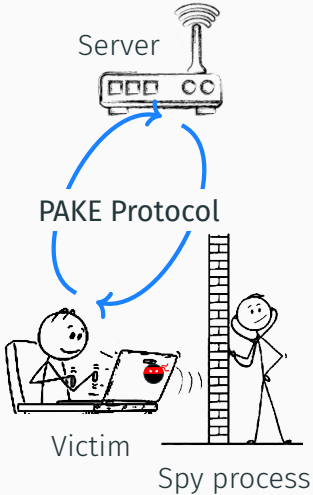

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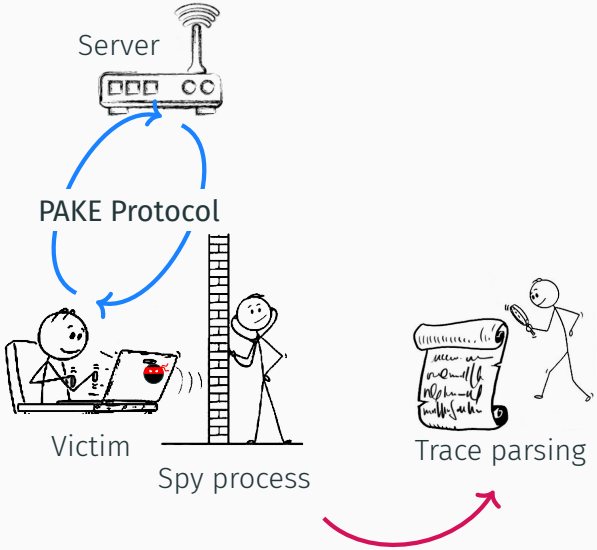

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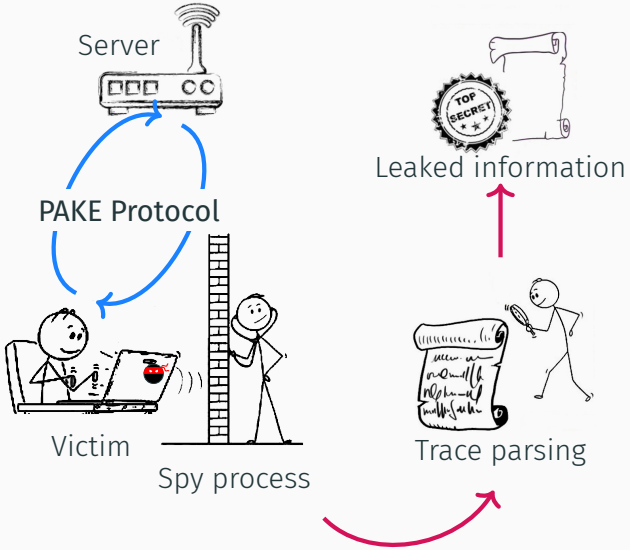

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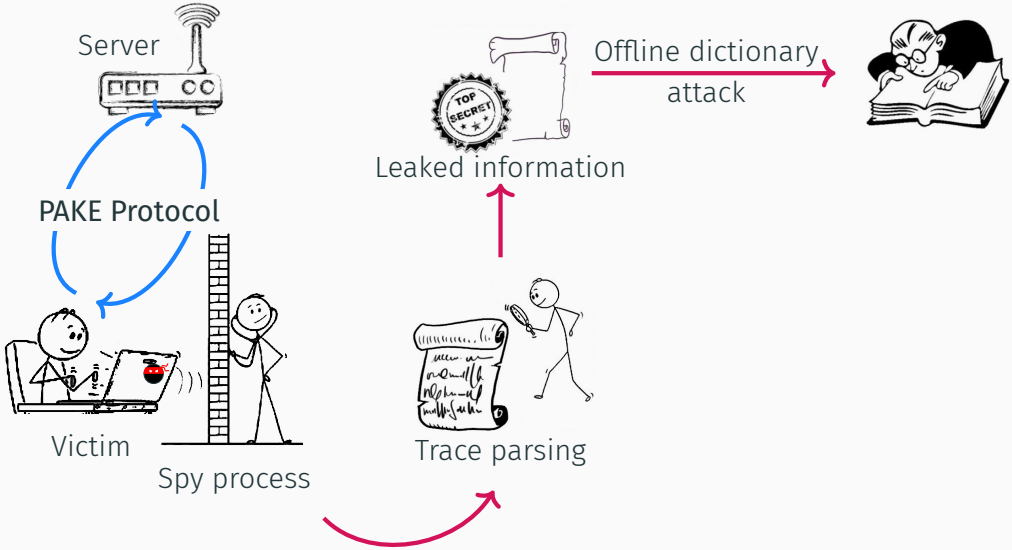

