Systems and Internet Infrastructure Security

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CMPSC 447
Confused Deputy

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Android External Storage

- Android has its apps use "external storage" (used to be an SD-card) to store its code and configurations
  - A shared filesystem space for use by apps
- **Problem**: Multiple apps can write files in the same directories
  - Why could that be a problem?

Android External Storage

- Android has its apps use “external storage” (used to be an SD-card) to store its code and configurations
  - A shared filesystem space for use by apps
- Problem: Multiple apps can write files in the same directories
  - Why could that be a problem?
- A malicious app that knows the name of a file that will be created by another app can create that file in advance
  - E.g., for library files
  - E.g., for symbolic links
  - Why could these cause an issue?

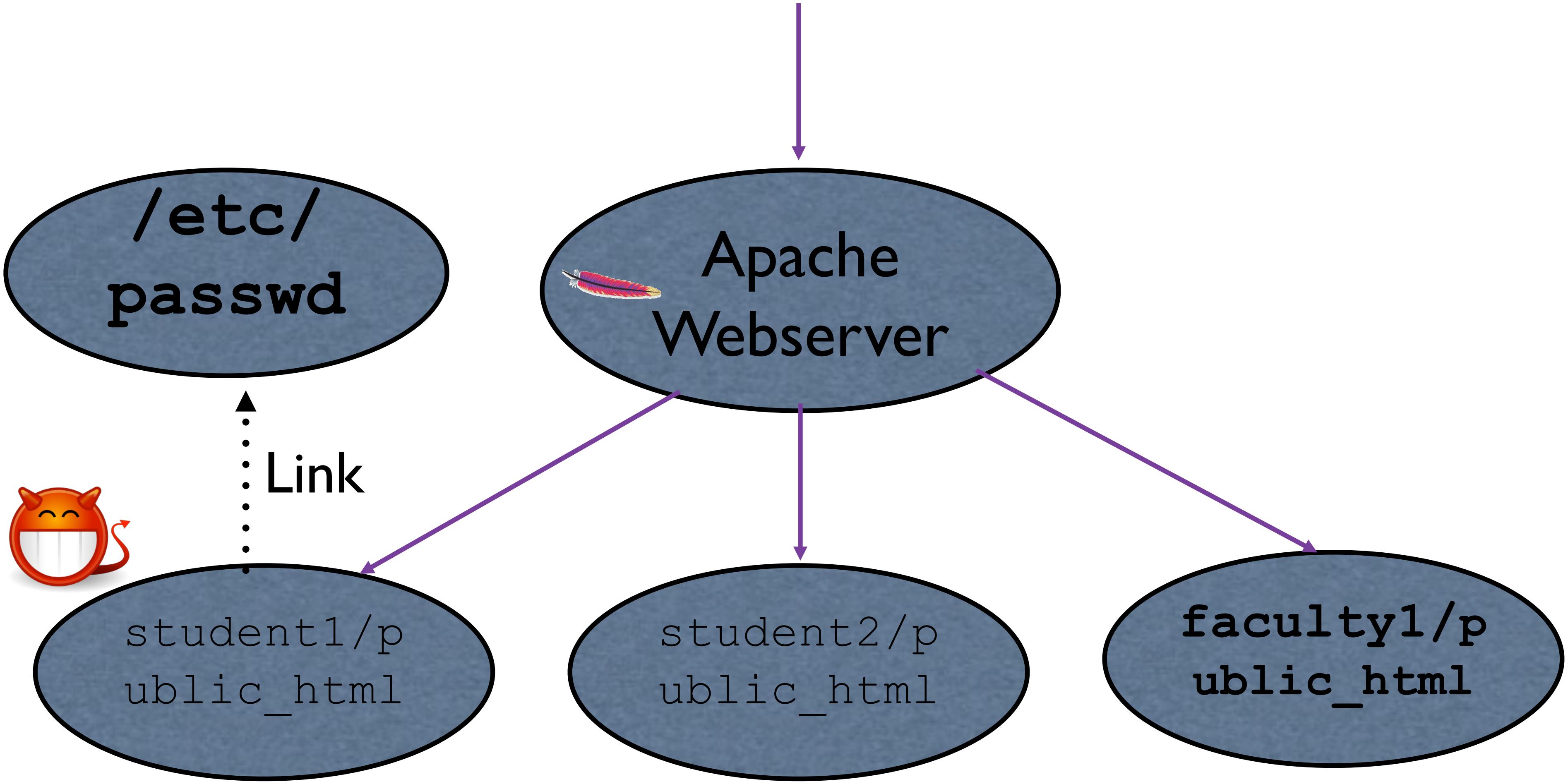
File Open

- 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

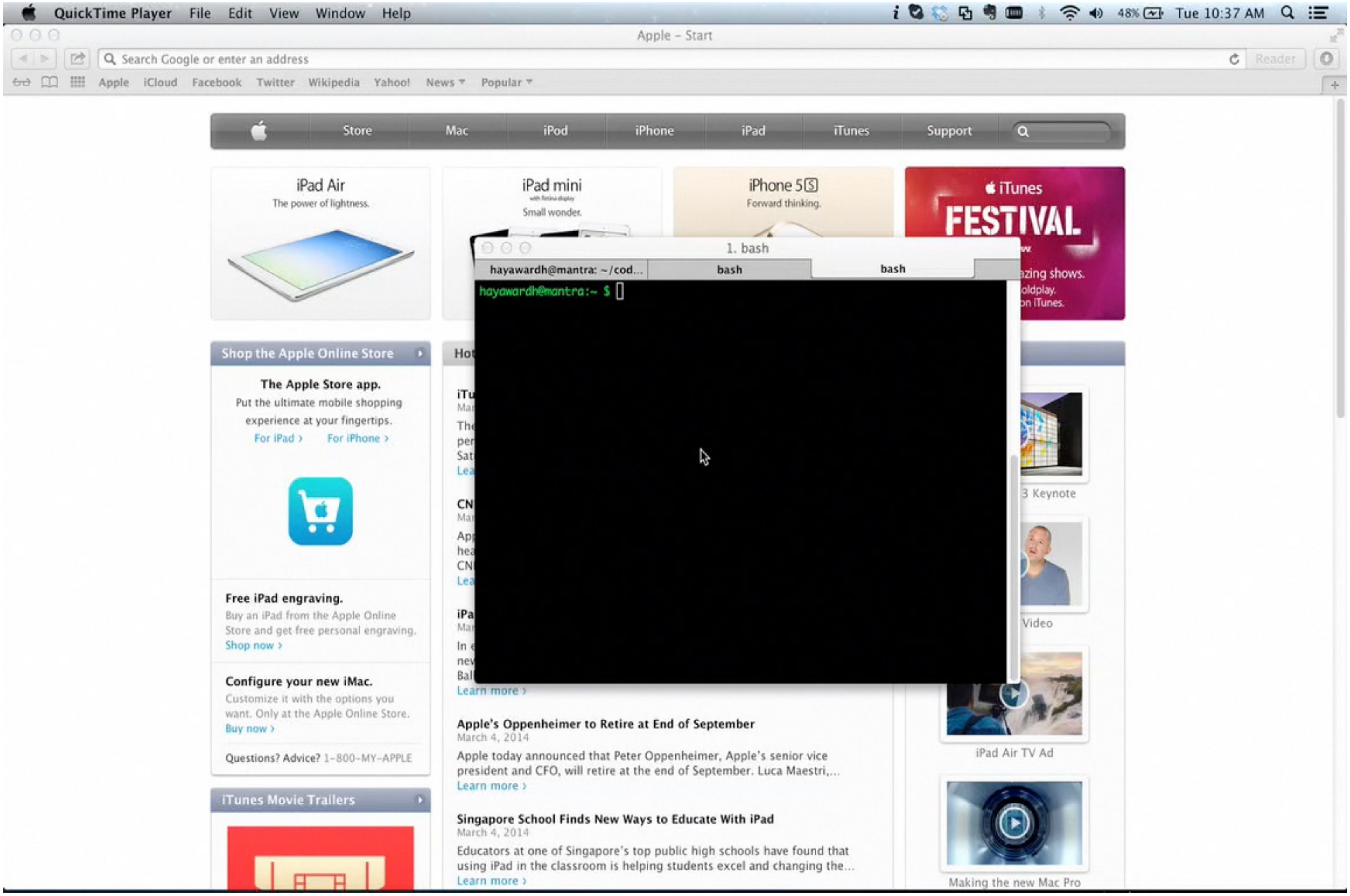
Link

student1/public_html

student2/public_html

faculty1/public_html

Attack Video



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

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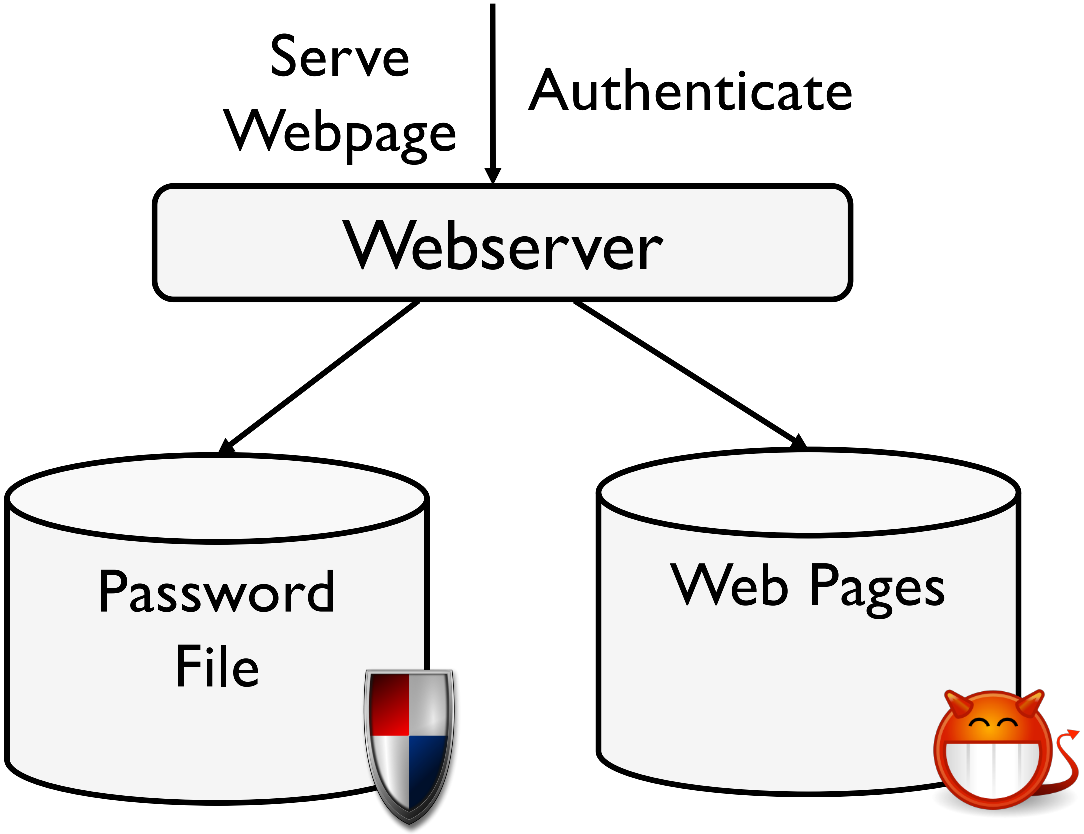
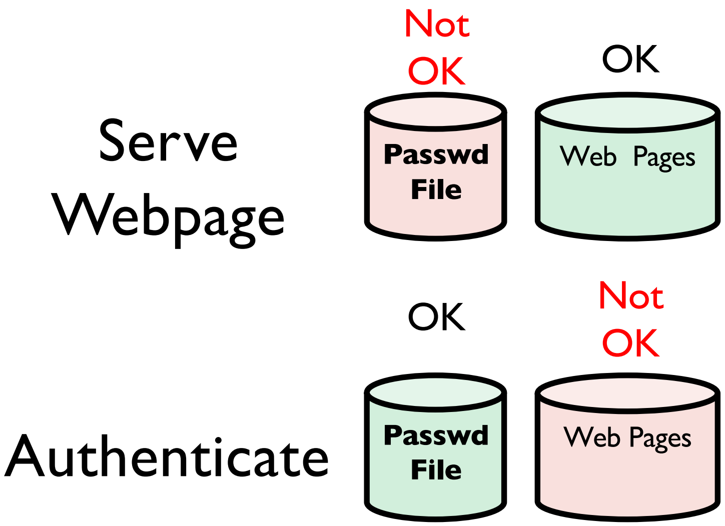
What Just Happened?



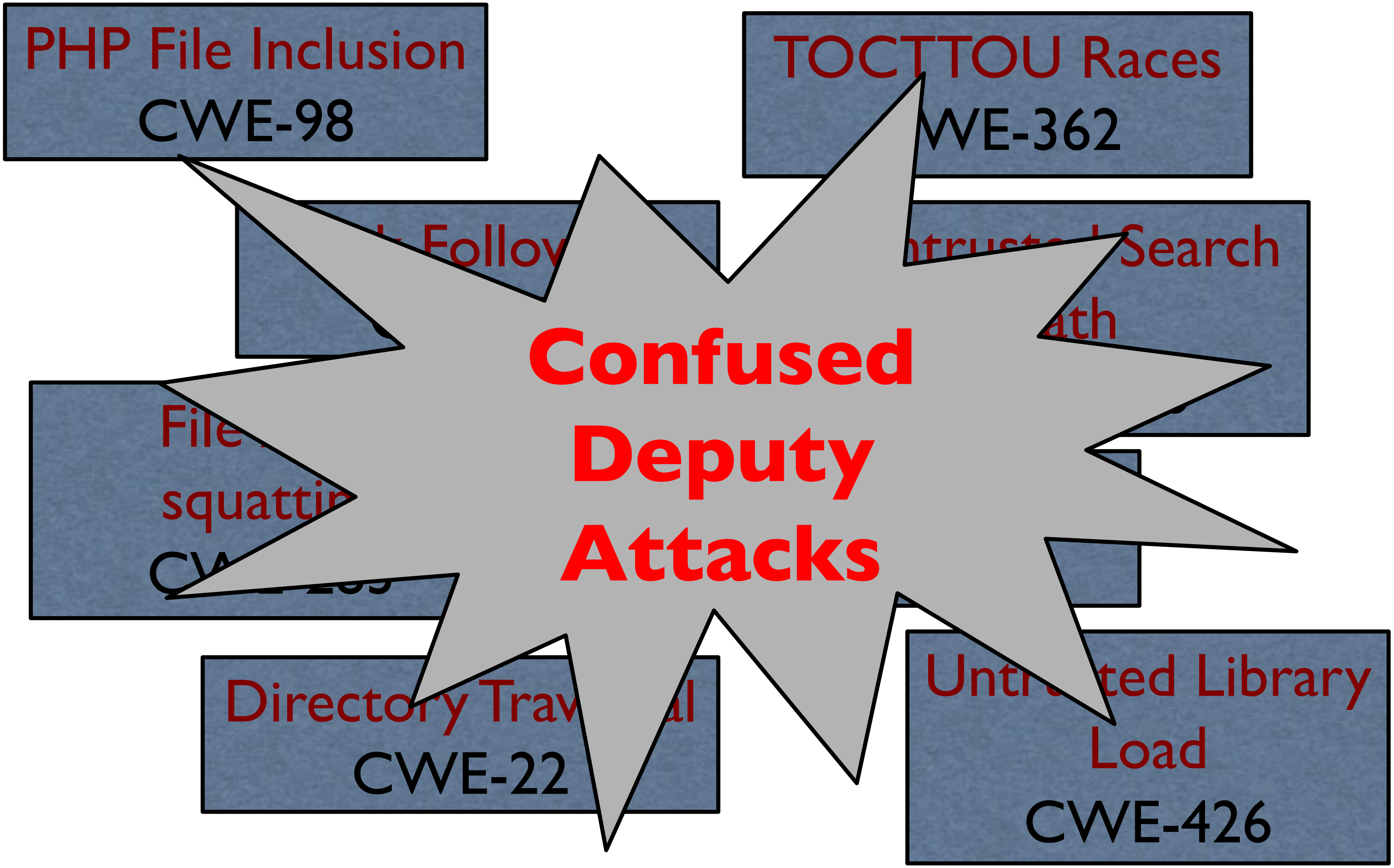


- Program acts as a *confused deputy*
  - 😈 when expecting 🛡
  - 🛡 when expecting 😈

