CSE 484: Computer Security and Privacy

Signatures, Certificates, and Web

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Logistics

- Lab 1b grades will be delayed

- Lab 2 will go out later this week
  - We’ll adjust content or duration due to starting it later

Review: RSA Cryptosystem [Rivest, Shamir, Adleman 1977]

- Key generation:
  - Generate large primes p, q
    - Say, 2048 bits each (need primality testing, too)
  - Compute **n**=pq and **φ(n)**=(p-1)(q-1)
  - Choose small **e**, relatively prime to φ(n)
    - Typically, **e=3** or **e=2^16+1=65537**
  - Compute unique **d** such that ed ≡ 1 mod φ(n)
    - Modular inverse: d ≡ e^{-1} mod φ(n)
  - Public key = (e,n); private key = (d,n)
- Encryption of m: c = m^e mod n
- Decryption of c: c^d mod n = $(m^e)^d$ mod n = m

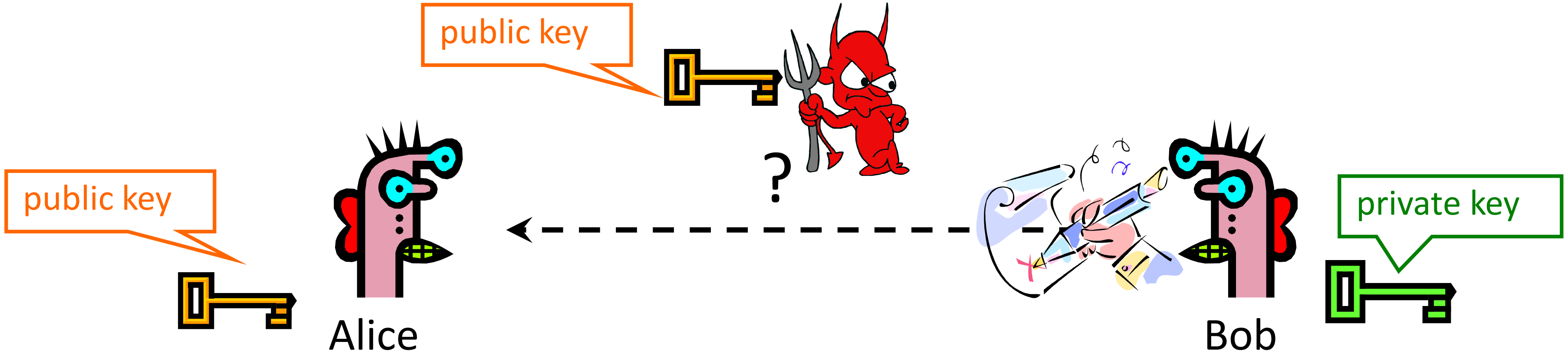
Actually, RSA is bad and stop using it

- Math is OK, implementation isn’t
  - Yes, all the implementations

- https://blog.trailofbits.com/2019/07/08/fuck-rsa/

- Sorry I just spent time teaching it to you
  - Maybe you would’ve preferred projected coordinate math on elliptic curves?

Digital Signatures: Basic Idea



Given: Everybody knows Bob's public key
Only Bob knows the corresponding private key

Goal: Bob sends a "digitally signed" message

1. To compute a signature, must know the private key
2. To verify a signature, only the public key is needed

RSA Signatures

- Public key is **(n,e)**, private key is **(n,d)**
- To sign message m: s = m^d mod n
  - Signing & decryption are same **underlying** operation in RSA
  - It's infeasible to compute **s** on **m** if you don't know **d**
- To verify signature s on message m:

  verify that s^e mod n = $(m^d)^e$ mod n = m
  - Just like encryption (for RSA primitive)
  - Anyone who knows **n** and **e** (public key) can verify signatures produced with d (private key)
- In practice, also need padding & hashing
  - Without padding and hashing: Consider multiplying two signatures together
  - Standard padding/hashing schemes exist for RSA signatures

DSS Signatures

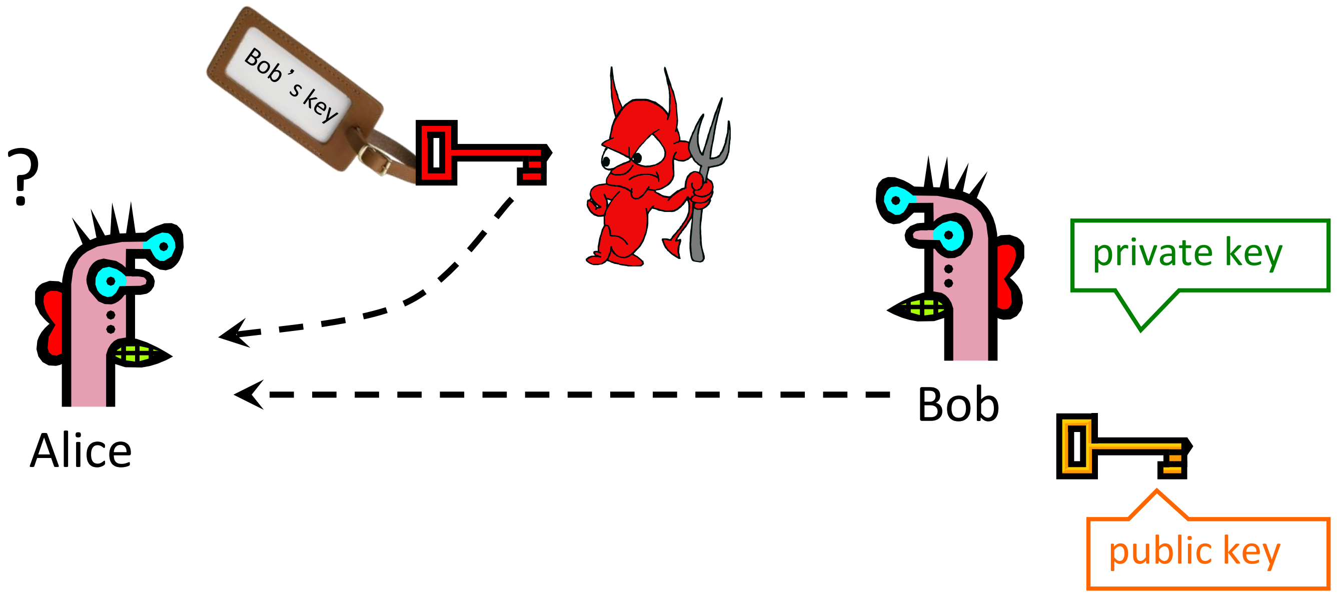
- Digital Signature Standard (DSS)
  - U.S. government standard (1991, most recent rev. 2013)
- Public key: (p, q, g, $y=g^x \bmod p$), private key: x
- Each signing operation picks a new random value, to use during signing. Security breaks if two messages are signed with that same value.
- Security of DSS requires hardness of discrete log
  - If could solve discrete logarithm problem, would extract x (private key) from $g^x \bmod p$ (public key)
- Again: We've discussed discrete logs modulo integers; significant advantages to using elliptic curve groups instead.

