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CS1660: Intro to Computer Systems Security
Spring 2026

Lecture 17: OS Security III

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BROWN

CS1660: Announcements

- Course updates
  - Completed: Project 1, project 2, HW1, HW2, midterm
  - Project 3 is due April 3
  - Project 4 comes out tomorrow
  - 4 weeks left

Last class

- Cryptography
- Authentication
- Web security
- OS security
  - Access control, OS access control

Today

- Cryptography
- Authentication
- Web security
- OS security
  - Access control, OS access control, file-system access control

17.1 File-system access control

Linux Vs. Windows

- Linux
  - Allow-only ACEs
  - Access to file depends on ACL of file and of all its ancestor folders
  - Start at root of file system
  - Traverse path of folders
  - Each folder must have execute (cd) permission
  - Different paths to same file not equivalent
  - File's ACL must allow requested access
- Windows
  - Allow and deny ACEs
  - By default, deny ACEs precede allow ones
  - Access to file depends only on file's ACL
  - ACLs of ancestors ignored when access is requested
  - Permissions set on a folder usually propagated to descendants (inheritance)
  - System keeps track of inherited ACE's

Linux file AC

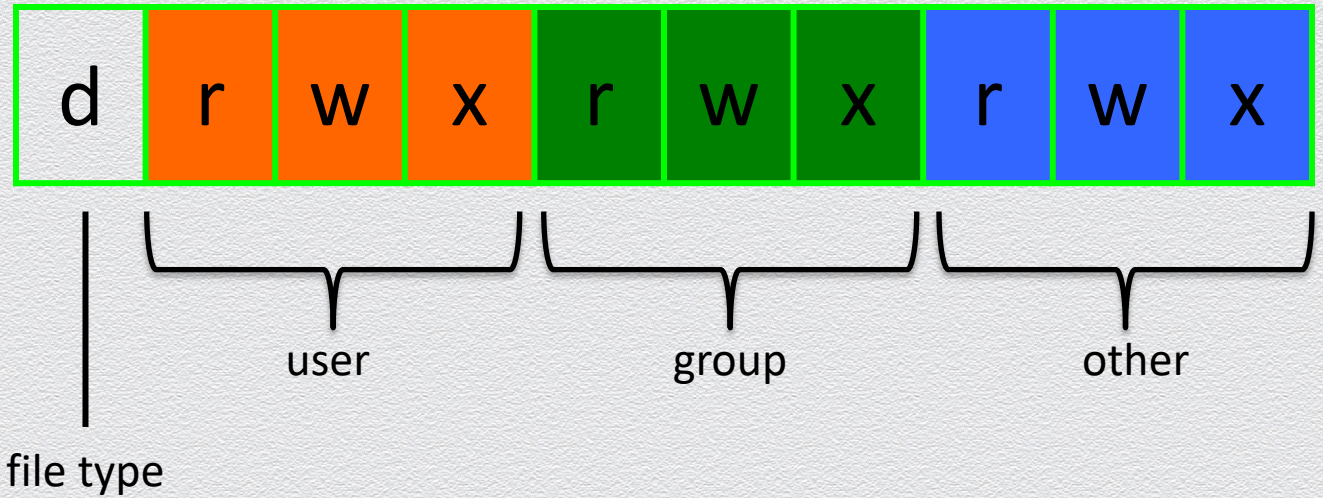
- File Access Control for:
  - Files
  - Directories
  - Therefore…
    - \dev\ : *devices*
    - \mnt\ : *mounted file systems*
    - What else? *Sockets, pipes, symbolic links*…

Unix permissions

- Standard for all UNIXes
- Every file is owned by a user and has an associated group
- Permissions often displayed in compact 10-character notation
- To see permissions, use ls –l

```
jk@sphere:~/test$ ls –l
total 0
-rw-r-----  1 jk ugrad 0 2005-10-13 07:18 file1
-rwxrwxrwx  1 jk ugrad 0 2005-10-13 07:18 file2
```

