CSE 490K Lecture 13

# Network Security (TCP/IP and DNS)

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Some slides based on Dan Boneh's and Vitaly Shmatikov's

# Programming Project #2

- Out today, Tuesday, May 8
- Due Thursday, May 24, 11:59pm
  - Submit via Catalyst system
- Teams of up to three people
  - New teams OK (old teams also OK)

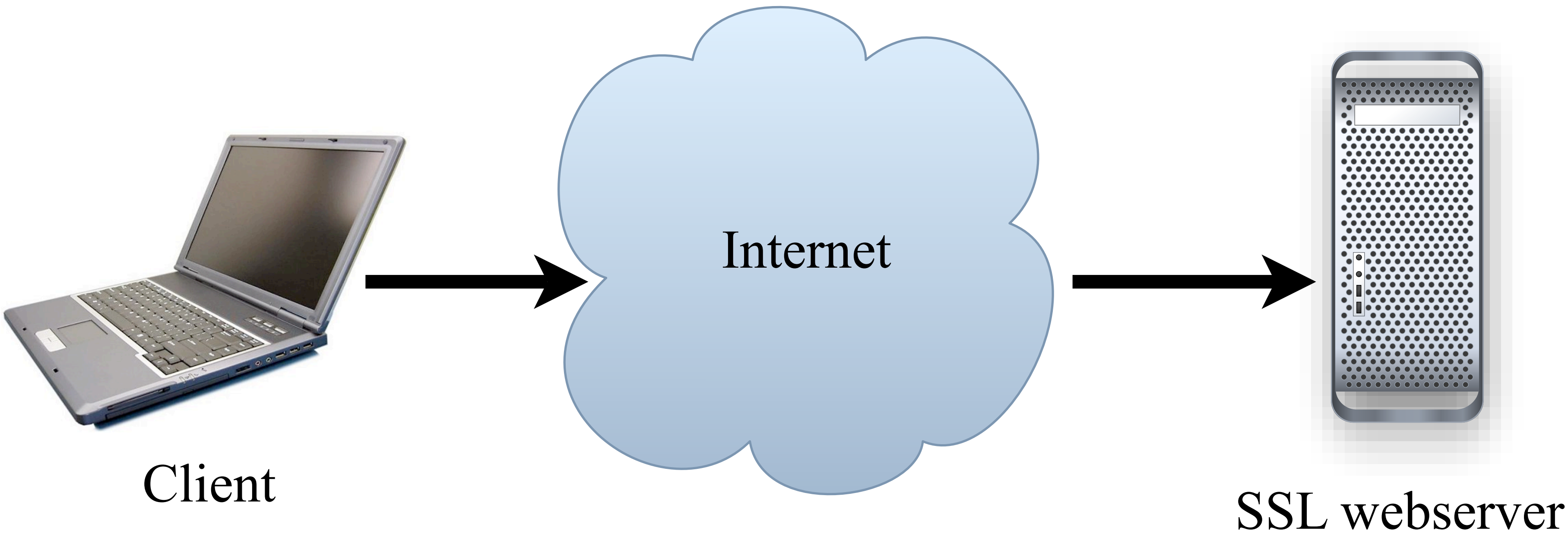
- Basic idea: Implement a "Man-in-the-Middle" attack against SSL
- Recall Security and Privacy Code of Ethics form
- Based on Dan Boneh's CS255 project (Stanford)
  - Slides: http://crypto.stanford.edu/~dabo/cs255/proj2_pres.pdf

# Overview

- MITM attack against SSL
  - Not at network layer (not re-writing packets, etc)
  - At SSL Proxy Layer, in Java
    - Networking
    - SSL
    - Certificates
- Password-based authentication for MITM server
  - Hashed, salted passwords
  - Password file encrypted with an authenticated encryption scheme.

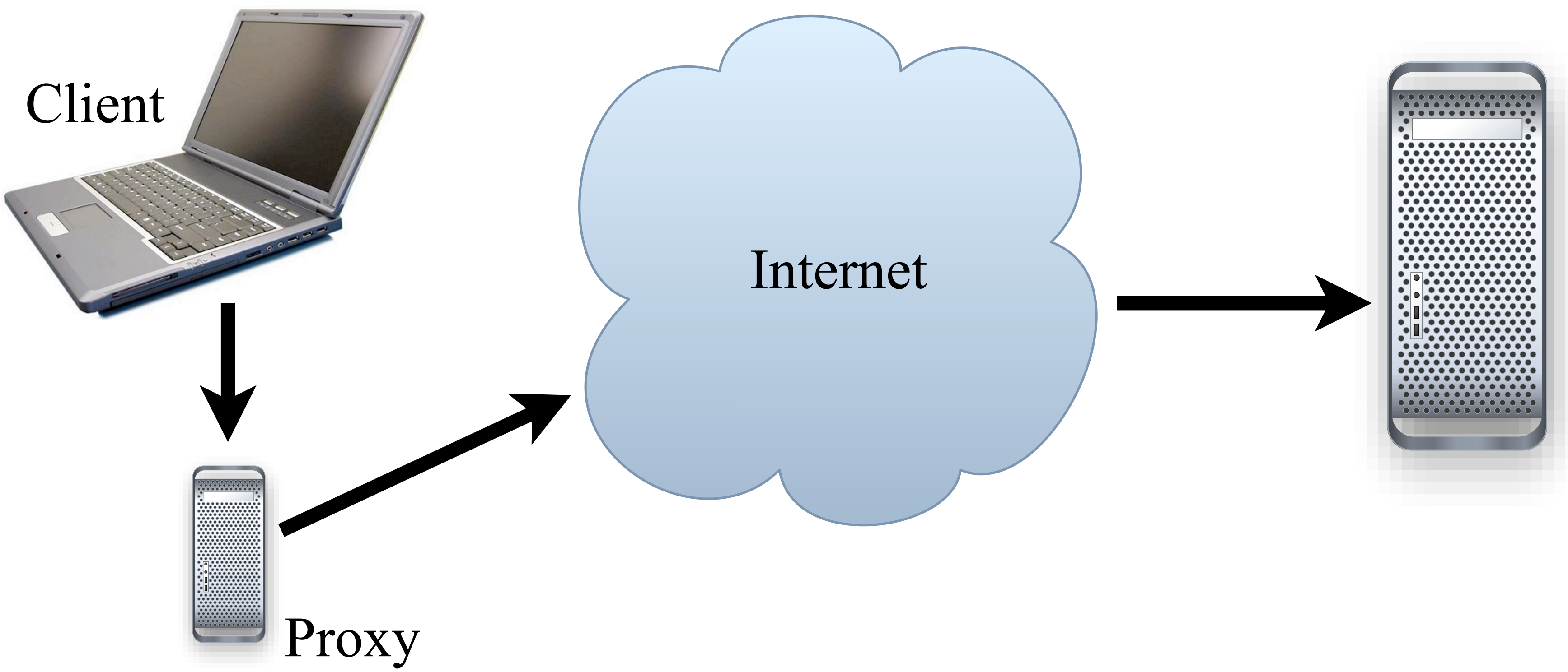
# Overview

- Normal SSL
  - SSL encrypted data routed like normal TCP/IP over Internet



# Proxy Server

- Browser connects to proxy
- Proxy connects to web server and forwards between the two



# "Man in the Middle"

- Instead of forwarding encrypted data between the two hosts, the proxy will set up two different SSL connections
  - Proxy <--> Remote Server
    - Normal SSL client connection to remote site
  - Proxy <--> Browser
    - SSL server connection to the browser, using its own certificate, with some data cloned from the remote hosts' certificate
    - If browser accepts this fake certificate, the proxy has access to the data in the clear!

# What we provided

- Basic Proxy Server setup
  - Parses CONNECT request and sets up a connection between client and remote server
- Basic Admin Server/Client
  - Server listens for connections on plain socket and parses out username/password/command that client sends

# Basic Admin Server/Client

- Goal: Experience in adding security features to an application
  - Secure connection between admin client and proxy server using SSL
  - Password based authentication for client
    - Secure storage of password file (authenticated encryption)
    - Passwords stored, hashed, using public and private salt
  - Extra credit: Challenge / Response authentication
    - In addition to password authentication, not instead of.

# Proxy Server

- Already listens for browser CONNECT requests and sets up the needed SSL connections
- You should
  - Understand the connections being made
  - Obtain the remote server certificate from the remote SSL connection
  - Copy the relevant fields and sign a forged certificate using your CA cert (from your keystore); use IAIK
  - Modify the code creating the client SSL connection to use the newly forged certificate

# Signing Certificate

- Build a self-signed certificate for the proxy server (the proxy server's "CA" certificate)
  - keytool -genkey -keyalg RSA
  - Store this in a JKS keystore for use by your proxy server
  - Use it for signing your programmatically generated certs
  - Your proxy pretends to be the CA
- Submit a keystore with your project

# Generating Certs "On the Fly"

- Not easy to generate certificates programmatically using standard Java libraries
- Instead, use the IAIK-JCE library
  - iaik.x509.X509Certificate (class)

# iaik.x509.X509Certificate

- To convert from a java certificate:
  - new X509Certificate(javaCert.getEncoded());
- Signing
  - cert.sign(AlgorithmID.sha256withRSAEncryption, issuerPk);
- See iaik.asn1.structures.Name
  - For extracting info (e.g., common name) from the certificate's distinguished name (cert.getSubjectDN())

# Managing Certs and SSL Sockets

- Use the KeyStore class for
  - Loading certificates from file (e.g., your CA certificate)
  - Storing programmatically generated certificates
- Use SSLContext class for setting up certificates to be used with SSLServerSocket
  - Create a certificate
  - Load into new KeyStore
  - Init a KeyManagerFactory with new KeyStore
  - Init SSLContext with new KeyManagerFactory and provided “TrustEveryone” TrustManager
- Use SSLContext for creating SSLSocketFactories
- See MITMSSLSocketFactory.java

# Admin Server

- Already listens for client connections and parses the data sent using plain sockets
- You should
  - Modify code to use SSL sockets (see the proxy server code for examples)
  - Implement authentication for the transmitted username and password
  - Implement required admin commands
    - Shutdown
    - Stats

# Password file

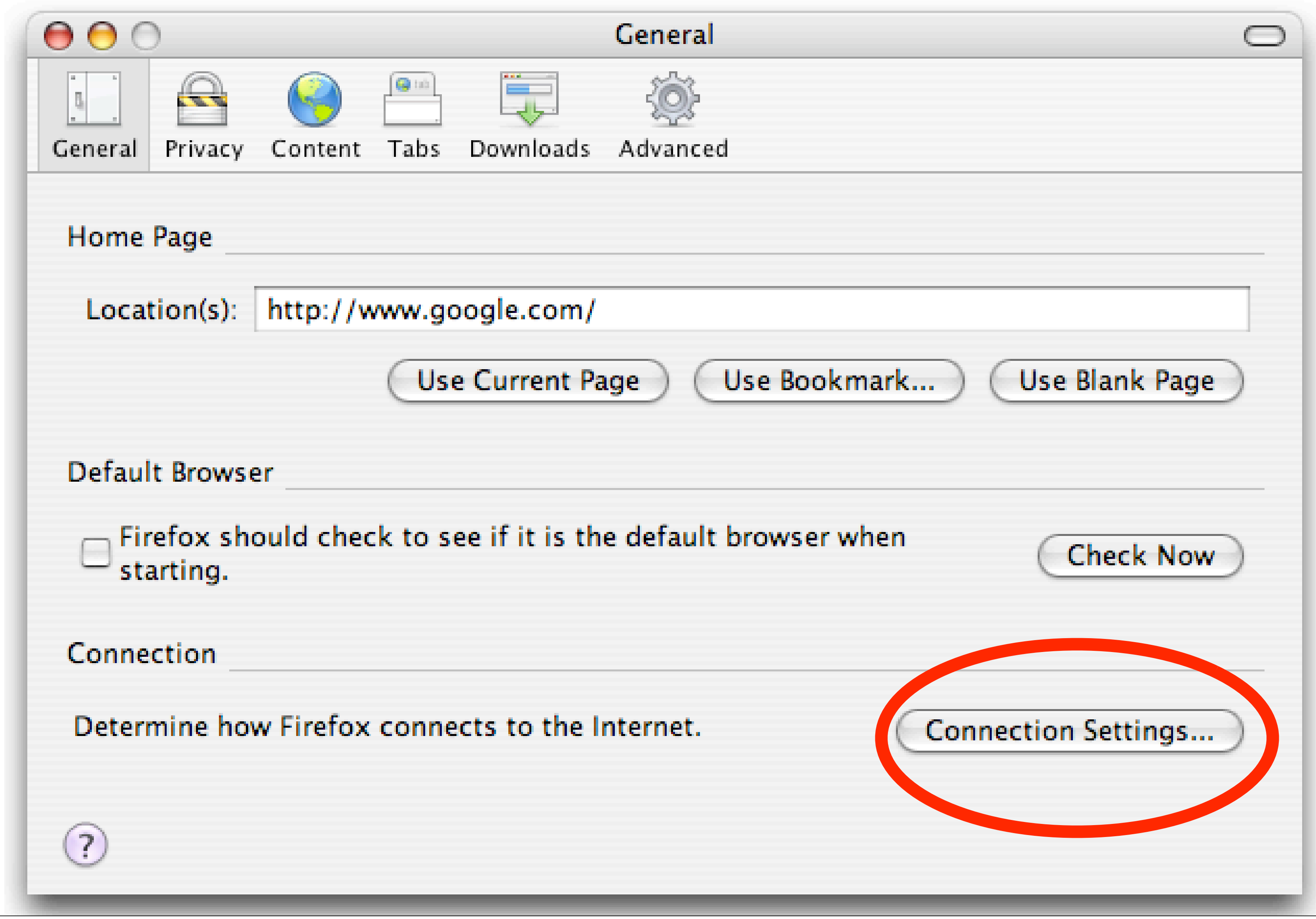
- Need to store a file containing usernames, salts, and hashed passwords
  - Both public and secret salts (aka pepper)
- Should be stored encrypted with an authenticated encryption scheme
  - I recommend Encrypt-then-MAC
  - Maybe AES in CTR mode to Encrypt, and HMAC-SHA1 to MAC
  - But be careful about security!!

