View access control as a matrix

Objects

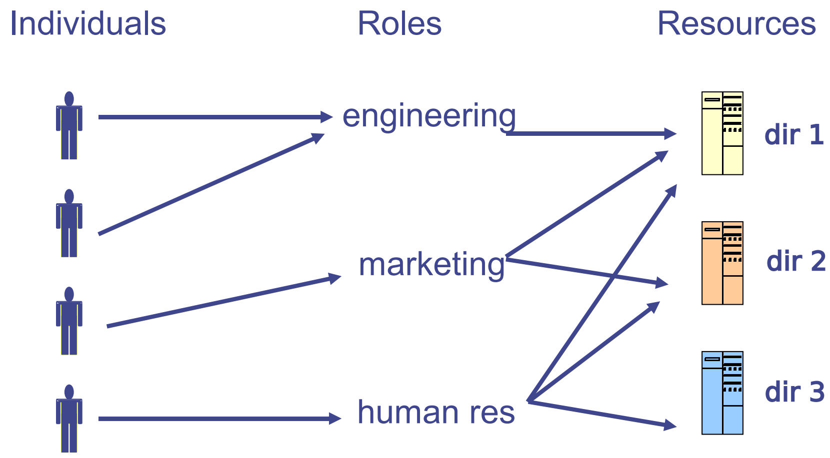
Subjects

	File 1	File 2	File 3	…	File n
User 1	read	write	-	-	read
User 2	write	write	write	-	-
User 3	-	-	-	read	read
…					
User m	read	write	read	write	read

- **Subjects (processes/users) access objects (e.g., files)**
- **Each cell of matrix has allowed permissions**

Specifying policy

- **Manually filling out matrix would be tedious**
- **Use tools such as groups or *role-based access control*:**



Two ways to slice the matrix

- **Along columns:**
  - Kernel stores list of who can access object along with object
  - Most systems you've used probably do this
  - Examples: Unix file permissions, Access Control Lists (ACLs)
- **Along rows:**
  - Capability systems do this
  - More on these later…

Example: Unix protection

- **Each process has a User ID & one or more group IDs**
- **System stores with each file:**
  - User who owns the file and group file is in
  - Permissions for user, any one in file group, and other
- **Shown by output of `ls -l` command:**

user group other owner group

```
- rw- rw- r-- dm cs140 ... index.html
```

  - Each group of three letters specifies a subset of `r`ead, `w`rite, and `e`xecute permissions
  - User permissions apply to processes with same user ID
  - Else, group permissions apply to processes in same group
  - Else, other permissions apply

Unix continued

- **Directories have permission bits, too**
  - Need write perm. on directory to create or delete a file
- **Special user `root` (UID 0) has all privileges**
  - E.g., Read/write any file, change owners of files
  - Required for administration (backup, creating new users, etc.)
- **Example:**
  - `drwxr-xr-x 56 root wheel 4096 Apr 4 10:08 /etc`
  - Directory writable only by root, readable by everyone
  - Means non-root users cannot directly delete files in `/etc`
  - Execute permission means ability to use pathnames in the directory, separate from read permission which allows listing

Non-file permissions in Unix

- **Many devices show up in file system**
  - E.g., `/dev/tty1` permissions just like for files
- **Other access controls not represented in file system**
- **E.g., must usually be root to do the following:**
  - Bind any TCP or UDP port number less than 1,024
  - Change the current process's user or group ID
  - Mount or unmount file systems
  - Create device nodes (such as `/dev/tty1`) in the file system
  - Change the owner of a file
  - Set the time-of-day clock; halt or reboot machine

Example: Login runs as root

- **Unix users typically stored in files in `/etc`**
  - Files `passwd`, `group`, and often `shadow` or `master.passwd`
- **For each user, files contain:**
  - Textual username (e.g., "`dm`", or "`root`")
  - Numeric user ID, and group ID(s)
  - One-way hash of user's password: $\{\text{salt}, H(\text{salt}, \text{passwd})\}$
  - Other information, such as user's full name, login shell, etc.
- **`/usr/bin/login` runs as root**
  - Reads username & password from terminal
  - Looks up username in `/etc/passwd`, etc.
  - Computes $H(\text{salt}, \text{typed password})$ & checks that it matches
  - If matches, sets group ID & user ID corresponding to username
  - Execute user's shell with `execve` system call