Unix file types and basic permissions



Permission examples (regular files)

-rw-r—r--	read/write for owner, read-only for everyone else
-rw-r-----	read/write for owner, read-only for group, forbidden to others
-rwx------	read/write/execute for owner, forbidden to everyone else
-r--r--r--	read-only to everyone, including owner
-rwxrwxrwx	read/write/execute to everyone

Permissions for directories

- Permissions bits interpreted differently for directories
- *Read* bit allows listing names of files in directory, but not their properties like size and permissions
- *Write* bit allows creating and deleting files within the directory
- *Execute* bit allows entering the directory and getting properties of files in the directory
- Lines for directories in ls –l output begin with d, as below:

```
jk@sphere:~/test$ ls –l

Total 4

drwxr-xr-x  2 jk ugrad 4096 2005-10-13 07:37 dir1

-rw-r--r--  1 jk ugrad    0 2005-10-13 07:18 file1
```

Permission examples (directories)

drwxr-xr-x	all can enter and list the directory, only owner can add/delete files
drwxrwx---	full access to owner and group, forbidden to others
drwx--x---	full access to owner, group can access known filenames in directory, forbidden to others
-rwxrwxrwx	full access to everyone

Changing permissions

- Permissions are changed with chmod or through a GUI (e.g., KDE Konqueror)
- Only the file owner or root can change permissions
- If a user owns a file, the user can use chgrp to set its group to any group of which the user is a member
- root can change file ownership with chown (and can optionally change group in the same command)
- chown, chmod, and chgrp can take the -R option to recur through subdirectories

Changing permissions examples

chown -R root dir1	Changes ownership of dir1 and everything within it to root
chmod g+w,o-rwx file1 file2	Adds group write permission to file1 and file2, denying all access to others
chmod -R g=rwX dir1	Adds group read/write permission to dir1 and everything within it, and group execute permission on files or directories where someone has execute permission
chgrp testgrp file1	Sets file1's group to testgrp, if the user is a member of that group
chmod u+s file1	Sets the setuid bit on file1. (Doesn't change execute bit.)

Special permission bits

- Three other permission bits exist
  - Set-user-ID (“suid” or “setuid”) bit
  - Set-group-ID (“sgid” or “setgid”) bit
  - Sticky bit

Set-user-ID

- Set-user-ID (“suid” or “setuid”) bit
  - On executable files, causes the program to run as file owner regardless of who runs it
  - Ignored for everything else
  - In 10-character display, replaces the 4th character (x or -) with s (or S if not also executable)

    -rwsr-xr-x: setuid, executable by all

    -rwxr-xr-x: executable by all, but not setuid

    -rwSr--r--: setuid, but not executable - not useful

Setuid programs

- Unix processes have two user IDs:
  - real user ID: user launching the process
  - effective user ID: user whose privileges are granted to the process
- An executable file can have the set-user-ID property (setuid) enabled
- If a user A executes setuid file owned by B, then the effective user ID of the process is B and not A

Setuid programs (cont.)

- System call setuid(uid) allows a process to change its effective user ID to uid
- Some programs that access system resources are owned by root and have the setuid bit set (setuid programs)
  - e.g., passwd and su
- Writing secure setuid programs is tricky because vulnerabilities may be exploited by malicious user actions

Set-group-ID

- Set-group-ID (“sgid” or “setgid”) bit
- On executable files, causes the program to run with the file’s group, regardless of whether the user who runs it is in that group
- On directories, causes files created within the directory to have the same group as the directory, useful for directories shared by multiple users with different default groups
- Ignored for everything else
- In 10-character display, replaces 7th character (x or -) with s (or S if not also executable)

