CS 5430

Certificates, part 2

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Review: Certificates

- Digital certificate is a signature binding together:
  - **identity** of principal
  - **public key** of that principal (might be encryption or verification key)
  - (maybe more)
- **Notation:** Cert(S; I) is a certificate issued by principal I for principal S
  - let b = id_S, K_S, …
  - Cert(S; I) = b, Sign(b; k_I)
  - Issuer I is certifying that K_S belongs to subject id_S

Review: PKI

- System for managing distribution of certificates
- Two main philosophies:
    - **Decentralized:** anarchy, no leaders
    - **Centralized:** oligarchy, leadership a few elite

PKI Example 2: CAs

- Uses a centralized PKI philosophy (at least as evolved in marketplace)
- Invented (?) by Digital [Gasser et al. 1989], used in early Netscape browsers
- Certificate authority (CA): principal whose purpose is to issue certificates

Using a CA

- Everyone enrolls with the CA to get a certificate
  - E.g., Alice enrolls and gets Cert(Alice; CA)
- Your system comes pre-installed with CA's self-signed certificate Cert(CA; CA)
- When you receive a message signed by Alice:
  - you contact CA to get Cert(Alice; CA)
  - or Alice just includes that certificate with her message

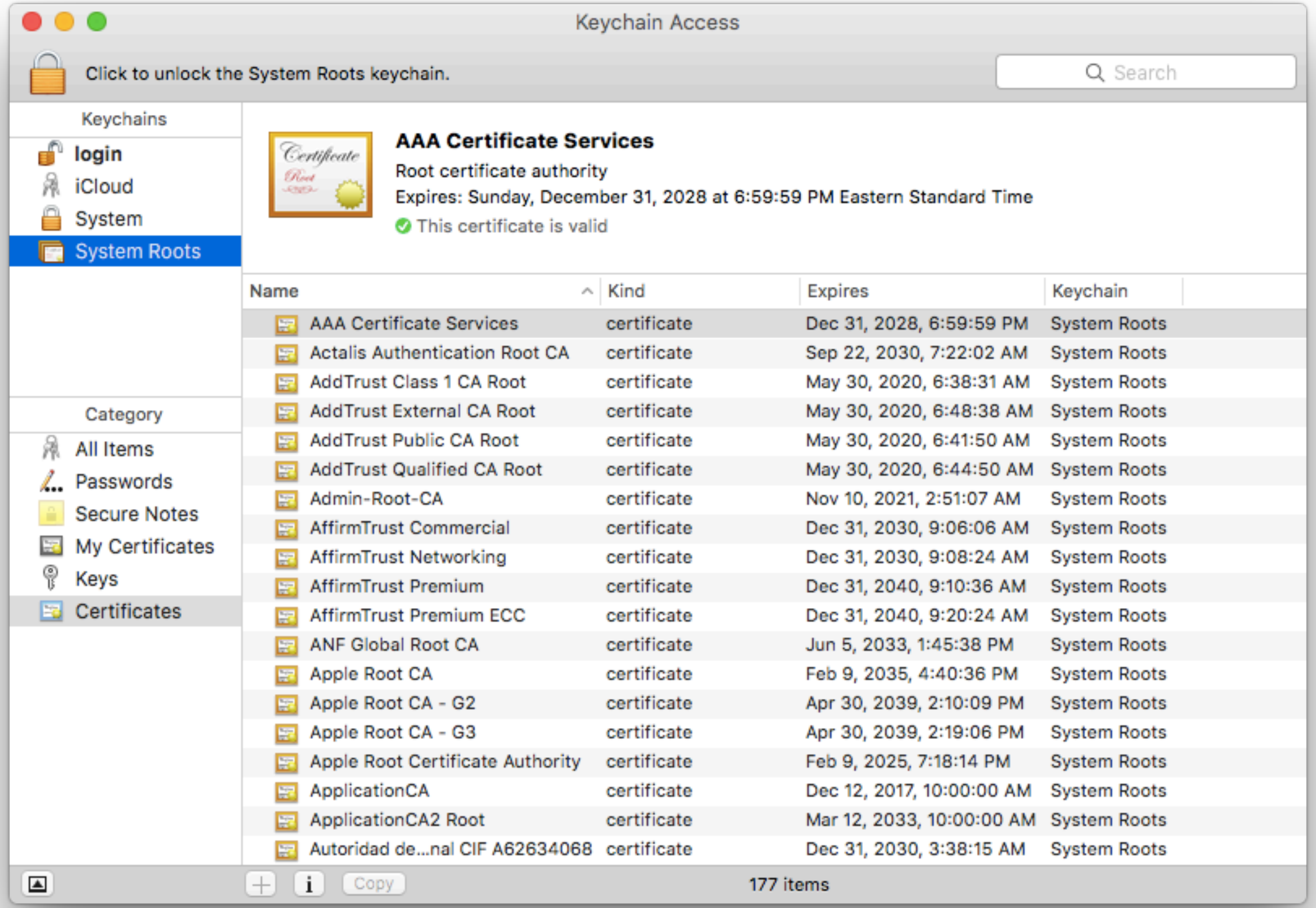
CAs and web browsers

- Web server has certificate Cert(server; CA) installed
    - Server’s identity is its URL
    - CA is a root for which Cert(CA; CA) is installed in browser
- Browser authenticates web server
    - Using server’s URL and public key from certificate
    - Perhaps based on protocol from last lecture
    - Perhaps based on SSL (this lecture)
- Machines are authenticating machines

Many CAs

- There can't be **only one**
  - No single CA is going to be trusted by all the world's governments, militaries, businesses
  - Though within an organization such trust might be possible
- So there are **many**
