PBKDF2: performance matters

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1. Quick intro to PBKDF2

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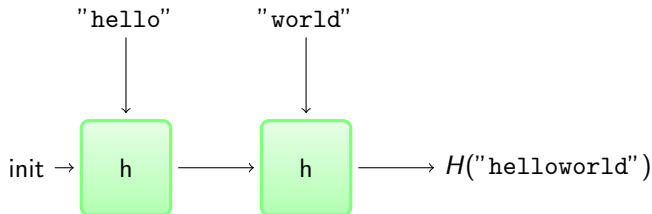
4. A faster PBKDF2

Intro: Merkle-Damgård hash functions

Basic construction of most hash functions: MD5, SHA-1, SHA-2.



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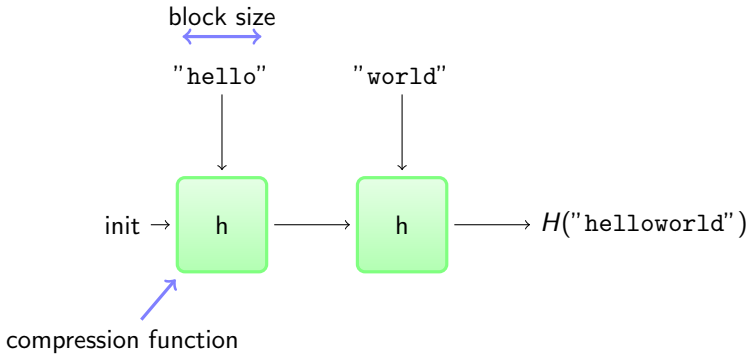
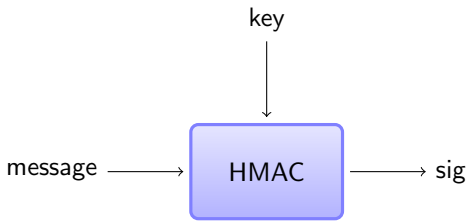
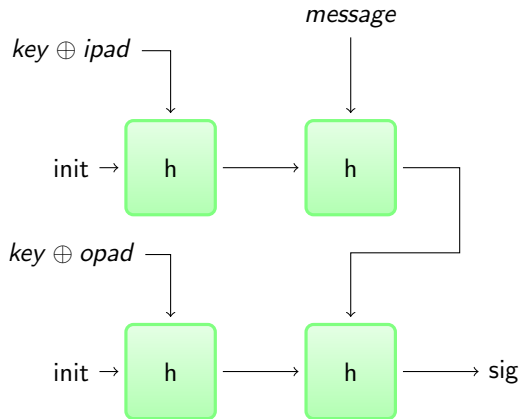


Intro: HMAC

Making secure symmetric signatures out of MD hash functions.



Intro: HMAC innards

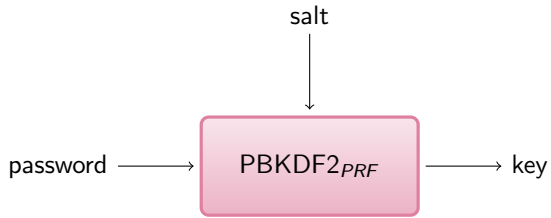


HMAC-H(key, $message$) := H($key \oplus$ opad $\|$ H($key \oplus$ ipad $\|$ $message$))

(for messages shorter than a block!)

Intro: PBKDF2

Slowly derive a key from a password and salt.



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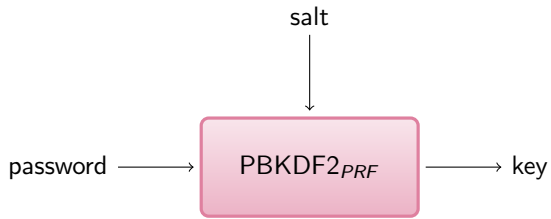

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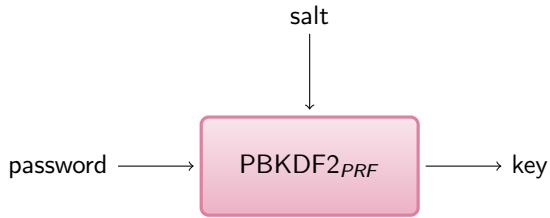

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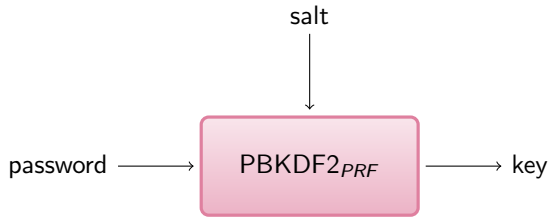

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- Tunable computation cost, with iteration count.
- Origin: RSA labs, 1999. Described in PKCS#5 and then RFC2898.

