Some thoughts on SSL/TLS from a (nearly) 6-year PhD student

Olivier Levillain

ANSSI

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Who am I?

Olivier Levillain (`@pictyeye`)

- M2 internship in cryptography: study of a hash function
- member of the systems lab at ANSSI (2007-2012)
- head of the network lab at ANSSI (2012-2015)
- head of the training center (CFSSI) (2015-)

Research

- part of the low-level x86 security work (SMM/ACPI)
- PhD student working on SSL/TLS since 2011
- Participation to languages studies since 2007
- some work on binary *parsers*

Teaching

- cryptography: hash function and cryptanalysis
- systems module for the CFSSI
- courses on SSL/TLS, and more recently on secure development

ANSSI

ANSSI (French Network and Information Security Agency) has InfoSec (and no Intelligence) missions:

- detect and early react to cyber attacks
- prevent threats by supporting the development of trusted products and services
- provide reliable advice and support
- communicate on information security threats and the related means of protection

These missions concern:

- governmental entities
- companies
- the general public

TLS: a quick tour

SSL/TLS: an essential building block of Internet

- `https://` invented by Netscape in 1995
  - the beginning of the e-commerce
- Massive usage of SSL/TLS today
  - HTTPS, well beyond e-commerce websites
  - A way to secure other protocols (SMTP, IMAP, LDAP...)
  - SSL VPN
  - EAP TLS

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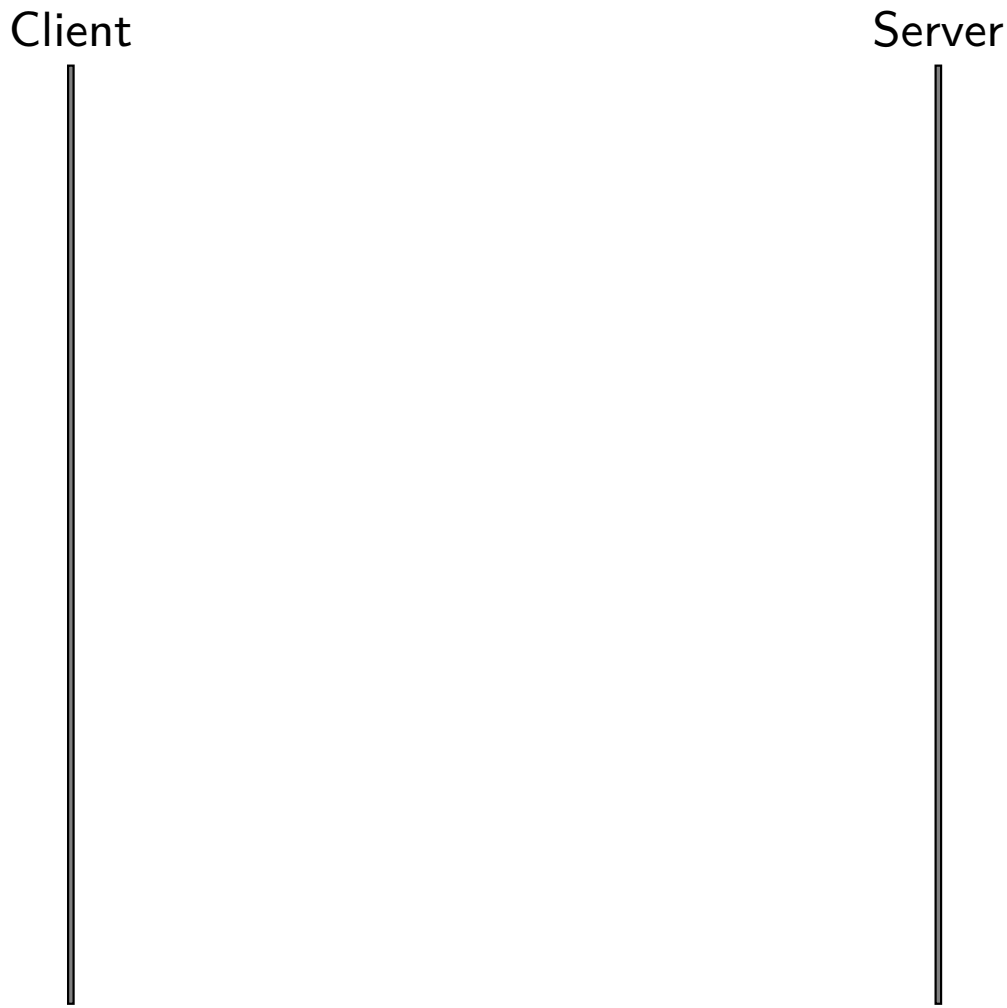
  - A way to secure other protocols (SMTP, IMAP, LDAP...)
  - SSL VPN
  - EAP TLS
- SSL (*Secure Sockets Layer*) or TLS (*Transport Layer Security*) ?
  - SSLv2 (1995) and v3 (1996) designed by Netscape
  - TLS 1.0 (2001) a.k.a. SSLv3.1, handled by IETF
  - New revisions since: 1.1 (2006), 1.2 (2008) and 1.3 (2016?)

