CSE 484 / CSE M 584: Asymmetric Cryptography

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Announcements

- Physical security lecture: Wednesday, March 9

Begin Review Slides

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

End Review Slides

- To sign message m: $s = m^d \bmod n$
- Suppose sign m = 1 ➔ $s = m^d \bmod n$ is 1
- Suppose sign m for any m ➔ $s = m^d \bmod n$ is 1
  - Adversary gets m and s
  - Adversary computes $s' = s^2 \bmod n$ and $m' = m^2 \bmod n$
  - Adversary sends s',m' to receiver
  - Signature s' on m' verifies as correct
    - $(s')^e \bmod n = (s^2)^e \bmod n = (m^{d2})^e \bmod n = m^2$
- Suppose adversary receives two message-signature pairs (m1,s1), (m2,s2)?
- Thus, sign H(m), not m, where H hashes to a number between 0 and n-1

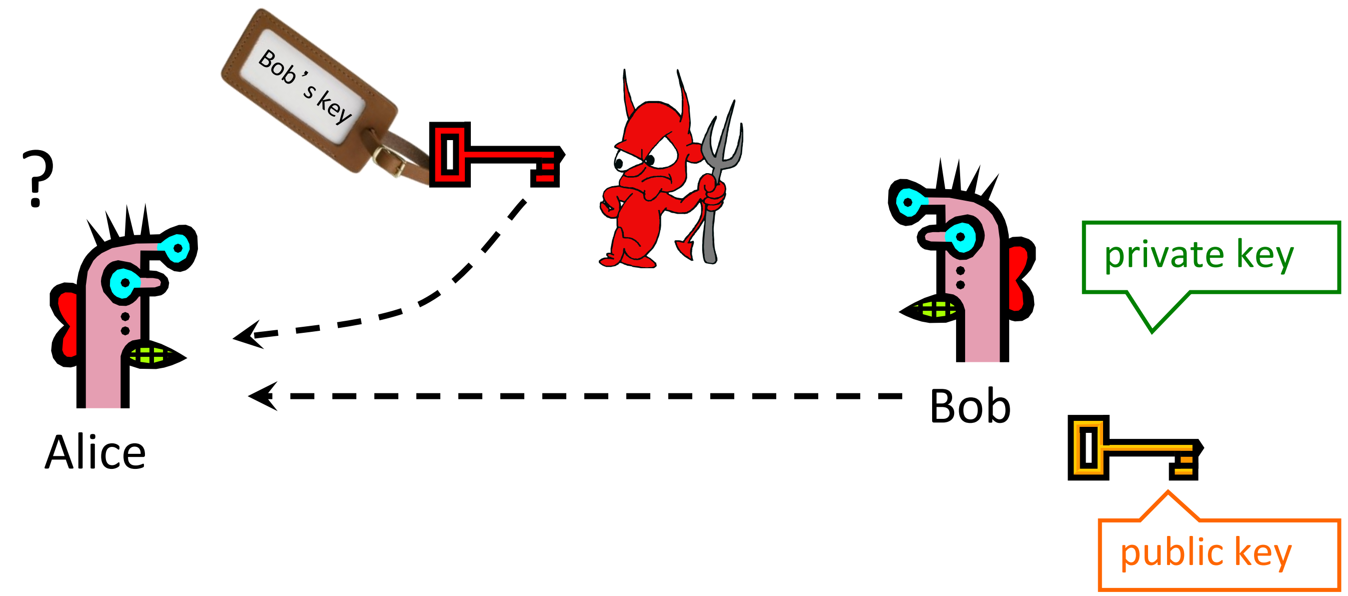
DSS Signatures

- 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 mod p (public key)
- Again: We've discussed discrete logs modulo integers; significant advantages to using elliptic curve groups instead.

