Set-UID Privileged Programs

Need for Privileged Programs

- Password Dilemma
  - Permissions of /etc/shadow File:

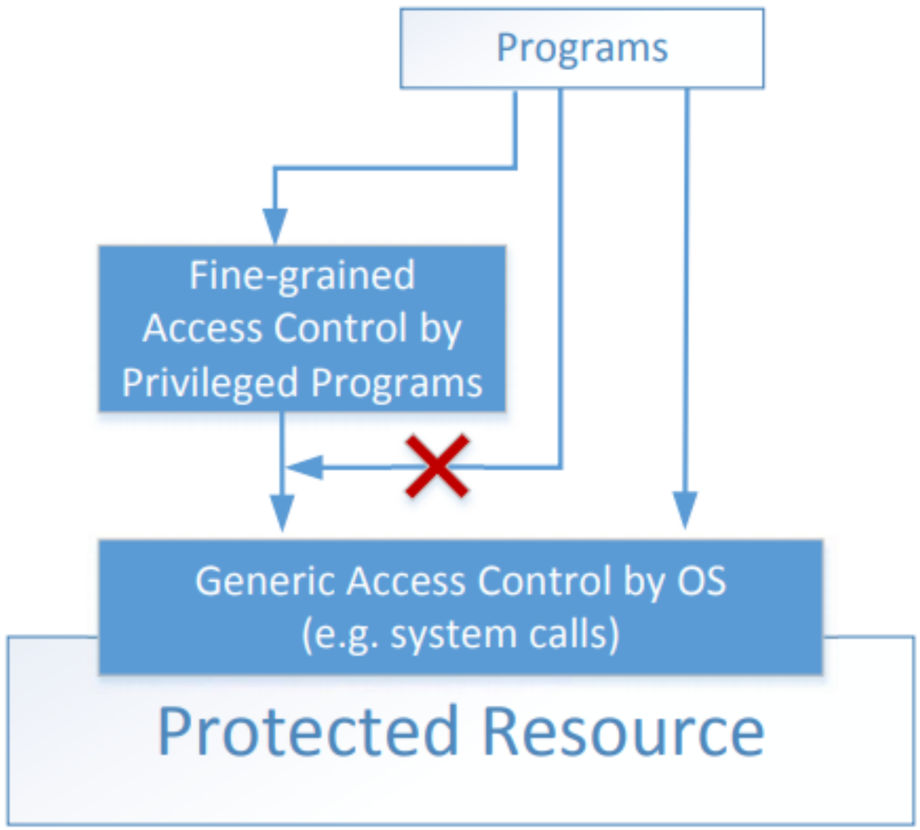
```
-rw-r----- 1 root shadow 1443 May 23 12:33 /etc/shadow
  ↑ Only writable to the owner
```

  - How would normal users change their password?

```
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWbQI1cFjn0R25yqtqrSrFeWfCgybQWWnwR4ks/.rjqyM7Xw
h/pDyc5U1BWOzkWh7T9ZGu.:15933:0:99999:7:::
daemon:*:15749:0:99999:7:::
bin:*:15749:0:99999:7:::
sys:*:15749:0:99999:7:::
sync:*:15749:0:99999:7:::
games:*:15749:0:99999:7:::
man:*:15749:0:99999:7:::
lp:*:15749:0:99999:7:::
```

Two-Tier Approach

- Implementing fine-grained access control in operating systems make OS over complicated.
- OS relies on extension to enforce fine-grained access control
- Privileged programs are such extensions



Types of Privileged Programs

- Daemons
  - Computer program that runs in the background
  - Needs to run as root or other privileged users

- Set-UID Programs
  - Widely used in UNIX systems
  - Program marked with a special bit

Set-UID Concept

- **Allow user to run a program with the program owner's privilege.**
- Allow users to run programs with temporary elevated privileges
- Example: the `passwd` program

```
$ ls -l /usr/bin/passwd
-rwsr-xr-x 1 root root 41284 Sep 12  2012 /usr/bin/passwd
```

Set-UID Concept

- Every process has two User IDs.
- **Real UID (RUID)**: Identifies real owner of process
- **Effective UID (EUID)**: Identifies privilege of a process
  - Access control is based on EUID
- When a normal program is executed, RUID = EUID, they both equal to the ID of the user who runs the program
- When a Set-UID is executed, RUID ≠ EUID. RUID still equal to the user's ID, but EUID equals to the program **owner**'s ID.
  - If the program is owned by root, the program runs with the root privilege.

