CS 5435

Adventures in TLS

Vitaly Shmatikov

What Is SSL / TLS?

Secure Sockets Layer and
Transport Layer Security protocols

- Same protocol design, different crypto algorithms

De facto standard for Internet security

- "The primary goal of the TLS protocol is to provide privacy and data integrity between two communicating applications"

Deployed in every Web browser; also VoIP, payment systems, distributed systems, etc.

SSL / TLS Guarantees

End-to-end secure communications in the presence of a network attacker

- Attacker completely 0wns the network: controls Wi-Fi, DNS, routers, his own websites, can listen to any packet, modify packets in transit, inject his own packets into the network

Scenario: you are reading your email from an Internet café connected via a r00ted Wi-Fi access point to a dodgy ISP in a hostile authoritarian country

SSL Basics: Two Protocols

Handshake protocol

- Uses public-key cryptography to establish several shared secret keys between the client and the server

Record protocol

- Uses the secret keys established in the handshake protocol to protect confidentiality, integrity, and authenticity of data exchange between the client and the server

SSL Handshake Protocol

Runs between a client and a server

- For example, client = Web browser, server = website

Negotiate version of the protocol and the set of cryptographic algorithms to be used

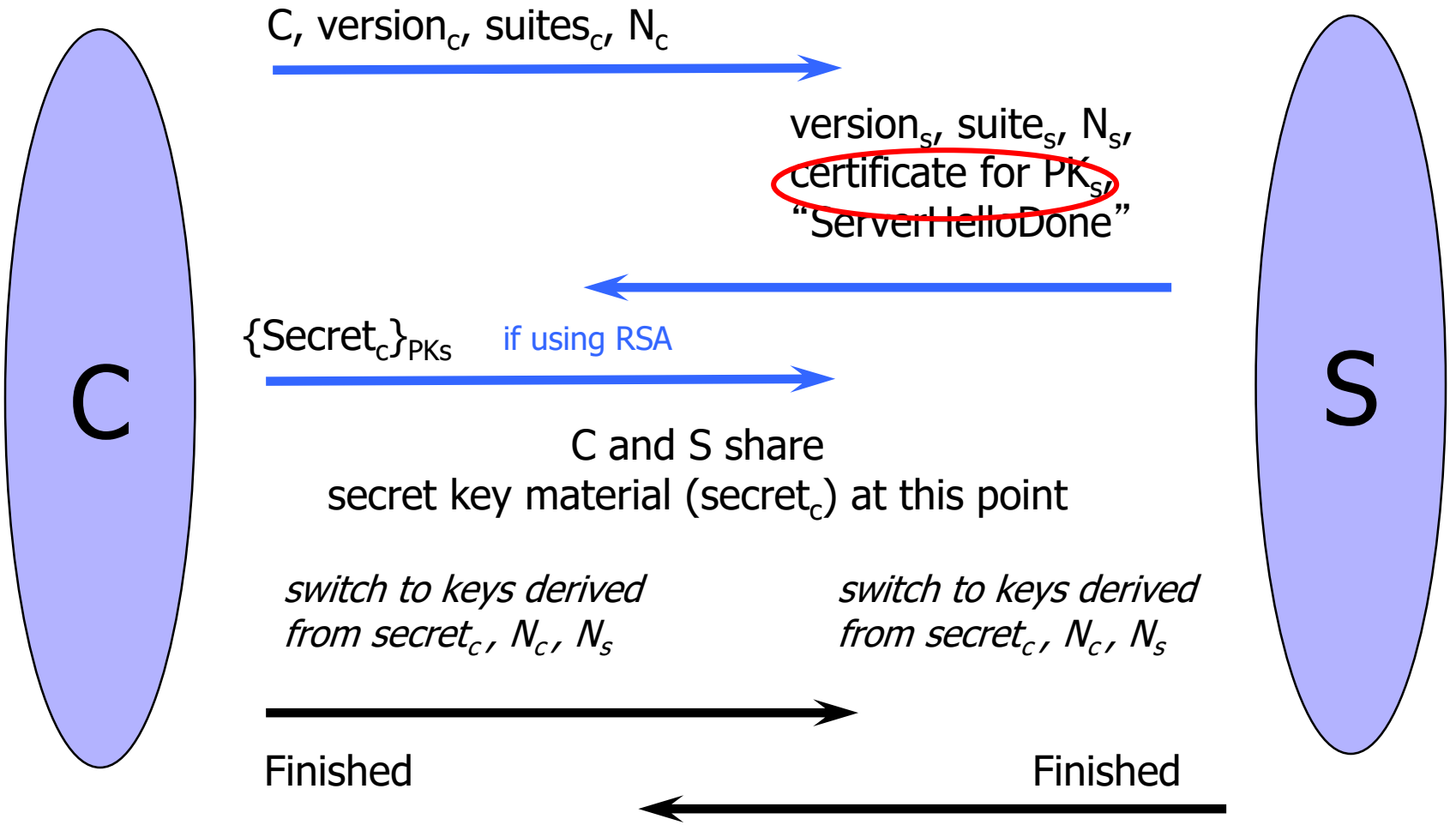
- Interoperability between different implementations

Authenticate server and client (optional)

- Use digital certificates to learn each other's public keys and verify each other's identity
- Often only the server is authenticated

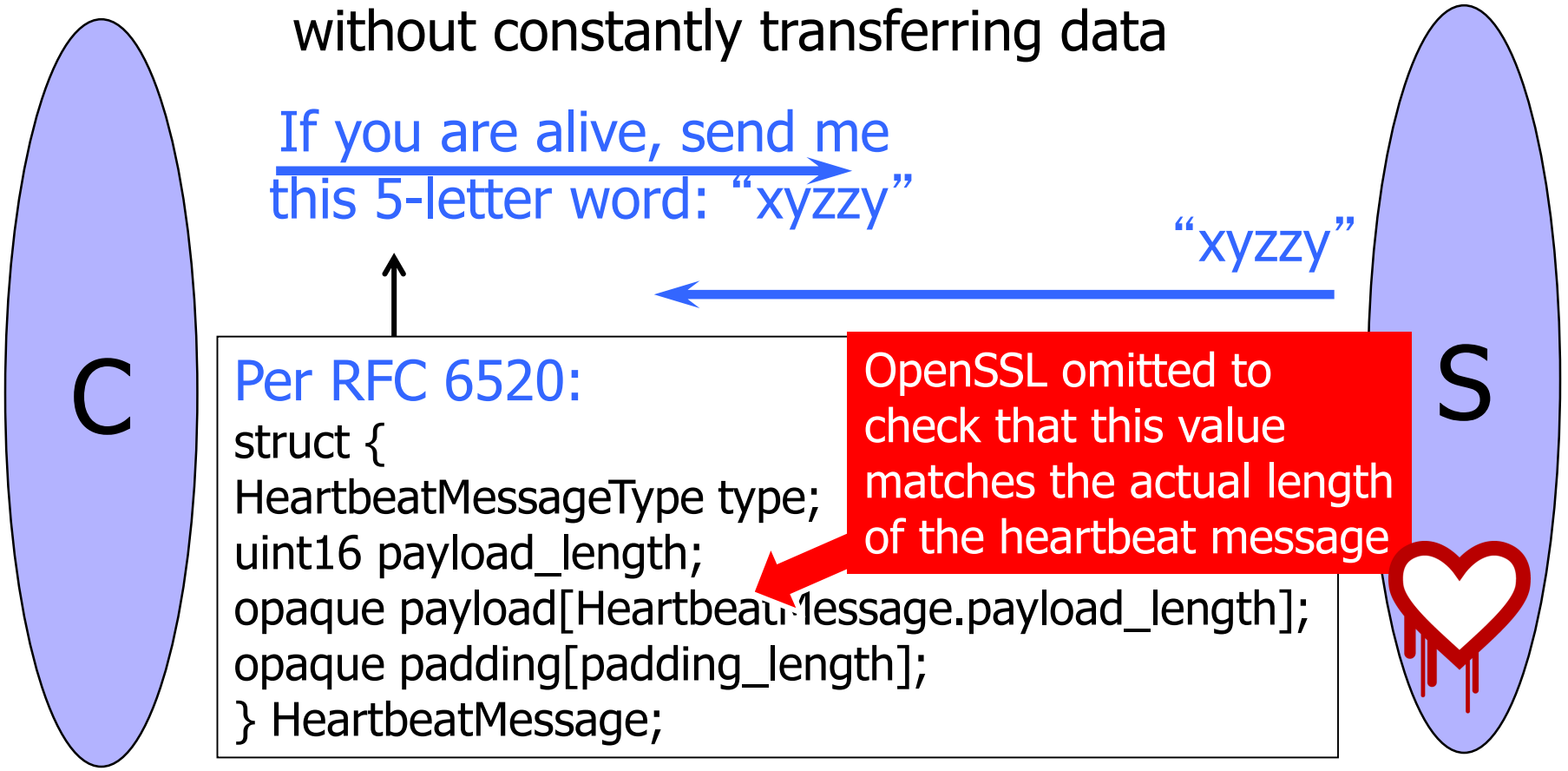
Use public keys to establish a shared secret

“Core” SSL Handshake



TLS Heartbeat

A way to keep TLS connection alive without constantly transferring data



Heartbleed Consequences

Attacker can obtain chunks of server memory

- Passwords, contents of other users' communications, even the server's private RSA key
- Why is the RSA key still in memory? Long story:

https://www.lightbluetouchpaper.org/2014/04/25/heartbleed-and-rsa-private-keys/

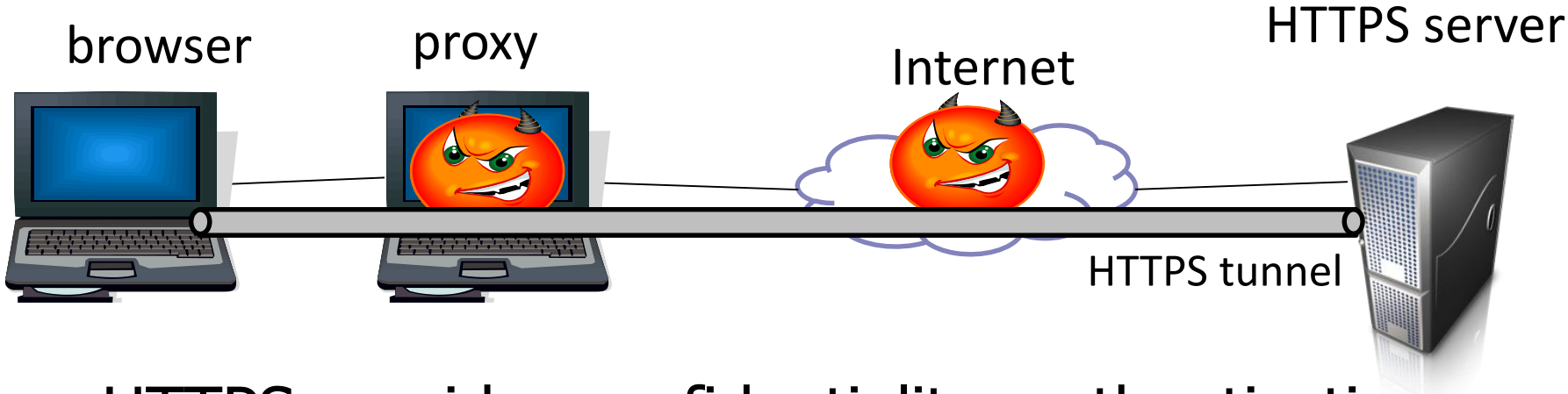
Assisted by a custom allocator that does not zero out malloc'd memory (for "performance," natch!)

