

# Set-UID Privileged Programs

# Need for Privileged Programs

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

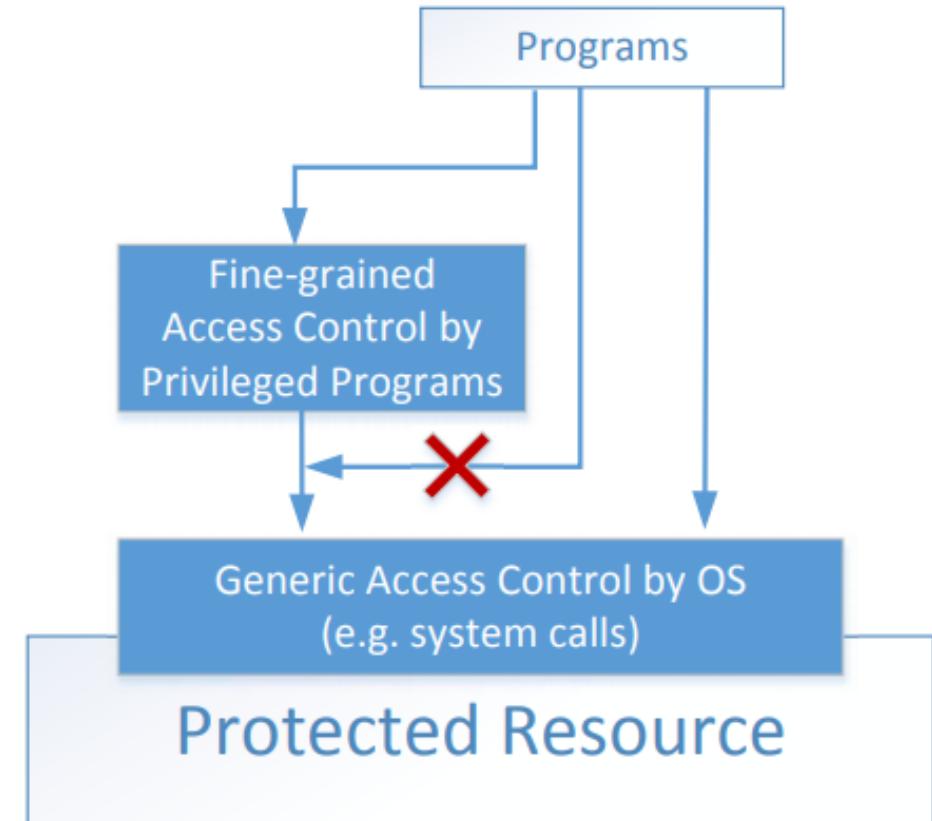
```
-rw-r----- 1 root shadow 1443 May 23 12:33 /etc/shadow
↑ Only writable to the owner
```

- How would normal users change their password?

```
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWbQI1cFjn0R25yqtqrSrFeWfCgybQWWnwR4ks/.rjqyM7Xw
h/pDyc5U1BW0zkWh7T9ZGu.: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

# Superman Story

- Power Suit
  - Superpeople: Directly give them the power
  - Issues: bad superpeople
- Power Suit 2.0
  - Computer chip
  - Specific task
  - No way to deviate from pre-programmed task
- Set-UID mechanism: A Power Suit mechanism implemented in Linux OS



# 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  $\neq$  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/B8cLWbQI1cFjn0
h/pDyc5U1BW0zkWh7T9ZGu.: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) euuid=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
```

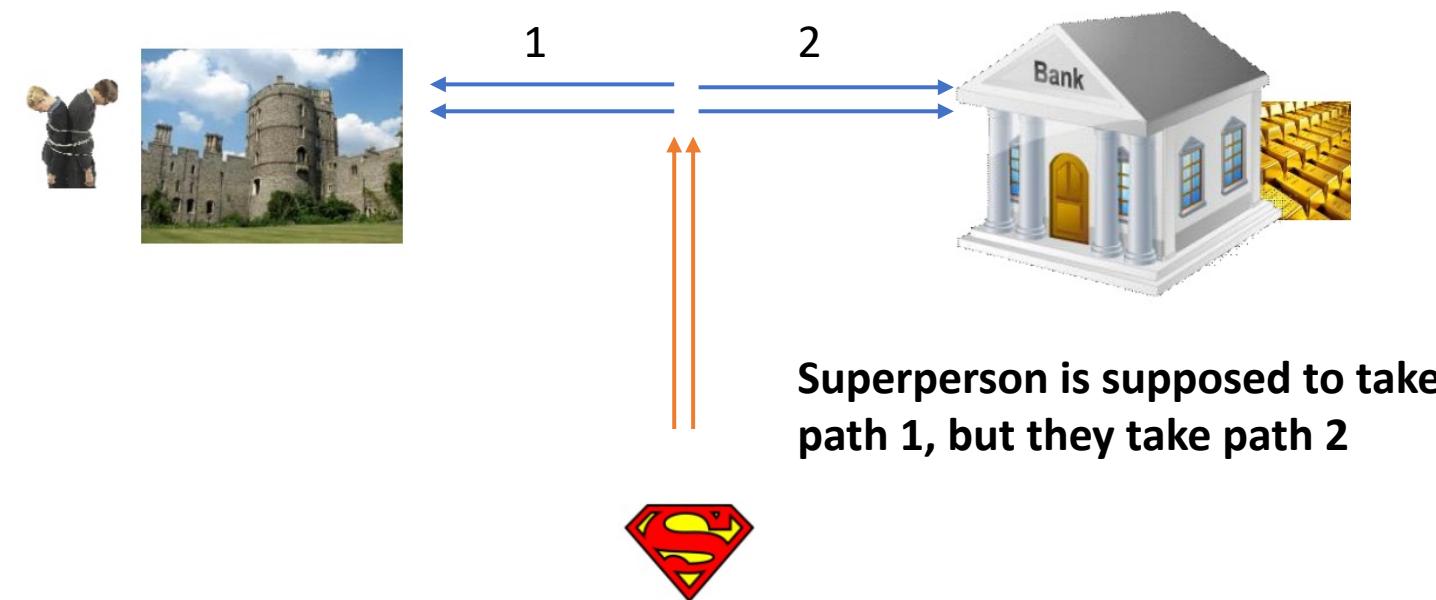
← It is still a privileged program, but not the root privilege