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
WE-362

k Follow

ntrusted Search
ath

File
squatti
CW

Directory Trav al
CWE-22

Untr ted Library
Load
CWE-426

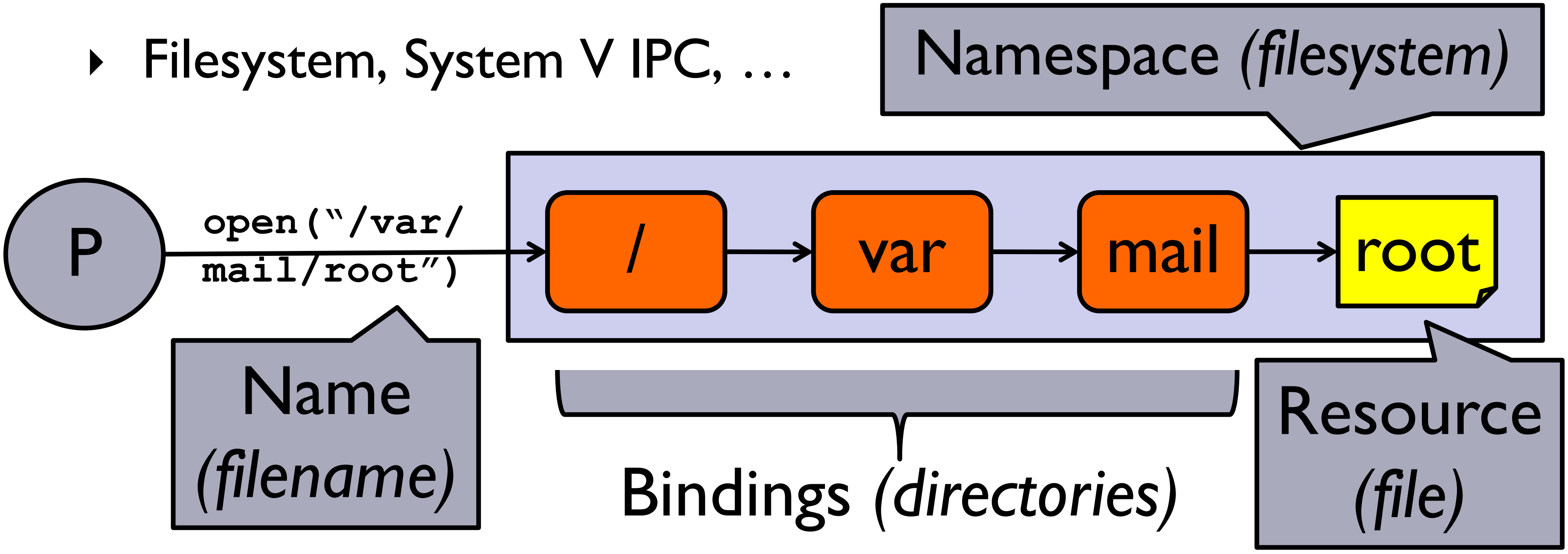
Confused Deputy Attacks

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

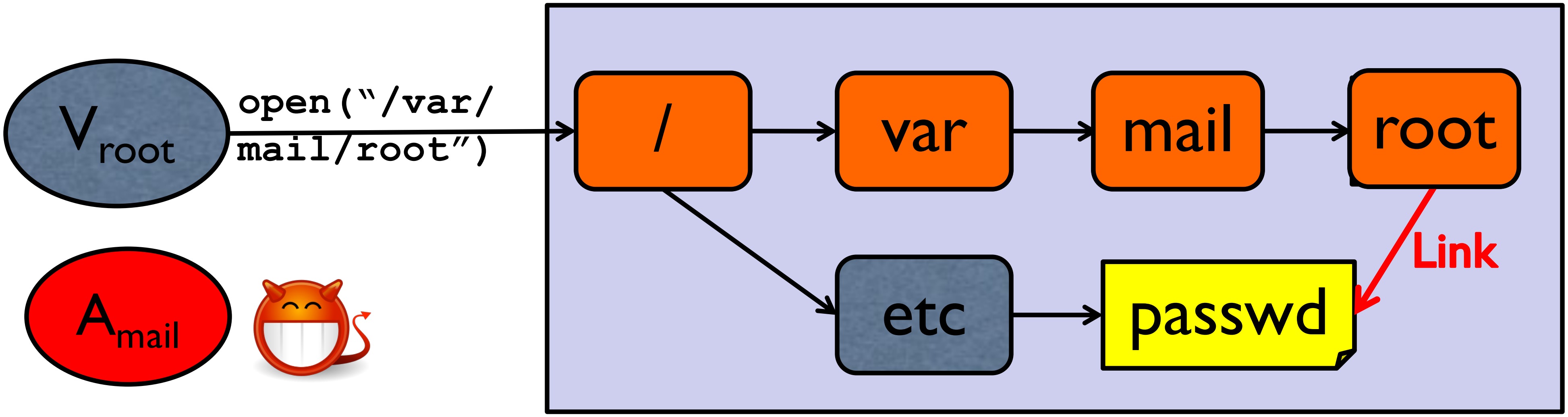
Name Resolution

- Processes often use *names* to obtain access to *system resources*
- A *nameserver* (e.g.,OS) performs *name resolution* using *namespace bindings* (e.g., *directory*) to convert a *name* (e.g., *filename*) 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 adversary-accessible resource, gets a protected resource instead



V_{root}

`open(“/var/mail/root”)`

A_{mail}

/

var

mail

root

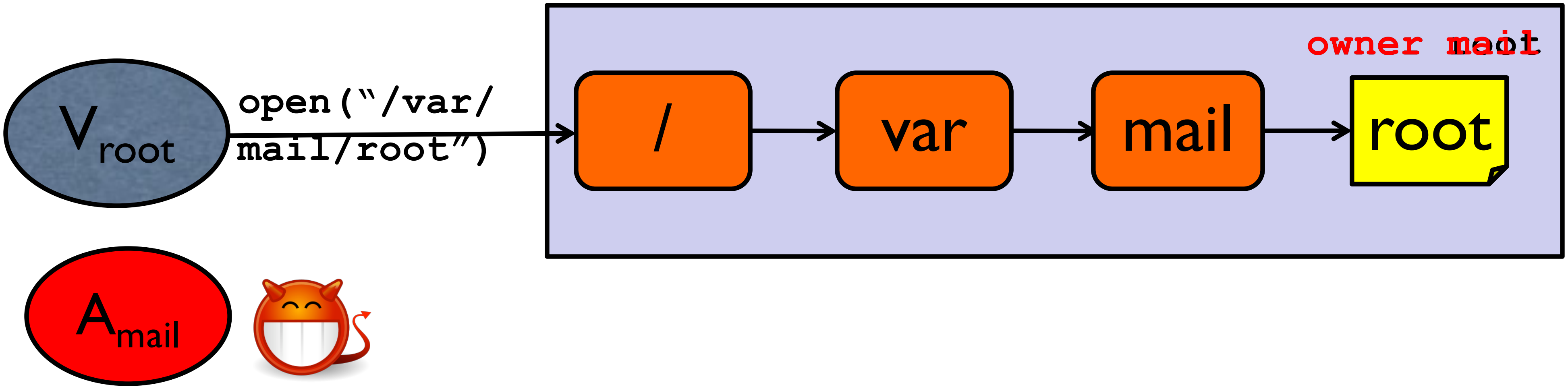
etc

passwd

Link

File Squatting Attack

- Adversary controls final resource enabling the adversary to control input that the victim may depend on
- Victim expects protected resource, gets an adversary-controlled resource 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

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 asks to open the file path "/tmp/just_a_normal_file_here"
  - What file will you 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