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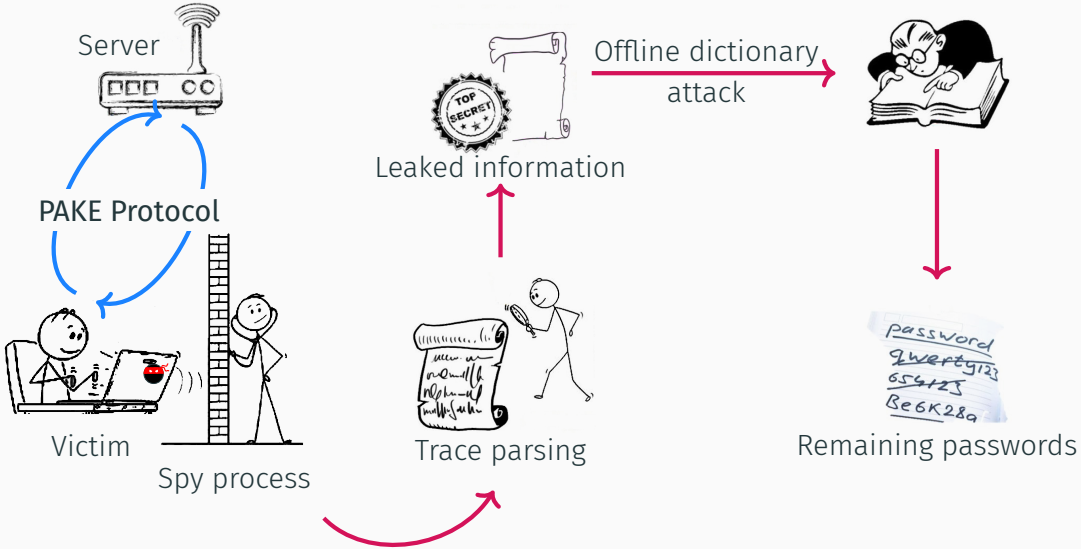

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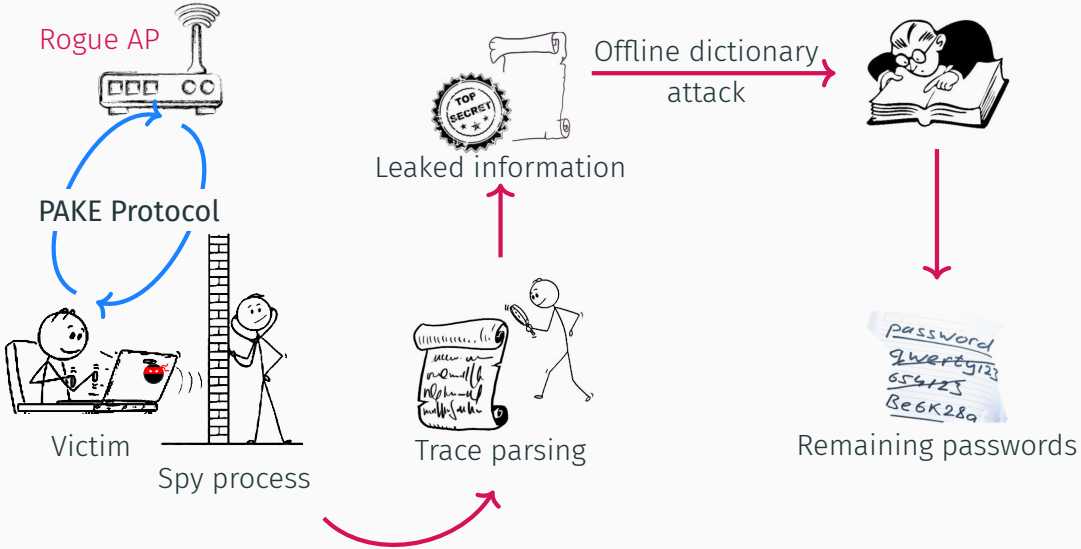

