

Secure Sockets Layer (SSL) / Transport Layer Security (TLS)

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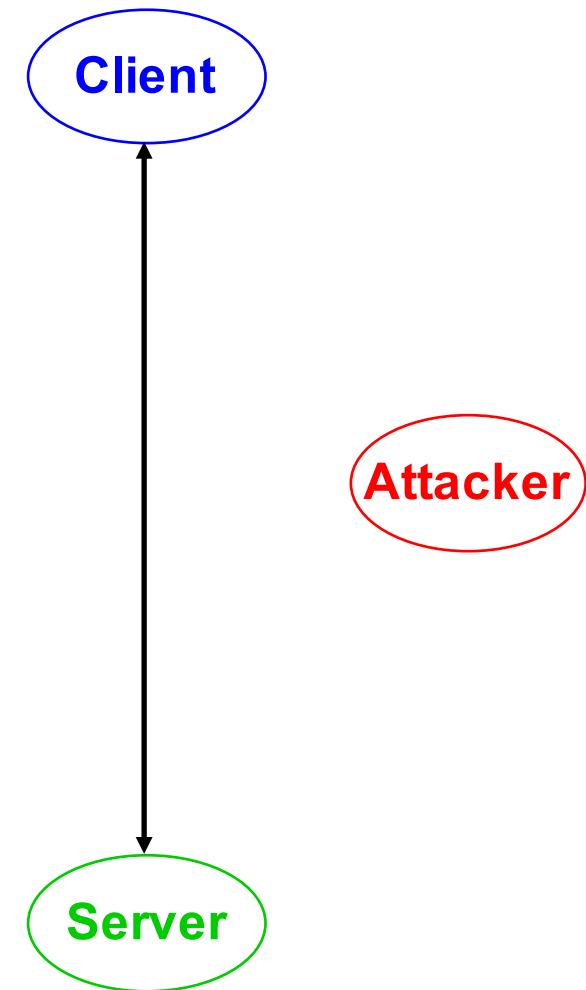
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What Problems Do SSL/TLS Solve?

- Two parties, client and server, **not previously known to one another**
 - i.e., haven't been able to establish a shared secret in a secure room
- Want to **authenticate** one another
 - in today's lecture, focus on client authenticating server; e.g., "am I talking to the real amazon.com server?"
- Want **secrecy** and **integrity** of communications in both directions

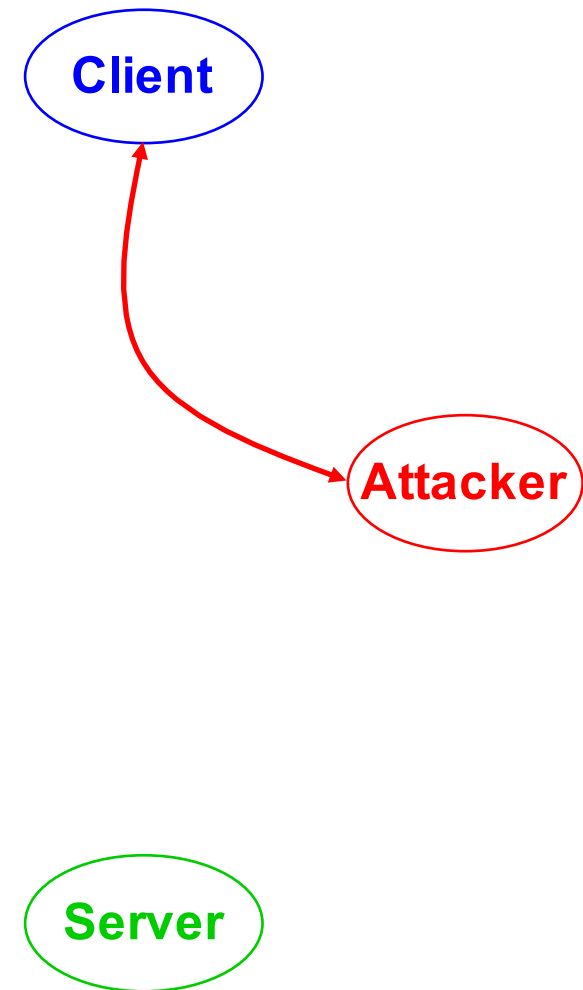
Problem: Man in the Middle Attacks

- Recall: public-key cryptography alone not enough to give robust authentication
 - Client can ask server to prove identity by signing data
 - But how does client know he has real server's public key?
- Attacker may impersonate server
 - Gives client his own public key, claiming to be server
 - Client may send sensitive data to attacker
 - Attacker may send incorrect data back to client