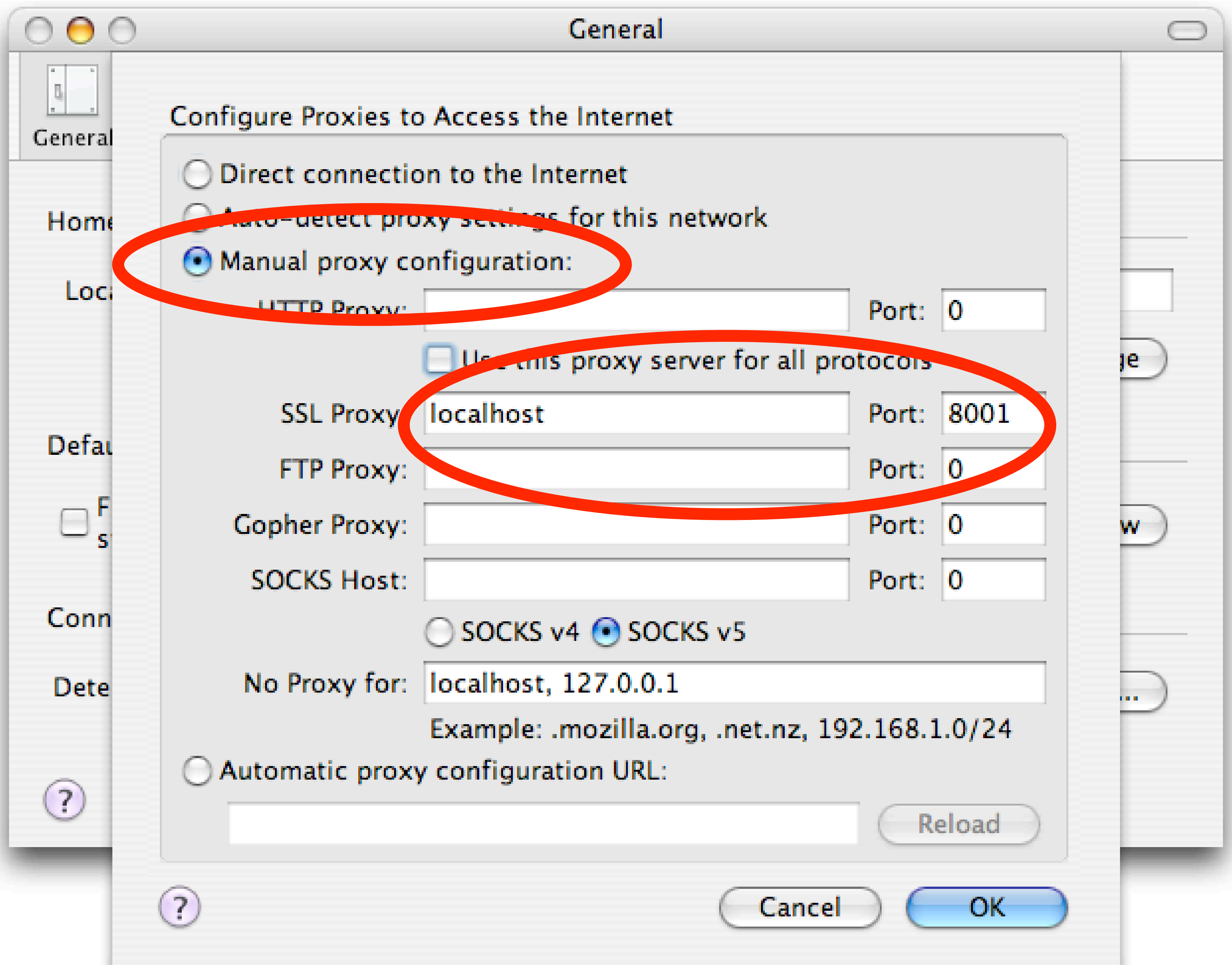
| Username | Salt | Hashed password |
|---|---|---|
| Alice | S | H(Pwd\|\|S\|\|P) |
| Bob | … | … |

# Password File Utility

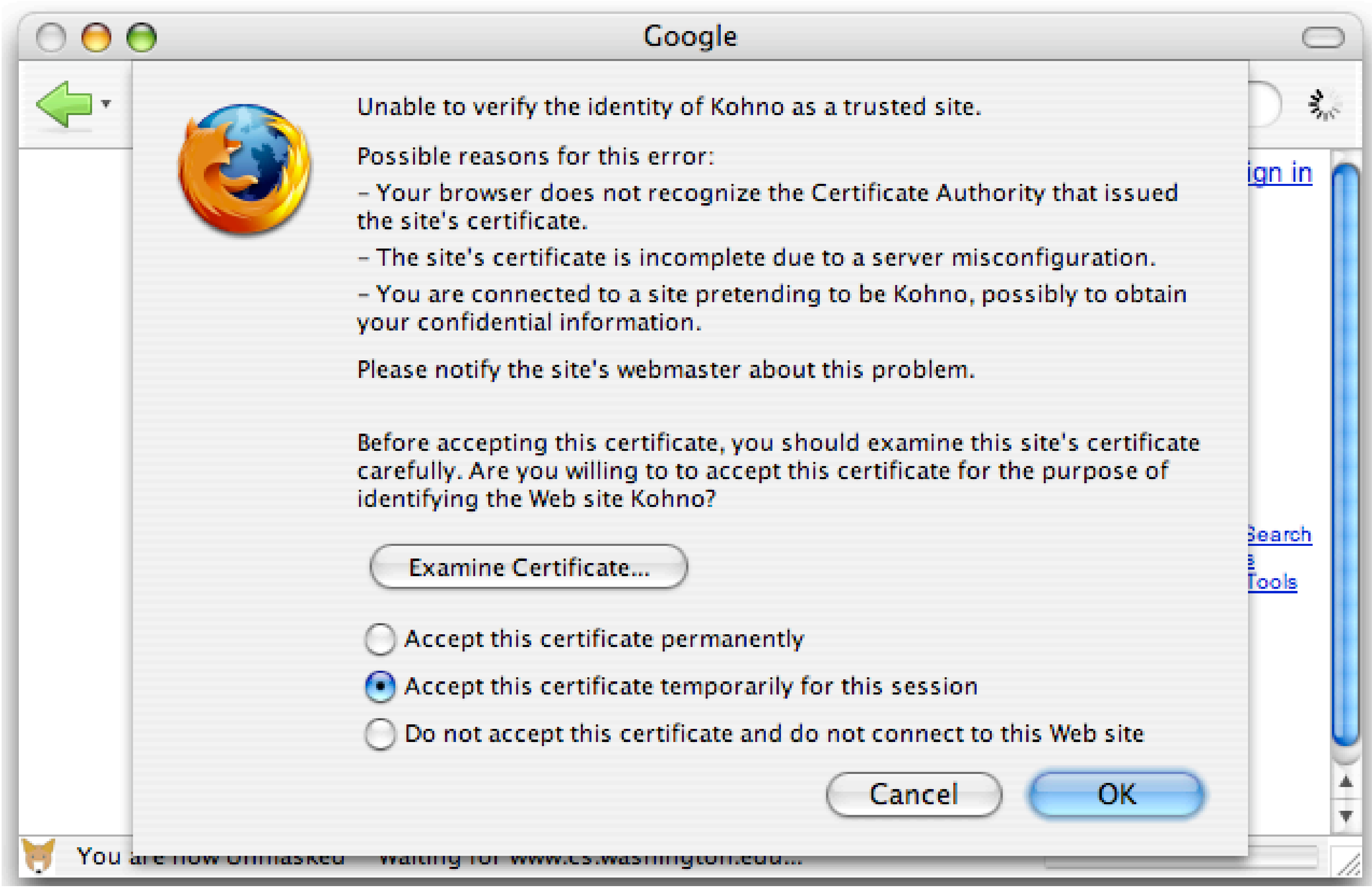
- You should add a utility for creating these password files
- Simple method:
  - Make a class to take a file and a list of usernames and passwords, and covert it to a password file.

# Configuring Firefox (under OS X, similar for Linux)




General
General
Configure Proxies to Access the Internet
Direct connection to the Internet
Manual proxy configuration:
SSL Proxy:
localhost
Port:
8001
FTP Proxy:
Port:
0
Gopher Proxy:
Port:
0
SOCKS Host:
Port:
0
SOCKS v4
SOCKS v5
No Proxy for:
localhost, 127.0.0.1
Example: .mozilla.org, .net.nz, 192.168.1.0/24
Automatic proxy configuration URL:
Reload
Cancel
OK

# When going to https://www.cs.washington.edu



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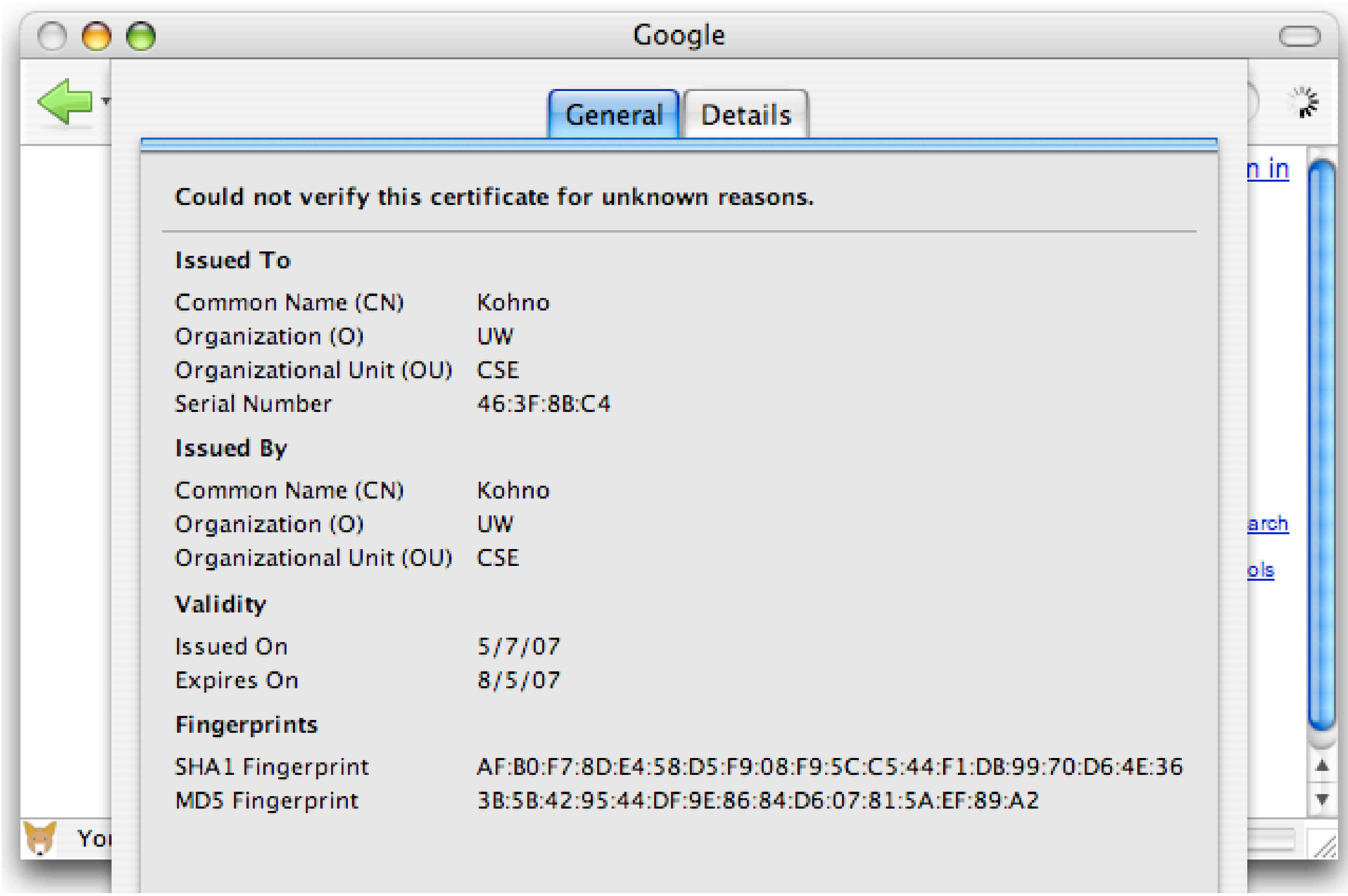