Side Channels in Dragonfly/SAE (WPA3)

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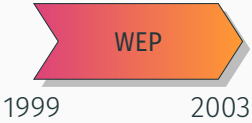

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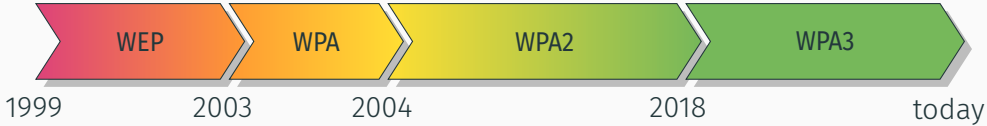

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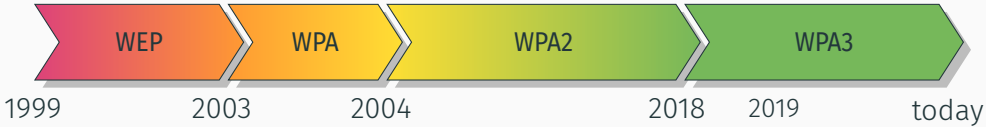

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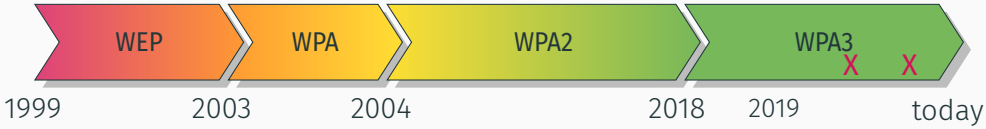

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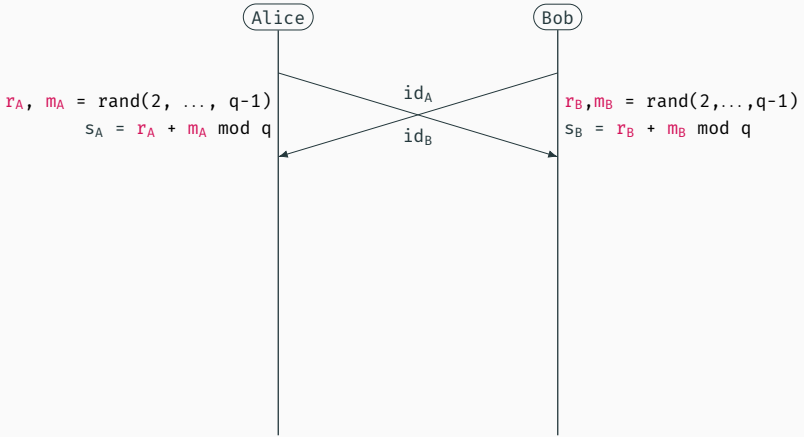

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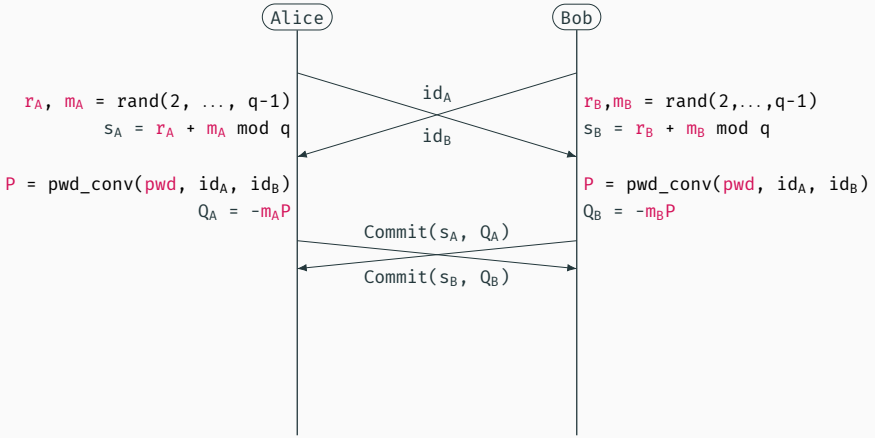

