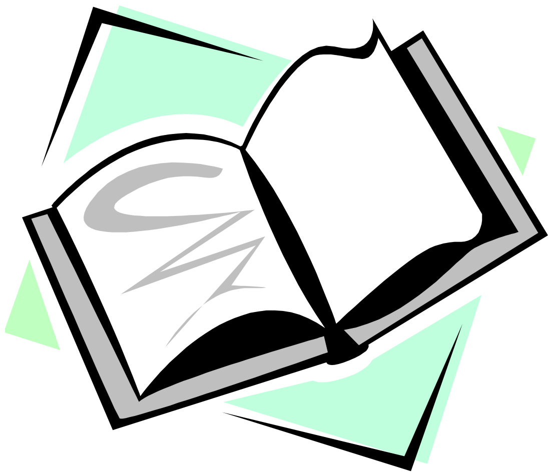
Information Security
CS 526

Topic 14: Key Distribution & Agreement, Secure Communication

Readings for This Lecture

- On Wikipedia
  - Needham-Schroeder protocol (only the symmetric key part)
  - Public Key Certificates
  - HTTP Secure



Outline and Objectives

- Key distribution among multiple parties
- Kerberos
- Distribution of public keys, with public key certificates
- Diffie-Hellman Protocol
- TLS/SSL/HTTPS

Symmetric Key Agreement among Multiple Parties

- For a group of N parties, every pair needs to share a different symmetric key
  - What is the number of keys?
  - What secure channel to use to establish the keys?

- How to establish such keys
  - Symmetric Encryption - Use a central authority, a.k.a. (TTP).
  - Asymmetric Encryption – PKI.

Needham-Schroeder Shared-Key Protocol

- Parties: A, B, and trusted server T
- Setup: A and T share K_{AT}, B and T share K_{BT}
- Goal:
  - Security: Mutual entity authentication between A and B; key establishment, Secure against active attacker & replay
  - Efficiency: Minimize the involvement of T; T can be stateless
- Messages:

$A \rightarrow T$: A, B, N_A (1)

$A \leftarrow T$: $E[K_{AT}]$ (N_A, B, k, $E[K_{BT}]$(k,A)) (2)

$A \rightarrow B$: $E[K_{BT}]$ (k, A) (3)

$A \leftarrow B$: E[k] (N_B) (4)

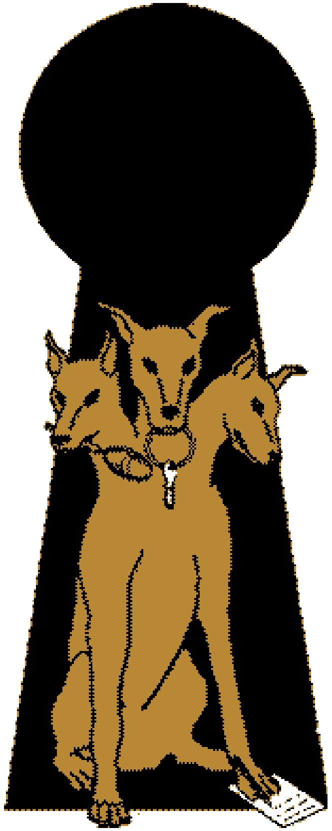
$A \rightarrow B$: E[k] (N_B-1) (5)

What bad things can happen if there is no N_A?

Another subtle flaw in Step 3.

Kerberos

- Implements the idea of Needham-Schroeder protocol
- Kerberos is a **network authentication protocol**
- Provides authentication and secure communication
- Relies entirely on **symmetric cryptography**
- Developed at MIT: http://web.mit.edu/kerberos/www
- Used in many systems, e.g., Windows 2000 and later as default authentication protocol