Post-Quantum

- If quantum computer become a reality
  - It becomes much more efficient to break conventional asymmetric encryption schemes (e.g., factoring becomes “easy”)

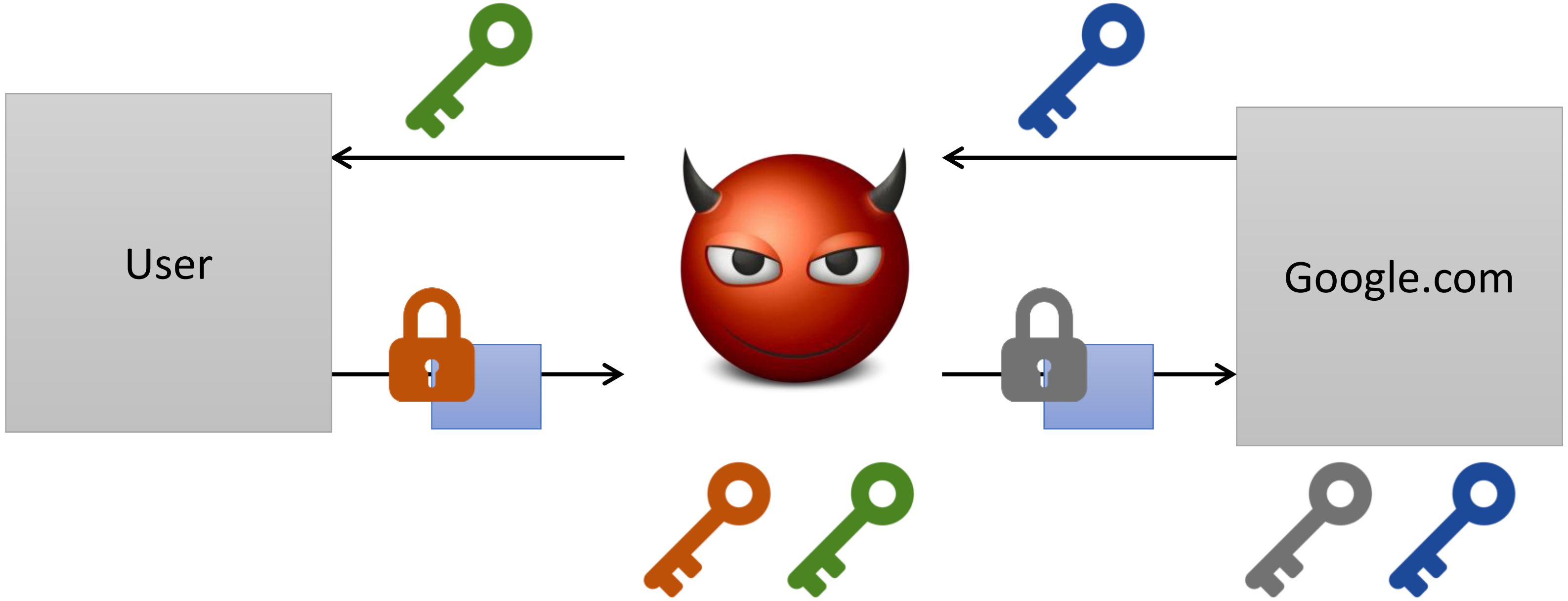
- There exists efforts to make quantum-resilient asymmetric encryption schemes
  - (Check out NIST’s PQC competition!)

Authenticity of Public Keys



Problem: How does Alice know that the public key they received is really Bob's public key?

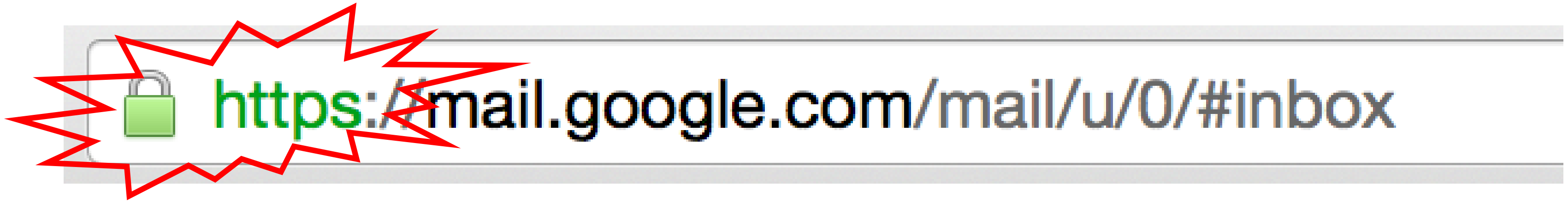
Threat: Person-in-the Middle



Distribution of Public Keys

- Public announcement or public directory
  - Risks: forgery and tampering
- Public-key certificate
  - Signed statement specifying the key and identity
    - sig_{CA}(“Bob”, PK_B)
    - Additional information often signed as well (e.g., expiration date)
- Common approach: certificate authority (CA)
  - Single agency responsible for certifying public keys
  - After generating a private/public key pair, user proves their identity and knowledge of the private key to obtain CA’s certificate for the public key (offline)
  - Every computer is pre-configured with CA’s public key

You encounter this every day…

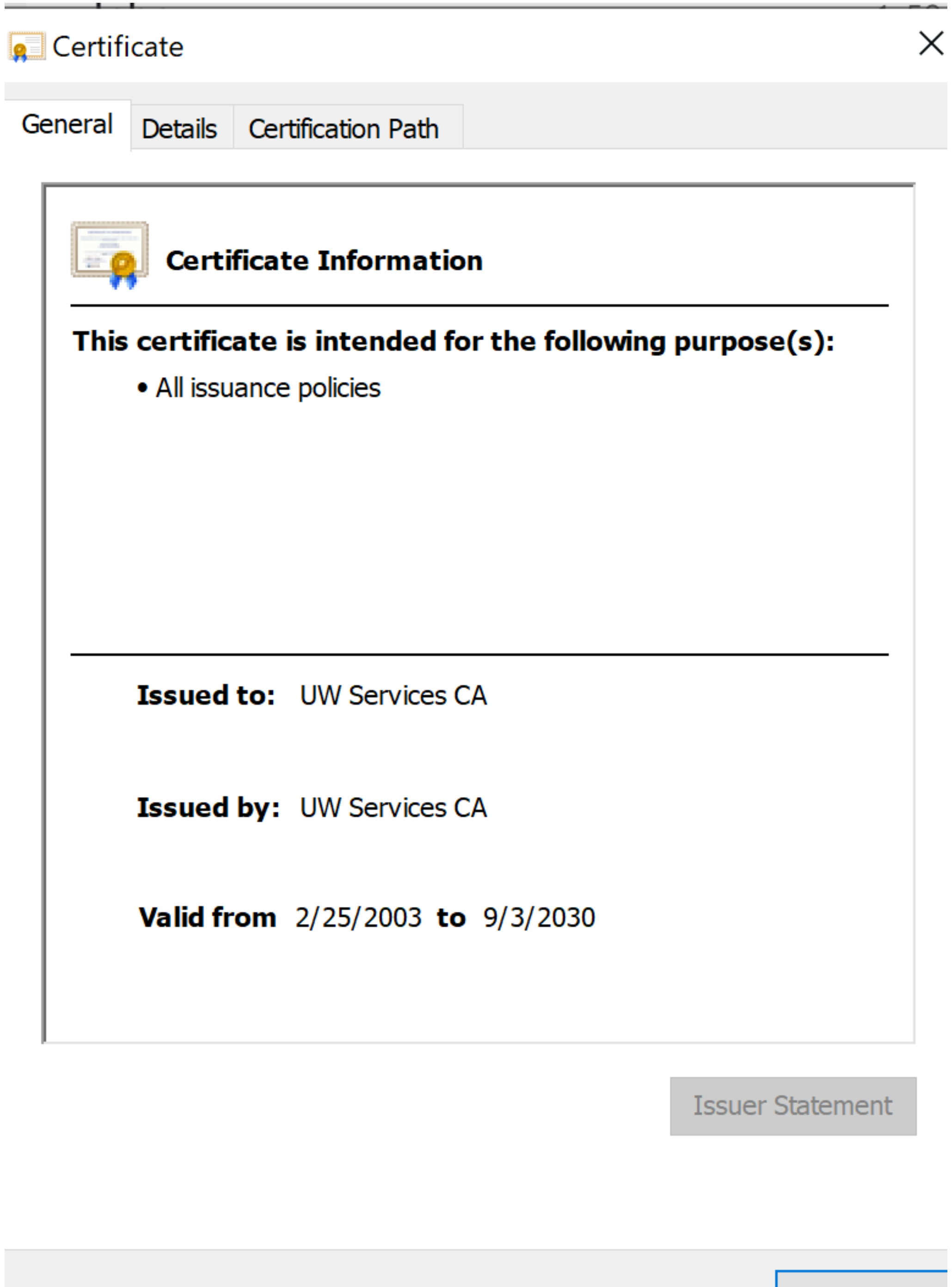


https://mail.google.com/mail/u/0/#inbox

SSL/TLS: Encryption & authentication for connections

SSL/TLS High Level

- SSL/TLS consists of two protocols
  - Familiar pattern for key exchange protocols
- Handshake protocol
  - Use public-key cryptography to establish a shared secret key between the client and the server
- Record protocol
  - Use the secret symmetric key established in the handshake protocol to protect communication between the client and the server