Fonctionnement du protocole



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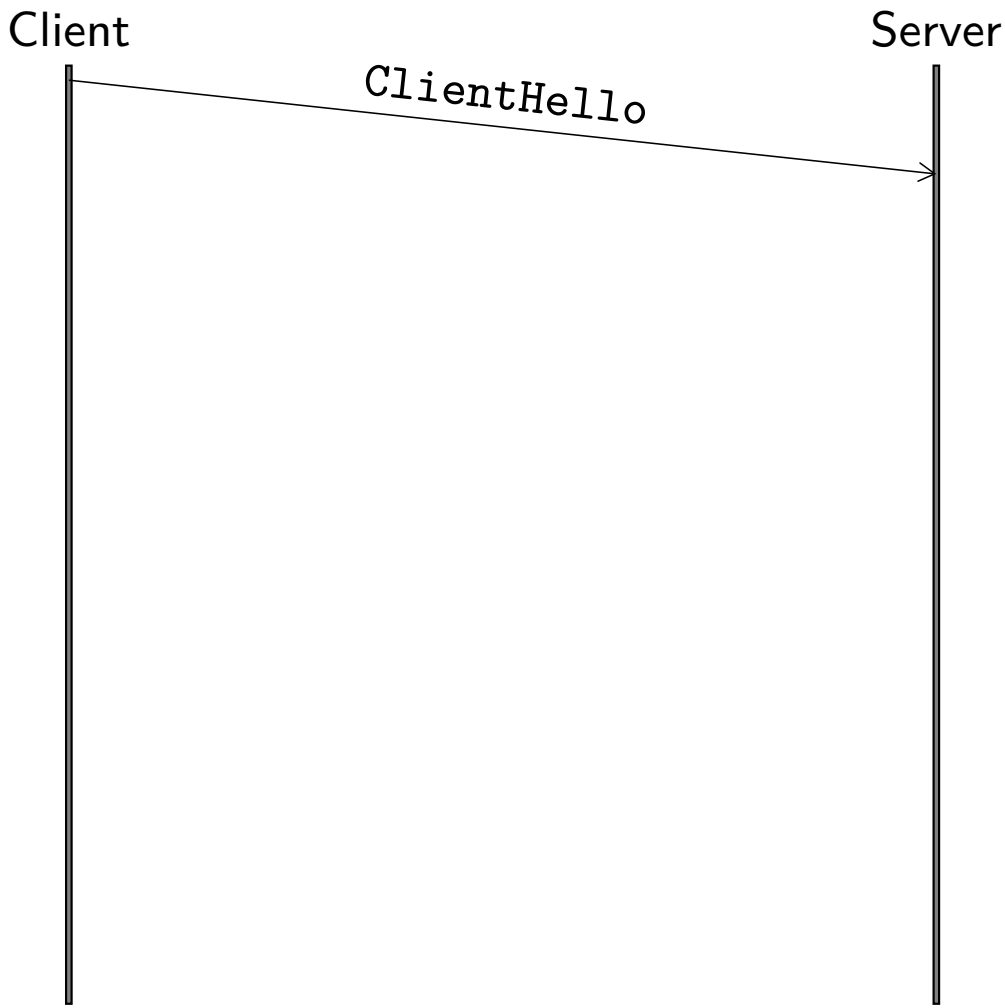

