EECS 388

Introduction to Computer Security

Lecture 10:

HTTPS Attacks and Defenses

September 28
Prof. Halderman

Web and Network Security

Last week:

- The Web Platform
- Web Attacks and Defenses

This week:

- HTTPS and the Web PKI
- **HTTPS Attacks and Defenses**

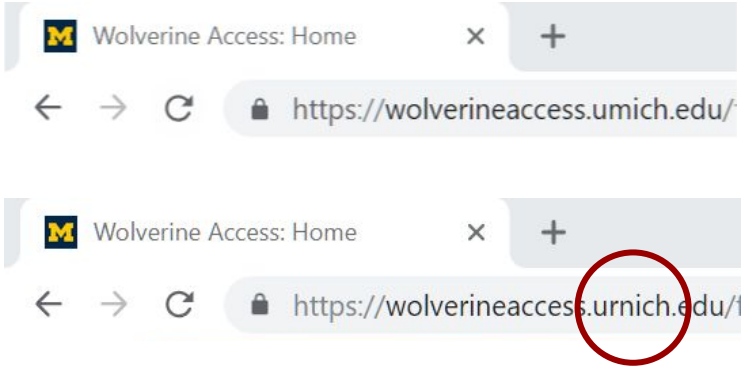
Next week:

- Networking 101
- Networking 102

Later:

- Network Defense
- User Authentication
- Online Privacy and Anonymity

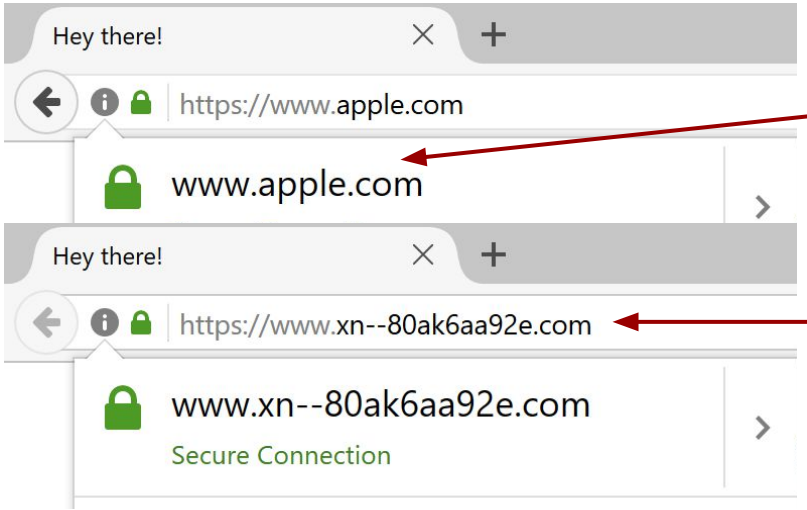
1. Fooling Users: Homographs



Homograph attacks use visually similar domain to trick users. It's simple but effective.

Attackers buy look-alike domain and acquire a legitimate cert, then set up a phishing site.

IDN homograph attacks use international characters for a pixel-perfect match.



Cyrillic letters that look just like "apple"

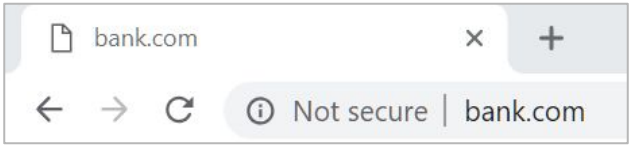
Punycode (ASCII) encoding of same name

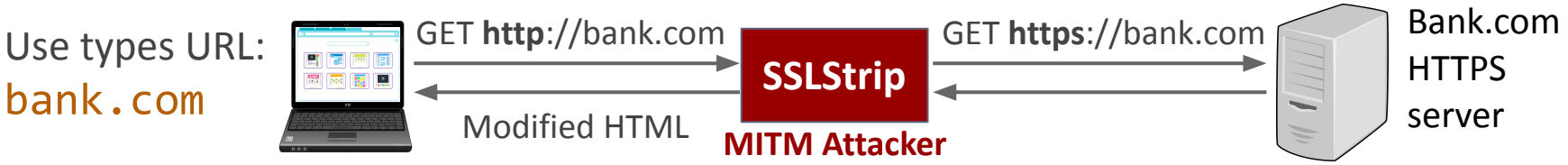
Mitigation: Browsers use heuristics to block many IDN homographs, but users beware!

1. Fooling Users: Stripping

Many browsers still default to HTTP unless HTTPS explicitly specified in URL. This enables the **SSLStrip attack**:

Users may not notice security indicator





Mitigation:
HTTP Strict Transport Security (HSTS)

Server sends special HTTP header:

```
Strict-Transport-Security: max-age=31536000
```

Browser will exclusively use HTTPS for the domain for *max-age* seconds and refuse to bypass certificate errors.

What about **first time** a user visits the domain?