Certificate Information

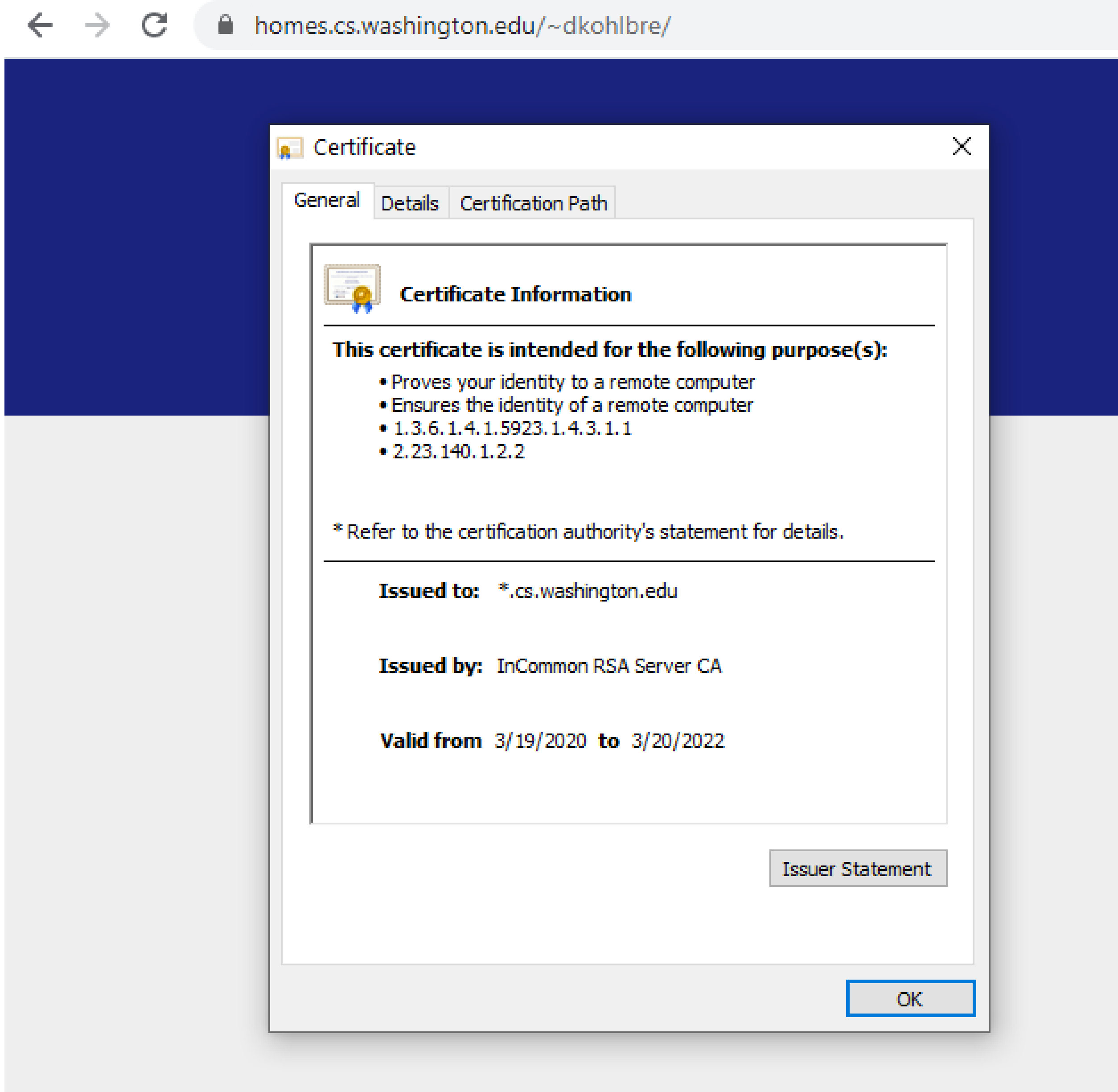
This certificate is intended for the following purpose(s):

- All issuance policies

Issued to: UW Services CA

Issued by: UW Services CA

Valid from 2/25/2003 **to** 9/3/2030



Certificate Information

This certificate is intended for the following purpose(s):

- Proves your identity to a remote computer
- Ensures the identity of a remote computer
- 1.3.6.1.4.1.5923.1.4.3.1.1
- 2.23.140.1.2.2

* Refer to the certification authority's statement for details.