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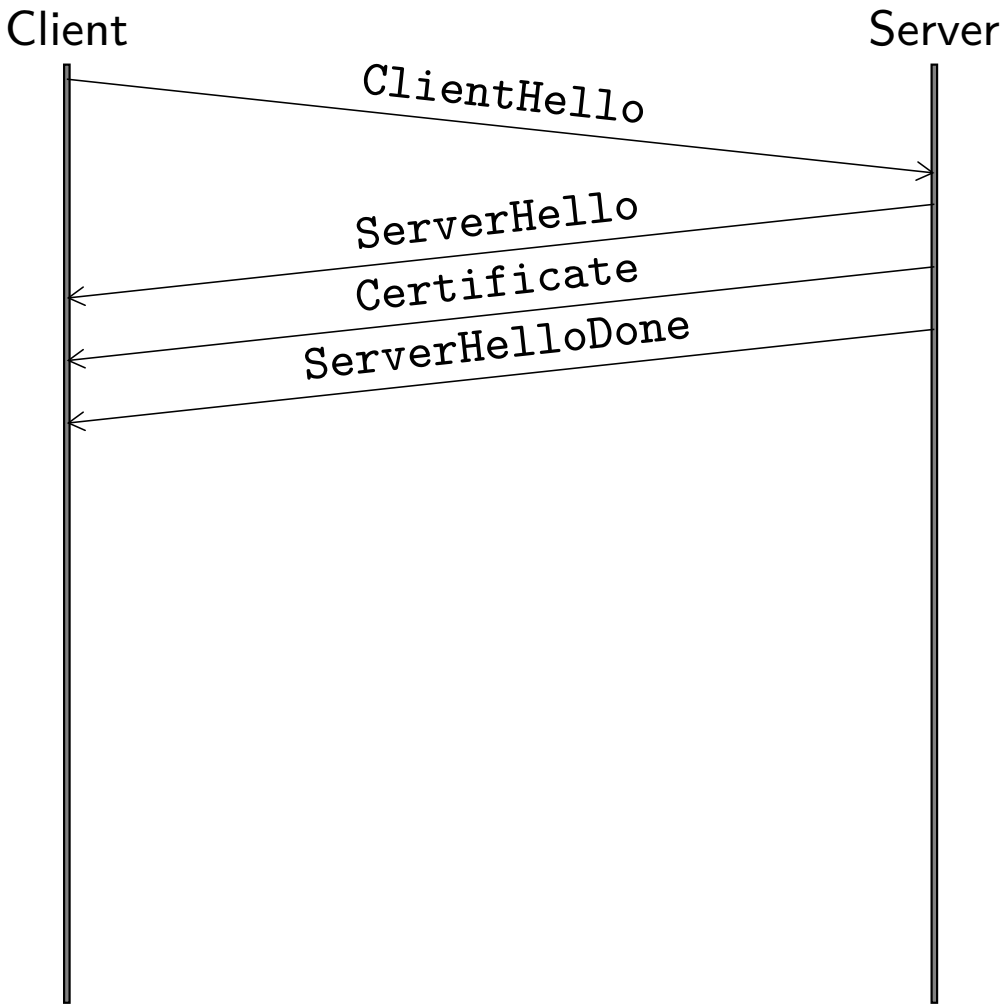

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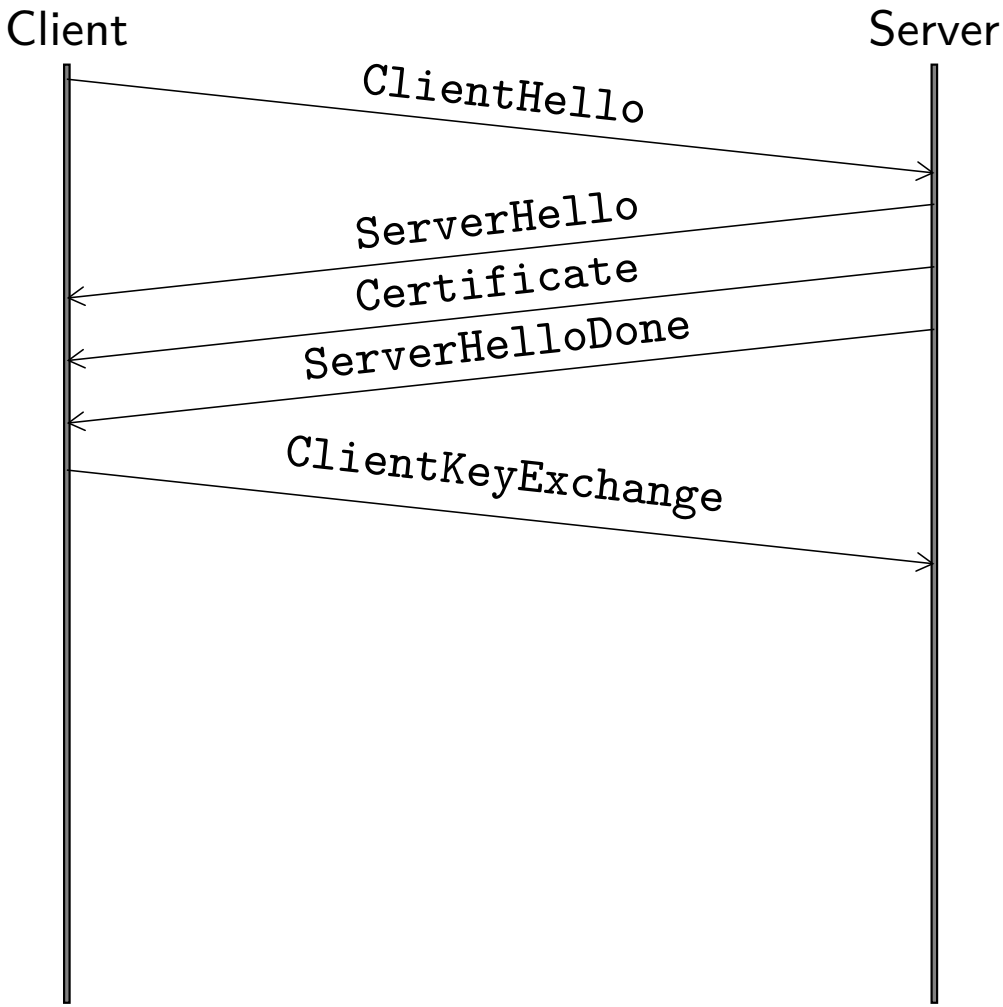

