CSci 5271
Introduction to Computer Security
Web/crypto/middleboxes combined slides

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Outline

HTTP header injection

- Untrusted data included in response headers
- Can include CRLF and new headers, or premature end to headers
- AKA "response splitting"

Content sniffing

- Browsers determine file type from headers, extension, and content-based guessing
  - Latter two for ~ 1% server errors
- Many sites host "untrusted" images and media
- Inconsistencies in guessing lead to a kind of XSS
  - E.g., "chimera" PNG-HTML document

Cross-site request forgery

- Certain web form on `bank.com` used to wire money
- Link or script on `evil.com` loads it with certain parameters
  - Linking is exception to same-origin
- If I'm logged in, money sent automatically
- Confused deputy, cookies are ambient authority

CSRF prevention

- Give site's forms random-nonce tokens
  - E.g., in POST hidden fields
  - Not in a cookie, that's the whole point
- Reject requests without proper token
  - Or, ask user to re-authenticate
- XSS can be used to steal CSRF tokens

Open redirects

- Common for one page to redirect clients to another
- Target should be validated
  - With authentication check if appropriate
- *Open redirect*: target supplied in parameter with no checks
  - Doesn't directly hurt the hosting site
  - But reputation risk, say if used in phishing
  - We teach users to trust by site

Misconfiguration problems

- Default accounts
- Unneeded features
- Framework behaviors
  - Don't automatically create variables from query fields

Openness tradeoffs

- Error reporting
  - Few benign users want to see a stack backtrace
- Directory listings
  - Hallmark of the old days
- Readable source code of scripts
  - Doesn't have your DB password in it, does it?

Using vulnerable components

- Large web apps can use a lot of third-party code
- Convenient for attackers too
  - OWASP: two popular vulnerable components downloaded 22m times
- Hiding doesn't work if it's popular
- Stay up to date on security announcements

Clickjacking

- Fool users about what they're clicking on
  - Circumvent security confirmations
  - Fabricate ad interest
- Example techniques:
  - Frame embedding
  - Transparency
  - Spoof cursor
  - Temporal "bait and switch"

Crawling and scraping

- A lot of web content is free-of-charge, but proprietary
  - Yours in a certain context, if you view ads, etc.
- Sites don't want it downloaded automatically (*web crawling*)
- Or parsed and user for another purpose (*screen scraping*)
- High-rate or honest access detectable

Outline

More web risks

Confidentiality and privacy

Announcements intermission

More crypto protocols

More causes of crypto failure

Firewalls and NAT boxes

Intrusion detection systems

Site perspective

- Protect confidentiality of authenticators
  - Passwords, session cookies, CSRF tokens
- Duty to protect some customer info
  - Personally identifying info ("identity theft")
  - Credit-card info (Payment Card Industry Data Security Standards)
  - Health care (HIPAA), education (FERPA)
  - Whatever customers reasonably expect

You need to use SSL

- Finally coming around to view that more sites need to support HTTPS
  - Special thanks to WiFi, NSA
- If you take credit cards (of course)
- If you ask users to log in
  - Must be protecting something, right?
  - Also important for users of Tor et al.

Server-side encryption

- Also consider encrypting data "at rest"
- (Or, avoid storing it at all)
- Provides defense in depth
  - Reduce damage after another attack
- May be hard to truly separate keys
  - OWASP example: public key for website $\rightarrow$ backend credit card info

Adjusting client behavior

- HTTPS and `password` fields are basic hints
- Consider disabling autocomplete
  - Usability tradeoff, save users from themselves
  - Finally standardized in HTML5
- Consider disabling caching
  - Performance tradeoff
  - Better not to have this on user's disk
  - Or proxy? You need SSL

User vs. site perspective

- User privacy goals can be opposed to site goals
- Such as in tracking for advertisements
- Browser makers can find themselves in the middle
  - Of course, differ in institutional pressures

Third party content / web bugs

- Much tracking involves sites other than the one in the URL bar
  - For fun, check where your cookies are coming from
- Various levels of cooperation
- *Web bugs* are typically 1x1 images used only for tracking

Cookies arms race

- Privacy-sensitive users like to block and/or delete cookies
- Sites have various reasons to retain identification
- Various workarounds:
  - Similar features in Flash and HTML5
  - Various channels related to the cache
  - *Evercookie*: store in n places, regenerate if subset are deleted