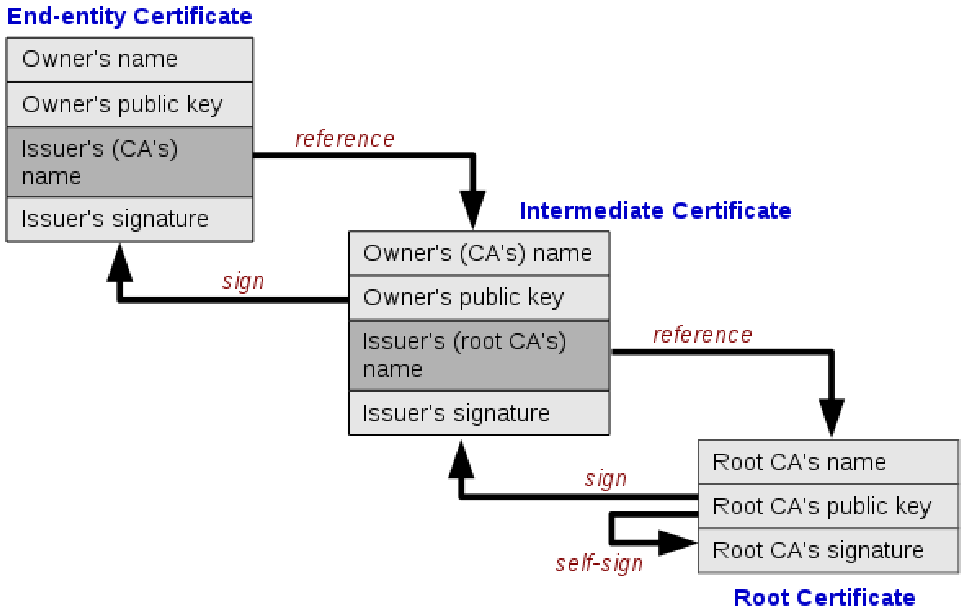
Issued to: *.cs.washington.edu

Issued by: InCommon RSA Server CA

Valid from 3/19/2020 **to** 3/20/2022

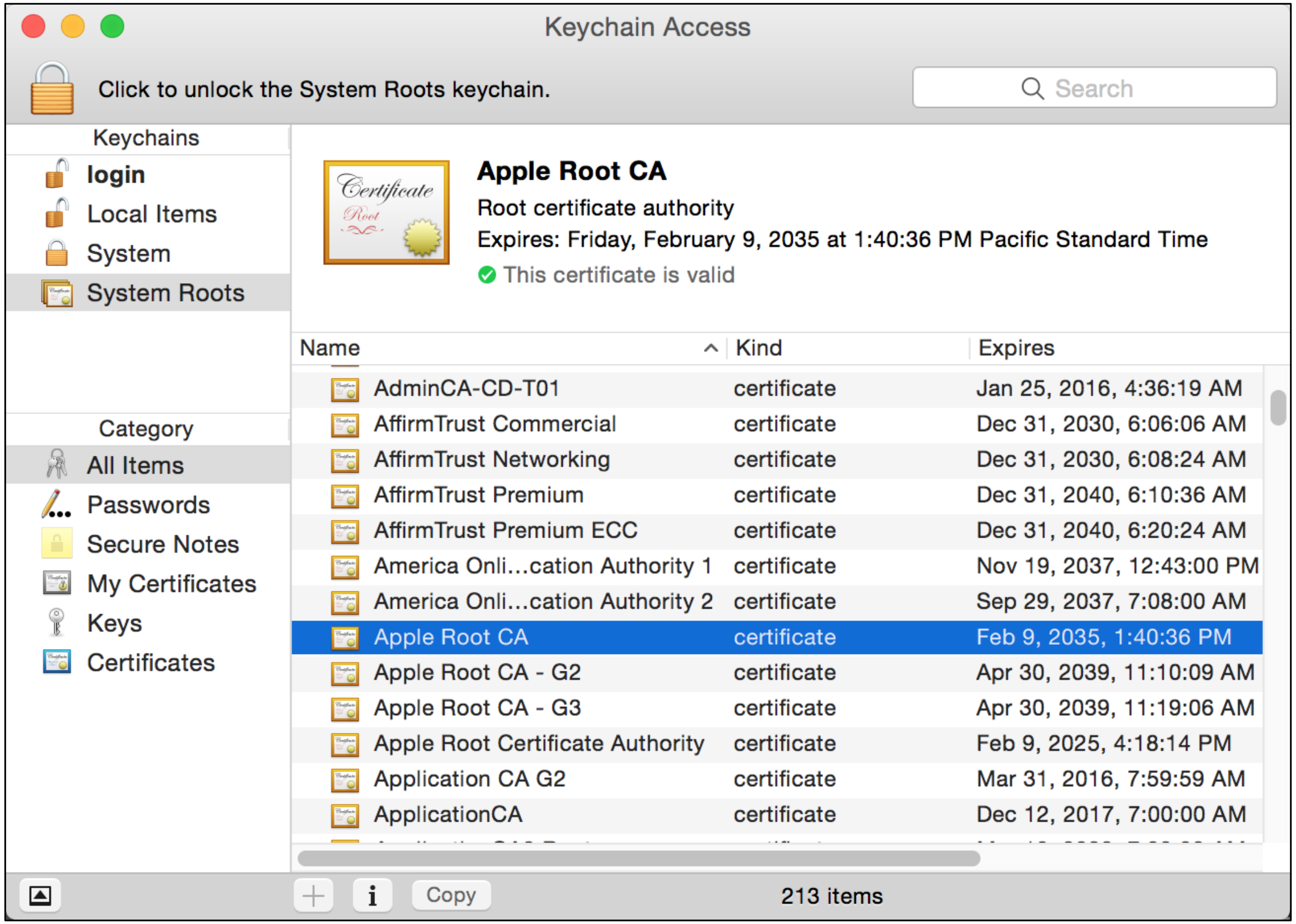
Hierarchical Approach

- Single CA certifying every public key is impractical
- Instead, use a trusted root authority (e.g., Verisign)
  - Everybody must know the root's public key
  - Instead of single cert, use a certificate chain
    - $\text{sig}_{\text{Verisign}}$("AnotherCA", $\text{PK}_{\text{AnotherCA}}$), $\text{sig}_{\text{AnotherCA}}$("Alice", PK_{A})
  - Not shown in figure but important:
    - Signed as part of each cert is whether party is a CA or not



- What happens if root authority is ever compromised?

Trusted(?) Certificate Authorities



Click to unlock the System Roots keychain.

Apple Root CA
Root certificate authority
Expires: Friday, February 9, 2035 at 1:40:36 PM Pacific Standard Time
✓ This certificate is valid

Name	Kind	Expires
AdminCA-CD-T01	certificate	Jan 25, 2016, 4:36:19 AM
AffirmTrust Commercial	certificate	Dec 31, 2030, 6:06:06 AM
AffirmTrust Networking	certificate	Dec 31, 2030, 6:08:24 AM
AffirmTrust Premium	certificate	Dec 31, 2040, 6:10:36 AM
AffirmTrust Premium ECC	certificate	Dec 31, 2040, 6:20:24 AM
America Onli...cation Authority 1	certificate	Nov 19, 2037, 12:43:00 PM
America Onli...cation Authority 2	certificate	Sep 29, 2037, 7:08:00 AM
Apple Root CA	certificate	Feb 9, 2035, 1:40:36 PM
Apple Root CA - G2	certificate	Apr 30, 2039, 11:10:09 AM
Apple Root CA - G3	certificate	Apr 30, 2039, 11:19:06 AM
Apple Root Certificate Authority	certificate	Feb 9, 2025, 4:18:14 PM
Application CA G2	certificate	Mar 31, 2016, 7:59:59 AM
ApplicationCA	certificate	Dec 12, 2017, 7:00:00 AM

213 items

Turtles All The Way Down…

The saying holds that the world is supported by a chain of increasingly large turtles. Beneath each turtle is yet another: it is "turtles all the way down".

[Image from Wikipedia]

Corporate CAs? -- Gradescope

- Many corporations require that all company machines have an additional **Root Certificate** installed, owned and controlled by the company IT.
- This would allow the company to create a certificate for any website, service, etc. they want and have it trusted by any company machine. (But not by anyone else’s).

- What does this let corporate IT do?
- Why might they want to do that?