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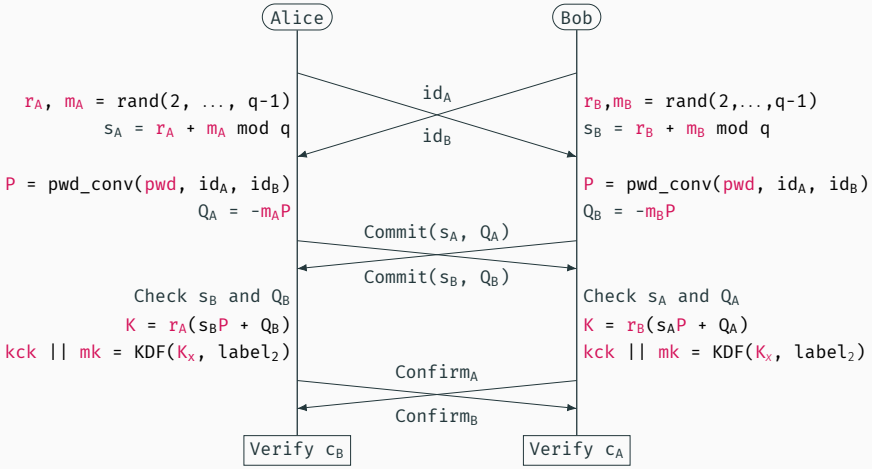

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Passive attacker can eliminate wrong passwords from a list

SAE - Probabilistic Password Conversion (EC)

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def HuntingAndPecking(pwd, MAC_A, MAC_B, k=40):
```

Hash pwd, MAC_A, MAC_B and a counter until we find a point coordinate. Do 40 iterations anyway, but save the first conversion

```
    y = set_coordinates(x, seed_x)
    return (x, y)
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  while not found or i < k:
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    x_cand = KDF(seed, label)
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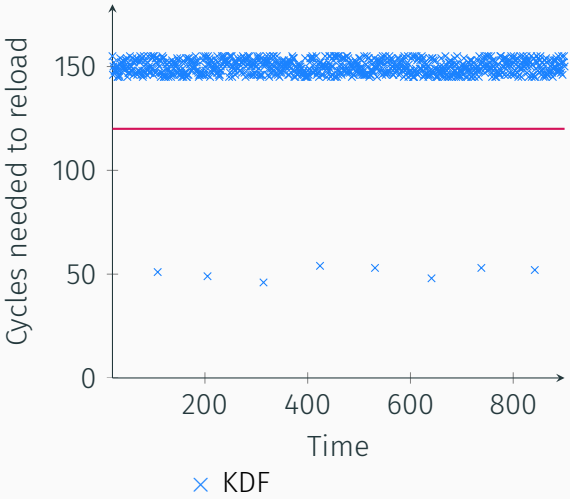
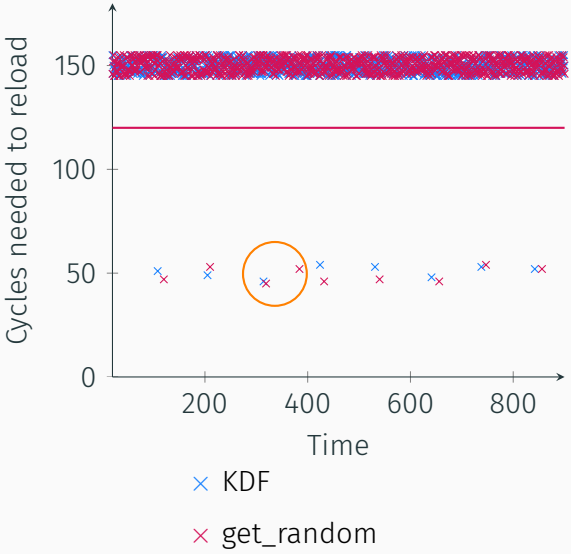
Now What?

- Iteration are easy to distinguish



Now What?

