Security

COS 518: *Advanced Computer Systems*
Lecture 17

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Basic security properties

- **Confidentiality:** Concealment of information or resources
- **Authenticity:** Identification and assurance of origin of info
- **Integrity:** Trustworthiness of data or resources in terms of preventing improper and unauthorized changes
- **Availability:** Ability to use desired info or resource
- **Non-repudiation:** Offer of evidence that a party indeed is sender or a receiver of certain information
- **Access control:** Facilities to determine and enforce who is allowed access to what resources (host, software, network)

Intro to crypto in 15 minutes

What is Cryptography?

- From Greek, meaning "secret writing"
- Confidentiality: encrypt data to hide content
- Include "signature" or "message authentication code"
  - – Integrity: Message has not been modified
  - – Authentication: Identify source of message

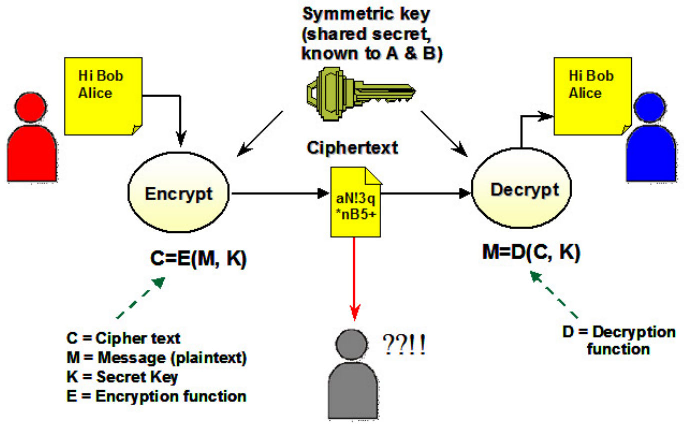
plaintext $\xrightarrow{\text{encryption}}$ ciphertext $\xrightarrow{\text{decryption}}$ plaintext

- Modern encryption:
  - – *Algorithm* public, *key* secret and provides security
  - – Symmetric (shared secret) or asymmetric (public-private key)

Symmetric (Secret Key) Crypto

- Sender and recipient share common key
  - **– Main challenge: How to distribute the key?**
- Provides dual use:
  - – Confidentiality (encryption)
  - – Message authentication + integrity (MAC)
- 1000x more computationally efficient than asymmetric

Symmetric Cipher Model



Symmetric key
(shared secret,
known to A & B)

Hi Bob
Alice

Encrypt

Ciphertext

aN!3q
*nB5+

Decrypt

Hi Bob
Alice

C=E(M, K)

M=D(C, K)

??!!

C = Cipher text
M = Message (plaintext)
K = Secret Key
E = Encryption function

D = Decryption
function

Public-Key Cryptography

- **Each party has (public key, private key)**
- **Alice's public key PK**
  - – Known by anybody
  - – Bob uses PK to encrypt messages *to* Alice
  - – Bob uses PK to verify signatures *from* Alice
- **Alice's private/secret key: sk**
  - – Known only by Alice
  - – Alice uses sk to decrypt ciphertexts sent to her
  - – Alice uses sk to generate new signatures on messages

Public-Key Cryptography

- (PK, sk) = generateKey(keysize)
- **Encryption API**
  - – ciphertext = encrypt (message, PK)
  - – message = decrypt (ciphertext, sk)
- **Digital signatures API**
  - – Signature = sign (message, sk)
  - – isValid = verify (signature, message, PK)

(Simple) RSA Algorithm

- Generating a key:
  - Generate composite **n = p * q**, where p and q are secret primes
  - Pick public exponent **e**
  - Solve for secret exponent **d** in $d \cdot e \equiv 1 \pmod{(p-1)(q-1)}$
  - Public key = (e, n), private key = d

- Encrypting message m: $c = m^e \bmod n$
- Decrypting ciphertext c: $m = c^d \bmod n$

- **Security** due to cost of factoring large numbers
  - Finding **(p,q)** given **n** takes $O(e^{\log n \log \log n})$ operations
  - n chosen to be 2048 or 4096 bits long

Cryptographic hash function

(and using them in systems)

Cryptography Hash Functions I

- Take message *m* of arbitrary length and produces fixed-size (short) number *H(m)*