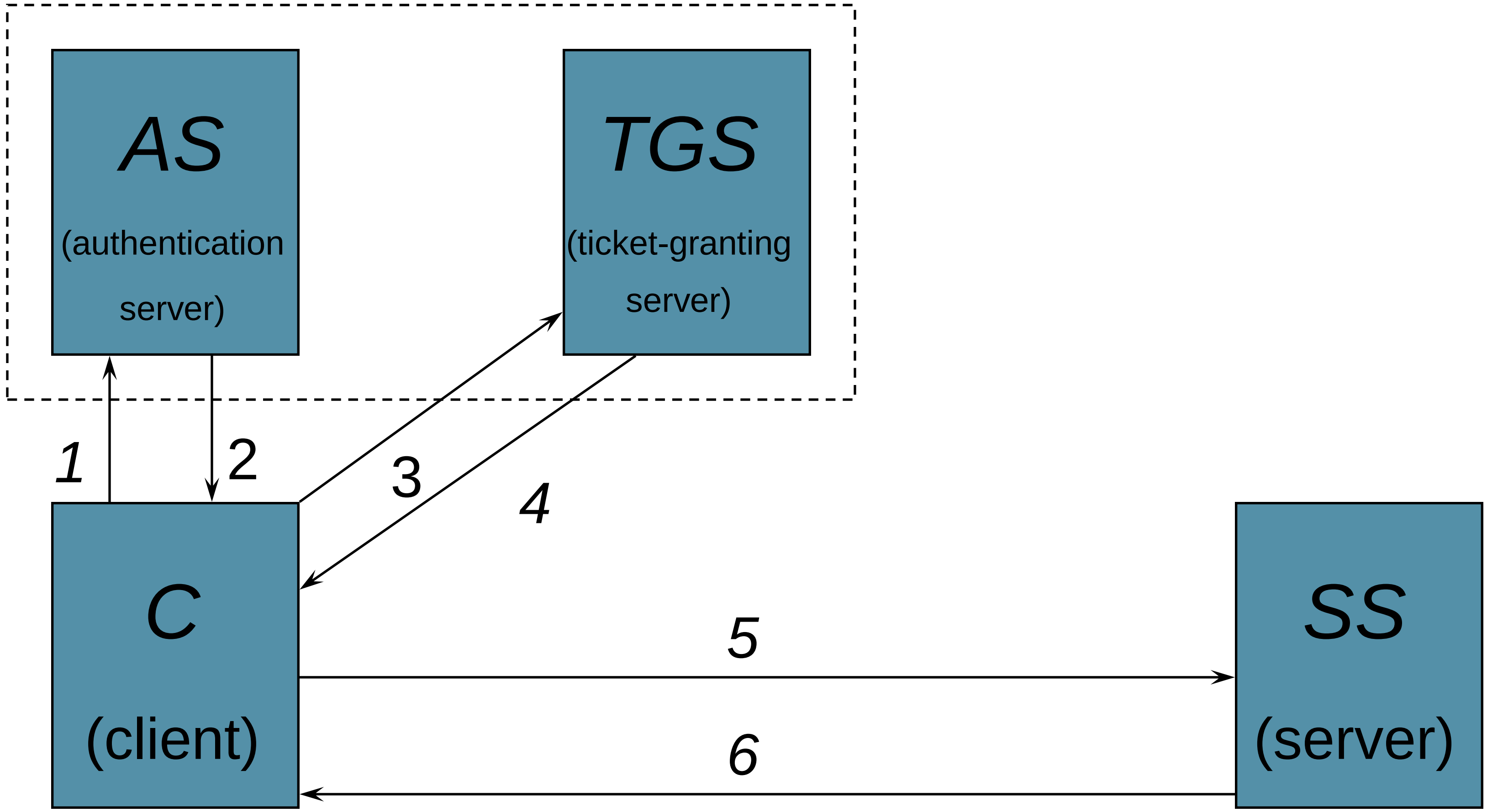


Kerberos Overview

- One issue of Needham-Schroeder – Needs [K_{AT}] to talk to any new service.
  - Think about a login session with K_{AT} derived from a password; either the password needs to be stored, or user needs to enter it every time
- Kerberos solution:
  - Separates TTP into an AS and a TGS.
- The client authenticates to AS using a long-term *shared secret* and receives a TGT [SSO].
- Use this TGT to get additional tickets from TGS without resorting to using the shared secret.

AS = Authentication Server
SS = Service Server
TGS = Ticket Granting Server
TGT = Ticket Granting Ticket

Kerberos Protocol - 1



Kerberos Protocol – 2 (Simplified)

1. $C \rightarrow AS$: $TGS \,||\, N_C$
2. $AS \rightarrow C$: $\{K_{C,TGS} \,||\, C\}_{K_{AS,TGS}} \,||\, \{K_{C,TGS} \,||\, N_C \,||\, TGS\}_{K_{AS,C}}$

   (Note that the **first** part of message 2 is the **ticket granting ticket (TGT)** for the TGS)

