CS165 – Computer Security

Filesystem Security

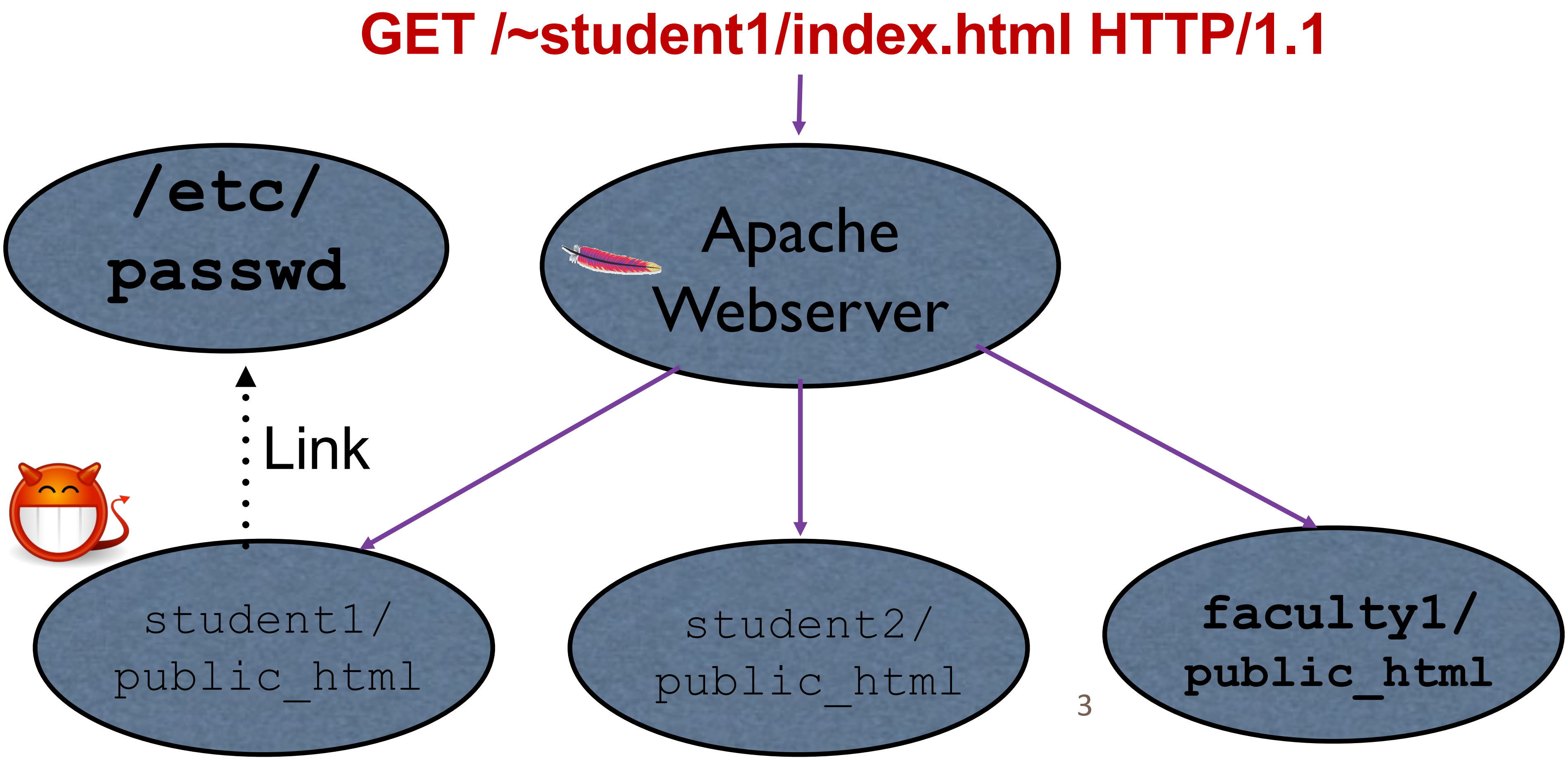
November 21, 2025

File Open

- Problem: Processes need resources from system
  - Just a simple `open(filepath, …)` right?
  - But, adversaries can cause victims to access resources of their choosing
  - And if your program has some valuable privileges, an adversary may want to trick you into using them to implement a malicious operation

