Using Frankencerts for Automated Adversarial Testing of Certificate Validation in SSL/TLS Implementations

Chad Brubaker[1] Suman Jana[1] Baishakhi Ray[2]
Sarfraz Khurshid[1] Vitaly Shmatikov[1]

[1]University of Texas at Austin

[2]University of California at Davis

Internet security = SSL/TLS

SSL/TLS security objectives

- End-to-end security even if the network is insecure
  - Authentication **= certificate validation!!**
  - Confidentiality
  - Integrity

Certificate validation in SSL/TLS implementations

How to check if implementations are correct?

```
bool is_cert_valid (cert_t *cert)
{
    return true;
}
```

How do people test SSL/TLS implementations?

Current state of the art

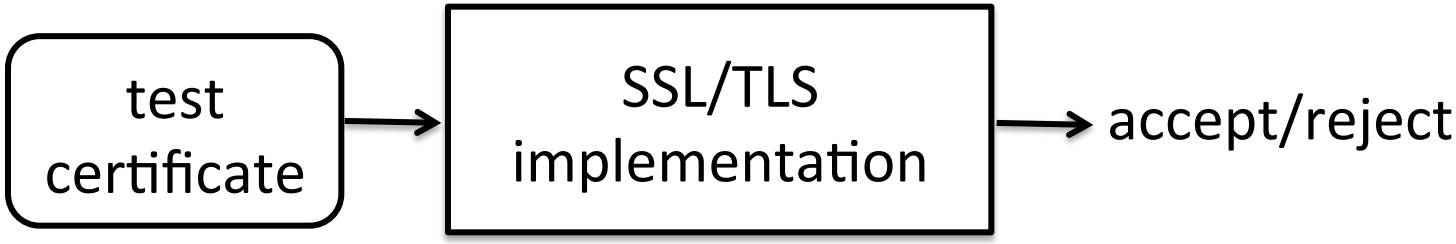
Implementation	Test certificate count
NSS	54
GnuTLS	51
OpenSSL	44
PolarSSL	18
CyaSSL	9
MatrixSSL	9

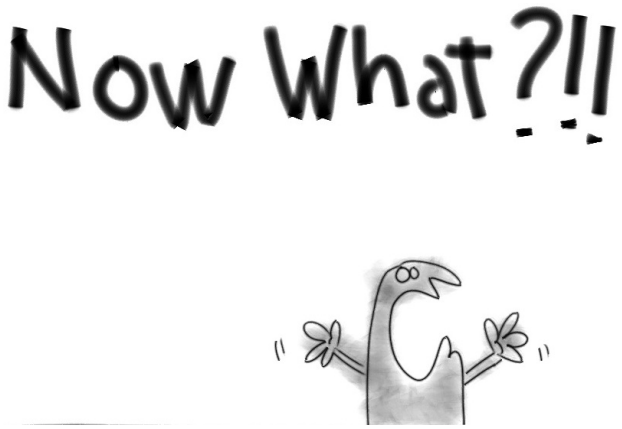
Most of these are just well-formed certificates!