3. $C \rightarrow TGS$: $SS \,||\, N'_C \,||\, \{K_{C,TGS} \,||\, C\}_{K_{AS,TGS}} \,||\, \{C||T_1\}_{K_{C,TGS}}$
4. $TGS \rightarrow C$: $\{K_{C,SS} \,||\, C\}_{K_{TGS,SS}} \,||\, \{K_{C,SS} \,||\, N'_C \,||\, SS\}_{K_{C,TGS}}$

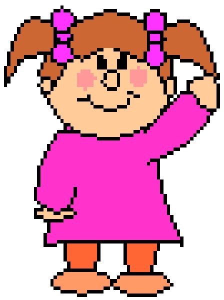
   (Note that the **first** part in message 4 is the **ticket** for the server S).

5. $C \rightarrow SS$: $\{K_{C,SS} \,||\, C\}_{K_{TGS,SS}} \,||\, \{C \,||\, T_2\}_{K_{C,SS}}$
6. $SS \rightarrow C$: $\{T_3\}_{K_{C,SS}}$

Kerberos Drawback

- Highly trusted TTP: KS
  - Malicious KS can silently eavesdrop in any communication
- Single point of failure:
- Security partially depends on tight clock synchronization.
- Useful primarily inside an organization
  - Does it scale to Internet? What is the main difficulty?

Public Keys and Trust



- Public Key: P_A
- Secret key: S_A

- Public Key: P_B
- Secret key: S_B

- **How are public keys stored?**
- **How to obtain the public key?**
- **How does Bob know or ‘trusts’ that P_A is Alice’s public key?**