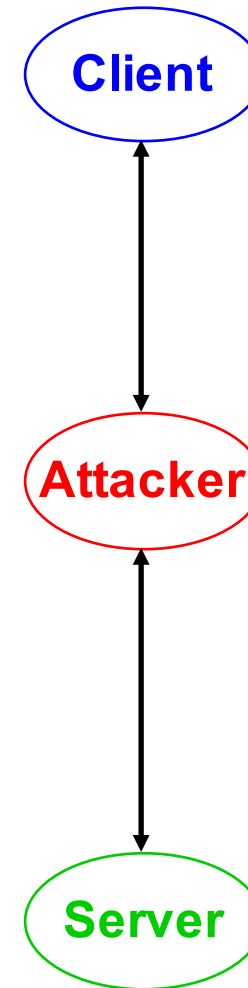
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Man in the Middle Attacks (2)

- Attacker may not appear like server
 - e.g., might not have same content as real web server's page
- Solution: attacker acts as **man in the middle**
 - Emulates server when talking to client
 - Emulates client when talking to server
 - Passes through **most messages as-is**
 - Substitutes **own public key for client's and server's**
 - **Records secret data, or modifies data to cause damage**



Challenge: Key Management

- Publish public keys in a **well-known broadcast medium**
 - e.g., in the telephone directory, or in the pages of the New York Times
 - How do you know you have the real phone directory, or New York Times?
 - How can software use these media?
- Exchange keys **with people in person**
- “Web of trust”: accept keys for others **via friends you trust** (used by PGP)

Approach to Key Management: Offline Certificate Authorities (CAs)

- Idea: use digital signatures to indicate endorsement of binding between principal and public key
 - i.e., if I sign {amazon.com, pubkey}, I am stating, "I attest that amazon.com's public key is pubkey."
- Certificate Authority (CA): third-party organization trusted by parties that wish to mutually authenticate
- Each CA has public/private key pair: K_{CA} , K_{CA}^{-1}
- CA creates certificate C_S for server S containing, e.g.,:
 - info = {"www.amazon.com", "Amazon, Inc.",
 K_S = www.amazon.com's public key, expiration date, CA's name}
 - sig = $\{H(\text{info})\}_{K_{CA}^{-1}}$
- Server S can present C_S to browser
- If browser knows K_{CA} , can validate that CA attests that S 's public key is K_S

Approach to Key Management: Offline Certificate Authorities (CAs)

- Idea: use digital signatures to indicate endorsement of binding between principal and public key

Key benefit: CA need not be reachable by C or S at time C wishes to authenticate S!

CAs and certificates are the heart of SSL's authentication mechanism

- CA creates certificate C_S for server S containing, e.g.,:
 - info = {"www.amazon.com", "Amazon, Inc.",
 K_S = www.amazon.com's public key, expiration date, CA's name}
 - sig = $\{H(\text{info})\}_{K_{CA}^{-1}}$
- Server S can present C_S to browser
- If browser knows K_{CA} , can validate that CA attests that S's public key is K_S

Offline Certificate Authorities (2)

- Key benefit: CA need not be reachable by C or S at time C wishes to authenticate S!
 - Hence **offline** certificate authority
- SSL/TLS model for browsers authenticating web servers:
 - **Everybody trusts CA**
 - **Everybody knows CA's public key** (i.e., pre-configured into web browser)

SSL 3.0 Handshake Overview (RSA)