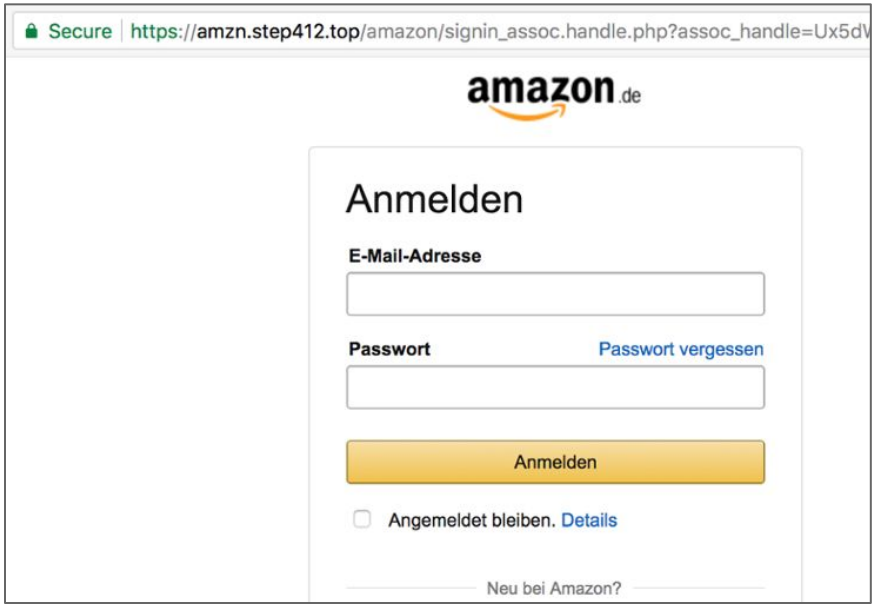
Domains can get on **HSTS Preload List** shipped with browsers.

https://hstspreload.org/

1. Fooling Users: Phishing

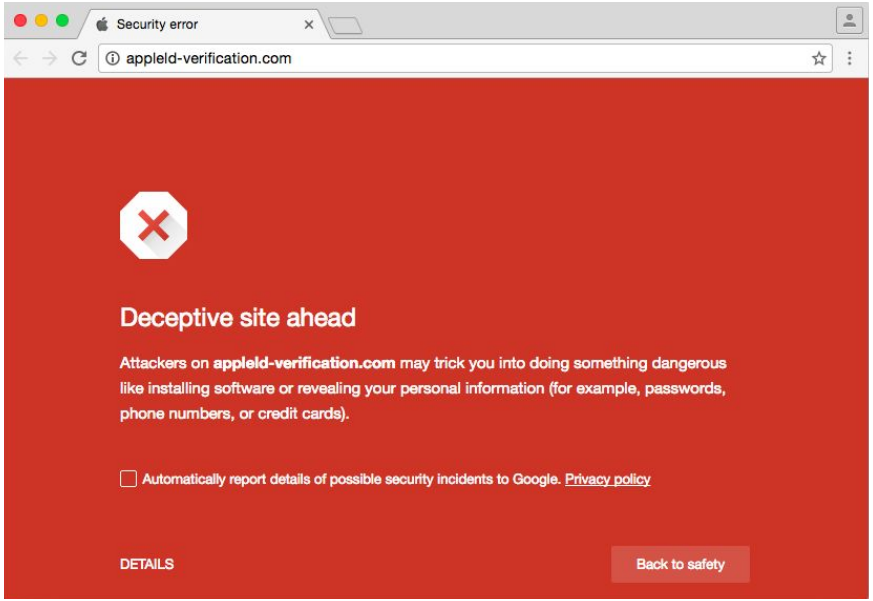
HTTPS cannot prevent phishing

Majority of phishing sites have valid certs.
CAs don't have visibility into site behavior.



Mitigation:

Google Safe Browsing uses ML to identify dangerous sites, warn users.



2. Problems with Site Design

Mixed Content (resources loaded over HTTP from inside an HTTPS page) can be modified or leak information.

Browsers block HTTP scripts but do allow images to be loaded over HTTP.

Mitigation: Use HTTPS for all resources.

By default, **cookies** set over HTTPS will be **sent unencrypted** if the browser later requests an HTTP URL from the domain.

Mitigation: Set the **Secure attribute** on cookies, so they will only be sent via HTTPS.

```
Set-Cookie: session=<TOKEN>; Secure
```

HTTPS reveals certain information about a site.

TLS <1.3: send certificate chain in plaintext.
All versions: send domain (but not URL) in plaintext **Server Name Indication (SNI)** header.

Privacy and censorship concerns.

Mitigation: Clients can use Tor or VPNs for privacy.

Mitigation: An emerging standard for **Encrypted SNI** can let servers hide domain.

3. CA Weaknesses: Fooling Validation

CA identity validation isn't foolproof.

If attacker can **falsely convince a CA** that they control a domain, they can obtain a certificate and fool browsers.

Example: Getting a cert for **`umich.edu`**

Attack 1: (Email validation)

CA emails confirmation code to **`administrator@umich.edu`**.

Attack 2: (HTTP validation)

Attacker becomes MITM between CA and U-M (e.g., by route hijacking) and redirects CA's GET request to own site.

