HTTPS: Attacks and Defense

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SSL

- **SSL** (Secure Socket Layer) -- Netscape
  - Version 2.0 -- Broken, don't use (disabled by default in modern browsers)
  - Version 3.0 (older but still in use)
- **TLS** (Transport Layer Security) -- IETF Standard
  - Version 1.0, 1.1, 1.2 (commonly used),
  - Version 1.3 (draft)

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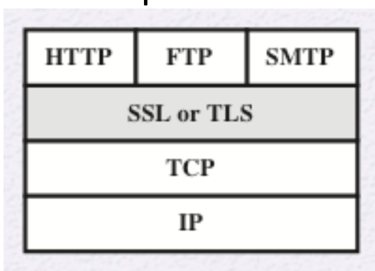
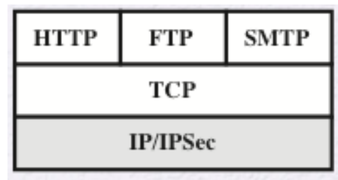
Different locations of security implementations

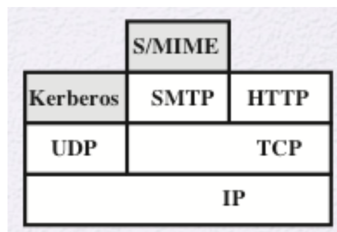
- Transport level



- Network level



- Application level



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Threat model

- Controls infrastructure (routers, DNS, wireless access points)
- Passive attacker: only eavesdrops
- Active attacker: eavesdrops, injects, blocks, and modifies packets
- What examples?
  - Internet Cafe, hotel, CSE, fake web site,
- Does not protect against:
  - Intruder on server
  - Spyware on client
  - SQL injection, XSS, CSRF

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Public-key cryptography

- Bob generates: SK_Bob, PK_Bob
- Alice can encrypt messages to Bob:
  - using PK_Bob encrypts messages, only Bob can decrypt
- Bob can sign messages that Alice can verify:
  - using SK_Bob signs message, anyone can verify
- What was the hard problem we haven't yet solved about this?

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Certificates

- This public key with SHA-256 hash (XXX) belongs to the site (name, e.g., Amazon.com)
  - Signed by a trusted authority (digital signature)
- Your browsers (e.g., Firefox, Chrome) trust a specific set of CAs as root CAs
  - Shipped with the public keys of the root CAs
  - Why do we need more than 1?

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Certificates

How does Alice (web browser) obtain PK_Bob?

Browser (Alice) | **Server (Bob)** | **Certificate Authority (CA)**
[Think of like a notary]

(Knows PK_CA) | (Keeps SK_CA Secret)

1. Choose (SK,PK)

--- PK and proof he is "Bob" -->

2. Checks proof

<-- Signs certificate with SK_CA ----
"Bob's key is PK -- Signed, CA"

3. Keeps cert on file

<-- Sends cert to Alice ----
"Bob's key is PK -- Signed, CA”

4. Verifies signature on cert.

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Certificates verification

- How is identity verification done?
  – Typically 'DV' (domain verification) – just an email based challenge to the address in the domain registration records (Or some default email address); minimally secure.
- Cert has expiration date (e.g., one year ahead) [-- Why?]

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SSL Certificates

- A trusted authority vouches that a certain public key belongs to a particular site
- Format called x.509 (complicated)
- Browsers ship with CA public keys for large number of trusted CAs [accreditation process]
- Important fields:
  - Common Name (CN) [e.g., *.google.com]
    Expiration Date [e.g. 2 years from now]
    Subject's Public Key
    Issuer -- e.g., Verisign
    Issuer's signature
- Common Name field
  - Explicit name, e.g. eecs.umich.edu
  - Or wildcard, e.g. *.umich.edu

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Certificate Chains

- CA can delegate ability to generate certificates for certain names: Intermediate CAs
- Root CA signs "certificate issuing certificate" for delegated authority
- Delegated authority signs cert for "eecs.umich.edu"
  - Delegated CA certificate: "pubkey=.... is allowed to sign certs for *.umich.edu"
- Browser that trusts root can examine certs to establish validity -- "Chain of trust"
- How to find out about all the CAs?
- More than 1000 trusted parties today, can sign for any domain – huge problem!

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How to invalidate certificates?