A Webserver’s Story …

- Consider a university department webserver …



GET /~student1/index.html HTTP/1.1

/etc/ passwd

Apache Webserver

Link

student1/ public_html

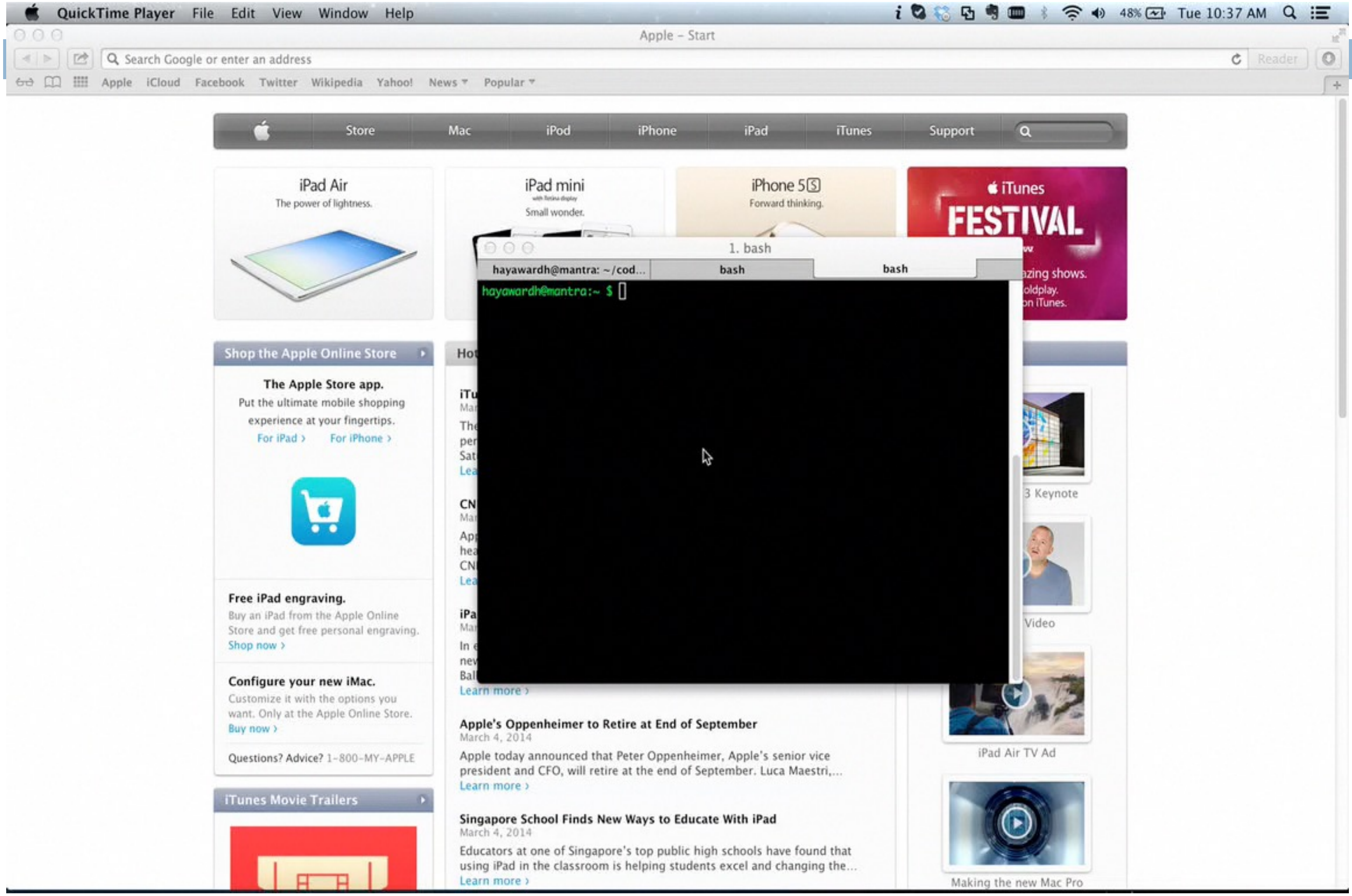
student2/ public_html

faculty1/ public_html

Symbolic Link

- Many file systems allow you to create a "link" to refer another file
  - I.e., file systems are not trees, but graphs
- There is a link command – "ln"
  - `ln -s target linkname`
  - Creates a "link" file named "linkname" in the current directory
- When you "open" the linkname, you actually open the target file
  - `ln -s /etc/passwd mylink`
  - `open("mylink", O_RDWR, …);`
  - Does what?