  -rwxr-sr-x: setgid file, executable by all

  drwxrwsr-x: setgid directory; files within will have group of directory

  -rw-r-Sr--: setgid file, but not executable - not useful

Sticky bit

- On directories, prevents users from deleting or renaming files they do not own
- Ignored for everything else
- In 10-character display, replaces 10th character (x or -) with t (or T if not also executable)

drwxrwxrwt: sticky bit set, full access for everyone

drwxrwx--T: sticky bit set, full access by user/group

drwxr--r-T: sticky, full owner access, others can read *(useless)*

Symbolic link

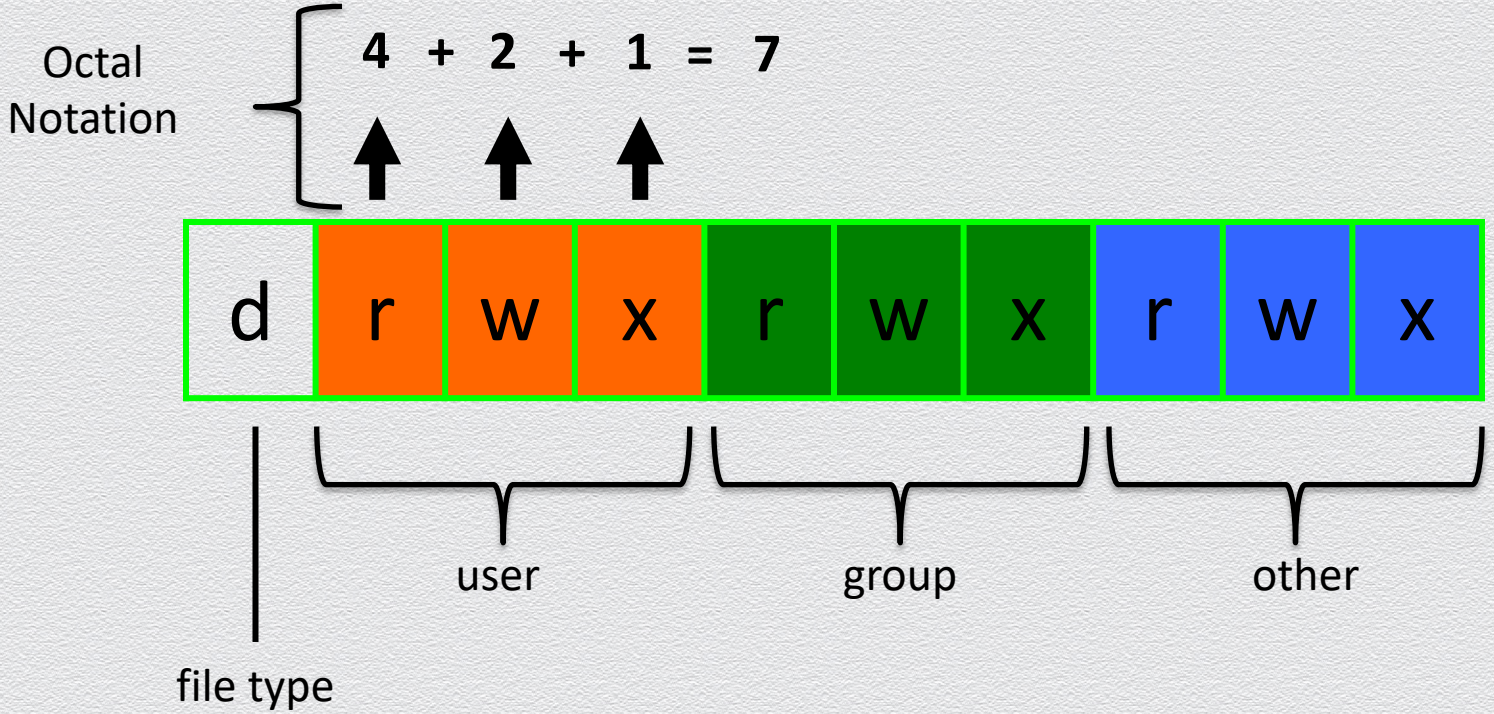
- In Unix, a symbolic link (aka symlink) is a file that points to (stores the path of) another file
- A process accessing a symbolic link is transparently redirected to accessing the destination of the symbolic link
- Symbolic links can be chained, but not to form a cycle