Setuid

- **Some legitimate actions require more privs than UID**
  - E.g., how should users change their passwords?
  - Stored in root-owned `/etc/passwd` & `/etc/shadow` files
- **Solution: Setuid/setgid programs**
  - Run with privileges of file's owner or group
  - Each process has *real* and *effective* UID/GID
  - *real* is user who launched setuid program
  - *effective* is owner/group of file, used in access checks
- **Shown as "s" in file listings**
  - `-rws--x--x 1 root root 38464 Jan 26 14:26 /bin/passwd`
  - Obviously need to own file to set the setuid bit
  - Need to own file and be in group to set setgid bit

Setuid (continued)

- **Examples**
  - E.g., `/usr/bin/passwd` – changes user's password
  - E.g., `/bin/su` – acquire new user ID with correct password
  - E.g., `/usr/bin/netstat` – lists network connections (by reading kernel memory on some OSes)
- **Have to be very careful when writing setuid code**
  - Attackers can run setuid programs any time (no need to wait for root to run a vulnerable job)
  - Attacker controls many aspects of program's environment
- **Example attacks when running a setuid program**
  - Change PATH or IFS if setuid prog calls system(3)
  - Set maximum file size to zero (if app rebuilds DB)
  - Close fd 2 before running program—may accidentally send error message into protected file

Other permissions

- **When can proc. A send a signal to proc. B w. *kill*?**
  - Allow if sender and receiver have same effective UID
  - But need ability to kill processes you launch even if suid
  - So allow if real UIDs match, as well
  - Can also send SIGCONT w/o UID match if in same session
- **Debugger system call *ptrace***
  - Lets one process modify another's memory
  - Setuid gives a program more privilege than invoking user
  - So don't let process ptrace more privileged process
  - E.g., Require sender to match real & effective UID of target
  - Also disable/ignore setuid if ptraced target calls *exec*
  - Exception: root can *ptrace* anyone

A security hole

- **Even without root or setuid, attackers can trick root owned processes into doing things…**
- **Example: Want to clear unused files in `/tmp`**
- **Every night, automatically run this command as root:**

  ```
  find /tmp -atime +3 -exec rm -f -- {} \;
  ```

- **find identifies files not accessed in 3 days**
  - executes rm, replacing {} with file name
- **rm -f -- *path* deletes file *path***
  - Note "--" prevents *path* from being parsed as option
- **What's wrong here?**

An attack

find/rm	Attacker
	creat ("`/tmp/badetc/passwd`")
readdir ("`/tmp`") → "`badetc`"	
lstat ("`/tmp/badetc`") → DIRECTORY	
readdir ("`/tmp/badetc`") → "`passwd`"	
	rename ("`/tmp/badetc`" → "`/tmp/x`")
	symlink ("`/etc`", "`/tmp/badetc`")
unlink ("`/tmp/badetc/passwd`")	

- **Time-of-check-to-time-of-use (TOCTTOU) bug**
  - find checks that `/tmp/badetc` is not symlink
  - But meaning of file name changes before it is used

xterm command

- **Provides a terminal window in X-windows**
- **Used to run with setuid root privileges**
  - Requires kernel pseudo-terminal (pty) device
  - Required root privs to change ownership of pty to user
  - Also writes protected utmp/wtmp files to record users
- **Had feature to log terminal session to file**

```
fd = open (logfile, O_CREAT|O_WRONLY|O_TRUNC, 0666);
/* ... */
```