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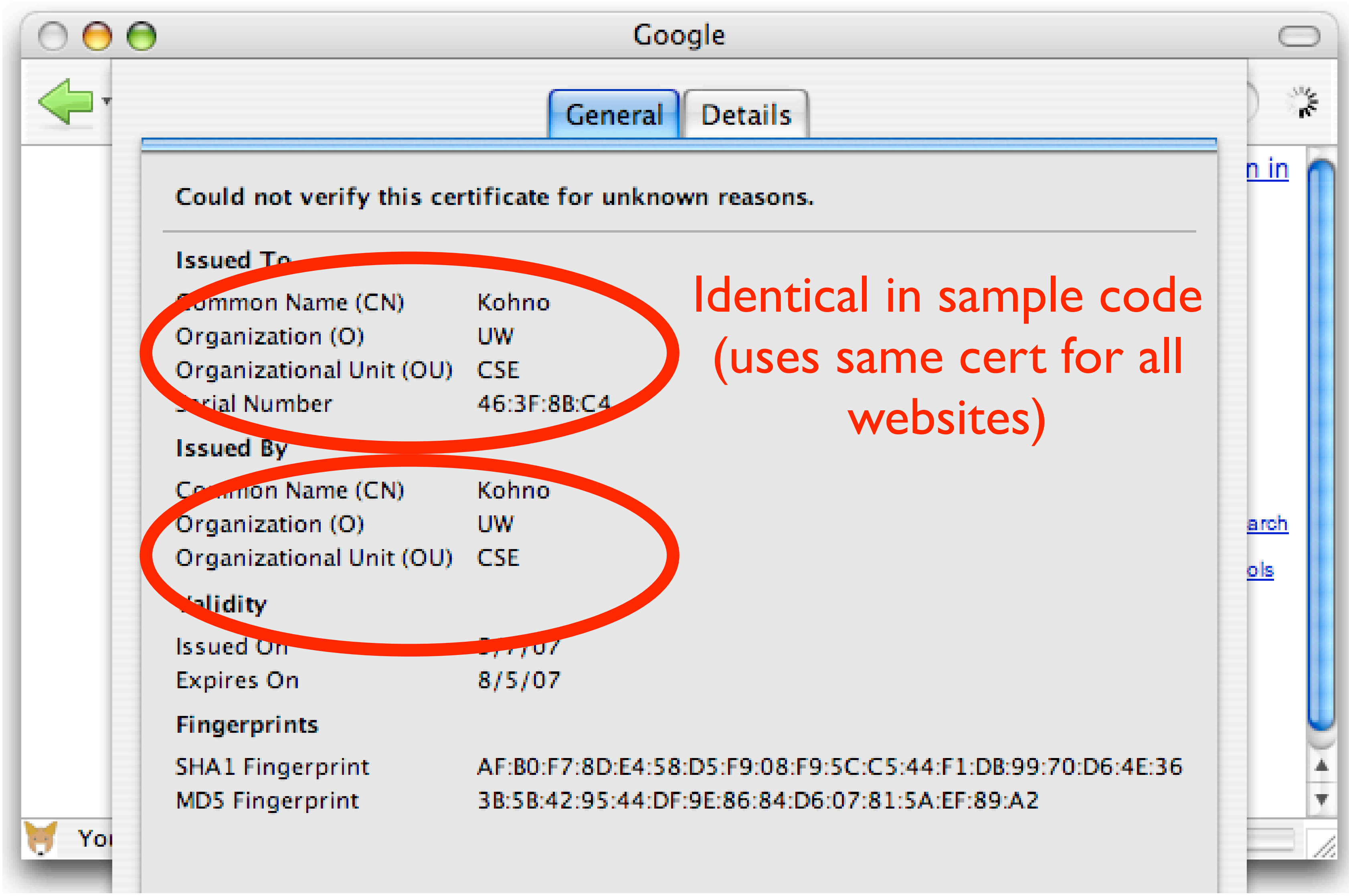
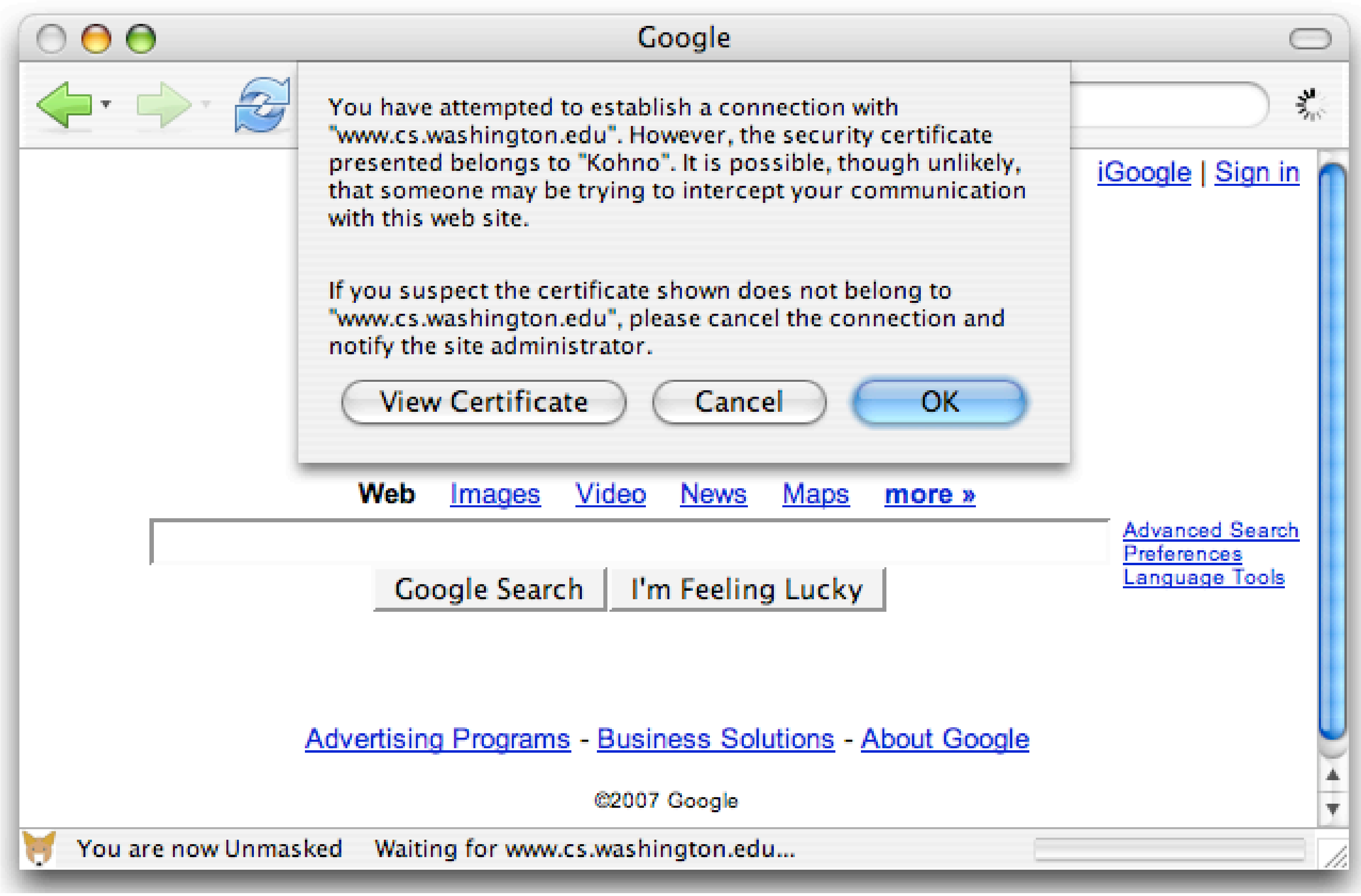
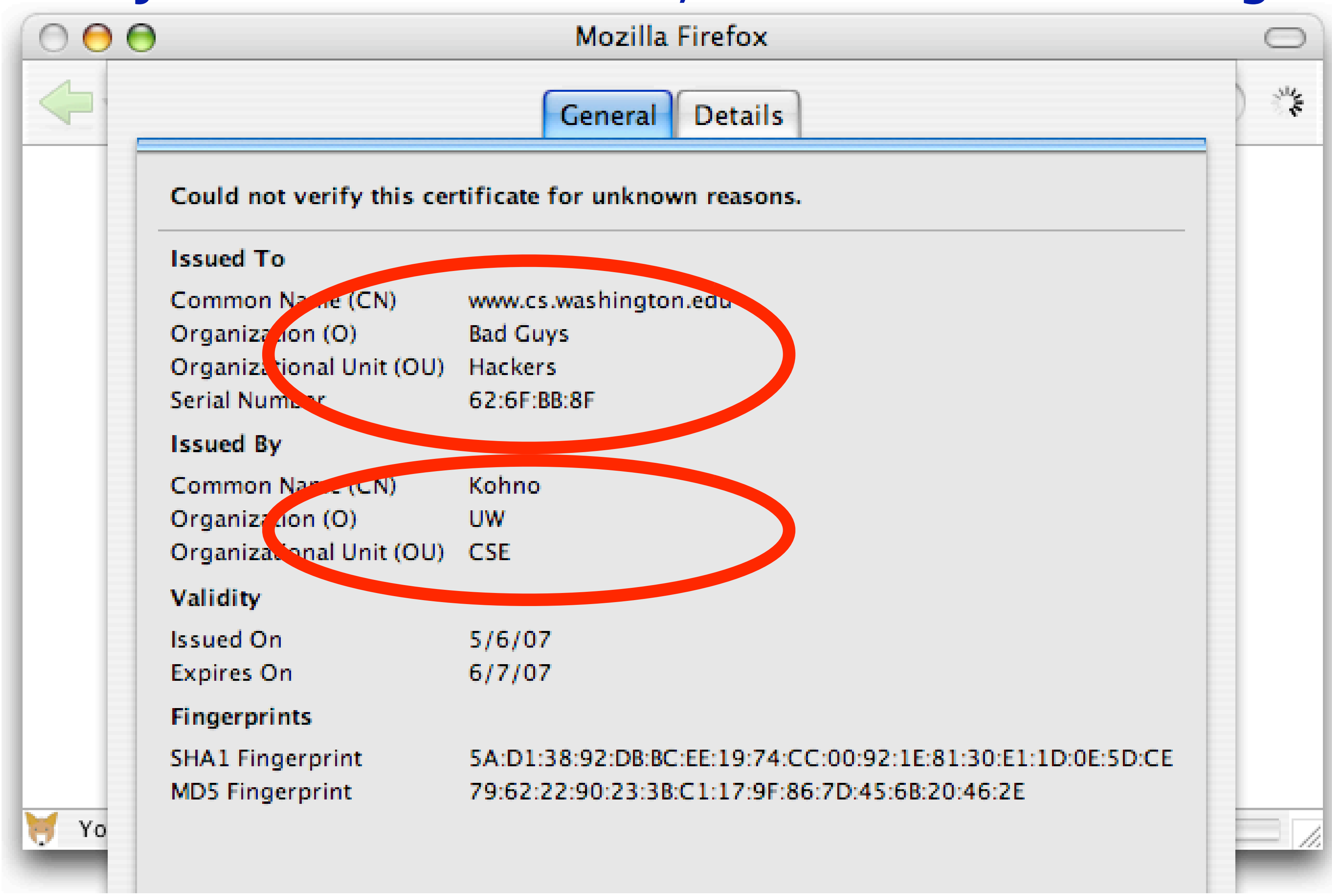


# Sample code causes this second warning



# Your job - new certificates, avoid second warning

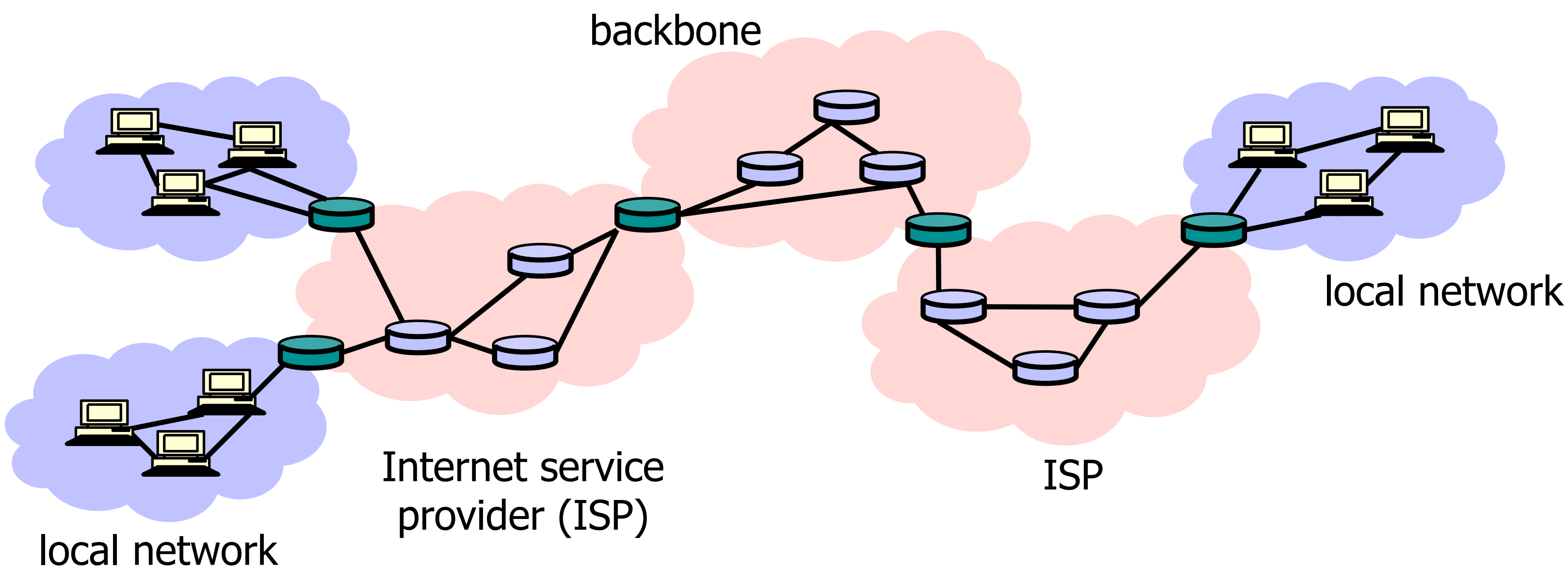


# Possible Problems

- You should be able to start up the proxy and connect to it "out of the box"
  - After you create your keystore with "keytool"
- If you are having problems
  - Is someone else trying to use your machine and that port?  (Default 8001.)
    - Try a different port on the command line
  - Firewall problems
    - Try to telnet to the needed ports (8001/8002/...)
  - Try running your browser on the same machine, and setting the proxy as "localhost"
- Course mailing list:  Great place to share knowledge