Testing certificate validation code

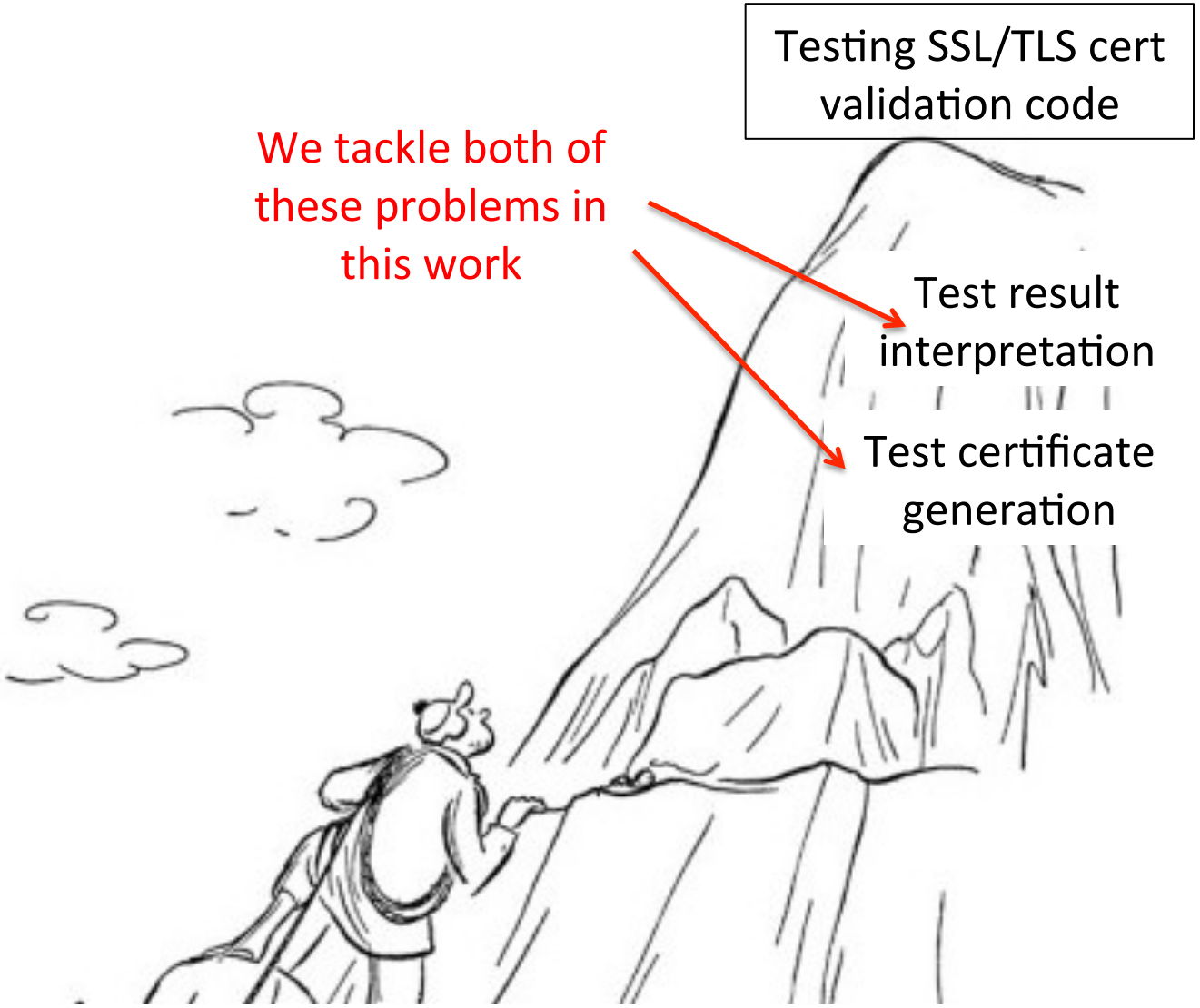
- Test input generation
  - Fuzzing - huge input space, a fuzzed string won't even parse as an X.509 cert

Interpreting test results





How do you know that the result is correct?


Testing SSL/TLS cert validation code
We tackle both of these problems in this work
Test result interpretation
Test certificate generation

How to generate test certificates?

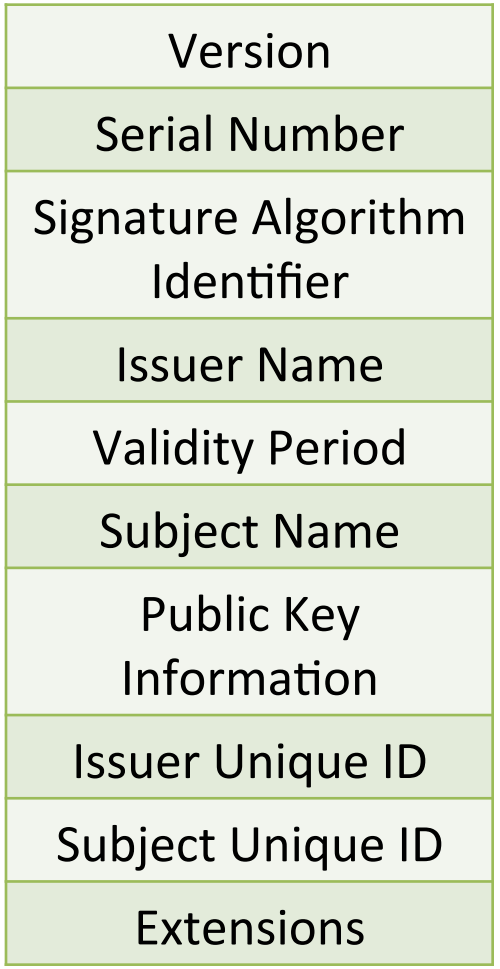
X.509 standards…ugh!