Attack Video



1. bash

hayawardh@mantra: ~/cod... | bash | bash

```
hayawardh@mantra:~ $ 
```

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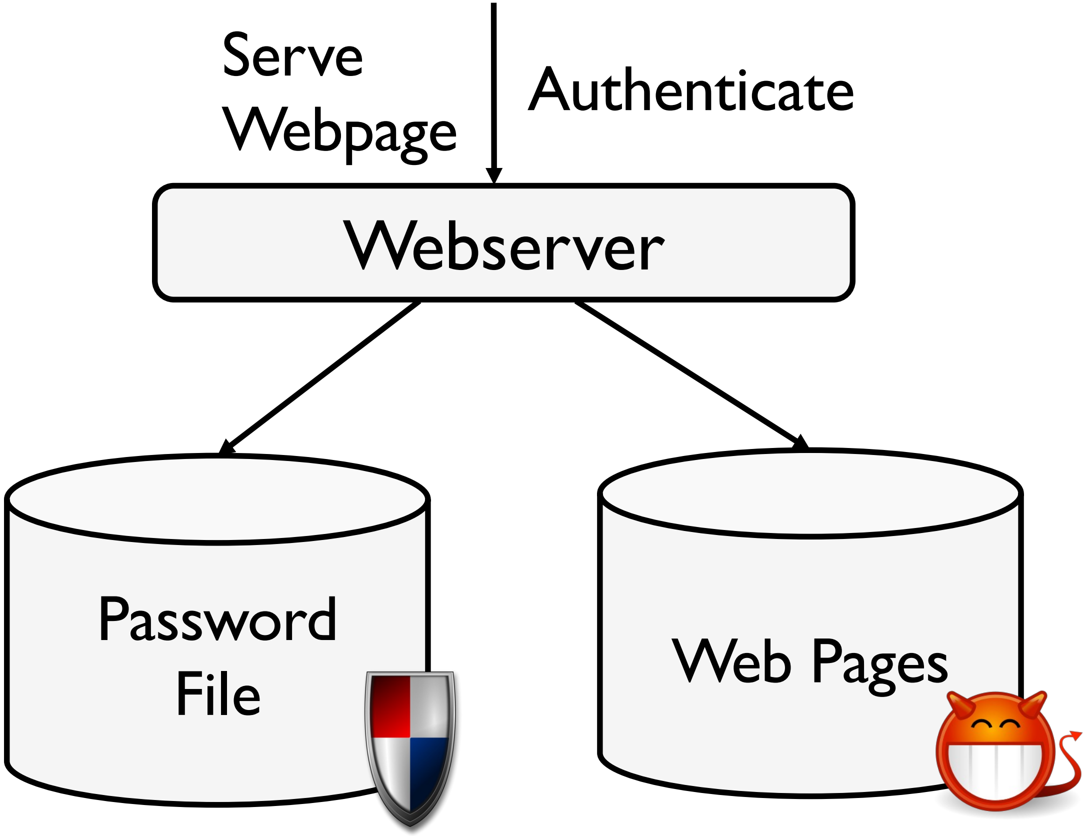
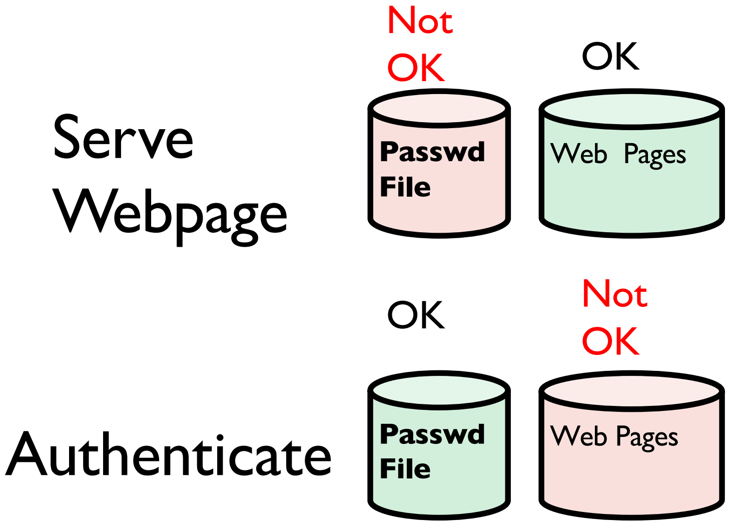
What Just Happened?



