cryptocoding v2

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academic background (EPFL crypto PhD)

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applied crypto research and outreach

BLAKE, BLAKE2, SipHash, NORX

Crypto Coding Standard

Password Hashing Competition

Open Crypto Audit Project board member
buffer = OPENSSL_malloc(1 + 2 + payload + padding);
bp = buffer;
*bp++ = TLS1_HB_RESPONSE;
s2n(payload, bp);
memcpy(bp, pl, payload);
r = ssl3_write_bytes(s, TLS1_RT_HEARTBEAT, buffer, \
    3 + payload + padding);
bugs are bad
software crashes, incorrect output, etc.
crypto bugs are really bad
leak of private keys, secret documents, past and future communications, etc.
crypto bugs are really bad
leak of private keys, secret documents, past and future communications, etc.

(ok, not as bad as root RCE exploits...)
threats to individuals’ privacy, sometimes lives organizations’ strategies, IP, etc.
hashOut.data = hashes + SSL_MD5_DIGEST_LEN;
hashOut.length = SSL_SHA1_DIGEST_LEN;
if ((err = SSLFreeBuffer(&hashCtx)) != 0)
    goto fail;
if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
    goto fail;
if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
    goto fail;
if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
    goto fail;

err = sslRawVerify(ctx,
    ctx->peerPubKey,  
    dataToSign, 
    dataToSignLen, 
    signature, 
    signatureLen); /* plaintext */
                        /* plaintext length */

if(err) {
    sslErrorLog("SSLDecodeSignedServerKeyExchange: sslRawVerify "
                "returned %d\n", (int)err);
    goto fail;
}
}
Heartbleed, gotofail: “silly bugs” by “experts”
not pure "crypto bugs", but bugs in the crypto
missing bound check
unconditional goto
"But we have static analyzers!"
not detected
(in part due to OpenSSL's complexity)
detected

(like plenty of other unreachable code)
crypto bugs (and bugs in crypto) vs "standard" security bugs:

less understood
fewer experts
fewer tools
everybody uses OpenSSL, Apple sometimes, some read the code

many more bugs in code that noone reads
Agenda

1. the poster child: OpenSSL
2. secure crypto coding guidelines
3. conclusion
"OpenSSL s*****"?
AIM HIGH

What's the worst that could happen?
ASN.1 parsing, CA/CRL management
crypto: RSA, DSA, DH*, ECDH*; AES,
CAMELLIA, CAST, DES, IDEA, RC2, RC4,
RC5; MD2, MD5, RIPEMD160, SHA*; SRP,
CCM, GCM, HMAC, GOST*, PKCS*,
PRNG, password hashing, S/MIME
X.509 certificate management, timestamping
some crypto accelerators, hardware tokens
clients and servers for SSL2, SSL3, TLS1.0,
TLS1.1, TLS1.2, DTLS1.0, DTLS1.2
SNI, session tickets, etc. etc.
*nix
BeOS
DOS
HP-UX
Mac OS Classic
NetWare
OpenVMS
ULTRIX
VxWorks
Win* (including 16-bit, CE)
OpenSSL is the space shuttle of crypto libraries. It will get you to space, provided you have a team of people to push the ten thousand buttons required to do so.

— Matthew Green
I promise nothing complete; because any human thing supposed to be complete, must not for that very reason infallibly be faulty.

— Herman Melville, in Moby Dick
OpenSSL code
buffer = OPENSSL_malloc(1 + 2 + payload + padding);
bp = buffer;
*bp++ = TLS1_HB_RESPONSE;
   payload, bp);
memcpy(bp, pl, payload);
r = ssl3_write_bytes(s, TLS1_RT_HEARTBEAT, buffer, \ 3 + payload + padding);

*payload is not the payload but its length (pl is the payload)
/* BIG UGLY WARNING! This is so damn ugly I wanna puke ... ARGH! ARGH! ARGH! Let's get rid of this macro package. Please? */

/* HAS BUGS! DON'T USE - this is only present for use in des.c */
void DES_3cbc_encrypt(...)

"user_pwd = NULL; /* abandon responsability

/* FIXME: the cast of the function seems unlikely to be a good idea */
(void)BIO_set_info_callback(dbio, (bio_info_cb *)data->info_callback)
1. Is OpenSSL thread-safe?