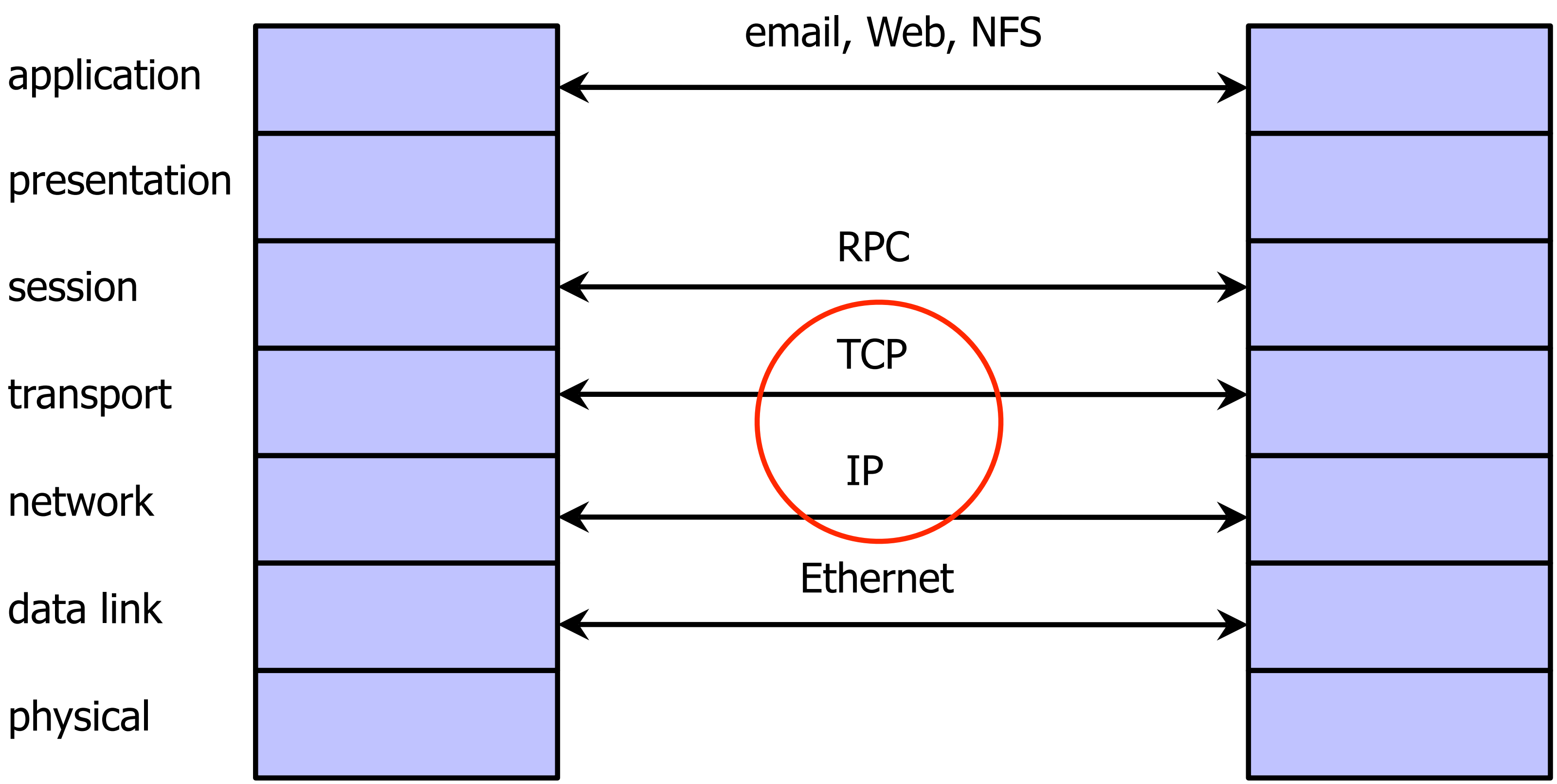
# Attacks on TCP/IP and DNS

# Internet Infrastructure

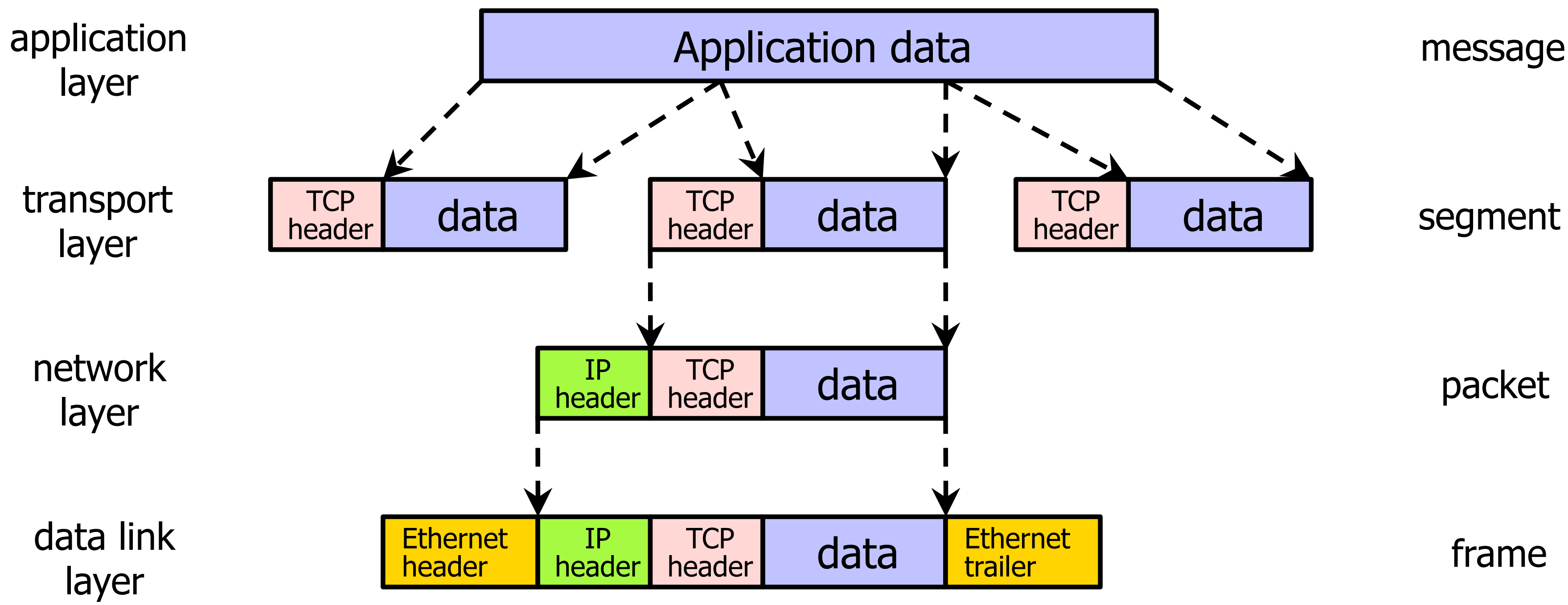



- TCP/IP for packet routing and connections
- Border Gateway Protocol (BGP) for route discovery
- Domain Name System (DNS) for IP address discovery

# OSI Protocol Stack

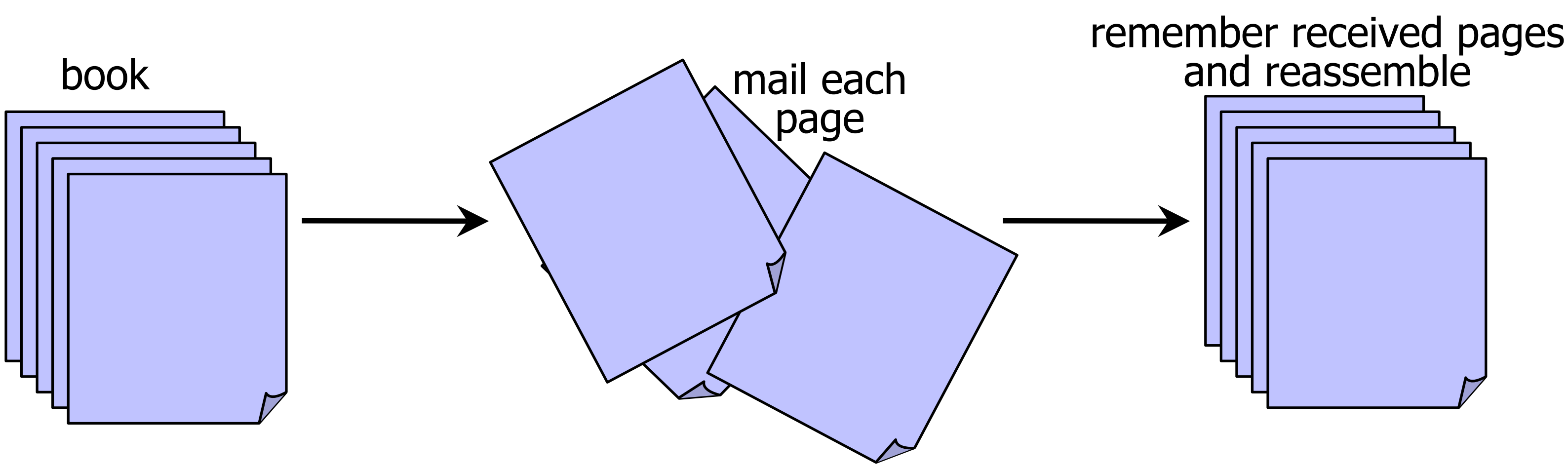


# Data Formats



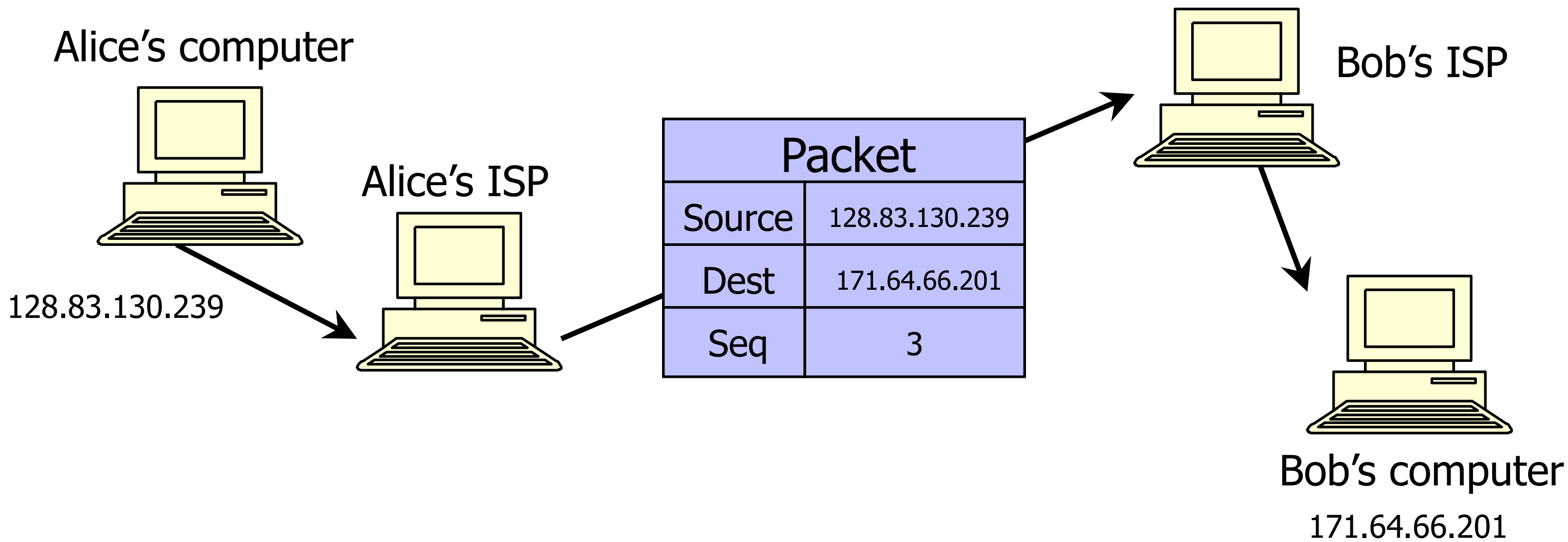
# TCP (Transmission Control Protocol)

