CSci 5271
Introduction to Computer Security
OS defensive design and security basics

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Preview question

In the Unix access control model, subjects are primarily identified by their:

A. email address
B. username
C. executable inode
D. program name
E. UID

Outline

Be careful with temporary files

- Create files exclusively with tight permissions and never reopen them
  - See detailed recommendations in Wheeler
- Not quite good enough: reopen and check matching device and inode
  - Fails with sufficiently patient attack

Give up privileges

- Using appropriate combinations of `set*id` functions
  - Alas, details differ between Unix variants
- Best: give up permanently
- Second best: give up temporarily
- Detailed recommendations: Setuid Demystified (USENIX'02)

Whitelist environment variables

- Can change the behavior of called program in unexpected ways
- Decide which ones are necessary
  - As few as possible
- Save these, remove any others

Outline

Historical background

- Traditional Unix MTA: Sendmail (BSD)
  - Monolithic setuid root program
  - Designed for a more trusting era
  - In mid-90s, bugs seemed endless
- Spurred development of new, security-oriented replacements
  - Bernstein's qmail
  - Venema et al.'s Postfix

Distinctive qmail features

- Single, security-oriented developer
- Architecture with separate programs and UIDs
- Replacements for standard libraries
- Deliveries into directories rather than large files

Ineffective privilege separation

- Example: prevent Netscape DNS helper from accessing local file system
- Before: bug in DNS code
  - → read user's private files
- After: bug in DNS code
  - → inject bogus DNS results
  - → man-in-the-middle attack
  - → read user's private web data

Effective privilege separation

- Transformations with constrained I/O
- General argument: worst adversary can do is control output
  - Which is just the benign functionality
- MTA header parsing (Sendmail bug)
- `jpegtopnm` inside `xloadimage`

Eliminating bugs

- Enforce explicit data flow
- Simplify integer semantics
- Avoid parsing
- Generalize from errors to inputs

Eliminating code

- Identify common functions
- Automatically handle errors
- Reuse network tools
- Reuse access controls
- Reuse the filesystem

The "qmail security guarantee"

- $500, later $1000 offered for security bug
- Never paid out
- Issues proposed:
  - Memory exhaustion DoS
  - Overflow of signed integer indexes
- Defensiveness does not encourage more submissions

qmail today

- Originally had terms that prohibited modified redistribution
  - Now true public domain
- Latest release from Bernstein: 1998; netqmail: 2007
- Does not have large market share
- All MTAs, even Sendmail, are more secure now

Outline

Restricted languages

- Main application: code provided by untrusted parties
- Packet filters in the kernel
- JavaScript in web browsers
  - Also Java, Flash ActionScript, etc.

SFI

- Software-based Fault Isolation
- Instruction-level rewriting like (but predates) CFI
- Limit memory stores and sometimes loads
- Can't jump out except to designated points
- E.g., Google Native Client

Separate processes

- OS (and hardware) isolate one process from another
- Pay overhead for creation and communication
- System call interface allows many possibilities for mischief

System-call interposition

- Trusted process examines syscalls made by untrusted
- Implement via `ptrace` (like strace, gdb) or via kernel change
- Easy policy: deny

Interposition challenges

- Argument values can change in memory (TOCTTOU)
- OS objects can change (TOCTTOU)
- How to get canonical object identifiers?
- Interposer must accurately model kernel behavior
- Details: Garfinkel (NDSS'03)

Separate users

- Reuse OS facilities for access control
- Unit of trust: program or application
- Older example: qmail
- Newer example: Android
- Limitation: lots of things available to any user

`chroot`

- Unix system call to change root directory
- Restrict/virtualize file system access
- Only available to root
- Does not isolate other namespaces

OS-enabled containers

- One kernel, but virtualizes all namespaces
- FreeBSD jails, Linux LXC, Solaris zones, etc.
- Quite robust, but the full, fixed, kernel is in the TCB

(System) virtual machines

- Presents hardware-like interface to an untrusted kernel
- Strong isolation, full administrative complexity
- I/O interface looks like a network, etc.