Post-Quantum

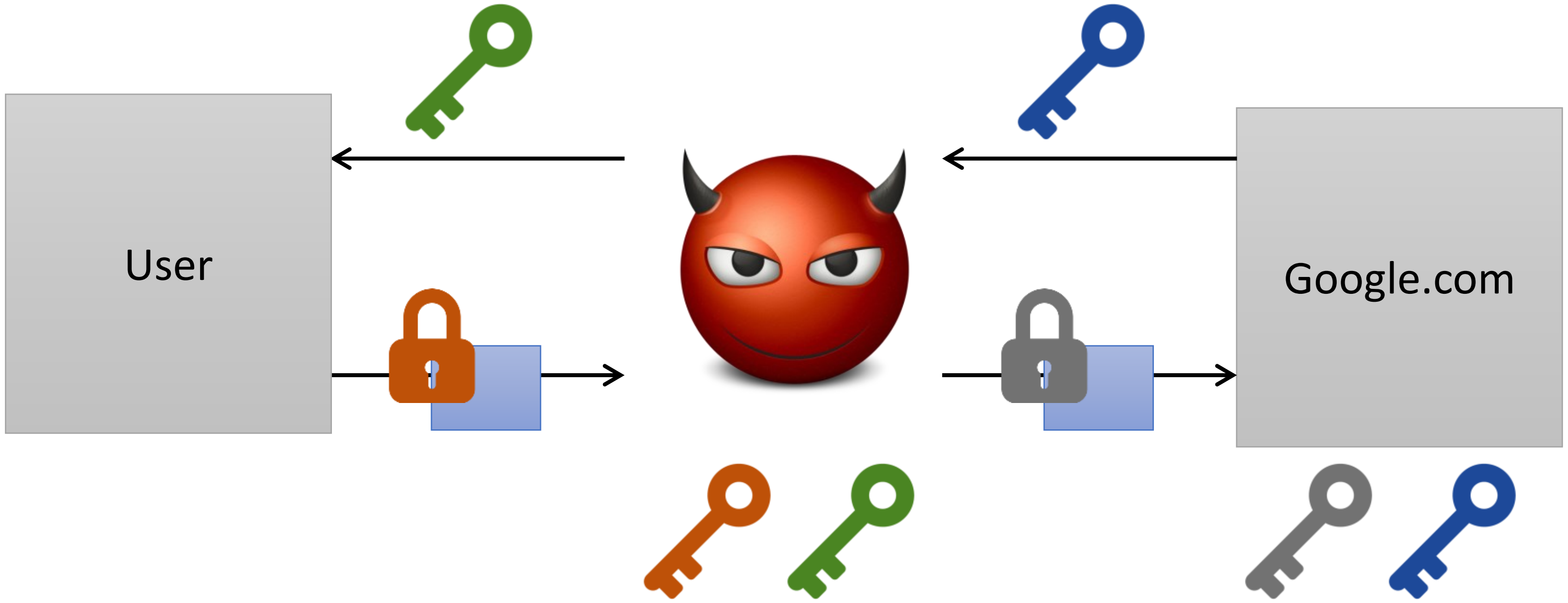
- If quantum computer become a reality
  - It becomes much more efficient to break conventional asymmetric encryption schemes (e.g., factoring becomes “easy”)
  - For block ciphers (symmetric encryption), use 256-bit keys for 128-bits of security
- There exists efforts to make quantum-resilient asymmetric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

