CSE 484 : Computer Security and Privacy

Cryptography with Hints Toward Web Security

Fall 2021

David Kohlbrenner

dkohlbre@cs

Thanks to Franzi Roesner, Dan Boneh, Dieter Gollmann, Dan Halperin, David Kohlbrenner, Yoshi Kohno, Ada Lerner, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Admin

- HW 2 out, still due Fri Nov 5th
- Lab 1 due today!

- No class next Wednesday

Re: DES, DUAL_EC DRBG, etc.

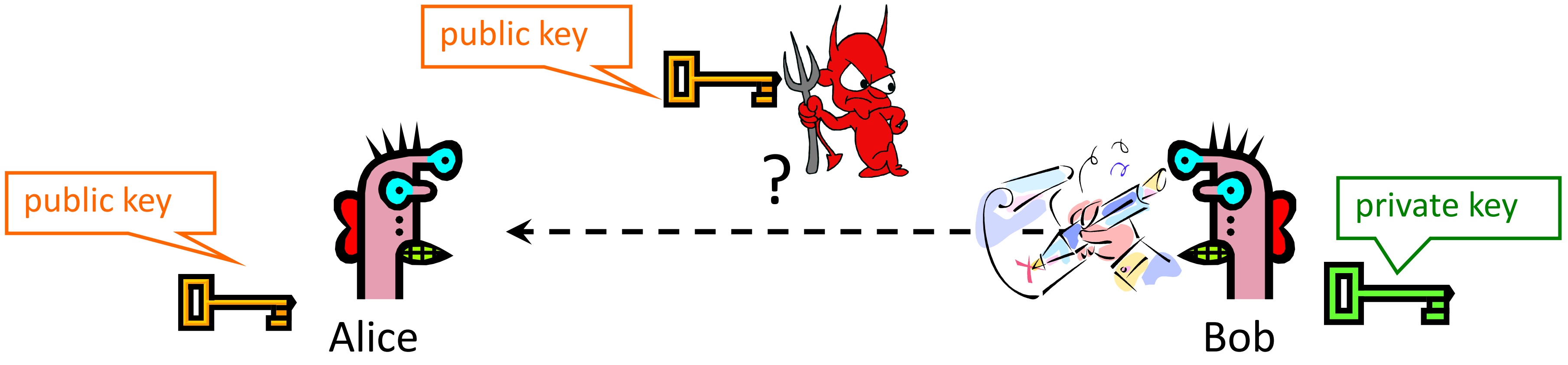
- Canvas discussion!

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: $d \equiv e^{-1} \bmod \varphi(n)$
  - Public key = (e,n); private key = (d,n)
- Encryption of m: $c = m^e \bmod n$
- Decryption of c: $c^d \bmod n = (m^e)^d \bmod n = m$

$\longleftarrow$ How to compute?

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 = $m^d \bmod n$
  - 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 $s^e \bmod n = (m^d)^e \bmod n = m$
  - 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