Intro: PBKDF2

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Performance profile is *important* for defenders. Aim: to maximise attacker work for defender computation budget.

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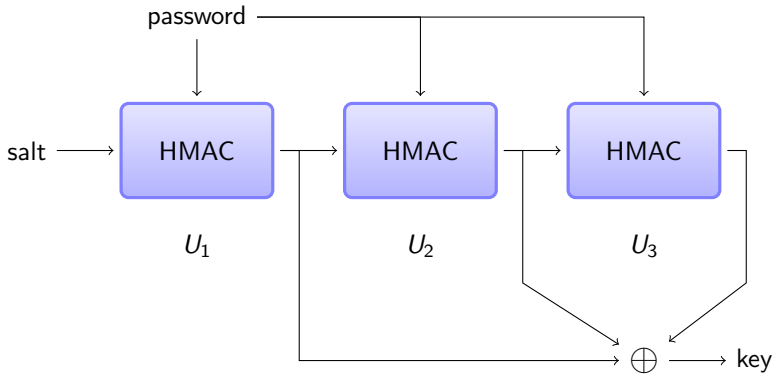
Simplification

PBKDF2 can produce arbitrary length output.
We're going to ignore this capability: assume it produces the same length output as the underlying hash.

Intro: PBKDF2$_{HMAC}$ with 3 iterations



$$\text{PBKDF2}_{\text{HMAC}}(\text{password}, \text{salt}, \text{i}) \coloneqq U_1 \oplus U_2 \oplus \cdots \oplus U_{\text{i}}$$

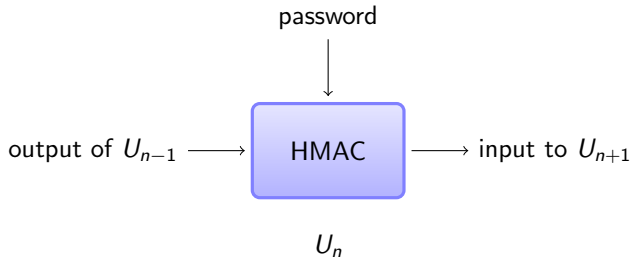
where

$$U_1 \coloneqq \text{HMAC}(\text{password}, \text{salt})$$

$$U_n \coloneqq \text{HMAC}(\text{password}, U_{n-1})$$

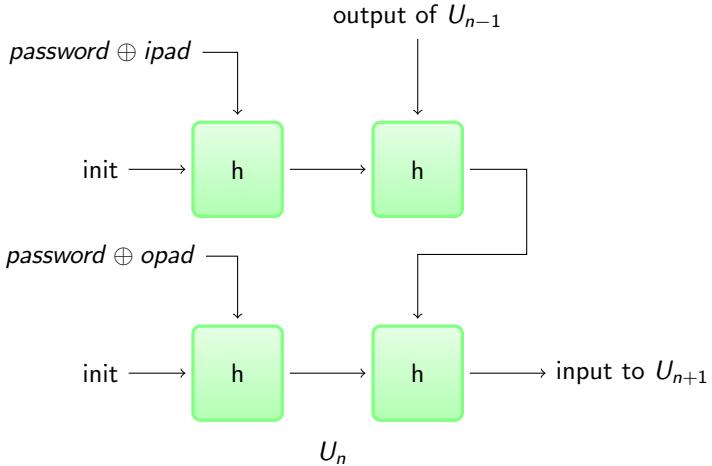
PBKDF2: perf vs. iteration count

One HMAC per iteration.



How many compression function applications?