  - Around 1500 observed on public internet
  - Your OS and/or browser comes with some pre-installed
- Organizations act as their own CA, e.g....
  - Company issues certificates to employees for VPN
  - Bank issues certificates to customers
  - Central bank issues certificates to other banks
  - Manufacturer issues certificates to sensing devices

Demo: OS X Keychain Access



AAA Certificate Services

Root certificate authority

Expires: Sunday, December 31, 2028 at 6:59:59 PM Eastern Standard Time

✓ This certificate is valid

Name	Kind	Expires	Keychain
AAA Certificate Services	certificate	Dec 31, 2028, 6:59:59 PM	System Roots
Actalis Authentication Root CA	certificate	Sep 22, 2030, 7:22:02 AM	System Roots
AddTrust Class 1 CA Root	certificate	May 30, 2020, 6:38:31 AM	System Roots
AddTrust External CA Root	certificate	May 30, 2020, 6:48:38 AM	System Roots
AddTrust Public CA Root	certificate	May 30, 2020, 6:41:50 AM	System Roots
AddTrust Qualified CA Root	certificate	May 30, 2020, 6:44:50 AM	System Roots
Admin-Root-CA	certificate	Nov 10, 2021, 2:51:07 AM	System Roots
AffirmTrust Commercial	certificate	Dec 31, 2030, 9:06:06 AM	System Roots
AffirmTrust Networking	certificate	Dec 31, 2030, 9:08:24 AM	System Roots
AffirmTrust Premium	certificate	Dec 31, 2040, 9:10:36 AM	System Roots
AffirmTrust Premium ECC	certificate	Dec 31, 2040, 9:20:24 AM	System Roots
ANF Global Root CA	certificate	Jun 5, 2033, 1:45:38 PM	System Roots
Apple Root CA	certificate	Feb 9, 2035, 4:40:36 PM	System Roots
Apple Root CA - G2	certificate	Apr 30, 2039, 2:10:09 PM	System Roots
Apple Root CA - G3	certificate	Apr 30, 2039, 2:19:06 PM	System Roots
Apple Root Certificate Authority	certificate	Feb 9, 2025, 7:18:14 PM	System Roots
ApplicationCA	certificate	Dec 12, 2017, 10:00:00 AM	System Roots
ApplicationCA2 Root	certificate	Mar 12, 2033, 10:00:00 AM	System Roots
Autoridad de...nal CIF A62634068	certificate	Dec 31, 2030, 3:38:15 AM	System Roots