Browser fingerprinting

- Combine various server or JS-visible attributes passively
  - User agent string (10 bits)
  - Window/screen size (4.83 bits)
  - Available fonts (13.9 bits)
  - Plugin verions (15.4 bits)

(Data from `panopticlick.eff.org`, far from exhaustive)

History stealing

- History of what sites you've visited is not supposed to be JS-visible
- But, many side-channel attacks have been possible
  - Query link color
  - CSS style with external image for visited links
  - Slow-rendering timing channel
  - Harvesting bitmaps
  - User perception (e.g. fake CAPTCHA)

Browser and extension choices

- More aggressive privacy behavior lives in extensions
  - Disabling most JavaScript (NoScript)
  - HTTPS Everywhere (whitelist)
  - Tor Browser Bundle
- Default behavior is much more controversial
  - Concern not to kill advertising support as an economic model

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Upcoming events

- Inidividual progress reports due tonight
- Exercise set 4 out, due next Wednesday
- Project meetings next week
- HA2 due a week from Friday

Outline

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

$A \to B : N_B, \{T_0, B, N_B\}_{K_B}$

- $A \to B$: message sent from Alice intended for Bob
- B (after :): Bob's name
- $\{\cdots\}_K$: encryption with key K

Needham-Schroeder

Mutual authentication via nonce exchange, assuming public keys (core):

$$\begin{aligned} A \to B &: \{N_A, A\}_{E_B} \\ B \to A &: \{N_A, N_B\}_{E_A} \\ A \to B &: \{N_B\}_{E_B} \end{aligned}$$

Needham-Schroeder MITM

$$\begin{aligned} A \to C &: \{N_A, A\}_{E_C} \\ C \to B &: \{N_A, A\}_{E_B} \\ B \to C &: \{N_A, N_B\}_{E_A} \\ C \to A &: \{N_A, N_B\}_{E_A} \\ A \to C &: \{N_B\}_{E_C} \\ C \to B &: \{N_B\}_{E_B} \end{aligned}$$

Certificates, Denning-Sacco

- A certificate signed by a trusted third-party S binds an identity to a public key
  - $C_A = \text{Sign}_S(A, K_A)$
- Suppose we want to use S in establishing a session key K_{AB}:

$$\begin{aligned} A \to S &: A, B \\ S \to A &: C_A, C_B \\ A \to B &: C_A, C_B, \{\text{Sign}_A(K_{AB})\}_{K_B} \end{aligned}$$

Attack against Denning-Sacco

$$\begin{aligned} A \to S &: A, B \\ S \to A &: C_A, C_B \\ A \to B &: C_A, C_B, \{\text{Sign}_A(K_{AB})\}_{K_B} \\ \hline B \to S &: B, C \\ S \to B &: C_B, C_C \\ B \to C &: C_A, C_C, \{\text{Sign}_A(K_{AB})\}_{K_C} \end{aligned}$$

By re-encrypting the signed key, Bob can pretend to be Alice to Charlie

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

Outline

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 → 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

- 2012: around 1% of the SSL 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

New problem with WPA (CCS'17)

- Session key set up in a 4-message handshake
- Key reinstallation attack: replay #3
  - Causes most implementations to reset nonce and replay counter
  - In turn allowing many other attacks
  - One especially bad case: reset key to 0
- Protocol state machine behavior poorly described in spec
  - Outside the scope of previous security proofs

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 by Snowden leaks
  - NIST and RSA immediately recommend withdrawal

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Internet addition: middleboxes

- Original design: middle of net is only routers
  - End-to-end principle
- Modern reality: more functionality in the network
- Security is one major driver

Security/connectivity tradeoff

- A lot of security risk comes from a network connection
  - Attacker could be anywhere in the world
- Reducing connectivity makes security easier
- Connectivity demand comes from end users

What a firewall is

- Basically, a router that chooses not to forward some traffic
  - Based on an a-priori policy
- More complex architectures have multiple layers
  - *DMZ*: area between outer and inner layers, for outward-facing services

Inbound and outbound control

- Most obvious firewall use: prevent attacks from the outside
- Often also some control of insiders
  - Block malware-infected hosts
  - Employees wasting time on Facebook
  - Selling sensitive info to competitors
  - Nation-state Internet management
- May want to log or rate-limit, not block

Default: deny

- Usual whitelist approach: first, block everything
- Then allow certain traffic
- Basic: filter packets based on headers
- More sophisticated: *proxy* traffic at a higher level