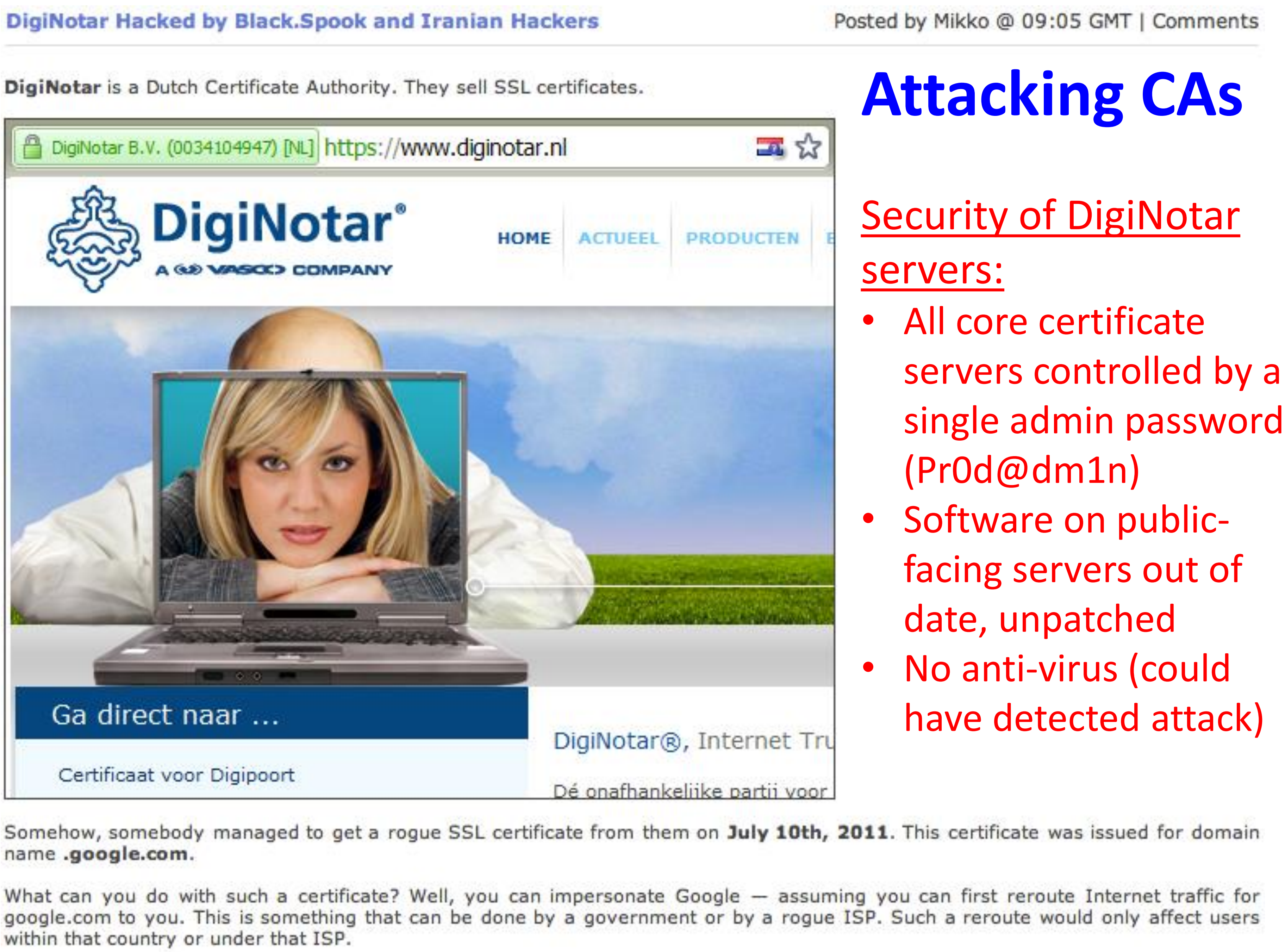
Many Challenges…

- Hash collisions
- Weak security at CAs
  - Allows attackers to issue rogue certificates
- Users don't notice when attacks happen
  - We'll talk more about this later in the course
- How do you revoke certificates?

Attacking CAs

Security of DigiNotar servers:

- All core certificate servers controlled by a single admin password (Pr0d@dm1n)
- Software on public-facing servers out of date, unpatched
- No anti-virus (could have detected attack)



DigiNotar Hacked by Black.Spook and Iranian Hackers

Posted by Mikko @ 09:05 GMT | Comments

DigiNotar is a Dutch Certificate Authority. They sell SSL certificates.

Somehow, somebody managed to get a rogue SSL certificate from them on **July 10th, 2011**. This certificate was issued for domain name **.google.com**.

What can you do with such a certificate? Well, you can impersonate Google — assuming you can first reroute Internet traffic for google.com to you. This is something that can be done by a government or by a rogue ISP. Such a reroute would only affect users within that country or under that ISP.

More Rogue Certs

- 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 filter SSL traffic from its network
- This rogue *.google.com certificate was trusted by every browser in the world

Bad CAs

- DarkMatter (https://groups.google.com/g/mozilla.dev.security.policy/c/nnLVNfqgz7g/m/TseYqDzaDAAJ and https://bugzilla.mozilla.org/show_bug.cgi?id=1427262)
  - Security company wanted to get CA status
  - Questionable practices
- Symantec! (https://wiki.mozilla.org/CA:Symantec_Issues)
  - Major company, regular participant in standards
  - Poor practices, mismanagement 2013-2017
  - CA distrusted in Oct 2018
- Recall: Turtles all the way down. How can we trust the CAs? What happens if we can’t?

Certificate Revocation

- Revocation is very important
- Many valid reasons to revoke a certificate
  - Private key corresponding to the certified public key has been compromised
  - User stopped paying their certification fee to this CA and CA no longer wishes to certify them
  - CA's private key has been compromised!
- Expiration is a form of revocation, too
  - Many deployed systems don't bother with revocation
  - Re-issuance of certificates is a big revenue source for certificate authorities

Certificate Revocation Mechanisms

- Certificate revocation list (CRL)
  - CA periodically issues a signed list of revoked certificates
    - Credit card companies used to issue thick books of canceled credit card numbers
  - Can issue a “delta CRL” containing only updates
- Online revocation service
  - When a certificate is presented, recipient goes to a special online service to verify whether it is still valid
    - Like a merchant dialing up the credit card processor

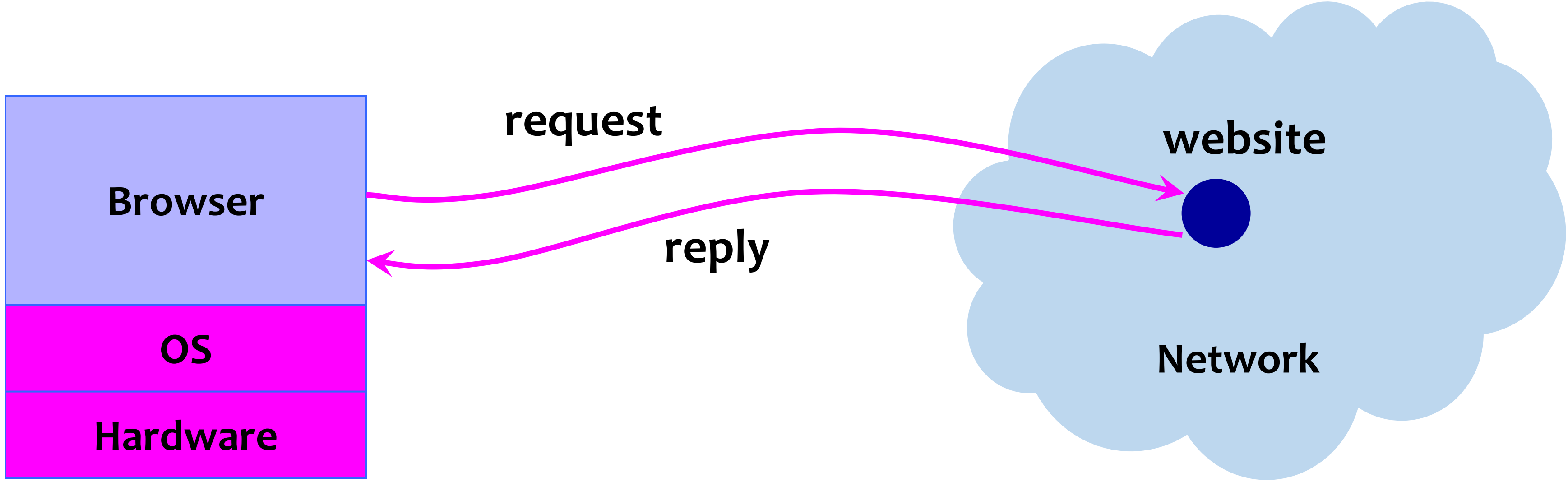
Attempt to Fix CA Problems: Certificate Transparency

- **Problem:** browsers will think nothing is wrong with a rogue certificate until revoked
- **Goal:** make it impossible for a CA to issue a bad certificate for a domain *without the owner of that domain knowing*
- **Approach:** auditable certificate logs
  - Certificates published in public logs
  - Public logs checked for unexpected certificates

