The security impact of a new cryptographic library

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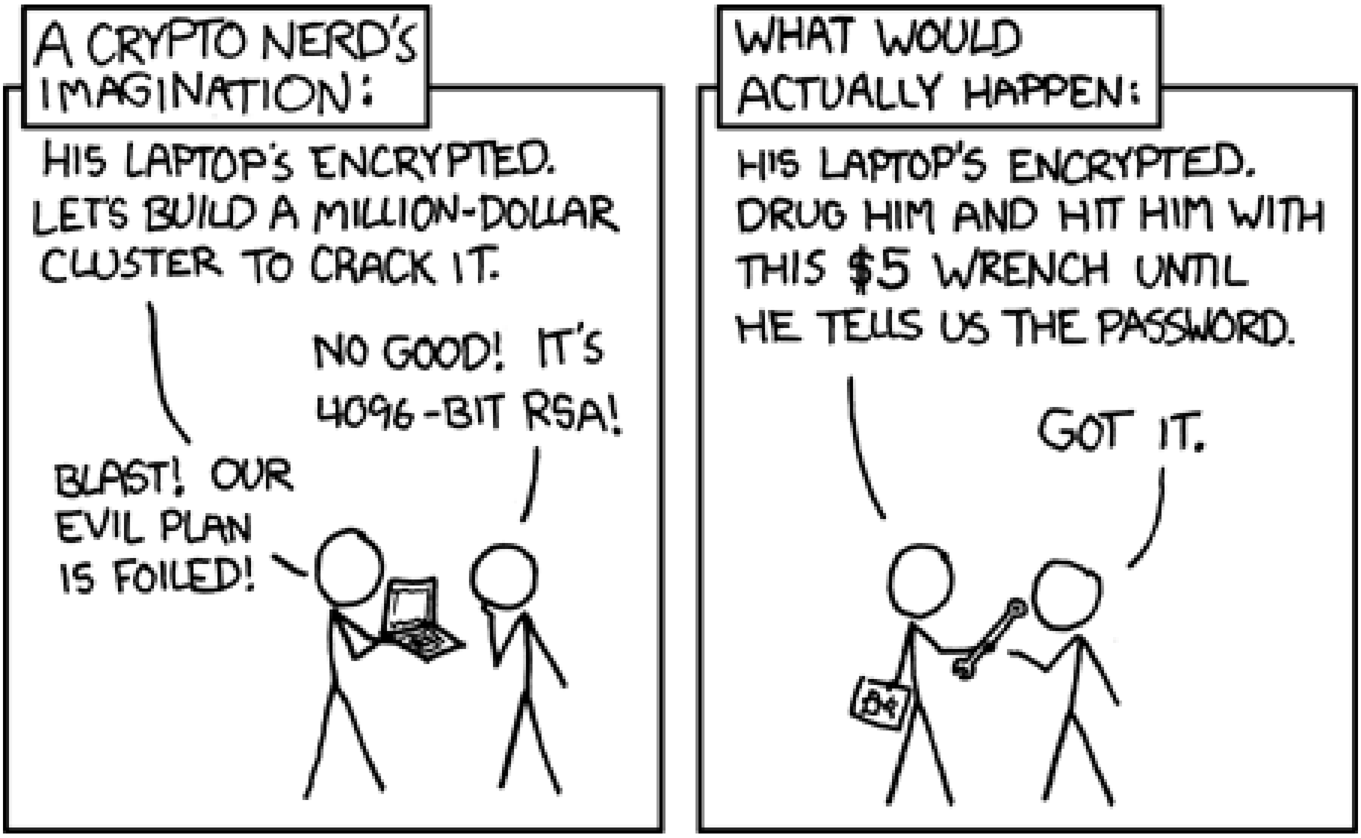

http://xkcd.com/538/

AES-128, RSA-2048, etc.
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Obviously infeasible to break
by best attacks in literature.

Implementations are available
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But cryptography is still
a disaster! Complete failures
of confidentiality and integrity.

We have designed+implemented a new cryptographic library, NaCl ("salt"), to address the underlying problems.

nacl.cace-project.eu, nacl.cr.yp.to: source and extensive documentation.

Acknowledgments:
code contributions from
Matthew Dempsky (Mochi Media), Niels Duif (Eindhoven), Emilia Käsper (Leuven), Adam Langley (Google), Bo-Yin Yang (Academia Sinica).

Most of the Internet
is cryptographically unprotected.
Primary goal of NaCl: Fix this.