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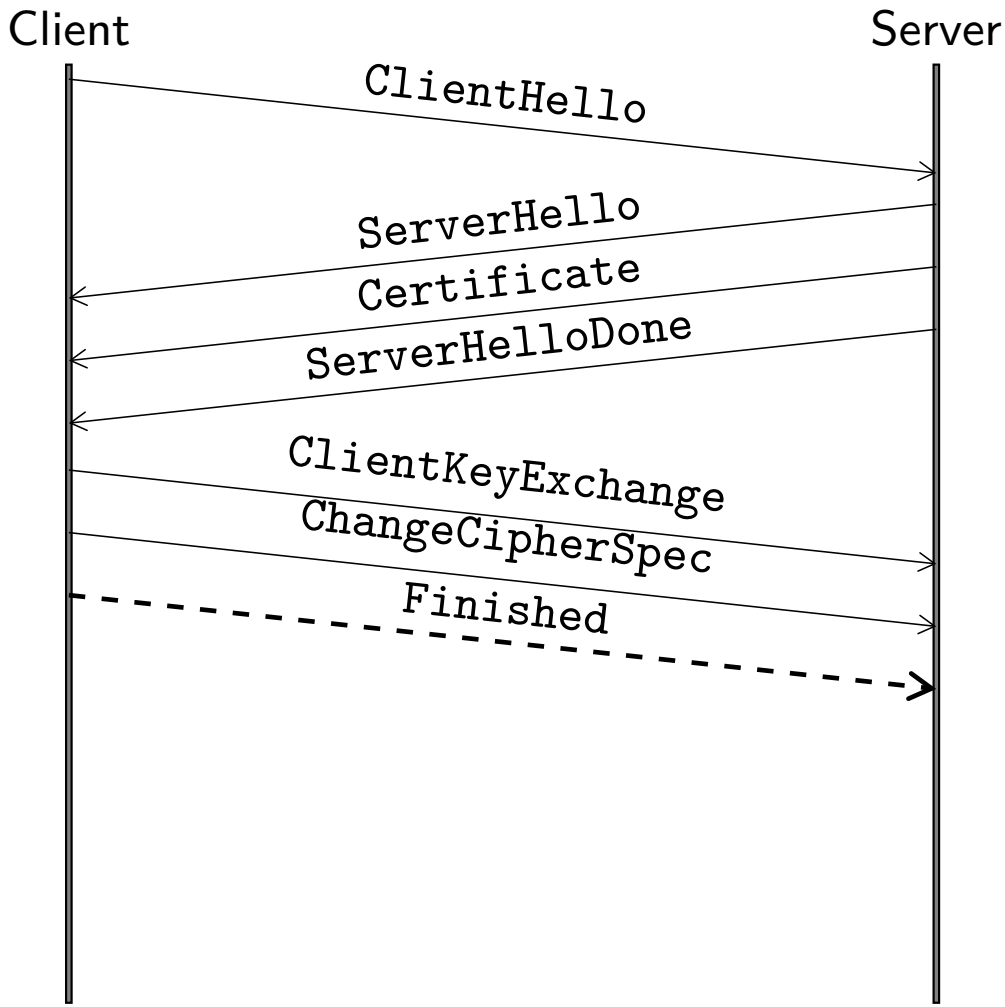