Enrollment with a CA

- You create a key pair: **you** do this so that CA doesn't learn your private key
- You generate a certificate signing request (CSR); it contains the identity you are claiming
- You send the CSR to a CA, perhaps along with payment
- The CA verifies your identity (maybe)
- The CA signs your key, thus creating a certificate, and sends certificate to you

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Identity verification

- Extended validation (EV) certificate:
  - CA does extra checking of your identity
  - Certificate marked as having received EV
  - Web browser reflects EV mark in UI
- Examples of extra checking:
  - Verify legal existence of organization including some sort of registration number; record legal business number as part of subject's identity in certificate
  - Verify physical operation of organization by a site visit
  - Verify phone number as listed by a public phone company
- CA record all those data in the certificate as part of subject's identity
- Example: https://www.paypal.com

Issuing certificates

Conflicting goals:

- CA private signing key must be kept secret
  - the public verification key is pre-installed on user systems; hard to update
  - if ever leaked, signing key could be used to forge certificates
  - easy way to realize goal: keep it in *cold storage*
- CA private signing key must be available for use
  - to sign new certificates when users request them
  - easy way to realize goal: keep it in computer's memory

Issuing certificates

Solution: use root and intermediate CAs

- **root CA:** the certificate at root of trust in a chain; pre-installed; key kept in highly secure storage
- **intermediate CA(s):** certified by root CA, themselves certify user keys; might be run by a different organization than root
- example: https://www.facebook.com

Authentication

	Humans	Machines
Humans authenticating…	Faces, tickets, passwords	Secure attention key, visual secrets
Machines authenticating…	Passwords, biometrics	Tokens, CAs as used in web

Success!

We've solved the phonebook problem!

To publish public key, user can:

- distribute it as part of web of trust
- or engage CA to provide certificate

...or, have we???

PROBLEMS WITH PKI

Problem 1: Revocation

- Keys (subject's, issuer's) get compromised
- Or subject leaves an organization

  …certificates therefore need to be revoked

- **There's no perfect solution**
  - Fast expiration
  - Certificate revocation lists (CRLs)
  - Online certificate validation

Revocation

Fast expiration

- **Idea:**
  - Validity internal is short, e.g. 10 min to 24 hr
  - A kind of revocation thus happens automatically
  - Any compromise is bounded
- **Problem:**
  - CAs have to issues new certificates frequently, including checking identities
  - Machines have to update certificates frequently

Revocation

Certificate revocation lists (CRLs)

- **Idea:**
  - CA posts list of revoked certificates
  - Clients download and check every time they need to validate certificate
- **Problems:**
  - Clients don't (because usability)
  - Or they cache, leading to TOCTOU attack
  - CRL must always be available (so an attractive DoS target)
- Chromium does this, with a CRL limited to 250kb

Revocation

Online certificate validation

- **Idea:**
  - CA runs *validation server*
  - Clients contact it each time to validate certificate
- **Problems:**
  - Clients don't
  - Server must always be available (so an attractive DoS target)
  - Reveals to CA which websites you want to access

Revocation

Online certificate validation

- **Follow-on solution:** stapling
  - Certificates must be accompanied by fresh assertion from CA that certificate is still valid
  - Whoever presents certificate to client is responsible for acquiring assertion
- Firefox does this but doesn't *hard fail* because "[validation servers] aren't yet reliable enough”
  - Unless web site has previously served up a certificate to browser with Must Staple extension set

Problem 2: Authority

- CAs go rogue, get hacked, issue certificates that **they** should never have issued
  - e.g., Dutch CA DigiNotar (2011), which was included in many root sets: 500 bogus certificates issued, including for Google, Yahoo, Tor
- Missing a means for authorization of who may issue certificates for which principals