PBKDF2: perf vs. iteration count



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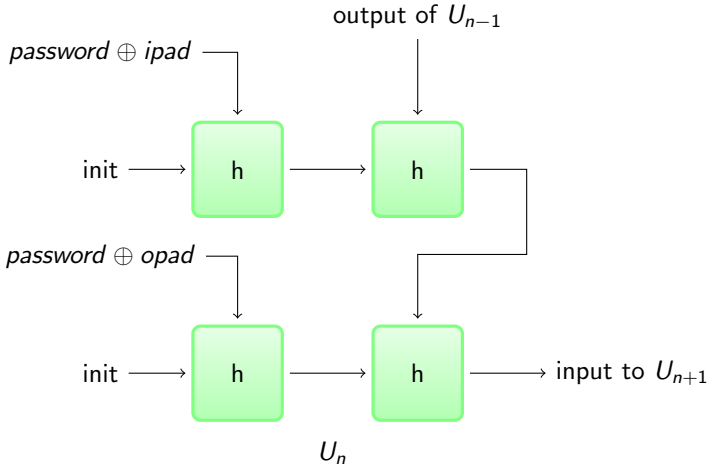
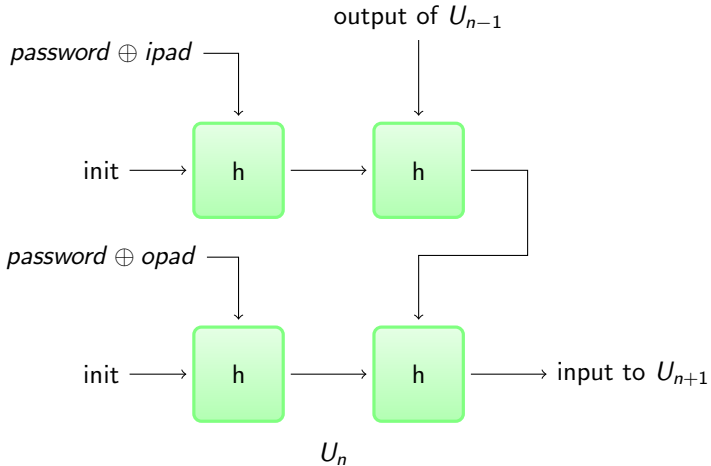


Conclusion: $4i$ compression function applications for i iterations.

Nope!

This is suboptimal. Neither of the standards mention this, or even describe the expected performance :(



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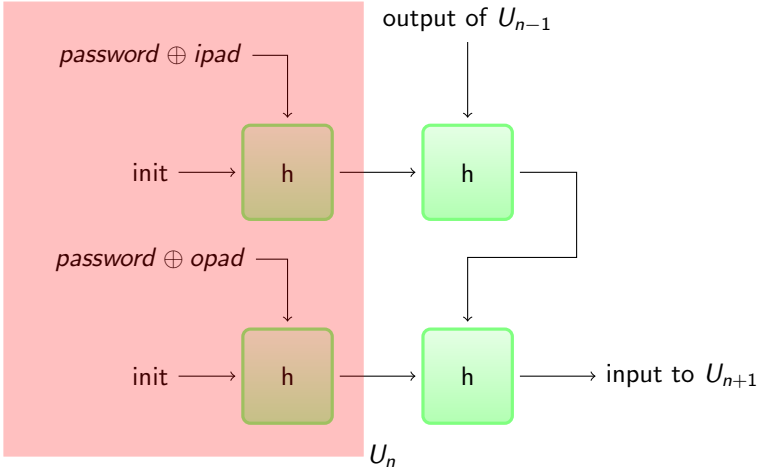
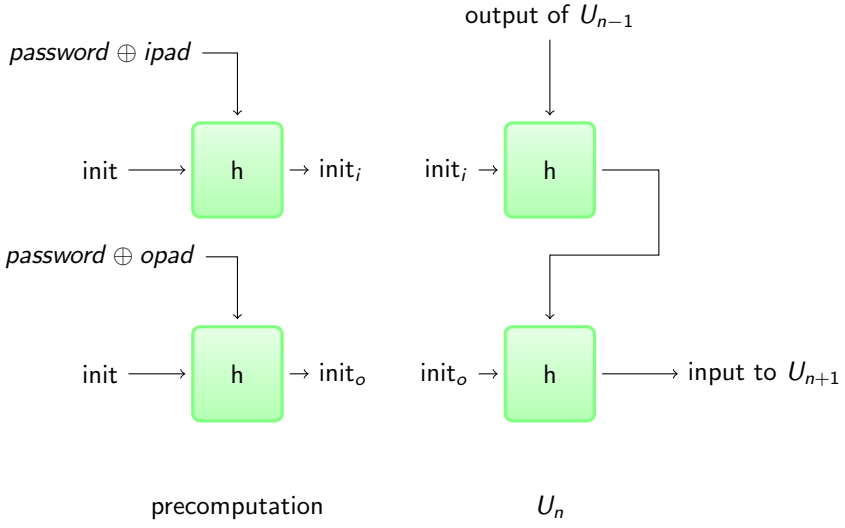
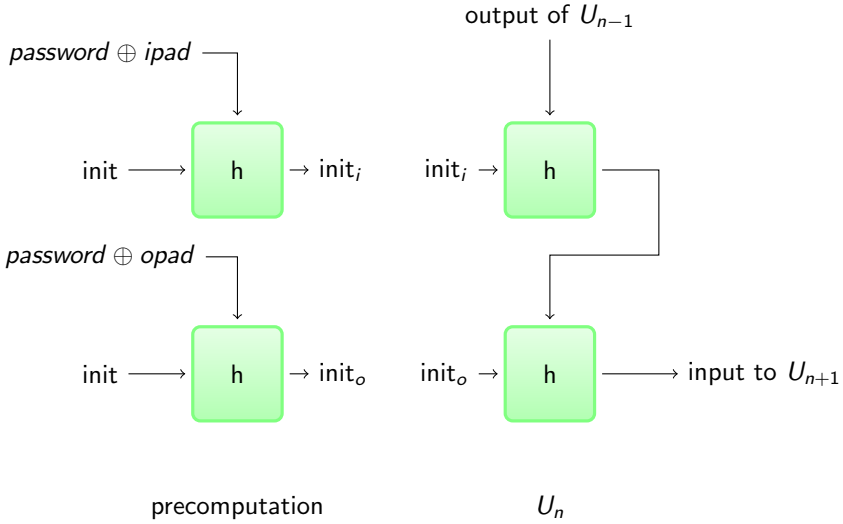