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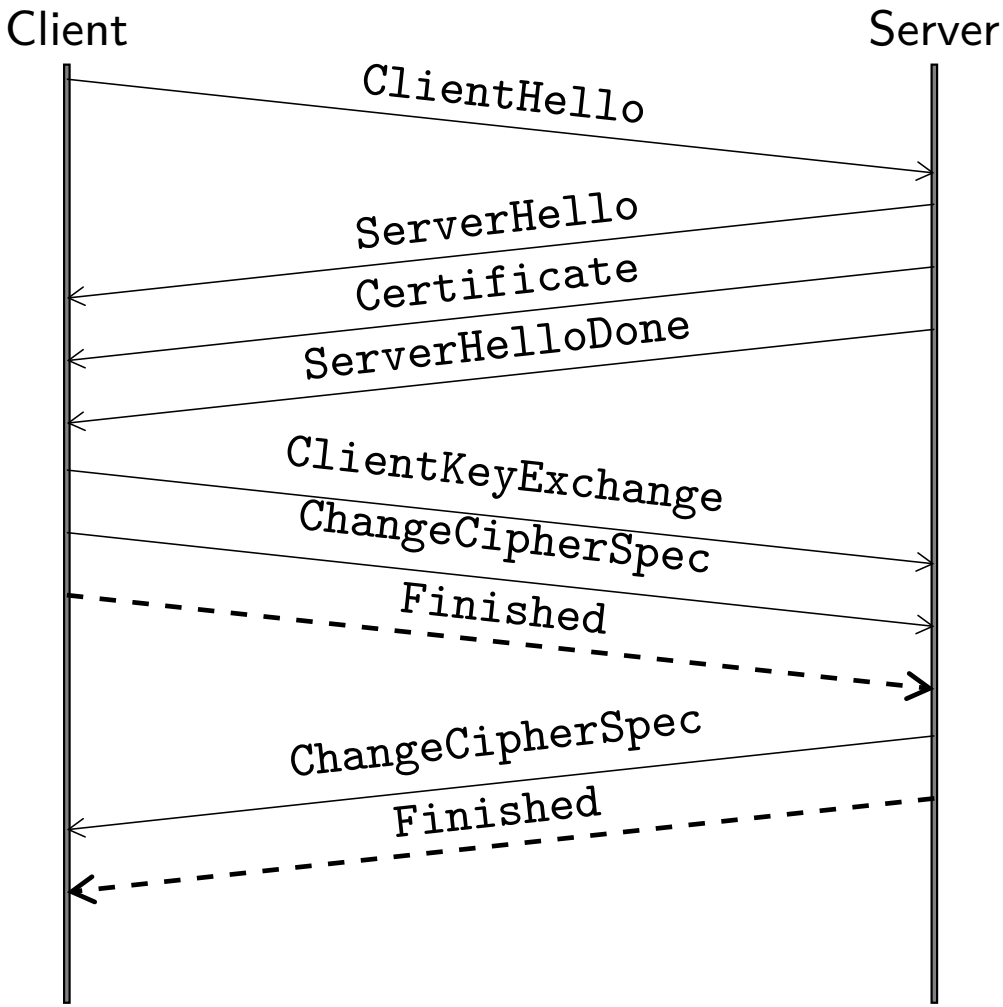

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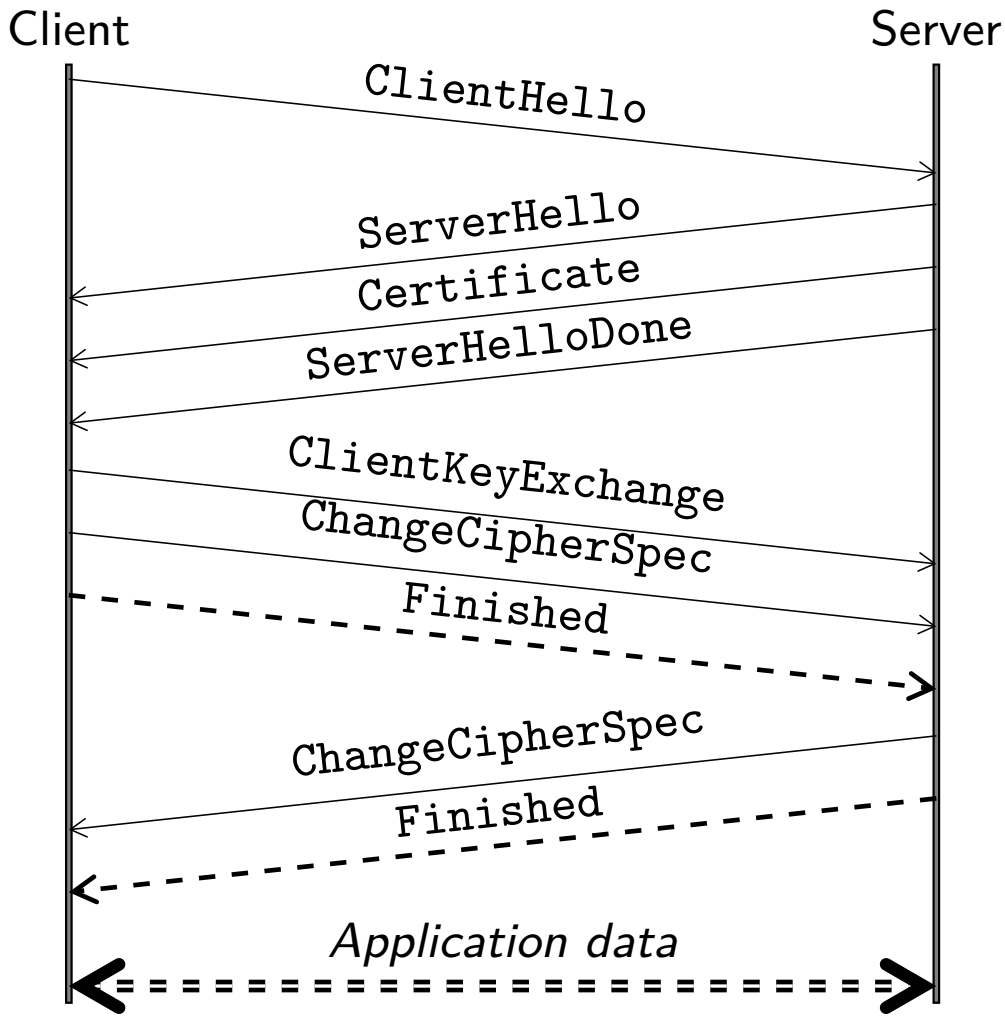