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```
if (access (logfile, W_OK) < 0)
  return ERROR;
fd = open (logfile, O_CREAT|O_WRONLY|O_TRUNC, 0666);
/* ... */
```

- `xterm` **is root, but shouldn't log to file user can't write**
- `access` **call avoids dangerous security hole**
  - Does permission check with *real*, not *effective* UID

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- `xterm` **is root, but shouldn't log to file user can't write**
- `access` **call avoids dangerous security hole**
  - Does permission check with *real*, not *effective* UID
  - **Wrong: Another TOCTTOU bug**

An attack

xterm	Attacker
	creat ("`/tmp/X`")
access ("`/tmp/X`") → OK	
	unlink ("`/tmp/X`")
	symlink ("`/tmp/X`" → "`/etc/passwd`")
open ("`/tmp/X`")	

- **Attacker changes `/tmp/X` between check and use**
  - xterm unwittingly overwrites `/etc/passwd`
  - Another TOCTTOU bug
- **OpenBSD man page: "CAVEATS: access() is a potential security hole and should never be used."**

SSH configuration files

- **SSH 1.2.12 – secure login program, runs as root**
  - Needs to bind TCP port under 1,024 (privileged operation)
  - Needs to read client private key (for host authentication)
- **Also needs to read & write files owned by user**
  - Read configuration file `~/.ssh/config`
  - Record server keys in `~/.ssh/known_hosts`
- **Author wanted to avoid TOCTTOU bugs:**
  - First binds socket & reads root-owned secret key file
  - Then drops all privileges before accessing user files—real and effective user IDs those of invoking user
  - Idea: avoid using any user-controlled arguments/files until you have no more privileges than the user
  - What might still have gone wrong?

Trick question: ptrace bug

- **Actually do have more privileges than user!**
  - Bound privileged port and read host private key
- **Dropping privs allows user to "debug" SSH**
  - Depends on OS, but at the time several had *ptrace* implementations that made SSH vulerable
- **Once in debugger**
  - Could use privileged port to connect anywhere
  - Could read secret host key from memory
  - Could overwrite local user name to get privs of other user
- **The fix: restructure into 3 processes!**
  - Perhaps overkill, but really wanted to avoid problems

A Linux security hole

- **Some programs acquire then release privileges**
  - E.g., `su user` is setuid root, becomes `user` if password correct
- **Consider the following:**
  - A and B unprivileged processes owned by attacker
  - A ptraces B
  - A executes "`su user`" to its own identity
  - While `su` is superuser, B execs `su root`
    (A is superuser, so this is not disabled)
  - A types password, gets shell, and is attached to `su root`
  - Can manipulate `su root`'s memory to get root shell

Editorial

- **Previous examples show two limitations of Unix**
- **Many OS security policies *subjective* not *objective***
  - When can you signal/debug process? Re-bind network port?
  - Rules for non-file operations somewhat incoherent
  - Even some file rules weird (Creating hard links to files)
- **Correct code is much harder to write than incorrect**
  - Delete file without traversing symbolic link
  - Read SSH configuration file (requires 3 processes??)
  - Write mailbox owned by user in dir owned by root/mail
- **Don't *just* blame the application writers**
  - Must also blame the interfaces they program to

Another security problem [Hardy]

- **Setting: A multi-user time sharing system**
  - This time it's not Unix
- **Wanted fortran compiler to keep statistics**
  - Modified compiler `/sysx/fort` to record stats in `/sysx/stat`
  - Gave compiler "home files license"—allows writing to anything in `/sysx` (kind of like Unix setuid)
- **What's wrong here?**

A confused deputy

- **Attacker could overwrite any files in `/sysx`**
  - System billing records kept in `/sysx/bill` got wiped
  - Probably command like `fort -o /sysx/bill file.f`
- **Is this a bug in the compiler `fort`?**
  - Original implementors did not anticipate extra rights
  - Can't blame them for unchecked output file
- **Compiler is a "confused deputy"**
  - Inherits privileges from invoking user (e.g., read `file.f`)
  - Also inherits privileges from home files license
  - Which master is it serving on any given system call?
  - OS doesn't know if it just sees `open ("/sysx/bill", ...)`

Recall access control matrix

Objects

Subjects

	File 1	File 2	File 3	…	File n
User 1	read	write	-	-	read
User 2	write	write	write	-	-
User 3	-	-	-	read	read
…					
User m	read	write	read	write	read

Capabilities

- **Slicing matrix along rows yields capabilities**
  - E.g., For each process, store a list of objects it can access
  - Process explicitly invokes particular capabilities
- **Can help avoid confused deputy problem**
  - E.g., Must give compiler an argument that both specifies the output file and conveys the capability to write the file (think about passing a file descriptor, not a file name)
  - So compiler uses no *ambient authority* to write file
- **Three general approaches to capabilities:**
  - Hardware enforced (Tagged architectures like M-machine)
  - Kernel-enforced (Hydra, KeyKOS)
  - Self-authenticating capabilities (like Amoeba)
- **Good history in [Levy]**