Outline

OS security: protection and isolation
OS security: authentication
Announcements intermission
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

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**Linux 32-bit example**

![Linux 32-bit example diagram]

**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 (\( s \rightarrow s \), 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

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Error rates: ROC curve

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
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

<table>
<thead>
<tr>
<th></th>
<th>grades.txt</th>
<th>/dev/hda</th>
<th>/usr/bin/bcvi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alice</td>
<td>r</td>
<td>rw</td>
<td>rx</td>
</tr>
<tr>
<td>Bob</td>
<td>rw</td>
<td>-</td>
<td>rx</td>
</tr>
<tr>
<td>Carol</td>
<td>r</td>
<td>-</td>
<td>rx</td>
</tr>
</tbody>
</table>

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 (~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