# How is Set-UID Secure?

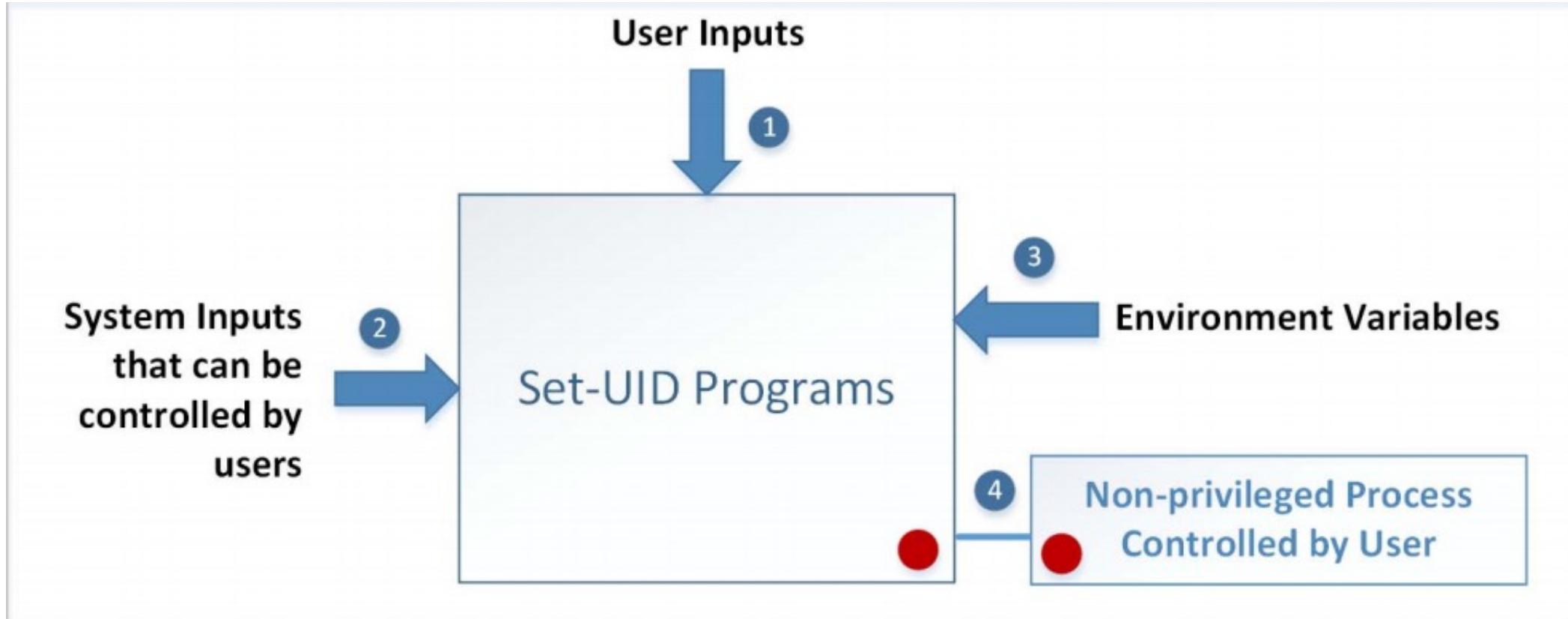
- Allows normal users to escalate privileges
  - This is different from directly giving the privilege (sudo command)
  - Restricted behavior – similar to superman designed computer chips
- Unsafe to turn all programs into Set-UID
  - Example: /bin/sh
  - Example: vi

# Attack on Superman

- Cannot assume that user can only do whatever is coded
  - Coding flaws by developers
- Superperson Mallroy
  - Fly north then turn left
  - How to exploit this code?
- Superperson Malorie
  - Fly North and turn West
  - How to exploit this code?



# 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
bbbbbbbbbbbbbbbb
$ echo aaaaaaaaaa > /etc/zzz
bash: /etc/zzz: Permission denied ← Cannot write to the file
$ cap_leak
fd is 3
$ echo cccccccccccc >& 3
$ exit
$ cat /etc/zzz
bbbbbbbbbbbbbbbb
cccccccccccc ← Using the leaked capability
$ rm /etc/zzz
$ cat /etc/zzz
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" ← Got the root shell!
/bin/cat: aa: No such file or directory
# 
# 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)`

Command name  
is provided here  
(by the program)

`v[0]`

Input data are  
provided here  
(can be by user)

`v`

## 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