Some figures about SSL/TLS

- More than 50 RFC
- 5 protocol versions for the moment
- More than 300 ciphersuites
- More than 20 extensions
- Some *interesting* features
  - compression
  - renegotiation
  - session resumption (2 methods)
- A dozen well known implementations
- How many home-made implementations ?

Home-made SSL/TLS stacks (1/3)

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The explanation is a little sad:

- a ciphersuite is a 16-bit integer
- until (relatively) recently, all ciphersuites were of the form `00 XX`
- so why bother with the most significant byte?

Home-made SSL/TLS stacks (2/3)

- In 2010, Google proposed some extensions, *False Start* and *Snap Start*
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- One year later, the same problem reappears in another context
- On the WG mailing list (`tls@ietf.org`), someone speaks up and explains the issue: the `ClientHello` is too big...

Home-made SSL/TLS stacks (3/3)

Here is the beginning of a 258-byte long `ClientHello`

16	03	01	01	02

TLS

Type	Version	Length
HS	*TLS 1.0*	*258*

SSLv2

Length	Pad.	Type
5635	...	*CH*

A TLS `ClientHello` with a size between 256 and 511 can be seen as an SSLv2 `ClientHello`!

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In the end, all is well

- Google's new proposal: an extension to pad `ClientHello`...

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SSL/TLS design flaws in the first phase

The first step in an SSL/TLS connection is to authenticate the server and share a common secret

Some examples of what could go wrong

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The first step in an SSL/TLS connection is to authenticate the server and share a common secret

Some examples of what could go wrong

- SSLv2 down-negotiation: only the random values exchanged were authenticated
- Renegotiation / Triple Handshake: different sessions/epochs were not bound in a secure manner

About *master secret* and key derivation (1/2)

The *master secret* is derived from

- the result of the key exchange algorithm
- random values sent in plaintext

Integrity is only guaranteed afterwards when `Finished` messages are exchanged

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Several attacks rely on this limited coverage in the derivation

- theoretical cross-protocol attacks were presented in 1999
- (almost) practical instanciations were published in 2012
- Triple Handshake used this in 2014
- SMACK/FREAK 2015
- LogJam in 2015

About *master secret* and key derivation (2/2)

Fix proposal

- session-hash extension: the derivation should hash all the previously exchanged messages
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However, this is not enough, as *LogJam* proved it

- the DH group is chosen by the server using unauthenticated information (possibly a weak one such as 512-bit DH group)
- the chosen group is signed along with the exchanged random values
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The real fix: sign all the previously exchanged messages, not only the random values