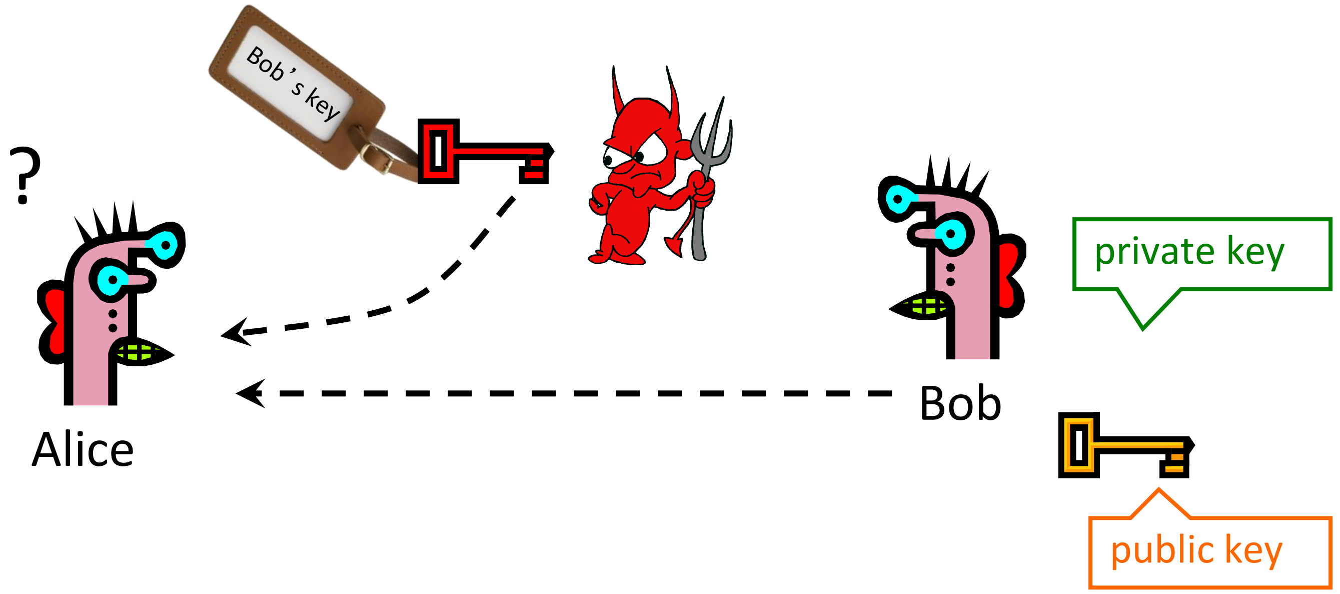
DSS Signatures

- Digital Signature Standard (DSS)
  - U.S. government standard (1991, most recent rev. 2013)
- Public key: (p, q, g, $y=g^x$ 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 elliptic curve groups instead.

Post-Quantum

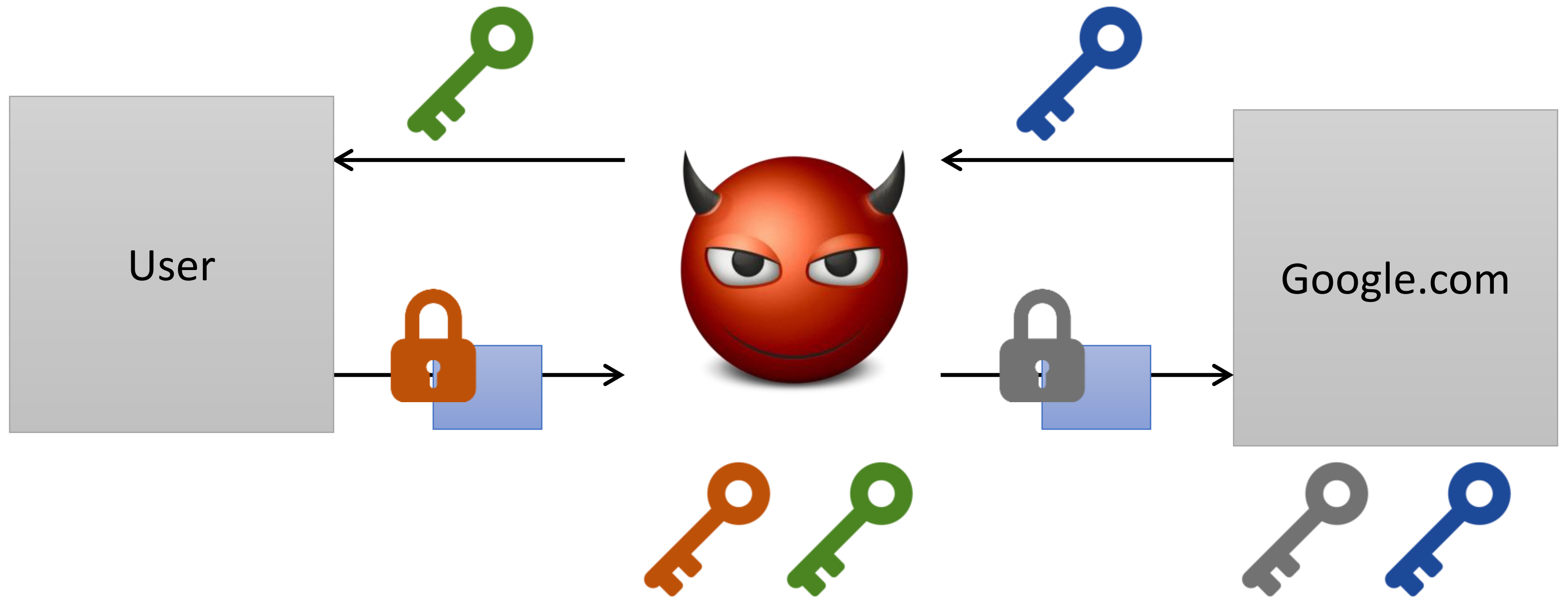
- If quantum computer become a reality
  - It becomes much more efficient to break conventional asymmetric encryption schemes (e.g., factoring becomes "easy")
  - For block ciphers (symmetric encryption), use 128-bit keys for 256-bits of security
- There exists efforts to make quantum-resilient asymmetric encryption schemes