Mitigation:

Domains can **limit which CAs** can issue certs for them by creating a DNS record called **Certification Authority Authorization (CAA)**:

```
eecs388.org. IN CAA 0 issue "letsencrypt.org"
```

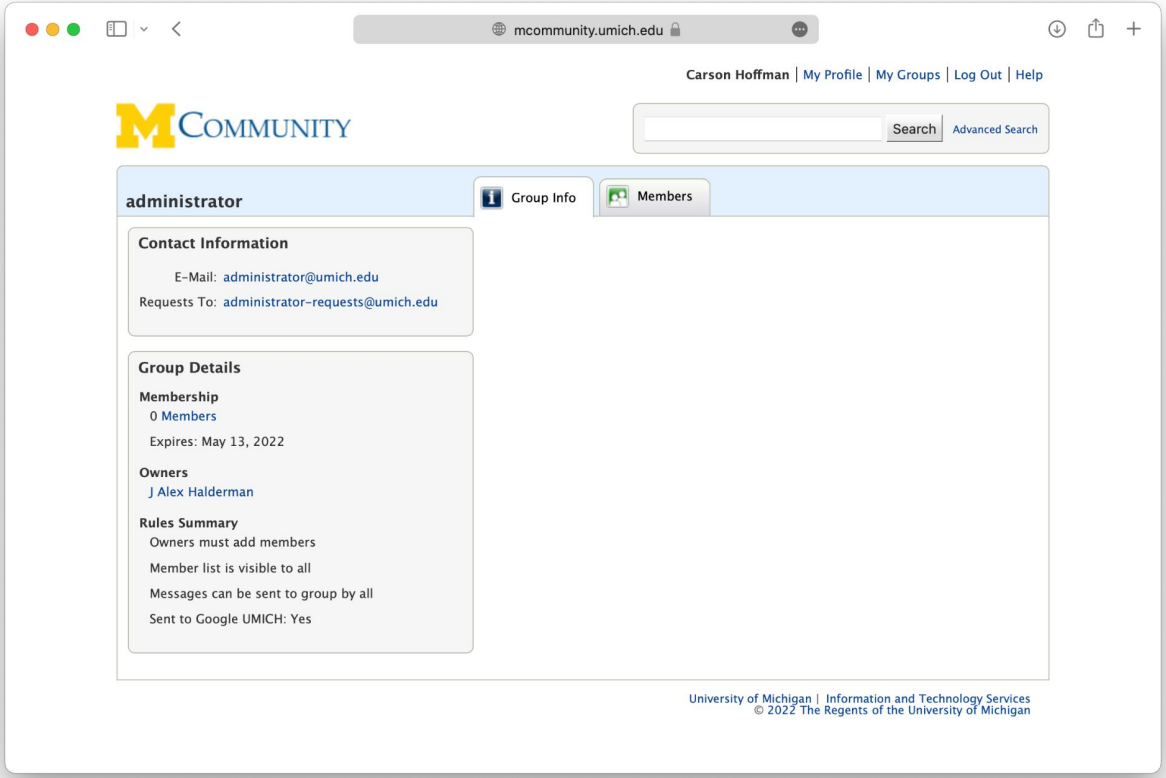
Mitigation:

Sites must prohibit users creating these email addresses: administrator, admin, webmaster, hostmaster, postmaster.

Mitigation:

CAs such as Let's Encrypt are introducing **multi-perspective validation**, which makes MITM attacks on the CA more difficult.

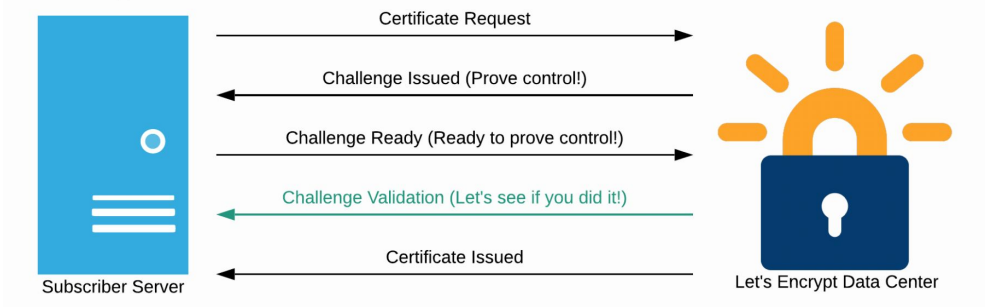
Email Validation



Single vs. Multi-Perspective Domain Validation

Single Perspective Domain Validation

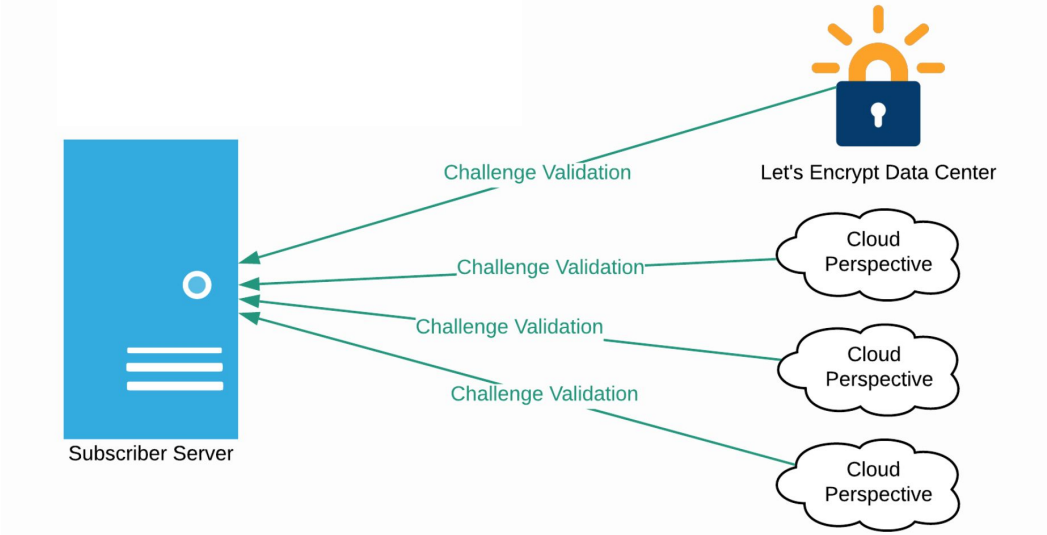
Site must satisfy one challenge validation check from a single CA data center.