Client

Server

ClientHello: client_version, client_random, client_cipher_list

ServerHello: server_version, server_random, server_cipher_list

ServerCertificate: server_certificate_list

ClientKeyExchange: $\{\text{pre_master_secret}\}_{K_s}$

ChangeCipherSpec: client_cipher

Finished: $\text{MAC}\langle \text{master_secret}, \text{all messages} \rangle$

ChangeCipherSpec: server_cipher

Finished: $\text{MAC}\langle \text{master_secret}, \text{all messages} \rangle$

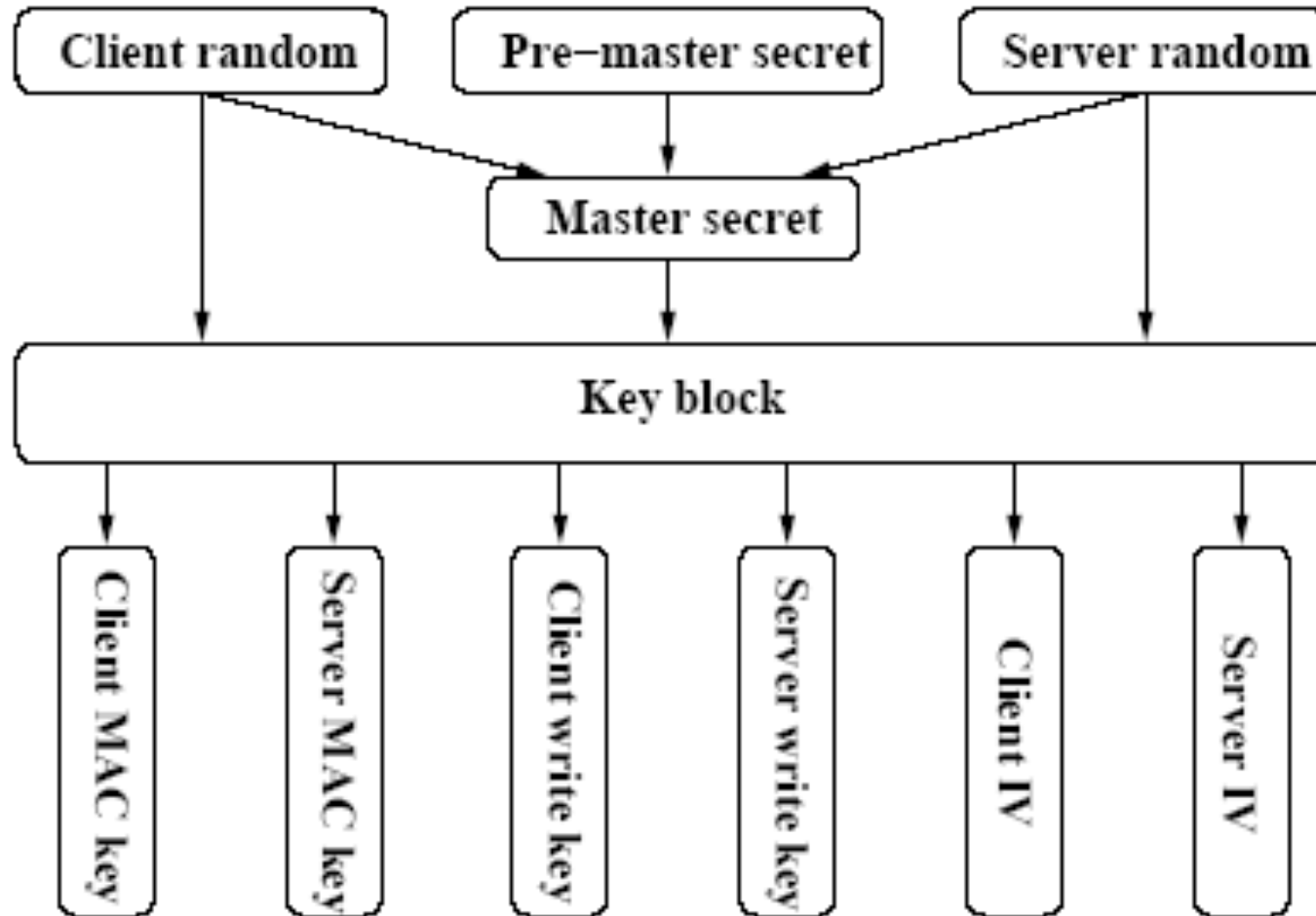
compute
session keys

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Establishing Session Keys

- Client **randomly generates pre-master secret**, sends to server encrypted with server's public key
- Server **also contributes randomness** in server_random
- Using both pre-master secret and server_random, server and client **independently compute symmetric session keys**:
 - Client MAC key
 - Server MAC key
 - Client Write key
 - Server Write key
 - Client IV
 - Server IV

Establishing Session Keys (2)



[*SSL and TLS*, Eric Rescorla]

Using Session Keys to Send Data

- Data encrypted by client and server using each's own write key
- Data MAC'ed by client and server using each's own MAC key
- Each SSL record (block) includes a sequence number for that sender, and a MAC over:
 - Sequence number
 - Data **plaintext**
 - Data **length**

Why MAC Data Length?

