A couple more security goals

- Non-repudiation: principal cannot later deny having made a commitment
  - I.e., consider proving fact to a third party
- Forward secrecy: recovering later information does not reveal past information
  - Motivates using Diffie-Hellman to generate fresh keys for each session

Abstract protocols

- Outline of what information is communicated in messages
  - Omit most details of encoding, naming, sizes, choice of ciphers, etc.
- Describes honest operation
  - But must be secure against adversarial participants
- Seemingly simple, but many subtle problems

Protocol notation

A → B : N B ; f T 0 ; B; N B g K B
A → B : message sent from Alice intended for Bob
B (after :) : Bob's name
f g K : encryption with key K

Example: simple authentication

A → B : A; f A; N g K A
E.g., Alice is key fob, Bob is garage door
Alice proves she possesses the pre-shared key K A
Without revealing it directly
Using encryption for authenticity and binding, not secrecy

Nonce

N is a nonce: a value chosen to make a message unique
Best practice: pseudorandom
In constrained systems, might be a counter or device-unique serial number

Replay attacks

- A nonce is needed to prevent a verbatim replay of a previous message
- Garage door difficulty: remembering previous nonces
  - Particularly: lunchtime/roommate/valet scenario
- Or, door chooses the nonce: challenge-response authentication
**Man-in-the-middle attacks**
- Gender neutral: middleperson attack
- Adversary impersonates Alice to Bob and vice-versa, relays messages
- Powerful position for both eavesdropping and modification
- No easy fix if Alice and Bob aren't already related

**Chess grandmaster problem**
- Variant or dual of MITM
- Adversary forwards messages to simulate capabilities with his own identity
- How to win at correspondence chess
- Anderson's MiG-in-the-middle

**Outline**
- Cryptographic protocols, pt. 1
- Key distribution and PKI
- Announcements intermission
- SSH
- SSL/TLS
- DNSSEC

**Public key authenticity**
- Public keys don't need to be secret, but they must be right
- Wrong key → can't stop MITM
- So we still have a pretty hard distribution problem

**Symmetric key servers**
- Users share keys with server, server distributes session keys
- Symmetric key-exchange protocols, or channels
- Standard: Kerberos
- Drawback: central point of trust

**Certificates**
- A name and a public key, signed by someone else
  - $C_A = \text{Sign}_S(A; K_A)$
- Basic unit of transitive trust
- Commonly use a complex standard “X.509”

**Certificate authorities**
- “CA” for short: entities who sign certificates
- Simplest model: one central CA
- Works for a single organization, not the whole world

**Web of trust**
- Pioneered in PGP for email encryption
- Everyone is potentially a CA: trust people you know
- Works best with security-motivated users
  - Ever attended a key signing party?
CA hierarchies
- Organize CAs in a tree
- Distributed, but centralized (like DNS)
- Check by follow a path to the root
- Best practice: sub CAs are limited in what they certify

PKI for authorization
- Enterprise PKI can link up with permissions
- One approach: PKI maps key to name, ACL maps name to permissions
- Often better: link key with permissions directly, name is a comment
  - More like capabilities

The revocation problem
- How can we make certs “go away” when needed?
- Impossible without being online somehow
  1. Short expiration times
  2. Certificate revocation lists
  3. Certificate status checking

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Note to early readers
- This is the section of the slides most likely to change in the final version
- If class has already happened, make sure you have the latest slides for announcements

Short history of SSH
- Started out as freeware by Tatu Ylönen in 1995
- Original version commercialized
- Fully open-source OpenSSH from OpenBSD
- Protocol redesigned and standardized for “SSH 2”

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OpenSSH t-shirt
SSH host keys
- Every SSH server has a public/private keypair
- Ideally, never changes once SSH is installed
- Early generation a classic entropy problem
  - Especially embedded systems, VMs

Authentication methods
- Password, encrypted over channel
- `.ssh/hosts`: like `.rhosts`, but using client host key
- User-specific keypair
  - Public half on server, private on client
- Plugins for Kerberos, PAM modules, etc.

Old crypto vulnerabilities
- 1.x had only CRC for integrity
  - Worst case: when used with RC4
- Injection attacks still possible with CBC
  - CRC compensation attack
- For least-insecure 1.x-compatibility, attack detector
- Alas, detector had integer overflow worse than original attack

Newer crypto vulnerabilities
- IV chaining: IV based on last message ciphertext
  - Allows chosen plaintext attacks
  - Better proposal: separate, random IVs
- Some tricky attacks still left
  - Send byte-by-byte, watch for errors
  - Of arguable exploitability due to abort
- Now migrating to CTR mode

SSH over SSH
- SSH to machine 1, from there to machine 2
  - Common in these days of NATs
- Better: have machine 1 forward an encrypted connection (cf. HA1)
  1. No need to trust 1 for secrecy
  2. Timing attacks against password typing

SSH (non-)PKI
- When you connect to a host freshly, a mild note
- When the host key has changed, a large warning