Common Use of SSL/TLS

HTTPS and Its Adversary Model

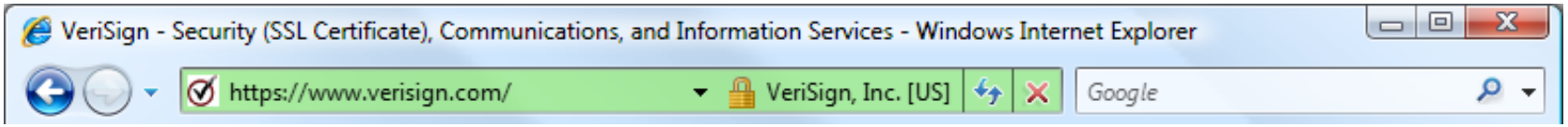
HTTPS: end-to-end secure protocol for Web

Designed to be secure against network attackers, including man-in-the-middle (MITM) attacks



HTTPS provides confidentiality, authentication (usually for server only), and integrity checking

The Lock Icon



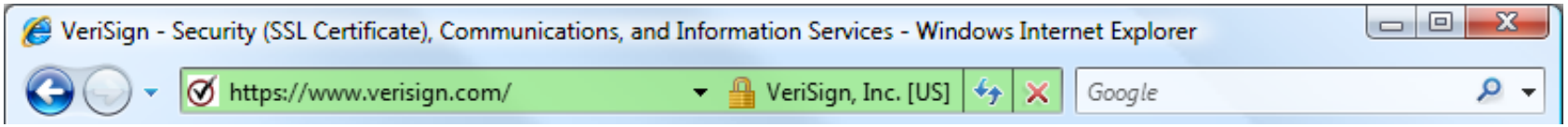
Goal: identify secure connection

- SSL/TLS is being used between client and server to protect against active network attacker

Lock icon should only be shown when the page is secure against network attacker

- Semantics subtle and not widely understood by users
- Problem in user interface design

HTTPS Security Guarantees



The origin of the page is what it says in the address bar

- User must interpret what he sees

Contents of the page have not been viewed or modified by a network attacker

Problematic UI

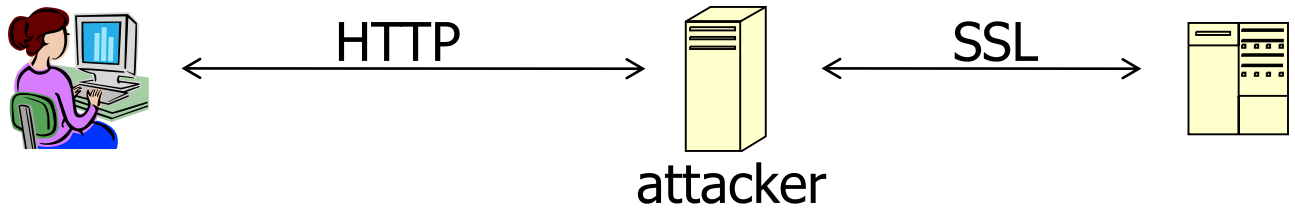
Guideline:
Response to **http://login.site.com** should redirect to location: **https://login.site.com**

HTTP → HTTPS and Back

Typical pattern: HTTPS upgrade

- Come to site over HTTP, redirect to HTTPS for login
- Browse site over HTTP, redirect to HTTPS for checkout

sslstrip: network attacker downgrades connection

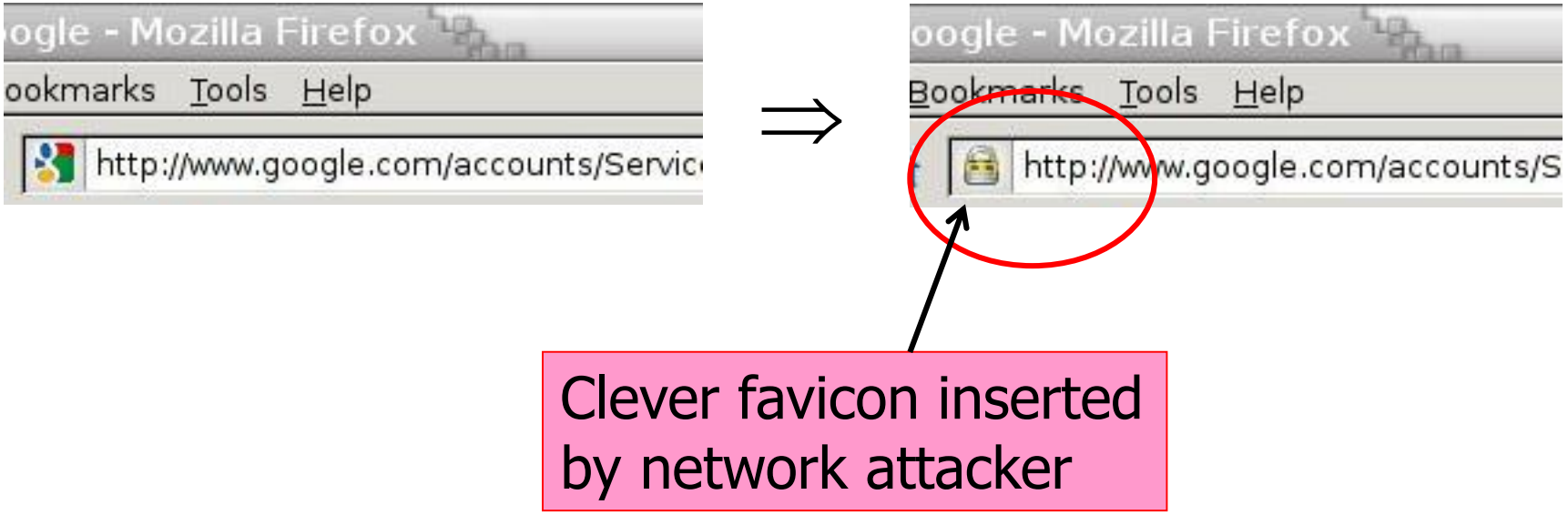


- Rewrite <a href=https://…> to <a href=http://…>
- Redirect Location: https://... to Location: http://...
- Rewrite <form action=https://… > to <form action=http://…>

Can the server detect this attack?

Will You Notice?

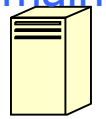
[Moxie Marlinspike]



HSTS: Strict Transport Security

Strict-Transport-Security: max-age=63072000; includeSubDomains

(ignored if not over HTTPS)



Header tells browser to always connect over HTTPS

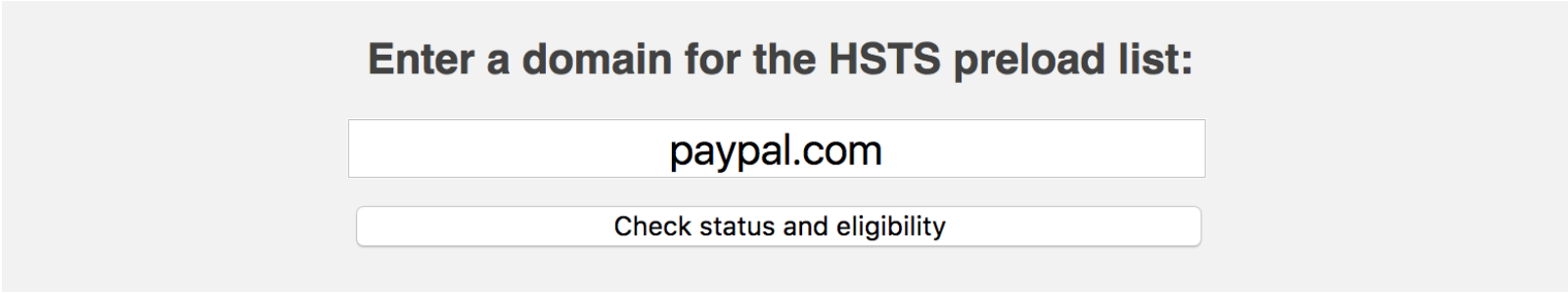
Subsequent visits must be over HTTPS (self signed certs result in an error)

- Browser refuses to connect over HTTP or if site presents an invalid cert
- Requires that entire site be served over valid HTTPS

HSTS flag deleted when user "clears private data" : security vs. privacy

Preloaded HSTS List

https://hstspreload.org/



Strict-Transport-Security: max-age=63072000; includeSubDomains; **preload**

Preload list hard-coded in Chrome source code. Examples:
Google, Paypal, Twitter, Simple, Linode, Stripe, Lastpass, …

Using CSP to Upgrade to HTTPS

Problem: many pages use <img src="http://site.com/img">
Makes it difficult to migrate a section of a site to HTTPS

Solution: gradual transition using CSP

Content-Security-Policy: upgrade-insecure-requests

<img src="http://site.com/img">
<img src="http://othersite.com/img">
<a href="http://site.com/img">
<a href="http://othersite.com/img">

<img src="https://site.com/img">
<img src="https://othersite.com/img">
<a href="https://site.com/img">
<a href="http://othersite.com/img">

Common Use of SSL/TLS

Distribution of Public Keys

Public announcement or public directory

- Risks: forgery and tampering

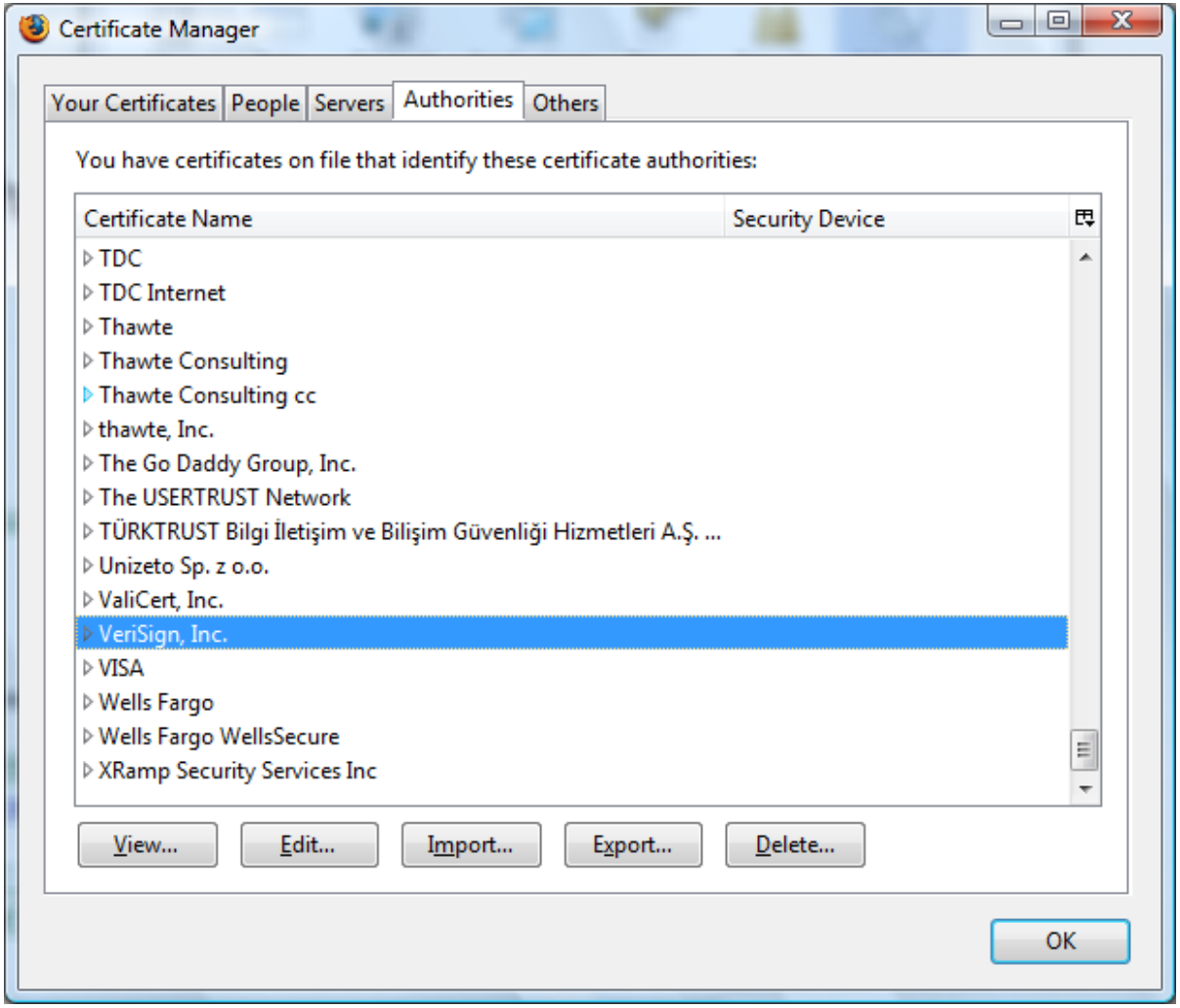
Public-key certificate

- Signed statement specifying the key and identity
  - sig_{Alice}(“Bob”, PK_B)