Yes (with limitations: an SSL connection may not concurrently be used by and many Unix systems, OpenSSL automatically uses the multi-threaded version your platform is not one of these, consult the INSTALL file.

in the RNG:

/* may compete with other threads */
state[st_idx++] ^= local_md[i];

(crypto/rand/md_rand.c)
RFC 5246: TLS 1.2

1. Generate a string $R$ of 46 random bytes

2. Decrypt the message to recover the plaintext $M$

3. If the PKCS#1 padding is not correct, or the length of message $M$ is not exactly 48 bytes:
   - Set $\text{pre-master-secret} = $ ClientHello.client_version || $R$
   - Else if ClientHello.client_version <= TLS 1.0, and version number check is explicitly disabled:
     - $\text{pre-master-secret} = M$
   - Else:
     - $\text{pre-master-secret} = $ ClientHello.client_version || $M[2..47]$

OpenSSL 1.0.1c

```c
i = RSA_private_decrypt((int)n, p, rsa, RSA_PKCS1_PADDING);
```

```c
al = -1;

if (al != -1)
{
    /* Some decryption failure -- use random value instead as countermeasure
       * against Bleichenbacher's attack on PKCS #1 v1.5 RSA padding
       * (see RFC 2246, section 7.4.7.1). */
    ERR_clear_error();
    i = SSL_MAX_MASTER_KEY_LENGTH;
    p[0] = s->client_version >> 8;
    p[1] = s->client_version & 0xff;
    if (RAND_pseudo_bytes(p+2, i-2) <= 0)
        /* should be RAND_bytes, but we cannot work around a failure */
        goto err;
}

s->session->master_key_length=
    s->method->ssl3_enc->generate_master_secret(s,
        s->session->master_key,
        p, i);
```
I TOLD YOU SO!

I have been getting a ton of requests to make more comments so here goes. I told you so, la la la, I told you so!

Joking aside, this is the worst security bug I have ever dealt with. Who knew that running crypto was worse than not running it at all? This is NOT the last catastrophic bug lurking in this code. Buyer beware, this will happen again. I was in NYC when the Internet went into full meltdown and could not respond earlier. Once things calm down I might do another round of pointing out amazing things I ran across in OpenSSL. There is no end to the amount of awe when reading through that code. For now, enjoy the old rant that is going around the tubes, again.

OpenSSL is written by monkeys

ranting about OpenSSL is easy
we should not blame the devs
let's try to understand..
So, Why did "We" the community let OpenSSL happen..

Nobody Looked.

Or nobody admitted they looked.

I am Jon Snow

and I know nothing.

http://www.openbsd.org/papers/bsdcan14-libressl/mgp00004.html

(slide credit: Bob Beck, OpenBSD project)
OpenSSL prioritizes speed, portability, functionalities at the price of "best efforts" and "dirty tricks"...
/* Quick and dirty OCSP server: read in and parse input request */

/* Quick, cheap and dirty way to discard any device and directory */

/* kind of dirty hack for Sun Studio */

#ifndef STD_ERROR_HANDLE /* what a dirty trick! */

/* Dirty trick: read in the ASN1 data into a STACK_OF (ASN1_TYPE): */
of lesser priority
usability
security
consistency
robustness
OpenSSL Security Policy

Last modified 7th September 2014

Introduction

Recent flaws have captured the attention of the media and highlighted how much of the internet infrastructure is based on OpenSSL. We've never published our policy on how we internally handle security issues; that process being based on experience and has evolved over the years.

Reporting security issues

We have an email address which can be used to notify us of possible security vulnerabilities. A subset of OpenSSL team members receive this mail, and messages can be sent using PGP encryption. Full details are at https://www.openssl.org/news/vulnerabilities.html

Internal handling of security issues

This leads us to our policy for security issues notified to us or found by our team which are not yet public.

Prenotification policy

Where we are planning an update that fixes security issues we will notify the openssl-anonymous list via this page to give our scheduled update release date and time and the severity of issues, etc.
Who should design cryptographic libraries

In order to create a proper SSL/TLS implementation you need to be a master of:

- Cryptographic algorithms.
- Cryptographic practice.
- Software engineering.
- Software optimization.
- The language(s) used.
- Domain specific knowledge.

crypto by "real programmers" often yields cleaner code, but dubious choices of primitives and/or broken implementations (cf. messaging apps)
it's probably unrealistic to build a better secure/fast/usable/consistent/certified toolkit+lib in reasonable time

what are the alternatives?
really better? (maybe TLS itself is the problem?)

it’s not just OpenSSL, NSS too...