IPv4 address scarcity

- Design limit of 2^{32} hosts
  - Actually less for many reasons
- Addresses becoming gradually more scarce over a many-year scale
- Some high-profile exhaustions in 2011
- IPv6 adoption still quite low, occasional signs of progress

Network address translation (NAT)

- Middlebox that rewrites addresses in packets
- Main use: allow inside network to use non-unique IP addresses
  - RFC 1918: 10.*, 192.168.*, etc.
  - While sharing one outside IP address
- Inside hosts not addressable from outside
  - De-facto firewall

Packet filtering rules

- Match based on:
  - Source IP address
  - Source port
  - Destination IP address
  - Destination port
  - Packet flags: TCP vs. UDP, TCP ACK, etc.
- Action, e.g. allow or block
- Obviously limited in specificity

Client and server ports

- TCP servers listen on well-known port numbers
  - Often $<$ 1024, e.g. 22 for SSH or 80 for HTTP
- Clients use a kernel-assigned random high port
- Plain packet filter would need to allow all high-port incoming traffic

Stateful filtering

- In general: firewall rules depend on previously-seen traffic
- Key instance: allow replies to an outbound connection
- See: port 23746 to port 80
- Allow incoming port 23746
  - To same inside host
- Needed to make a NAT practical

Circuit-level proxying

- Firewall forwards TCP connections for inside client
- Standard protocol: SOCKS
  - Supported by most web browsers
  - Wrapper approaches for non-aware apps
- Not much more powerful than packet-level filtering

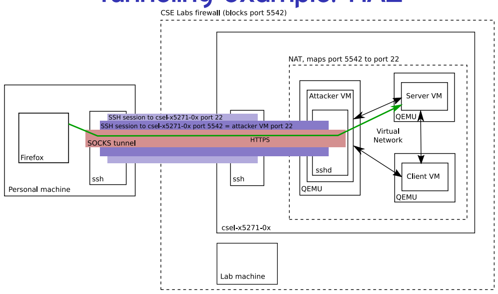
Application-level proxying

- Knows about higher-level semantics
- Long history for, e.g., email, now HTTP most important
- More knowledge allows better filtering decisions
  - But, more effort to set up
- Newer: "transparent proxy"
  - Pretty much a man-in-the-middle

Tunneling

- Any data can be transmitted on any channel, if both sides agree
- E.g., encapsulate IP packets over SSH connection
  - Compare covert channels, steganography
- Powerful way to subvert firewall
  - Some legitimate uses

Tunneling example: HA2



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Basic idea: detect attacks

- The worst attacks are the ones you don't even know about
- Best case: stop before damage occurs
  - Marketed as "prevention"
- Still good: prompt response
- Challenge: what is an attack?

Network and host-based IDSes

- Network IDS: watch packets similar to firewall
  - But don't know what's bad until you see it
  - More often implemented offline
- Host-based IDS: look for compromised process or user from within machine

Signature matching

- *Signature* is a pattern that matches known bad behavior
- Typically human-curated to ensure specificity
- See also: anti-virus scanners

Anomaly detection

- Learn pattern of normal behavior
- "Not normal" is a sign of a potential attack
- Has possibility of finding novel attacks
- Performance depends on normal behavior too

Recall: FPs and FNs

- False positive: detector goes off without real attack
- False negative: attack happens without detection
- Any detector design is a tradeoff between these (ROC curve)

Signature and anomaly weaknesses

- Signatures
  - Won't exist for novel attacks
  - Often easy to attack around
- Anomaly detection
  - Hard to avoid false positives
  - Adversary can train over time

Base rate problems

- If the true incidence is small (low base rate), most positives will be false
  - Example: screening test for rare disease
- Easy for false positives to overwhelm admins
- E.g., 100 attacks out of 10 million packets, 0.01% FP rate
  - How many false alarms?

Adversarial challenges

- FP/FN statistics based on a fixed set of attacks
- But attackers won't keep using techniques that are detected
- Instead, will look for:
  - Existing attacks that are not detected
  - Minimal changes to attacks
  - Truly novel attacks

Wagner and Soto mimicry attack

- Host-based IDS based on sequence of syscalls
- Compute $A \cap M$, where:
  - A models allowed sequences
  - M models sequences achieving attacker's goals
- Further techniques required:
  - Many syscalls made into NOPs
  - Replacement subsequences with similar effect

Next time

- Malware and network denial of service