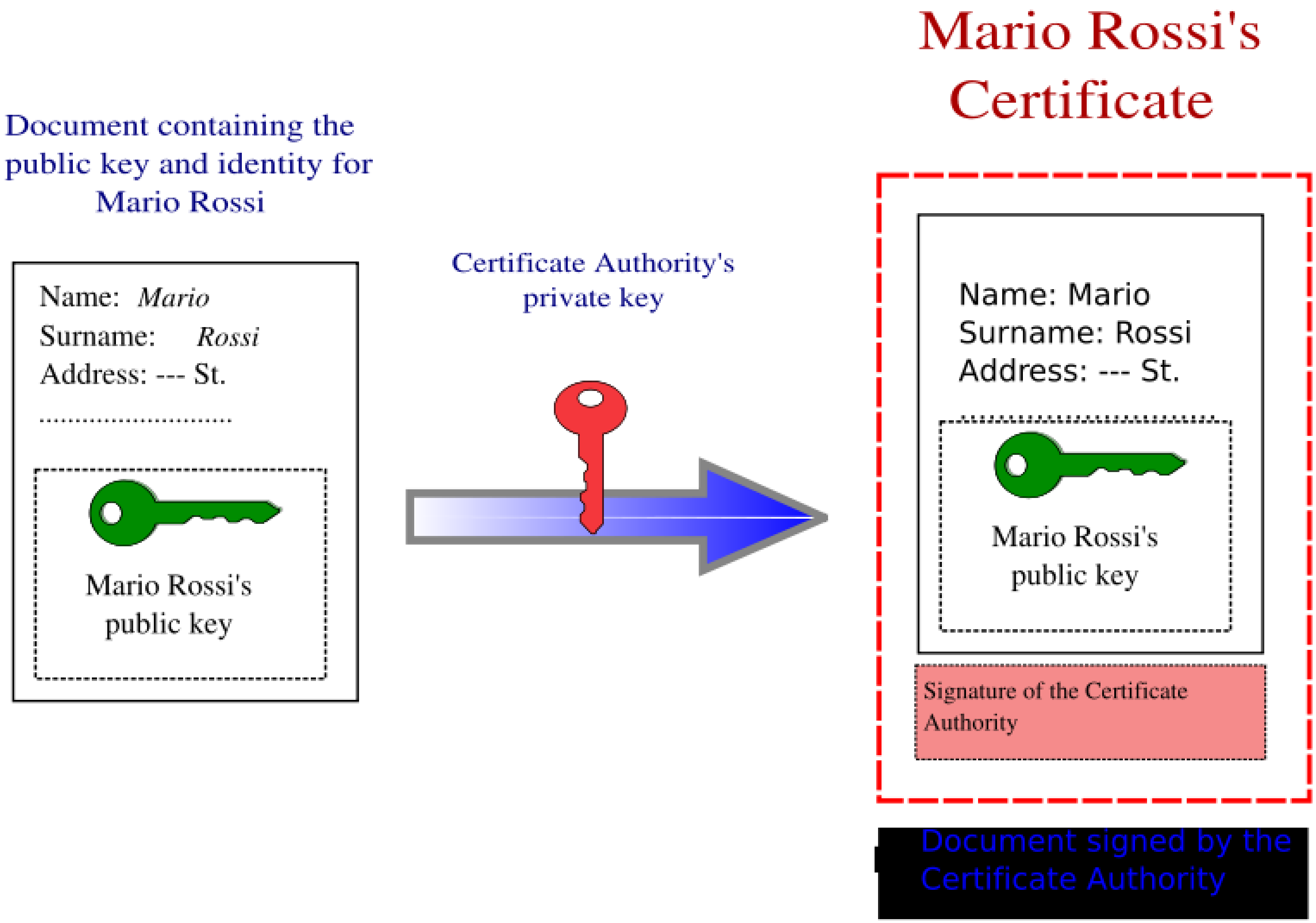
Distribution of Public Keys

- **Public announcement**: users distribute public keys to recipients or broadcast to community at large.
- **Publicly available directory**: can obtain greater security by registering keys with a public directory.
- Both approaches have problems, and are vulnerable to forgeries

Public-Key Certificates

- A certificate binds identity (or other information) to public key
- Contents digitally signed by a trusted Public-Key or Certificate Authority (CA)
  - Can be verified by anyone who knows the public-key authority's public-key.
- For Alice to send an encrypted message to Bob, obtains a certificate of Bob's public key

Public Key Certificates

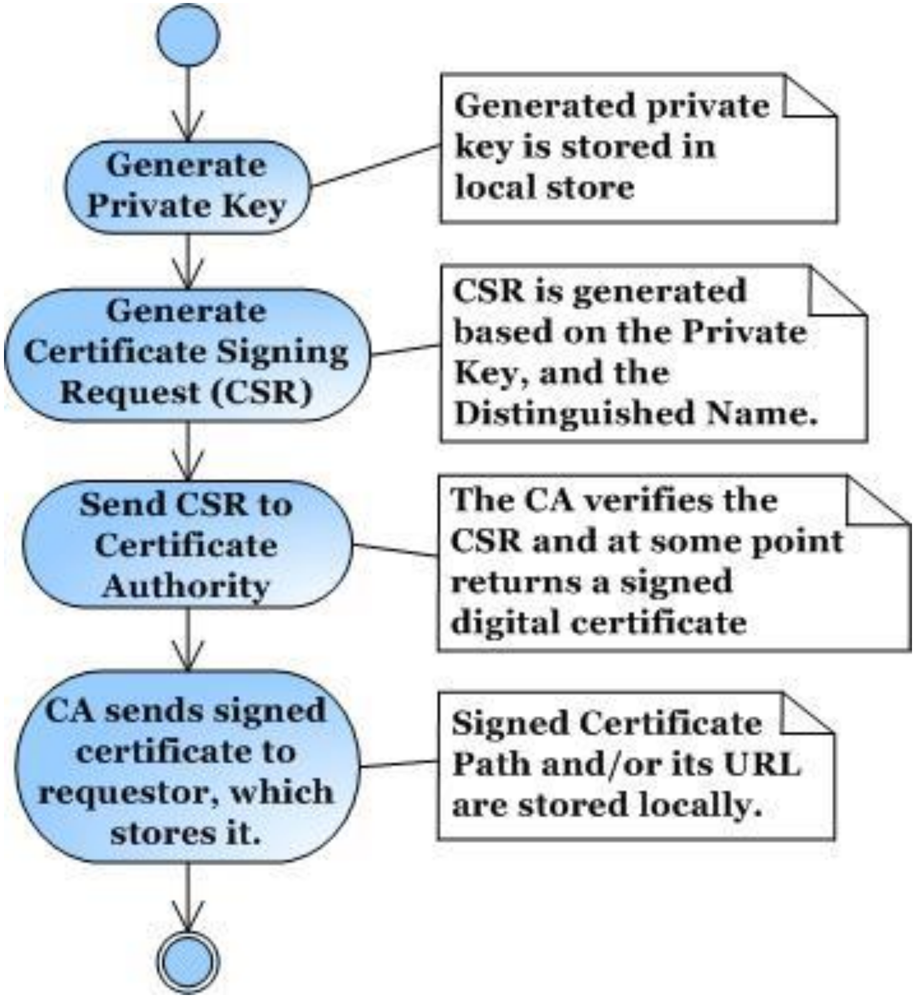


X.509 Certificates

- Part of X.500 directory service standards.
  - Started in 1988
- Defines framework for authentication services:
  - Defines that public keys stored as **certificates** in a public directory.
  - Certificates are **issued and signed** by an entity called **certification authority (CA).**
- Used by numerous applications: SSL, IPSec, SET
- Example: see certificates accepted by your browser

How to Obtain a Certificate?