- Plaintext padded to fit symmetric cipher block length
- Length of data (without padding) must be sent to receiver
- SSL 2.0 didn't MAC data length; only MAC'ed padded data itself
 - Active adversary could change plaintext data length field
 - MAC over data would still verify
 - **Attacker could truncate plaintext as desired!**

Why MAC Data Length?

- Plaintext padded to fit symmetric cipher

Lesson:

Always MAC “what you mean,” including all context used to interpret message at receiver

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 - Active adversary could change plaintext data length field
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Properties Provided by SSL (1)

- Secrecy: passive eavesdropper can't decrypt data; pre-master secret encrypted with server's public key, and server's private key secret
- Authentication of server by client: can trust each data record came from server that holds private key matching public key in certificate
- Authentication of client by server? Not without client certificates...or client can send username/password over encrypted SSL channel
- Key exchange can't be replayed; new random nonce from each side each time

Properties Provided by SSL (2)

- Data from earlier in session can't be replayed
 - Caught by MAC
- Fake server can't impersonate real one using real certificate and public key
 - Doesn't know real server's private key, so can't decrypt pre-master secret from client
- Fake server obtains own certificate for own domain name from valid CA, supplies to client
 - If domain name differs from one in https:// URL, client detects mismatch when validating certificate

Forward Secrecy

- Suppose attacker records entire communication between client and server
- At later time, attacker obtains server's private key
- If attacker cannot decrypt data from recorded session, scheme provides forward secrecy
- Does this RSA variant of SSL 3.0 provide forward secrecy?
 - No.

Cipher Roll-Back

- SSL supports various ciphers of various key lengths and strengths
- Suppose attacker modifies cipher selection messages, to force client and server into using weak ciphers
- Each direction of handshake ends with MAC of all messages
- Can attacker adjust this MAC so it verifies?
 - No. Doesn't know master_secret!

What Is CA Actually Certifying?

- That a public key belongs to someone authorized to represent a hostname?
- That a public key belongs to someone who is associated in some way with a hostname?
- That a public key belongs to someone who has many paper trails associated with a company related to a hostname?
- That the CA has **no liability?**
- >100-page Certification Practice Statement (CPS)!

How to Get a VeriSign Certificate

- Pay VeriSign (\$300)
- Get DBA license from city hall (\$20)
 - No on-line check for name conflicts; can I do business as Microsoft?
- Letterhead from company (free)
- Notarize document (need driver's license) (free)
- Easy to get fraudulent certificate
 - Maybe hard to avoid being prosecuted afterwards...
- But this is just VeriSign's policy
 - many other CAs...

CA Security

- How trustworthy is a VeriSign certificate?

In mid-March 2001, VeriSign, Inc., advised Microsoft that on January 29 and 30, 2001, it issued two. . . [fraudulent] certificates. . . The common name assigned to both certificates is "Microsoft Corporation."

VeriSign has revoked the certificates. . . .
However. . . it is not possible for any browser's CRL-checking mechanism to locate and use the VeriSign CRL.

– Microsoft Security Bulletin MS01-017

CA Security (2)

- In 2011, it was reported that DigiNotar, a Dutch CA, had its servers compromised
 - Believed DigiNotar unaware of compromise for **weeks**
- Intruders generated **over 500 forged SSL certificates, including for google.com**
- Between 27 July 2011 and 29 August 2011, **over 300K IP addresses** accessed web sites presenting this forged SSL certificate for google.com
 - 99% of IP addresses in Iran
 - Assumption by press: **forged certificate used to monitor Iranian Gmail users' email**

CA Security (2)

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Lesson:

The weakest CA your browser trusts by default may be very weak indeed

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Recent News: POODLE Vulnerability

- October 14th, 2014: Google reports vulnerability in SSL 3.0
- But all major browsers support TLS 1.0 or later
- But many browsers fell back to SSL 3.0 when TLS not supported by server!