- ln -s really_long_directory/even_longer_file_name myfile

Octal notation

- Standard syntax is nice for simple cases, but bad for complex changes
  - Alternative is octal notation, i.e., three or four digits from 0 to 7
- Digits from left (most significant) to right(least significant):
  [special bits][user bits][group bits][other bits]
- Special bit digit =
  (4 if setuid) + (2 if setgid) + (1 if sticky)
- All other digits =
  (4 if readable) + (2 if writable) + (1 if executable)

Unix file types and octal notation



Octal notation examples

644 or 0644	read/write for owner, read-only for everyone else
775 or 0775	read/write/execute for owner and group, read/execute for others
640 or 0640	read/write for owner, read-only for group, forbidden to others
2775	same as 775, plus setgid (useful for directories)
777 or 0777	read/write/execute to everyone *(dangerous!)*
1777	same as 777, plus sticky bit

Root

- “root” account is a super-user account, like Administrator on Windows
- Multiple roots possible
- File permissions do not restrict root
- This is *dangerous*, but necessary, and OK with good practices

Becoming root

- su
  - Changes home directory, PATH, and shell to that of root, but doesn't touch most of environment and doesn't run login scripts
- sudo <command>
  - Run just one command as root
- su [-] <user>
  - Become another non-root user
  - Root does not require to enter password

The /tmp directory

- In Unix systems, directory /tmp is
  - Readable by any user
  - Writable by any user
  - Usually wiped on reboot
- Convenience
  - Place for temporary files used by applications
  - Files in /tmp are not subject to the user's space quota
- What could go wrong?
  - Sharing of resources may lead to vulnerabilities

Limitations of Unix permissions

- Unix permissions are not perfect
  - Groups are restrictive
  - Limitations on file creation
- Linux optionally uses POSIX ACLs
  - Builds on top of traditional Unix permissions
  - Several users and groups can be named in ACLs, each with different permissions
  - Allows for finer-grained access control
- Each ACL is of the form *type*:[*name*]:*rwx*
  - Setuid, setgid, and sticky bits are outside the ACL system

Gone for 10 seconds

- You leave your desk for 10 seconds without locking your machine
- The attacker sits at your desk and types:

  % cp /bin/sh /tmp

  % chmod 4777 /tmp/sh
- The first command makes a copy of shell sh
- The second command makes sh accessible
- What happens next?
- The attacker can run the copy of the shell with your privileges
- For example:
  - Can read your files
  - Can change your files

Historical setuid Unix vulnerabilities: lpr

- Command lpr
  - running as root setuid
  - copied file to print, or symbolic link to it, to spool file named with 3-digit job number (e.g., print954.spool) in /tmp
  - Did not check if file already existed
  - Random sequence was predictable and repeated after 1,000 times
- How can we exploit this?

- Attack
  - A dangerous combination: setuid, /tmp, symlinks, …
  - Create new password file newpasswd
  - Print a very large file
  - lpr –s /etc/passwd
  - Print a small file 999 times
  - lpr newpasswd
  - The password file is overwritten with newpasswd

Beyond setuid and files

- Writing setuid programs is tricky
  - Easy to inadvertently create security vulnerabilities
  - Unix variants have subtle different behaviors in setuid-related calls
- Access control to files is tricky
  - A user file can be accessed by any user process
  - Shared folders and predictable file names create security vulnerabilities
- Consider alternatives
  - Manage system resources via services
  - Use databases instead of files and shared folders
  - Use RPCs (including database queries) to request access to system resources

15.2 setuid/setgid vulnerabilities

setuid/setgid

Special permissions bits:

- setuid (Set User ID)
  - executable runs with privileges of owner, regardless of who runs it
- setgid (Set Group ID)
  - executable runs with privileges of group, regardless of who runs it

Unprivileged user can run program with higher privileges!
=> Powerful, but very dangerous

setuid/gid: The effects

Disclaimer

setuid/setgid is dangerous. Using it incorrectly can cause serious problems.