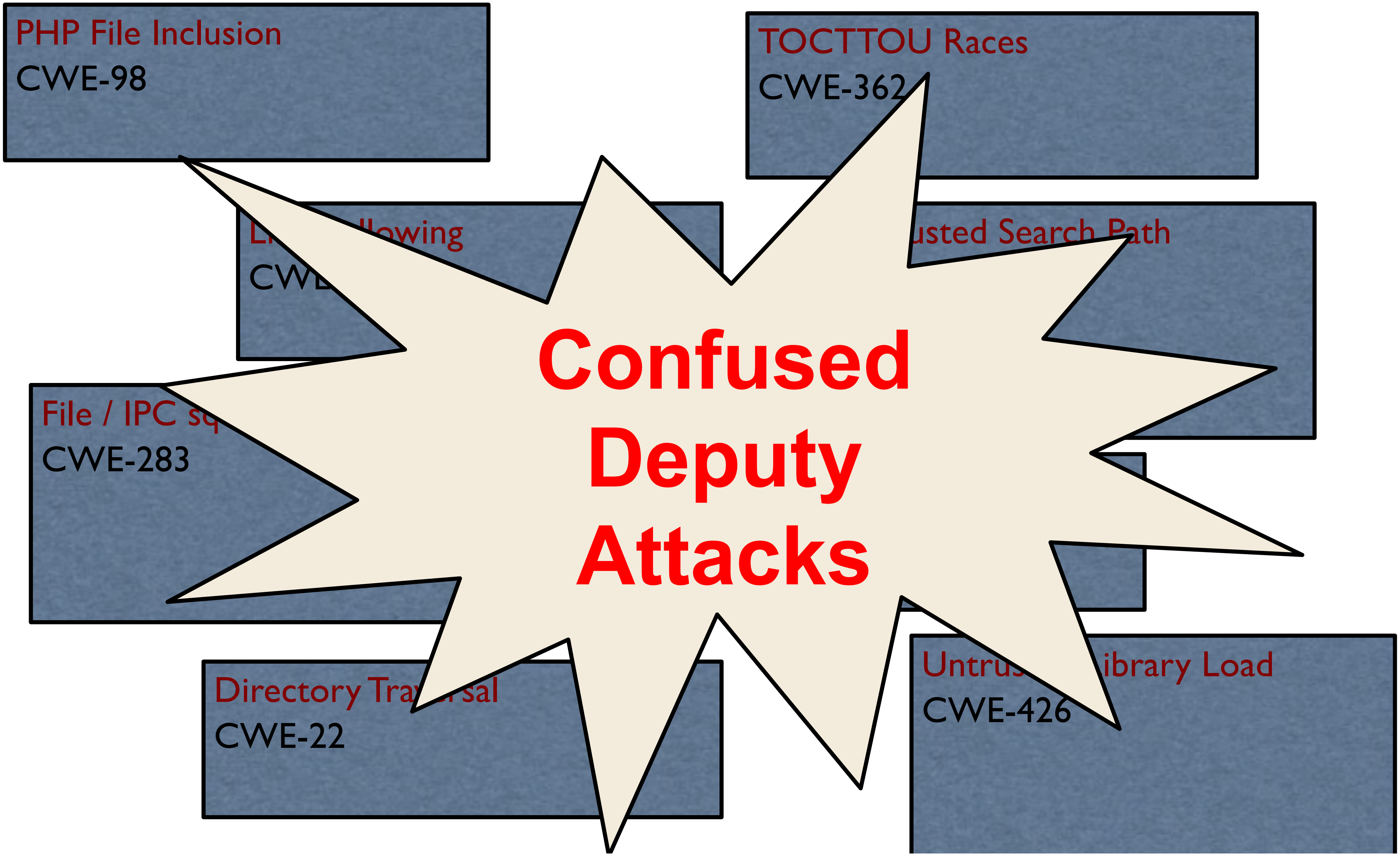


- Program acts as a *confused deputy*
  - 😈 when expecting 🛡
  - 🛡 when expecting 😈

Integrity (and Secrecy) Threat

- Confused Deputy
  - *Process is tricked into performing an operation on an adversary's behalf that the adversary could not perform on their own*
    - Write to (read from) a privileged file