- Define your own CA (use openssl or Java Keytool)
  - Certificates unlikely to be accepted by others
- Obtain certificates from one of the vendors: VeriSign, Thawte, and many others



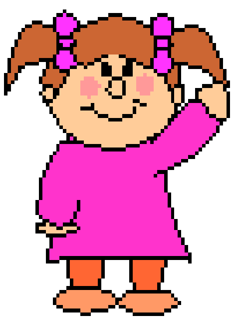
CAs and Trust

- Certificates are trusted if signature of CA verifies
- Chain of CA's can be formed, head CA is called root CA
- In order to verify the signature, the public key of the root CA should be obtain.
- TRUST is centralized (to root CA's) and hierarchical
- What bad things can happen if the root CA system is compromised?
- How does this compare with the TTP in Needham/Schroeder protocol?

Key Agreement: Diffie-Hellman Protocol

Key agreement protocol, both A and B contribute to the key

Setup: p prime and g generator of Z_p^*, p and g public.



$g^a \bmod p$ →

← $g^b \bmod p$

Pick random, secret (a)

Compute and send $g^a \bmod p$

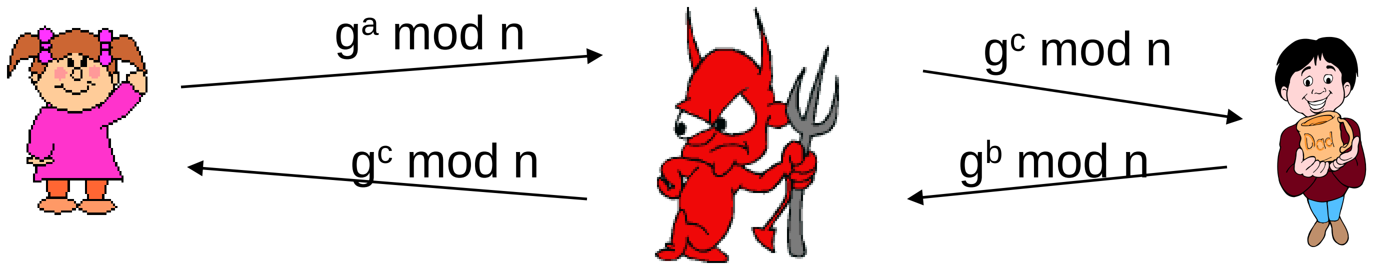
$K = (g^b \bmod p)^a = g^{ab} \bmod p$

Pick random, secret (b)