Common approach: certificate authority (CA)

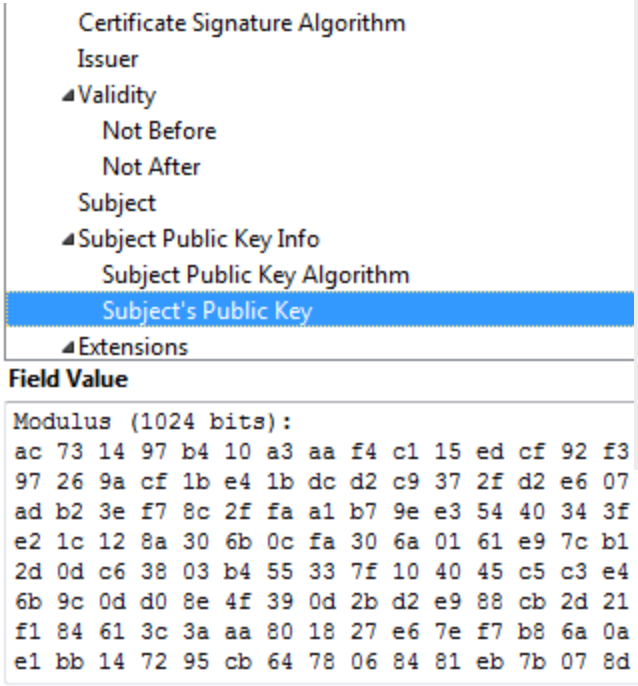
- An agency responsible for certifying public keys
- Browsers are pre-configured with 100+ of trusted CAs
- A public key for any website in the world will be accepted by the browser if certified by one of these CAs

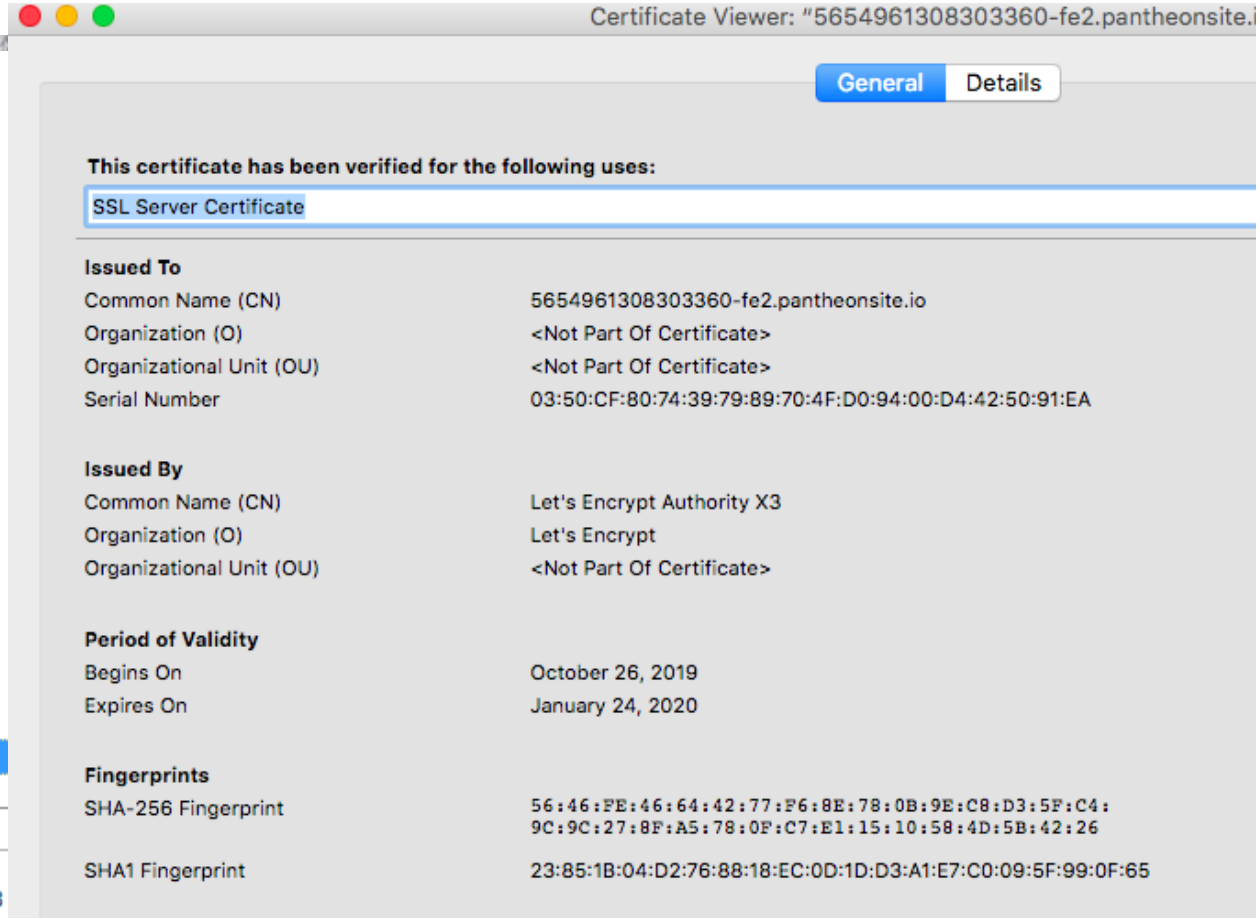
Trusted Certificate Authorities



Example of a Certificate

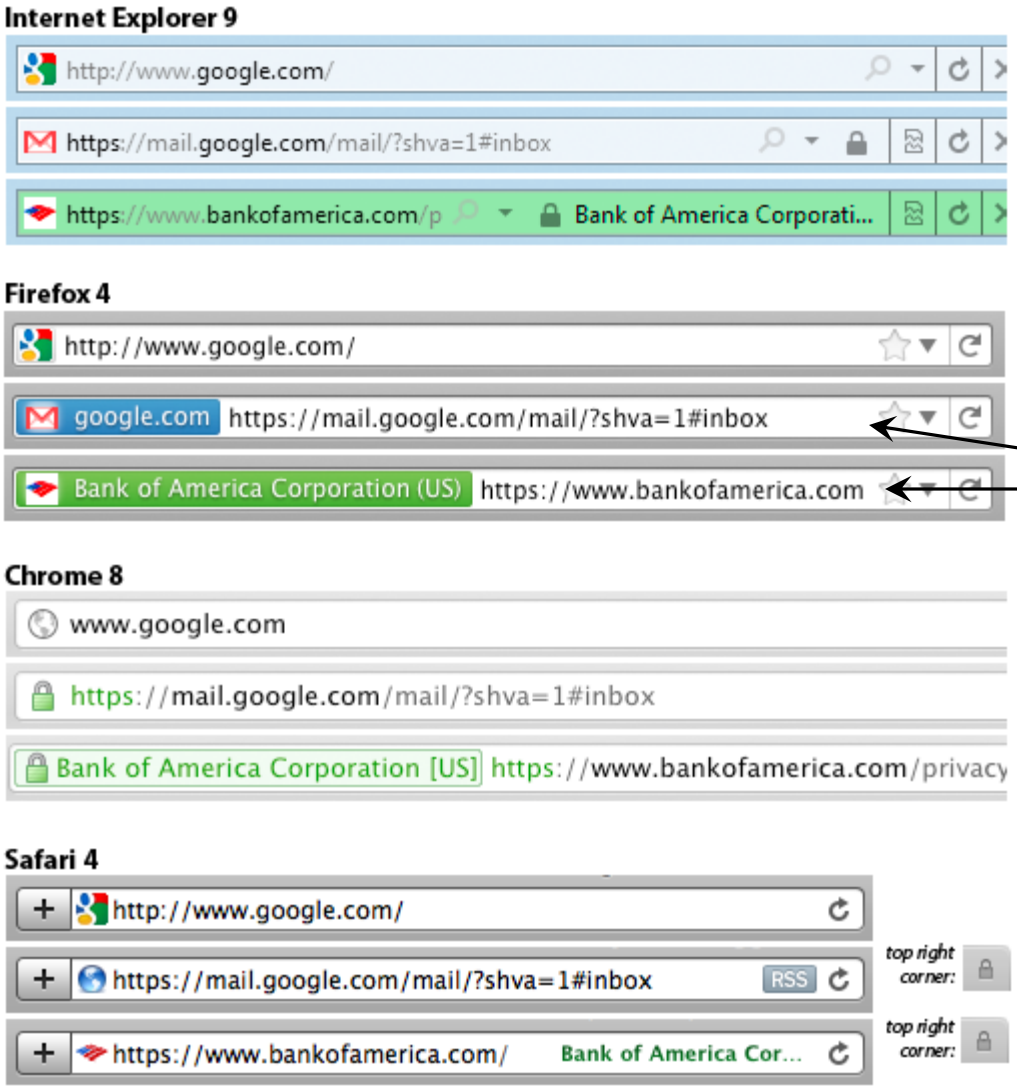
Important fields





Meaning of Color

[Schultze]