- Expiration date of certs
- Certificate invalidation
- What happens if a CA's secret key is leaked?
  - Can we trust the old certs from that CA?
- Interesting fact:
  - Google has instrumented Chrome such that when it observes a certificate for Google.com that it doesn't recognize, it panics…. (has happened several times)

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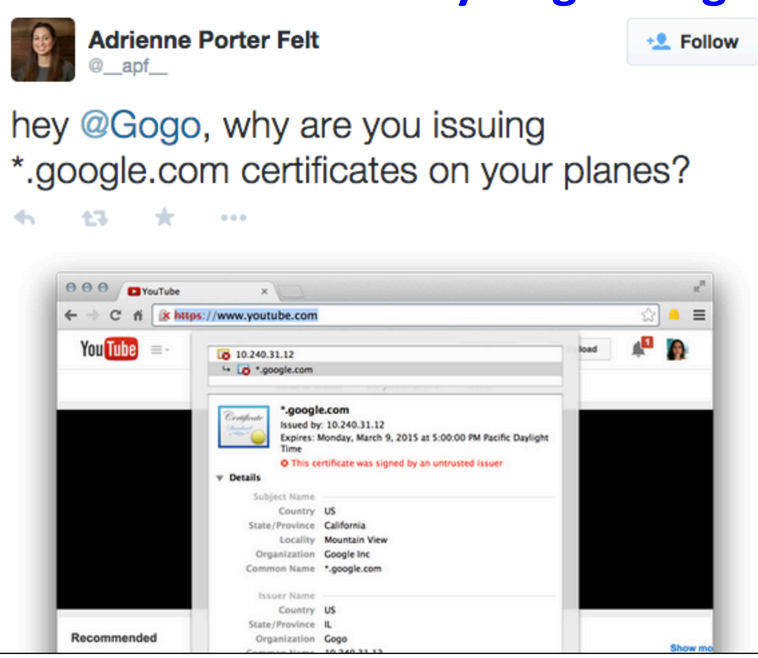
Man in the middle by Gogo inflight



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Self-signed Certificates

- Issuer signs their own certificate
  - A loop in the owner and signer
- Avoid CA fees, useful for testing
- Browsers display warnings that users have to override
- Protects only against passive attacker

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Question

- Can a web sever obtain SSL server certificates from two or more certification authorities? Justify your answer.
- Yes, the administrator of the website can apply for a certificate from multiple certification authorities. However, only one of these certificates is returned to the client as part of the HTTPS protocol.

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Exercise

- Which of the following security goals are addressed by the HTTPS protocol: (a) privacy, (b) confidentiality, (c) availability, (d) integrity,
- Does HTTPS authenticate the user?
  - User names and passwords are often used.

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How do we translate?

Cryptographic Primitives

Symmetric Encryption
RSA
PKI
HMAC
Certificate
Public Key
RC4
Diffie-Hellman
DSA
ECDSA
Asymmetric Encryption

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Objectives

Message Integrity

Confidentiality

Authentication

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Typical HTTPS Connection

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Case Study: SSL/TLS

- Arguably the most important (and widely used) cryptographic protocol on the Internet
- Almost all encrypted protocols (minus SSH) use SSL/TLS for transport encryption
- HTTPS, POP3, IMAP, SMTP, FTP, NNTP, XMPP (Jabber), OpenVPN, SIP (VoIP), …

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SSL vs. TLS

- SSL := Secure Sockets Layer (Netscape)
- TLS := Transport Layer Security (IETF)
- Terms are used interchangeably
- SSL 3.0 is predecessor to TLS 1.0

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Browser TLS Support

Browser	Platforms	TLS 1.0	TLS 1.1	TLS 1.2
Chrome 0–22	Linux, Mac OS X, Windows (XP, Vista, 7)[a]	Yes	No	No
Chrome 22–	Linux, Mac OS X, Windows (XP, Vista, 7)[a]	Yes	Yes	No
Firefox 2–	Linux, Mac OS X, Windows (XP, Vista, 7)	Yes[34]	No[35]	No[36]
IE 1–7	Mac OS X, Windows (XP, Vista, 7)[b]	Yes	No	No
IE 8–	Windows 7[b]	Yes	Yes	Yes
Opera 10–	Linux, Mac OS X, Microsoft Windows[c]	Yes	Yes, disabled	Yes, disabled
Safari 5–	Mac OS X, Windows (XP, Vista, 7)[d]	Yes	?	?

source: http://en.wikipedia.org/wiki/Transport_Layer_Security

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Where does TLS live?