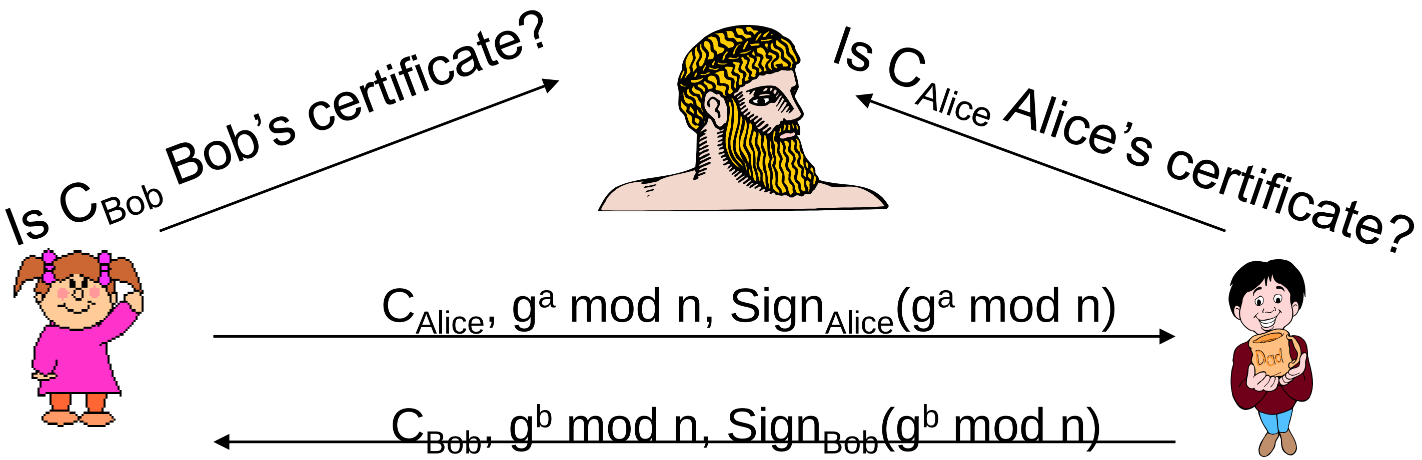
Compute and send $g^b \bmod p$

$K = (g^a \bmod p)^b = g^{ab} \bmod p$

Authenticated Diffie-Hellman



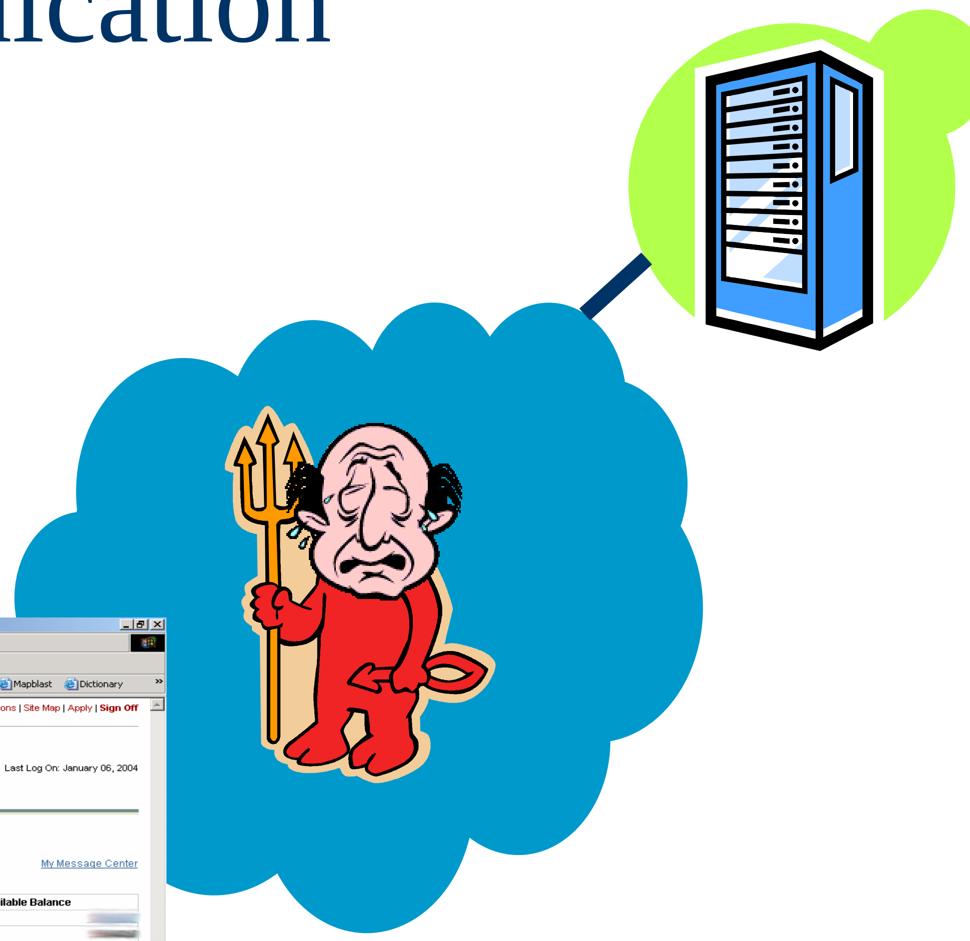
- Alice computes g^{ac} mod n and Bob computes g^{bc} mod n !!!