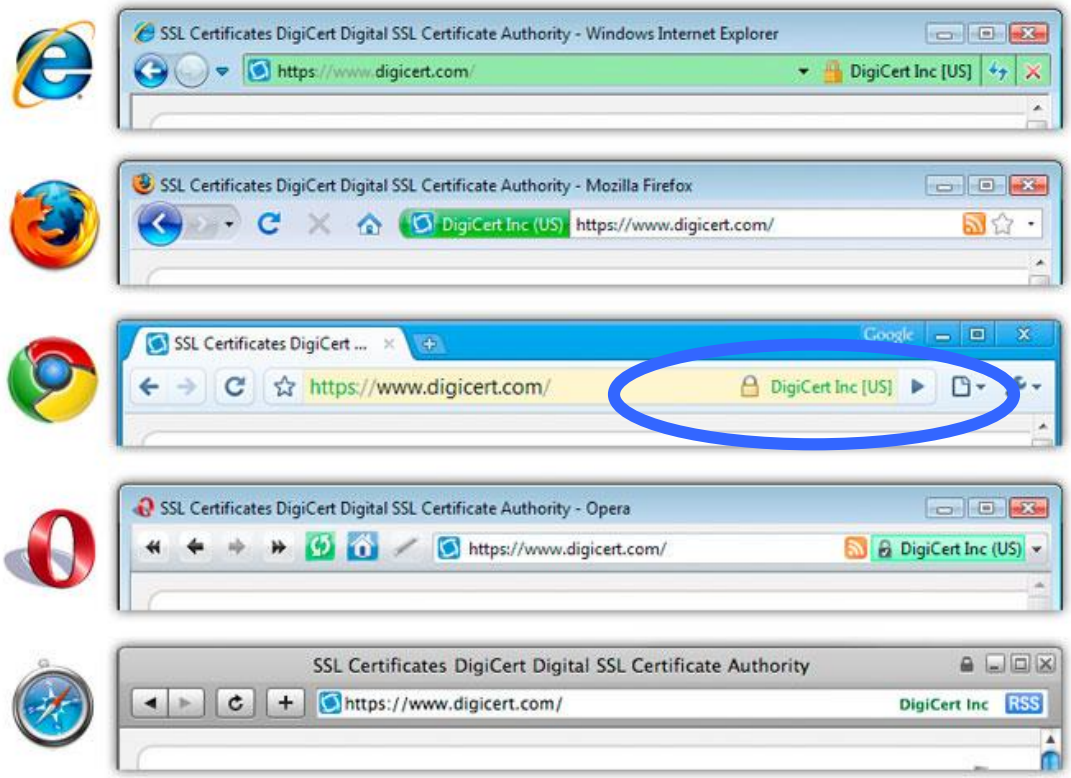
What is the difference?

Domain Validation (DV) certificate
vs.
Extended Validation (EV) certificate

Means what?

Extended Validation (EV) Certificates

Certificate request must be approved by a human lawyer at the certificate authority



Helps block "semantic attacks": www.bankofthevvest.com

UI ineffective, removed from Chrome in 2019

Questions about EV Certificates

What does EV certificate mean?

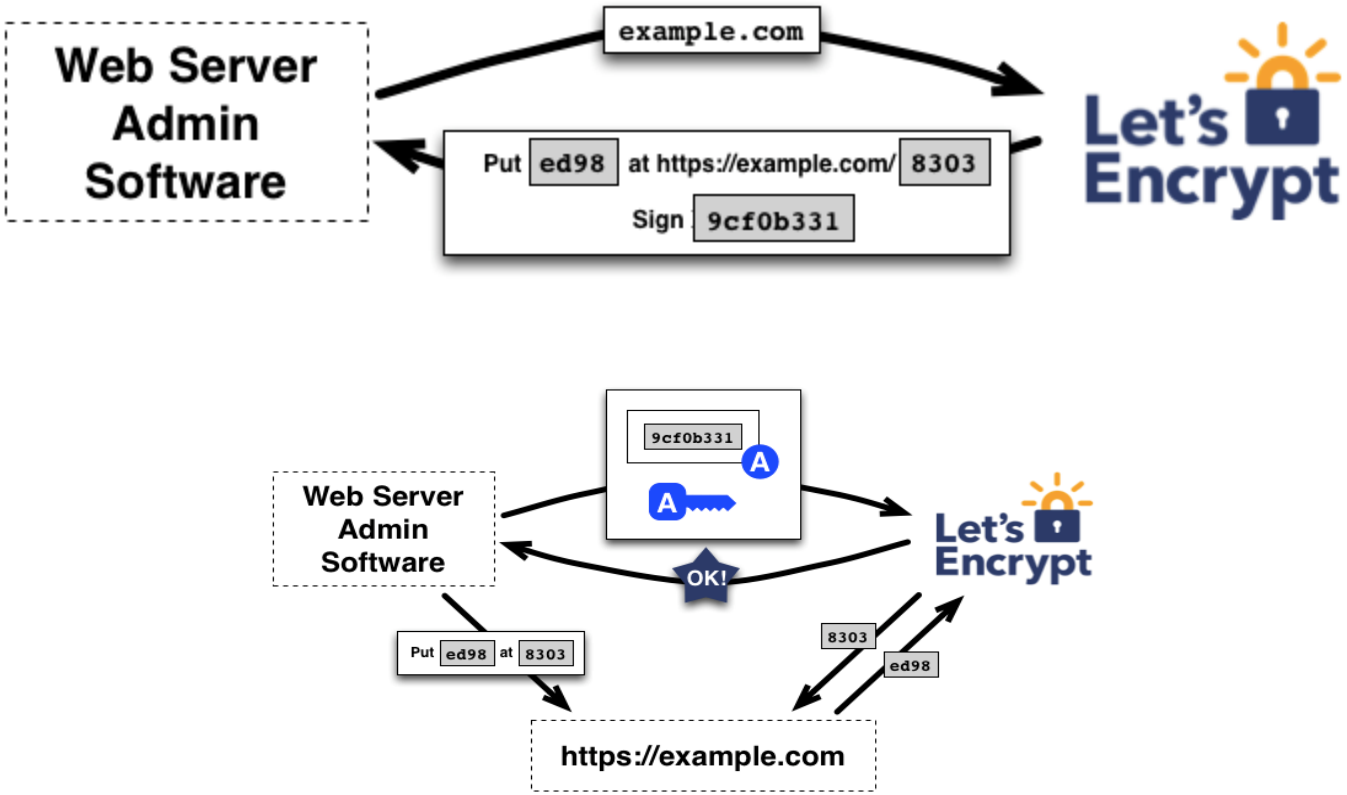
What is the difference between an HTTPS connection that uses a regular certificate and an HTTPS connection that uses an EV certificate?

If an attacker has somehow obtained a non-EV certificate for bank.com, can he inject a script into https://bank.com content?

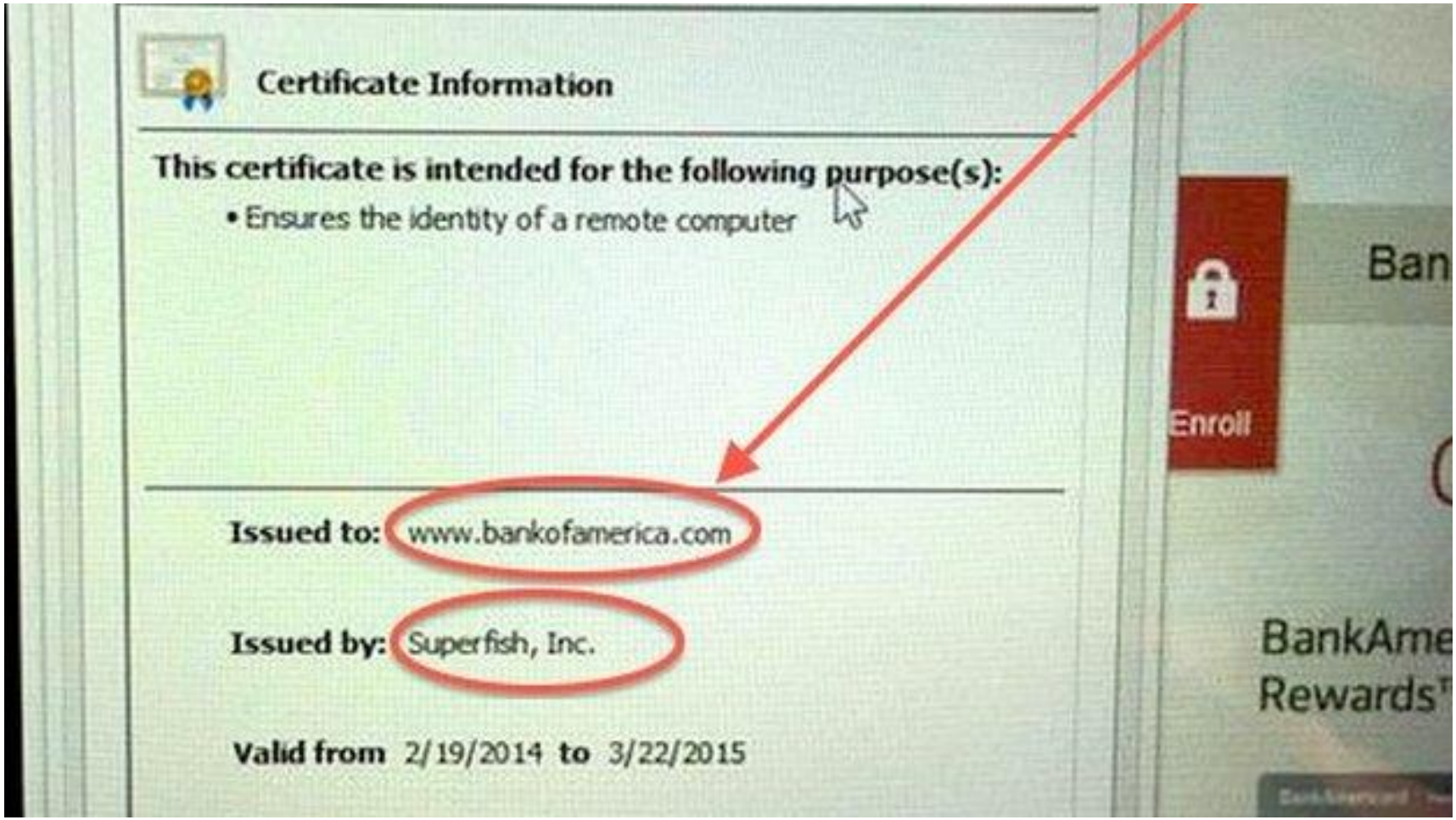
- What is the origin of the script? Can it access or modify content that arrived from actual bank.com via HTTPS?

What would the browser show – blue or green?

Free CAs


Web Server Admin Software
example.com
Put ed98 at https://example.com/ 8303
Sign 9cf0b331
Let's Encrypt
9cf0b331
A
A
OK!
Web Server Admin Software
Let's Encrypt
Put ed98 at 8303
8303
ed98
https://example.com

Another Example of a Certificate



Root Certificates in Lenovo

In the news

Lenovo hit by lawsuit over Superfish adware
CNET - 3 days ago
Sarah Tew/CNET. **Lenovo** may find itself in a courtroom over its **Superfish adware** fiasco.

Interview with Lenovo's CTO will scare anyone still thinking of buying a Lenovo product
BGR - 2 days ago

Lenovo's Chief Technology Officer Discusses the Superfish Adware Fiasco - NYTimes.com
Bits - The New York Times - 3 days ago

More news for lenovo superfish adware

Lenovo Sued Over Superfish Adware : NPR
www.npr.org › News › Business NPR
2 days ago - Renee Montagne talks to Jordan Robertson of Bloomberg News about computer maker **Lenovo**, which allowed controversial spyware to be ...

Lenovo users lawyer up over hole-filled, HTTPS-breaking ...
arstechnica.com/.../**lenovo**-users-lawyer-up-over-hole-filled... Ars Technica
4 days ago - In the wake of last week's **Lenovo's Superfish** debacle, at least one ... and that **Superfish adware** "does not present a security risk," despite ...

Lenovo's Chief Technology Officer Discusses the Superfish ...
bits.blogs.nytimes.com/.../**lenovos**-chief-technology-officer-discusses-the...
3 days ago - The **adware** was intended to serve **Lenovo** users targeted ads, but the company **Lenovo** partnered with to do this, **Superfish**, did so by hijacking ...