How to generate test certificates?

- Requirements
  - Must generate “semantically bad” certificates
  - Should be syntactically correct, otherwise won’t exercise most of the cert validation code
  - Must scale to millions of certs
- Idea 
  - X.509 certs contain structured data, can we exploit that?

X.509 certificate structure

- Multilayered structured data
- Syntactic constraints for each piece
  - Ex: Version must be an integer
- Semantic constraints for individual piece or across multiple pieces
  - Ex: Version must be 0, 1, or 2
  - Ex: if version!=2, extensions must be NULL



How to generate test certificates?

Create X.509 certs using randomly picked syntactically valid pieces

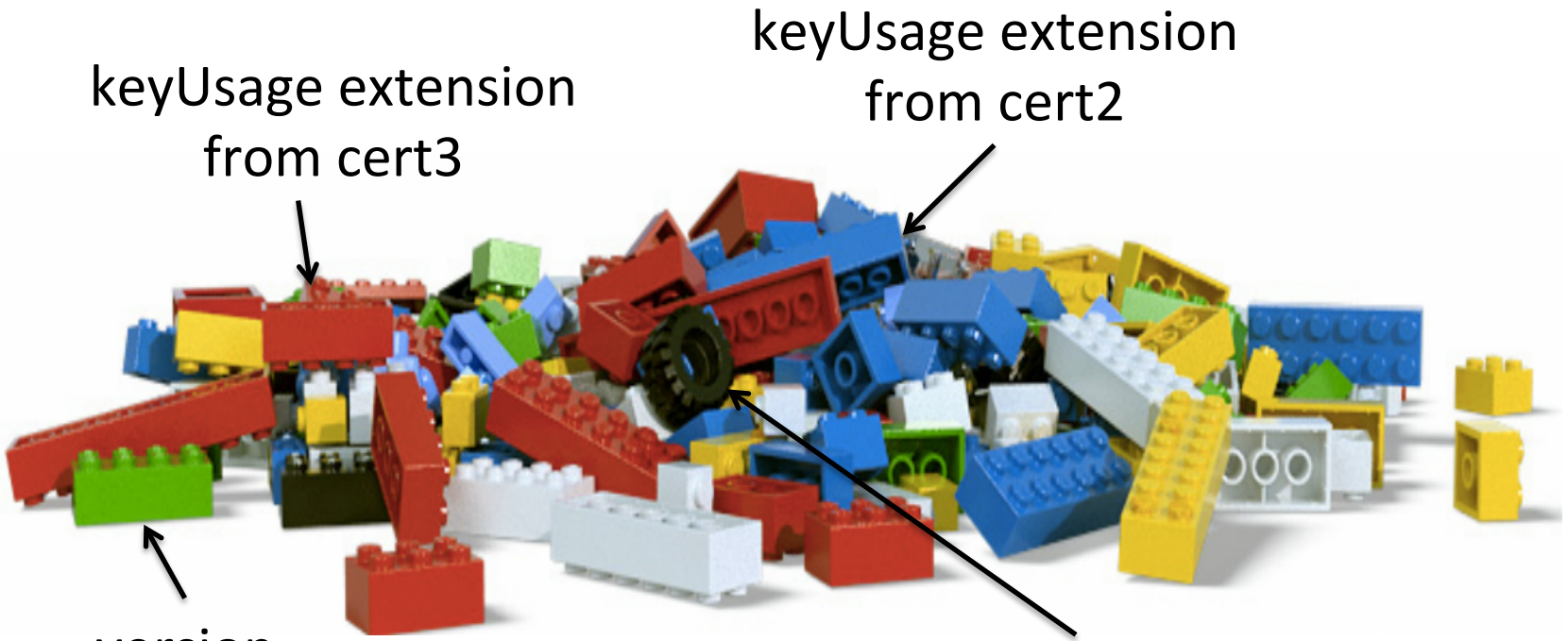
Likely to violate some semantic constraints i.e. will generate "bad" test certs just as we wanted

Wait, but how can we generate a large set of such syntactically valid pieces without reading X.509 specs?