Link Traversal

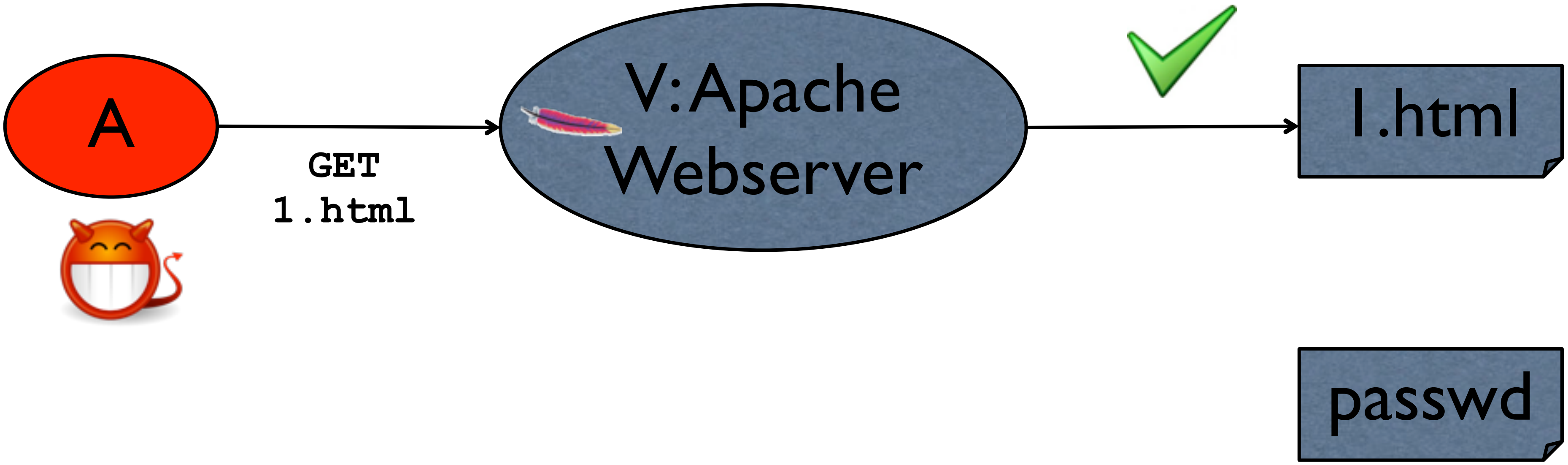
- Suppose your program is asked to open the file path “/tmp/just_a_normal_file_here”
  - What file will you open?
    - An adversary could have created this as a symbolic link to any file in the system
    - And it is difficult/expensive to verify that this is not a symbolic link
      - lstat – provides file system information (like “stat”) for the file referenced by a link if the path name refers to a link
      - RACES: But, adversary could place a file at the time of the lstat check and replace with a link before the open
  - Causes your program to access an adversary-chosen file

TOCTTOU Races

- Time-of-check-to-time-of-use Race Attacks
- Check System Calls
  - Does the requesting party have access to the file? (stat, access)
  - Is the file accessed via a symbolic link? (lstat)
- Use System Calls
  - Convert the file name to a file descriptor (open)
  - Modify the file metadata (chown, chmod)
- Can an adversary modify the filesystem in between?

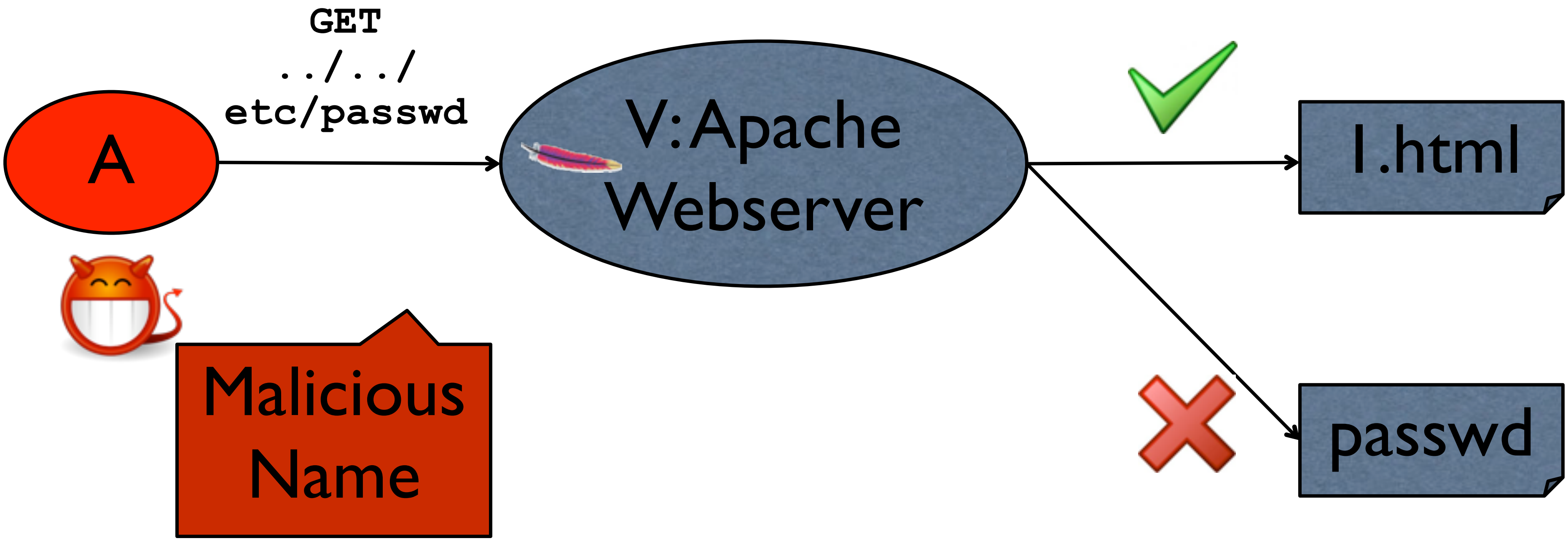
Directory Traversal

- Adversary controls the name to direct victim to an adversary inaccessible (high integrity) resource



Directory Traversal

- Adversary controls the name to direct victim to an adversary inaccessible (high integrity) resource
- Victim expects adversary accessible (low integrity) resource



Common Threat

- What is the threat that enables directory traversal attacks?

Common Threat

- What is the threat that enables directory traversal attacks?
- In this case, the victim uses adversary input to construct file names
  - Any parts of file names

File Name Input

- Suppose your program uses network input to construct a file name
  - What can go wrong?

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  - What can go wrong?
- Suppose your program appends network input to the path "/tmp/" to open the file /tmp/<input>
  - Safe?

Common Threat

- What is the threat that enables directory traversal attacks?
- Suppose your program appends input to the path "/tmp/" to open the file /tmp/<input>
  - Safe?
  - No. An adversary could input: "../etc/shadow"
    - What file will be opened?

Overall Lesson

- What is the takeaway lesson from all these vulnerabilities?

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- What is the takeaway lesson from all these vulnerabilities?
  - Any time you use adversary-controlled inputs in your programs you must be careful to vet that input
    - The same for using program input and filesystem resources as input
  - Does this correspond to any security principle you learned in CMPSC 443?

