Crypto Code

The 9 circles of testing

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Everybody does it; it's just that nobody talks about it.

Why it’s hard

You need to know crypto and software

Methodologies aren’t documented

Tools aren’t always available

Street cred

Wrote and reviewed some crypto code

Like code for millions unpatchable devices

Made many mistakes

Tested many tests

What do we want?

Functional testing & security testing

Functional testing

Valid inputs give valid output

Invalid inputs trigger appropriate errors

Goal: test all execution paths

Security testing

Program can’t be abused

Doesn’t leak secrets

Overlaps with functional testing

What we’re testing

Code against code or against specs

Usually C code, which doesn’t help

Code against code

Easiest case

When porting to a new language/platform

You'll assume that the ref code is correct (Though it's probably not)

Can generate all test vectors you want

Code against specs

Often occurs with standards (ex: SHA-3)

Only a handful of test vectors, if any

Specs can be incomplete or incorrect

Try to have 2 independent implementers

The 9 circles

From most basic to most sophisticated

You may not need all of those

The “what” more than the ”how”

I probably missed important points

1. Test vectors

Unit-test ciphers, hashes, parsers, etc.

Maximize code coverage by varying inputs lengths and values

Make coherence tests, as in BRUTUS
https://github.com/mjosaarinen/brutus

To avoid storing thousands values, record only a checksum (as in SUPERCOP)

1. Test vectors

Against specs, test vectors less useful

Bug in BLAKE ref code unnoticed for 7 years

```
/* compress remaining data filled with new bits */
-  if( left && ( ((databitlen >> 3) & 0x3F) >= fill ) ) {
+  if( left && ( ((databitlen >> 3) ) >= fill ) ) {
     memcpy( (void *) (state->data32 + left),
    (void *) data, fill );
```

Found by a careful user (thanks!)

```
/* key schedule */
if ( block_key( e1, k1 ) ) return "block_key returns nonzero";

for ( j = 0; j < klen + 16; ++j )
  if ( k1[j] != k2[j] ) return "block_key writes to input";

for ( j = elen; j < elen + 16; ++j )
  if ( e1[j] != e2[j] ) return "block_key writes after output";

if ( block_key( e2, k2 ) ) return "block_key returns nonzero";

for ( j = 0; j < elen; ++j ) if ( e2[j] != e1[j] ) return "block_key produces different keys";

/* encrypt and check for errors */
if ( block_enc( c1, m1, e1 ) ) return "block_enc returns nonzero";

for ( j = 0; j < mlen + 16; ++j )    if ( m2[j] != m1[j] ) return "block_enc writes to input";

for ( j = mlen; j < mlen + 16; ++j ) if ( c2[j] != c1[j] ) return "block_enc writes after output";

for ( j = 0; j < elen + 16; ++j )    if ( e2[j] != e1[j] ) return "block_enc writes to key";

if ( block_enc( c2, m2, e2 ) ) return "block_enc returns nonzero";

for ( j = 0; j < mlen; ++j ) if ( c2[j] != c1[j] ) return "block_enc produces different ciphertexts";

/* check enc overlap support */
if ( block_enc( m2, m2, e2 ) ) return "block_enc returns nonzero";

for ( j = 0; j < mlen; ++j ) if ( m2[j] != c1[j] ) return "block_enc does not handle overlap";

/* check dec soundness and overlap support */
if ( block_dec( m2, c1, e1 ) ) return "block_dec returns nonzero";

for ( j = 0; j < mlen; ++j ) if ( m2[j] != m1[j] ) return "block_dec decrypts incorrectly";

for ( j = 0; j < mlen + 16; ++j )    if ( c2[j] != c1[j] ) return "block_dec writes to input";
```

2. Basic software tests

Against memory corruption, leaks, etc.

Secure coding very basics

Static analyzers (Coverity, PREfast, etc.)

Valgrind, Clang sanitizers, etc.

Dumb fuzzing (afl-fuzz, etc.)