- One-way function
  - Efficient: Easy to compute *H(m)*
  - **Hiding property:** Hard to find an *m*, given *H(m)*
    - Assumes “m” has sufficient entropy, not just {“heads”, “tails”}
  - **Random:** Often assumes for output to “look” random

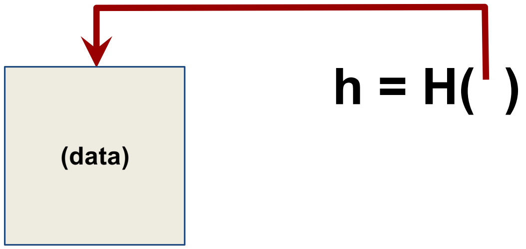
Cryptography Hash Functions II

- Collisions exist: | possible inputs | >> | possible outputs |

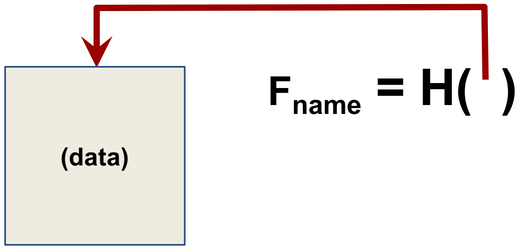
  … but hard to find

- Collision resistance:
  - Strong resistance: Find any m != m’ such that H(m) == H(m’)
  - Weak resistance: Given m, find m’ such that H(m) == H(m’)
  - For 160-bit hash (SHA-1)
    - Finding any collision is birthday paradox: 2^{160/2} = 2^80
    - Finding specific collision requires 2^160

Hash Pointers

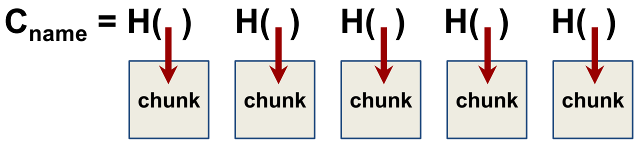


Self-certifying names



- P2P file sharing software (e.g., Limewire)
  - File named by F_{name} = H (data)
  - Participants verify that H (downloaded) == F_{name}

Self-certifying names



- BitTorrent
  - Large file split into smaller chunks (~256KB each)
  - Torrent file specifies the name/hash of each chunk
  - Participants verify that H (downloaded) == C_{name}
  - Security relies on getting torrent file from trustworthy source

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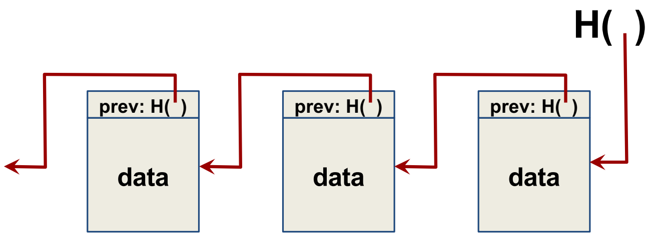
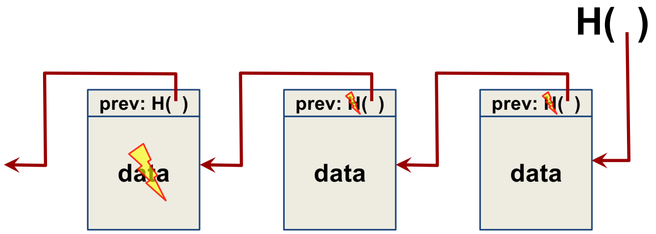
Hash chains



Creates a “tamper-evident” log of data

Hash chains



If data changes, all subsequent hash pointers change

Otherwise, found a hash collision!