Overall Lesson

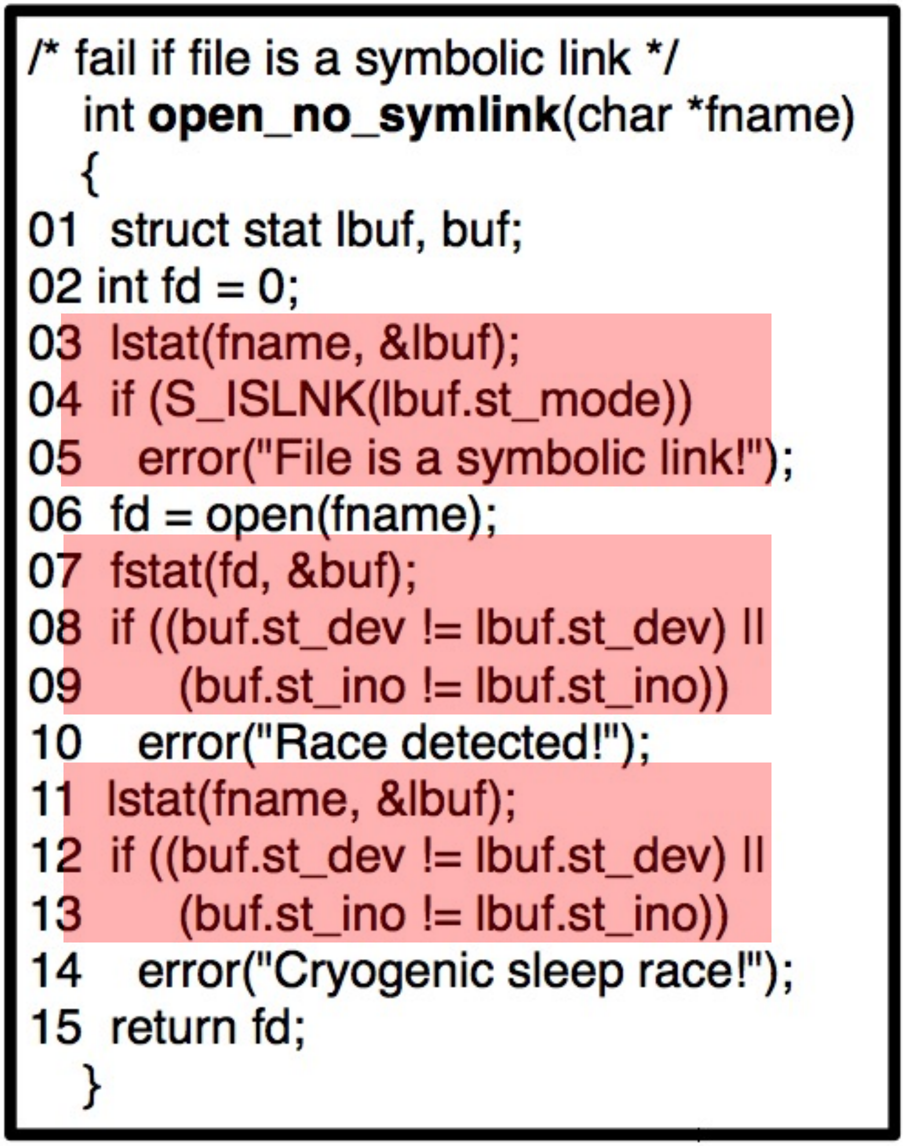
- What is the takeaway lesson from all lthese vulnerabilities?
  - Any time you use adversary-controlled inputs in processing you must be careful to vet that input
  - Does this correspond to any security principle you learned in CMPSC 443?
    - How about Biba integrity?
    - Low-water mark integrity?
    - Clark-Wilson integrity?

Current Defenses

- Are there defenses to prevent such attacks?
- For filesystem inputs (file squat and link traversal)
  - Yes, but the defenses are not comprehensive
- For using inputs to construct filenames (directory traversal)
  - No, you are on your own
  - Some research defenses have been proposed, but need to know about the program
    - May need programmers to do more in the future

Open_No_Symlink Defense

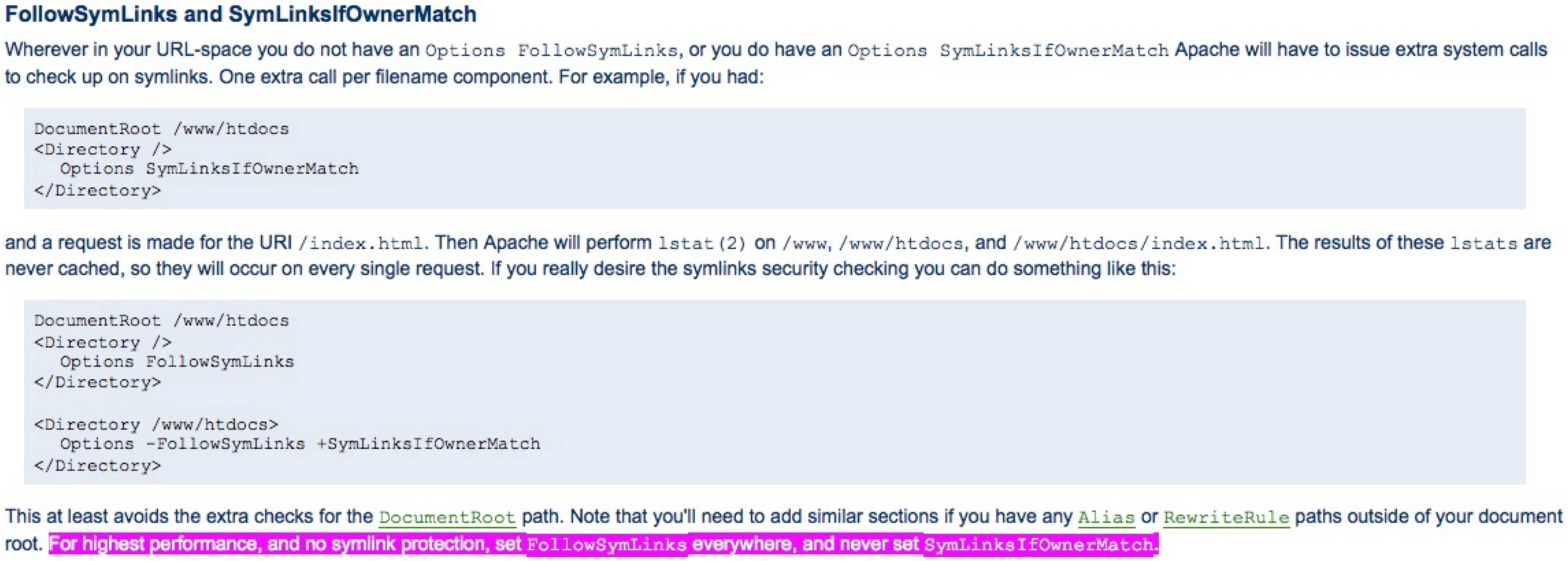
- Check for symbolic link (lstat)
- Check for lstat-open race
- Check for inode recycling
- Do checks for each path component (`safe_open`)
    - /, var, mail, …
- What if you want to use symlinks – just safely?



```
/* fail if file is a symbolic link */
   int open_no_symlink(char *fname)
   {
   struct stat lbuf, buf;
  int fd = 0;
   lstat(fname, &lbuf);
   if (S_ISLNK(lbuf.st_mode))
     error("File is a symbolic link!");
   fd = open(fname);
   fstat(fd, &buf);
   if ((buf.st_dev != lbuf.st_dev) II
        (buf.st_ino != lbuf.st_ino))
     error("Race detected!");
   lstat(fname, &lbuf);
   if ((buf.st_dev != lbuf.st_dev) II
        (buf.st_ino != lbuf.st_ino))
     error("Cryogenic sleep race!");
   return fd;
   }
```

Problem - Inefficient

- Checking retrieved resources is expensive
  - Single open() requires *4 * path length* additional syscalls
  - Programmers omit checks to improve performance
    - Example: Apache documentation recommended switching off resource access checks



FollowSymLinks and SymLinksIfOwnerMatch

Wherever in your URL-space you do not have an `Options FollowSymLinks`, or you do have an `Options SymLinksIfOwnerMatch` Apache will have to issue extra system calls to check up on symlinks. One extra call per filename component. For example, if you had:

```
DocumentRoot /www/htdocs
<Directory />
  Options SymLinksIfOwnerMatch
</Directory>
```

and a request is made for the URI `/index.html`. Then Apache will perform `lstat(2)` on `/www`, `/www/htdocs`, and `/www/htdocs/index.html`. The results of these `lstats` are never cached, so they will occur on every single request. If you really desire the symlinks security checking you can do something like this:

```
DocumentRoot /www/htdocs
<Directory />
  Options FollowSymLinks
</Directory>

<Directory /www/htdocs>
  Options -FollowSymLinks +SymLinksIfOwnerMatch
</Directory>
```

This at least avoids the extra checks for the `DocumentRoot` path. Note that you'll need to add similar sections if you have any `Alias` or `RewriteRule` paths outside of your document root. For highest performance, and no symlink protection, set `FollowSymLinks` everywhere, and never set `SymLinksIfOwnerMatch`.