2. Basic software tests

Most frequent, can find high impact bugs (Heartbleed, gotofail)

```
Qualys Security Advisory

LibreSSL (CVE-2015-5333 and CVE-2015-5334)


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Contents
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Summary
Memory Leak (CVE-2015-5333)
Buffer Overflow (CVE-2015-5334)
```

http://www.openwall.com/lists/oss-security/2015/10/16/1

3. Invalid use

Test that it triggers the expected error

Invalid values, malformed input, etc.

For length parameters, parsers

3. Invalid use

Argon2 omitted a parameter range check:

```
/* Validate memory cost */
    if (ARGON2_MIN_MEMORY > context->m_cost) {
        return ARGON2_MEMORY_TOO_LITTLE;
    }

+    if (context->m_cost < 8*context->lanes) {
+        return ARGON2_MEMORY_TOO_LITTLE;
+    }
+
```

4. Optional features

Don’t forget features buried under #ifdefs

In OpenSSL’s DES optional weak key check

```
Last Thursday it was reported to the openssl-dev mailing list by Ben Kaduk
that there was a defect in this optional code: it had a syntax error and
didn't even compile.  It had a typo of "!!" instead of "||":
     if (DES_set_key_checked(&deskey[0], &data(ctx)->ks1)
         !! DES_set_key_checked(&deskey[1], &data(ctx)->ks2))

The LibreSSL response?  The #ifdefs and code in them have been deleted.

The OpenSSL response?  The code... that in 11 years had never been used...
for a deprecated cipher... was *fixed* on Saturday, retaining the #ifdefs
```

http://marc.info/?l=openbsd-tech&m=144472550016118

5. Randomness

Hard to catch bugs

Statistical tests are a bare minimum

Ensure distinct outputs across reboots

And across devices (see mining p’s & q’s)

5. Randomness

A classic: Debian's PRNG bug (2008)

```
/* DO NOT REMOVE THE FOLLOWING CALL TO MD_Update()! */
if (!MD_Update(m, buf, j))
    goto err;
/*
 * We know that line may cause programs such as purify and valgrind
 * to complain about use of uninitialized data.  The problem is not,
 * it's with the caller.  Removing that line will make sure you get
 * really bad randomness and thereby other problems such as very
 * insecure keys.
 */
```

OpenSSH keys ended up with 15-bit entropy

6. Timing leaks

When execution time depends on secrets

Avoid branchings, beware memcmp, etc.

Check the assembly, not just C source

Langley's ctgrind https://github.com/agl/ctgrind

https://github.com/veorq/misc/blob/master/ctgrind_valgrind-3.11.0.patch

See also openssl/include/internal/constant_time_locl.h

7. Fuzzing

Dumb fuzzing for exploring parameters' space, parsed formats, bignum arithmetic

CVE-2015-3193 in OpenSSL's BN_mod_exp

CVE-2016-1938 in NSS' mp_div/_exptmod

Integer overflow in Argon2
https://github.com/P-H-C/phc-winner-argon2/issues/5

7. Fuzzing

Smart fuzzing, designed for specific APIs

What Cryptosense is doing for PKCS#11

More for high-level protocols than algorithms

8. Verification

Mathematically proven correctness

Cryptol language http://cryptol.net/ http://galois.com/
+ SAW to extract models from LLVM, Java