Scan the internet for certificates

Collect 243,246 X.509 server certificates

Extract syntactically valid pieces



Generate 8 million frankencerts from random combinations of certificate pieces

Interpret frankencert test results

- Differential testing of SSL/TLS implementations
- Multiple implementations of SSL/TLS should implement the same certificate validation logic
- If a certificate is accepted by some and rejected by others, what does this mean?

Which one is rotten ?

No false positives though some instances might be different interpretations of X.509

Test results summary

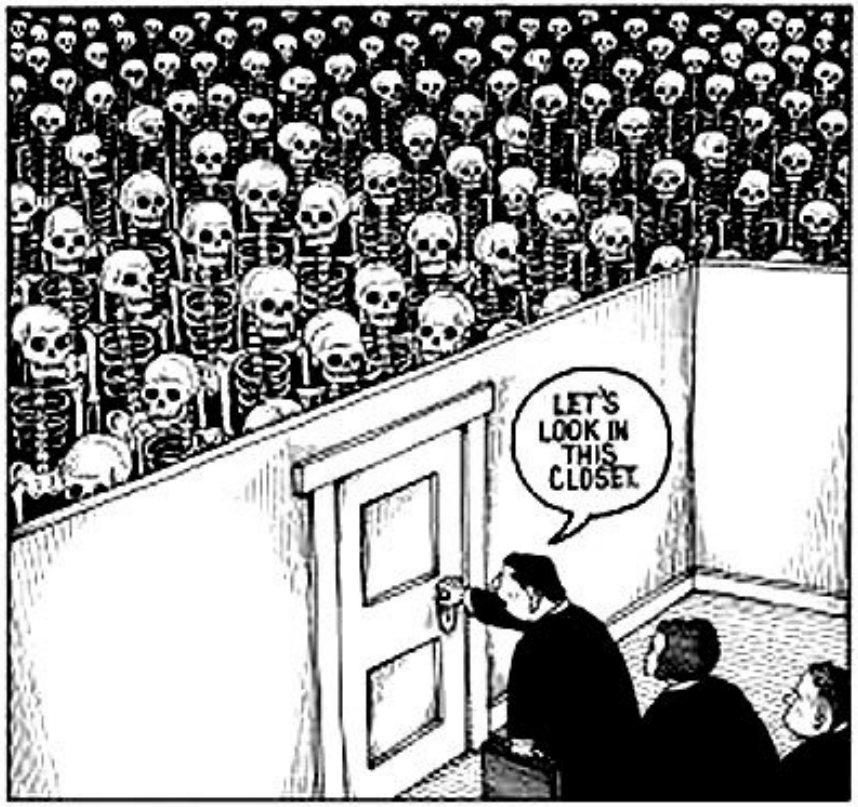
- Tested 14 different SSL/TLS implementations
- 208 discrepancies due to 15 root causes
- Multiple bugs
  - Accepting fake and unauthorized intermediate Certificate Authorities (CAs)

attacker can impersonate any website!