Authenticity of Public Keys



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

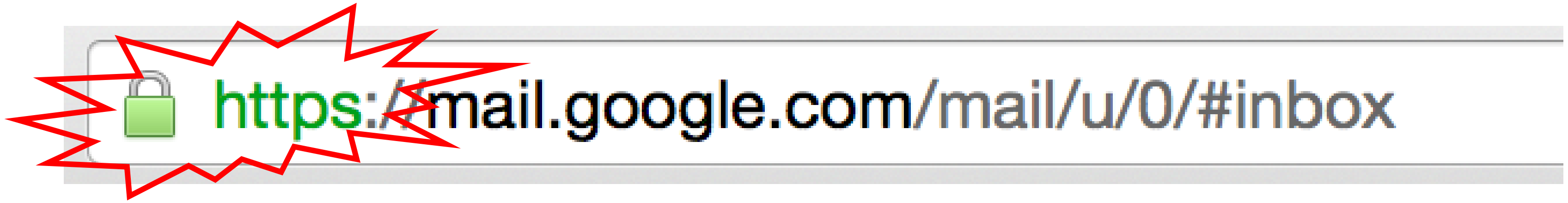
Threat: Person-in-the Middle



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…

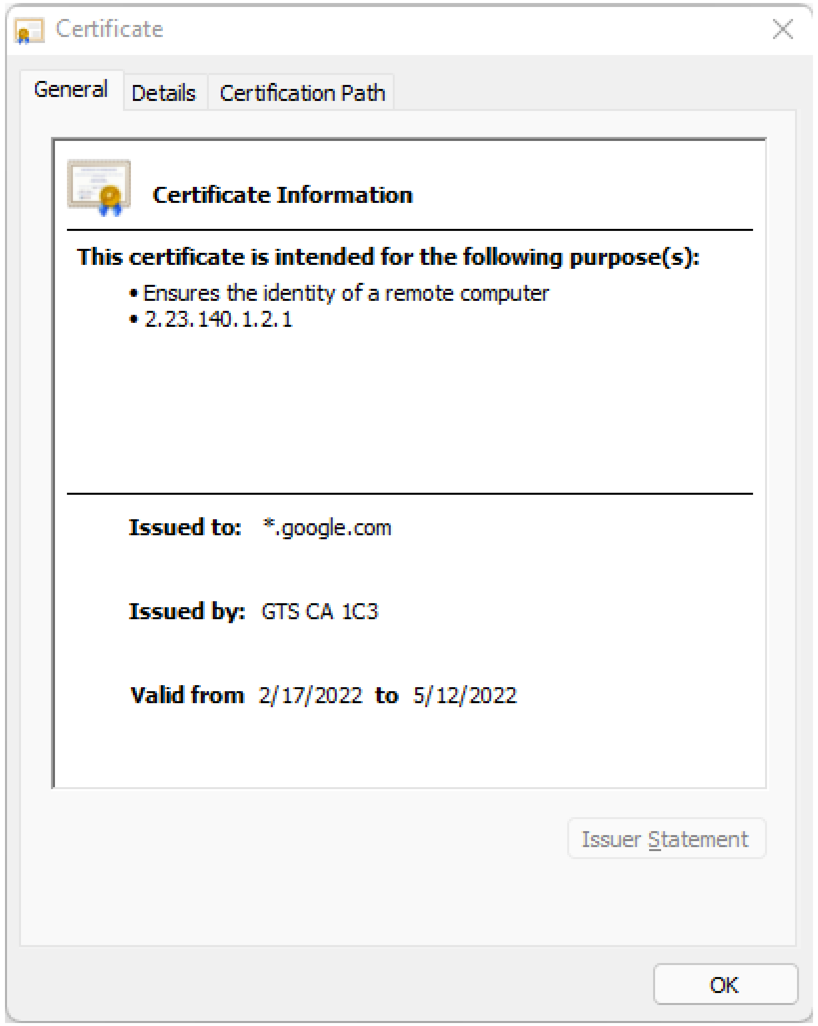


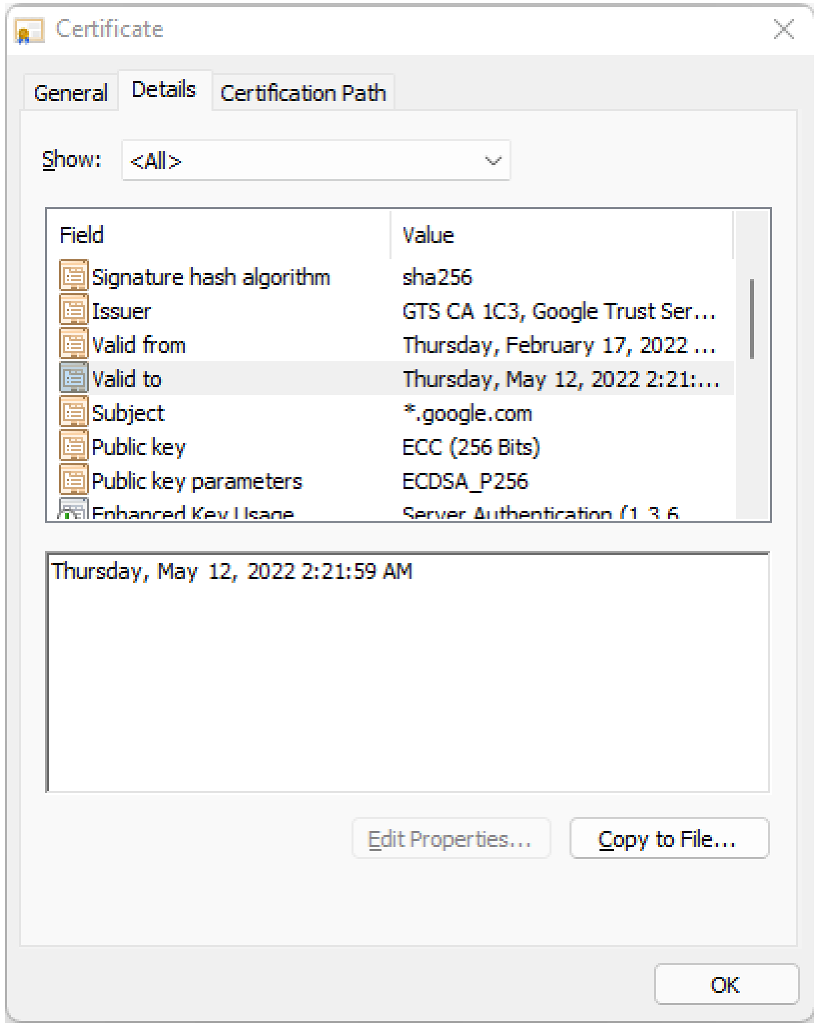
SSL/TLS: Encryption & authentication for connections