Lenovo Sued Over Superfish Adware | News & Opinion ...
www.pcmag.com › Reviews › Software › Security PC Magazine
4 days ago - Not surprisingly, the controversy over **Lenovo** installing **Superfish adware** into its consumer PCs has resulted in a lawsuit. According to the suit, ...

CA Hierarchy

Browsers, operating systems, etc. have trusted root certificate authorities

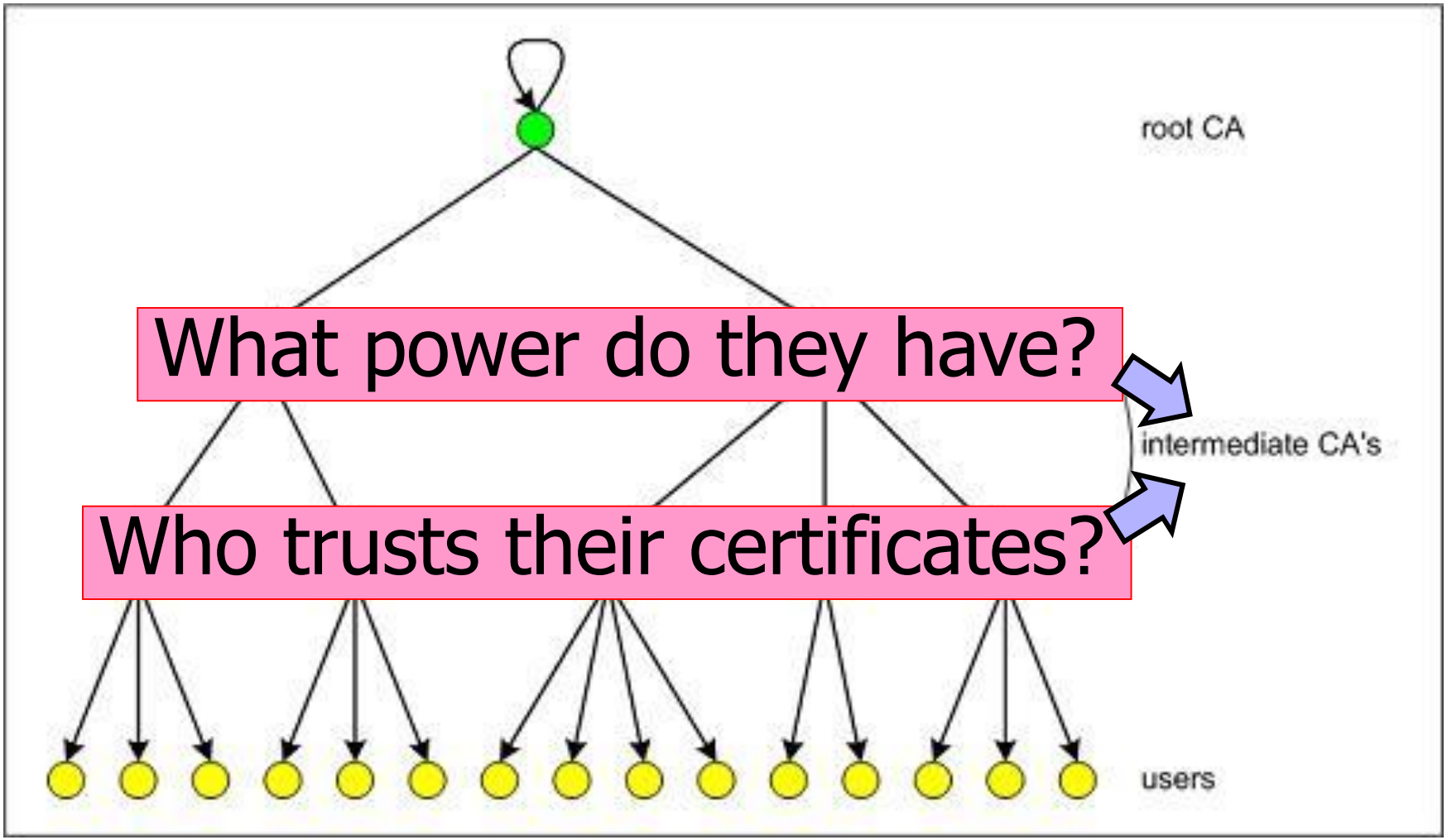
- Chrome includes certificates of ~200 trusted root CAs

A Root CA signs certificates for intermediate CAs, they sign certificates for lower-level CAs, etc.

- Certificate "chain of trust"
  - $sig_{Verisign}$("Cornell", $PK_{Cornell}$), $sig_{Cornell}$("Vitaly S.", PK_{Vitaly})

CA is responsible for verifying the identities of certificate requestors, domain ownership

Certificate Hierarchy



HTTPS Certificate Ecosystem

"1,800 entities that are able to issue certificates vouching for the identity of any website"

- Durumeric et al. Analysis of the HTTPS Certificate Ecosystem (2013) http://conferences.sigcomm.org/imc/2013/papers/imc257-durumericAemb.pdf

Flame

Cyber-espionage virus (2010-2012)

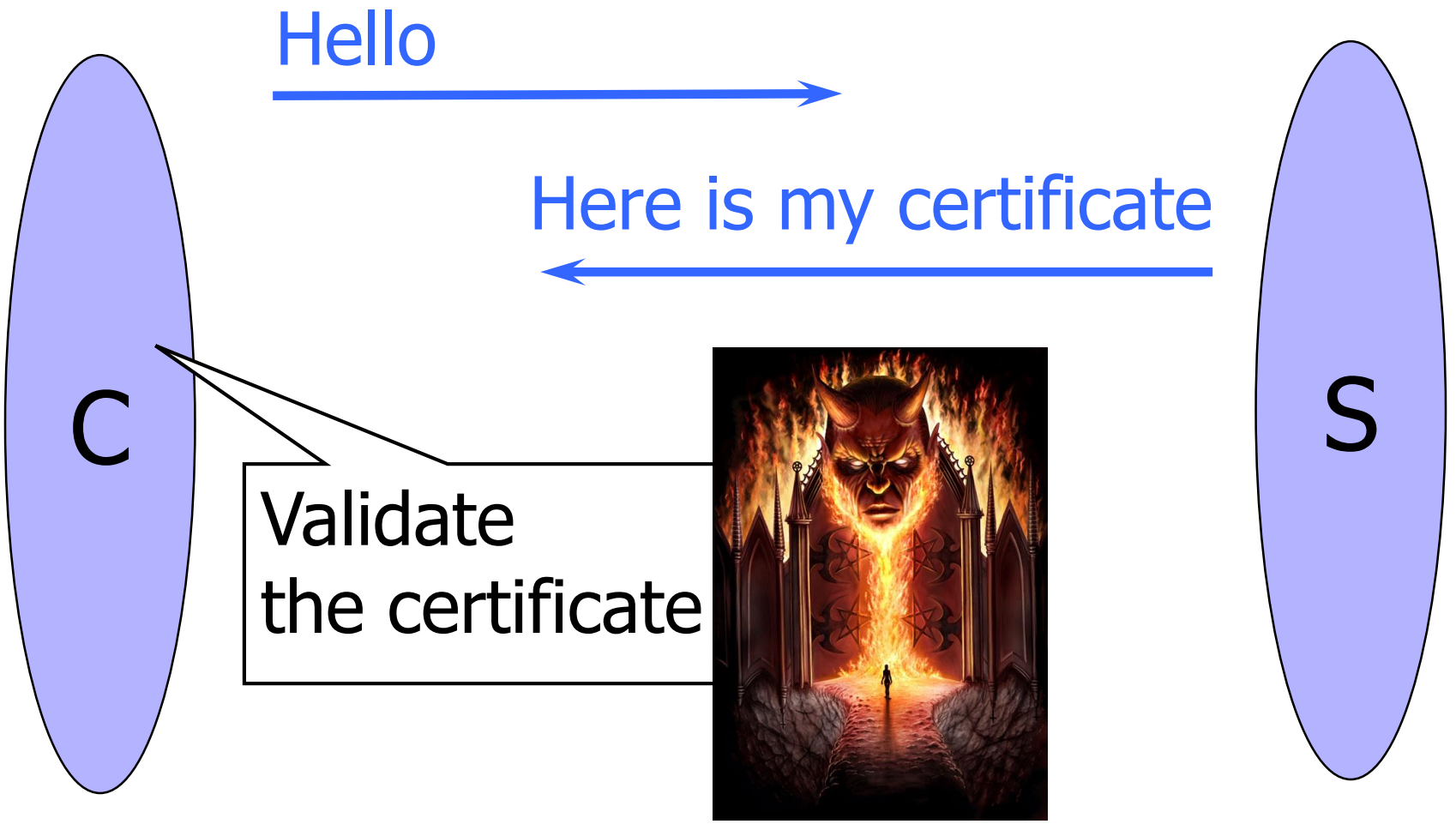
Signed with a fake intermediate CA certificate accepted by any Windows Update service

- Fake intermediate CA certificate was created using an MD5 chosen-prefix collision against an obscure Microsoft Terminal Server Licensing Service certificate that was enabled for code signing and still used MD5

MD5 collision technique possibly pre-dates academic publication of MD5 collisions

- Evidence of state-level cryptanalysis?

SSL/TLS Handshake



SSL/TLS Handshake

Hello

I am Chase.com
Here is my certificate

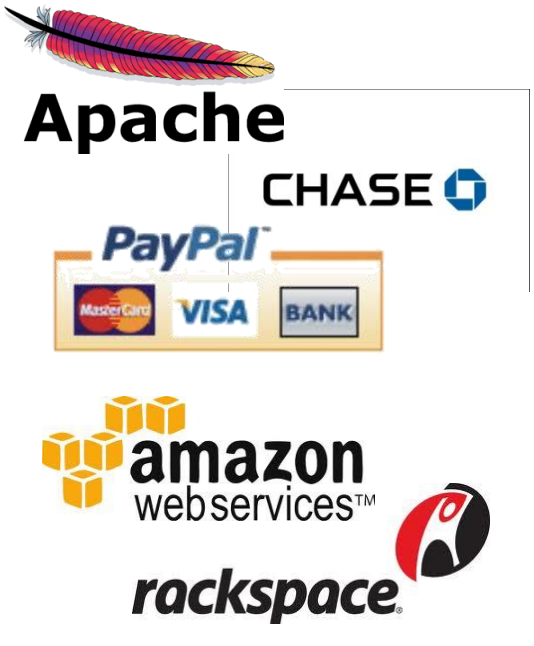
Issued by GoDaddy to
AllYourSSLAreBelongTo.us

CHASE

Android app

Ok!