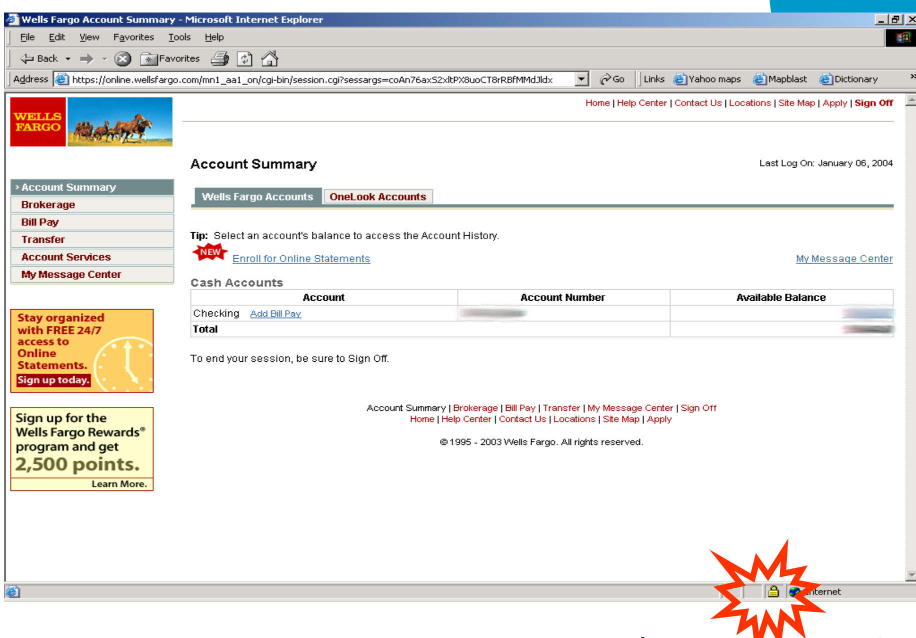


Forward Secrecy

- Compromise of long-term keys does not compromise past session keys.
  - I.e., a session that is secure now remains secure in future
  - Violated in secret-key based protocols such as Needham-Schroeder and used in Kerberos
- Can be satisfied by ephemeral Diffie-Hellman
  - Do not store secrets such as a, b after computing g^{ab}.
  - Long-term secret (digital signature signing keys) used only for authenticity
    - Stealing a key cannot compromise authenticity of past sessions

Secure communication





Transport Layer Security (TLS)

- Predecessors: Secure socket layer (SSL): Versions 1.0, 2.0, 3.0
- TLS 1.0 (SSL 3.1); Jan 1999
- TLS 1.1 (SSL 3.2); Apr 2006
- TLS 1.2 (SSL 3.3); Aug 2008
- Standard for Internet security
  - Originally designed by Netscape
  - Goal: "... provide privacy and reliability between two communicating applications"
- Two main parts
  - Handshake Protocol
    - Establish shared secret key using public-key cryptography
    - Signed certificates for authentication
  - Record Layer
    - Transmit data using negotiated key, encryption function

Usage of SSL/TLS

- Applied on top of transport layer (typically TCP)
- Used to secure HTTP (HTTPS), SMTP, etc.
- One or both ends can be authenticated using public key and certificates
  - Typically only the server is authenticated

- Client & server negotiate a cipher suite, which includes
  - A key exchange algorithm, e.g., RSA, Diffie-Hellman, SRP, etc.
  - An encryption algorithm, e.g., RC4, Triple DES, AES, etc.
  - A MAC algorithm, e.g., HMAC-MD5, HMC-SHA1, etc.

What Goes Wrong in Real World?

- Heartbleed software bug in OpenSSL
  - Improper input validation (missing bounds check)
  - Buffer over-read: Exploitation is able to read data in memory, including private key, etc.
- SSL Certificate validation errors
- Non-random private keys in RSA n=pq (the same primes are occasionally generated)
- Pre-computation can be used to break Diffie-Hellman used in TLS
  - (Optional) See “Imperfect Forward Secrecy: How Diffie-Hellman Fails in Practice” in CCS 2015

Viewing HTTPS web sites

- Browser needs to communicate to the user the fact that HTTPS is used
  - E.g., a golden lock indicator on the bottom or on the address bar
  - Check some common websites
  - When users correctly process this information, can defeat phishing attacks
  - Security problems exist
    - People don’t know about the security indicator
    - People forgot to check the indicator
    - Browser vulnerabilities enable incorrect indicator to be shown
    - Use confusing URLs, e.g.,
      - https:// homebanking.purdueefcu.com@host.evil.com/
    - Stored certificate authority info may be changed

Coming Attractions …

- Malware Defense & Intrusion Detection