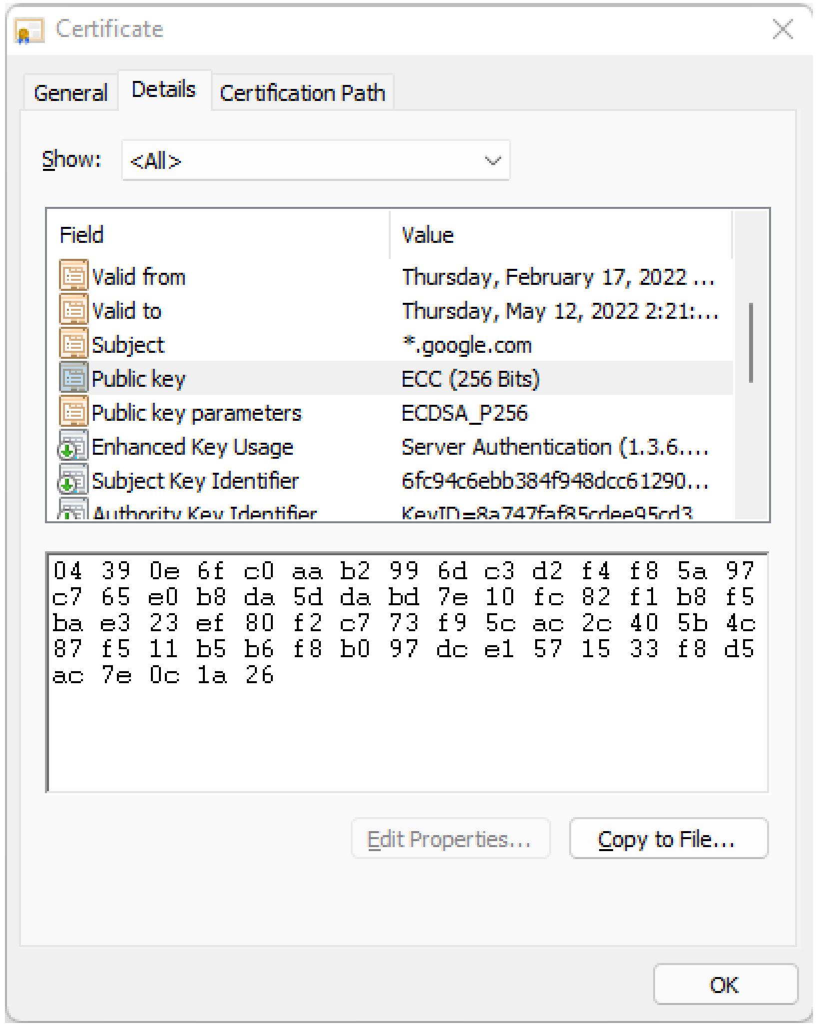
SSL/TLS High Level

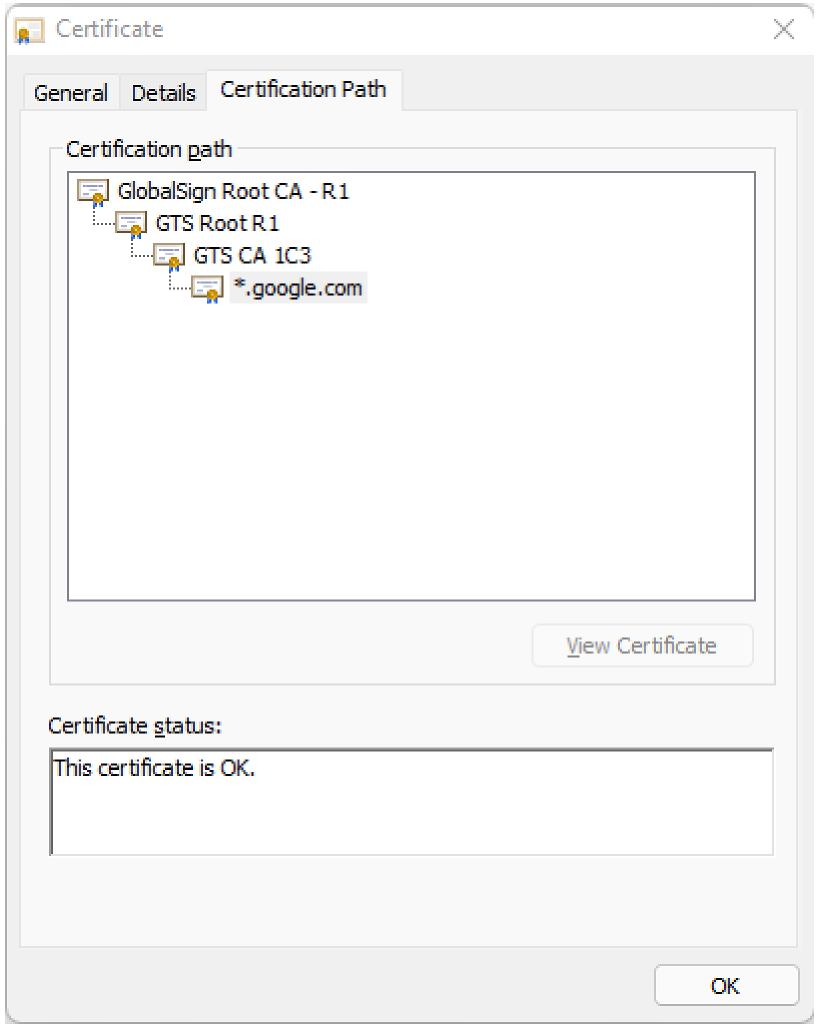
- SSL/TLS consists of two protocols
  - Familiar pattern for key exchange protocols
- Handshake protocol
  - Use public-key cryptography to establish a shared secret key between the client and the server
- Record protocol