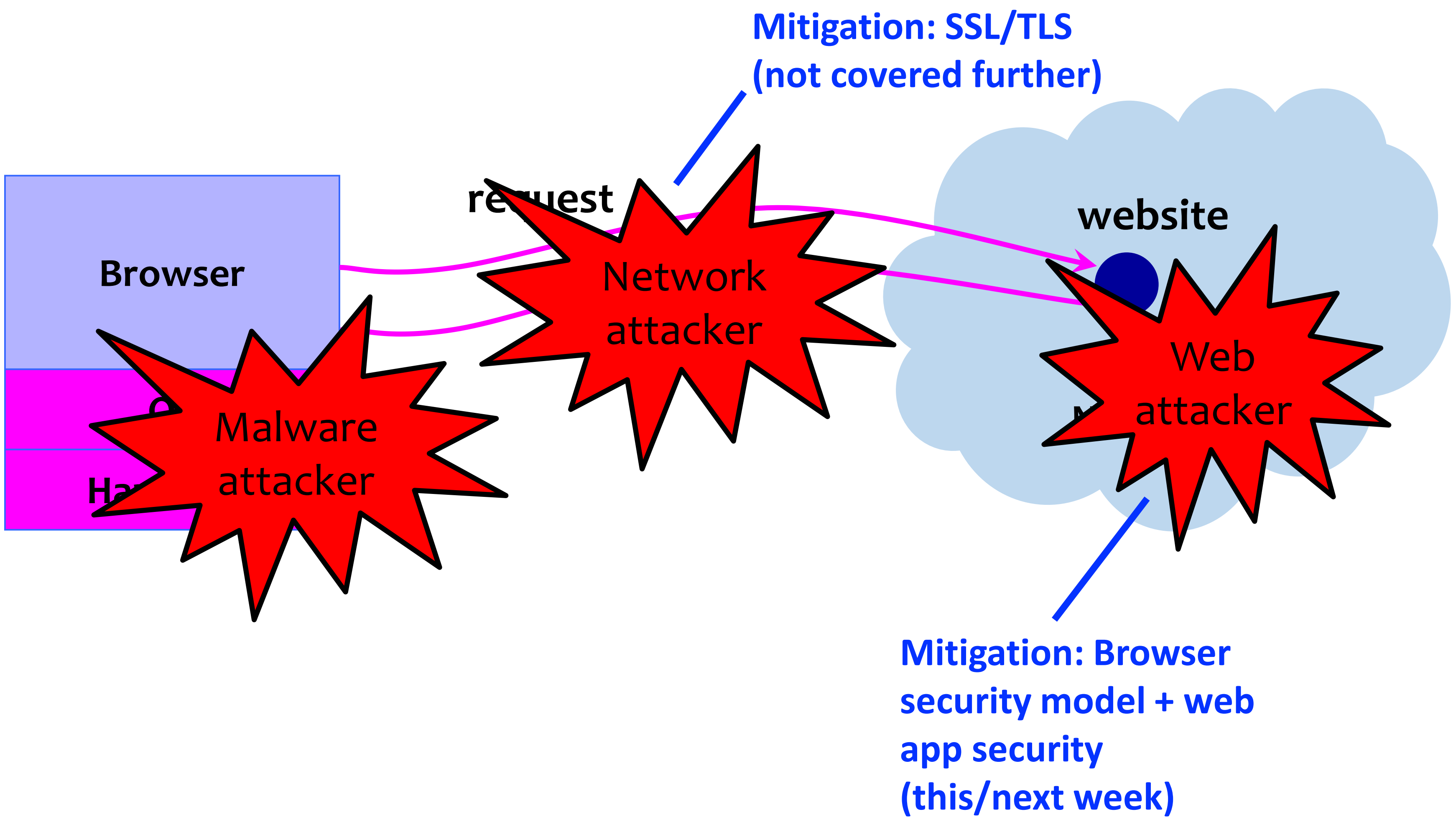
www.certificate-transparency.org

Next Major Topic!
Web+Browser Security

Big Picture: Browser and Network



Where Does the Attacker Live?



Mitigation: SSL/TLS (not covered further)

Mitigation: Browser security model + web app security (this/next week)

Two Sides of Web Security

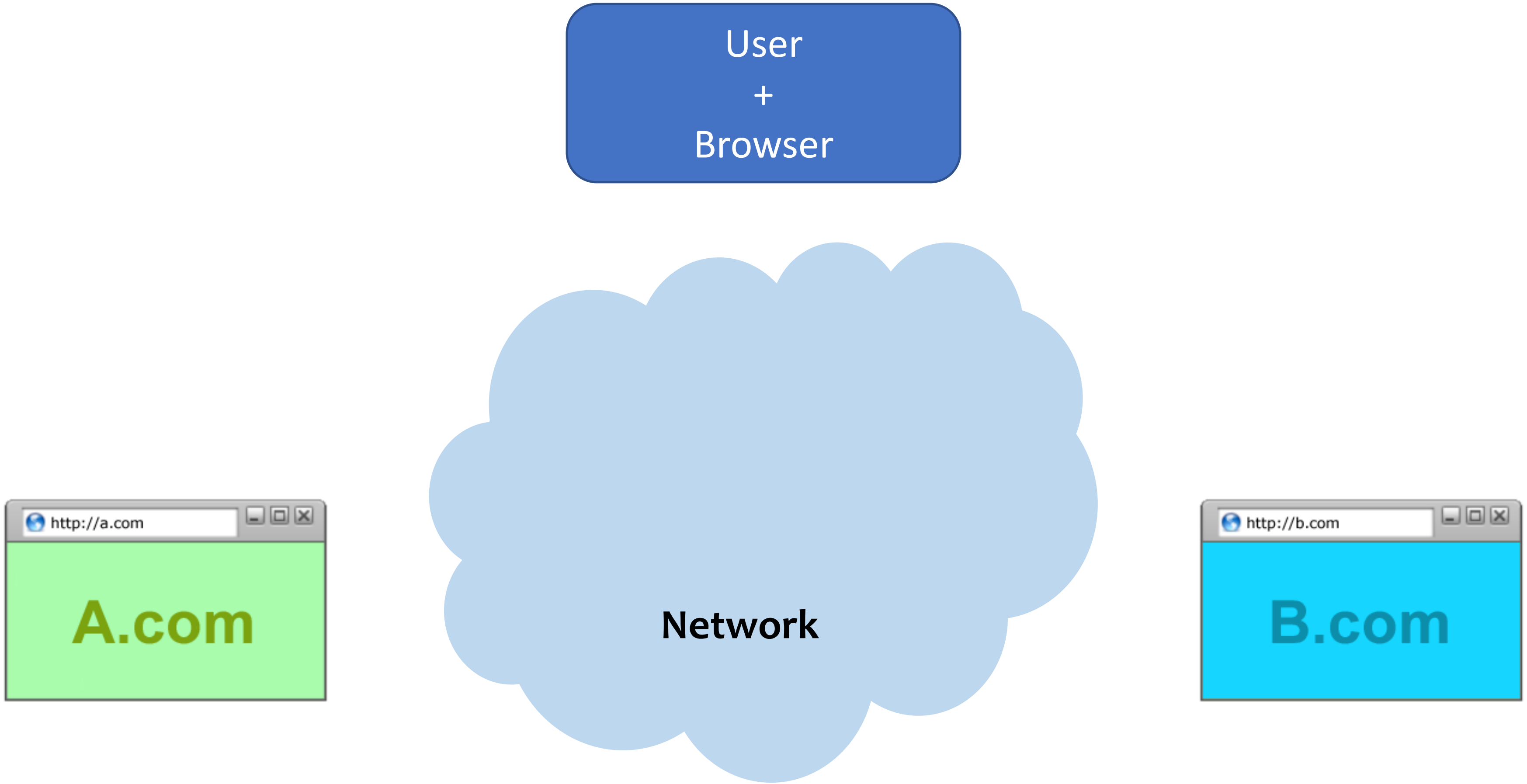
(1) Web browser

- Responsible for securely confining content presented by visited websites

(2) Web applications

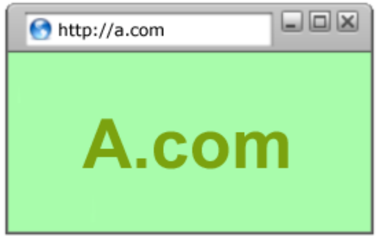
- Online merchants, banks, blogs, Google Apps …
- Mix of server-side and client-side code
  - Server-side code written in PHP, JavaScript, C++ etc.
  - Client-side code written in JavaScript (… sort of)
- Many potential bugs: XSS, XSRF, SQL injection

But at least 3 actors!