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SSL/TLS
- Developed at Netscape in early days of the public web
  - Usable with other protocols too, e.g. IMAP
- SSL 1.0 pre-public, 2.0 lasted only one year, 3.0 much better
- Renamed to TLS with RFC process
  - TLS 1.0 improves SSL 3.0
- TLS 11 and 12 in 2006 and 2008, only gradual adoption
**IV chaining vulnerability**
- TLS 1.0 uses previous ciphertext for CBC IV
- But, easier to attack in TLS:
  - More opportunities to control plaintext
  - Can automatically repeat connection
- "BEAST" automated attack in 2011: TLS 1.1 wakeup call

**Compression oracle vuln.**
- \( \text{Compr}(S \ || \ A) \), where \( S \) should be secret and \( A \) is attacker-controlled
- Attacker observes ciphertext length
- If \( A \) is similar to \( S \), combination compresses better
- Compression exists separately in HTTP and TLS

**But wait, there's more!**
- Too many vulnerabilities to mention them all in lecture
- Kaloper-Meršinjak et al. have longer list
- "Lessons learned" are variable, though
- Meta-message: don't try this at home

**HTTPS hierarchical PKI**
- Browser has order of 100 root certs
  - Not same set in every browser
  - Standards for selection not always clear
- Many of these in turn have sub-CAs
- Also, "wildcard" certs for individual domains

**Hierarchical trust?**
- No. Any CA can sign a cert for any domain
- A couple of CA compromises recently
- Most major governments, and many companies you've never heard of, could probably make a google.com cert
- Still working on: make browser more picky, compare notes

**CA vs. leaf checking bug**
- Certs have a bit that says if they're a CA
- A couple of CA compromises recently
- Most major governments, and many companies you've never heard of, could probably make a google.com cert
- Still working on: make browser more picky, compare notes
- All but last entry in chain should have it set
- Browser authors repeatedly fail to check this bit
- Allows any cert to sign any other cert

**MD5 certificate collisions**
- MD5 collisions allow forging CA certs
- Create innocuous cert and CA cert with same hash
  - Requires some guessing what CA will do, like sequential serial numbers
  - Also 200 PS3s
- Oh, should we stop using that hash function?

**CA validation standards**
- CA's job to check if the buyer really is foo.com
- Race to the bottom problem:
  - CA has minimal liability for bad certs
  - Many people want cheap certs
  - Cost of validation cuts out of profit
- "Extended validation" (green bar) certs attempt to fix
HTTPS and usability

- Many HTTPS security challenges tied with user decisions
- Is this really my bank?
- Seems to be a quite tricky problem
  - Security warnings often ignored, etc.
  - We'll return to this as a major example later

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DNS: trusted but vulnerable

- Almost every higher-level service interacts with DNS
- UDP protocol with no authentication or crypto
  - Lots of attacks possible
- Problems known for a long time, but challenge to fix compatibly

DNSSEC goals and non-goals

+ Authenticity of positive replies
+ Authenticity of negative replies
+ Integrity
  - Confidentiality
  - Availability

First cut: signatures and certificates

- Each resource record gets an RRSIG signature
  - Eg, A record for one name—address mapping
  - Observe: signature often larger than data
  - Signature validation keys in DNSKEY RRs
  - Recursive chain up to the root (or other “anchor”)

Add more indirection

- DNS needs to scale to very large flat domains like .com
- Facilitated by having single DS RR in parent indicating delegation
- Chain to root now includes DSes as well

Negative answers

- Also don't want attackers to spoof non-existence
  - Gratuitous denial of service, force fallback, etc.
- But don't want to sign “x does not exist” for all x
- Solution 1, NSEC: “there is no name between acacia and baobab”

Preventing zone enumeration

- Many domains would not like people enumerating all their entries
- DNS is public, but “not that public”
- Unfortunately NSEC makes this trivial
- Compromise: NSEC3 uses password-like salt and repeated hash, allows opt-out
DANE: linking TLS to DNSSEC

- “DNS-based Authentication of Named Entities”
- DNS contains hash of TLS cert, don't need CAs
- How is DNSSEC's tree of certs better than TLS’s?

Signing the root

- Political problem: many already distrust US-centered nature of DNS infrastructure
- Practical problem: must be very secure with no single point of failure
- Finally accomplished in 2010
  - Solution involves 'key ceremonies', international committees, smart cards, safe deposit boxes, etc.

Deployment

- Standard deployment problem: all cost and no benefit to being first mover
- Servers working on it, mostly top-down
- Clients: still less than 20%
- Will probably be common for a while: insecure connection to secure resolver

What about privacy?

- Users increasingly want privacy for their DNS queries as well
- Older DNSCurve and DNSCrypt protocols were not standardized
- More recent "DNS over TLS" and "DNS over HTTPS" are RFCs
- DNS over HTTPS in major browsers might have serious centralization effects