Confused Deputy Attacks



PHP File Inclusion
CWE-98

TOCTTOU Races
CWE-362

Li llowing
CWE

usted Search Path

File / IPC sq
CWE-283

Directory Tra rsal
CWE-22

Untrus ibrary Load
CWE-426

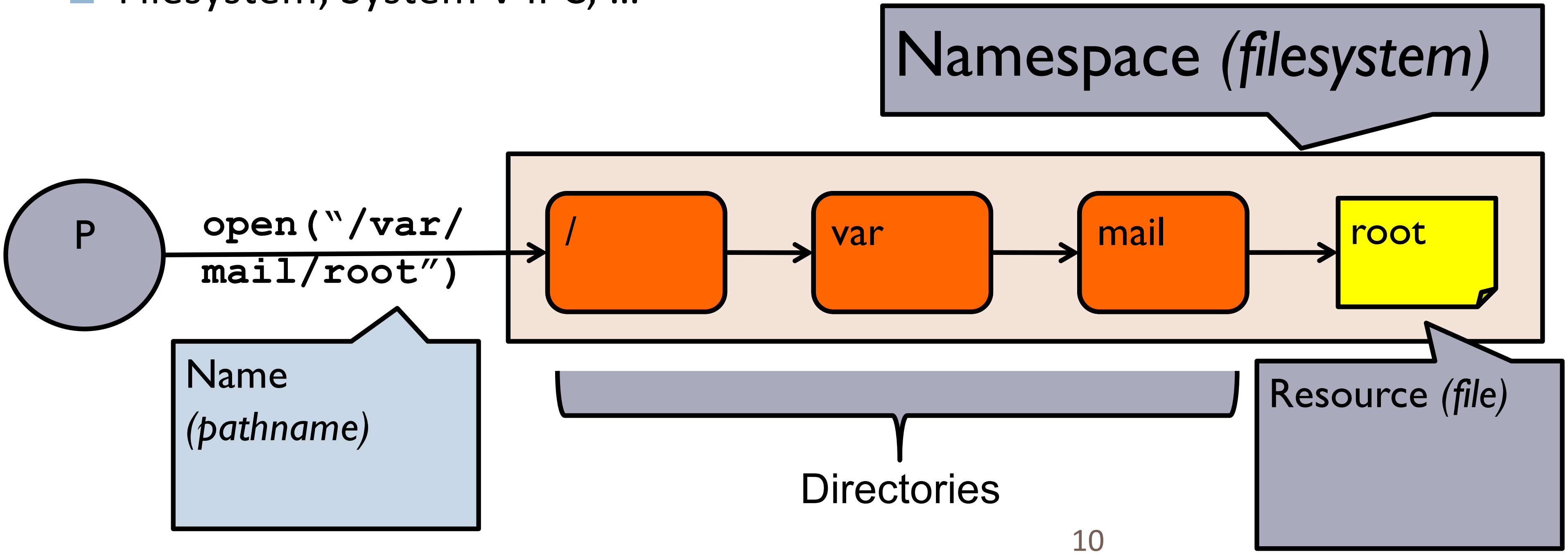
Confused Deputy Attacks

Lesson

- Opening a file is fraught with danger
  - We must be careful when using an input that may be adversary controlled when opening a file
    - Or anything else…

