Robot-in-the-middle attacks

- 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

Envelopes analogy

- Encrypt then sign, or vice-versa?
- On paper, we usually sign inside an envelope, not outside. Two reasons:
  - Attacker gets letter, puts in his own envelope (c.f. attack against X.509)
  - Signer claims “didn’t know what was in the envelope” (failure of non-repudiation)

Design robustness principles

- Use timestamps or nonces for freshness
- Be explicit about the context
- Don’t trust the secrecy of others’ secrets
- Whenever you sign or decrypt, beware of being an oracle
- Distinguish runs of a protocol

Implementation principles

- Ensure unique message types and parsing
- Design for ciphers and key sizes to change
- Limit information in outbound error messages
- Be careful with out-of-order messages
Random numbers and entropy

- Cryptographic RNGs use cipher-like techniques to provide indistinguishability
- But rely on truly random seeding to stop brute force
  - Extreme case: no entropy $\rightarrow$ always same “randomness”
- Modern best practice: seed pool with 256 bits of entropy
  - Suitable for security levels up to $2^{256}$

Netscape RNG failure

- Early versions of Netscape SSL (1994-1995) seeded with:
  - Time of day
  - Process ID
  - Parent process ID
- Best case entropy only 64 bits
  - (Not out of step with using 40-bit encryption)
- But worse because many bits guessable

Debian/OpenSSL RNG failure (1)

- OpenSSL has pretty good scheme using /dev/urandom
- Also mixed in some uninitialized variable values
  - “Extra variation can’t hurt”
- From modern perspective, this was the original sin
  - Remember undefined behavior discussion?
- But had no immediate ill effects

Debian/OpenSSL RNG failure (2)

- Debian maintainer commented out some lines to fix a Valgrind warning
  - “Potential use of uninitialized value”
- Accidentally disabled most entropy (all but 16 bits)
- Brief mailing list discussion didn’t lead to understanding
- Broken library used for ~2 years before discovery

Detected RSA/DSA collisions

- Up to about 1% of the SSL and SSH keys on the public net are breakable
  - Some sites share complete keypairs
  - RSA keys with one prime in common (detected by large-scale GCD)
- One likely culprit: insufficient entropy in key generation
  - Embedded devices, Linux /dev/urandom vs. /dev/random
- DSA signature algorithm also very vulnerable
Side-channel attacks
- Timing analysis:
  - Number of 1 bits in modular exponentiation
  - Unpadding, MAC checking, error handling
  - Probe cache state of AES table entries
- Power analysis
  - Especially useful against smartcards
- Fault injection
- Data non-erasure
  - Hard disks, “cold boot” on RAM

WEP “privacy”
- First WiFi encryption standard: Wired Equivalent Privacy (WEP)
- F&S: designed by a committee that contained no cryptographers
- Problem 1: note “privacy”: what about integrity?
  - Nope: stream cipher + CRC = easy bit flipping

WEP shared key
- Single key known by all parties on network
- Easy to compromise
- Hard to change
- Also often disabled by default
- Example: a previous employer

WEP key size and IV size
- Original sizes: 40-bit shared key (export restrictions) plus 24-bit IV = 64-bit RC4 key
  - Both too small
- 128-bit upgrade kept 24-bit IV
  - Vague about how to choose IVs
  - Least bad: sequential, collision takes hours
  - Worse: random or everyone starts at zero

WEP RC4 related key attacks
- Only true crypto weakness
- RC4 “key schedule” vulnerable when:
  - RC4 keys very similar (e.g., same key, similar IV)
  - First stream bytes used
- Not a practical problem for other RC4 users like SSL
  - Key from a hash, skip first output bytes

Trustworthiness of primitives
- Classic worry: DES S-boxes
- Obviously in trouble if cipher chosen by your adversary
- In a public spec, most worrying are unexplained elements
- Best practice: choose constants from well-known math, like digits of π
### Dual_EC_DRBG (1)
- Pseudorandom generator in NIST standard, based on elliptic curve
- Looks like provable (slow enough!) but strangely no proof
- Specification includes long unexplained constants
- Academic researchers find:
  - Some EC parts look good
  - But outputs are statistically distinguishable

### Dual_EC_DRBG (2)
- Found 2007: special choice of constants allows prediction attacks
  - Big red flag for paranoid academics
- Significant adoption in products sold to US govt. FIPS-140 standards
  - Semi-plausible rationale from RSA (EMC)
- NSA scenario basically confirmed recently by Snowden leaks
  - NIST and RSA immediately recommend withdrawal

### Outline
- Cryptographic protocols, cont’d
- More causes of crypto failure
- Key distribution and PKI
- HW1 debrief
- 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
- 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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BCVS vulnerabilities

- Type 1: Buffer overflows and similar
  - Some easy to spot, but hard to exploit
- Type 2: Logic errors in running programs, file accesses, etc.
  - Usually easier to exploit once found

BCVS exploiting overflows

- Make sure control flow reaches the return
- Compensate for collateral damage
- Find your shellcode
- Writing shellcode

BCVS design changes

- Avoid unnecessary changes to benign functionality
  - Restricting length or character sets of arguments
  - Though, what is the benign functionality?
- Not a great candidate for privilege separation

Final crypto textbook show and tell

- Paar and Pelzl, Understanding Cryptography
- A real textbook, but pretty practical
- Gives full details of DES and AES, for instance

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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”
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/authorized_keys`: 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. HW1)
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

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!  
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now
(man-in-the-middle attack)!
It is also possible that a host key has just been changed.

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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 1.1 and 1.2 in 2006 and 2008, only gradual adoption

IV chaining vulnerability
Like SSH, TLS 1.0 uses old 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.
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
Meyer and Schwenk 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
- 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
  - E.g., 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 10%
- Will be probably common: insecure connection to secure resolver

Next time
- Web security, server side