password ⊕ ipad
init
h
→ init$_i$
password ⊕ opad
init
h
→ init$_o$
precomputation
output of U_{n-1}
init$_i$ →
h
init$_o$ →
h
input to U_{n+1}
U_n



Actually $2 + 2i$ compression function applications for i iterations.

Survey of defender implementations

I looked at the following PBKDF2s:

- FreeBSD 10
- GRUB 2.0
- Truecrypt 7.1a
- Android (disk encryption)
- Android (BouncyCastle)
- Django
- OpenSSL
- Python core ($\geq$3.4)
- Python (pypi pbkdf2)
- Ruby (pbkdf2 gem)
- Go (go.crypto)
- OpenBSD
- PolarSSL/mbedTLS
- CyaSSL/wolfSSL
- SJCL
- Java
- Common Lisp (ironclad)
- Perl (Crypt::PBKDF2)
- PHP5
- .NET framework
- scrypt/yescrypt[1]
- BouncyCastle

[1] never called for scrypt/yescrypt with iterations != 1

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Measured on Intel Atom N2800 (1.86GHz), best of five runs, CPU time in user mode.

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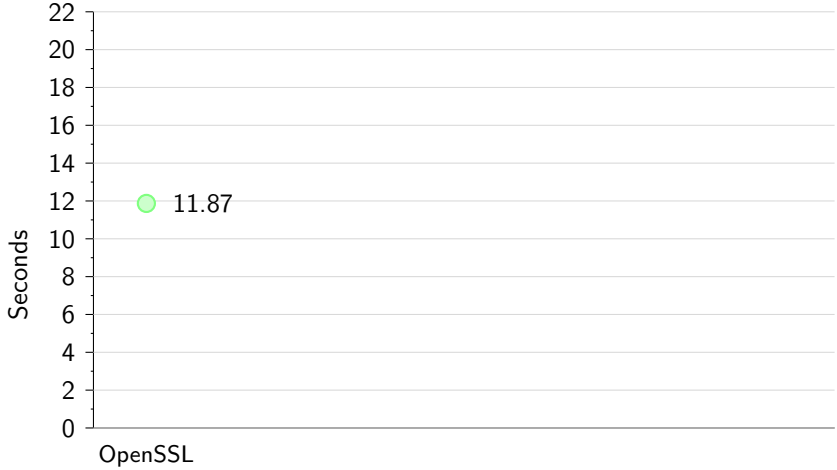