Application (HTTP)

Transport (TCP)

Network (IP)

Data-Link (1gigE)

Physical (copper)

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Goals

- ✓ Confidentiality (Symmetric Crypto)
- ✓ Message Integrity (HMACs)
- ✓ Authentication (Public Key Crypto)

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Client Server

"the handshake"

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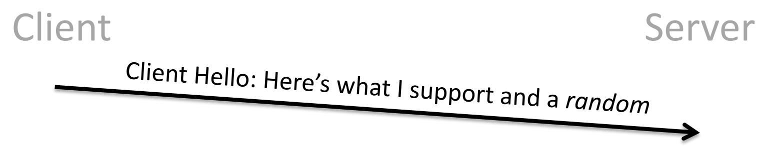
Client
Server
Client Hello: Here's what I support and a *random*

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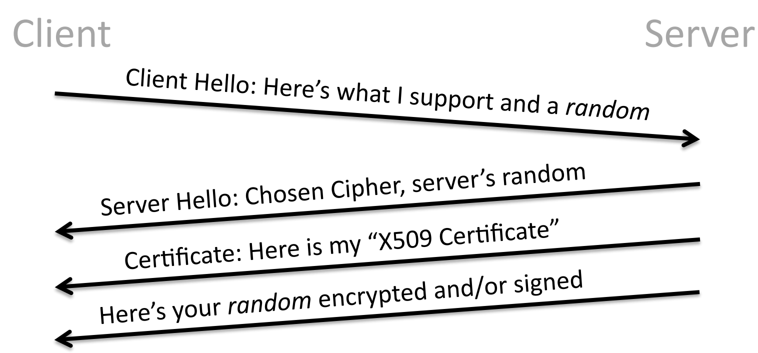
Client
Server
Client Hello: Here's what I support and a *random*
Server Hello: Chosen Cipher, server's random
Certificate: Here is my "X509 Certificate"
Here's your *random* encrypted and/or signed

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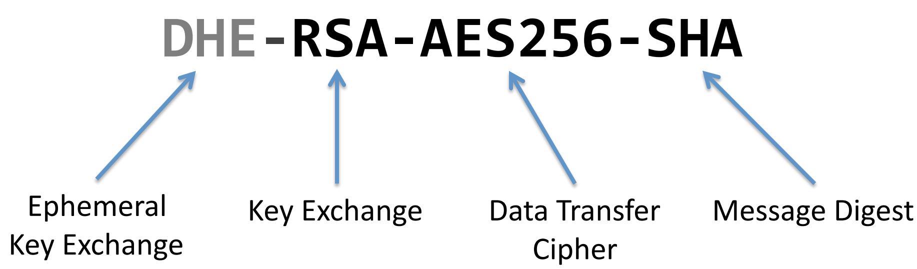
Cipher Suites



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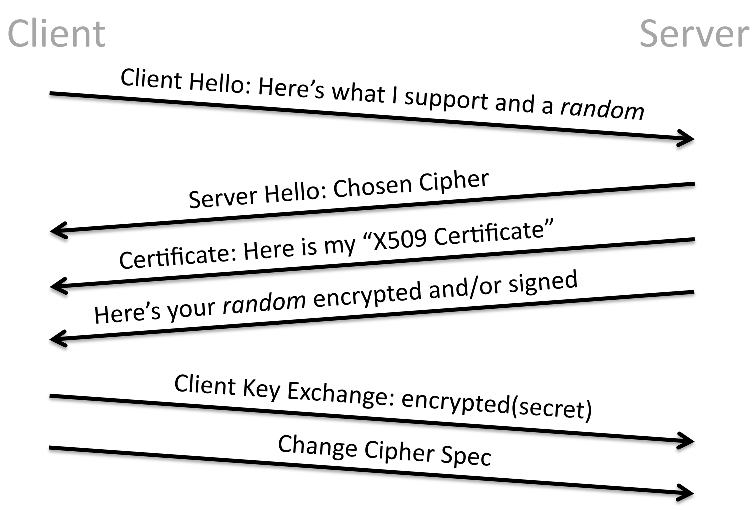

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HTTPS key exchange

1. RSA key exchange
   – Use RSA for encryption to achieve confidentiality
2. Ephemeral Diffie Hellman (EPH)
   – Use RSA for signature to achieve authentication

- Which one to use?
  – RSA is simpler, EPH is more work
  – What about forward secrecy guarantees?
- At the end of the exchange, a secret is used to generate 4 keys