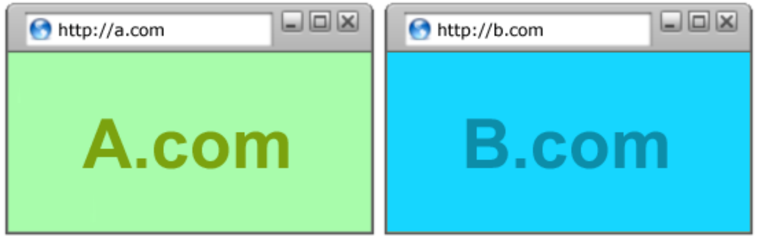


Browser: All of These Should Be Safe

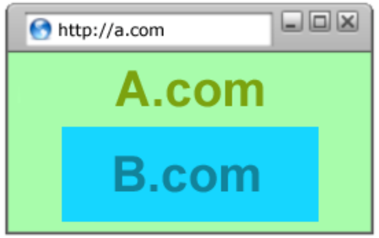
- Safe to visit an evil website



- Safe to visit two pages
  - Simultaneously
  - Sequentially



- Safe delegation

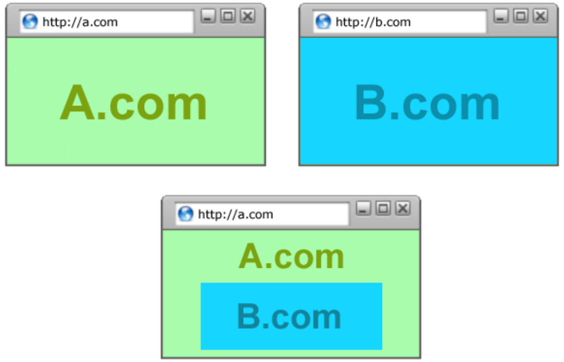


Browser Security Model

Goal 1: Protect local system from web attacker
→ Browser Sandbox

http://a.com
A.com

Goal 2: Protect/isolate web content from other web content
→ Same Origin Policy

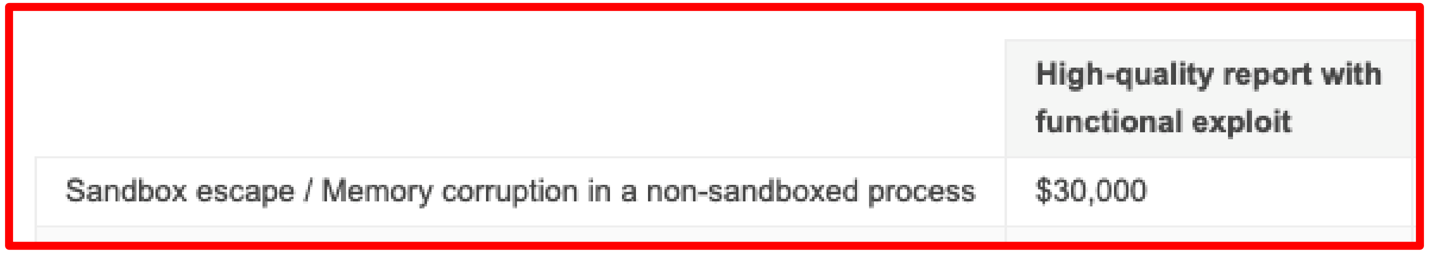


Browser Sandbox

Goals: Protect local system from web attacker; *protect websites from each other*

- E.g., safely execute JavaScript provided by a website
- No direct file access, limited access to OS, network, browser data, content from other websites
- Tabs and iframes in their own processes
- Implementation is browser and OS specific*

*For example, see: https://chromium.googlesource.com/chromium/src/+/master/docs/design/sandbox.md



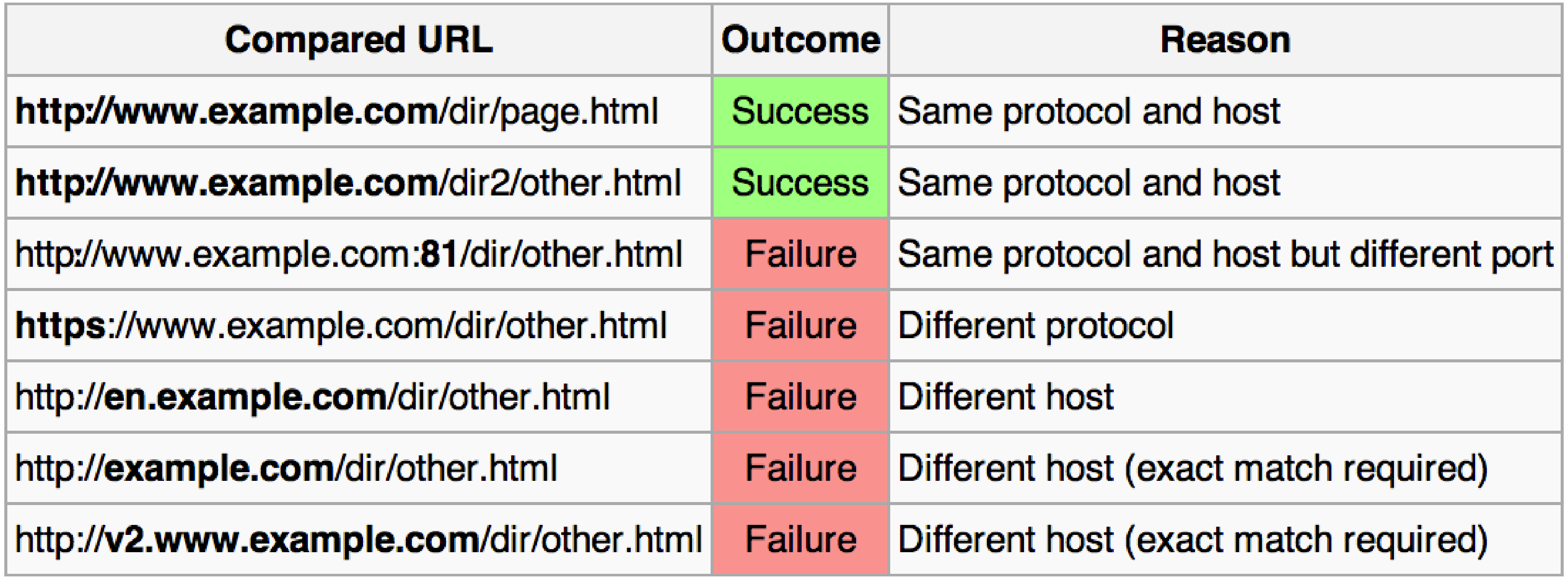
	High-quality report with functional exploit
Sandbox escape / Memory corruption in a non-sandboxed process	$30,000

From Chrome Bug Bounty Program

Same Origin Policy

Goal: Protect/isolate web content from other web content

Website origin = (scheme, domain, port)



Compared URL	Outcome	Reason
http://www.example.com/dir/page.html	Success	Same protocol and host
http://www.example.com/dir2/other.html	Success	Same protocol and host
http://www.example.com:**81**/dir/other.html	Failure	Same protocol and host but different port
https://www.example.com/dir/other.html	Failure	Different protocol
http://**en.example.com**/dir/other.html	Failure	Different host
http://**example.com**/dir/other.html	Failure	Different host (exact match required)
http://**v2.www.example.com**/dir/other.html	Failure	Different host (exact match required)

[Example from Wikipedia]

Same Origin Policy is Subtle!