Failing to Check Hostname

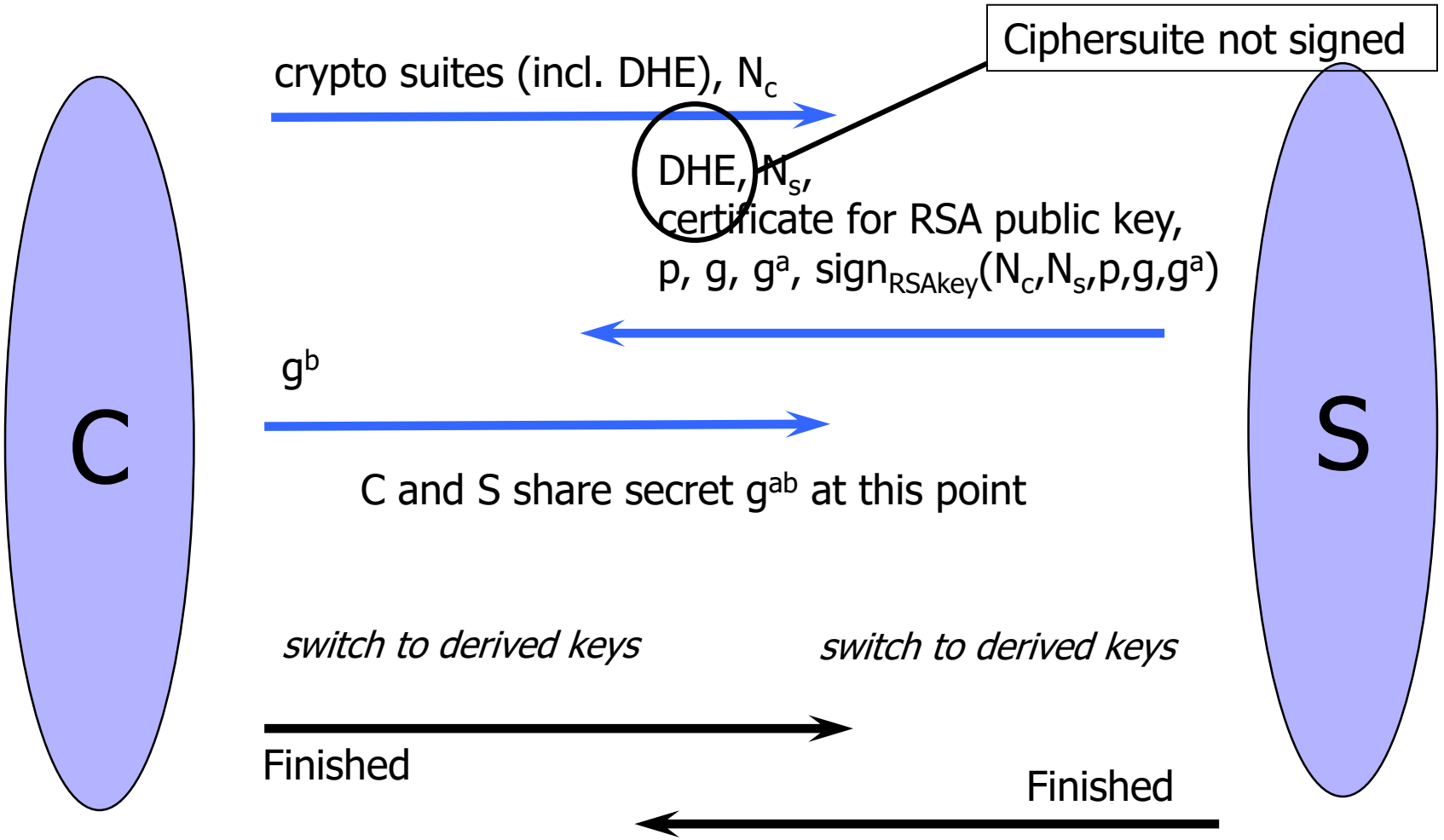


"Researchers at the University of Texas at Austin and Stanford University have discovered that poorly designed APIs used in SSL implementations are to blame for vulnerabilities in many critical non-browser software packages. Serious security vulnerabilities were found in programs such as Amazon's EC2 Java library, Amazon's and PayPal's merchant SDKs, Trillian and AIM instant messaging software, popular integrated shopping cart software packages, Chase mobile banking software, and several Android applications and libraries. SSL connections from these programs and many others are vulnerable to a man in the middle attack..."

- Threatpost (Oct 2012)

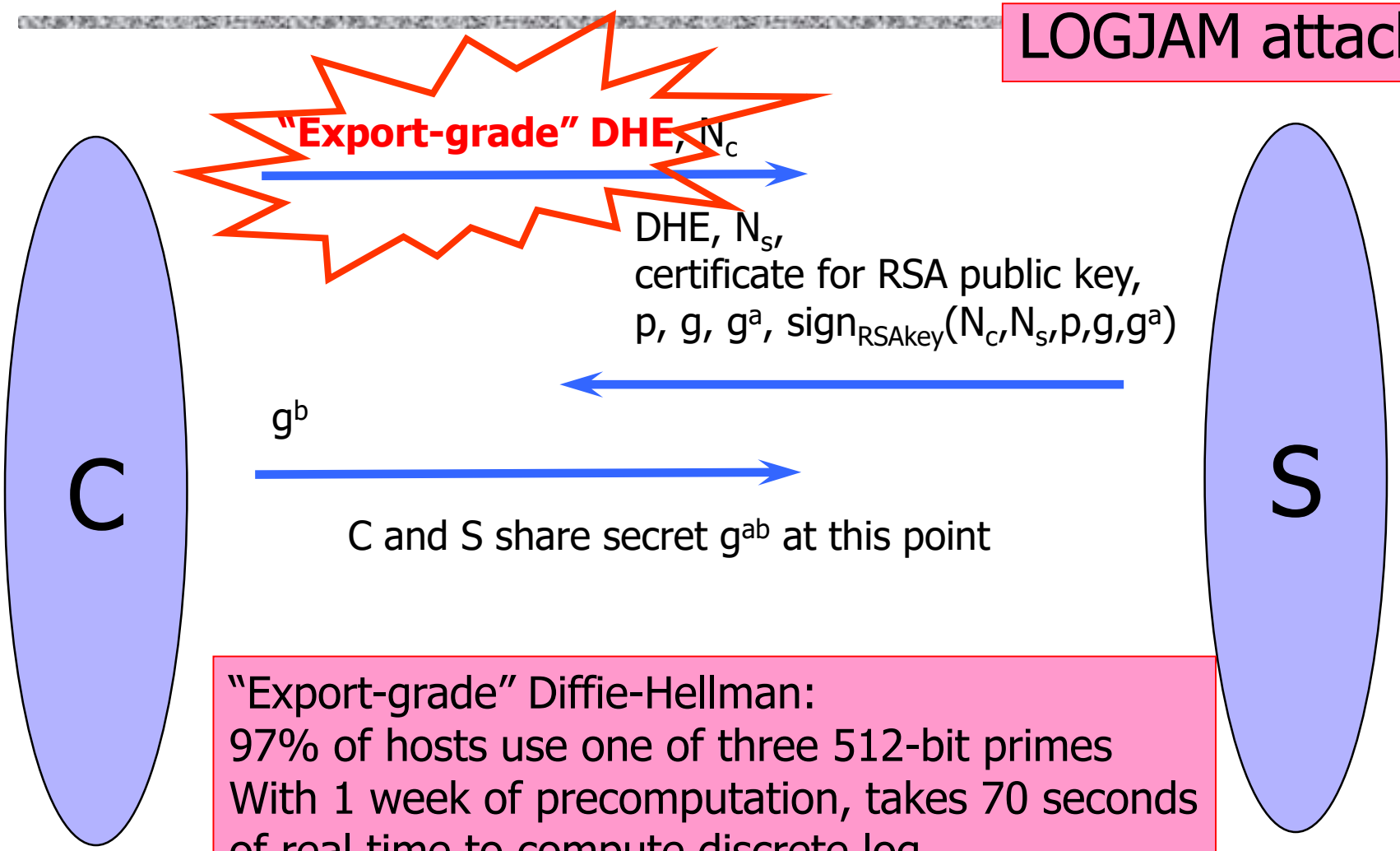
Major payment processing gateways, client software for cloud computing, integrated e-commerce software, etc.

TLS/SSL with Diffie-Hellman

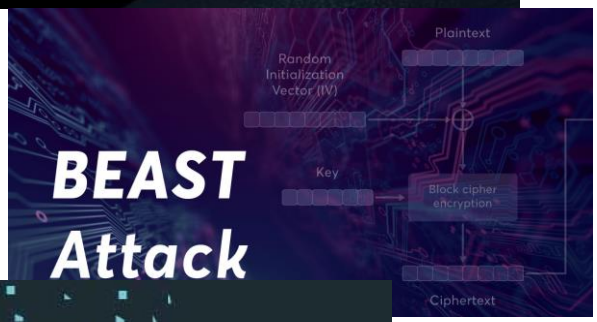


DH Downgrade by MITM

LOGJAM attack



"Export-grade" Diffie-Hellman:
97% of hosts use one of three 512-bit primes
With 1 week of precomputation, takes 70 seconds of real time to compute discrete log

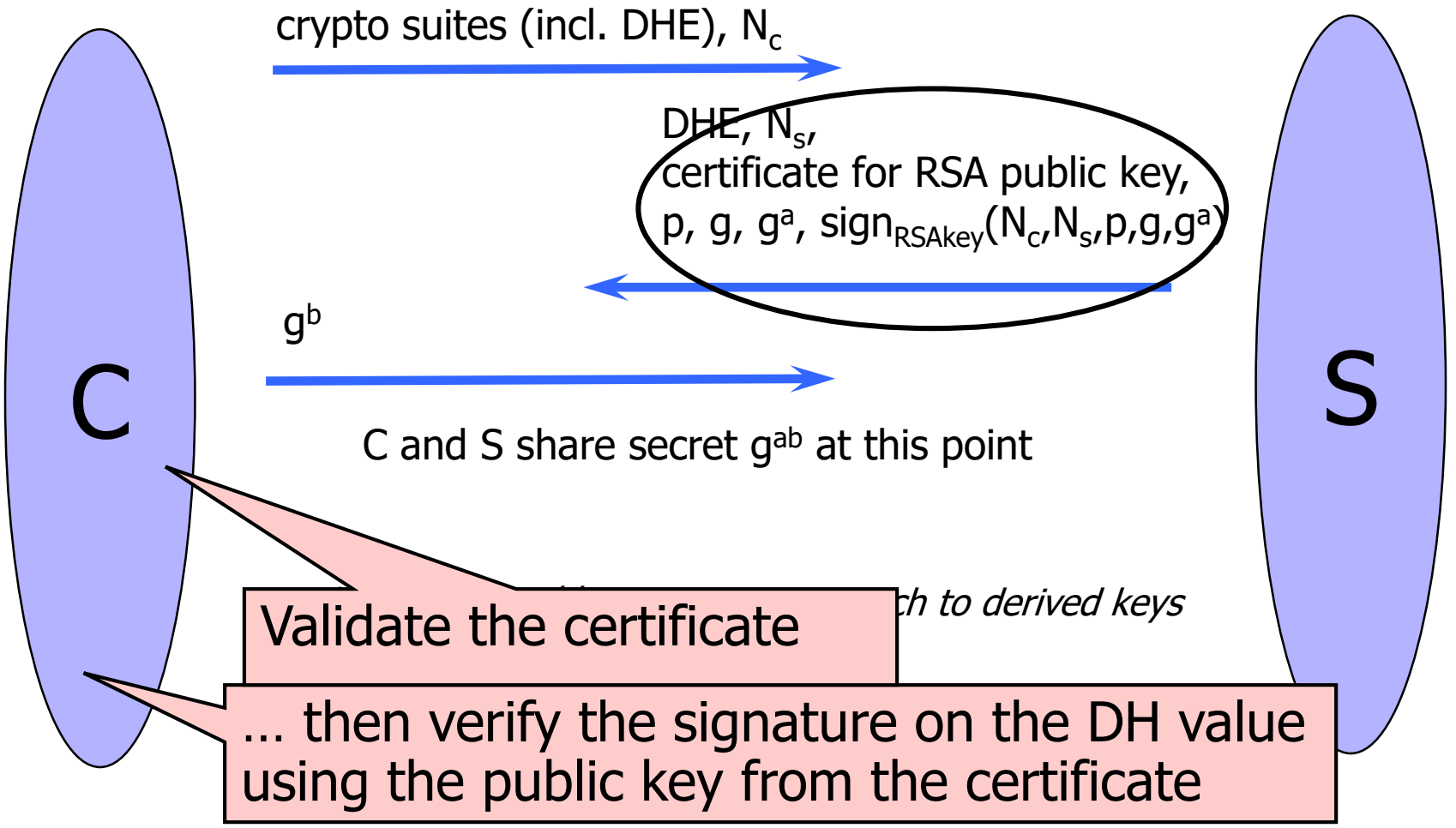


A Perfect CRIME?