Multi-Perspective Domain Validation

Site must satisfy several challenge validation checks arriving from multiple network locations.

To defeat, adversary would have to eavesdrop on all of the network paths.



3. CA Weaknesses: Attacks on CAs

Web PKI uses a distributed architecture. Thousands of intermediate CAs can issue certificates for any domain.

Occasionally CAs get hacked.

In 2011, a cert for `*.google.com` was issued to an attacker who broke into **DigiNotar**, a small Dutch CA.

Cert was used for MITM attacks in Iran.

Nobody noticed the attack until somebody found the certificate in the wild…

Google, Microsoft, Apple and Mozilla distrusted all DigiNotar certs, and the CA ceased operation.

Mitigation:

CAs can **revoke** (i.e., cancel) certs they issue by adding them to a **Certificate Revocation List (CRL)** that they sign and publish.

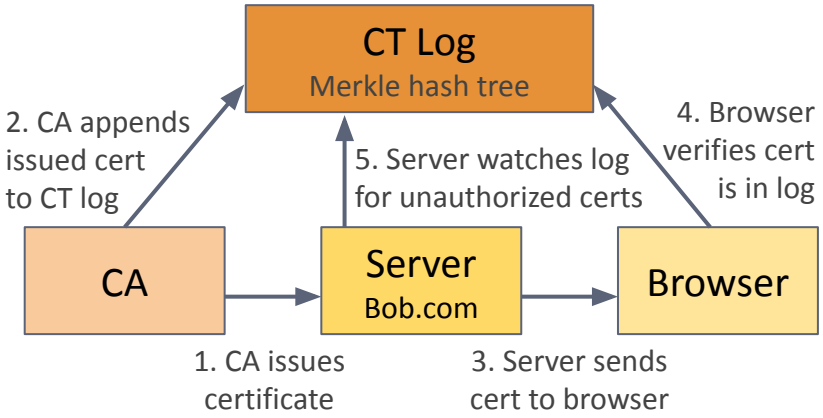
Browser companies crawl CRLs and push updates to users.

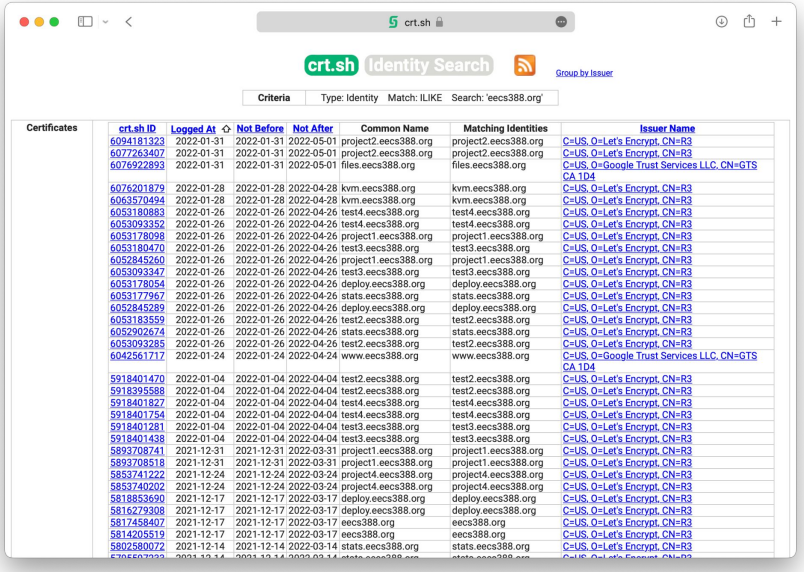
Mitigation:

Certificate Transparency helps ensure that compromises will be discovered quickly.

Mitigation: Certificate Transparency

Browsers require CAs to record every cert they issue in a public ledger, called a **Certificate Transparency (CT) log**.





crt.sh CT log search tool

Servers can **monitor** CT logs to detect if any CA issues an improper cert for their names.

Be aware: Due to CT, your domain will be publicly visible as soon as you acquire a cert.

4. Bugs in TLS Implementations

TLS is a complicated protocol. Security bugs can be hard to spot during routine testing.

Apple Goto Fail (2014)

Apple TLS libraries skipped certificate checking for almost a year due to a stray goto statement

Mozilla BERsek (2014)

Bug in verifying certificate signatures allowed spoofing certs, probably since the beginning…

```
    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;
        goto fail;
    if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
        goto fail;

    err = sslRawVerify(ctx,
            ctx->peerPubKey,
            dataToSign,
            dataToSignLen,
            signature,
            signatureLen);
    if (err) {
        sslErrorLog("SSLDecodeSignedServerKeyExchange: sslRawVerify "
                    "returned %d\n", int(err))
        goto fail;
    }

fail:
    SSLFreeBuffer(&signedHashes);
    SSLFreeBuffer(&hashCtx);
    return err;
```

4. Bugs in TLS Implementations

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Null Prefix Attack (2009)

Most browsers use C-style strings (null terminated), but X.509 uses Pascal-style strings (length field, then value)

What if a domain name in a certificate contains "\0"?
`gmail.com\0.badguy.com`

CA validates `badguy.com` (Pascal string)
Browser thinks cert is for `gmail.com` (C string)!