Defenses

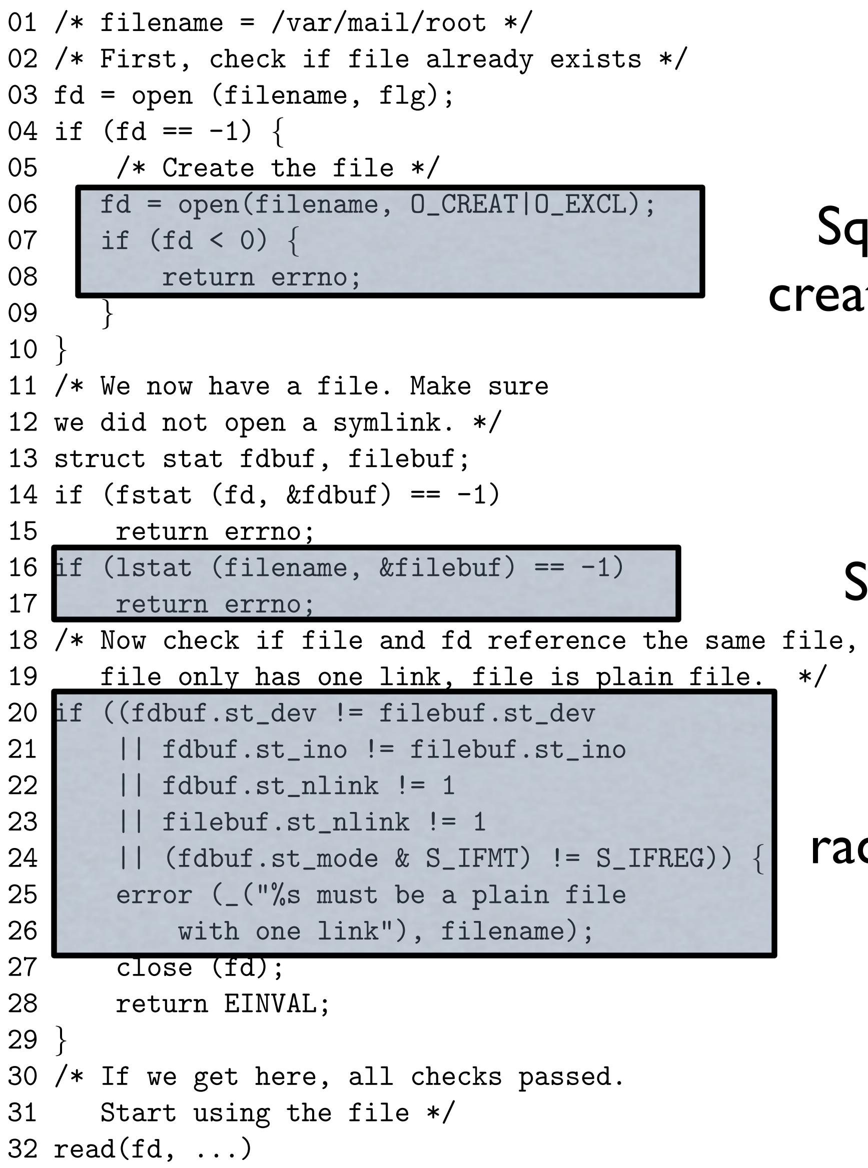
- Variants of the “open” system call
  - Flag “O_NOFOLLOW” – do not follow any symbolic links (prevent link traversal)
    - Does not help if you need to follow symbolic links
    - May not be available on your system
  - Flag “O_EXCL” and “O_CREAT” – do not open unless the new file is created (prevent file squatting)
    - Does not help if the file may or may not be created already
- 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 part of the name resolution (for dirfd) and prevent further use of links
  - Supports O_NOFOLLOW
    - *int openat(int dirfd, const char *path, int oflag, ...);*
  - Helps if resolution of directory “dirfd” is unsafe, but is limited if resolution of the “path” is unsafe
    - Check “dirfd” with the “fstat” syscall – “stat” for descriptors
- The “openat2” system call
  - More flags limiting “how” name resolution is done for “path”