Authenticity of Public Keys



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

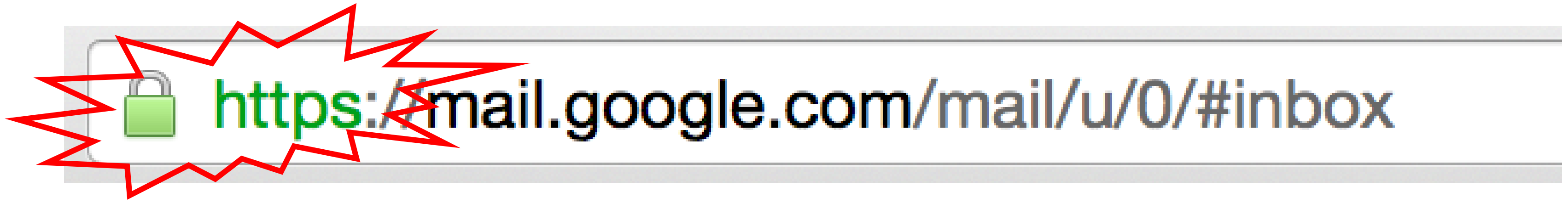
Threat: Person-in-the Middle



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…

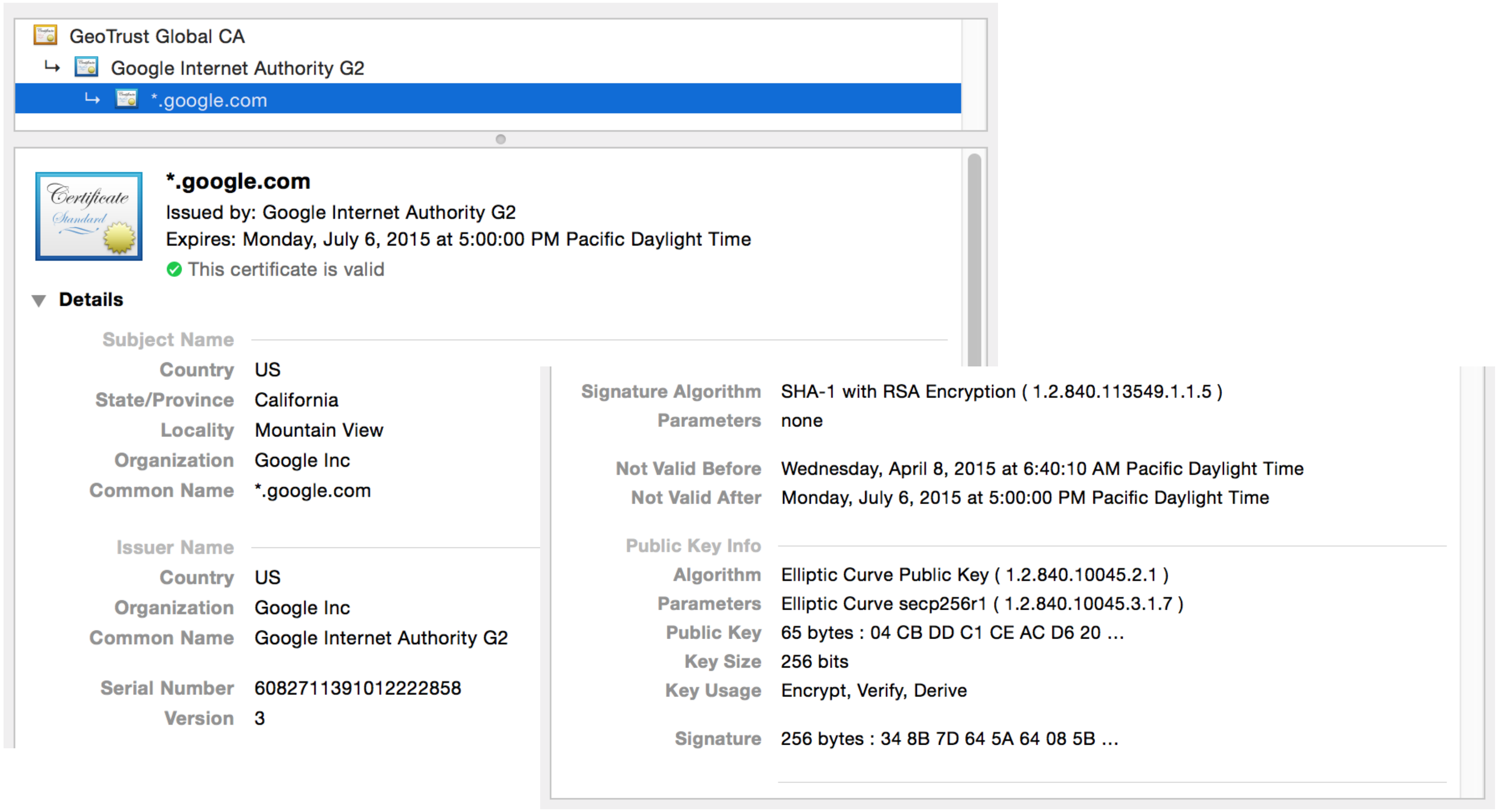


SSL/TLS: Encryption & authentication for connections

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

Example of a Certificate



GeoTrust Global CA
↳ Google Internet Authority G2
↳ *.google.com