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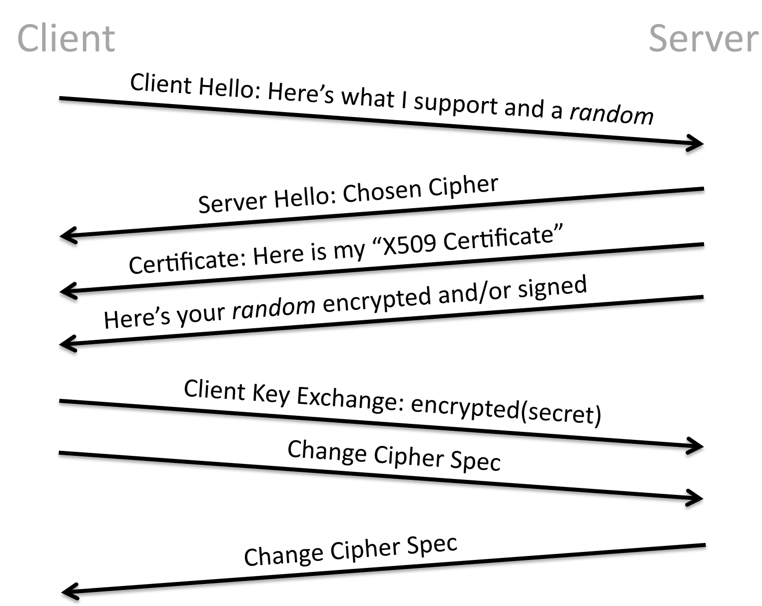

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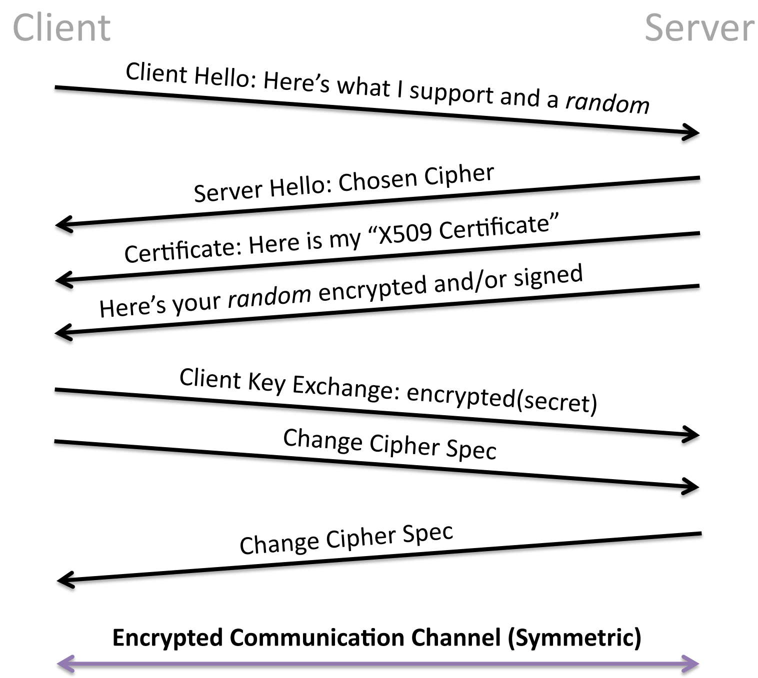

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X509 Certificates

Subject: C=US/O=Google Inc/CN=www.google.com
Issuer: C=US/O=Google Inc/CN=Google Internet Authority
Serial Number: 01:b1:04:17:be:22:48:b4:8e:1e:8b:a0:73:c9:ac:83
Expiration Period: Jul 12 2010 - Jul 19 2012
Public Key Algorithm: rsaEncryption
Public Key: 43:1d:53:2e:09:ef:dc:50:54:0a:fb:9a:f0:fa:14:58:ad:a0:81:b0:3d 7c:be:b1:82:19:b9:7c3:8:04:e9:1e5d:b5:80:af:d4:a0:81:b0:b0:68:5b:a4:a4 :ff:b5:8a:3a:a2:29:e2:6c:7c3:8:04:e9:1e5d:b5:7c3:8:04:e9:39:23:46

Signature Algorithm: sha1WithRSAEncryption

Signature: 39:10:83:2e:09:ef:ac:50:04:0a:fb:9a:f0:fa:14:58:ad:a0:81:b0:3d 7c:be:b1:82:19:b9:7c3:8:04:e9:1e5d:b5:80:af:d4:a0:81:b0:b0:68:5b:a4:a4 :ff:b5:8a:3a:a2:29:e2:6c:7c3:8:04:e9:1e5d:b5:7c3:8:04:e9:1e:5d:b5