- Iteration are easy to distinguish
- We can guess which iteration is converting the password



Dictionary Reduction

	Iter. for MAC_A, MAC_{B_1}
Leakage	3
pwd_1	
pwd_2	
pwd_3	
pwd_4	
...	
pwd_5	

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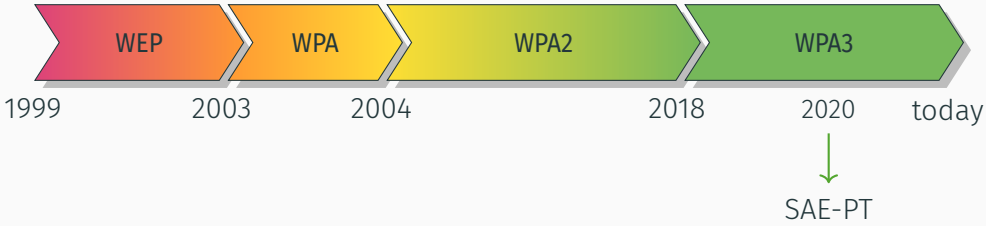
Improving the password conversion



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We should have caught this in the first analysis!

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Multiple areas..

- Design level
  - Protocol verification (symbolic / computational model)
- Functional correctness / efficiency
  - Correctness, memory safety, ...
- Implementation security

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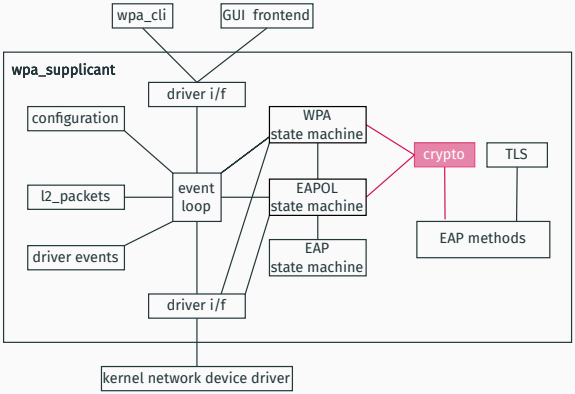
- Generating formally verified binaries

Fixing hostap



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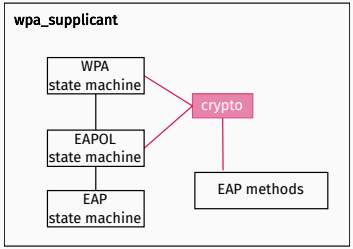

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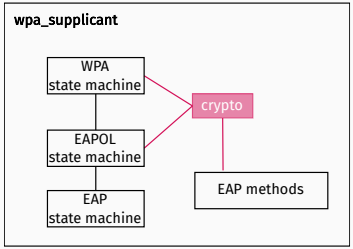


```
crypto/
  ...
  crypto.h

  crypto_mbedtls.c
  crypto_openssl.c
  crypto_wolfssl.c
  ...
```