***.google.com**
Issued by: Google Internet Authority G2
Expires: Monday, July 6, 2015 at 5:00:00 PM Pacific Daylight Time
✓ This certificate is valid

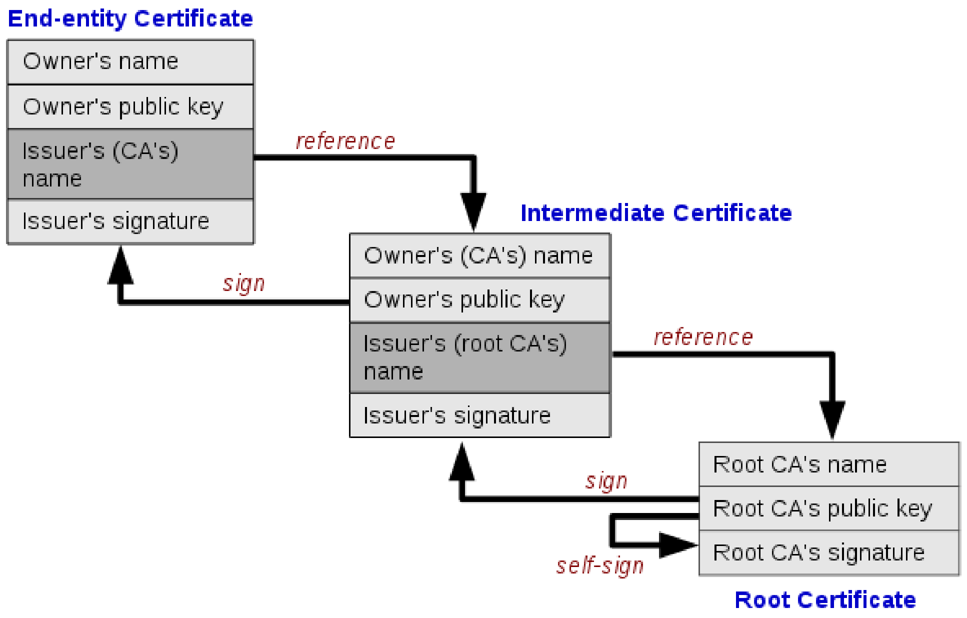
Details

Subject Name	
Country	US
State/Province	California
Locality	Mountain View
Organization	Google Inc
Common Name	*.google.com
Issuer Name	
Country	US
Organization	Google Inc
Common Name	Google Internet Authority G2
Serial Number	6082711391012222858
Version	3

