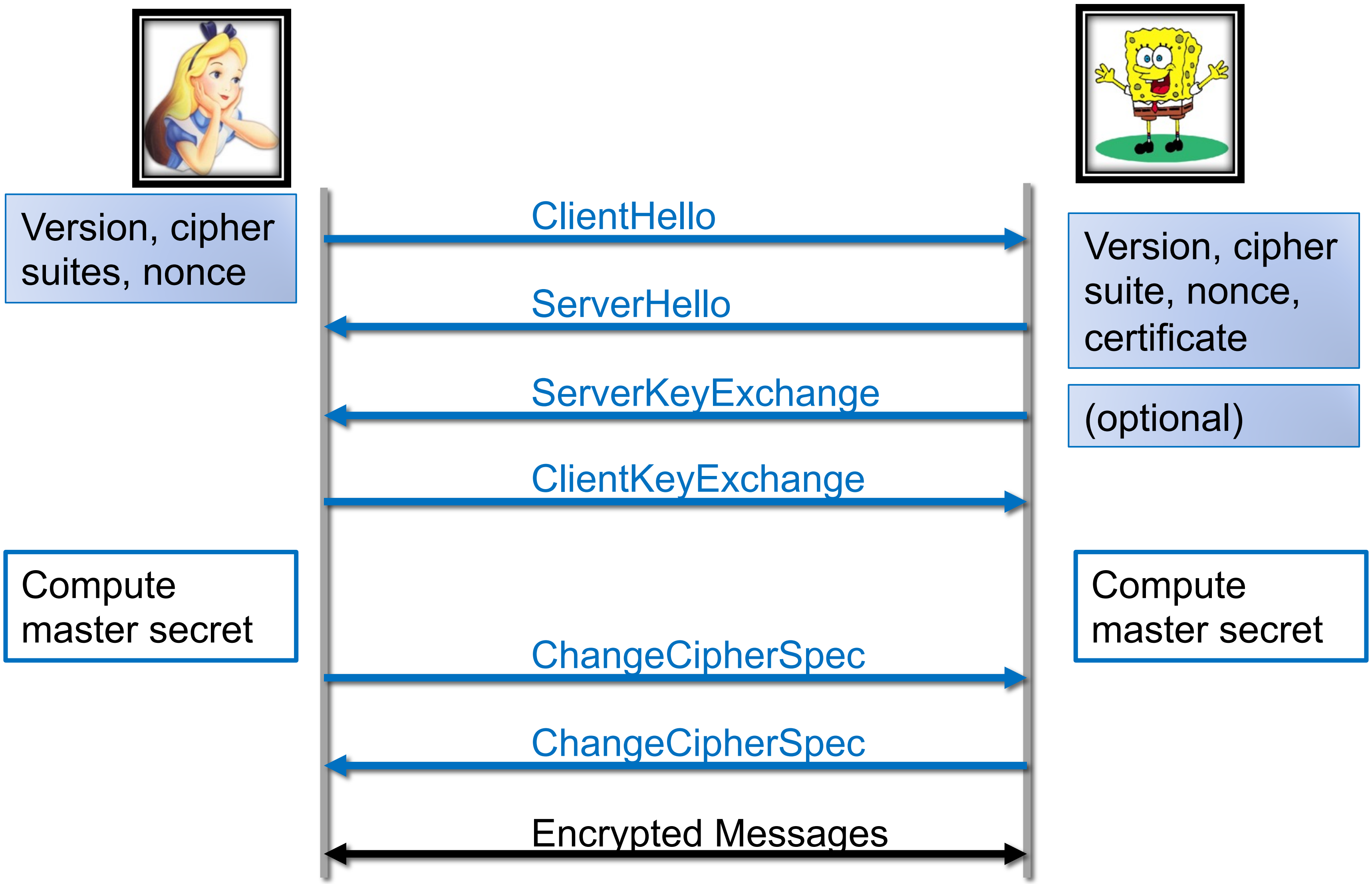
Lecture 12: Certificates

CS 181S

Spring 2024

SSL/TLS Handshake



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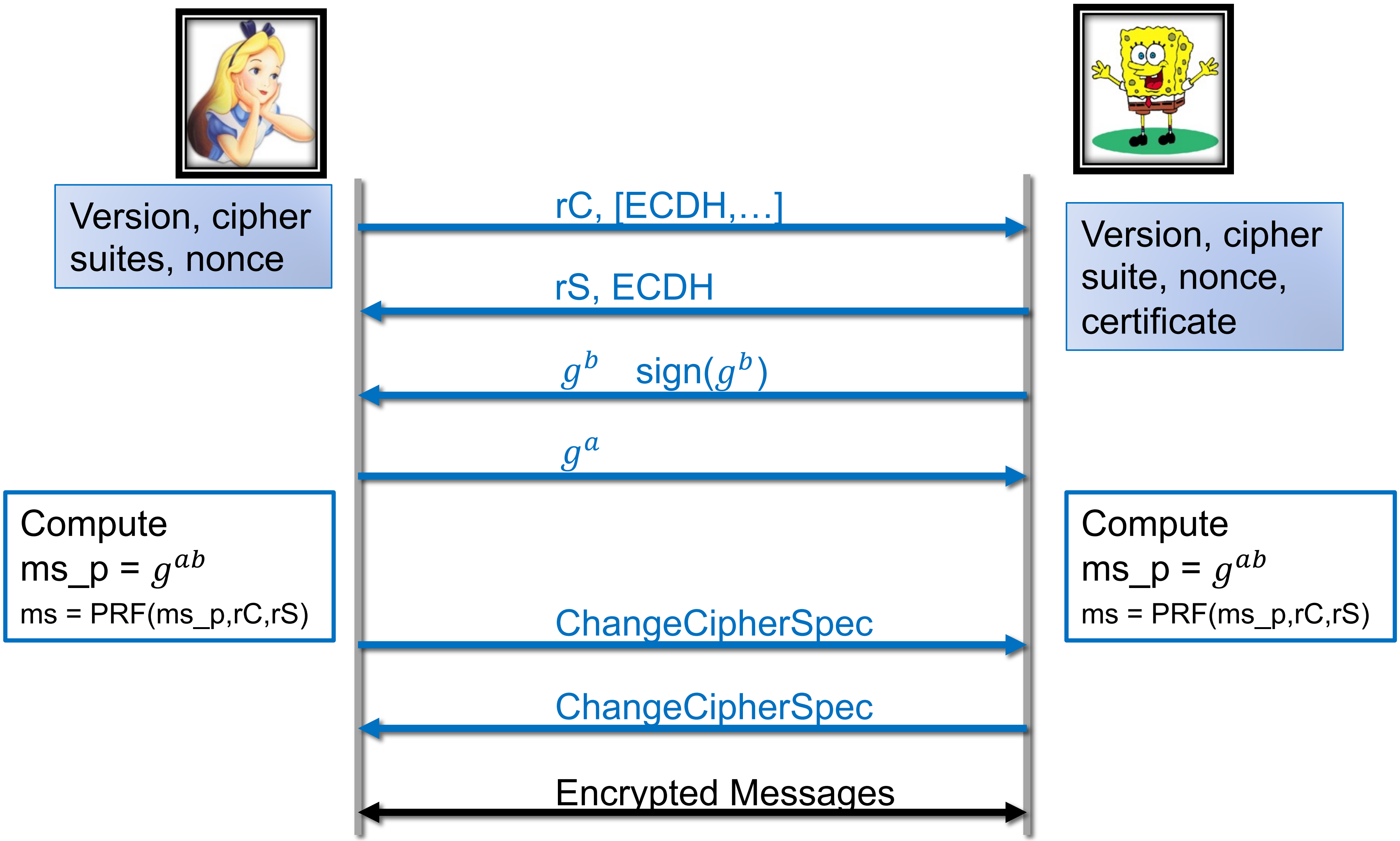

Certificates

- **Digital certificate** is a document binding together:
  - **identity** of principal
  - **public key** of that principal (might be encryption or verification key)
- binding together = signed
- **Notation:** Cert(S; I) is a certificate issued by principal I for principal S
  - Cert(S; I) = (id_s, K_S, Sign(id_s, K_S; k_I))
  - Issuer I is certifying that K_S belongs to subject id_S
- Fingerprint: H(Cert(S; I))

Public-key infrastructure (PKI)

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

PKI Example 1: PGP

- Uses a decentralized PKI philosophy
- "Pretty Good Privacy" [Zimmerman 1991]
  - toolset for PKI, encryption, signing of files and emails
  - OpenPGP is implemented by GNU Privacy Guard (GPG)
- Users manage a keyring:
  - Alice has her own key in her keyring
  - When Alice meets up with Bob at a key-signing party...

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

X.509 certificates

[RFC 5280]

Contents of certificate:

- subject *distinguished name*
- subject public key (and the algorithm)
- issuer *distinguished name*
- serial number (unique within certs issued by this issuer)
- validity interval (start and end time)
- extensions...
- issuer's signature on the above (and the name of the algorithm)

Finding a useful certificate

Certificate chain: sequence of certificates that certify each other

- on one end, a certificate for the principal you want to authenticate
- on the other end, a certificate for a principal you already know: the *root* of trust
- you must trust every issuer in the chain to issue certificates

A constraint extension

- **"Basic constraint":** two values:
  - a Boolean: is this key permitted to be used to verify other certificates? i.e., can it be an issuer's key?
    - At best redundant w.r.t key usage extension, which itself is more precise
  - an integer: number of intermediate certificates permitted to follow this one in a chain
  - ought to be marked critical

Using a 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

Exercise 1: Using A CA

- In your web browser, visit a website you frequently use over https
- Inspect the TLS certificate for that web server:
  1) How many certificates are in the certificate chain?
  2) Who is the root CA for that certificate chain?

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

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

Exercise 2: Root CAs

- How many root CA certificates are installed on your computer for your preferred browser?
- Is the root CA you identified in Exercise 1 on that list?

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

Issuing certificates

Conflicting goals:

- CA private signing key must be kept
  - 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

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