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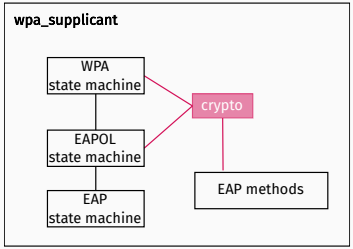


```
crypto/
  ...
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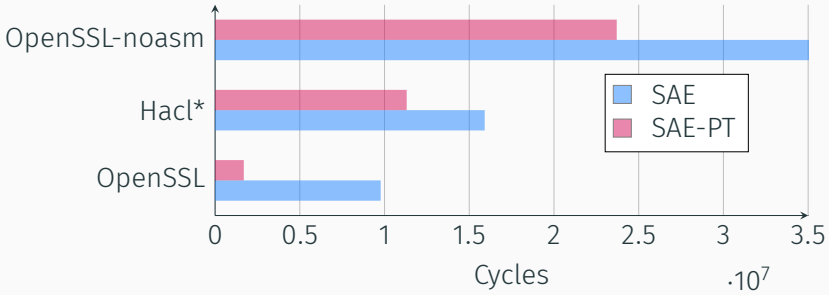
Benchmarks


OpenSSL-noasm
Hacl*
OpenSSL
SAE
SAE-PT
0
0.5
1
1.5
2
2.5
3
3.5
Cycles
$\cdot 10^7$

Constant-time Tools & Usability

Many Tools, Presumably Low Adoption

Tool	Target	Technique
ABPV13	C	Formal
Binsec/Rel	Binary	Symbolic
Blazer	Java	Formal
BPT17	C	Symbolic
CacheAudit	Binary	Formal
CacheD	Trace	Symbolic
COCO-CHANNEL	Java	Symbolic
ctgrind	Binary	Dynamic
ct-fuzz	LLVM	Dynamic
ct-verif	LLVM	Formal
CT-WASM	WASM	Formal
DATA	Binary	Dynamic
dudect	Binary	Statistics

Tool	Target	Technique
FaCT	DSL	Formal
FlowTracker	LLVM	Formal
haybale-pitchfork	LLVM	Symbolic
KMO12	Binary	Formal
MemSan	LLVM	Dynamic
MicroWalk	Binary	Dynamic
SC-Eliminator	LLVM	Formal
SideTrail	LLVM	Formal
Themis	Java	Formal
timecop	Binary	Dynamic
tis-ct	C	Symbolic
VirtualCert	x86	Formal

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- Are developers aware of the threat?
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Why do we still find textbook issues?

- Are they waiting for specific features?

Let’s ask them!

“They’re not that hard to mitigate”: What Cryptographic Library Developers Think About Timing Attacks

Jan Jancar[1], Marcel Fourné[2], Daniel De Almeida Braga[3], Mohamed Sabt[3], Peter Schwabe[2], Gilles Barthe[2], Pierre-Alain Fouque[3] and Yasemin Acar[2,4]

CROCS Centre for Research on Cryptography and Security [1]

MAX PLANCK INSTITUTE FOR SECURITY AND PRIVACY [2]

UMR IRISA [3]

THE GEORGE WASHINGTON UNIVERSITY [4]
WASHINGTON, DC

Survey

27 librairies

OpenSSL, BearSSL, libgcrypt, s2n (Amazon), RustCrypto, ...

44 valid responses

Various roles (developers, maintainers, committers, ...)

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Interesting responses

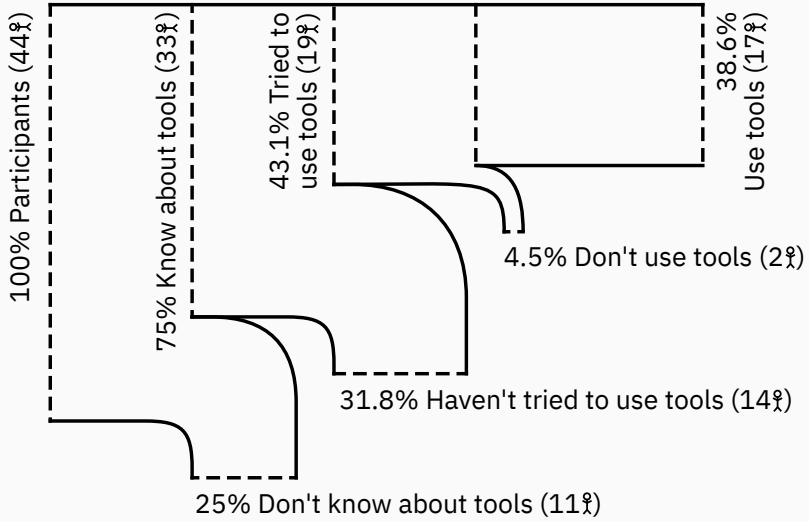
"It was totally obvious for everybody right from the start that protection against timing attacks is ***necessary****."*

"I'm very interested in these sorts of tools, but so far it seems formal analysis tools (at least where we've tried to apply it to correctness) are ***not really usable by mere mortals yet****."*

"For many cases there ***aren't enough real world attacks*** *to justify spending time on preventing timing leaks."*

"They're ***not that hard to mitigate****, at least with the compilers I'm using right now."*

Leaky pipeline



Recommendations

Tool developers

- Make usable tools
- Promote them

Crypto developers

- Use the tools
- Annotate your code

Complier writers

- Support secret types
- Give more control to developers

Standardization bodies

- Encourage to use tools and give recommendations
- Require constant-time code

- PAKEs are spreading
- They are particularly prone to side-channel attacks
- Computer-aided cryptography is nice
- We need more usable tools

Thank you for your attention!

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