Attacks 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, ...)
```

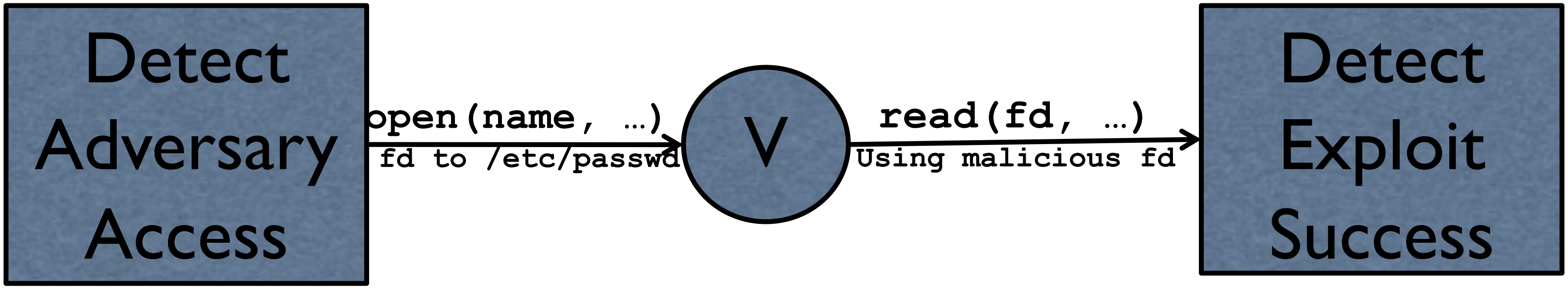
Squat during create (resource)

Symbolic link

Hard link, race conditions

Runtime Testing [STING]

- We actively change the namespace whenever an adversary can write to a directory in resolution
  - Fundamental problem: adversaries may be able to write directories used in name resolution
- Use adversary model to identify program adversaries and vulnerable directories



Detect Adversary Access

open(name, …)

fd to /etc/passwd

V

read(fd, …)

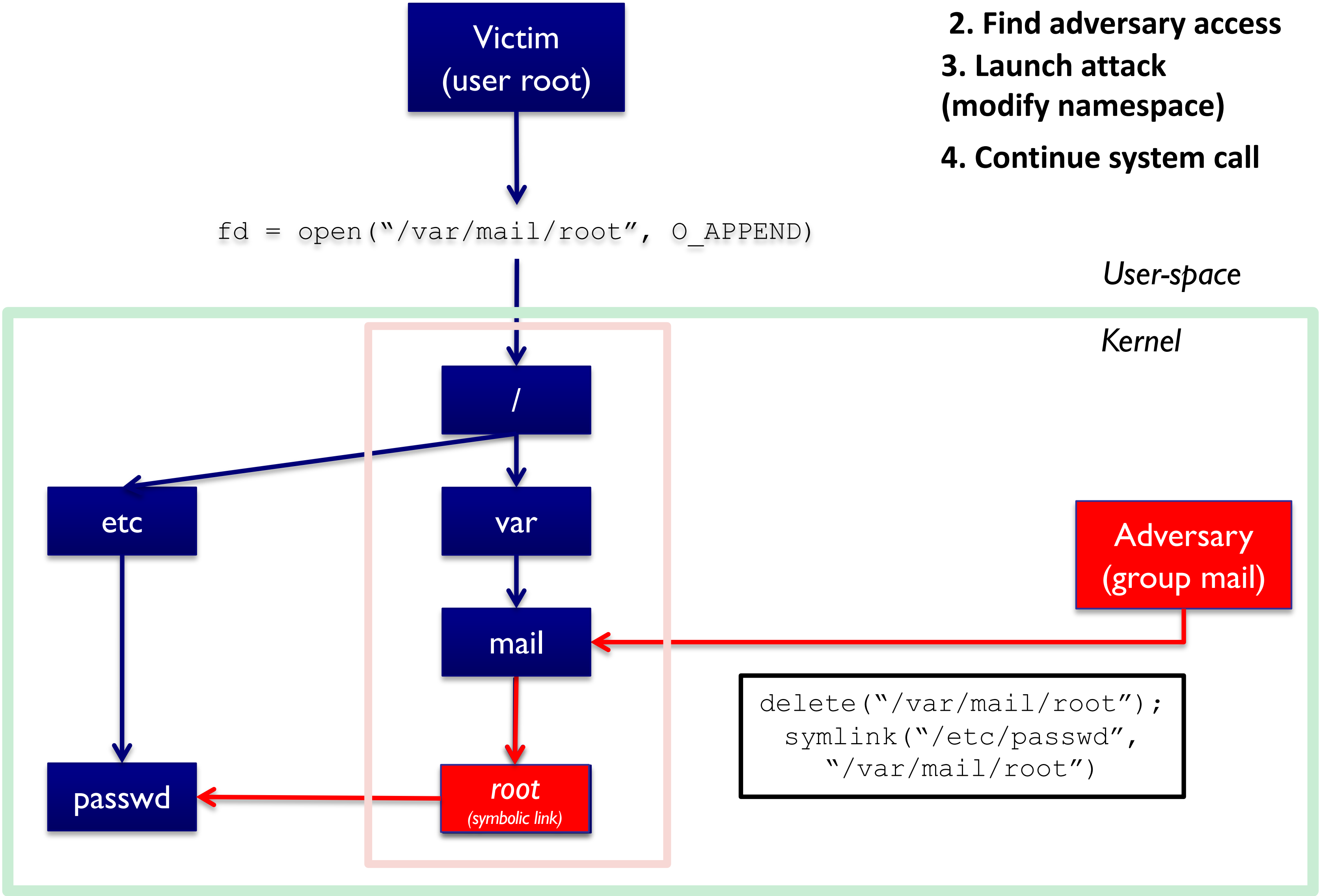
Using malicious fd

Detect Exploit Success

Vulnerable!

STING Launch Phase

1. **Find bindings**
2. **Find adversary access**
3. **Launch attack (modify namespace)**
4. **Continue system call**

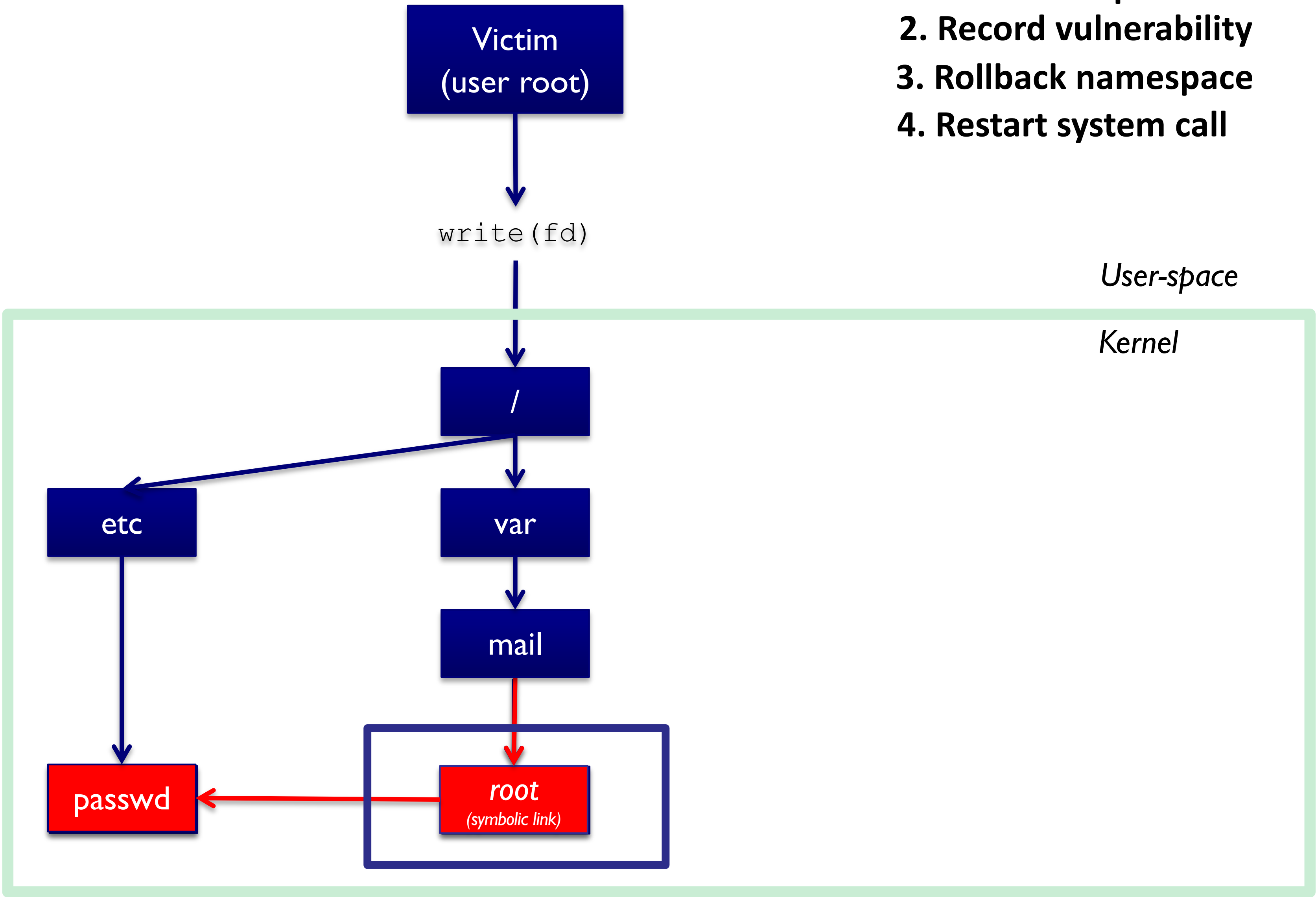