PBKDF2-HMAC-SHA1, one block output, 2^{22} iterations

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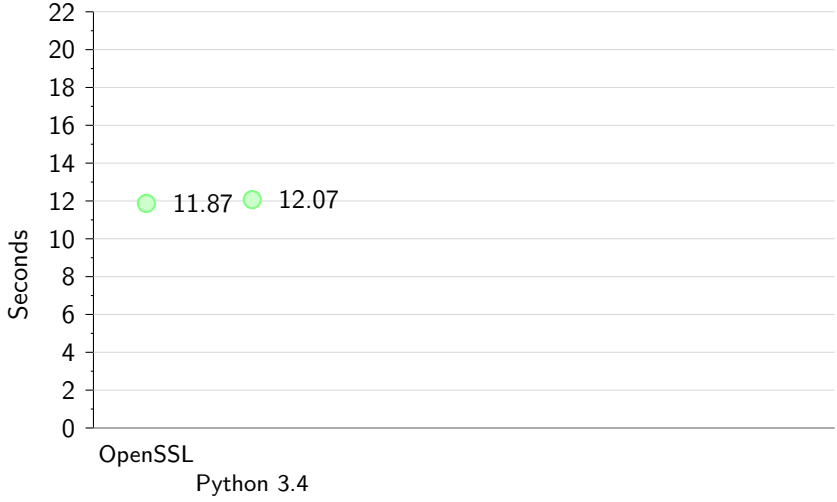

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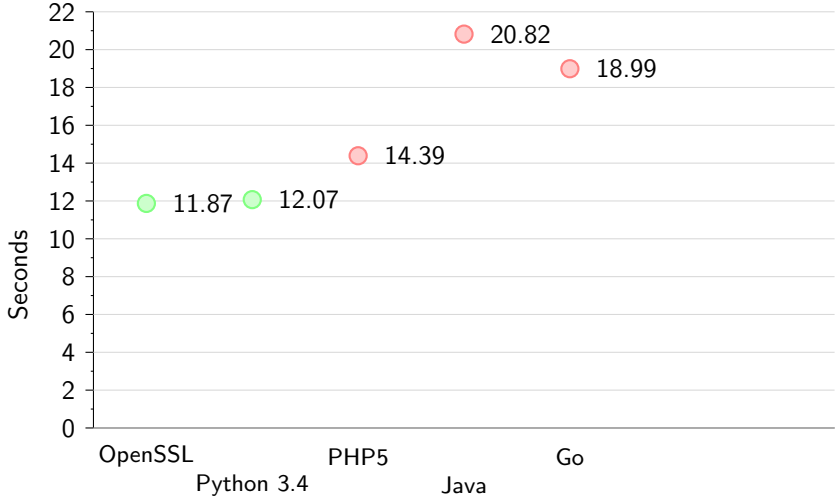

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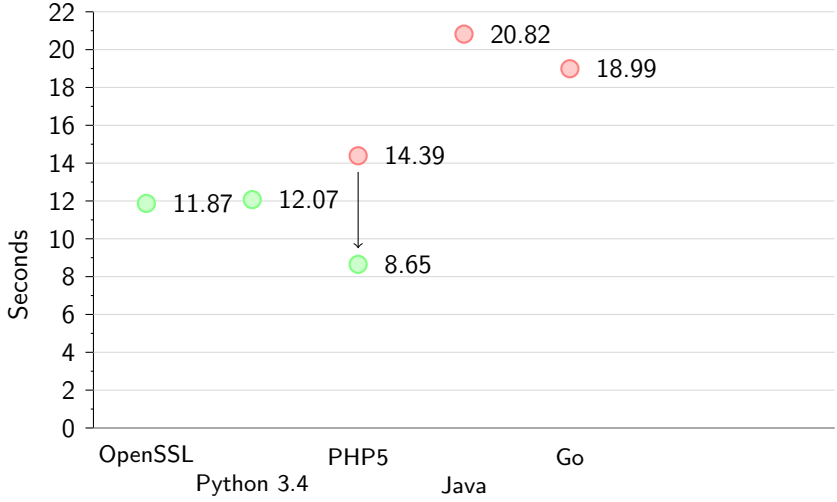