  - Use the secret symmetric key established in the handshake protocol to protect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

Example of a Certificate



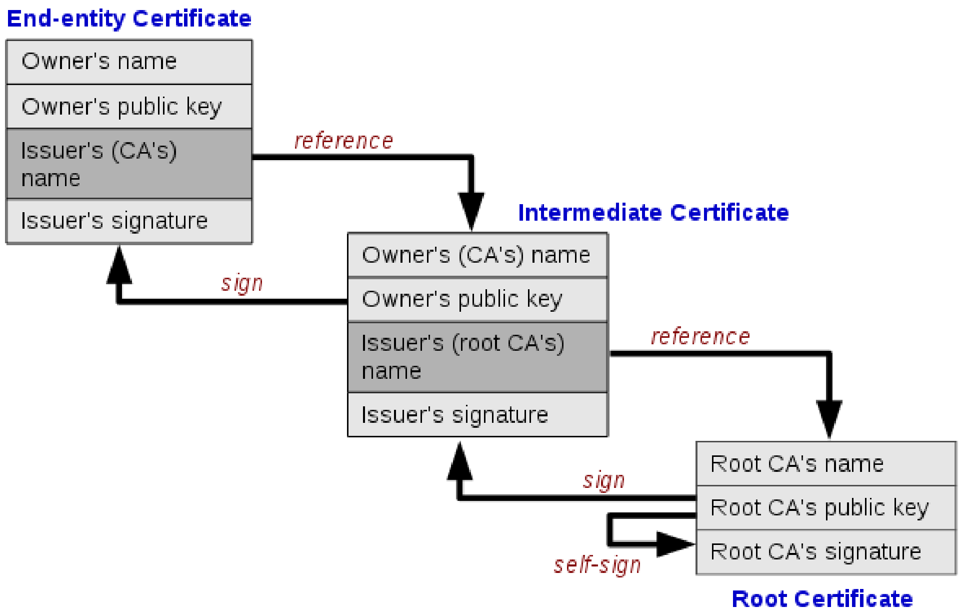





Certificate
General
Details
Certification Path
Certification path
GlobalSign Root CA - R1
GTS Root R1
GTS CA 1C3
*.google.com
View Certificate
Certificate status:
This certificate is OK.
OK