Attacks against the Record Protocol

Since 2011, a lot of practical attacks targetting the Record Protocol

- BEAST: against CBC with implicit IV (versions before TLS 1.1)
- CRIME: refined with TIME and BREACH, using TLS (or HTTP) compression as a side-channel
- Lucky 13: padding oracle against CBC
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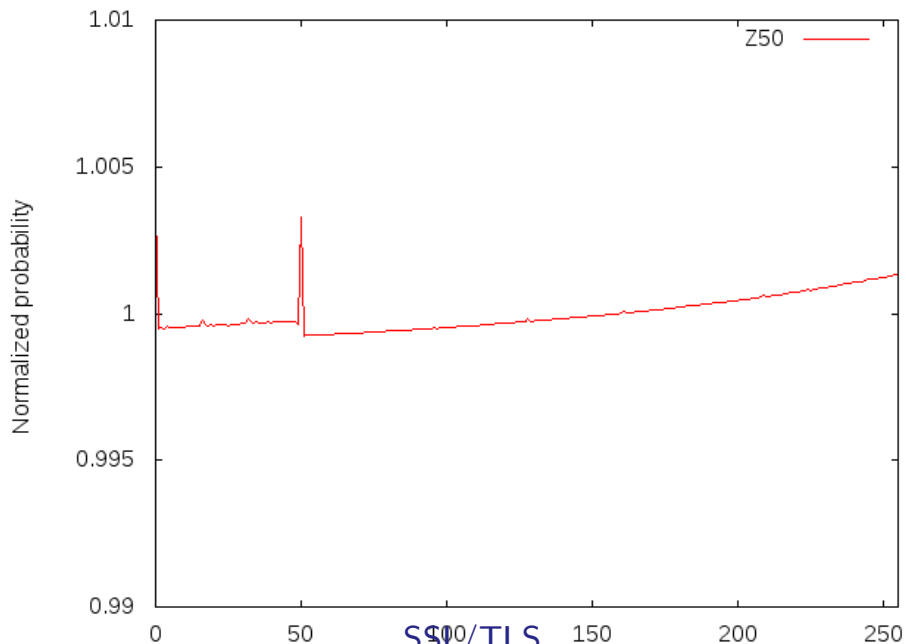
All these have similarities: they target HTTP authenticated cookies

- indeed, cookies are repeated across TLS sessions, making some attacks possible

Focus on RC4

- 1987: RC4, a proprietary streamcipher designed by Rivest
- 1994: RC4 leaks under the name ARCFOUR
- 1995-2000: biases related to the first bytes of the keystream
- 2001: WEP (which uses correlated keys) is broken by Flührer, Mantin, and Shamir
- 2013: exploitable biases are discovered in the TLS use case
- 2014: more, better, attacks



Some thoughts about CBC mode

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- Beware of padding oracles with CBC mode in TLS
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Bodo Möller (2004-05-20)

- Beware of padding oracles with CBC mode in TLS
- CBC mode with implicit IV may be subject to attacks
- With SSLv3, the padding is not well specified, which aggravates padding oracles
- ... he was describing Lucky 13, BEAST and POODLE

2014: terrible year for TLS

In 2014, all major TLS stacks were affected by a critical vulnerability

- February : `goto fail` in Apple
- February : `goto fail` in GnuTLS
- April : *Heartbleed* in OpenSSL
- June : *Early CCS* in OpenSSL
- September : Universal signature forgery (Berserk?) in NSS (Mozilla)
- September : Universal signature forgery (Berserk?) in CyaSSL
- September : Universal signature forgery (Berserk?) in PolarSSL (now mbedTLS)
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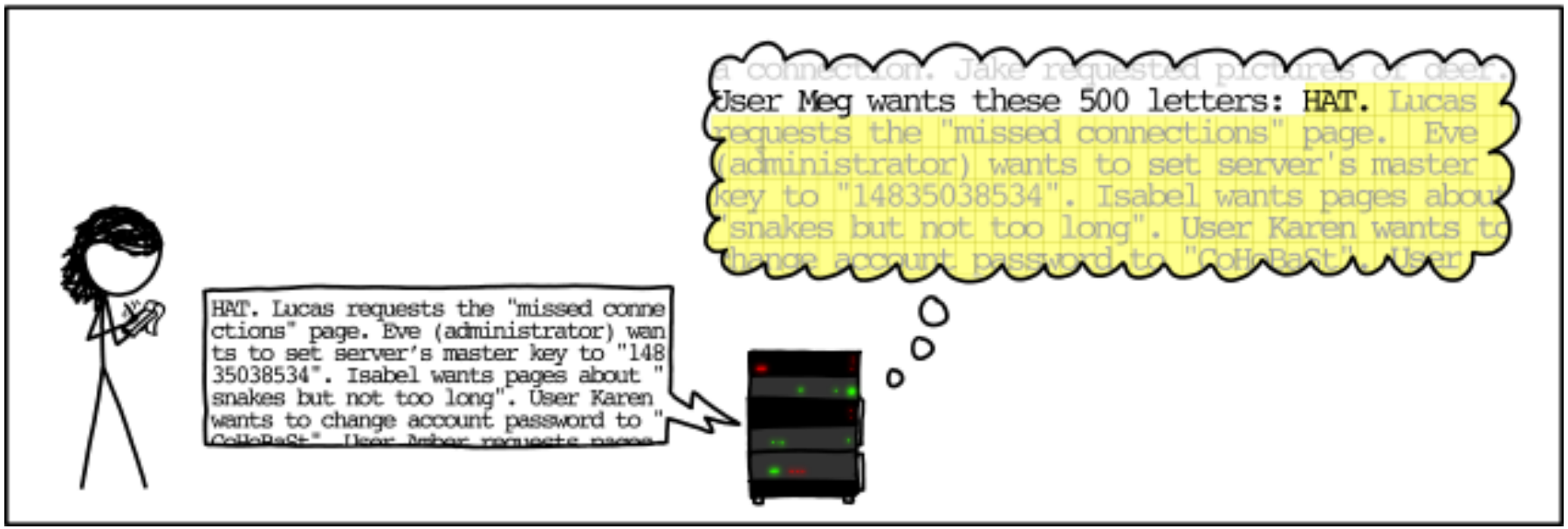
Quizz