<table>
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<tr>
<th>#</th>
<th>CVE ID</th>
<th>CWE ID</th>
<th># of Exploits</th>
<th>Vulnerability Type(s)</th>
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<td>CVE-2014-1568</td>
<td>310</td>
<td></td>
<td></td>
<td>2014-09-25</td>
<td>2014-10-04</td>
<td>7.5</td>
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</tbody>
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|    | Mozilla Network Security Services (NSS) before 3.16.2.1, 3.16.x before 3.16.5, and 3.17.x before 3.17.1, as used in Mozilla Firefox before 32.1, Thunderbird before 24.8.1 and 31.x before 31.1.2, Mozilla SeaMonkey before 2.29.1, Google Chrome before 37.0.2062.124 on Windows and ASN.1 values in X.509 certificates, which makes it easier for remote attackers to spoof RSA signatures via a crafted certificate, aka a "signature forgery" vulnerability.

|    | Use-after-free vulnerability in the CERT_DestroyCertificate function in libnss3.so in Mozilla Network Security Services (NSS) 3.x, as used in Firefox allows remote attackers to execute arbitrary code via vectors that trigger certain improper removal of an NSSCertificate structure from a trusted store.

| 3  | CVE-2014-1492   | 20      |              |                       | 2014-03-25   | 2014-07-18   | 4.3   | None                |
|    | The cert_TestHostName function in lib/certdb/certdb.c in the certificate-checking implementation in Mozilla Network Security Services (NSS) allows internationalized domain name's U-label, which might allow man-in-the-middle attackers to spoof SSL servers via a crafted certificate.

| 4  | CVE-2014-1491   | 310    |              |                       | 2014-02-06   | 2014-07-18   | 5.0   | None                |
|    | Mozilla Network Security Services (NSS) before 3.15.4, as used in Mozilla Firefox before 27.0, Firefox ESR 24.x before 24.3, Thunderbird before 24.10.13, Mozilla SeaMonkey before 2.29.1, Google Chrome before 37.0.2062.124 on Windows and values in Diffie-Hellman key exchanges, which makes it easier for remote attackers to bypass cryptographic protection mechanisms in the SSL server.

| 5  | CVE-2014-1490   | 399    |              |                       | 2014-02-06   | 2014-07-18   | 5.0   | None                |
|    | Race condition in libssl in Mozilla Network Security Services (NSS) before 3.15.4, as used in Mozilla Firefox before 27.0, Firefox ESR 24.x before 24.3, Thunderbird before 24.10.13, Mozilla SeaMonkey before 2.29.1, Google Chrome before 37.0.2062.124 on Windows and values in Diffie-Hellman key exchanges, which makes it easier for remote attackers to bypass cryptographic protection mechanisms in the SSL server.

**MOZILLA PATCHES RSA SIGNATURE FORGERY IN FIREFOX, THUNDERBIRD, NSS**
let's just use closed-source code!

How Does Heartbleed Alter the 'Open Source Is Safer' Discussion?

Soulskill posted about a month ago | from the or-at-least-marginally-less-unsafe dept.

jammag writes:

"Heartbleed has dealt a blow to the image of free and open source software. In the self-mythology of FOSS, bugs like Heartbleed aren't supposed to happen when the source code is freely available and being worked with daily. As Eric Raymond famously said, 'given enough eyeballs, all bugs are shallow.' Many users of proprietary software, tired of FOSS's continual claims of superior security, welcome the idea that Heartbleed has punctured FOSS's pretensions. But is that what has happened?"
It’s not just OpenSSL, it’s not an open-source thing.

— Bob Beck
open- vs. closed-source software security:

- well-known debate
- no definite answer, depends on lots of factors; see summary on

for crypto, OSS has a better track record

- better assurance against "backdoors"
- flaws in closed-source can often be found in a "black-box" manner
What did we do? We gutted the junk. We started rewriting lots of functions. We added some cool new crypto support, for things like ChaCha20.


initiative of the OpenBSD community

big progress in little time

portable version and OpenBSD version

OpenSSL patches unlikely to directly apply

replacement API for OpenSSL “ressl” (WIP)
LibreSSL: still lot of work needed

Fork-unsafety on Linux in LibreSSL’s first release...