Turn a Program into Set-UID

- Change the owner of a file to root :

```
seed@VM:~$ cp /bin/cat ./mycat
seed@VM:~$ sudo chown root mycat
seed@VM:~$ ls -l mycat
-rwxr-xr-x 1 root seed 46764 Nov  1 13:09 mycat
seed@VM:~$
```

- Before Enabling Set-UID bit:

```
seed@VM:~$ mycat /etc/shadow
mycat: /etc/shadow: Permission denied
seed@VM:~$
```

- After Enabling the Set-UID bit :

```
seed@VM:~$ sudo chmod 4755 mycat
seed@VM:~$ mycat /etc/shadow
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWbQI1cFjn
h/pDyc5U1BWOzkWh7T9ZGu.:15933:0:99999:7:::
daemon:*:15749:0:99999:7:::
bin:*:15749:0:99999:7:::
sys:*:15749:0:99999:7:::
```

How it Works

A Set-UID program is just like any other program, except that it has a special marking, which a single bit called Set-UID bit

```
$ cp /bin/id ./myid
$ sudo chown root myid
$ ./myid
uid=1000(seed) gid=1000(seed) groups=1000(seed), ...
```

```
$ sudo chmod 4755 myid
$ ./myid
uid=1000(seed) gid=1000(seed) euid=0(root) ...
```

Example of Set UID

```
$ cp /bin/cat ./mycat
$ sudo chown root mycat
$ ls -l mycat
-rwxr-xr-x 1 root seed 46764 Feb 22 10:04 mycat
$ ./mycat /etc/shadow
./mycat: /etc/shadow: Permission denied
```

↰ Not a privileged program

```
$ sudo chmod 4755 mycat
$ ./mycat /etc/shadow
root:$6$012BPz.K$fbPkT6H6Db4/B8c...
daemon:*:15749:0:99999:7:::
...
```

↰ Become a privileged program

```
$ sudo chown seed mycat
$ chmod 4755 mycat
$ ./mycat /etc/shadow
./mycat: /etc/shadow: Permission denied
```

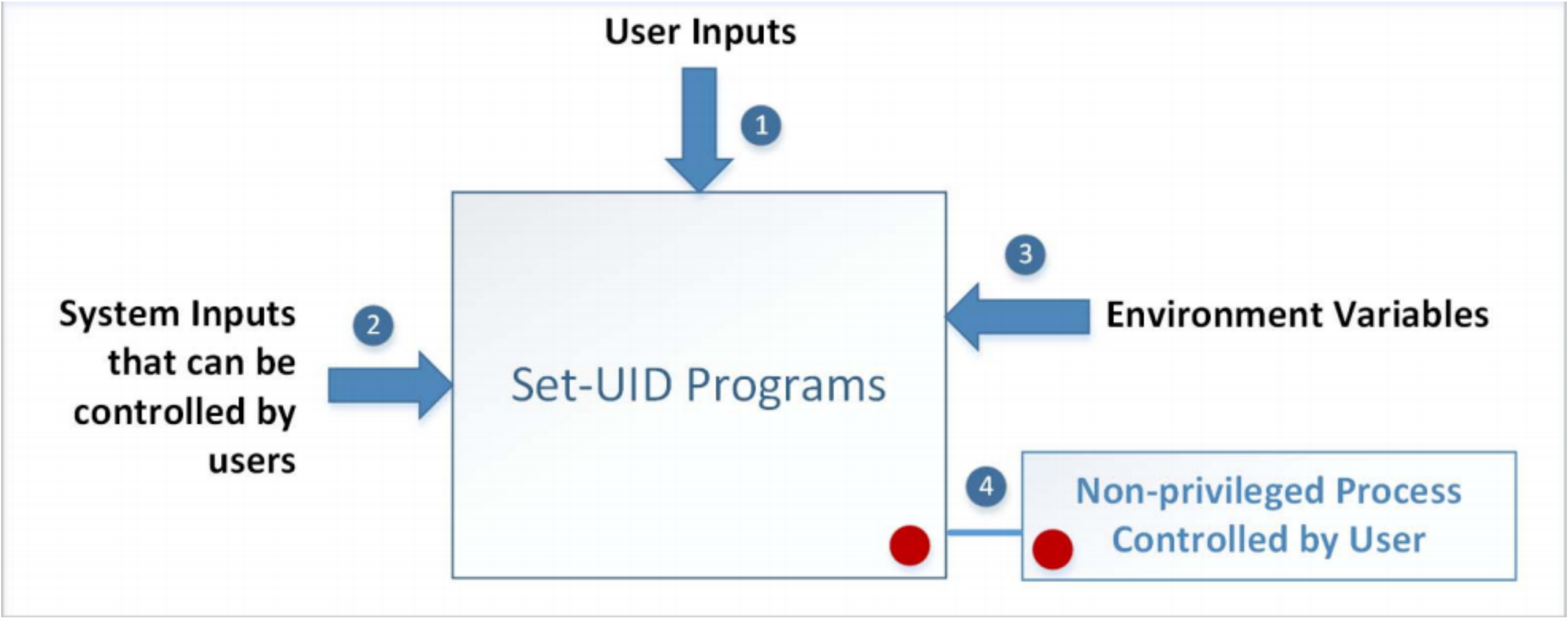
↰ It is still a privileged program, but not the root privilege

How is Set-UID Secure?