Mitigation:

Formal verification techniques can be used to check software correctness using a proof.

miTLS is a formally verified TLS library.

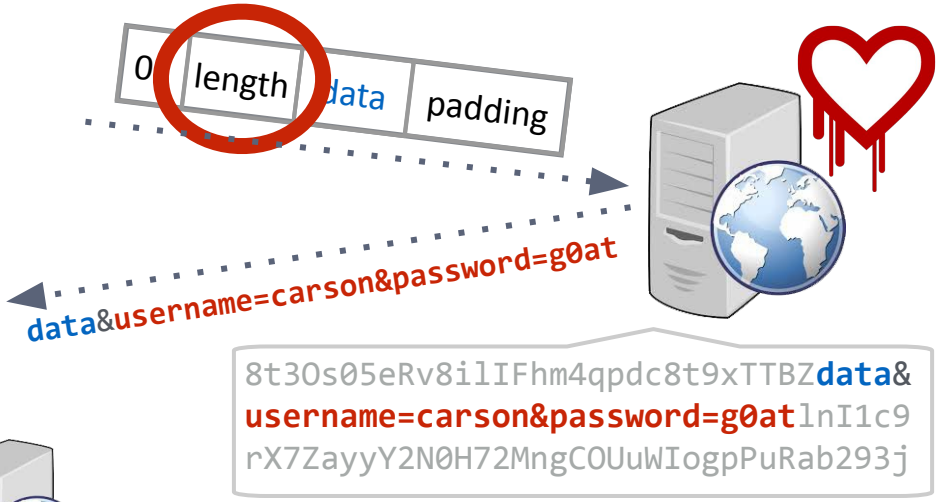
4. Bugs in TLS Implementations

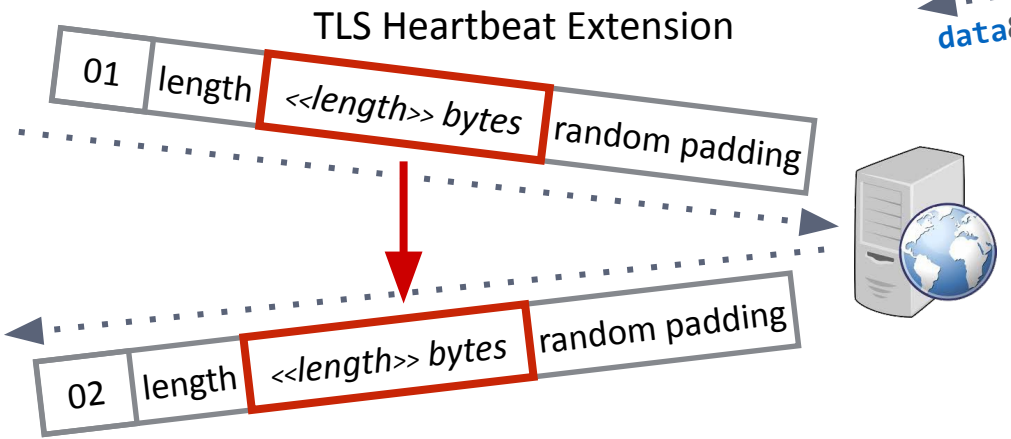
OpenSSL Heartbleed (2014)

Catastrophic bug in widely used TLS library allowed attackers to **dump process's memory**. Leaked private keys, passwords, other secrets.

24–55% of all HTTPS websites were vulnerable.

Vulnerability: OpenSSL trusted user-provided length field and echoed back memory following request data.





Mitigation: Update server software. Prefer TLS libraries written in memory-safe languages.

5. TLS Protocol Vulnerabilities

TLS versions <1.3 have many known weaknesses

RC4-related Attacks

Biases in RC4 stream cipher can be used to leak cookies and passwords.

CBC-related Attacks

BEAST and POODLE exploit weaknesses in TLS's use of CBC to leak data.

Compression-related Attacks

TLS and HTTP support compression, but TLS exposes length of the plaintext. The combination can leak data.