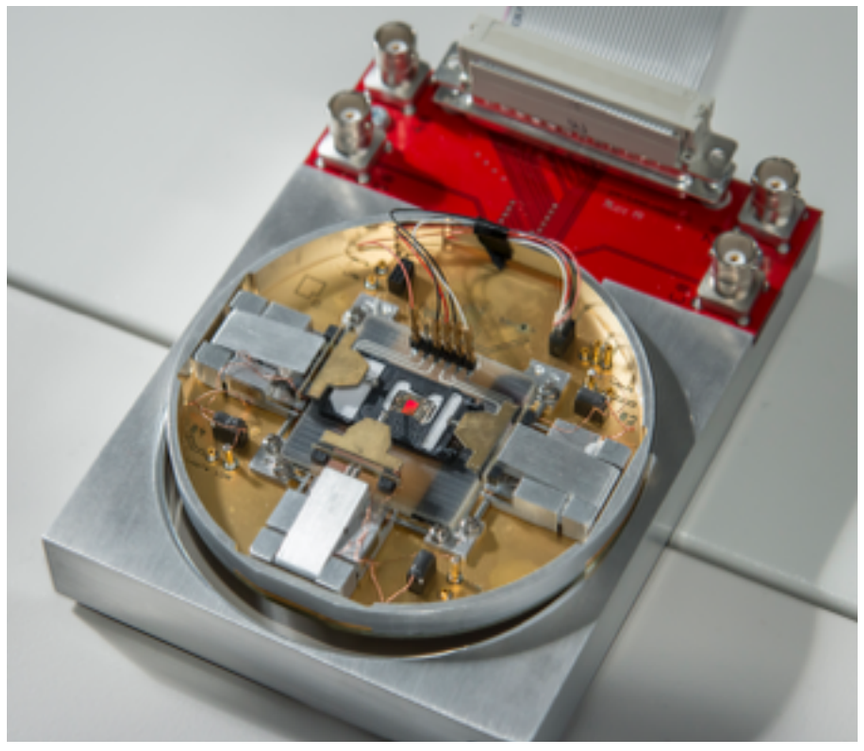
INRIA's verified TLS https://mitls.org/

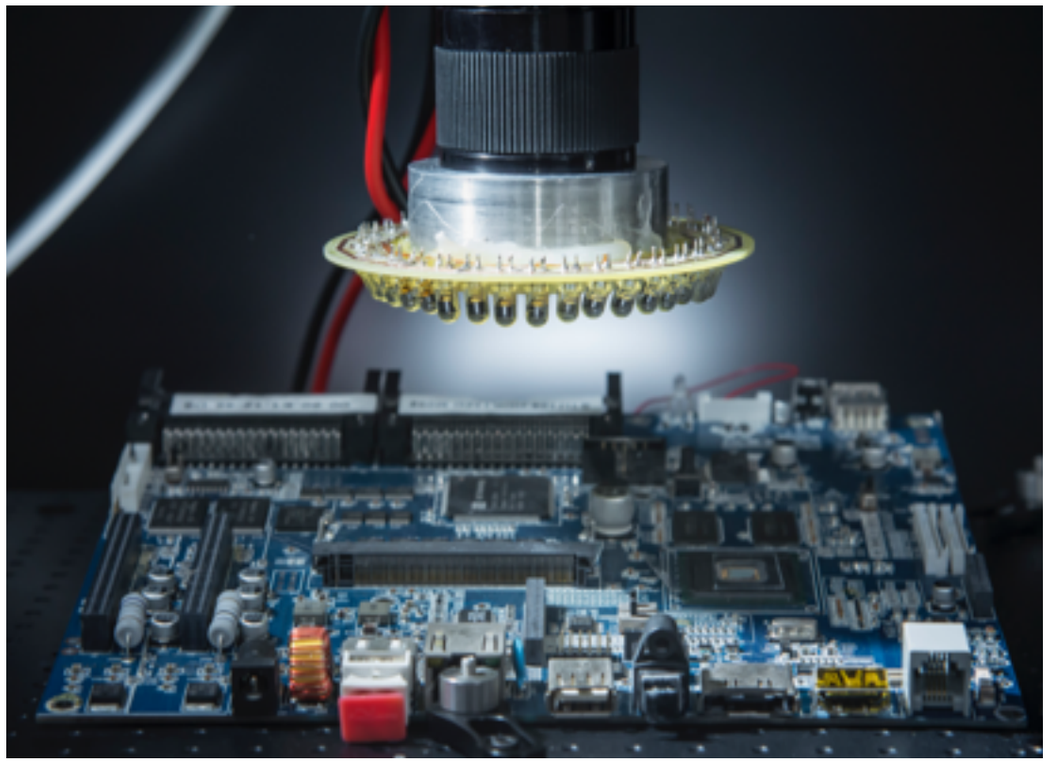
Verified security: LangSec?