Signature Algorithm	SHA-1 with RSA Encryption (1.2.840.113549.1.1.5)
Parameters	none
Not Valid Before	Wednesday, April 8, 2015 at 6:40:10 AM Pacific Daylight Time
Not Valid After	Monday, July 6, 2015 at 5:00:00 PM Pacific Daylight Time
Public Key Info	
Algorithm	Elliptic Curve Public Key (1.2.840.10045.2.1)
Parameters	Elliptic Curve secp256r1 (1.2.840.10045.3.1.7)
Public Key	65 bytes : 04 CB DD C1 CE AC D6 20 …
Key Size	256 bits
Key Usage	Encrypt, Verify, Derive
Signature	256 bytes : 34 8B 7D 64 5A 64 08 5B …

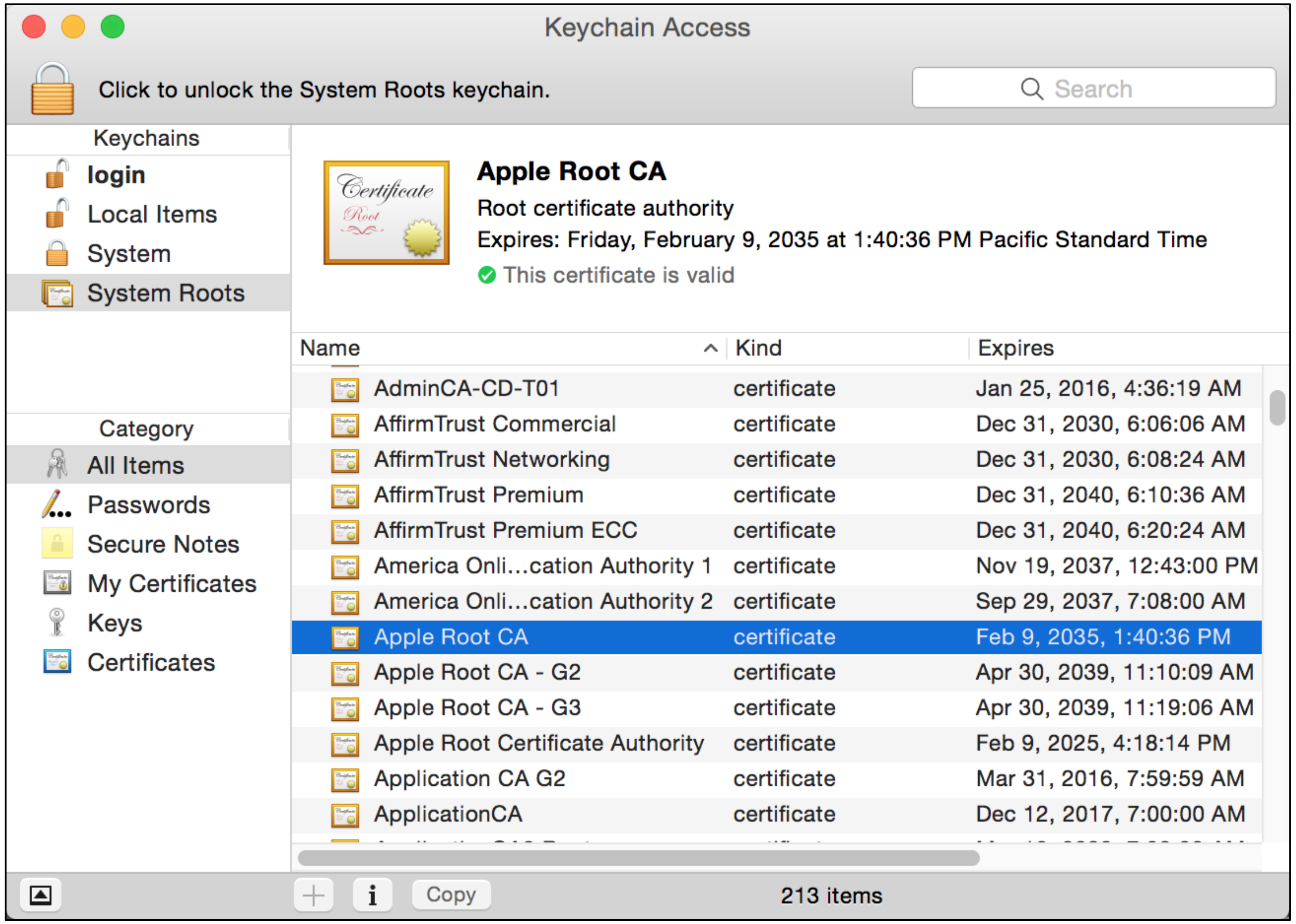
Hierarchical Approach

- 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?