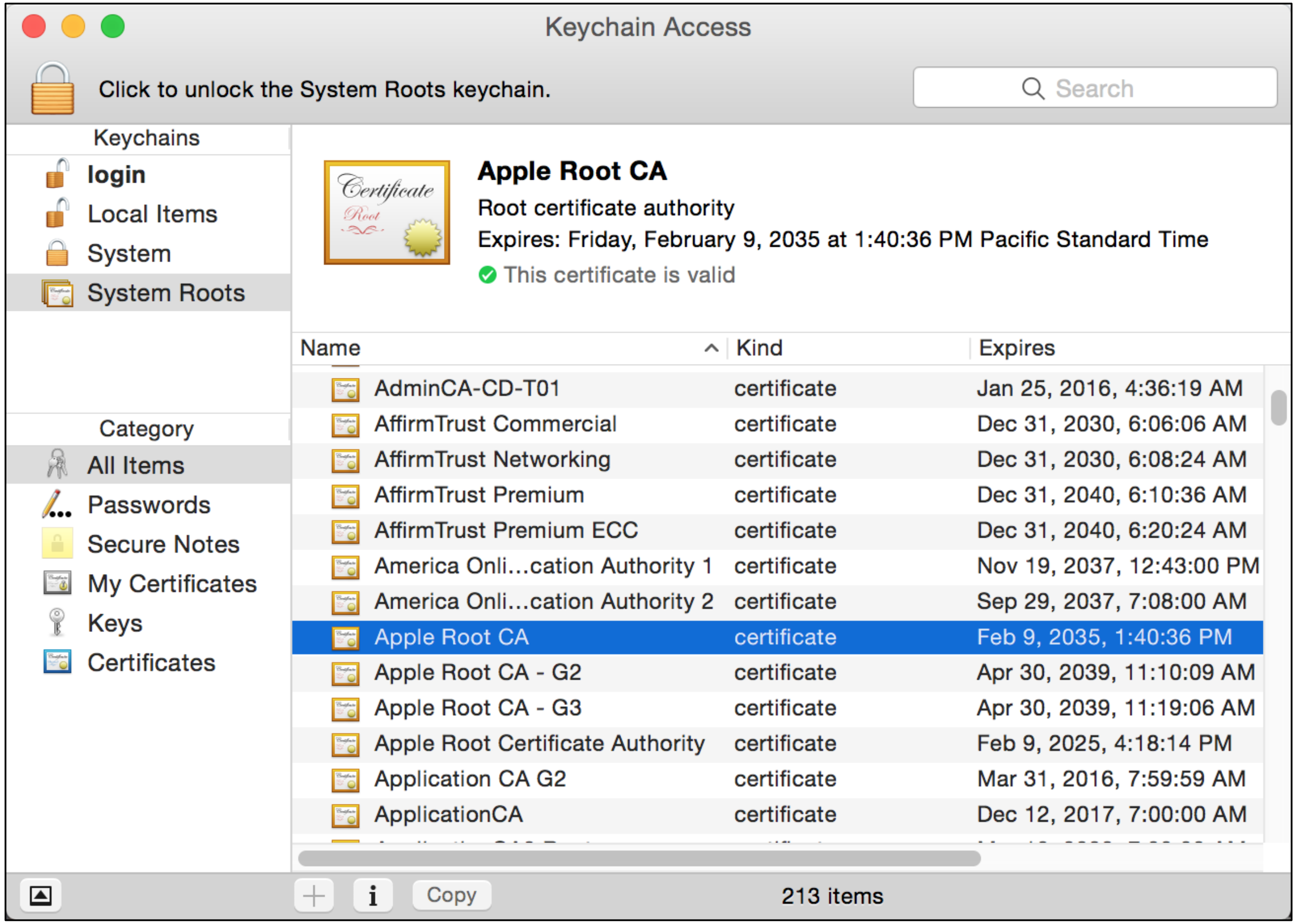
Hierarchical Approach

- 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
    - $sig_{Verisign}$("AnotherCA", $PK_{AnotherCA}$), $sig_{AnotherCA}$("Alice", PK_A)
  - Not shown in figure but important:
    - Part of each cert includes whether party is a CA or not



  - What happens if root authority is ever compromised?