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Certificate Chains

Mozilla Firefox Browser

Trust everything signed by this "root" certificate

Subject: C=US/…/OU=Equifax Secure Certificate Authority
Issuer: C=US/…/OU=Equifax Secure Certificate Authority
Public Key:
Signature: 39:10:83:2e:09:ef:ac:50:04:0a:fb:9a:38:c9:d1

I authorize and trust this certificate; here is my signature

Subject: C=US/…/CN=Google Internet Authority
Issuer: C=US/…/OU=Equifax Secure Certificate Authority
Public Key:
Signature: be:b1:82:19:b9:7c:5d:28:04:e9:1e:5d:39:cd

I authorize and trust this certificate; here is my signature

Subject: C=US/…/O=Google Inc/CN=*.google.com
Issuer: C=US/…/CN=Google Internet Authority
Public Key:
Signature: bf:dd:e8:46:b5:a8:5d:28:04:38:4f:ea:5d:49:ca

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Certificate Authority Ecosystem

Each browser trusts a set of CAs

- CAs can sign certificates for new CAs
- CAs can sign certificates for any web site

If a single CA is compromised, then the entire system is compromised

We ultimately place our complete trust of the Internet in the weakest CA

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Immediate Concerns

- Nobody has any idea who these CAs are…
- 1,733 *umich*-known browser trusted CAs
- History of CAs being hacked (e.g. Diginotar)
- Oooops, Korea gave every elementary school, library, and agency a CA certificate (1,324)
  – Luckily invalid due to a higher-up constraint

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Getting a Certificate

- Certificates are free (from StartSSL)!
  – https://cert.startcom.org/
- Certificates are cheap if you don't want to use the impossible-to-use StartSSL web interface
- Identity is almost always validated via e-mail to the default e-mail addresses
- Setting up SSL is hard. People are terrible at it.

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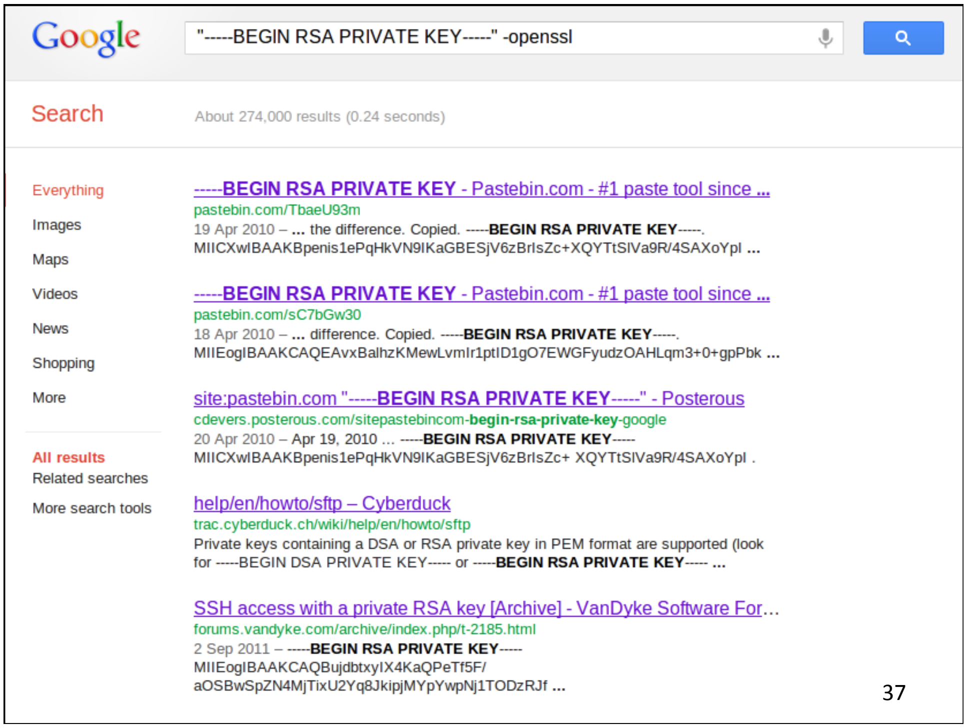

Attack Vectors

- Attack the weakest Certificate Authority
- Attack browser implementations
- Magically notice a bug in a key generation library that leads you to discovering all the private keys on the Internet
- Attack the cryptographic primitives
  - Math is hard, let's go shopping!