- Sender: break data into packets
  - Sequence number is attached to every packet
- Receiver: reassemble packets in correct order
  - Acknowledge receipt; lost packets are re-sent
- Connection state maintained on both sides



# IP (Internet Protocol)

- Connectionless
  - Unreliable, “best-effort” protocol
- Uses numeric addresses for routing
  - Typically several hops in the route



# IP Routing

- Routing of IP packets is based on IP addresses
- Routers use a forwarding table
  - Entry = destination, next hop, network interface, metric
  - For each packet, a table look-up is performed to determine how to route it
- Routing information exchange allows update of old routes and creation of new ones
  - RIP (Routing Information Protocol)
  - OSPF (Open Shortest Path First Protocol)
  - BGP (Border Gateway Protocol)

# Routing Attacks

- Source routing
  - Source of the packet specifies a particular route
    - For example, because the automatic route is dead
  - Attacker can spoof source IP address and use source routing to direct response through a compromised host
  - Solution: reject packets with source routing!
    - More heavy-duty: allow source route only via trusted gateways
- Routing Information Protocol (RIP)
  - Use bogus routing updates to intercept traffic
    - RIP implicitly assumes that routers are trusted
  - "Black hole" attacks and many others

# BGP Misconfiguration

- Domain advertises good routes to addresses it does not known how to reach
  - Result: packets go into a network “black hole”
- April 25, 1997: “The day the Internet died”
  - AS7007 (Florida Internet Exchange) de-aggregated the BGP route table and re-advertised all prefixes as if it originated paths to them
  - In effect, AS7007 was advertising that it has the best route to <u>every</u> host on the Internet
  - Huge network instability as incorrect routing data propagated and routers crashed under traffic

# ICMP (Control Message Protocol)

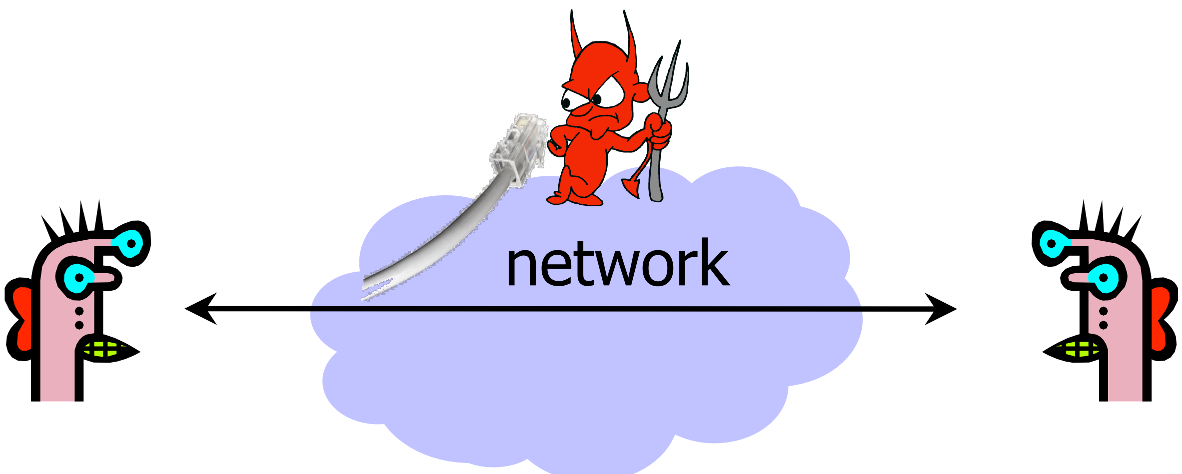
- Provides feedback about network operation
  - "Out-of-band" messages carried in IP packets
  - Error reporting, congestion control, reachability, etc.
- Example messages:
  - Destination unreachable
  - Time exceeded
  - Parameter problem
  - Redirect to better gateway
  - Reachability test (echo / echo reply)
  - Message transit delay (timestamp request / reply)

# Security Issues in TCP/IP

- Network packets pass by untrusted hosts
  - Eavesdropping (packet sniffing)
- IP addresses are public
  - Smurf attacks
- TCP connection requires state
  - SYN flooding
- TCP state is easy to guess
  - TCP spoofing and connection hijacking

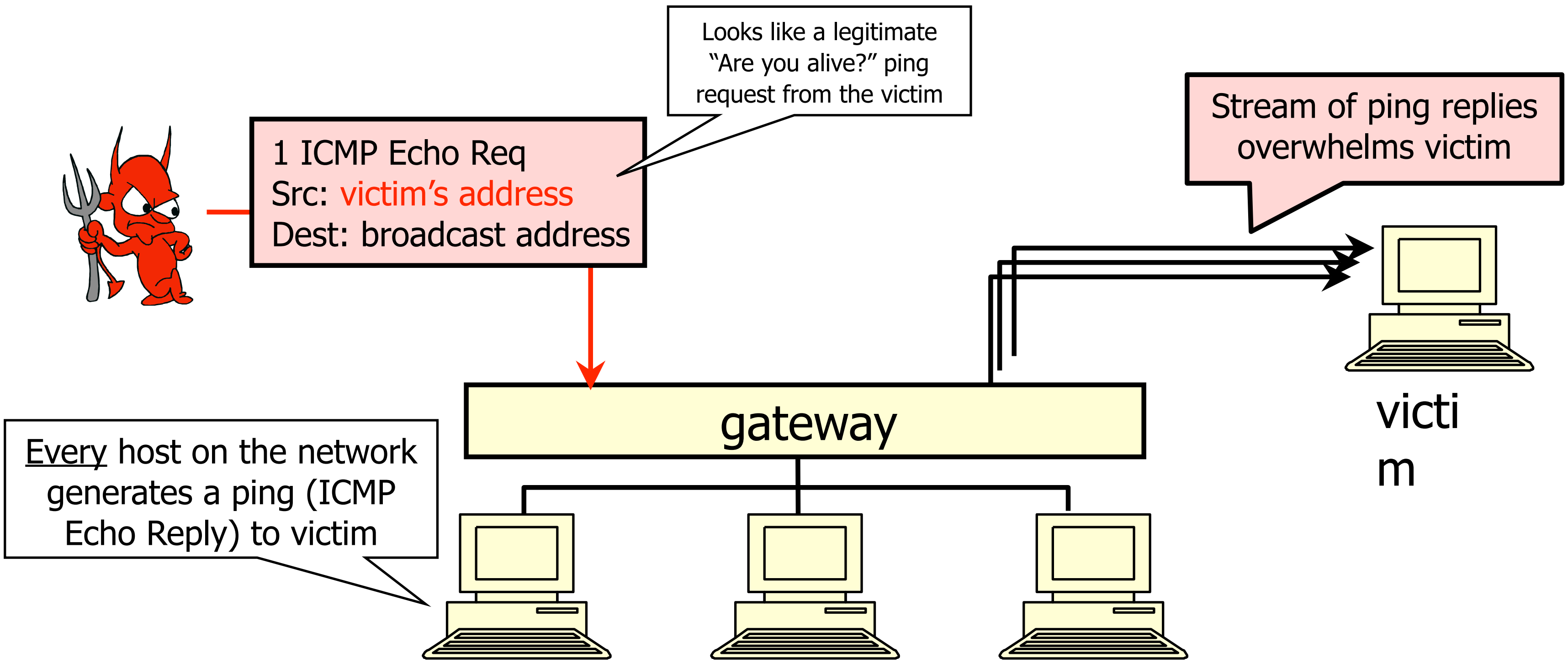
# Packet Sniffing

- Many applications send data unencrypted
  - ftp, telnet send passwords in the clear
- Network interface card (NIC) in "promiscuous mode" reads all passing data




Solution: encryption (e.g., IPSec), improved routing

# Smurf Attack




Solution: reject external packets to broadcast addresses

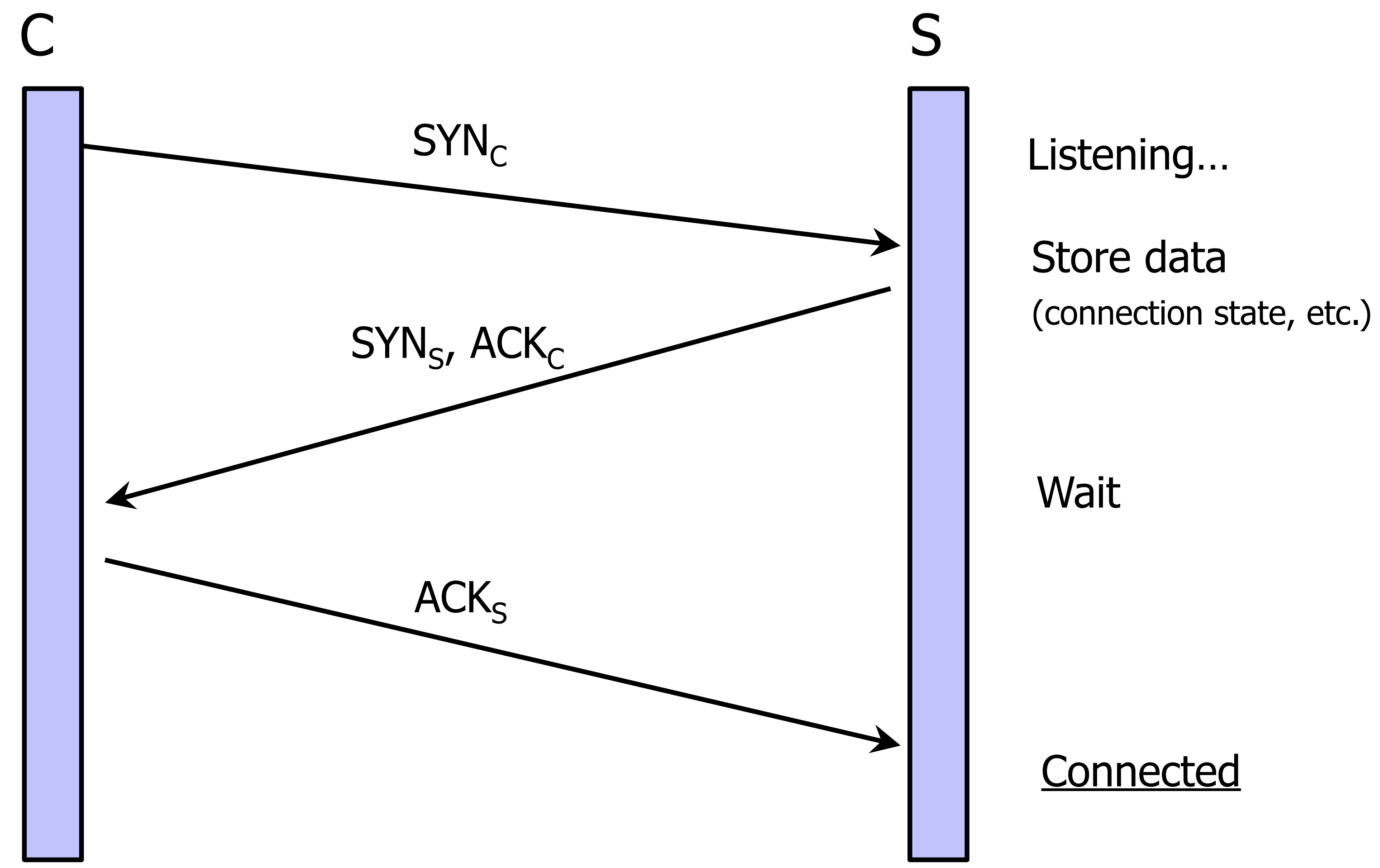
# "Ping of Death"

- If an old Windows machine received an ICMP packet with a payload longer than 64K, machine would crash or reboot
  - Programming error in older versions of Windows
  - Packets of this length are illegal, so programmers of Windows code did not account for them