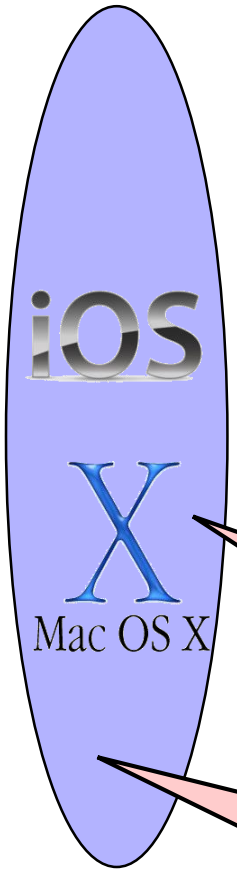
On

Padding oracles
Compression oracles
Downgrades to export cryptography
…

More Fun With Diffie-Hellman



MITM Presenting Valid Certificate



Hello

I am PayPal.com
(or whoever you want me to be)

Here is PayPal's certificate for
its RSA signing key
And here is my signed Diffie-Hellman value

Validate the certificate

… then verify the signature on the DH value
using the public key from the certificate

Goto Fail

Here is PayPal's certificate
And here is my signed Diffie-Hellman value

iOS

X

Mac OS X

… verify the signature on the DH value using the public key from the certificate

```
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(...);
…
fail: … return err …
```

??? Signature is verified here

Complete Fail Against MITM

Discovered in February 2014

All OS X and iOS software vulnerable to man-in-the-middle attacks

- Broken TLS implementation provides no protection against the very attack it was supposed to prevent

What does this tell you about quality control for security-critical software?

Comodo

COMODO
Creating Trust Online®

Comodo is one of the trusted root CAs

- Its certificates for any website in the world are accepted by every browser

Comodo accepts certificate orders submitted through resellers

- Reseller uses a program to authenticate to Comodo and submit an order with a domain name and public key, Comodo automatically issues a certificate for this site

Comodo Break-In

COMODO
Creating Trust Online®

An Iranian hacker broke into instantSSL.it and globalTrust.it resellers, decompiled their certificate issuance program, learned the credentials of their reseller account and how to use Comodo API

- username: gtadmin, password: globaltrust

Wrote his own program for submitting orders and obtaining Comodo certificates

On March 15, 2011, got Comodo to issue 9 rogue certificates for popular sites

- mail.google.com, login.live.com, login.yahoo.com, login.skype.com, addons.mozilla.org, “global trustee"

Consequences

Attacker needs to first divert users to an attacker-controlled site instead of Google, Yahoo, Skype, but then…

- For example, use DNS to poison the mapping of mail.yahoo.com to an IP address

… "authenticate" as the real site

… decrypt all data sent by users

- Email, phone conversations, Web browsing

Q: Does HTTPS help? How about EV certificates?

Message from the Attacker

http://pastebin.com/74KXCaEZ

I'm single hacker with experience of 1000 hacker, I'm single programmer with experience of 1000 programmer, I'm single planner/project manager with experience of 1000 project managers …

When USA and Isarel could read my emails in Yahoo, Hotmail, Skype, Gmail, etc. without any simple little problem, when they can spy using Echelon, I can do anything I can. It's a simple rule. You do, I do, that's all. You stop, I stop. It's rule #1 …

Rule#2: So why all the world got worried, internet shocked and all writers write about it, but nobody writes about Stuxnet anymore?... So nobody should write about SSL certificates.

Rule#3: I won't let anyone inside Iran, harm people of Iran, harm my country's Nuclear Scientists, harm my Leader (which nobody can), harm my President, as I live, you won't be able to do so. as I live, you don't have privacy in internet, you don't have security in digital world, just wait and see...

An update on attempted man-in-the-middle attacks

August 29, 2011

Posted by Heather Adkins, Information Security Manager

Today we received reports of attempted SSL man-in-the-middle (MITM) attacks against Google users, whereby someone tried to get between them and encrypted Google services. The people affected were primarily located in Iran. The attacker used a fraudulent SSL certificate issued by DigiNotar, a root certificate authority that should not issue certificates for Google (and has since revoked it).

DigiNotar Break-In

In June 2011, the same “ComodoHacker” broke into a Dutch certificate authority, DigiNotar

- Message found in scripts used to generate fake certificates:

  “THERE IS NO ANY HARDWARE OR SOFTWARE IN THIS WORLD EXISTS WHICH COULD STOP MY HEAVY ATTACKS MY BRAIN OR MY SKILLS OR MY WILL OR MY EXPERTISE"

Security of DigiNotar servers

- All core certificate servers in a single Windows domain, controlled by a single admin password (Pr0d@dm1n)
- Software on public-facing servers out of date, unpatched
- Tools used in the attack would have been easily detected by an antivirus… if it had been present

Consequences of DigiNotar Hack

Break-in not detected for a month

Rogue certificates issued for *.google.com, Skype, Facebook, www.cia.gov, and 527 other domains

99% of revocation lookups for these certificates originated from Iran

- Evidence that rogue certificates were being used, most likely by Iranian government or Iranian ISPs to intercept encrypted communications
  - Textbook man-in-the-middle attack
- 300,000 users were served rogue certificates
  - 95% in Iran

Another Message from the Attacker

http://pastebin.com/u/ComodoHacker

Most sophisticated hack of all time … I'm really sharp, powerful, dangerous and smart!

My country should have control over Google, Skype, Yahoo, etc. […] I'm breaking all encryption algorithms and giving power to my country to control all of them.

You only heards Comodo (successfully issued 9 certs for me -thanks by the way-), DigiNotar (successfully generated 500+ code signing and SSL certs for me -thanks again-), StartCOM (got connection to HSM, was generating for twitter, google, etc. CEO was lucky enough, but I have ALL emails, database backups, customer data which I'll publish all via cryptome in near future), GlobalSign (I have access to their entire server, got DB backups, their linux / tar gzipped and downloaded, I even have private key of their OWN globalsign.com domain, hahahaa).... BUT YOU HAVE TO HEAR SO MUCH MORE! SO MUCH MORE! At least 3 more, AT LEAST!

Revoking Certificates

Short expirations

CRLs (certificate revocation lists)

OCSP (online certificate status protocol)

- Client queries CA to check on validity of cert
  - Privacy concerns, performance / scalability issues
- Stapling: server periodically gets fresh, time-stamped OCSP signature from CA, sends to clients

In practice: 8% of in-use certificates revoked, many browsers don't bother to check

- Liu et al. An End-to-End Measurement of Certificate Revocation in the Web's PKI (2014)

Revoking DigiNotar Certificates

https://slate.com/technology/2016/12/how-the-2011-hack-of-diginotar-changed-the-internets-infrastructure.html

The discovery of the DigiNotar compromise left the browser and CA community—to say nothing of the Dutch government—reeling. Browser vendors rushed to revoke trust in DigiNotar certificates, but removing a root CA was not entirely straightforward. "We actually needed to push out an update to Firefox because the CA information was hard-coded to the browser," Firefox security lead Richard Barnes said. Additionally, many legitimate websites (including some operated by the Dutch government) were still relying on DigiNotar certificates, so the browser vendors were forced to hold off on a blanket ban. Instead, Mozilla decided to block all DigiNotar certificates issued after July 1, 2011, but allowed users to decide whether they wanted to trust certificates issued by the company before that date. But giving users that

In Netherlands, interior minister went on TV to warn Dutch citizens to immediately stop using secure government websites

TurkTrust

In Jan 2013, a rogue *.google.com certificate was issued by an intermediate CA that gained its authority from the Turkish root CA TurkTrust

- TurkTrust accidentally issued intermediate CA certs to customers who requested regular certificates
- Ankara transit authority used its certificate to issue a fake *.google.com certificate in order to intercept and filter SSL traffic from its network

This rogue *.google.com certificate was trusted by every browser in the world

More Rogue Certificates

2015: MCS Holdings (Egypt) issued rogue certificates for Google domains

- Root CA: CNNIC (China)

2015: WoSign (Chinese CA) issued rogue certificates for Github and Alibaba

Rogue Certs for Surveillance

https://www.businessinsider.com/apple-google-mozilla-block-kazakhstan-governments-browser-spying-tool-2019-8

- **Google, Mozilla, and Apple have blocked an encryption certificate issued by the Kazakhstan government, which citizens were asked to install on their browsers and that critics said enabled the government to monitor their internet traffic.**

- **The government reportedly said the software was a security measure but researchers from the University of Michigan found that installing the browser certificate allowed the government to surveil which sites people were accessing, and see anything a user types or posts.**

- **According to the researchers, the fake certificate targeted 37 sites including Google-owned messaging apps, Google Docs, Instagram, Gmail, Twitter, Facebook, and a number of Russian social media services.**

TrustWave

In Feb 2012, admitted issuing an intermediate CA certificate to a corporate customer

- Purpose: “re-sign” certificates for “data loss prevention”
- Translation: forge certificates of third-party sites in order to spy on employees’ encrypted communications with the outside world

Customer can now forge certificates for any site in world… and they will be accepted by any browser!

- What if a “re-signed” certificate leaks out?

Do other CAs do this?

Komodia

Israeli startup

From their website: “Our advanced SSL hijacker SDK is a brand new technology that allows you to access data that was encrypted using SSL and perform on the fly SSL decryption.”

- Installs its own root certificate
- Goal: re-sign SSL certificates, proxy/MITM connections

Same private key on all machines, easily extracted

- Anyone can issue fake Komodia certificates, do man-in-the-middle attacks on any machine with Komodia

It Gets Worse

https://blog.filippo.io/komodia-superfish-ssl-validation-is-broken/

What happens if a MITM attacker serves a self-signed certificate to a Komodia client?