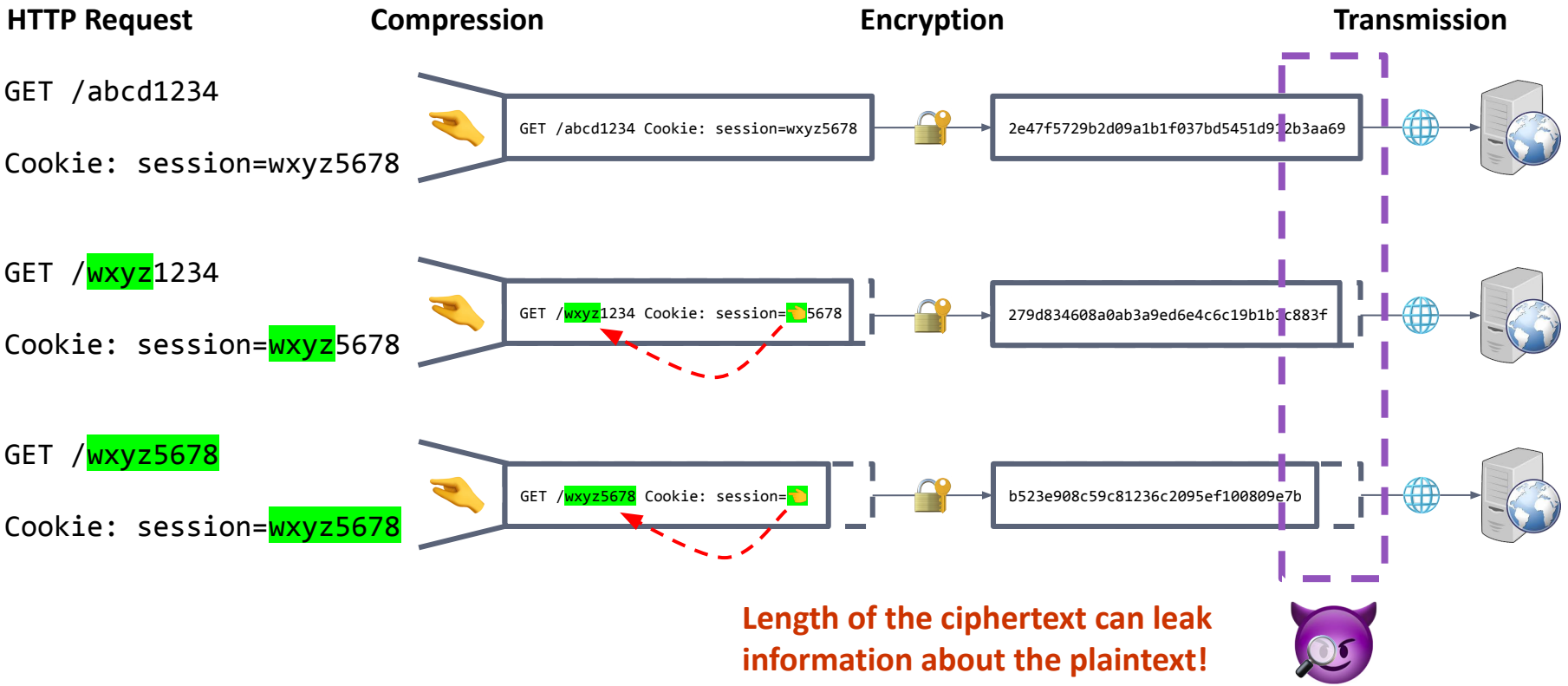
Example: Attacker causes user's browser to visit crafted URLs on a target site. If URLs match user's cookie, length of TLS data will be shorter. Use many requests to iteratively leak cookie.

Export-related Attacks

FREAK, Logjam, and DROWN exploit weaknesses in 1990s-era "export-grade" cryptography. Allowed MITM attacks against ≈30% of popular modern sites.

Mitigation: Safeguarding TLS <1.3 requires updates to servers and/or browsers.

TLS Compression Attack



Export-grade Cryptography

Until 2000, U.S. law limited strength of cryptography sold overseas to:

- 64-bit symmetric keys
- 512-bit RSA or DH

1990s browsers came in U.S. versions and “export” versions, with weakened crypto. SSL design let servers and clients negotiate the strongest keys they both supported.

Limits were lifted following legal challenge by cryptographer Dan Bernstein and EFF, arguing that code is a form of free speech.

No modern clients support export-grade crypto, but remnants remained in protocol design and implementations until TLS 1.3.