Consider a test program, `fork_rand`. When linked with OpenSSL, two different calls to `RAND_bytes` return different data, as expected:

```bash
$ cc -o fork_red fork_red.c -lcrypto
$ ./fork_red

Grandparent (PID = 2735) random bytes = f05a5e107f5ec880aadaead26cfff164e778bab8e5a44bdf5d
Grandchild (PID = 2735) random bytes = 03688e9834f1c020765c8c5ed2e7a50cdd324648ca36652523d
```

When the same program is linked with LibreSSL, two different calls to `RAND_bytes` return the same data, which is a catastrophic failure of the PRNG:

```bash
$ cc -o fork_red fork_red.c libressl-2.0.1/crypto/.libs/libcrypto.a -lrtc
$ ./fork_red

Grandparent (PID = 2728) random bytes = f5093dc49bc9527d6d8c3864be364368780ae1ed190ca0798bf
Grandchild (PID = 2728) random bytes = f5093dc49bc9527d6d8c3864be364368780ae1ed190ca0798bf
```

https://www.agwa.name/blog/post/libressls_prng_is_unsafe_on_linux
how to write secure crypto code?
write secure code!
The Power of Ten  
10 Rules for Writing Safety Critical Code

1. Restrict to simple control flow constructs.
2. Give all loops a fixed upper-bound.
3. Do not use dynamic memory allocation after initialization.
4. Limit functions to no more than 60 lines of text.
5. Use minimally two assertions per function on average.
6. Declare data objects at the smallest possible level of scope.
7. Check the return value of non-void functions, and check the validity of function parameters.
8. Limit the use of the preprocessor to file inclusion and simple macros.
9. Limit the use of pointers. Use no more than two levels of dereferencing per expression.
10. Compile with all warnings enabled, and use one or more source code analyzers.


http://spinroot.com/p10/
write secure crypto!

= 

defend against algorithmic attacks, timing attacks, "misuse" attacks, etc.
the best list I found: in NaCl [salt]

Branches

Do not use secret data to control a branch. In particular, do not use the memcmp function to compare secrets. Instead use crypto_verify_16, crypto_verify_32, etc., which perform constant-time string comparisons.

Even on architectures that support fast constant-time conditional-move instructions, always assume that a comparison in C is compiled into a branch, not a conditional move. Compilers can be remarkably stupid.

Array lookups

Do not use secret data as an array index.

Early plans for NaCl would have allowed exceptions to this rule inside primitives specifically labelled vulnerable, in particular to allow fast crypto_stream_aes128vulnerable, but subsequent research showed that this compromise was unnecessary.

Dynamic memory allocation

Do not use heap allocators (malloc, calloc, sbrk, etc.) or variable-size stack allocators (alloca, int x[n], etc.) in C NaCl.
so we tried to help
Welcome to the Cryptography Coding Standard homepage.

The Cryptography Coding Standard (CCS) is a set of coding rules to prevent the most common weaknesses in software cryptographic implementations. CCS was first presented and discussed at the Internet crypto workshop on Jan 23, 2013 (our slides are available).

The following pages are available:

- **Coding rules**: the list of coding rules, with for each rule a statement of the problem addressed or more proposed solutions
- **References**: a list of external references
- **FAQ**: the usual Q&As page

These pages can also be accessed with the navigation bar on the left.

https://cryptocoding.net

with help from Tanja Lange, Nick Mathewson, Samuel Neves, Diego F. Aranha, etc.
we tried to make the rules simple,
in a do-vs.-don’t style
secrets should be kept secret

= 

do not leak information on the secrets (timing, memory accesses, etc.)
compare strings in constant time

Microsoft C runtime library memcmp implementation:

EXTERN_C int __cdecl memcmp(const void *Ptr1, const void *Ptr2, size_t Count) {
    INT v = 0;
    BYTE *p1 = (BYTE *)Ptr1;
    BYTE *p2 = (BYTE *)Ptr2;

    while(Count-- > 0 && v == 0) {
        v = *(p1++) - *(p2++);
        /* execution time leaks the position of the first difference */
        /* may be exploited to forge MACs (cf. Google Keyczar’s bug) */
    }

    return v;
}
compare strings in constant time

Constant-time comparison function

```c
int util_cmp_const(const void * a, const void *b, const size_t size) {
    const unsigned char *_a = (const unsigned char *) a;
    const unsigned char *_b = (const unsigned char *) b;
    unsigned char result = 0;
    size_t i;
    for (i = 0; i < size; i++)
        result |= _a[i] ^ _b[i];
    /* returns 0 if equal, nonzero otherwise */
    return result;
}
```
avoid other potential timing leaks

make

● branchings
● loop bounds
● table lookups
● memory allocations

**independent** of secrets or user-supplied value
(private key, password, heartbeat payload, etc.)
prevent compiler interference with security-critical operations

Tor vs MS Visual C++ 2010 optimizations

int
crypto_pk_private_sign_digest(...) {
    char digest[DIGEST_LEN];
    (...) /* operations involving secret digest */
    memset(digest, 0, sizeof(digest));
    return r;
}

a solution: C11’s memset_s()
clean memory of secret data
(keys, round keys, internal states, etc.)