- What also happened on Heartbleed's day (April 8th, 2014)?
- What also happened on Berserk's day (September 24th, 2014)?

A typical buffer overflows: Heartbleed



Source: `http://xkcd.com/1354`

```
+        /* Read type and payload length first */
+        if (1 + 2 + 16 > s->s3->rrec.length)
+                return 0; /* silently discard */
```

Another silly buffer overflow: WinShock

- Client authentication using Elliptic Curve certificates rely on two more messages
- The `Certificate` message, containing the certificate chain
  - it contains the used curve
  - in particular, it indicates the length of the coordinates L
- The `CertificateVerify`, containing a signature covering previous messages
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Teaser: all vulnerable server stacks were nevertheless exploitable

Apple's goto fail

```
/* Extract from Apple's sslKeyExchange.c */
if ((err=SSLHashSHA1.update(&hashCtx,&serverRandom))!=0)
    goto fail;
if ((err=SSLHashSHA1.update(&hashCtx,&signedParams))!=0)
    goto fail;
    goto fail;
if ((err=SSLHashSHA1.final(&hashCtx,&hashOut))!=0)
    goto fail;
```

Syntax doesn't help, but the compiler doesn't seem concerned about signaling obviously dead code...

True, False, FILE_NOT_FOUND

Focus CVE-2014-0092 on GnuTLS, in March 2014:

> *But this bug is arguably much worse than* Apple*'s, as it has allowed crafted certificates to evade validation check for all versions of* GnuTLS *ever released since that project got started in late 2000.[...]*
> *The* `check_if_ca` *function is supposed to return true (any non-zero value in C) or false (zero) depending on whether the issuer of the certificate is a certificate authority (CA). A true return should mean that the certificate passed muster and can be used further, but the bug meant that error returns were misinterpreted as certificate validations.*

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By the way, a similar bug was found in OpenSSL... in 2008 (CVE-2008-5077).

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Maybe we should not always blame the developer... and improve our languages/tools/specs

Bleichenbacher

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- application to TLS: the so-called Million Message Attack

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The attack reappeared in 2014

- In Java crypto library, a padding error leads to an exception
- To avoid a timing attack, one must reimplement the algorithm
- A TLS implementer has to choose between code reuse and security

MAC-then-Encrypt

Padding issues also exist in symmetric crypto

- Using *MAC-then-CBC* is vulnerable
- 2002: Vaudenay presents the attack principle
- 2011: *XML Encryption is broken* paper
- 2013: Lucky 13 proves applicability to TLS

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Fix?

- duct-tape (add an implementation note in the standard)
- a sordid patch to ensure constant-time decryption
- use `Encrypt-then-MAC` (RFC 7366) or secure AEAD schemes

Again, one had to choose between modularity and security

SMACK and FREAK

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In general, the state machine is drived by the received messages, whereas the implementation should keep track of the expected messages

Other problems with state machines

- Early CCS, also found by formal methods!
- In the previous SChannel vulnerability, even unsollicited client-sent `Certificate` and `CertificateVerify` messages were interpreted

All TLS stacks more or less vulnerable to similar attacks:

- Maybe the specs are too complicated?
- Maybe we need more tests?

TLS 1.3: a new hope?

Among the discussed flaws, a lot of them are *by design*

- Obsolete crypto, finally removed: PKCS#1 v1.5, RC4, CBC...
- State machine: the negotiation phase has been cleaned up
- In parallel to the specification efforts, the protocol is modeled and tested using formal methods (TRON workshop early 2016)

Yet, TLS 1.3 will not solve

- compatibility issues: we will still need to speak TLS 1.2 and earlier for some time...
- the complexity introduced by the new constructions
  - 0-RTT
  - Client authentication and key refresh are not stable yet...

Languages and methodology

Should not programming languages help us?

- Strong typing can help avoid simple bugs
- Memory mangagement done right

Tools can help us

- activate more warnings
- and handle them (`-Werror`)

Add more tests

- non-regression tests
- negative tests

Questions

Thank you for your attention

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