Security more broadly

Fortune favors the attacker

- Cost asymmetry
  - Defense must protect everything
  - Offense must find just one hole
- "Security" is a negative goal: hard to achieve
  - Policy: desired goal
  - Threat model: assumptions about what can go wrong

Ways to attack grades.txt

- Change permissions on grades.txt to get access
- Access disk blocks directly
- Access grades.txt via www.cs.princeton.edu
- Reuse memory after Mike's text editor exits, read data
- Read backup copy of grades.txt from Mike's text editor
- Intercept network packets to file server storing grades.txt
- Send Mike a trojaned text editor that emails out the file
- Steal disk from file server storing grades.txt
- Get discarded printout of grades.txt from the trash
- Call sysadmin, pretend to be Mike, reset his password
- …

Example from MIT 6.033

paymaxx.com (2005)

- https://my.paymaxx.com/
  - Requires username and password
  - If you authenticate, provides menu of options
  - One option is to get a PDF of your W2 tax form
- https://my.paymaxx.com/get-w2.cgi?id=1234
  - Gets a PDF of W2 tax form for ID 1234
  - get-w2.cgi forgot to check authorization
- Attacker manually constructs URLs to fetch all data

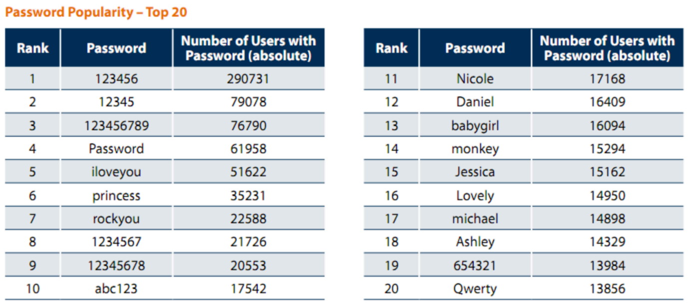
Example from MIT 6.033

Thinking about threat models…

Example: Passwords

- Can't store passwords in a file that could be read
  - Concerned with insider attacks / break-ins
- Must compare typed passwords to stored passwords
  - Does H (input) == H (password) ?
- Memory cheap: build table of all likely password hashes?

Password stats
(leaked 32M passwords, 2009)



Password Popularity – Top 20

Rank	Password	Number of Users with Password (absolute)
1	123456	290731
2	12345	79078
3	123456789	76790
4	Password	61958
5	iloveyou	51622
6	princess	35231
7	rockyou	22588
8	1234567	21726
9	12345678	20553
10	abc123	17542
11	Nicole	17168
12	Daniel	16409
13	babygirl	16094
14	monkey	15294
15	Jessica	15162
16	Lovely	14950
17	michael	14898
18	Ashley	14329
19	654321	13984
20	Qwerty	13856

- 5,000 unique passwords account for 20% users (6.4M)
- Similar statistics in Gawker breakin, 2010

Example: Passwords

- Can’t store passwords in a file that could be read
  - Concerned with insider attacks / break-ins
- Must compare typed passwords to stored passwords
  - Does H (input) == H (password) ?
- Memory cheap: build table of all likely password hashes?
  - Use “salt” to compute h = H (password || salt)
  - Store salt as plaintext in password file, not a secret
  - Then check whether H (input, salt) == h

Attacking specific accounts

- “Tar pit” connections
  - Failed logins take 2-3 seconds to respond
  - ...but can just retry within 100s of ms
  - ...or launch attack from many bots concurrently
- Max number of failed connections
  - “Lock” account and require additional information
- Two-factor auth
  - “What you have” + “what you know”

HTTP Security

“Securing” HTTP

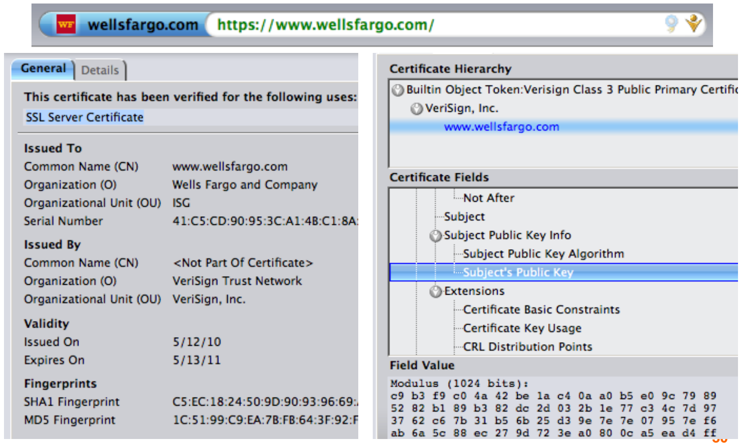
- Threat model
  - Eavesdropper listening on conversation (confidentiality)
  - Man-in-the-middle modifying content (integrity)
  - Adversary impersonating desired website (authentication, and confidentiality)
- Enter HTTP-S
  - HTTP sits on top of secure channel (SSL/TLS)
  - All (HTTP) bytes written to secure channel are encrypted and authenticated
  - Problem: What is actually authenticated to prevent impersonation? Which keys used for crypto protocols?