9. Physical testing

Test for side channels, fault resilience

As applied to smart cards or game consoles





Conclusions

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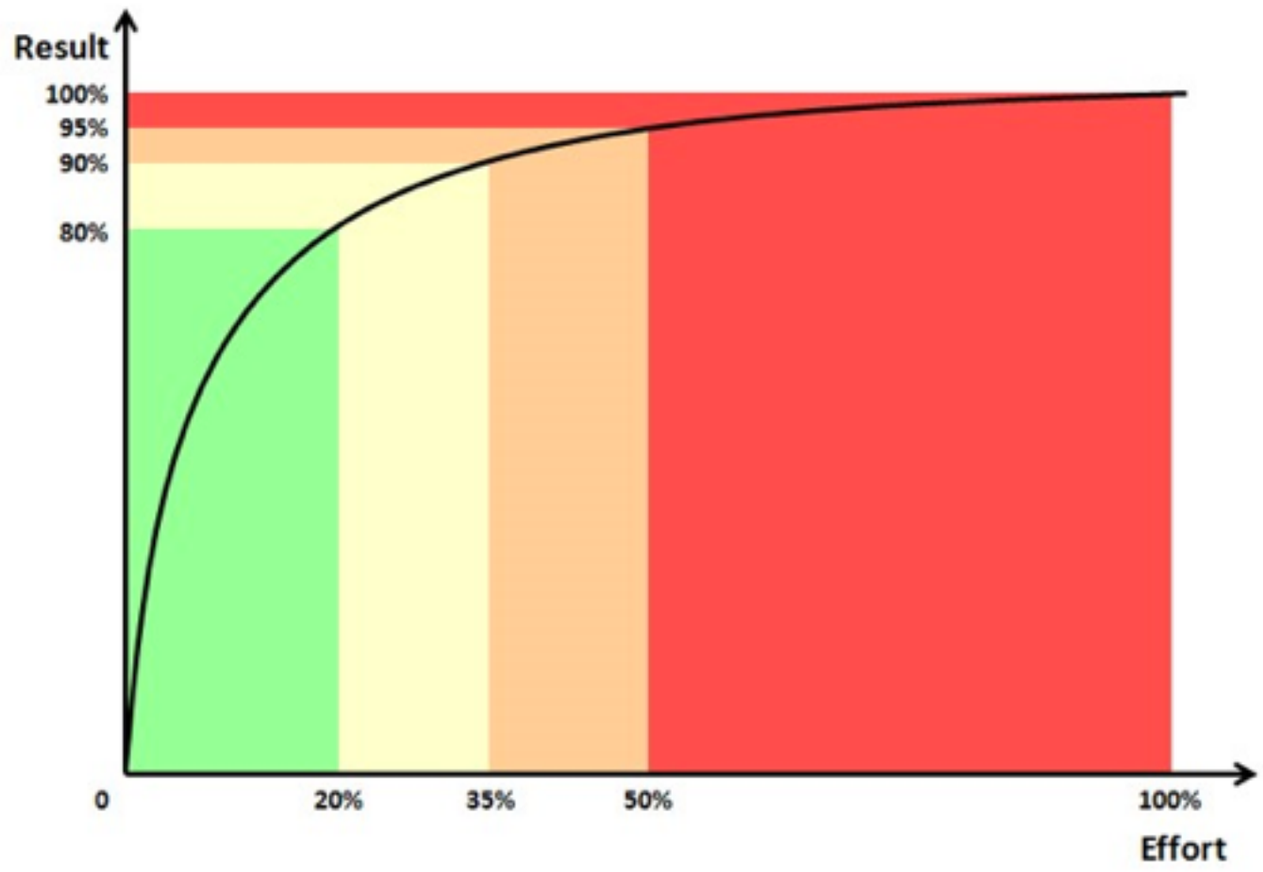
Pareto: test vectors will spot most bugs