Trusted(?) Certificate Authorities



Turtles All The Way Down…

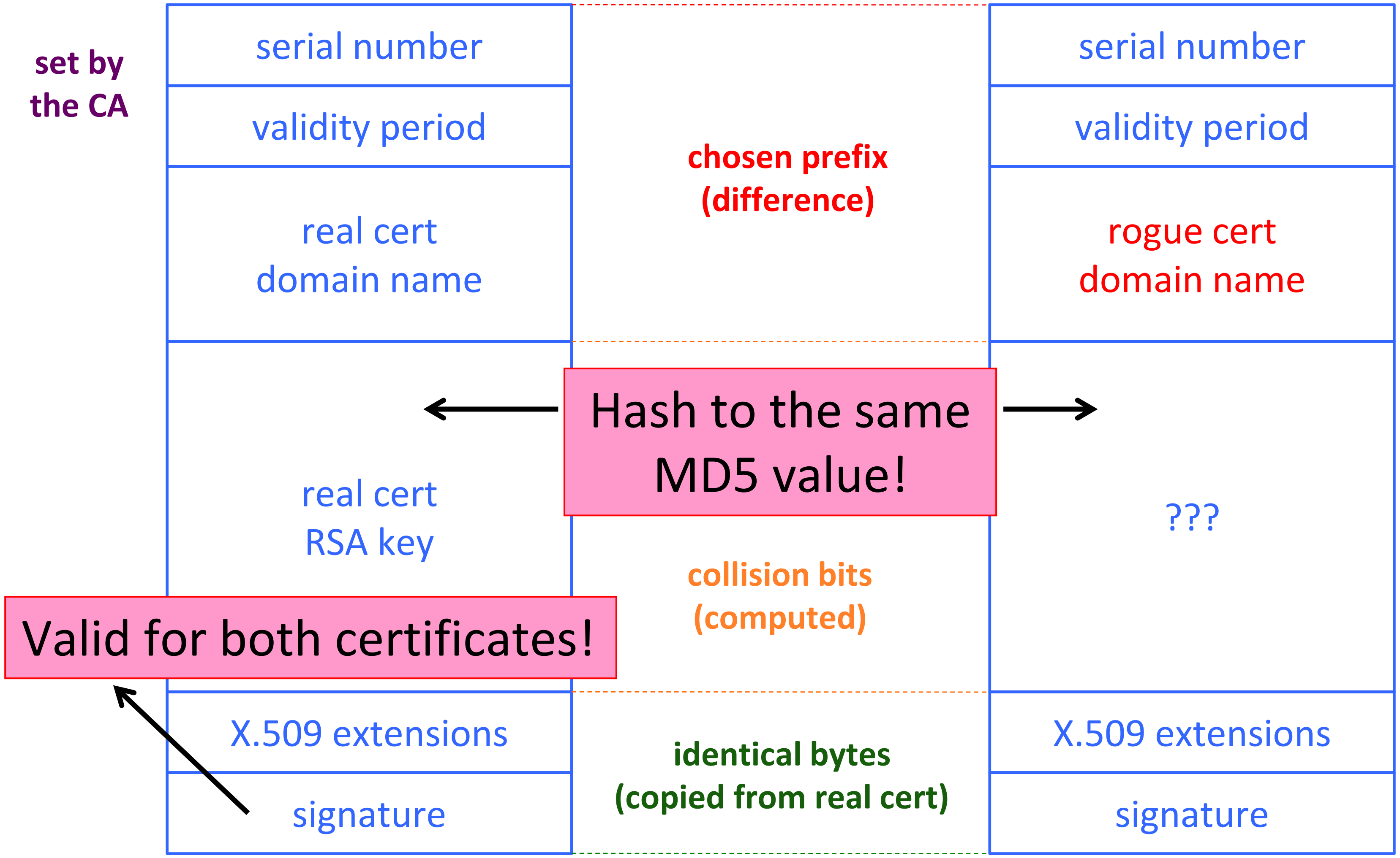
The saying holds that the world is supported by a chain of increasingly large turtles. Beneath each turtle is yet another: it is "turtles all the way down".

[Image from Wikipedia]

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?

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?

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

Attempt to Fix CA Problems:

Certificate Pinning

- Trust on first access: tells browser how to act on subsequent connections
- HPKP – HTTP Public Key Pinning
  - Use these keys!
  - HTTP response header field "`Public-Key-Pins`"
- HSTS – HTTP Strict Transport Security
  - Only access server via HTTPS
  - HTTP response header field "`Strict-Transport-Security`"