Court Hears Appeal in Encryption Case

By JOHN MARKOFF DEC. 9, 1997

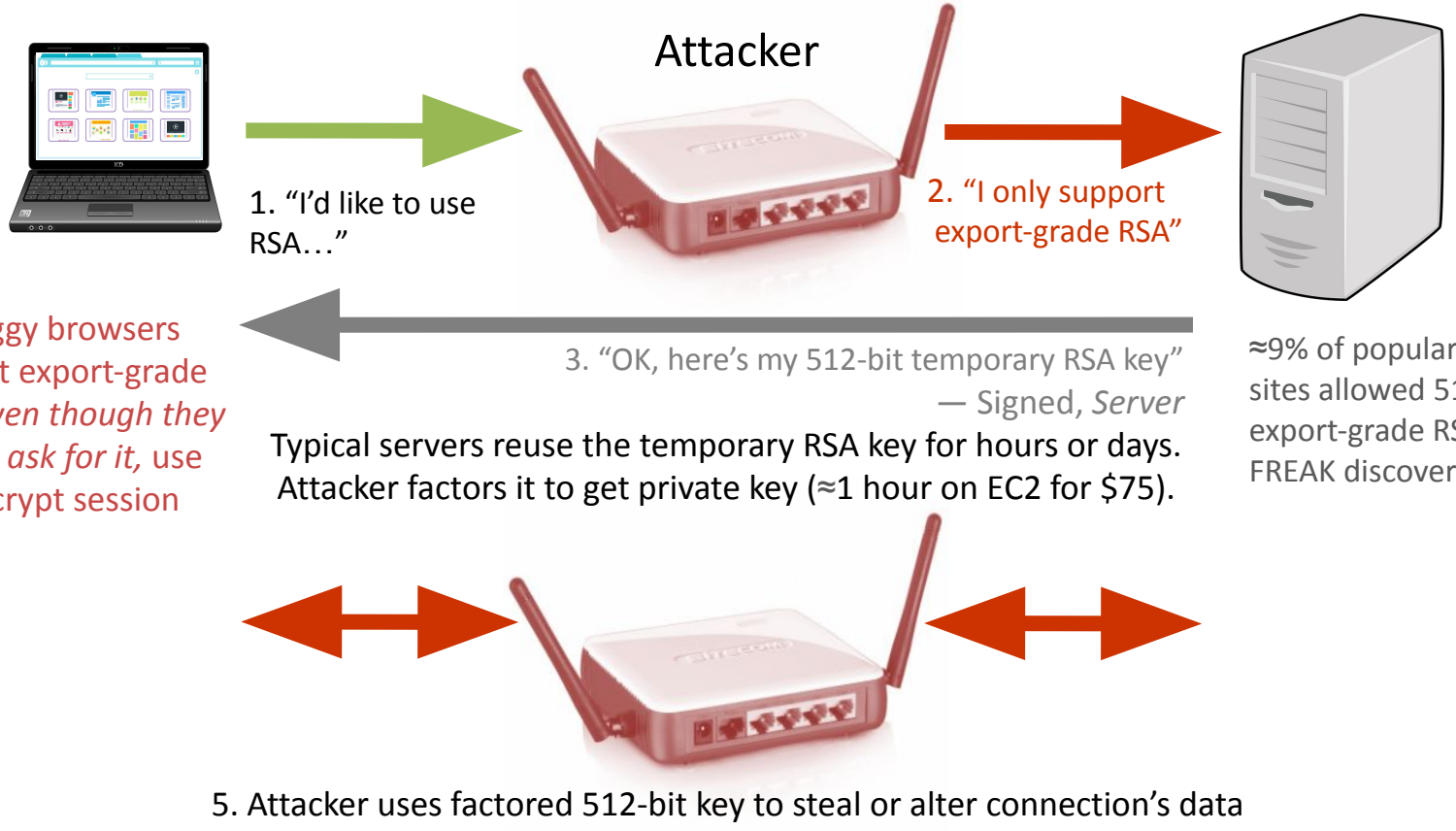
The power of the Internet to transcend national borders pitted personal rights against national security today when a Federal appeals court heard arguments in a suit contending that Government export controls on data-scrambling software illegally restrict free speech.

In a case that could have a profound effect on the future of electronic commerce and banking, a three-judge panel of the Court of Appeals for the Ninth Circuit here heard the Government's appeal of a December 1996 decision in which Judge Marilyn Hall Patel of Federal District Court ruled that Government attempts to control the export of encryption software were unconstitutional.

Her ruling came in a suit filed in February 1995 by Daniel J. Bernstein, then a graduate student at the University of California at Berkeley, after State Department officials said he would be required to register as a munitions dealer and secure an arms-trading license to export an electronic version of

The FREAK Attack

Deliberately weakened crypto from the 1990s harmed global security in 2015



≈9% of popular HTTPS sites allowed 512-bit export-grade RSA when FREAK discovered in 2015.