Some test results

Problem	Certificates triggering the problem occur in the original corpus	OpenSSL	PolarSSL	GnuTLS	CyaSSL	MatrixSSL	NSS	OpenJDK, Bouncy Castle	Browsers
Untrusted version 1 intermediate CA certificate	No	reject	reject	**accept**	reject	**accept**	reject	reject	reject
Untrusted version 2 intermediate CA certificate	No	reject	reject	reject	reject	**accept**	reject	reject	reject
Version 1 certificate with valid basic constraints	No	accept	reject	accept	accept	accept	reject	reject	Firefox: reject Opera, Chrome: accept
Intermediate CA not authorized to issue further intermediate CA certificates, but followed in the chain by an intermediate CA certificate	No	reject	reject	reject	reject	**accept**	reject	reject	reject
. . . followed by a leaf CA certificate	No	**reject**	**reject**	accept	**reject**	accept	**reject**	**reject**	**reject**
Intermediate CA not authorized to issue certificates for server's hostname	No	reject	reject	**accept**	**accept**	**accept**	reject	reject	reject
Certificate not yet valid	Yes	reject	**accept**	reject	reject	reject	reject	reject	reject
Certificate expired in its timezone	Yes	reject	**accept**	reject	reject	**accept**	reject	reject	reject
CA certificate not authorized for signing other certificates	No	reject	reject	**accept**	**accept**	**accept**	reject	reject	reject
Server certificate not authorized for use in SSL/TLS handshake	Yes	reject	**accept**	**accept**	**accept**	**accept**	reject	reject	reject
Server certificate not authorized for server authentication	Yes	reject	**accept**	**accept**	**accept**	**accept**	reject	reject	reject
Certificate with unknown critical extension	No	reject	reject	**accept**	**accept**	**accept**	reject	reject	reject
Certificate with malformed extension value	No	accept	reject	accept	accept	accept	reject	reject	reject
Certificate with the same issuer and subject and a valid chain of trust	No	reject	reject	**accept**	reject	**accept**	reject	reject	reject
Issuer name does not match AKI	No	reject	accept	accept	accept	accept	reject	reject	reject
Issuer serial number does not match AKI	No	reject	accept	reject	accept	accept	reject	reject	reject

Exhibits



Version 1 CA certificates

If an SSL/TLS implementation encounters a version 1 (v1) CA certificate that cannot be validated out of band, it must reject it

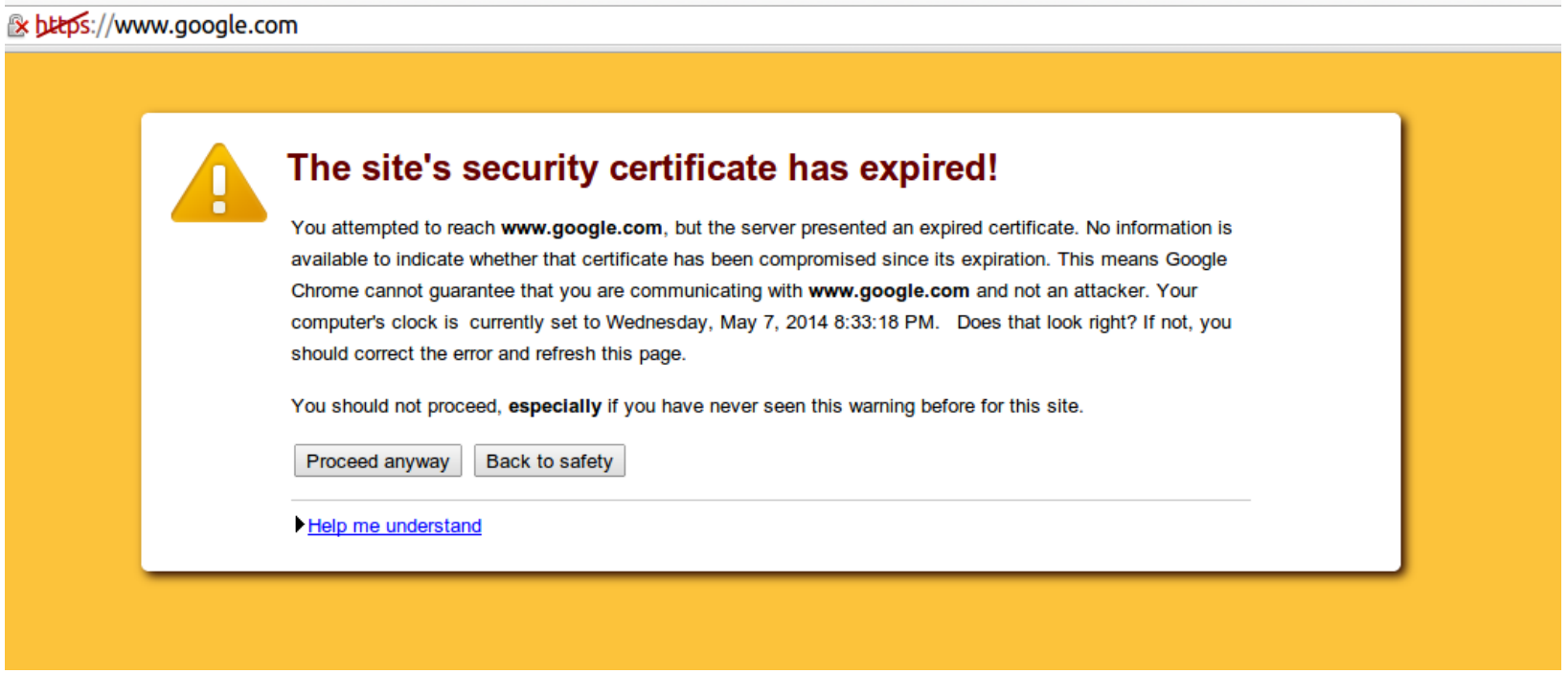
RFC 5280 Section 6.1.4(k)