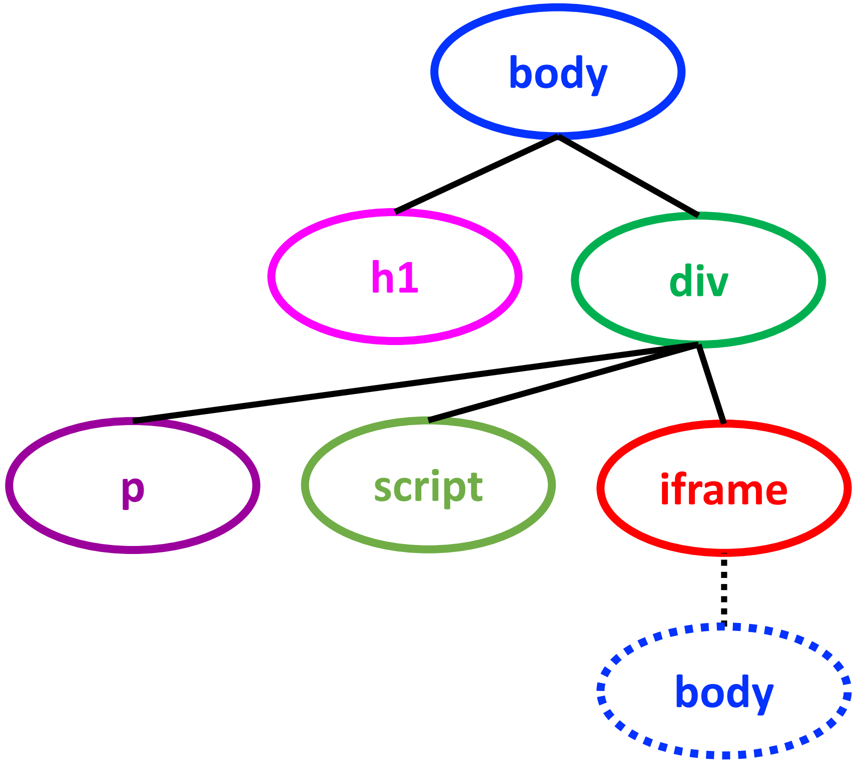
- Browsers didn‘t always get it right...
  - In 2023 we‘re pretty good though

- Lots of cases to worry about it:
  - DOM / HTML Elements
  - Navigation
  - Cookie Reading
  - Cookie Writing
  - Iframes vs. Scripts

HTML + DOM + JavaScript

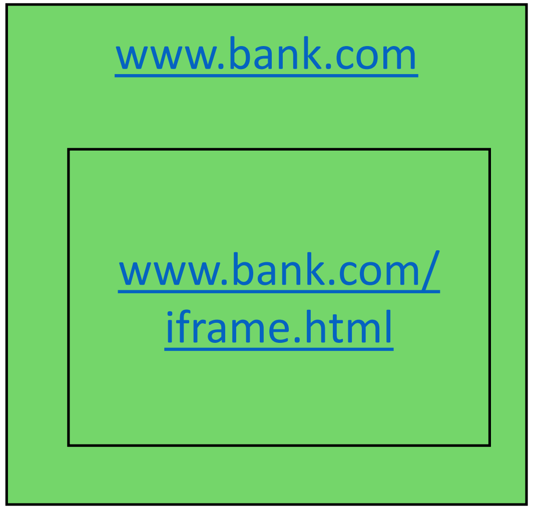
```
<html> <body>
<h1>This is the title</h1>
<div>
<p>This is a sample page.</p>
<script>alert(“Hello world”);</script>
<iframe src=“http://example.com”>
</iframe>
</div>
</body> </html>
```

Document Object Model (DOM)



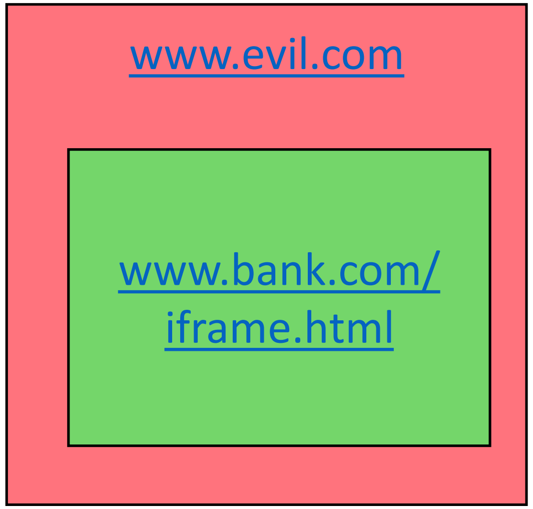
Same-Origin Policy: DOM

Only code from same origin can access HTML elements on another site (or in an iframe).



www.bank.com (the parent) **can** access HTML elements in the iframe (and vice versa).

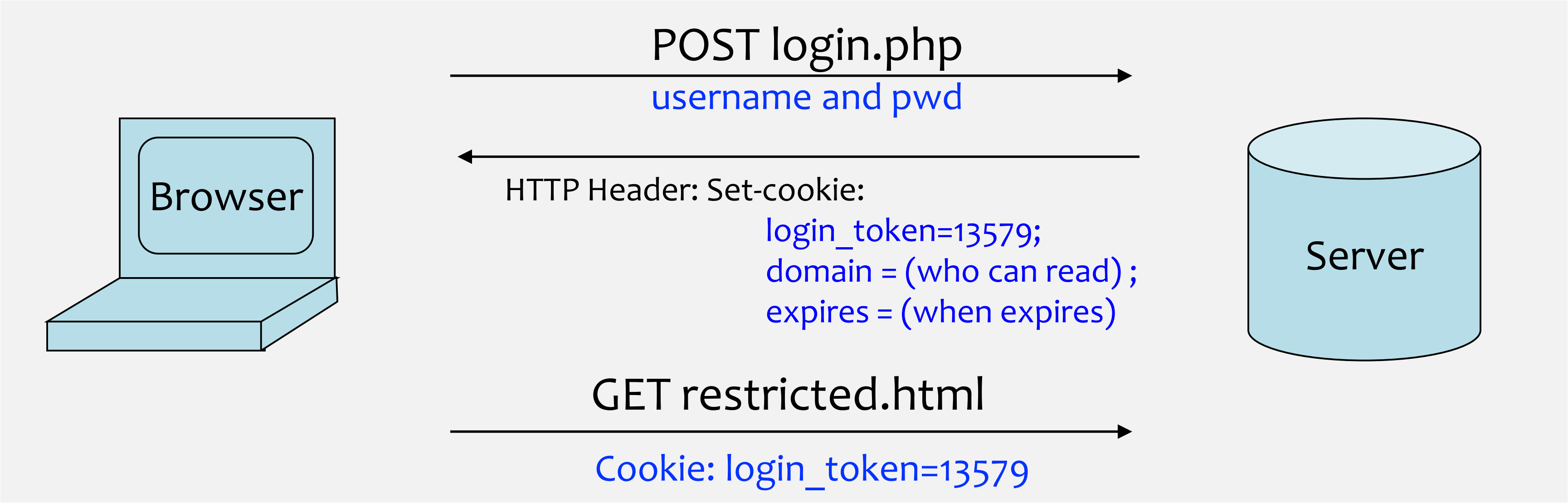
```
<html> <body>
<iframe
  src=“http://www.bank.com/iframe.html”>
</iframe>
</body> </html>
```



www.evil.com (the parent) **cannot** access HTML elements in the iframe (and vice versa).

Browser Cookies

- HTTP is stateless protocol
- Browser cookies are used to introduce state
  - Websites can store small amount of info in browser
  - Used for authentication, personalization, tracking…
  - Cookies are often secrets



POST login.php

username and pwd

HTTP Header: Set-cookie:
login_token=13579;
domain = (who can read) ;
expires = (when expires)

GET restricted.html

Cookie: login_token=13579

Same Origin Policy: Cookie Writing

Which cookies can be set by **login.site.com**?

allowed domains	disallowed domains
✓ **login.site.com**	✗ **othersite.com**
✓ **.site.com**	✗ **.com**
	✗ **user.site.com**

login.site.com can set cookies for all of **.site.com (domain suffix)**, but not for another site or top-level domain (TLD)