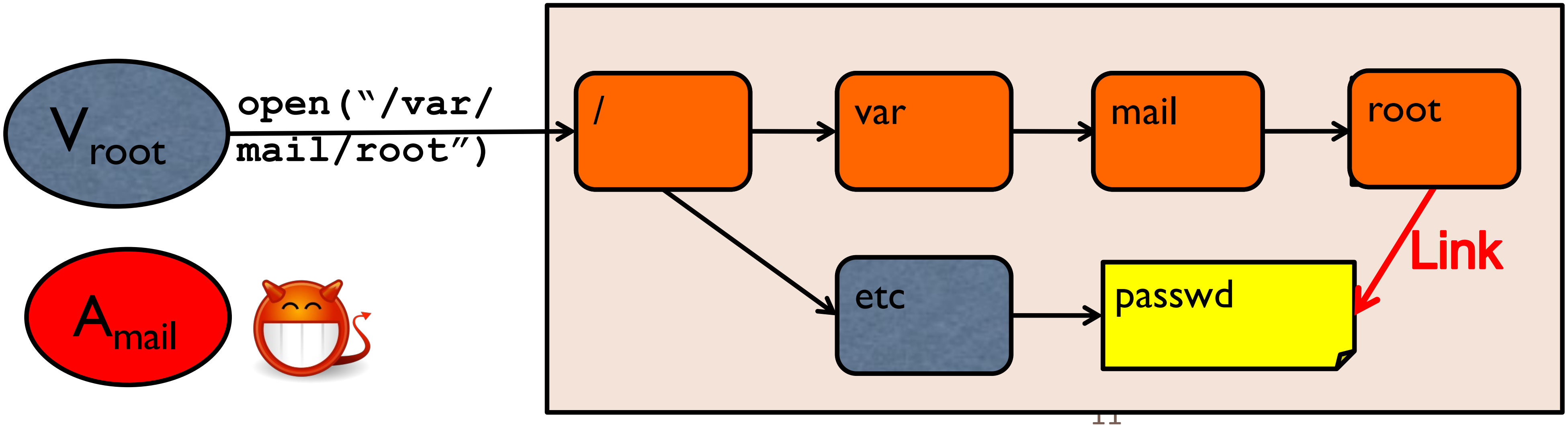
Name Resolution

- Processes often use *names* to obtain access to *system resources*
- A *nameserver* (e.g., OS) performs *name resolution* using a *namespace* (e.g., *directories*) to convert a *name* (e.g., *pathname*) into a *system resource* (e.g., *file*)
  - Filesystem, System V IPC, …



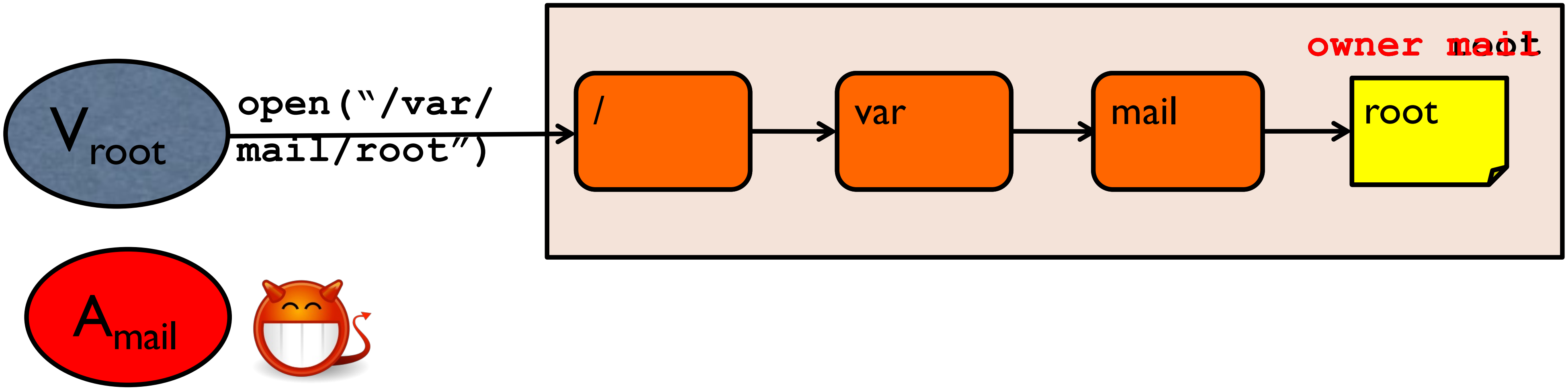
Link Traversal Attack

- Adversary controls links to direct a victim to a resource not normally accessible to the adversary
- Victim expects one resource, gets another instead



File Squatting Attack

- Adversary predicts a resource to be created by a victim – creates that resource in advance
- Victim accesses a resource controlled by an adversary instead



Common Threat

- What is the threat that enables link traversal and file squatting attacks?
  - Common to both

Common Threat

- What is the threat that enables link traversal and file squatting attacks?
  - Common to both
- In both cases, the adversary has write permission to a directory that a victim uses in name resolution
  - Could be any directory used in resolution, not just the last one
  - Enables the adversary to plant links and/or files/directories where they can write

Threat Example

- An adversary may be authorized to write to a directory you use in resolving a file path
- E.g., groups and others may have write permission to a directory
  - Consider the directory /tmp
  - `ls -la /tmp`
    - `drwxrwxrwx --- root root ---  .`
    - Means?

Threat Example

- Suppose your program wants to create a new file at “/tmp/just_a_normal_file_here”
  - What file will you create/open?

File Squatting

- Suppose your program wants to create a new file at “/tmp/just_a_normal_file_here”
  - What file will you open?
    - An adversary could have created this file already (file squat) and given you permissions, so that you can use it
      - Can be difficult to verify the origins of a file
  - Causes your program to use a file under adversary control when you expect your own file

Threat Example

- Suppose your program is asked to open the file path “/tmp/just_a_normal_file_here”
  - What file will you open?