- Allows normal users to escalate privileges
  - This is different from directly giving the privilege (sudo command)
  - Restricted behavior – similar to superman designed computer chips

- Unsafe to turn all programs into Set-UID
  - Example: /bin/sh
  - Example: vi

Attack Surfaces of Set-UID Programs



Attacks via User Inputs

User Inputs: Explicit Inputs

- Buffer Overflow – More information in Chapter 4
  - Overflowing a buffer to run malicious code
- Format String Vulnerability – More information in Chapter 6
  - Changing program behavior using user inputs as format strings

Attacks via User Inputs

CHSH – Change Shell

- Set-UID program with ability to change default shell programs
- Shell programs are stored in /etc/passwd file

Issues

- Failing to sanitize user inputs
- Attackers could create a new root account

Attack

```
bob:$6$jUODEFsfwfi3:1000:1000:Bob Smith,,,:/home/bob:/bin/bash
```

Attacks via System Inputs

System Inputs

- Race Condition – More information in Chapter 7
  - Symbolic link to privileged file from a unprivileged file
  - Influence programs
  - Writing inside world writable folder

Attacks via Environment Variables

- Behavior can be influenced by inputs that are not visible inside a program.
- Environment Variables : These can be set by a user before running a program.
- Detailed discussions on environment variables will be in Chapter 2.

Attacks via Environment Variables

- `PATH` Environment Variable
  - Used by shell programs to locate a command if the user does not provide the full path for the command
  - system(): call /bin/sh first
  - system("ls")
    - /bin/sh uses the PATH environment variable to locate "ls"
    - Attacker can manipulate the PATH variable and control how the "ls" command is found
- More examples on this type of attacks can be found in Chapter 2

Capability Leaking

- In some cases, Privileged programs downgrade themselves during execution
- Example: The `su` program
  - This is a privileged Set-UID program
  - Allows one user to switch to another user (say user1 to user2)
  - Program starts with EUID as root and RUID as user1
  - After password verification, both EUID and RUID become user2’s (via privilege downgrading)
- Such programs may lead to capability leaking
  - Programs may not clean up privileged capabilities before downgrading

Attacks via Capability Leaking: An Example

The /etc/zzz file is only writable by root

File descriptor is created (the program is a root-owned Set-UID program)

The privilege is downgraded

Invoke a shell program, so the behavior restriction on the program is lifted

```
fd = open("/etc/zzz", O_RDWR | O_APPEND);
if (fd == -1) {
   printf("Cannot open /etc/zzz\n");
   exit(0);
}

// Print out the file descriptor value
printf("fd is %d\n", fd);

// Permanently disable the privilege by making the
// effective uid the same as the real uid
setuid(getuid());

// Execute /bin/sh
v[0] = "/bin/sh"; v[1] = 0;
execve(v[0], v, 0);
```

Attacks via Capability Leaking (Continued)

The program forgets to close the file, so the file descriptor is still valid.

Capability Leak

```
$ gcc -o cap_leak cap_leak.c
$ sudo chown root cap_leak
[sudo] password for seed:
$ sudo chmod 4755 cap_leak
$ ls -l cap_leak
-rwsr-xr-x 1 root seed 7386 Feb 23 09:24 cap_leak
$ cat /etc/zzz
bbbbbbbbbbbbbbb
$ echo aaaaaaaaaa > /etc/zzz
bash: /etc/zzz: Permission denied   ← Cannot write to the file
$ cap_leak
fd is 3
$ echo cccccccccccc >& 3            ← Using the leaked capability
$ exit
$ cat /etc/zzz
bbbbbbbbbbbbbbb
cccccccccccc                        ← File modified
```

How to fix the program?

Destroy the file descriptor before downgrading the privilege (close the file)

Capability Leaking in OS X – Case Study

- OS X Yosemite found vulnerable to privilege escalation attack related to capability leaking in July 2015 (OS X 10.10)
- Added features to dynamic linker `dyld`
  - DYLD_PRINT_TO_FILE environment variable
- The dynamic linker can open any file, so for root-owned Set-UID programs, it runs with root privileges. The dynamic linker `dyld`, does not close the file. There is a capability leaking.
- Scenario 1 (safe): Set-UID finished its job and the process dies. Everything is cleaned up and it is safe.
- **Scenario 2 (unsafe):** Similar to the "`su`" program, the privileged program downgrade its privilege, and lift the restriction.