```
fd = open("/var/mail/root", O_APPEND)
```

```
delete("/var/mail/root");
symlink("/etc/passwd",
"/var/mail/root")
```

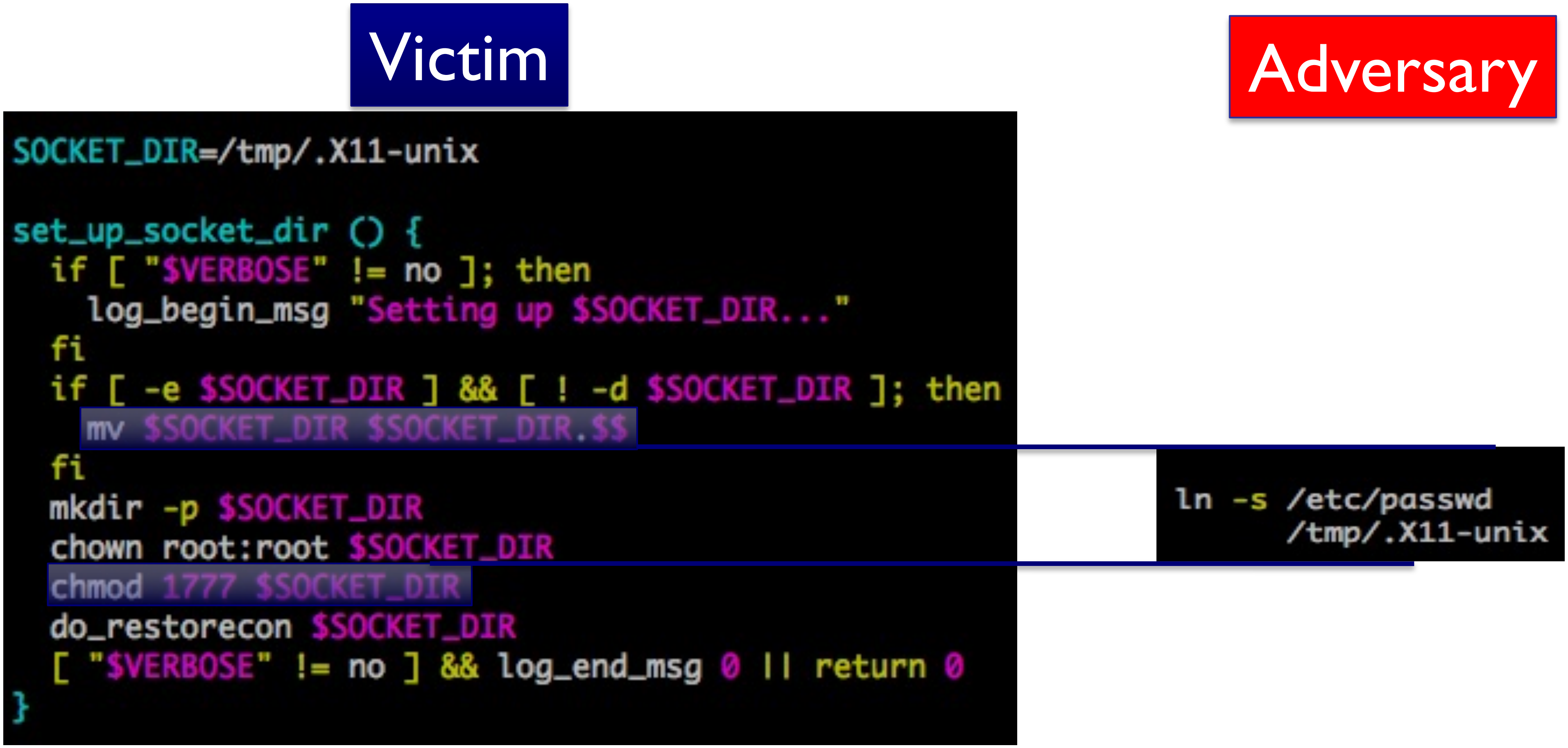
STING Detect Phase

1. Victim accepts resource
2. Record vulnerability
3. Rollback namespace
4. Restart system call



STING Detects TOCTTOU Races

- STING can deterministically create races, as it is in the OS



Victim

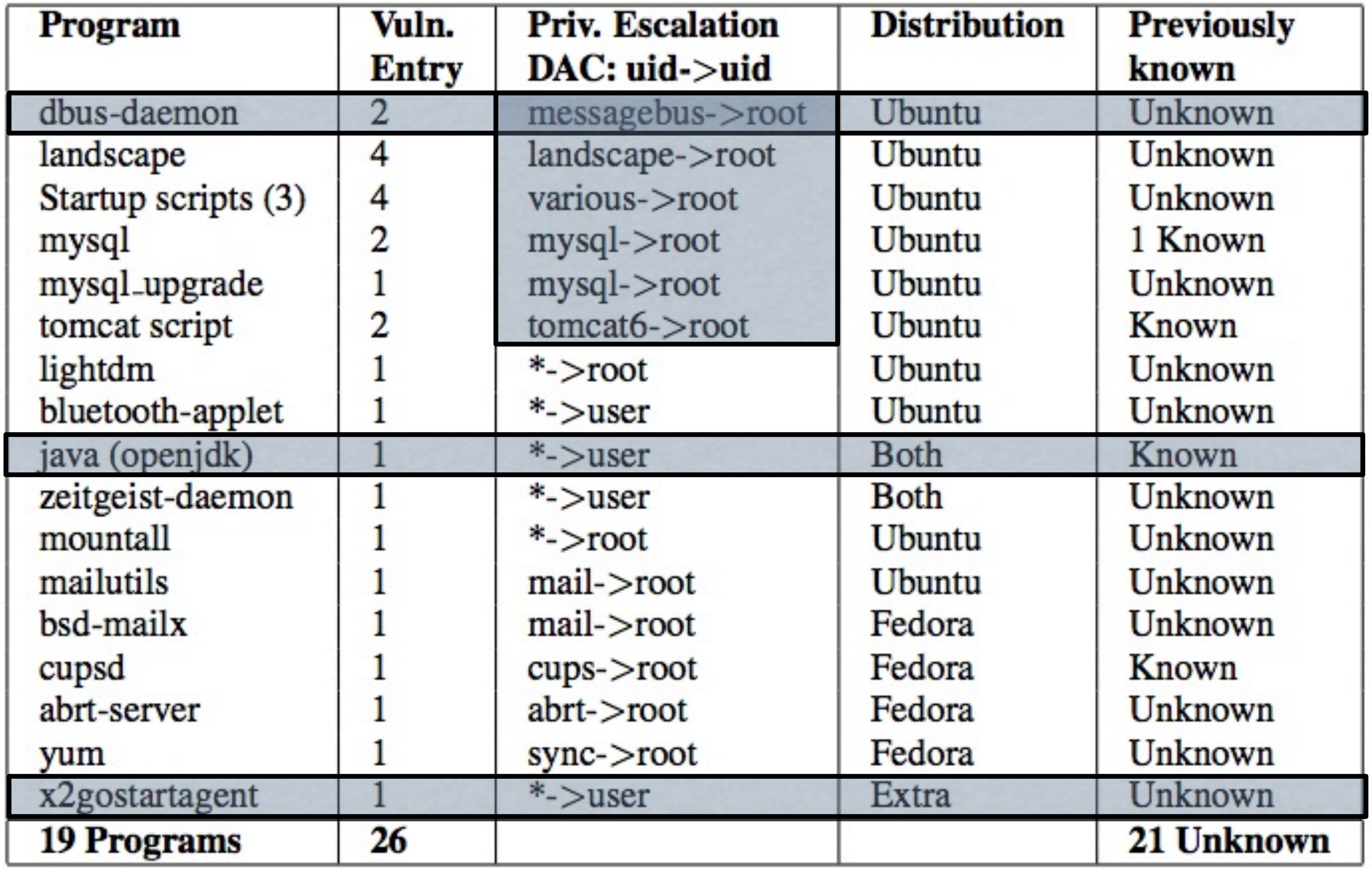
```
SOCKET_DIR=/tmp/.X11-unix

set_up_socket_dir () {
  if [ "$VERBOSE" != no ]; then
    log_begin_msg "Setting up $SOCKET_DIR..."
  fi
  if [ -e $SOCKET_DIR ] && [ ! -d $SOCKET_DIR ]; then
    mv $SOCKET_DIR $SOCKET_DIR.$$
  fi
  mkdir -p $SOCKET_DIR
  chown root:root $SOCKET_DIR
  chmod 1777 $SOCKET_DIR
  do_restorecon $SOCKET_DIR
  [ "$VERBOSE" != no ] && log_end_msg 0 || return 0
}
```

Adversary

```
ln -s /etc/passwd
      /tmp/.X11-unix
```

Results - Vulnerabilities



Program	Vuln. Entry	Priv. Escalation DAC: uid->uid	Distribution	Previously known
dbus-daemon	2	messagebus->root	Ubuntu	Unknown
landscape	4	landscape->root	Ubuntu	Unknown
Startup scripts (3)	4	various->root	Ubuntu	Unknown
mysql	2	mysql->root	Ubuntu	1 Known
mysql_upgrade	1	mysql->root	Ubuntu	Unknown
tomcat script	2	tomcat6->root	Ubuntu	Known
lightdm	1	*->root	Ubuntu	Unknown
bluetooth-applet	1	*->user	Ubuntu	Unknown
java (openjdk)	1	*->user	Both	Known
zeitgeist-daemon	1	*->user	Both	Unknown
mountall	1	*->root	Ubuntu	Unknown
mailutils	1	mail->root	Ubuntu	Unknown
bsd-mailx	1	mail->root	Fedora	Unknown
cupsd	1	cups->root	Fedora	Known
abrt-server	1	abrt->root	Fedora	Unknown
yum	1	sync->root	Fedora	Unknown
x2gostartagent	1	*->user	Extra	Unknown
19 Programs	**26**			**21 Unknown**

Both old and new programs

Special users to root

Known but unfixed!

Take Away

- Programs can be exploited when retrieving system resources
    - Because adversaries may share access to resources and/or namespaces
    - Called Confused Deputy Attacks – trick a program into performing an operation of an adversary's choosing
- Adversaries may control two kinds of inputs
    - Filesystem configuration - where directories are shared
    - Program inputs – where could be from an untrusted party
- Can improve security through careful use of syscall APIs and through better runtime testing