CSci 5271
Introduction to Computer Security
Day 10: OS security: access control

Stephen McCamant
University of Minnesota, Computer Science & Engineering

Outline

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 → $, 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)

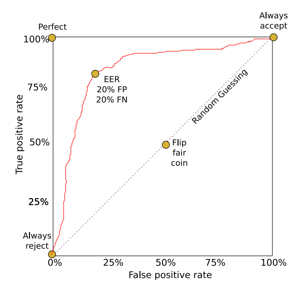
Biometric authentication

- 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



Outline

- OS security: authentication
- Basics of access control
- Announcements intermission
- Unix-style access control
- Multilevel and mandatory access control
- Capability-based 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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Project updates

- I met last week with every group who submitted a pre-proposal on time
- Next step, due Wednesday night, is individual project reports
- For the next cycle the meetings will be a bit earlier

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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

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MAC vs. DAC

- Discretionary access control (DAC)
  - Users mostly decide permissions on their own files
  - If you have information, you can pass it on to anyone
  - E.g., traditional Unix file permissions
- Mandatory access control (MAC)
  - Restrictions enforced regardless of subject choices
  - Typically specified by an administrator

Motivation: it's classified

- Government defense and intelligence agencies use *classification* to restrict access to information
- E.g.: Unclassified, Confidential, Secret, Top Secret
- Multilevel Secure (MLS) systems first developed to support mixing classification levels under timesharing

Motivation: system integrity

- Limit damage if a network server application is compromised
  - Unix DAC is no help if server is root
- Limit damage from browser-downloaded malware
  - Windows DAC is no help if browser is "administrator" user

Bell-LaPadula, linear case

- State-machine-like model developed for US DoD in 1970s

1. A subject at one level may not read a resource at a higher level
   - Simple security property, "no read up"
2. A subject at one level may not write a resource at a lower level
   - * property, "no write down"

High watermark property

- Dynamic implementation of BLP
- Process has security level equal to highest file read
- Written files inherit this level

Biba and low watermark

- Inverting a confidentiality policy gives an integrity one
- Biba: no write up, no read down
- Low watermark policy
- BLP $\wedge$ Biba $\Rightarrow$ levels are isolated

Information-flow perspective

- Confidentiality: secret data should not flow to public sinks
- Integrity: untrusted data should not flow to critical sinks
- Watermark policies are process-level conservative abstractions

Covert channels

- Problem: conspiring parties can misuse other mechanisms to transmit information
- Storage channel: writable shared state
  - E.g., screen brightness on mobile phone
- Timing channel: speed or ordering of events
  - E.g., deliberately consume CPU time

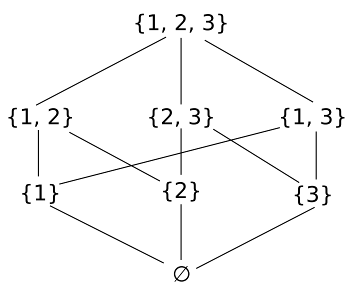
Multilateral security / compartments

- In classification, want finer divisions based on need-to-know
- Also, selected wider sharing (e.g., with allied nations)
- Many other applications also have this character
  - Anderson's example: medical data
- How to adapt BLP-style MAC?

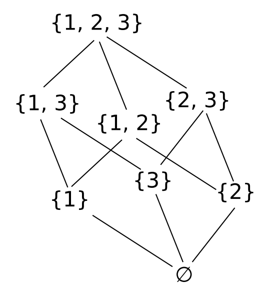
Partial orders and lattices

- $\leq$ on integers is a *total order*
  - Reflexive, antisymmetric, transitive, $a \leq b$ or $b \leq a$
- Dropping last gives a *partial order*
- A *lattice* is a partial order plus operators for:
  - Least upper bound or join $\sqcup$
  - Greatest lower bound or meet $\sqcap$
- Example: subsets with $\subseteq$, $\cup$, $\cap$