Link Traversal

- Suppose your program is asked to open the file path "/tmp/just_a_normal_file_here"
  - What file will you open?
    - An adversary could have created this as a symbolic link to any file in the system that you can access
    - And it is difficult/expensive to verify that this is not a symbolic link
      - stat – provides file system information – e.g., permissions
      - lstat – provides file system information (like "stat") for the link, rather than the file/directory the link refers to
  - Causes your program to access an adversary-chosen file

Prevent File System Attacks

- How would you prevent such attacks?

Check and Use

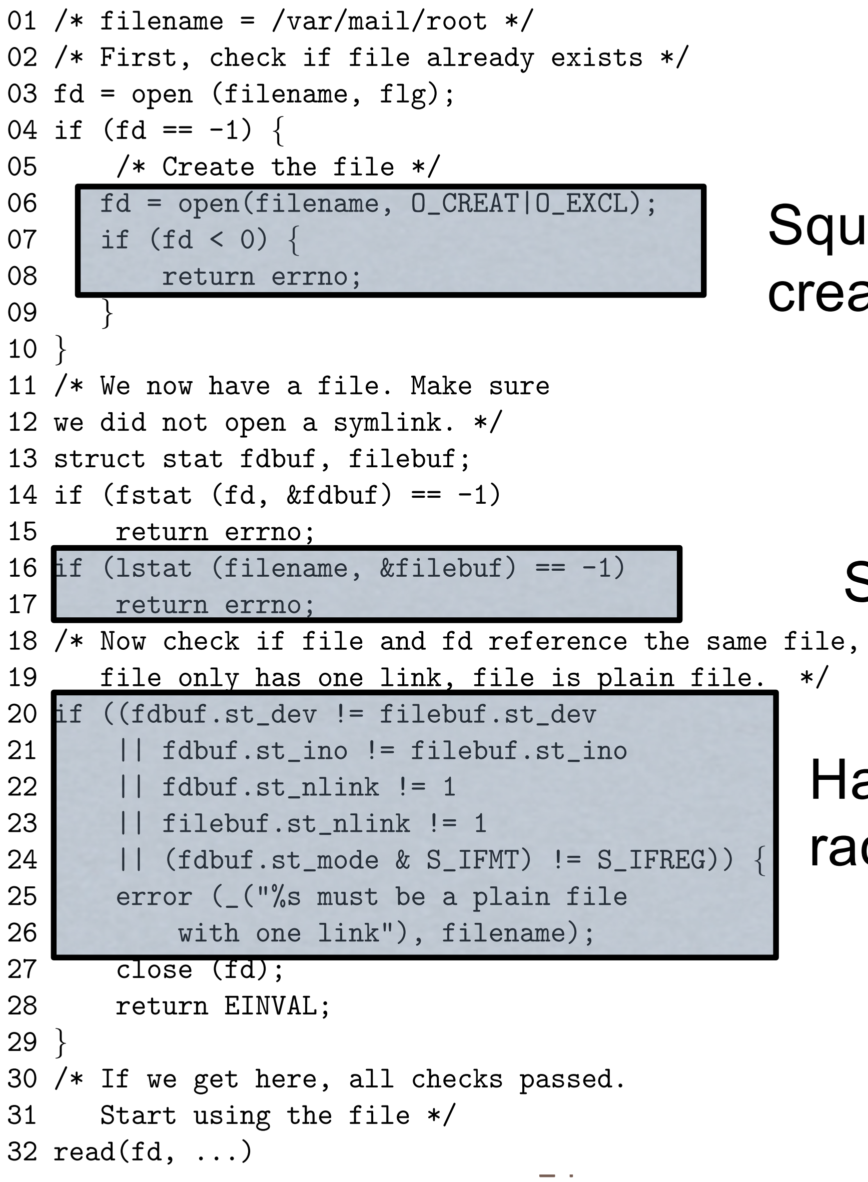
- Some system calls enable checking of the file (check)
  - Does the requesting party have access to the file? (stat, access)
  - Is the file accessed via a symbolic link? (lstat)
- Some system calls use the file (use)
  - Convert the file name to a file descriptor (open)
  - Modify the file metadata (chown, chmod)
- Can an adversary modify the filesystem in between check and use system calls?