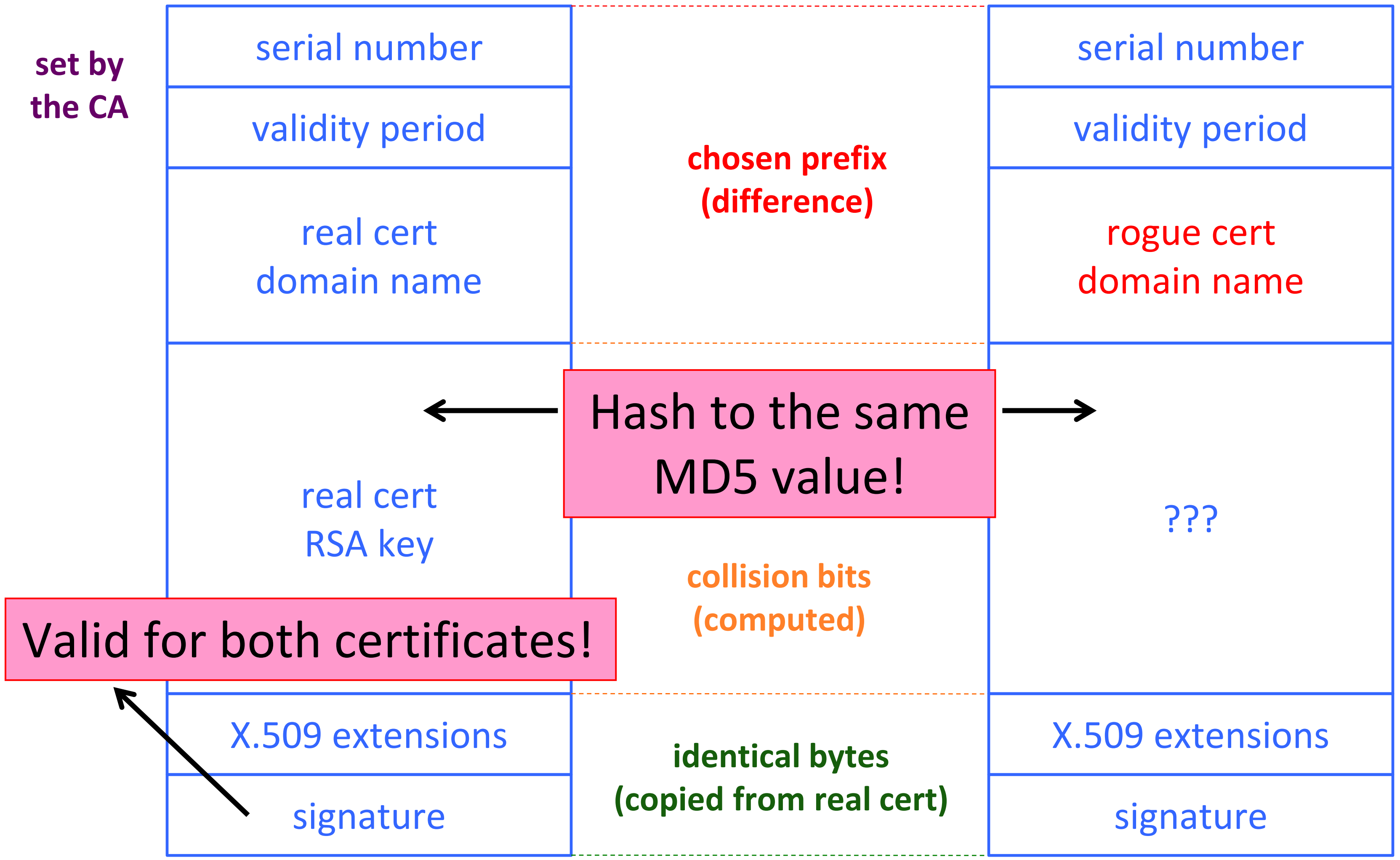
- Canvas!

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?

[Sotirov et al. "Rogue Certificates"]

Colliding Certificates



Attacking CAs

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.

<u>Security of DigiNotar servers:</u>

- 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)

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

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?