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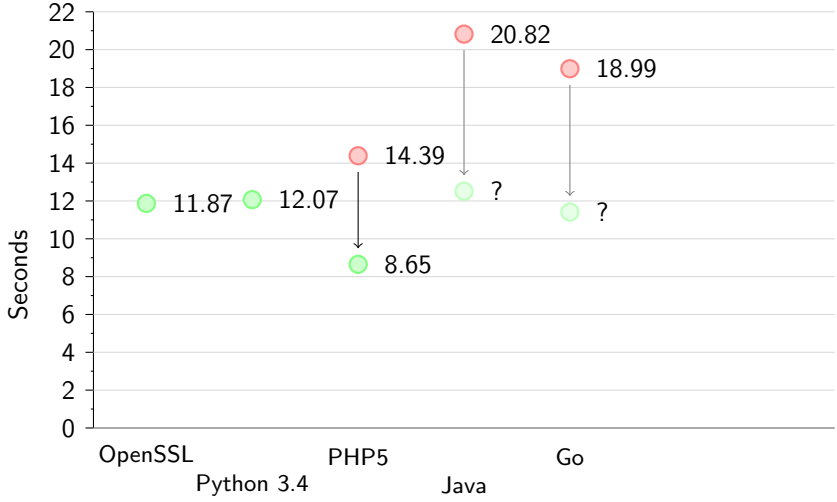

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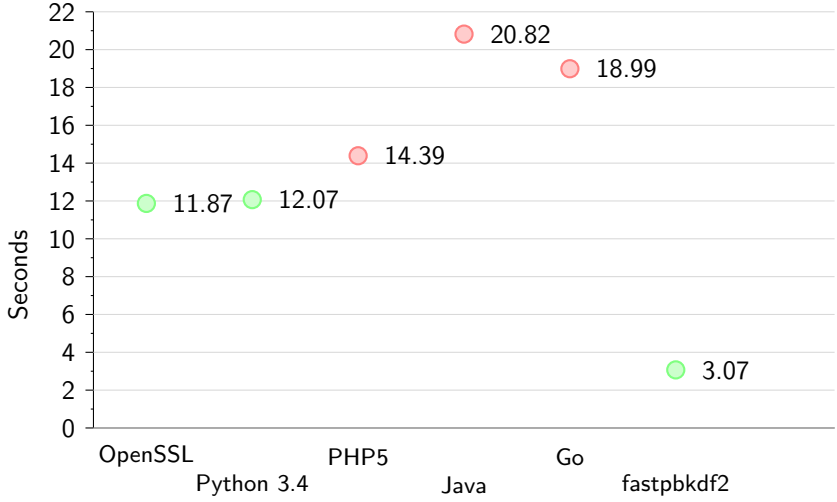

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- https://github.com/ctz/fastpbkdf2/

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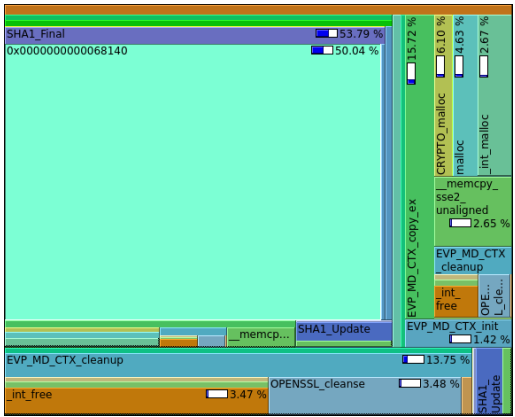

OpenSSL

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But, in any case, fastpbkdf2 optionally parallelises this.