TOCTTOU Races

- Time-of-check-to-time-of-use (TOCTTOU) Race Attacks
- Some system calls enable checking of the file (check)
  - Does the requesting party have access to the file? (stat, access)
  - Is the file accessed via a symbolic link? (lstat)
- Some system calls use the file (use)
  - Convert the file name to a file descriptor (open)
  - Modify the file metadata (chown, chmod)
- Can an adversary modify the filesystem in between check and use system calls? Yes. Pretty reliably.

Vulnerabilities Easily Overlooked

- □ Manual checks can easily overlook vulnerabilities
- □ Misses file squat at line 03!



```
01 /* filename = /var/mail/root */
02 /* First, check if file already exists */
03 fd = open (filename, flg);
04 if (fd == -1) {
05     /* Create the file */
06    fd = open(filename, O_CREAT|O_EXCL);
07    if (fd < 0) {
08        return errno;
09    }
10 }
11 /* We now have a file. Make sure
12 we did not open a symlink. */
13 struct stat fdbuf, filebuf;
14 if (fstat (fd, &fdbuf) == -1)
15     return errno;
16 if (lstat (filename, &filebuf) == -1)
17     return errno;
18 /* Now check if file and fd reference the same file,
19    file only has one link, file is plain file.  */
20 if ((fdbuf.st_dev != filebuf.st_dev
21     || fdbuf.st_ino != filebuf.st_ino
22     || fdbuf.st_nlink != 1
23     || filebuf.st_nlink != 1
24     || (fdbuf.st_mode & S_IFMT) != S_IFREG)) {
25     error (_("%s must be a plain file
26         with one link"), filename);
27     close (fd);
28     return EINVAL;
29 }
30 /* If we get here, all checks passed.
31    Start using the file */
32 read(fd, ...)
```

Squat during create (resource)

Symbolic link

Hard link, race conditions

Current Defenses

- Are there defenses to prevent such attacks?
  - Yes, but the defenses are not comprehensive

Defenses

- Variants of the “open” system call
  - Flag “O_NOFOLLOW” – do not follow any symbolic links (prevent link traversal)
    - Does not help if you may need to follow symbolic links
    - May not be available on your system
  - Flag “O_EXCL” and “O_CREAT” – do not open unless the new file is created (prevent file squatting)
    - Does not help if you if your program does not know whether the file may need to be created
- These lack flexibility for protection in general

More Advanced Defenses

- The “openat” system call
  - Can open the directory (dirfd) separately from opening the file (path) to check the safety of that part of the name resolution
    - *int openat(int dirfd, const char *path, int oflag, ...);*
  - Control some aspects of opening “path” (e.g., no links)
    - E.g., used in libc

```
libc_open (const char *file, int oflag, …)
```

to

```
return SYSCALL_CANCEL (openat, AT_FDCWD, file, oflag, …);
```

- The “openat2” system call
  - More flags limiting “how” name resolution is done for “path”
  - Not standard

Openat Usage Example

- Suppose you want to open “/var/mail/root” safely with “openat”
  - How would you do it?

```
int openat(int dirfd, const char *path, int oflag, ...);
```

- Three steps
  - (1) Open “/var/mail” to obtain a “dirfd”
  - (2) Validate that the resulting file descriptor refers to “/var/mail”
  - (3) Open the file “root” using “openat” using options to protect the open from attacks
    - O_NOFOLLOW to prevent use of symbolic links (i.e., prevent link traversal)
    - O_EXCL with O_CREAT to ensure a fresh file is created (i.e., to prevent file squatting)

Validating Directories

- How do you validate a directory for “dirfd”?
- Three steps
  - (1) Open “/var/mail” to obtain its “fd”
  - (2) Collect the “stat” structure for this “fd”
    - From the file descriptor using fstat

    ```
    int fstat(int fd, struct stat *buf);
    ```
  - (3) Check that this “fd” refers to expected directory inode

    ```
    S_ISDIR(mode_t buf.st_mode);  // see ”struct stat” format
    Check value of st_ino field
    ```
- openat is a limited defense
  - Does not impact absolute pathnames or help if validation is imperfect

Conclusions

- Adversaries can attack your use of the filesystem
- Local exploit on shared access to the filesystem that your program may use in name resolution
  - If an adversary has write permission to any directory used
    - File squatting can control file content used by your program
    - Link traversal can redirect your program to other files
- Can use available system calls, such as openat, to prevent most forms of these attacks, but not all

Questions