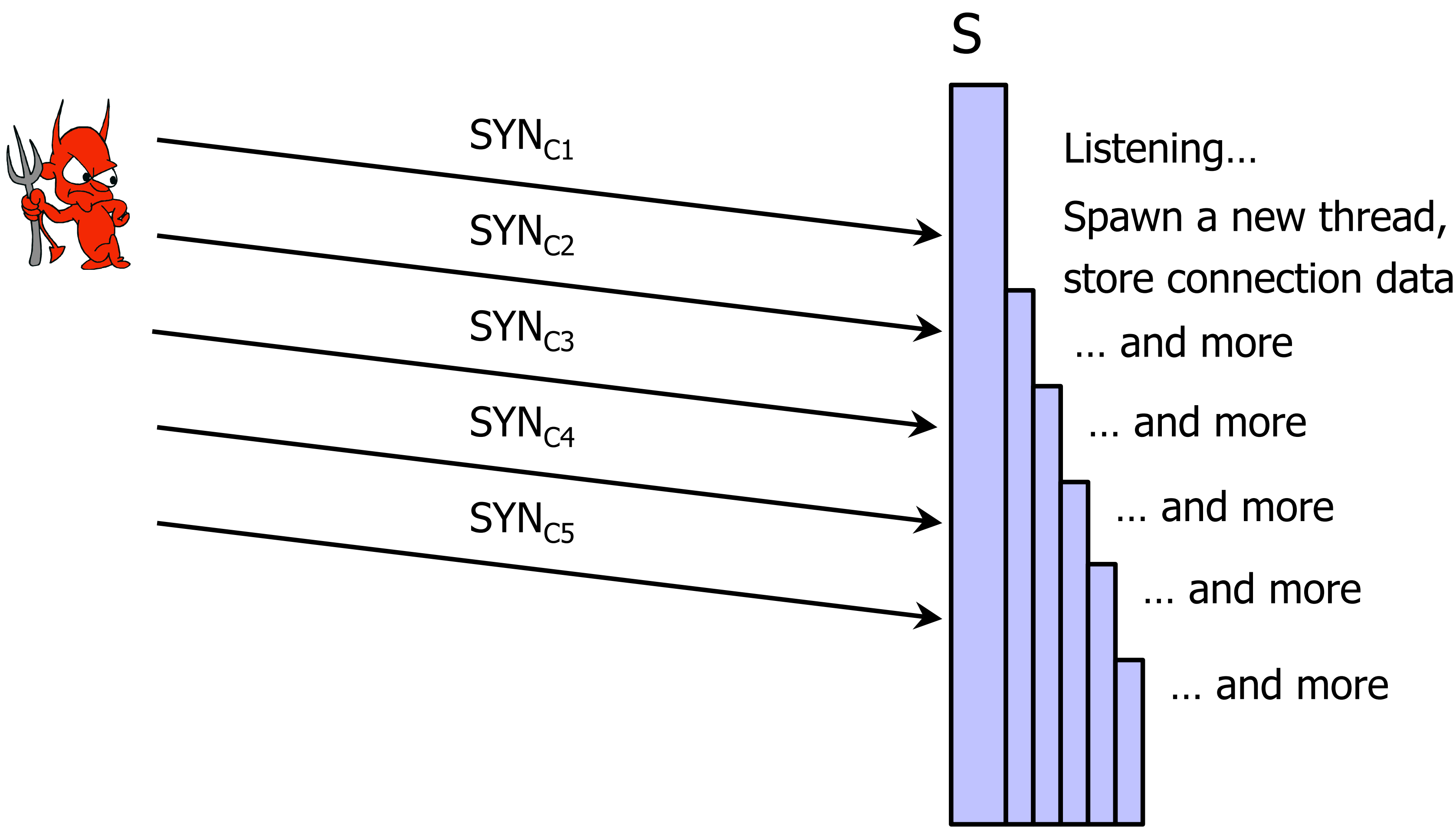
- Recall "security theme" of this course - every line of code might be the target of an adversary

Solution: patch OS, filter out ICMP packets

# TCP Handshake



# SYN Flooding Attack



# SYN Flooding Explained

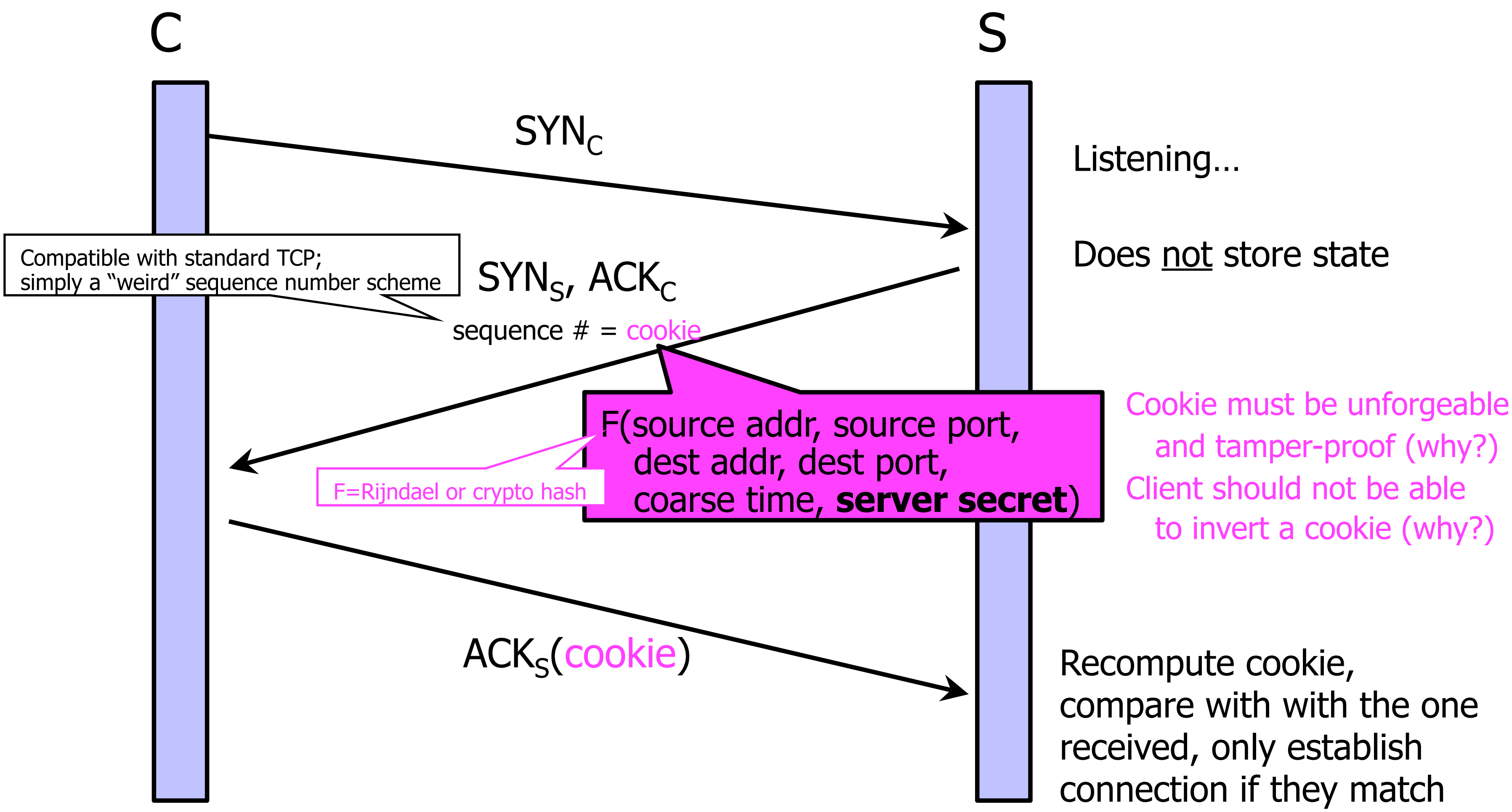
- Attacker sends many connection requests with spoofed source addresses
- Victim allocates resources for each request
  - Connection state maintained until timeout
  - Fixed bound on half-open connections
- Once resources exhausted, requests from legitimate clients are denied
- This is a classic denial of service (DoS) attack
  - Common pattern: it costs nothing to TCP initiator to send a connection request, but TCP responder must allocate state for each request (asymmetry!)

# Preventing Denial of Service

- DoS is caused by asymmetric state allocation
  - If responder opens a state for each connection attempt, attacker can initiate thousands of connections from bogus or forged IP addresses
- Cookies ensure that the responder is stateless until initiator produced at least 2 messages
  - Responder's state (IP addresses and ports of the connection) is stored in a cookie and sent to initiator
  - After initiator responds, cookie is regenerated and compared with the cookie returned by the initiator

# SYN Cookies

[Bernstein and Schenk]

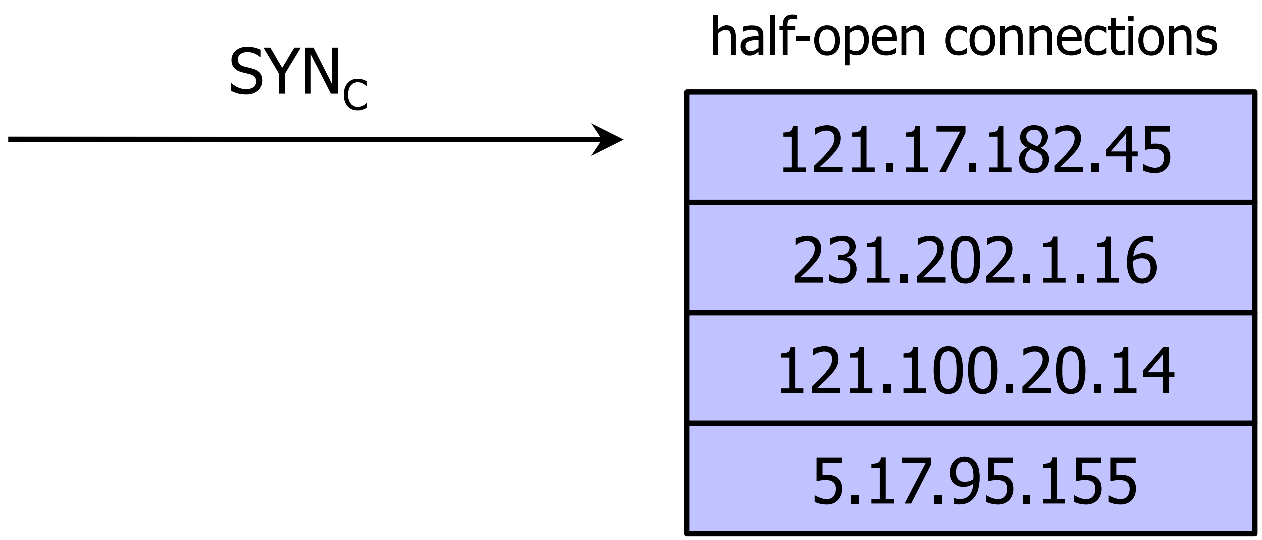



More info: http://cr.yp.to/syncookies.html

# Anti-Spoofing Cookies: Basic Pattern

- Client sends request (message #1) to server
- Typical protocol:
  - Server sets up connection, responds with message #2
  - Client may complete session or not (potential DoS)
- Cookie version:
  - Server responds with hashed connection data instead of message #2
  - Client confirms by returning hashed data
    - If source IP address is bogus, attacker can't confirm
  - Need an extra step to send postponed message #2, except in TCP (SYN-ACK already there)

# Another Defense: Random Deletion

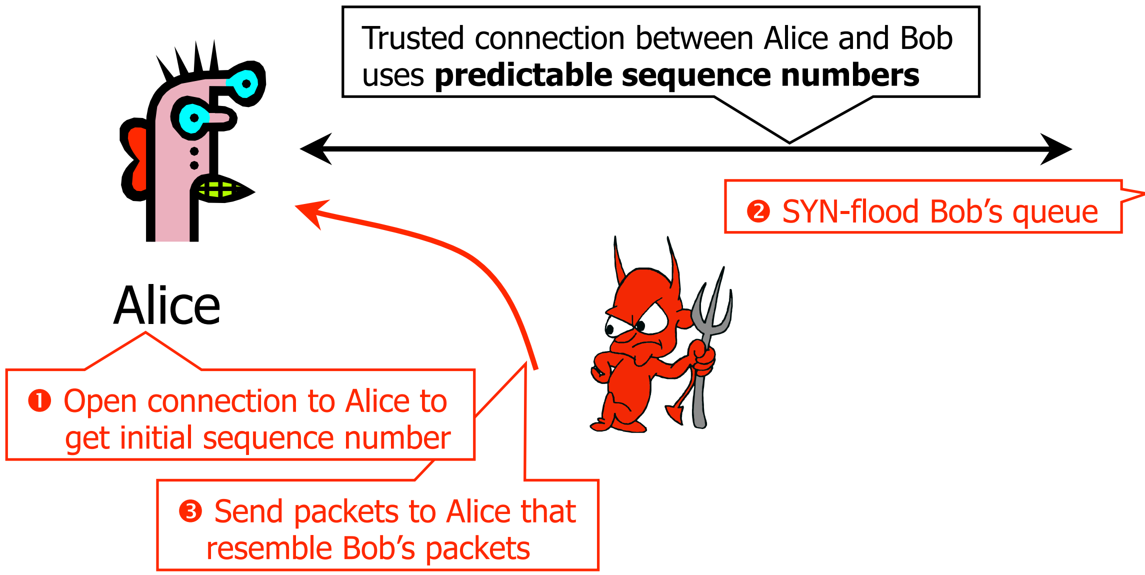



- If SYN queue is full, delete random entry
  - Legitimate connections have a chance to complete
  - Fake addresses will be eventually deleted
- Easy to implement

# TCP Connection Spoofing

- Each TCP connection has an associated state
  - Sequence number, port number
- TCP state is easy to guess
  - Port numbers are standard, sequence numbers are often predictable
  - Can inject packets into existing connections
- If attacker knows initial sequence number and amount of traffic, can guess likely current number
  - Send a flood of packets with likely sequence numbers

# “Blind” IP Spoofing Attack




- Can’t receive packets sent to Bob, but maybe can penetrate Alice’s computer if Alice uses IP address-based authentication
  - For example, rlogin and many other remote access programs uses address-based authentication