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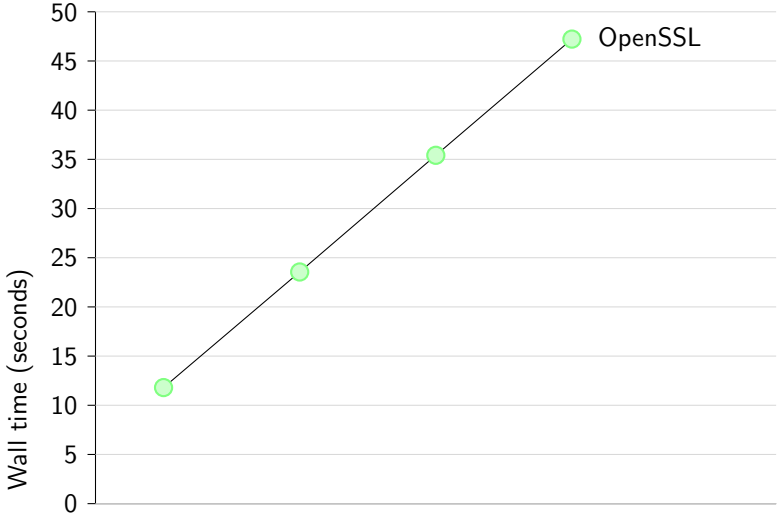

PBKDF2-HMAC-SHA1, one-four blocks output, 2^{22} iterations, two cores + HT

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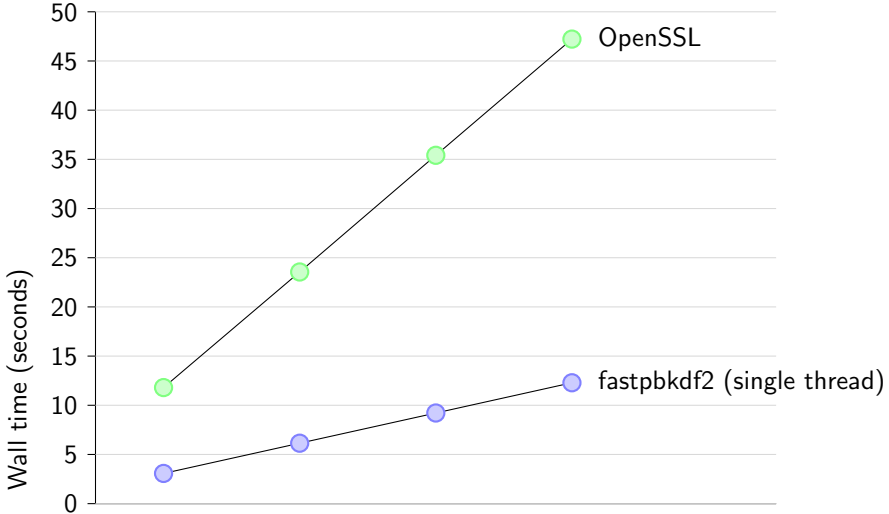

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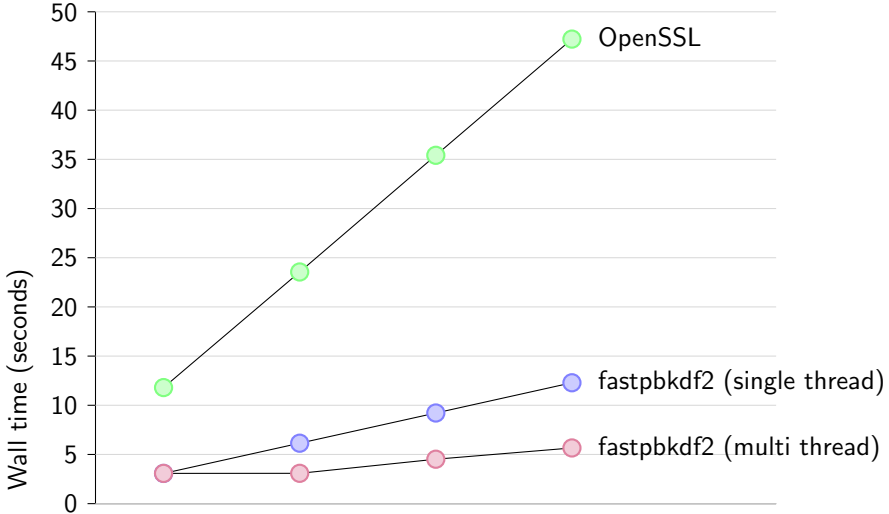

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- Most implementations waste time and power.
- If you use PBKDF2, you can probably drop in a faster implementation (and either increase security margin, or improve time/power performance.)

Thank you!

Questions?

Twitter: @jpixton
Mail: jbp@jbp.io
Web: https://jbp.io/
Slides and benchmarking code: https://github.com/ctz/talks/
fastpbkdf2 code: https://github.com/ctz/fastpbkdf2/