v1 CA certs do not support the CA bit:
anybody with a valid v1 certificate can
pretend to be a CA

Exhibit 1: GnuTLS

```
  /* Disable V1 CA flag to prevent version 1 certificates in a supplied
chain. */
  flags &= ~(GNUTLS_VERIFY_ALLOW_X509_V1_CA_CRT);
  ret = _gnutls_verify_certificate2 (flags,..))
```

Exhibit 2: Google Chrome



OK to click through?

Exhibit 2: Google Chrome

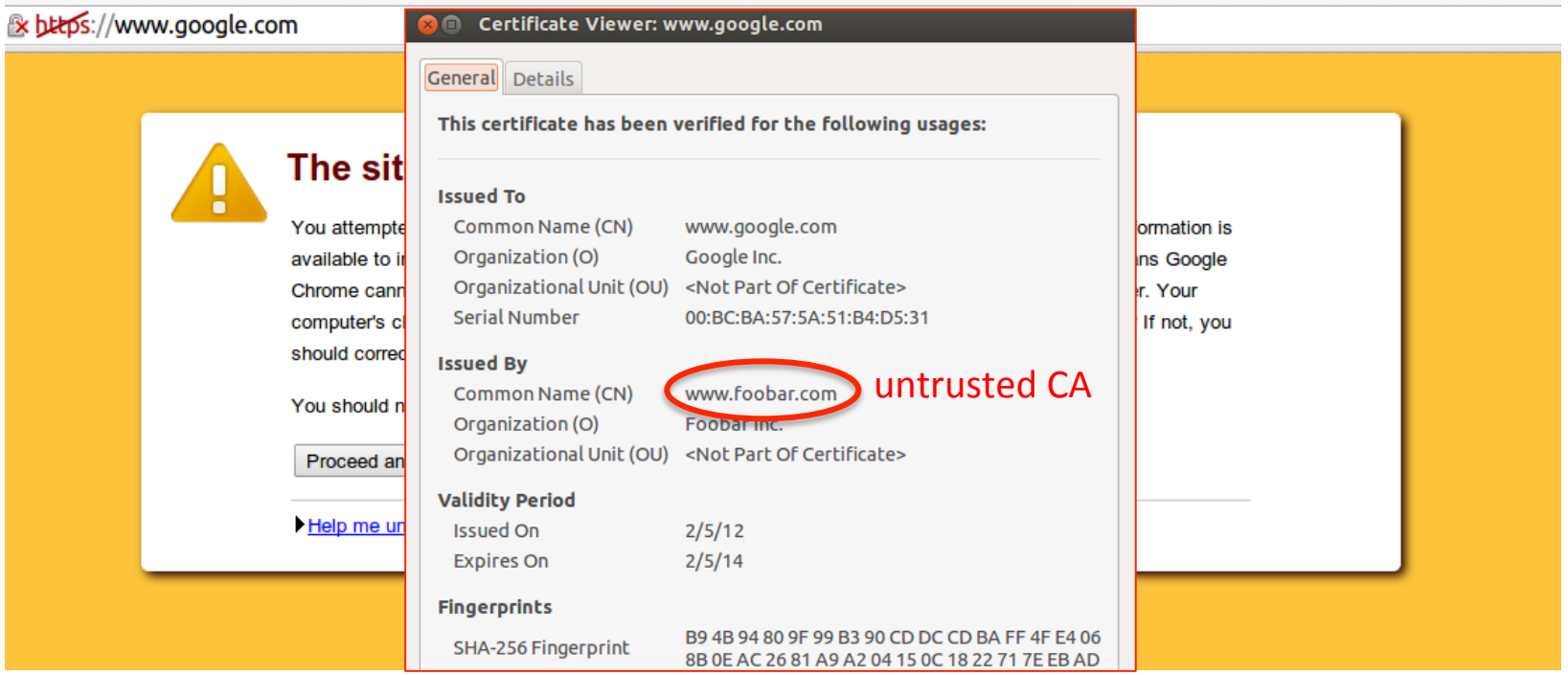


Exhibit 2: underlying cause

- Chrome uses a modified version of NSS for SSL certificate validation
- If a certificate is issued by a untrusted CA and is expired, the validation code only returns the expired error
- Firefox uses a glue layer called Personal Security Manager (PSM) over NSS and thus is not affected

Check the paper for more such goodies!!

Conclusions

- Differential testing with frankencerts is an effective technique for finding flaws in SSL/TLS implementations