# DoS by Connection Reset

- If attacker can guess current sequence number for an existing connection, can send Reset packet to close it
  - With 32-bit sequence numbers, probability of guessing correctly is $1/2^{32}$ (not practical)
  - Most systems accept large windows of sequence numbers $\Rightarrow$ much higher probability of success
    - Need large windows to handle massive packet losses

# User Datagram Protocol (UDP)

- UDP is a connectionless protocol
  - Simply send datagram to application process at the specified port of the IP address
  - Source port number provides return address
  - Applications: media streaming, broadcast
- No acknowledgement, no flow control, no message continuation
- Denial of service by UDP data flood

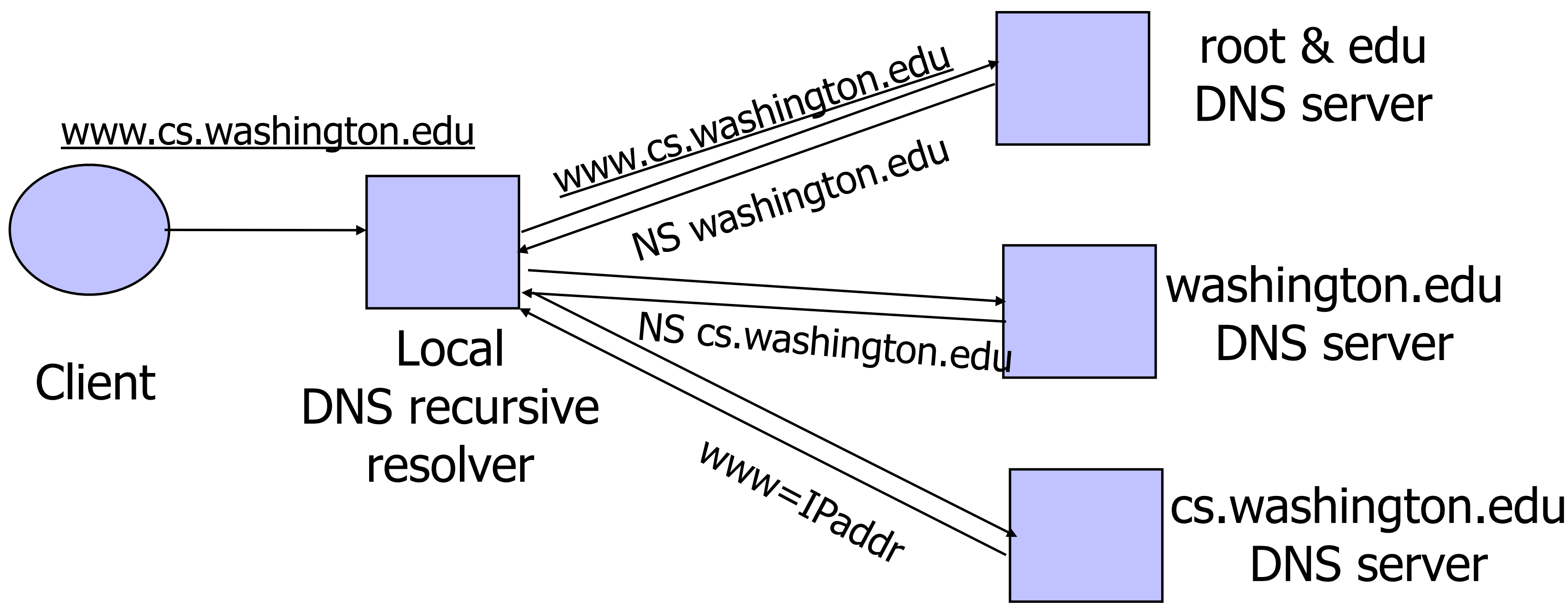
# Countermeasures

- Above transport layer: Kerberos
  - Provides authentication, protects against spoofing
  - Does not protect against connection hijacking
- Above network layer: SSL/TLS and SSH
  - Protects against connection hijacking and injected data
  - Does not protect against DoS by spoofed packets
- Network (IP) layer: IPSec
  - Protects against hijacking, injection, DoS using connection resets, IP address spoofing

# DNS: Domain Name Service

DNS maps symbolic names to numeric IP addresses

(for example, www.cs.washington.edu ↔ 128.208.3.88)



# DNS Caching

- DNS responses are cached
  - Quick response for repeated translations
  - Other queries may reuse some parts of lookup
    - NS records for domains
- DNS negative queries are cached
  - Don't have to repeat past mistakes
    - For example, misspellings
- Cached data periodically times out
  - Lifetime (TTL) of data controlled by owner of data
  - TTL passed with every record

# DNS Vulnerabilities

- DNS host-address mappings are not authenticated
- DNS implementations have vulnerabilities
  - Reverse query buffer overrun in old releases of BIND
    - Gain root access, abort DNS service…
  - MS DNS for NT 4.0 crashes on chargen stream
    - telnet ntbox 19 | telnet ntbox 53
- Denial of service is a risk
  - Oct ’02: ICMP flood took out 9 root servers for 1 hour

# Reverse DNS Spoofing

- Trusted access is often based on host names
  - E.g., permit all hosts in .rhosts to run remote shell
- Network requests such as rsh or rlogin arrive from numeric source addresses
  - System performs reverse DNS lookup to determine requester's host name and checks if it's in .rhosts
- If attacker can spoof the answer to reverse DNS query, he can fool target machine into thinking that request comes from an authorized host
  - No authentication for DNS responses and typically no double-checking (numeric → symbolic → numeric)

# Other DNS Risks

- DNS cache poisoning
  - False IP with a high time-to-live will stay in the cache of the DNS server for a long time
  - Basis of pharming
- Spoofed ICANN registration and domain hijacking
  - Authentication of domain transfers based on email addr
  - Aug '04: teenager hijacks eBay's German site
  - Jan '05: hijacking of panix.com (oldest ISP in NYC)
    - "The ownership of panix.com was moved to a company in Australia, the actual DNS records were moved to a company in the United Kingdom, and Panix.com's mail has been redirected to yet another company in Canada."
- Misconfiguration and human error

# JavaScript/DNS Intranet attack (I)

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- Attacker at evil.org gets good.net user to browse www.evil.org

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- Consider a Web server intra.good.net
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- Places Javascript on www.evil.org that accesses sensitive application on intra.good.net

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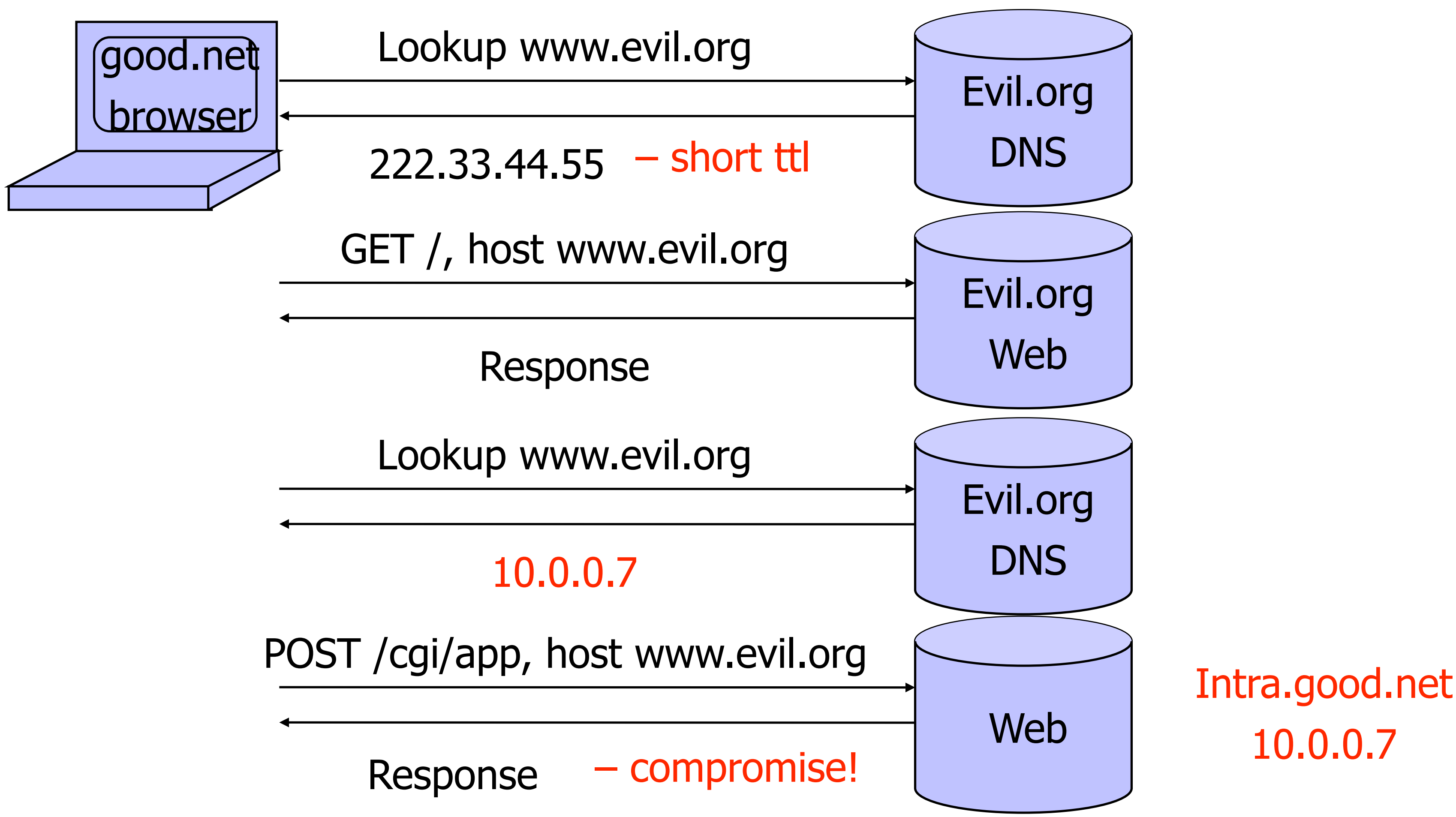
  - Hosts sensitive CGI applications
- Attacker at evil.org gets good.net user to browse www.evil.org
- Places Javascript on www.evil.org that accesses sensitive application on intra.good.net
  - This doesn't work because Javascript is subject to "same-origin" policy

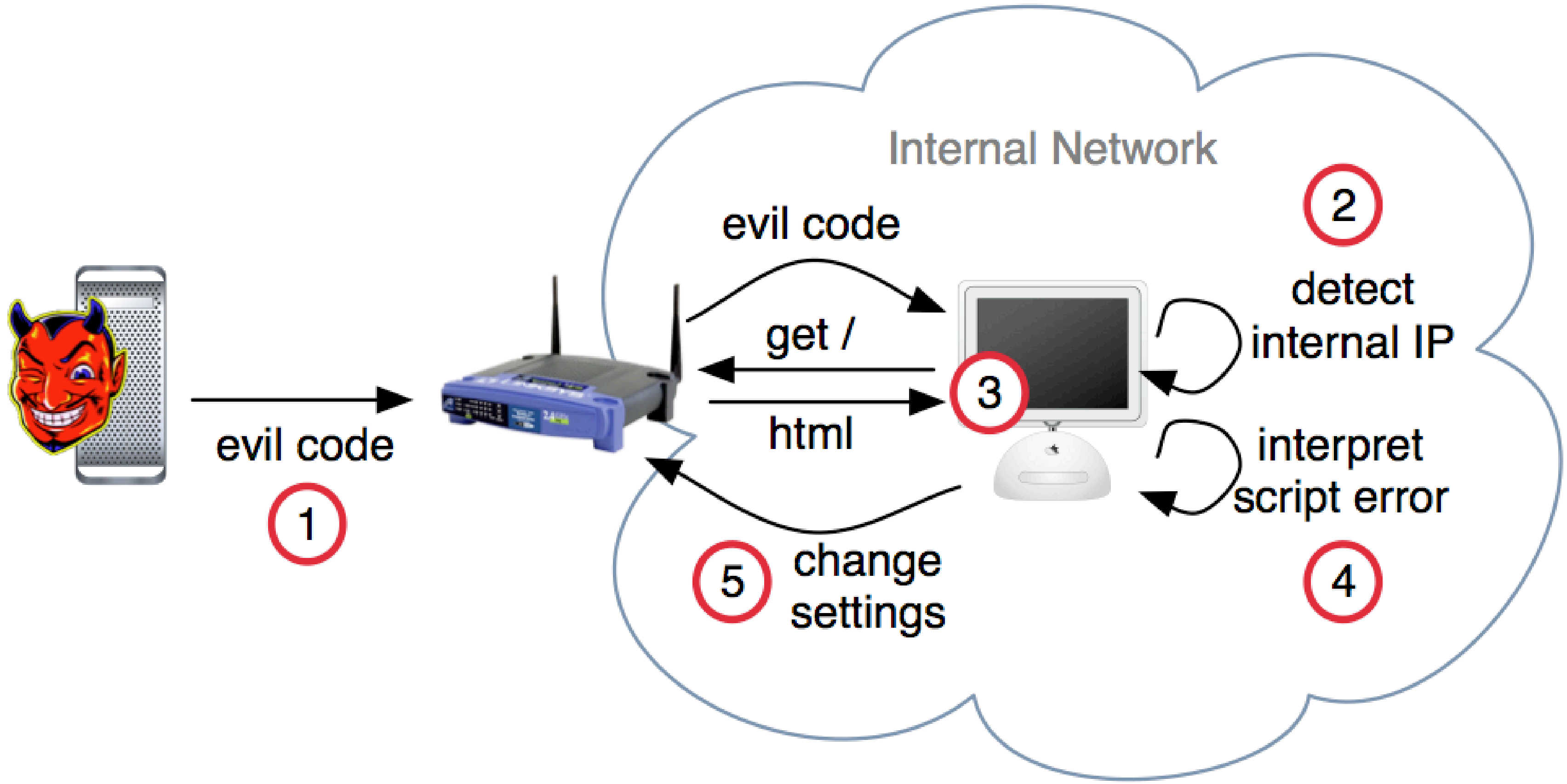
# JavaScript/DNS Intranet attack (I)