Authority

There's no perfect solution

- Key pinning: upon first connection to a server, client learns a set of public keys for server; in future connections, certificate must contain one of those keys
- Certificate transparency: maintain a public log of issued certificates; require any presented certificate to be in that log; monitor log to notice misbehavior
- Certificate Authority Authorization (CAA): piggyback on DNS system; DNS record for entity specifies allowed CAs; a good CA won't issue cert unless they are authorized
- DNS-based Authentication of Named Entities (DANE): piggyback like CAA; client checks whether cert comes from authorized CA

USING CAs IN SSL

SSL

Secure Sockets Layer (SSL)

- aka Transport Layer Security (TLS)
- SSL 3.1 = TLS 1.0 (1999)
  - Broken by attack in 2011 based on improper choice of IVs for CBC mode
- SSL 3.2 = TLS 1.1 (2006)
  - Fixes IVs
- SSL 3.3 = TLS 1.2 (2008)
  - Upgrades crypto primitives (AES, SHA-256, etc.)

Network stack

Layer	e.g.	Connects
Application	HTTP	processes
Transport	TCP	hosts
Internet	IP	networks
Link	WiFi	devices

Network stack

Layer	e.g.	Connects
Application	HTTP	processes
	SSL	
Transport	TCP	hosts
Internet	IP	networks
Link	WiFi	devices

- SSL provides secure channel atop underlying guarantees of transport layer
- HTTPS = HTTP + SSL

SSL terminology

- Record: message sent during session
- Session:
  - communication channel
  - between client and server
  - logical
  - bi-directional (and direction matters)
  - **optionally** secured for confidentiality and/or integrity against Dolev-Yao attacker

SSL protocols

- Handshake protocol: initial channel setup
- Record protocol: exchange of messages

Caveats:

- *what follows is common way of configuring those protocols, not the only way*
- *no official rationale for the protocol*

Record protocol

Connection state:

- **cmk:** client HMAC key
- **smk:** server HMAC key
- **cek:** client symmetric encryption key
- **sek**: server symmetric encryption key
- **civ:** client IV
- **siv:** server IV
- **cseq:** client sequence number
- **sseq:** server sequence number

Record protocol

Directional communication:

- both client and server are meant to know the entire state, but...
- from client to server uses cXX state
- from server to client uses sXX state

... defends against reflection attacks

Record protocol

For client to send record to server:

```
1. C: t = MAC(r, cseq; cmk);
      c = Enc(r, t; civ; cek);
      cseq++;  // if overflow, re-key
      civ = rand()
2. C -> S: c
```

MAC-then-Enc

Server to client is the same with sXX part of connection state

Handshake protocol

- Purpose:
  - Establish ciphersuite
  - Then establish connection state
- **Ciphersuite:** triple of cryptographic choices...
  1. Protocol for key establishment
  2. Block cipher and mode
  3. PRF (typically a hash function for HMAC)
- Example ciphersuites:
  - `RSA, AES128/CBC, SHA-256`
  - `DH_anon, 3DES/CBC, SHA-1` (beware DH_anon!)
  - `null, null, null`
- Henceforth assume RSA key establishment...

Handshake protocol

Warning:

- attacks on SSL sometimes involve rollback to deprecated algorithms that your crypto library still supports
- YOUR responsibility to make sure only current algorithms are enabled

Handshake protocol

```
1. C->S: Suites_C, N_C
2. S->C: Suite_S, Cert(S; CA), N_S
3. C: PS = rand();  // premaster secret
      ePS = Enc(PS; K_S)
4. C->S: ePS
5. S: PS = Dec(ePS; k_S)
6. C and S:
     MS = PRF(PS, "master secret"; N_C+N_S);
     derive connection state from MS
       by splitting into bits
```

Could be a chain

Handshake protocol

See online notes for some omitted details:

- Verify that client and server have agreed on same keys
- Unilateral vs. mutual authentication:
  - **unilateral:** server authenticates to client
  - **mutual:** server authenticates to client and client authenticates to server

Upcoming events

- [Fri] A4 due; happy Dragon Day!
- [next week] Happy Spring Break!

Do not believe anything just because you heard it from a seeming authority. – The Buddha