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SSL in the browser

- Lock icon
  - HTTPS cert must be issued by a CA trusted by browser
  - HTTPS cert is valid (e.g., not expired or revoked)
  - CommonName in cert matches domain in URL
- Extended Validation (EV) certificates
  - CA does extra work to verify identity -- expensive, but more secure
- Invalid certificate warnings

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Attacking site design

- SSLstrip attack
  - Proxy through the content w/o HTTPS
- Defense
  - Default HTTPS for all web sites?
  - HSTS (hypertext strict transport security): header says: always expect HTTPS, enforced by browsers.
  - HTTPS Everywhere: browser extension
  - EV: Extended Validation (compared to DV: Domain Validation)

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Attacking site design

- Mixed Content attack -- Page loads over HTTPS but contains content over HTTP
  - e.g. JavaScript, Flash
  - Active attacker can tamper with HTTP content to hijack session
- Defense: Browser warnings: ["This page contains insecure content"],
  - but inconsistent and often ignored

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UI interface based attacks

- Invalid certs
  - Expired, Common Name != URL, unknown CA (e.g., self-signed)
- Defense: browser warnings, anti-usability to bypass…
- Picture-in-picture attack: spoof the user interface
  - Attacker page draws fake browser window with lock icon
- Defense: individualized image

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Attacking the PKI: CA compromise Example: DigiNotar

- DigiNotar ***was*** a Dutch Certificate Authority
- On June 10, 2011, **`*.google.com`** cert was issued to an attacker and subsequently used to orchestrate MITM attacks in Iran
- Nobody noticed the attack until someone found the certificate in the wild… and posted to *pastebin*

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DigiNotar Contd.

- DigiNotar later admitted that dozens of fraudulent certificates were created
- Google, Microsoft, Apple and Mozilla all revoked the root Diginotar certificate
- Dutch Government took over Diginotar
- Diginotar went bankrupt and died

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Attacking the PKI: Hash collisions

- MD5 is known to be broken -- Can generate collisions
- In 2008, researchers showed that they could create a rogue CA certificate using an MD5 collision
- Attack: Make colliding messages A, B, with same MD5 hash:
  - A: Site certificate: "cn=attack.com, pubkey=...."
  - B: Delegated CA certificate: "pubkey=.... is allowed to sign certs for *"
  - Get CA to sign A -- Signature is Sign(MD5(message))
  - Signature also valid for B (same hash)
  - Attacker is now a CA!
  - Make a cert for any site, browsers will accept it

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MD5 considered harmful

- MD5 CA certificates still exist, but CAs have stopped signing certificates with them
  - 879,705 certificates still have MD5 signatures

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Attacking implementations: Null Termination Attack

- ASN.1 utilizes Pascal-style strings
- Web browsers utilize use C-style strings
- Announced by Moxie in 2009

`gmail.com\0.badguy.com`

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Null Termination Attack

- www.attacker.com
  - [CAs verify cert by looking up who owns the last part of the domain via DNS record]
  - emails "webmaster@attack.com" --> "Click here to validate cert request"
- x.509 certs encode CN field as a Pascal string (length +data)
- Browsers copy it into a C string (data+\0)
- What if CA contains "\0"?
  - www.paypal.com\0.attacker.com?
  - CA contacts "attacker.com" to verify (last part of domain name)
  - Browsers copy to C string, terminates at "\0" -- see only paypal.com
  - Attacker now has a cert that works for Paypal!

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Other implementation-based attacks

- Goto fail, Feb. 2014 (Apple SSL bug; skipped certificate check for almost a year!)
- Heartbleed, April 2014 (OpenSSL bug; leaked data, possibly including private key!)
- Mozilla BERserk vulnerability, Oct 2014 (Bug in verifying cert signatures, allowed spoofing certs, probably since the beginning….!)

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Take aways

- Use HTTPS! It's so much better than nothing .
- SSL keeps breaking. Use it, but don't rely on it exclusively.
- Have a backup plan for times when it's broken.

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Exercise

- Suppose a web client and web server for a popular shopping web site have performed a key exchange so that they now share a secret session key. Describe a secure method for the client to visit the shopping site.
- Your solution cannot use HTTPS, so it does not need to achieve confidentiality. It should be resistant to HTTP session hijacking even from someone who can sniff all the packets.

- **Solution:** Seed the PRNG with the secret key and include in each HTTP request the next pseudo-random number in the sequence, as well as a userID, as a part of the URL. The server can determine that this is the specified user, because even an eavesdropper would not be able to determine the next number in the PRNG.

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