- Consider a Web server intra.good.net
  - IP: 10.0.0.7, inaccessible outside good.net network
  - Hosts sensitive CGI applications
- Attacker at evil.org gets good.net user to browse www.evil.org
- Places Javascript on www.evil.org that accesses sensitive application on intra.good.net
  - This doesn't work because Javascript is subject to "same-origin" policy
  - … but the attacker controls evil.org DNS

# JavaScript/DNS Intranet attack (II)



# Drive-by pharming




Reference: http://www.cs.indiana.edu/pub/techreports/TR641.pdf

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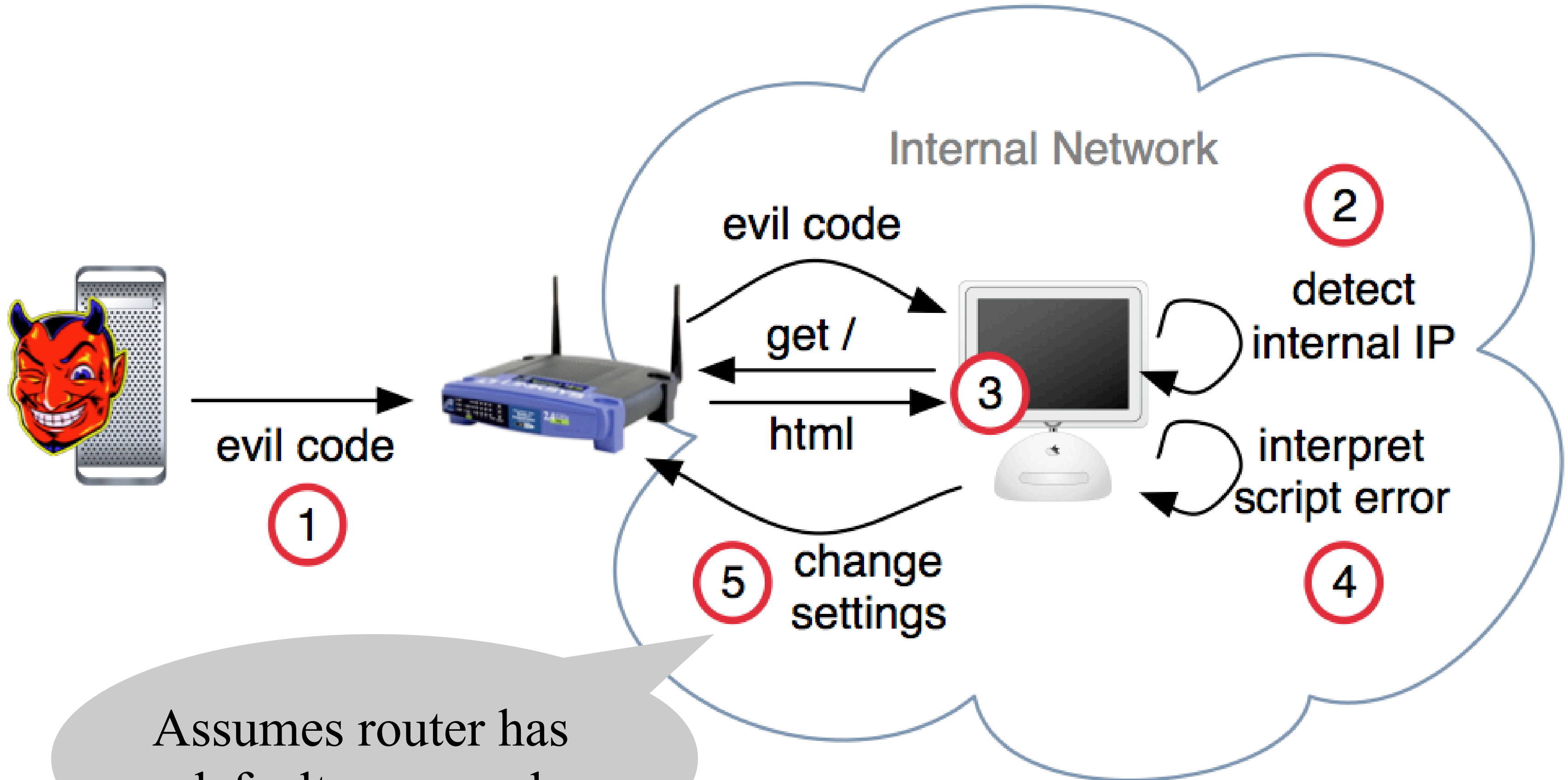


Assumes router has default password

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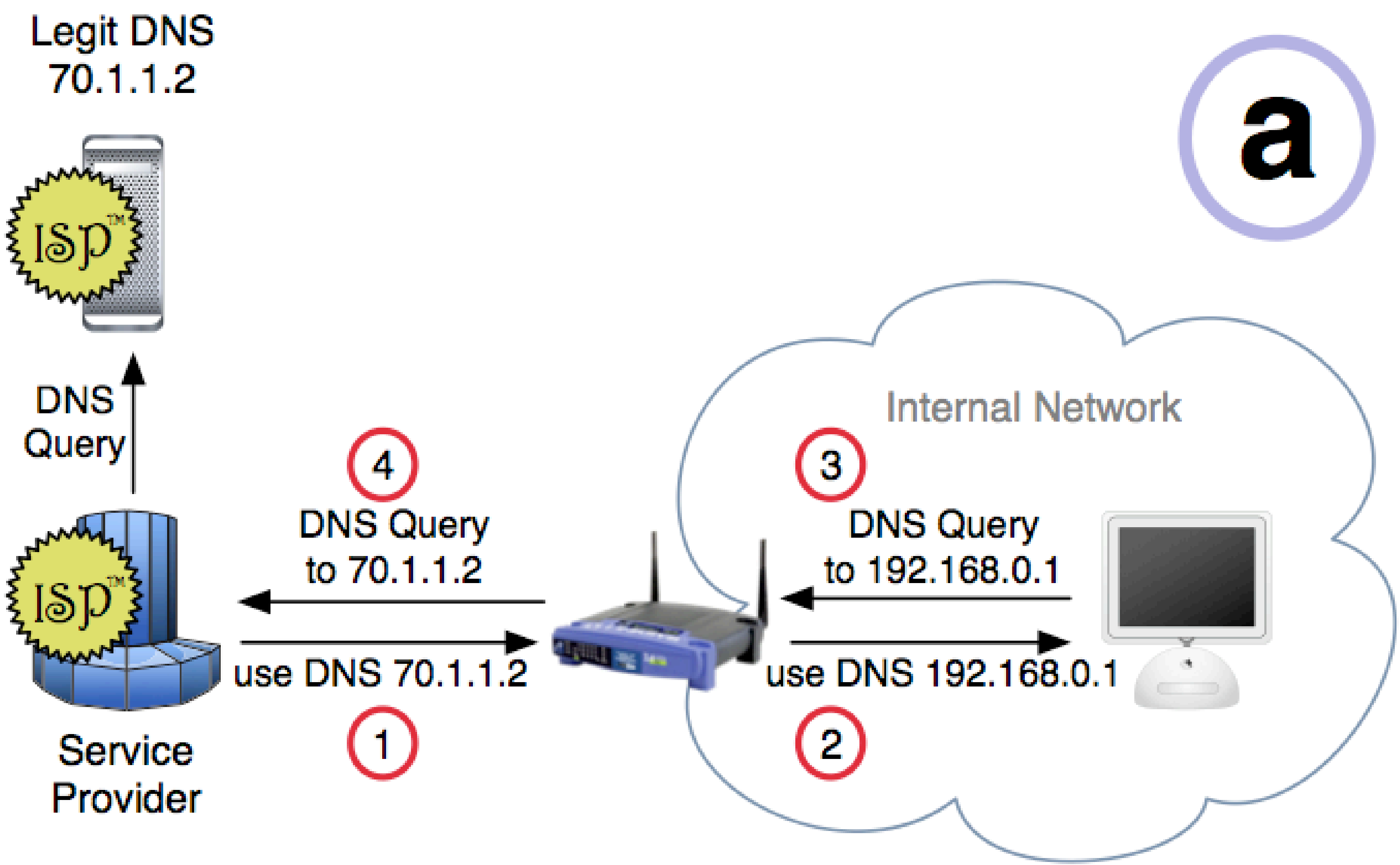


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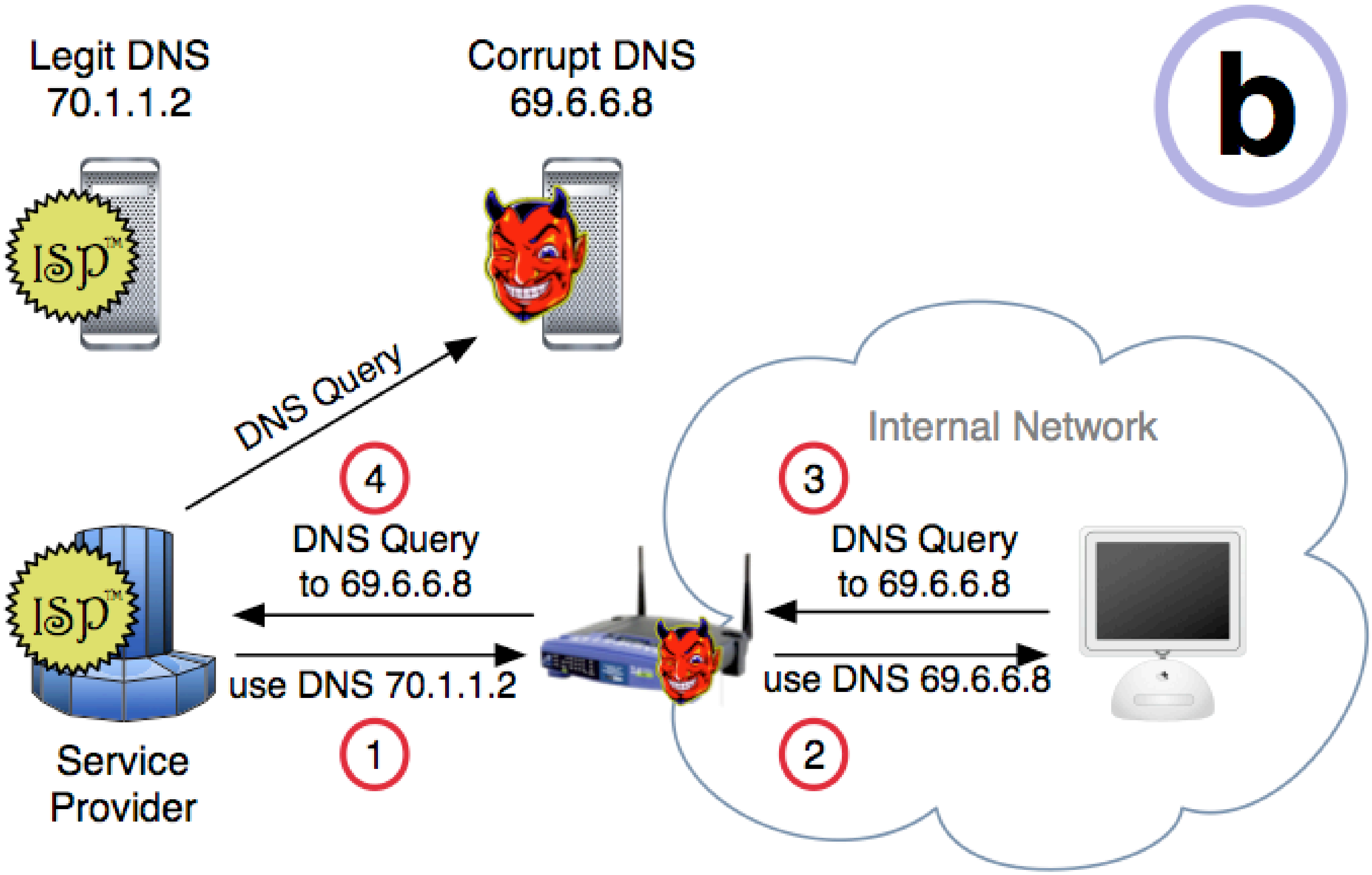


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# DNSSEC

- Goals: authentication and integrity of DNS requests and responses
- PK-DNSSEC (public key)
  - DNS server signs its data (can be done in advance)
- SK-DNSSEC (symmetric key)
  - Encryption and MAC: $E_k(m, MAC(m))$
  - Each message contains a nonce to avoid replay
  - Each DNS node shares a symmetric key with its parent
  - Zone root server has a public key (hybrid approach)