Invoking Programs

- Invoking external commands from inside a program
- External command is chosen by the Set-UID program
  - Users are not supposed to provide the command (or it is not secure)
- Attack:
  - Users are often asked to provide input data to the command.
  - If the command is not invoked properly, user’s input data may be turned into command name. This is dangerous.

Invoking Programs : Unsafe Approach

```
int main(int argc, char *argv[])
{
  char *cat="/bin/cat";

  if(argc < 2) {
    printf("Please type a file name.\n");
    return 1;
  }

  char *command = malloc(strlen(cat) + strlen(argv[1]) + 2);
  sprintf(command, "%s %s", cat, argv[1]);
  system(command);
  return 0 ;
}
```

- The easiest way to invoke an external command is the system() function.
- This program is supposed to run the `/bin/cat` program.
- It is a root-owned Set-UID program, so the program can view all files, but it can't write to any file.

Question: Can you use this program to run other command, with the root privilege?

Invoking Programs : Unsafe Approach (Continued)

```
$ gcc -o catall catall.c
$ sudo chown root catall
$ sudo chmod 4755 catall
$ ls -l catall
-rwsr-xr-x 1 root seed 7275 Feb 23 09:41 catall
$ catall /etc/shadow
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWb....
daemon:*:15749:0:99999:7:::
bin:*:15749:0:99999:7:::
sys:*:15749:0:99999:7:::
sync:*:15749:0:99999:7:::
games:*:15749:0:99999:7:::

$ catall "aa;/bin/sh"
/bin/cat: aa: No such file or directory
#        ← Got the root shell!
# id
uid=1000(seed) gid=1000(seed) euid=0(root) groups=0(root), ...
```

We can get a root shell with this input

Problem: Some part of the data becomes code (command name)

A Note

- In Ubuntu 16.04, /bin/sh points to /bin/dash, which has a countermeasure
  - It drops privilege when it is executed inside a set-uid process
- Therefore, we will only get a normal shell in the attack on the previous slide
- Do the following to remove the countermeasure

```
Before experiment: link /bin/sh to /bin/zsh
$ sudo ln -sf /bin/zsh /bin/sh

After experiment: remember to change it back
$ sudo ln -sf /bin/dash /bin/sh
```

Invoking Programs Safely: using **execve()**

```
int main(int argc, char *argv[])
{
  char *v[3];

  if(argc < 2) {
    printf("Please type a file name.\n");
    return 1;
  }

  v[0] = "/bin/cat"; v[1] = argv[1]; v[2] = 0;
  execve(v[0], v, 0);

  return 0 ;
}
```

```
execve(v[0], v, 0)
```

- `v[0]`: Command name is provided here (by the program)
- `v`: Input data are provided here (can be by user)

Why is it safe?

Code (command name) and data are clearly separated; there is no way for the user data to become code

Invoking Programs Safely (Continued)

```
$ gcc -o safecatall safecatall.c
$ sudo chown root safecatall
$ sudo chmod 4755 safecatall
$ safecatall /etc/shadow
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWb....
daemon:*:15749:0:99999:7:::
bin:*:15749:0:99999:7:::
sys:*:15749:0:99999:7:::
sync:*:15749:0:99999:7:::
games:*:15749:0:99999:7:::

$ safecatall "aa;/bin/sh"
/bin/cat: aa;/bin/sh: No such file or directory    ← Attack failed!
```

The data are still treated as data, not code

Additional Consideration

- Some functions in the exec() family behave similarly to execve(), but may not be safe
  - execlp(), execvp() and execvpe() duplicate the actions of the shell. These functions can be attacked using the PATH Environment Variable

Invoking External Commands in Other Languages

- Risk of invoking external commands is not limited to C programs
- We should avoid problems similar to those caused by the system() functions
- Examples:
  - Perl: open() function can run commands, but it does so through a shell
  - PHP: system() function

```
<?php
  print("Please specify the path of the directory");
  print("<p>");
  $dir=$_GET['dir'];
  print("Directory path: " . $dir . "<p>");
  system("/bin/ls $dir");
?>
```

  - Attack:
    - `http://localhost/list.php?dir=.;date`
    - Command executed on server : “`/bin/ls .;date`”

Principle of Isolation

Principle: Don’t mix code and data.

Attacks due to violation of this principle :

- system() code execution
- Cross Site Scripting – More Information in Chapter 10
- SQL injection - More Information in Chapter 11
- Buffer Overflow attacks - More Information in Chapter 4

Principle of Least Privilege

- A privileged program should be given the power which is required to perform it’s tasks.
- Disable the privileges (temporarily or permanently) when a privileged program doesn’t need those.
- In Linux, seteuid() and setuid() can be used to disable/discard privileges.
- Different OSes have different ways to do that.

Summary

- The need for privileged programs
- How the Set-UID mechanism works
- Security flaws in privileged Set-UID programs
- Attack surface
- How to improve the security of privileged programs