Just as you should never implement your own crypto,

you should not write your own setuid/setgid programs.

You are about to see why.

Background: environment variables

System variables that control how processes execute

Set up when a user logs in, as part of shell

```
# Get variables
cs1660-user@6010f6e96b02:~$ echo $TERM
xterm
cs1660-user@6010f6e96b02:~$ echo $PWD
/home/cs1660-user

# Set a variable
cs1660-user@6010f6e96b02:~$ export SOMETHING=hello
cs1660-user@6010f6e96b02:~$ echo $SOMETHING
Hello

# Show the environment
cs1660-user@6010f6e96b02:~$ env
. . .
```

Scope is per-shell: log out/open new term => different vars

Background: $PATH

Where the shell looks when you run programs

=> List separated by ":", traversed in order

```
# Get variables
cs1660-user@6010f6e96b02:~$ echo $PATH
/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/bin:/usr/local/go/bin


# which:  $PATH lookup
cs1660-user@6010f6e96b02:~$ which ls
/usr/bin/ls

cs1660-user@6010f6e96b02:~$ which go
/usr/local/go/bin/go
```

Problems

Input from user pollutes execution environment

=> Another form of code injection!

Not every command can be overridden…

Background: symbolic links

Indirection in the filesystem: path of one file can point to another

```
# Create a symlink
registrar@ceres:~$ ln –sv scripts/reg-v01.sh reg.sh
reg.sh -> scripts/reg-v01.sh


# How it looks
registrar@ceres:~$ ls –la reg.sh
lrwxrwxrwx 1 reg reg 9 Mar 12 16:40 reg.sh -> scripts/reg-v01.sh



# eg. Use it like a normal file
registrar@ceres:~$ ./reg.sh
```

Problem: anyone can create a symlink to anything!
=> Permissions checked on **access**, not at **creation**

What can go wrong?

TOCTOU: Time of check/time of use

```
# Check for access
if ! __effective_user_can_access $code_from_user; then
       echo "You don't have permission to view this file"
       exit 1
fi



# Do the access
if cmp --silent $code_expected $code_from_user; then
   echo "Override code approved!"
   add_to_course $course $user
else
   echo "Please use a valid override code"
fi
```

A race condition!

So why is setuid/gid bad?

So why is setuid/gid bad?

Up to the developer to decide what parts of the program can run with elevated privileges

=> Particularly dangerous for shell scripts

So setuid/setgid is dangerous...

setuid/setgid is dangerous...

In modern times: only for programs that really need it

- System programs that changing passwords/users, legacy programs
  - Don't do this yourself!
- Very very bad idea for shell scripts

What else can we do?

When do we need this?

In the shell: su, sudo

- Run as another user (if you have permissions)

```
user@shell:~$ su –c "command" other user
```

- Run commands as root (or another user) based on system config file (/etc/sudoers)
  - Can restrict to specific commands, environment, ...

```
user@shell:~$ sudo whoami
root
```

```
/etc/sudoers:
%wheel ALL=(ALL) NOPASSWD: ALL

...
```

From man page on /etc/sudoers: (aka sudoers(5))

```
ALL          CDROM = NOPASSWD: /sbin/umount /CDROM,\
             /sbin/mount -o nosuid\,nodev /dev/cd0a /CDROM


Any user may mount or unmount a CD-ROM on the machines in the CDROM
Host_Alias (orion, perseus, hercules) without entering a password.
```

sudo has a LOT of features, see
man sudoers for details!

Race Condition

- A race condition occurs when two threads want to access the same memory

- Run Thread 1() and Thread 2()
  - Outcome is 1 or 2