Learning a valid public key

wellsfargo.com https://www.wellsfargo.com/

- What is that lock?
  - Securely binds domain name to public key (PK)
    - Believable only if you trust the attesting body
    - Bootstrapping problem: Who to trust, and how to tell if this message is actually from them?
  - If PK is authenticated, then any message signed by PK cannot be forged by non-authorized party

How to authenticate PK



wellsfargo.com https://www.wellsfargo.com/

This certificate has been verified for the following uses:

SSL Server Certificate

Issued To

Common Name (CN)	www.wellsfargo.com
Organization (O)	Wells Fargo and Company
Organizational Unit (OU)	ISG
Serial Number	41:C5:CD:90:95:3C:A1:4B:C1:8A:

Issued By

Common Name (CN)	<Not Part Of Certificate>
Organization (O)	VeriSign Trust Network
Organizational Unit (OU)	VeriSign, Inc.

Validity

Issued On	5/12/10
Expires On	5/13/11

Fingerprints

SHA1 Fingerprint	C5:EC:18:24:50:9D:90:93:96:69:
MD5 Fingerprint	1C:51:99:C9:EA:7B:FB:64:3F:92:F

Certificate Hierarchy

- Builtin Object Token:Verisign Class 3 Public Primary Certific
  - VeriSign, Inc.
    - www.wellsfargo.com

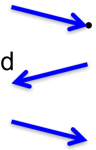
Certificate Fields

Field Value

```
Modulus (1024 bits):
c9 b3 f9 c0 4a 42 be 1a c4 0a a0 b5 e0 9c 79 89
52 82 b1 89 b3 82 dc 2d 03 2b 1e 77 c3 4c 7d 97
37 62 c6 7b 31 b5 6b 25 d3 9e 7e 7e 07 95 7e f6
ab 6a 5c 88 ec 27 9d 72 3e a0 80 0c a5 ea d4 ff
```

Transport Layer Security (TLS)

(Enhances/Replaces SSL)



- Send new random value, list of supported ciphers
- Send pre-secret, encrypted under PK
- Create shared secret key from pre-secret and random
- Switch to new symmetric-key cipher using shared key

- Send new random value, digital certificate with PK
- Create shared secret key from pre-secret and random
- Switch to new symmetric-key cipher using shared key

Comments on HTTPS

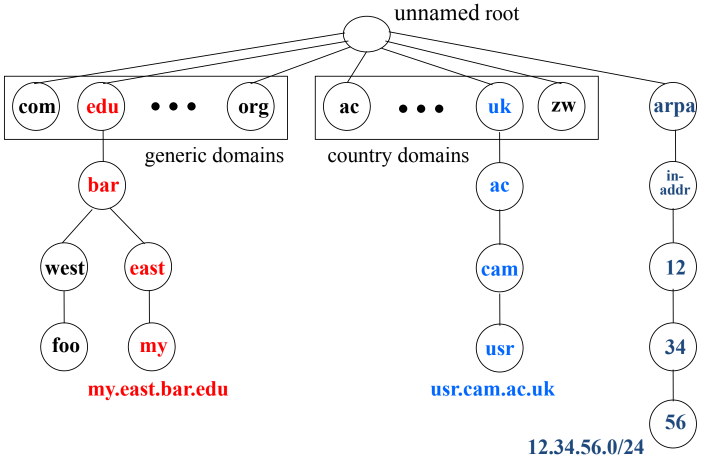
- Note that HTTPS authenticates server, not content
- Switch to symmetric-key crypto after public-key ops
  - Symmetric-key crypto much faster (100-1000x)
  - PK crypto can encrypt message only approx. as large as key (2048 bits – this is a simplification) – afterwards uses hybrid
- HTTPS on top of TCP, so reliable byte stream
  - Can leverage fact that transmission is reliable to ensure: each data segment received exactly once
  - Adversary can't successfully drop or replay packets

The trouble with CAs

- Browse/OS vendors pick which CAs to trust
  - Sometimes they revoke this trust – e.g. DigiNotar.
- No notion of CAs having authority over only given TLD
- Trust the {Iranian, Chinese, US} national authorities?
- What standards does Apple use to pick root certs? Google? MSFT?
  - There's a restraint-of-trade issue here. Can't enter the CA business without vendor support…

DNS Security

Hierarchical naming in DNS



DNS Integrity: Trust the TLD operators?