- Start integrating frankencerts with the test harness of your SSL/TLS implementation. The code is available at: https://github.com/sumanj/frankencert

Backup Slides

Frankencert features

- Frankencerts are random, yet syntactically correct X.509 certificates with …
  - Unusual extensions
  - Rare and malformed values for these extensions
  - Strange key usage constraints
  - Rare combination of extensions
  - … and many other unusual features

Mutate a few pieces randomly

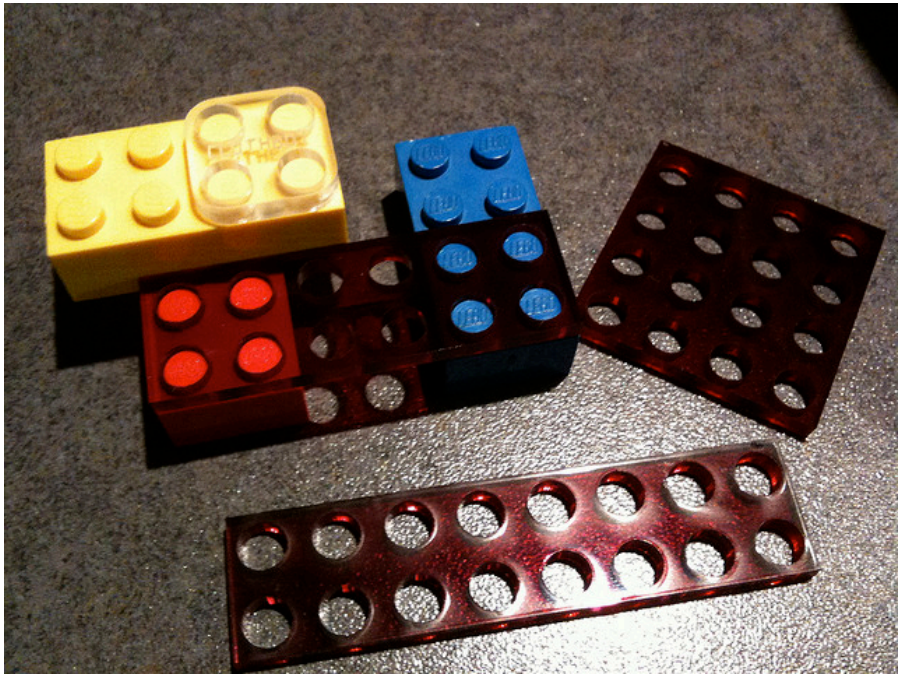


Exhibit 2: MatrixSSL

```
/* Certificate authority constraint only available in
version 3 certs */
if ((ic->version > 1) && (ic->extensions.bc.ca<= 0)) {
   psTraceCrypto("no CA permissions\n");
   sc->authStatus = PS_CERT_AUTH_FAIL_BC;
   return PS_CERT_AUTH_FAIL_BC;
}
```