Main task: **public-key authenticated encryption**.

Alice has a message m for Bob.

Uses Bob's public key and
Alice's secret key to compute
authenticated ciphertext c.
Sends c to Bob.

Bob uses Alice's public key
and Bob's secret key
to verify and recover m.

Alice using a
typical cryptographic library:

Generate random AES key.
Use AES key to encrypt packet.
Hash encrypted packet.
Read RSA key from wire format.
Use key to sign hash.
Read Bob's key from wire format.
Use key to encrypt signature etc.
Convert to wire format.

Plus more code:
allocate storage,
handle errors, etc.

Alice using NaCl:

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c = crypto_box(m,n,pk,sk)
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32-byte secret key `sk`.
32-byte public key `pk`.
24-byte nonce `n`.
`c` is 16 bytes longer than `m`.

All objects are C++ `std::string` variables represented in wire format, ready for storage/transmission.

C NaCl: similar, using pointers; no memory allocation, no failures.

Bob verifying, decrypting:

`m=crypto_box_open(c,n,pk,sk)`

Initial key generation:

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Can instead use **signatures**
for public messages:

`pk = crypto_sign_keypair(&sk)`

64-byte secret key,
32-byte public key.

`sm = crypto_sign(m,sk)`

64 bytes overhead.

`m = crypto_sign_open(sm,pk)`

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Examples of applications
using NaCl’s `crypto_box`:

DNSCurve and DNSCrypt,
high-security authenticated
encryption for DNS queries;
deployed by OpenDNS.

QuickTun, VPN from Ivo Smits.

Ethos, OS from Jon Solworth.

Prototype implementation
of CurveCP: high-security
cryptographic version of TCP.

No secret load addresses

2005 Osvik–Shamir–Tromer:
65ms to steal Linux AES key
used for hard-disk encryption.
Attack process on same CPU
but without privileges.

Almost all AES implementations
use fast lookup tables.
Kernel's secret AES key
influences table-load addresses,
influencing CPU cache state,
influencing measurable timings
of the attack process.
65ms to compute influence^{-1}.

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Not confidence-inspiring;
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NaCl systematically avoids *all* loads from addresses that depend on secret data. Eliminates this type of disaster.

2010 Langley `ctgrind`: verify this automatically.

No secret branch conditions

2011 Brumley–Tuveri:
minutes to steal another
machine's OpenSSL ECDSA key.
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variations in timing:
e.g., `memcmp` for IPsec MACs.

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No padding oracles

1998 Bleichenbacher:
Decrypt SSL RSA ciphertext
by observing server responses
to $\approx 10^6$ variants of ciphertext.

SSL first inverts RSA,
then checks for "PKCS padding"
(which many forgeries have).
Subsequent processing applies
more serious integrity checks.

Server responses reveal
pattern of PKCS forgeries;
pattern reveals plaintext.

Typical defense strategy: try to hide differences between padding checks and subsequent integrity checks.

Hard to get this right: see, e.g., Crypto 2012 Bardou–Focardi–Kawamoto–Steel–Tsay.

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NaCl does not decrypt
unless message is authenticated.
Verification procedure rejects
all forgeries in constant time.
Attacks are further constrained
by per-nonce key separation
and standard nonce handling.

Centralizing randomness

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NaCl uses `/dev/urandom`, the OS random-number generator. Reviewing this kernel code is much more tractable than reviewing separate RNG code in every security library.

Avoiding unnecessary randomness

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NaCl has *deterministic* `crypto_box` and `crypto_sign`. Randomness only for `keypair`. Eliminates this type of disaster.

Also simplifies testing. NaCl uses automated test battery from eBACS (ECRYPT Benchmarking of Cryptographic Systems).

Avoiding pure crypto failures

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Fact: By 1996, a few years after the introduction of MD5, Preneel and Dobbertin were calling for MD5 to be scrapped.

NaCl *pays attention to cryptanalysis* and makes very conservative choices of cryptographic primitives.

Speed

Crypto performance problems often lead users to reduce cryptographic security levels or give up on cryptography.

Example 1:
Google SSL uses RSA-1024.

Security note:
Analyses in 2003 concluded that RSA-1024 was breakable; e.g., 2003 Shamir–Tromer estimated 1 year, $\approx 10^7$ USD.
RSA Labs and NIST response:
Move to RSA-2048 by 2010.

Example 2: Tor uses RSA-1024.