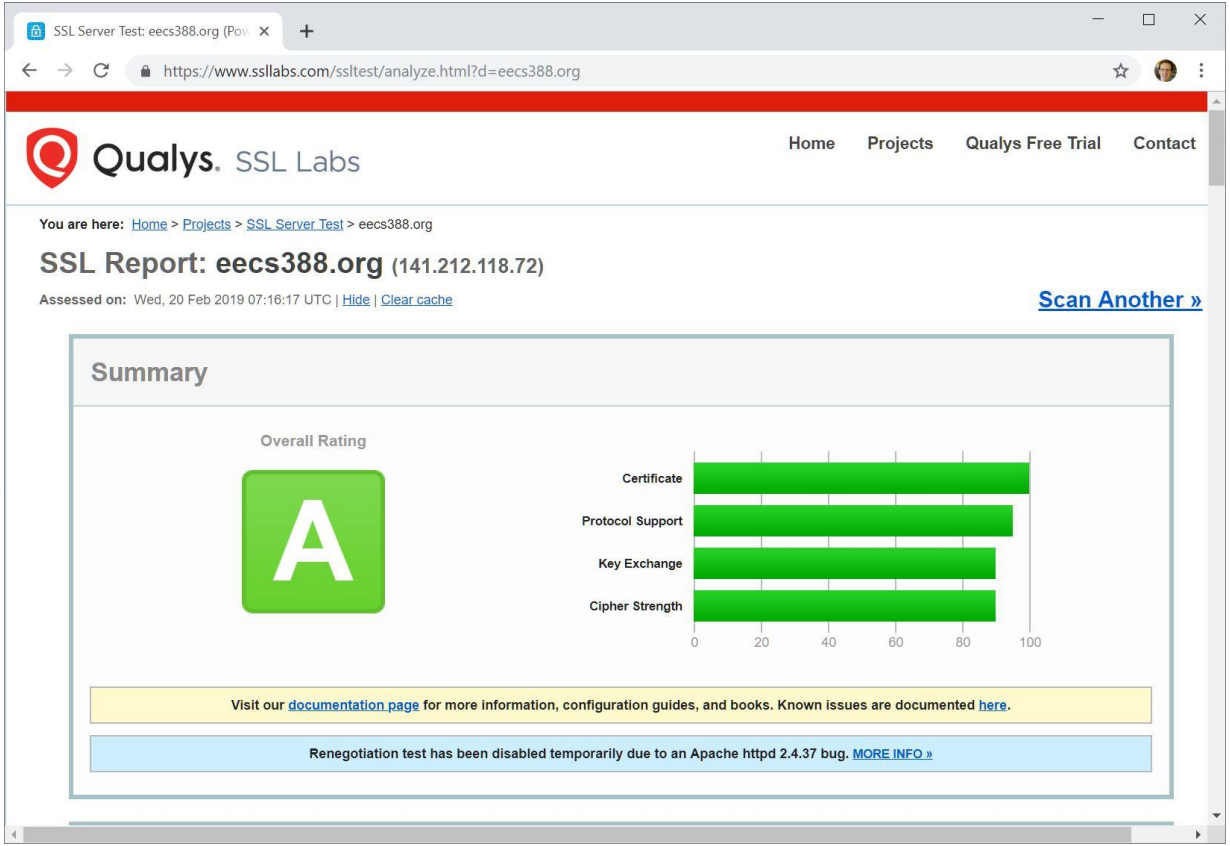
5. TLS Protocol Vulnerabilities

TLS server software is often insecure in its default configuration.

Common speedups, like session resumption, can also weaken security.

Mitigation:

Use tools such as **SSL Labs** to test your server, and apply mitigations.



6. Server Vulnerabilities

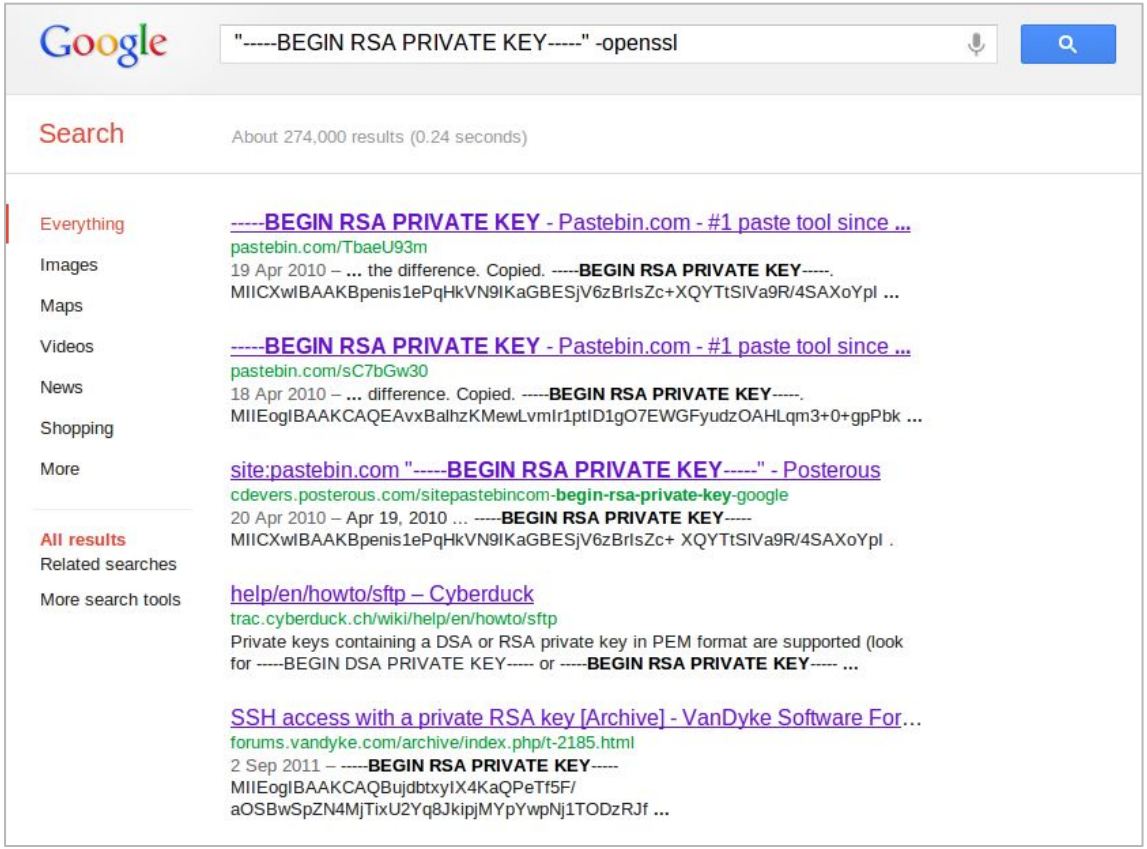
TLS servers must **protect their private keys**.

File permission errors, unencrypted backups, and intrusions can result in theft of private keys.

Mitigation:

Apply best practices of isolation and access control.

If keys leak, contact CA to have certificate revoked.



Coming Up

Reminders:

Lab Assignment 2 due TODAY at 6 PM

Project 2 due next Thursday, October 5, at 6 PM

Midterm Exam is Friday, October 20, 7-8:30 PM

Tuesday

Networking 101

Protocol layers, Ethernet, IP, routing

Thursday

Networking 102

TCP, UDP, and DNS attacks