- If domain name doesn't exist, DNS should return NXDOMAIN (non-existant domain) msg
- Verisign instead creates wildcard DNS record for all .com and .net domain names not yet registered
  - September 15 – October 4, 2003
- Redirection for these domain names to Verisign web portal: "to help you search"
  - and serve you ads…and get "sponsored" search
  - Verisign and online advertising companies make money…

DNS Integrity: Answer from authoritative server?

- DNS cache poisoning
  - Client asks for www.evil.com
  - Nameserver authoritative for www.evil.com returns additional section for (www.cnn.com, 1.2.3.4, A)
  - Thanks! I won't bother check what I asked for

DNS Integrity: Answer from authoritative server?

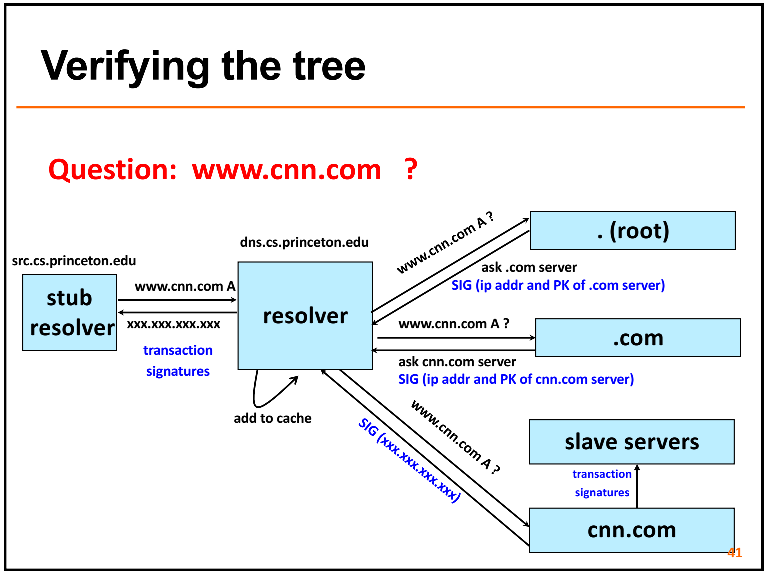
- To prevent cache poisoning, client remembers domain and 16-bit request ID (used to demux UDP response)
- But…DNS hijacking attack:
  - 16 bits: 65K possible IDs
    - What rate to enumerate all in 1 sec? 64B/packet
    - 64*65536*8 / 1024 / 1024 = 32 Mbps
  - Prevention: Also randomize the DNS source port
    - Windows DNS alloc's 2500 DNS ports: ~164M possible IDs
    - Would require 80 Gbps
    - Kaminsky attack: this source port…wasn't random after all

Let's strongly believe the answer! Enter DNSSEC

- DNSSEC protects against data spoofing and corruption
- DNSSEC also provides mechanisms to authenticate servers and requests
- DNSSEC provides mechanisms to establish authenticity and integrity

PK-DNSSEC (Public Key)

- The DNS servers sign the hash of resource record set with its private (signature) keys
- Public keys can be used to verify the SIGs
- Leverages hierarchy:
  - Authenticity of nameserver's public keys is established by a signature over the keys by the parent's private key
  - In ideal case, only roots' public keys need to be distributed out-of-band



Verifying the tree

Question: www.cnn.com ?

src.cs.princeton.edu

stub resolver

www.cnn.com A

xxx.xxx.xxx.xxx

transaction signatures

dns.cs.princeton.edu

resolver

add to cache

www.cnn.com A ?

. (root)

ask .com server

SIG (ip addr and PK of .com server)

www.cnn.com A ?

.com

ask cnn.com server

SIG (ip addr and PK of cnn.com server)

www.cnn.com A ?

SIG (xxx.xxx.xxx.xxx)

slave servers

transaction signatures

cnn.com