Example 3: DNSSEC uses RSA-1024: “tradeoff between the risk of key compromise and performance. . . ”

Example 4: OpenSSL continues to use secret AES load addresses.

Example 5: `https://sourceforge.net/account` is protected by SSL but `https://sourceforge.net/develop` redirects browser to `http://sourceforge.net/develop`, turning off the cryptography.

NaCl has no low-security options.

e.g. `crypto_box` always
encrypts *and* authenticates.

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Remaining risk:
Users find NaCl too slow $\Rightarrow$
switch to low-security libraries
or disable crypto entirely.

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How NaCl avoids this risk:
NaCl is exceptionally fast.
Much faster than other libraries.
Keeps up with the network.

NaCl operations per second for any common packet size, using AMD Phenom II X6 1100T CPU ($190 last year):

`crypto_box`: $>$80000.

`crypto_box_open`: $>$80000.

`crypto_sign_open`: $>$70000.

`crypto_sign`: $>$180000.

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Handles arbitrary packet floods up to $\approx$30 Mbps per CPU, depending on protocol details.

But wait, it's even faster!

1. Pure secret-key crypto
for any packet size:
80000 1500-byte packets/second
fill up a 1 Gbps link.

2. Pure secret-key crypto
for many packets
from same public key,
if application splits
`crypto_box` into
`crypto_box_beforenm` and
`crypto_box_afternm`.

3. Very fast rejection
of forged packets
under known public keys:
no time spent on decryption.

(This doesn't help much
for forgeries under *new* keys,
but flooded server can
continue providing fast service
to *known* keys.)

4. Fast batch verification,
doubling speed of
`crypto_sign_open`
for valid signatures.

Cryptographic details

The main work we did:
achieve these speeds
without compromising security.

ECC, not RSA:
much stronger security record.
Curve25519, not NSA/NIST
curves: twist-security et al.
Salsa20, not AES:
much larger security margin.
Poly1305, not HMAC:
information-theoretic security.
EdDSA, not ECDSA:
collision-resilience et al.

Case study: EdDSA

1985 ElGamal signatures:
(R, S) is signature of M
if $B^{H(M)} \equiv A^R R^S \pmod{q}$
and $R, S \in \{0, 1, \ldots, q-2\}$.

Here q is standard prime,
B is standard base,
A is signer's public key,
$H(M)$ is hash of message.

Signer generates A and R
as secret powers of B;
easily solves for S.

1990 Schnorr improvements:

1. Hash R in the exponent:
$B^{H(M)} \equiv A^{H(R)} R^S$.
Reduces attacker control.

2. Replace three exponents with two exponents:
$B^{H(M)/H(R)} \equiv A R^{S/H(R)}$.
Saves time in verification.

3. Simplify by relabeling S:
$B^{H(M)/H(R)} \equiv A R^S$.
Saves time in verification.

4. Merge the hashes:
$B^{H(R,M)} \equiv A R^S$.
⇒ Resilient to H collisions.

5. Eliminate inversions for signer: $B^S \equiv RA^{H(R,M)}$.

Simpler, faster.

6. Compress R to $H(R, M)$.

Saves space in signatures.

7. Use half-size H output.

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Patent expired in 2008.

EdDSA (CHES 2011 Bernstein–Duif–Lange–Schwabe–Yang):

Use elliptic curves in “complete -1-twisted Edwards” form.
$\Rightarrow$ very high speed,
natural side-channel protection,
no exceptional cases.

Skip signature compression.
Support batch verification.

Use double-size H output,
and include A as input.

Generate R deterministically
as a secret hash of M.
$\Rightarrow$ Avoid PlayStation disaster.

Advertisement: NEON crypto

(CHES 2012, to appear)

On 1GHz Cortex A8 core
(iPad 1, iPhone 4, etc.):

5.60 cycles/byte (1.4 Gbps),
2.30 cycles/byte (3.4 Gbps)
for Salsa20, Poly1305.

527102 cycles (1897/second),
624846 cycles (1600/second),
244655 cycles (4087/second)
for Curve25519 public-key
operations: DH, verify, sign.

On 1.782GHz Qualcomm Scorpion (S3) core:

5.42 cycles/byte (2.6 Gbps),
1.89 cycles/byte (7.5 Gbps)
for Salsa20, Poly1305.

457371 cycles (3896/second),
587896 cycles (3031/second),
269656 cycles (6608/second)
for same public-key operations.

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We don't have any useful Snapdragon documentation, so we can't really optimize; and we don't have any Krait (S4) devices.