Virtual machine designs

- (Type 1) hypervisor: 'superkernel' underneath VMs
- Hosted: regular OS underneath VMs
- Paravirtualizaion: modify kernels in VMs for ease of virtualization

Virtual machine technologies

- Hardware based: fastest, now common
- Partial translation: e.g., original VMware
- Full emulation: e.g. QEMU proper
  - Slowest, but can be a different CPU architecture

Modern example: Chrom(ium)

- Separates "browser kernel" from less-trusted "rendering engine"
  - Pragmatic, keeps high-risk components together
- Experimented with various Windows and Linux sandboxing techniques
- Blocked 70% of historic vulnerabilities, not all new ones
- `http://seclab.stanford.edu/websec/chromium/`

Outline

Secure use of the OS, cont'd
Bernstein's perspective
Techniques for privilege separation
OS security: protection and isolation
OS security: authentication
Basics of access control
Unix-style access control

OS security topics

- Resource protection
- Process isolation
- User authentication
- Access control

Protection and isolation

- Resource protection: prevent processes from accessing hardware
- Process isolation: prevent processes from interfering with each other
- Design: by default processes can do neither
- Must request access from operating system

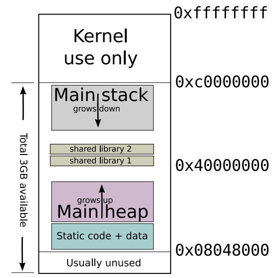
Reference monitor

- Complete mediation: all accesses are checked
- Tamperproof: the monitor is itself protected from modification
- Small enough to be thoroughly verified

Hardware basis: memory protection

- Historic: segments
- Modern: paging and page protection
  - Memory divided into pages (e.g. 4k)
  - Every process has own virtual to physical page table
  - Pages also have R/W/X permissions

Linux 32-bit example



Hardware basis: supervisor bit

- Supervisor (kernel) mode: all instructions available
- User mode: no hardware or VM control instructions
- Only way to switch to kernel mode is specified entry point
- Also generalizes to multiple "rings"

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Authentication factors

- Something you know (password, PIN)
- Something you have (e.g., smart card)
- Something you are (biometrics)
- CAPTCHAs, time and location, ...
- Multi-factor authentication

Passwords: love to hate

- Many problems for users, sysadmins, researchers
- But familiar and near-zero cost of entry
- User-chosen passwords proliferate for low-stakes web site authentication

Password entropy

- Model password choice as probabilistic process
- If uniform, $\log_2 |S|$
- Controls difficulty of guessing attacks
- Hard to estimate for user-chosen passwords
  - Length is an imperfect proxy

Password hashing

- Idea: don't store password or equivalent information
- Password 'encryption' is a long-standing misnomer
  - E.g., Unix `crypt(3)`
- Presumably hard-to-invert function h
- Store only $h(p)$

Dictionary attacks

- Online: send guesses to server
- Offline: attacker can check guesses internally
- Specialized password lists more effective than literal dictionaries
  - Also generation algorithms (s $\rightarrow$ \$, etc.)
- ~25% of passwords consistently vulnerable

Better password hashing

- Generate random salt s, store $(s, h(s, p))$
  - Block pre-computed tables and equality inferences
  - Salt must also have enough entropy
- Deliberately expensive hash function
  - AKA password-based key derivation function (PBKDF)
  - Requirement for time and/or space

Password usability

- User compliance can be a major challenge
  - Often caused by unrealistic demands
- Distributed random passwords usually unrealistic
- Password aging: not too frequently
- Never have a fixed default password in a product

Backup authentication

- Desire: unassisted recovery from forgotten password
- Fall back to other presumed-authentic channel
  - Email, cell phone
- Harder to forget (but less secret) shared information
  - Mother's maiden name, first pet's name
- Brittle: ask Sarah Palin or Mat Honan

Centralized authentication

- Enterprise-wide (e.g., UMN ID)
- Anderson: Microsoft Passport
- Today: Facebook Connect, Google ID
- May or may not be single-sign-on (SSO)

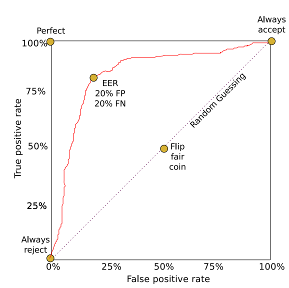
Biometric authentication

- Authenticate by a physical body attribute
- \+ Hard to lose
- — Hard to reset
- — Inherently statistical
- — Variation among people

Example biometrics

- (Handwritten) signatures
- Fingerprints, hand geometry
- Face and voice recognition
- Iris codes

Error rates: ROC curve



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- OS security: authentication
- **Basics of access control**
- Unix-style access control

Mechanism and policy

- Decision-making aspect of OS
- Should subject S (user or process) be allowed to access object (e.g., file) O?
- Complex, since admin must specify what should happen