Data in stack or heap may leak through crash dumps, memory reuse, hibernate files, etc.

Windows’ SecureZeroMemory()
OpenSSL’s OPENSSL_cleanse()

```c
void burn( void *v, size_t n )
{
    volatile unsigned char *p = ( volatile unsigned char * )v;
    while( n-- ) *p++ = 0;
}
```
last but not least
RANDOMNESS

You never saw it coming.
Randomness everywhere
key generation and key agreement
symmetric encryption (CBC, etc.)
RSA OAEP, El Gamal, (EC)DSA
side-channel defenses
etc. etc.
Netscape, 1996: ~ 47-bit security thanks to

RNG.GenerateRandomBytes() {
    return (..) /* something that depends only on
    ● microseconds time
    ● PID and PPID */
}
Mediawiki, 2012: **32-bit** Mersenne Twister seed

```php
/**
 * Return a random password. Sourced from mt_rand, so it's not particularly secure.
 * @todo hash random numbers to improve security, like generateToken()
 *
 * @return string New random password
 */
static function randomPassword() {
    global $wgMinimalPasswordLength;
    $pwchars = 'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz';
    $l = strlen($pwchars) - 1;

    $pwlengt = max(7, $wgMinimalPasswordLength);
    $digit = mt_rand(0, $pwlengt - 1);
    $np = ''; 
    for ($i = 0; $i < $pwlengt; $i++) {
        $np .= $i == $digit ? chr(mt_rand(48,57)) : $pwchars[mt_rand(0,$l)];
    } 
    return $np;
}
```
*nix: /dev/urandom

example: get a random 32-bit integer

    int randint, bytes_read;
    int fd = open("/dev/urandom", O_RDONLY);
    if (fd != -1) {
        bytes_read = read(fd, &randint, sizeof(randint));
        if (bytes_read != sizeof(randint)) return -1;
    }
    else { return -2; }
    printf("%08x\n", randint);
    close(fd);
    return 0;

more checks needed to ensure sanity of urandom...
(see LibreSSL’s getentropy_urandom)
“but /dev/random is better! it blocks!”

/dev/random may do more harm than good to your application, since
- blockings may be mishandled
- /dev/urandom is safe on reasonable OS’
Linux is introducing a syscall..

SYNOPSIS

#include <linux/random.h>

int getrandom(void *buf, size_t buflen, unsigned int flags);

DESCRIPTION

The system call getrandom() fills the buffer pointed to by buf with up to buflen random bytes which can be used to seed user space random number generators (i.e., DRBG's) or for other cryptographic processes. It should not be used Monte Carlo simulations or for other probabilistic sampling applications.

http://lists.openwall.net/linux-kernel/2014/07/17/235
int randombytes(unsigned char *out, size_t outlen) {
  static HCRYPTPROV handle = 0;
  if(!handle) {
    if(!CryptAcquireContext(&handle, 0, 0, PROV_RSA_FULL,
                              CRYPT_VERIFYCONTEXT | CRYPT_SILENT))
      return -1;
  }
  while(outlen > 0) {
    const DWORD len = outlen > 1048576UL ? 1048576UL : outlen;
    if(!CryptGenRandom(handle, len, out)) { return -2; }
    out += len;
    outlen -= len;
  }
  return 0;
}
it’s possible to fail in many ways, and _appear_ to succeed in many ways

non-uniform sampling
no forward secrecy
randomness reuse
poor testing
etc.
Thou shalt:

1. compare secret strings in constant time
2. avoid branchings controlled by secret data
3. avoid table look-ups indexed by secret data
4. avoid secret-dependent loop bounds
5. prevent compiler interference with security-critical operations
6. prevent confusion between secure and insecure APIs
7. avoid mixing security and abstraction levels of cryptographic primitives in the same API layer
8. use unsigned bytes to represent binary data
9. use separate types for secret and non-secret information
10. use separate types for different types of information
11. clean memory of secret data
12. use strong randomness
Learn the rules like a pro, so you can break them like an artist.

— Pablo Picasso
conclusion
let’s stop the blame game
(OpenSSL, “developers”, “academics”, etc.)
cryptographers (and scientists, etc.)

- acknowledge that you suck at coding
- get help from real programmers

programmers

- acknowledge that you suck at crypto
- get help from real cryptographers

in any case: get third-party reviews/audits!
спасибо!