Subset lattice example



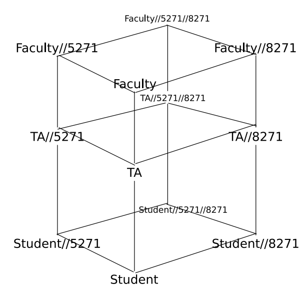
Subset lattice example



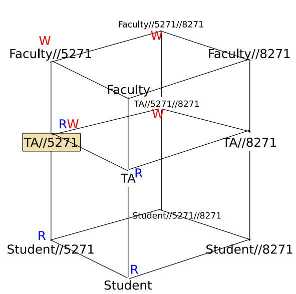
Lattice model

- Generalize MLS levels to elements in a lattice
- BLP and Biba work analogously with lattice ordering
- No access to incomparable levels
- Potential problem: combinatorial explosion of compartments

Classification lattice example



Lattice BLP example



Another notation

Faculty

$\rightarrow$ (Faculty, $\emptyset$)

Faculty//5271

$\rightarrow$ (Faculty, $\{5271\}$)

Faculty//5271//8271

$\rightarrow$ (Faculty, $\{5271, 8271\}$)

MLS operating systems

- 1970s timesharing, including Multics
- "Trusted" versions of commercial Unix (e.g. Solaris)
- SELinux (called "type enforcement")
- Integrity protections in Windows Vista and later

Multi-VM systems

- One (e.g., Windows) VM for each security level
- More trustworthy OS underneath provides limited interaction
- E.g., NSA NetTop: VMWare on SELinux
- Downside: administrative overhead

Air gaps, pumps, and diodes

- The lack of a connection between networks of different levels is called an *air gap*
- A *pump* transfers data securely from one network to another
- A *data diode* allows information flow in only one direction

Chelsea Manning cables leak

- Manning was an intelligence analyst deployed to Iraq
- PC in a T-SCIF connected to SIPRNet (Secret), air gapped
- CD-RWs used for backup and software transfer
- Contrary to policy: taking such a CD-RW home in your pocket `http://www.fas.org/sgp/jud/manning/022813-statement.pdf`

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ACLs: no fine-grained subjects

- Subjects are a list of usernames maintained by a sysadmin
- Unusual to have a separate subject for an application
- Cannot easily subset access (sandbox)

ACLs: ambient authority

- All authority exists by virtue of identity
- Kernel automatically applies all available authority
- Authority applied incorrectly leads to attacks

Confused deputy problem

- Compiler writes to billing database
- Compiler can produce debug output to user-specified file
- Specify debug output to billing file, disrupt billing

(Object) capabilities

- A *capability* both designates a resource and provides authority to access it
- Similar to an object reference
  - Unforgeable, but can copy and distribute
- Typically still managed by the kernel

Capability slogans (Miller et al.)

- No designation without authority
- Dynamic subject creation
- Subject-aggregated authority mgmt.
- No ambient authority
- Composability of authorities
- Access-controlled delegation
- Dynamic resource creation

Partial example: Unix FDs

- Authority to access a specific file
- Managed by kernel on behalf of process
- Can be passed between processes
  - Though rare other than parent to child
- Unix not designed to use pervasively

Distinguish: password capabilities

- Bit pattern itself is the capability
  - No centralized management
- Modern example: authorization using cryptographic certificates

Revocation with capabilities

- Use indirection: give real capability via a pair of middlemen
- $A \to B$ via $A \to F \to R \to B$
- Retain capability to tell R to drop capability to B
- Depends on composability

Confinement with capabilities

- A cannot pass a capability to B if it cannot communicate with A at all
- Disconnected parts of the capability graph cannot be reconnected
- Depends on controlled delegation and data/capability distinction

OKL4 and seL4

- Commercial and research microkernels
- Recent versions of OKL4 use capability design from seL4
- Used as a hypervisor, e.g. underneath paravirtualized Linux
- Shipped on over 1 billion cell phones

Joe-E and Caja

- Dialects of Java and JavaScript (resp.) using capabilities for confined execution
- E.g., of JavaScript in an advertisement
- Note reliance on Java and JavaScript type safety