Access control matrix

	grades.txt	/dev/hda	/usr/bin/bcvi
Alice	r	rw	rx
Bob	rw	-	rx
Carol	r	-	rx

Slicing the matrix

- $O(nm)$ matrix impractical to store, much less administer
- Columns: access control list (ACL)
  - Convenient to store with object
  - E.g., Unix file permissions
- Rows: capabilities
  - Convenient to store by subject
  - E.g., Unix file descriptors

Groups/roles

- Simplify by factoring out commonality
- Before: users have permissions
- After: users have roles, roles have permissions
- Simple example: Unix groups
- Complex versions called role-based access control (RBAC)

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UIDs and GIDs

- To kernel, users and groups are just numeric identifiers
- Names are a user-space nicety
  - E.g., `/etc/passwd` mapping
- Historically 16-bit, now 32
- User 0 is the special superuser `root`
  - Exempt from all access control checks

File mode bits

- Core permissions are 9 bits, three groups of three
- Read, write, execute for user, group, other
- `ls` format: `rwx r-x r--`
- Octal format: 0754

Interpretation of mode bits

- File also has one user and group ID
- Choose one set of bits
  - If users match, use user bits
  - If subject is in the group, use group bits
  - Otherwise, use other bits
- Note no fallback, so can stop yourself or have negative groups
  - But usually, $O \subseteq G \subseteq U$

Directory mode bits

- Same bits, slightly different interpretation
- Read: list contents (e.g., `ls`)
- Write: add or delete files
- Execute: traverse
- X but not R means: have to know the names

Process UIDs and `setuid(2)`

- UID is inherited by child processes, and an unprivileged process can't change it
- But there are syscalls root can use to change the UID, starting with `setuid`
- E.g., login program, SSH server

Setuid programs, different UIDs

- If 04000 "setuid" bit set, newly exec'd process will take UID of its file owner
  - Other side conditions, like process not traced
- Specifically the *effective UID* is changed, while the *real UID* is unchanged
  - Shows who called you, allows switching back

More different UIDs

- Two mechanisms for temporary switching:
  - Swap real UID and effective UID (BSD)
  - Remember *saved UID*, allow switching to it (System V)
- Modern systems support both mechanisms at the same time
- Linux only: *file-system UID*
  - Once used for NFS servers, now mostly obsolete

Setgid, games

- Setgid bit 02000 mostly analogous to setuid
- But note no supergroup, so UID 0 is still special
- Classic application: setgid `games` for managing high-score files

Special case: `/tmp`

- We'd like to allow anyone to make files in `/tmp`
- So, everyone should have write permission
- But don't want Alice deleting Bob's files
- Solution: "sticky bit" 01000

Special case: group inheritance

- When using group to manage permissions, want a whole tree to have a single group
- When 02000 bit set, newly created entries with have the parent's group
  - (Historic BSD behavior)
- Also, directories will themselves inherit 02000

Other permission rules

- Only file owner or root can change permissions
- Only root can change file owner
  - Former System V behavior: "give away `chown`"
- Setuid/gid bits cleared on `chown`
  - Set owner first, then enable setuid

Non-checks

- File permissions on `stat`
- File permissions on link, unlink, rename
- File permissions on read, write
- Parent directory permissions generally
  - Except traversal
  - I.e., permissions not automatically recursive

"POSIX" ACLs

- Based on a withdrawn standardization
- More flexible permissions, still fairly Unix-like
- Multiple user and group entries
  - Decision still based on one entry
- Default ACLs: generalize group inheritance
- Command line: `getfacl`, `setfacl`

ACL legacy interactions

- Hard problem: don't break security of legacy code
  - Suggests: "fail closed"
- Contrary pressure: don't want to break functionality
  - Suggests: "fail open"
- POSIX ACL design: old group permission bits are a mask on all novel permissions

"POSIX" "capabilities"

- Divide root privilege into smaller ($\sim$35) pieces
- Note: not real capabilities
- First runtime only, then added to FS similar to setuid
- Motivating example: `ping`
- Also allows permanent disabling

Privilege escalation dangers

- Many pieces of the root privilege are enough to regain the whole thing
  - Access to files as UID 0
  - `CAP_DAC_OVERRIDE`
  - `CAP_FOWNER`
  - `CAP_SYS_MODULE`
  - `CAP_MKNOD`
  - `CAP_PTRACE`
  - `CAP_SYS_ADMIN` (`mount`)

Legacy interaction dangers

- Former bug: take away capability to drop privileges
- Use of temporary files by no-longer setuid programs
- For more details: "Exploiting capabilities", Emeric Nasi

Next time

- Object capability systems
- Mandatory access control
- Information-flow security