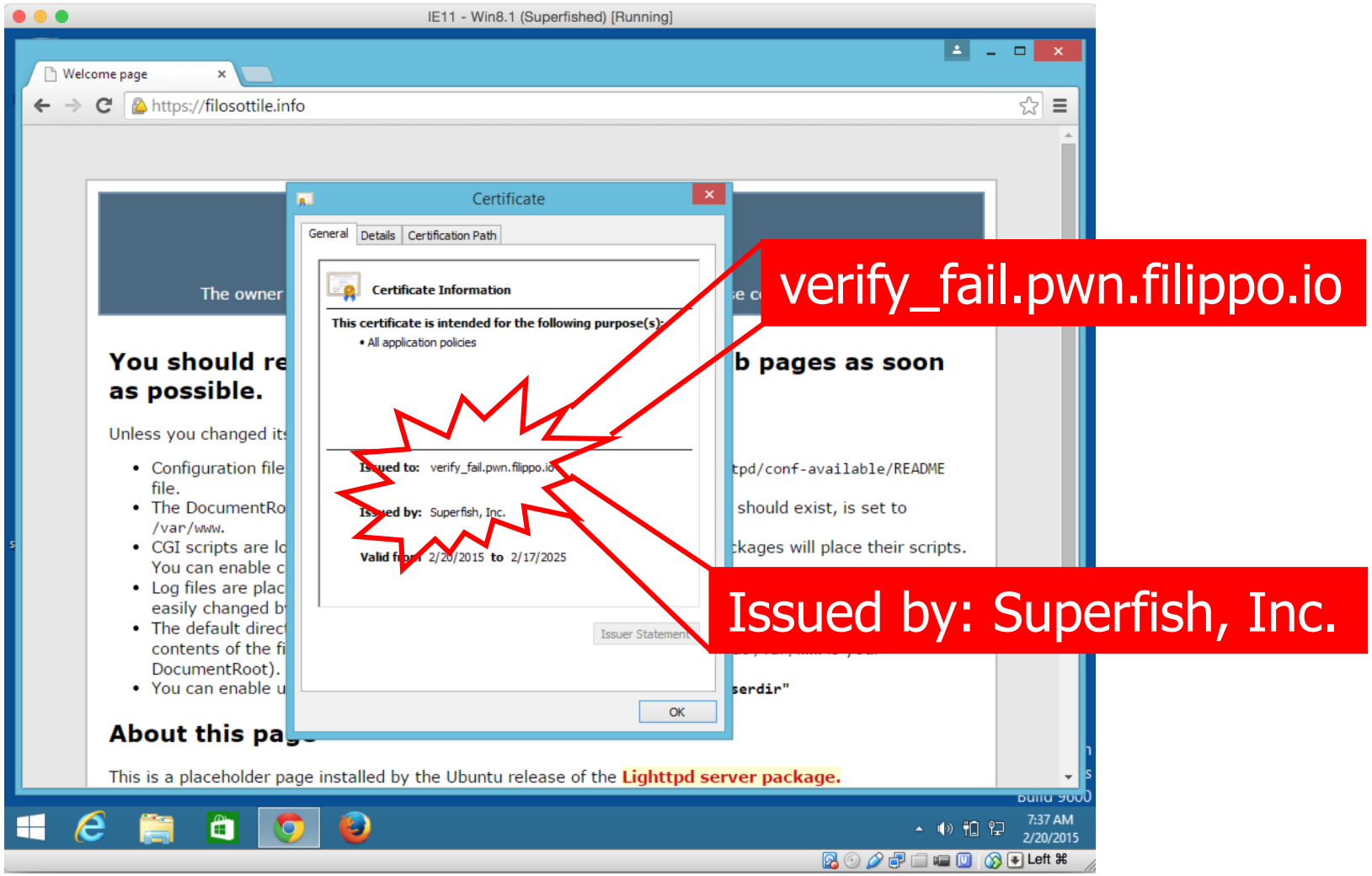
Komodia re-signs and turns it into a trusted certificate

- But it will also change the name in the certificate, which won't match what the browser is expecting and user will see a warning - maybe not so bad

But if attacker puts target domain into "alternate name" field, Komodia won't touch it and browser will think the certificate is completely valid

Complete SSL Fail

https://blog.filippo.io/komodia-superfish-ssl-validation-is-broken/



Software based on Komodia SDK

Superfish

CartCrunch Israel LTD

WiredTools LTD

Say Media Group LTD

Over the Rainbow Tech

System Alerts

ArcadeGiant

Objectify Media Inc

Catalytix Web Services

OptimizerMonitor

Statement from Superfish CEO

There has been significant misinformation circulating about Superfish software that was pre-installed on certain Lenovo laptops. The software shipped on a limited number of computers in 2014 in an effort to enhance the online shopping experience for Lenovo customers. Superfish's software utilizes visual search technology to help users achieve more relevant search results based on images of products they have browsed.

Despite the false and misleading statements made by some media commentators and bloggers, the Superfish software does not present a security risk. In no way does Superfish store personal data or share such data with anyone. Unfortunately, in this situation a vulnerability was introduced unintentionally by a 3rd party. Both Lenovo and Superfish did extensive testing of the solution but this issue wasn't identified before some laptops shipped. Fortunately, our partnership with Lenovo was limited in scale. We were able to address the issue quickly. The software was disabled on the server side (i.e., Superfish's search engine) in January 2015.

Not Just Komodia

PrivDog

- "Your privacy is under attack!"

Provides "private Web browsing"

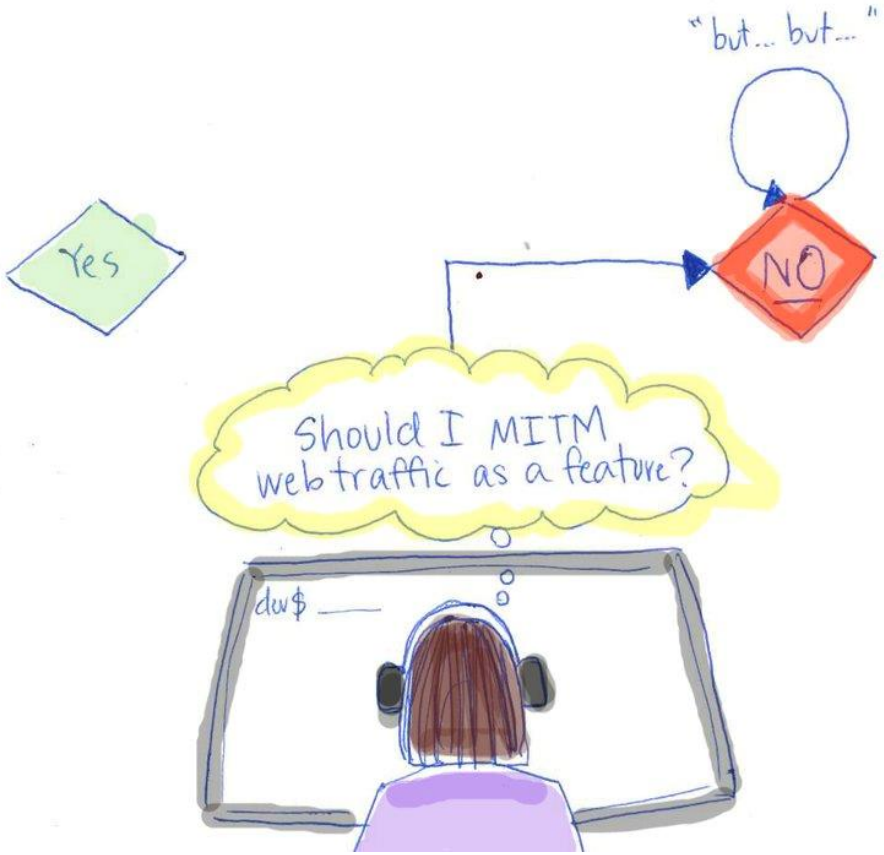
- Translation: replaces ads on webpages with other ads from "trusted sources"

Re-signs certificates to MITM SSL connections

Accepts self-signed certificates and turns them into trusted certificates

Founded by the CEO of Comodo CA

Just Say No



Credit: Adrienne Porter Felt (Google)

Russian hackers modify Chrome and Firefox to track secure web traffic

- Malware installs its own certificate
- Modifies pseudo-random generator to add encrypted hardware and software identifiers of the infected machine to the random nonce sent as part of the TLS handshake

https://securelist.com/compfun-successor-reductor/93633/

Certificate / Public Key Pinning

Idea: client knows what cert/PK to expect, rejects anything else

How?

- Pre-install some keys
- HPKP (HTTP Public Key Pinning)
  - HTTP header that lets servers set the hash of public key they will use

```
Public-Key-Pins:
    pin-sha256="d6qzRu9zOECb90Uez27xWltNsj0e1Md7GkYYkVoZWmM=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ=";
    max-age=259200
```

Note: Chrome never accepted fake DigitNotar certs

Certificate Transparency

Force CAs to log the certificates they sign in a public tamper-evident register

- Server attaches a signed statement from log (SCT) to certificate; browser will only use a cert if it is published on (two) log servers
- Companies can scan logs to look for invalid issuance

Google has been pushing this (+ has its own CA)

- Chrome requires it for EV certs + certs with path to root CA

If certificate is unlogged, will users pay attention to browser warnings?

Peeking Through SSL/TLS

Network traffic reveals length of HTTPS packets

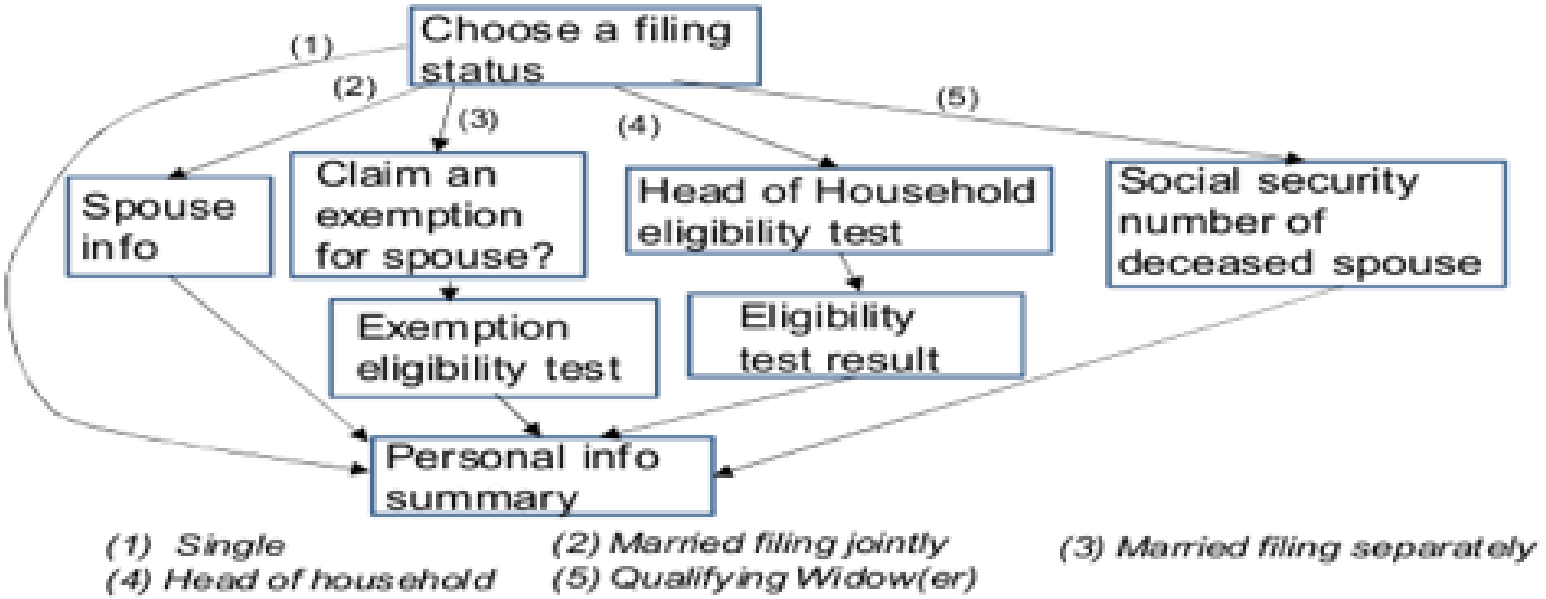
- TLS supports up to 256 bytes of padding

AJAX-rich pages have lots and lots of interactions with the server

These interactions expose specific internal state of the page

Traffic Analysis

Chen et al. "Side-Channel Leaks in Web Applications: a Reality Today, a Challenge Tomorrow"



No easy fix

Can also be used to identify traffic, fingerprint destinations