Signatures, Certificates, and Web

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Logistics

• Lab 1b last possible late day is Thursday
  • You have a bonus late day you can use here
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)
• Public key: \((p, q, g, y=g^x \mod p)\), 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 \(g^x \mod p\) (public key)
• Again: We’ve discussed discrete logs modulo integers; significant advantages to using \textbf{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
    • \( \text{sig}_{\text{CA}}(\text{“Bob”}, \text{PK}_B) \)
    • 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...

**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
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

*Refer to the certification authority's statement for details.*
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
    - $\text{sig}_{\text{Verisign}}(\text{“AnotherCA”}, \text{PK}_{\text{AnotherCA}})$,
    $\text{sig}_{\text{AnotherCA}}(\text{“Alice”}, \text{PK}_A)$
  - 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
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? -- canvas

• 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).

• Why would corporate IT want this capability?
• What might they use it for?
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)

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](https://groups.google.com/g/mozilla.dev.security.policy/c/nnLVNfqgz7g/m/TseYqDzaDAAJ) and [https://bugzilla.mozilla.org/show_bug.cgi?id=1427262](https://bugzilla.mozilla.org/show_bug.cgi?id=1427262))
  - Security company wanted to get CA status
  - Questionable practices

  - 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](http://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

**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

<table>
<thead>
<tr>
<th>High-quality report with functional exploit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandbox escape / Memory corruption in a non-sandboxed process</td>
</tr>
</tbody>
</table>

From Chrome Bug Bounty Program

4/26/2023
CSEP 564 - Fall 2022
Same Origin Policy

Goal: Protect/isolate web content from other web content

Website origin = (scheme, domain, port)

<table>
<thead>
<tr>
<th>Compared URL</th>
<th>Outcome</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.example.com/dir/page.html">http://www.example.com/dir/page.html</a></td>
<td>Success</td>
<td>Same protocol and host</td>
</tr>
<tr>
<td><a href="http://www.example.com/dir2/other.html">http://www.example.com/dir2/other.html</a></td>
<td>Success</td>
<td>Same protocol and host</td>
</tr>
<tr>
<td><a href="http://www.example.com:81/dir/other.html">http://www.example.com:81/dir/other.html</a></td>
<td>Failure</td>
<td>Same protocol and host but different port</td>
</tr>
<tr>
<td><a href="https://www.example.com/dir/other.html">https://www.example.com/dir/other.html</a></td>
<td>Failure</td>
<td>Different protocol</td>
</tr>
<tr>
<td><a href="http://en.example.com/dir/other.html">http://en.example.com/dir/other.html</a></td>
<td>Failure</td>
<td>Different host</td>
</tr>
<tr>
<td><a href="http://example.com/dir/other.html">http://example.com/dir/other.html</a></td>
<td>Failure</td>
<td>Different host (exact match required)</td>
</tr>
<tr>
<td><a href="http://v2.www.example.com/dir/other.html">http://v2.www.example.com/dir/other.html</a></td>
<td>Failure</td>
<td>Different host (exact match required)</td>
</tr>
</tbody>
</table>

[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>
<p>This is a sample page.</p>
<script>alert("Hello world");</script>
<iframe src="http://example.com"></iframe>
</body>
</html>
```
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).
- **www.evil.com** (the parent) **cannot** access HTML elements in the iframe (and vice versa).

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

Browser

```
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
✓ login.site.com
✓ .site.com

disallowed domains
✗ othersite.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)