But bugs on the (fat) tail can be critical



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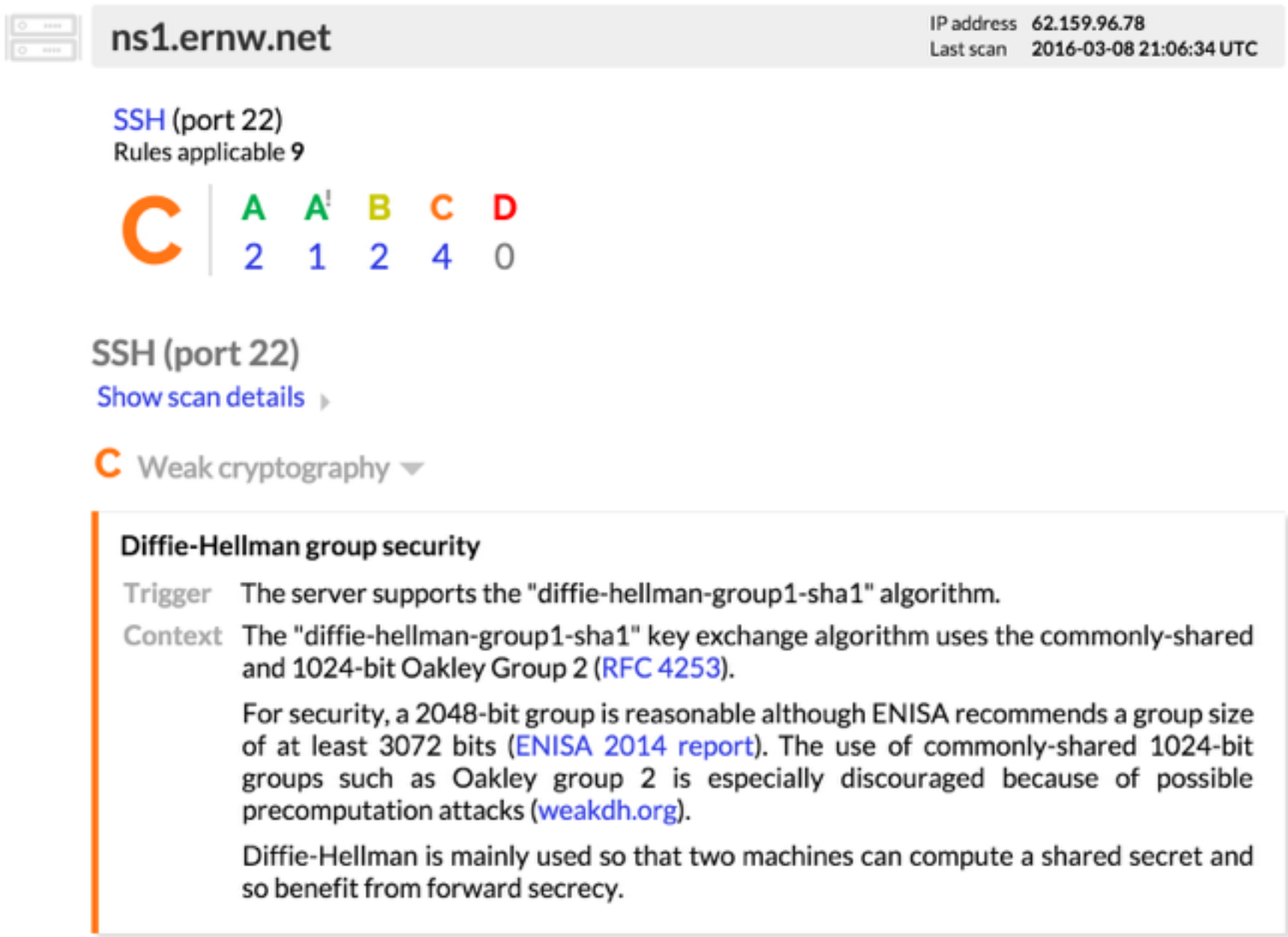

https://discovery.cryptosense.com/analyze/troopers.de/d4c7579

Conclusions

First do basic automated tests

Machine don’t replace human review though

Few capable people/companies for crypto

Make your code/APIs test/review-friendly

See coding rules on https://cryptocoding.net

Thanks!