Environment Variables
&
Attacks

Environment Variables

- A set of dynamic named values
- Part of the operating environment in which a process runs
- Affect the way that a running process will behave
- Introduced in Unix and also adopted by Microsoft Windows
- Example: PATH variable
  - When a program is executed the shell process will use the environment variable to find where the program is, if the full path is not provided.

How to Access Environment Variables

```c
#include <stdio.h>
void main(int argc, char* argv[], char* envp[])
{
   int i = 0;
   while (envp[i] !=NULL) {
      printf("%s\n", envp[i++]);
   }
}
```

From the main function

More reliable way:
Using the global variable

```c
#include <stdio.h>

extern char** environ;
void main(int argc, char* argv[], char* envp[])
{
   int i = 0;
   while (environ[i] != NULL) {
      printf("%s\n", environ[i++]);
   }
}
```

How Does a process get Environment Variables?

- **Process can get environment variables one of two ways:**
  - If a new process is created using *fork*() system call, the child process will inherits its parent process's environment variables.
  - If a process runs a new program in itself, it typically uses *execve*() system call. In this scenario, the memory space is overwritten and all old environment variables are lost. *execve*() can be invoked in a special manner to pass environment variables from one process to another.

- **Passing environment variables when invoking execve() :**

```
int execve(const char *filename, char *const argv[],
                char *const envp[])
```

execve() and Environment variables

- **The program executes a new program `/usr/bin/env`, which prints out the environment variables of the current process.**

- **We construct a new variable `newenv`, and use it as the 3rd argument.**

```
extern char ** environ;
void main(int argc, char* argv[], char* envp[])
{
  int i = 0; char* v[2]; char* newenv[3];
  if (argc < 2) return;

  // Construct the argument array
  v[0] = "/usr/bin/env";   v[1] = NULL;

  // Construct the environment variable array
  newenv[0] = "AAA=aaa"; newenv[1] = "BBB=bbb"; newenv[2] = NULL;

  switch(argv[1][0]) {
    case '1': // Passing no environment variable.
       execve(v[0], v, NULL);
    case '2': // Passing a new set of environment variables.
       execve(v[0], v, newenv);
    case '3': // Passing all the environment variables.
       execve(v[0], v, environ);
    default:
       execve(v[0], v, NULL);
  }
}
```

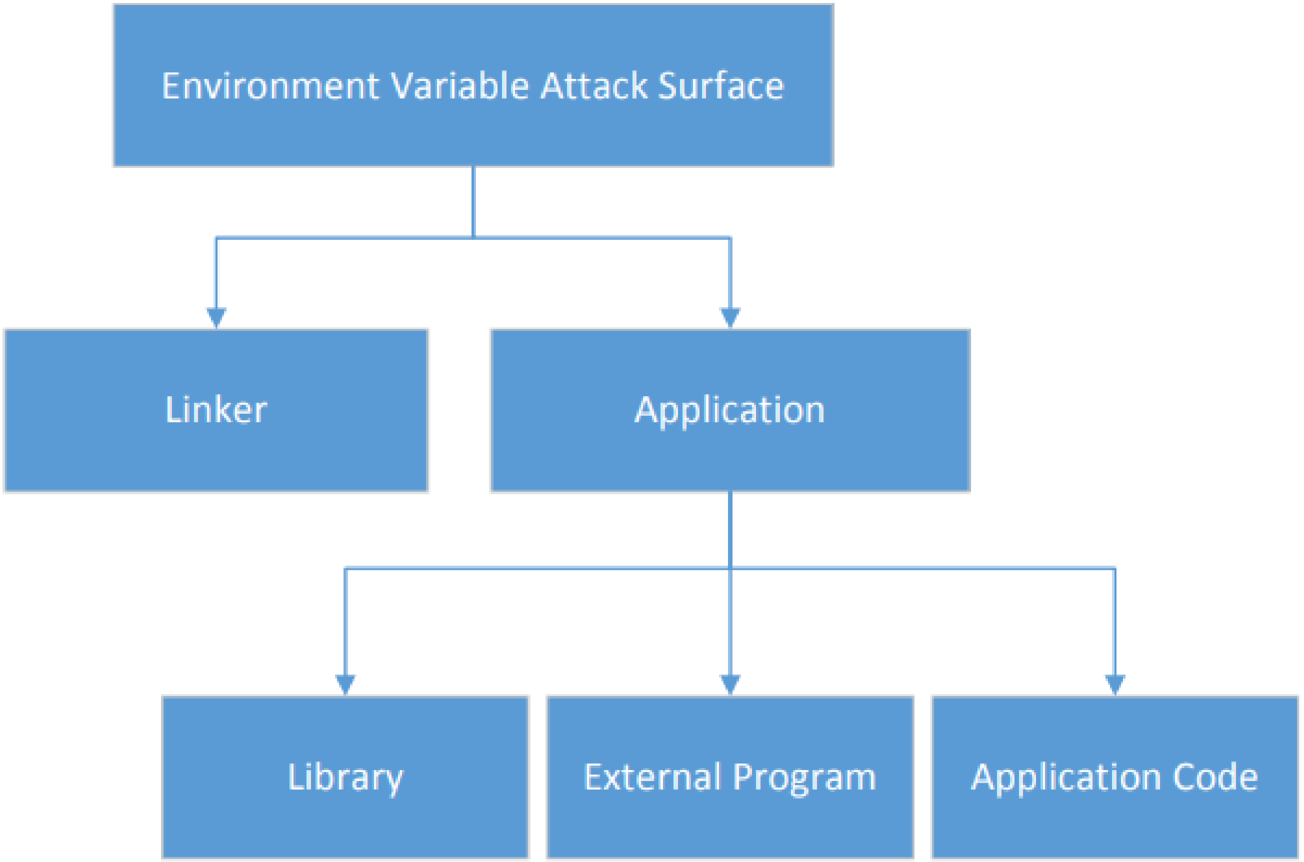
execve() and Environment variables

Obtained from the parent process

```
$ a.out 1       ← Passing NULL
$ a.out 2       ← Passing newenv[]
AAA=aaa
BBB=bbb
$ a.out 3       ← Passing environ
SSH_AGENT_PID=2428
GPG_AGENT_INFO=/tmp/keyring-12UoOe/gpg:0:1
TERM=xterm
SHELL=/bin/bash
XDG_SESSION_COOKIE=6da3e071019f...
WINDOWID=39845893
OLDPWD=/home/seed/Book/Env_Variables
...
```

Attack Surface on Environment Variables

- **Hidden usage of environment variables is dangerous.**
- **Since users can set environment variables, they become part of the attack surface on Set-UID programs.**



Attacks via Dynamic Linker

- **Linking finds the external library code referenced in the program**
- **Linking can be done during runtime or compile time:**
  - Dynamic Linking – uses environment variables, which becomes part of the attack surface
  - Static Linking
- **We will use the following example to differentiate static and dynamic linking:**

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

Attacks via Dynamic Linker

Static Linking

- The linker combines the program's code and the library code containing the printf() function

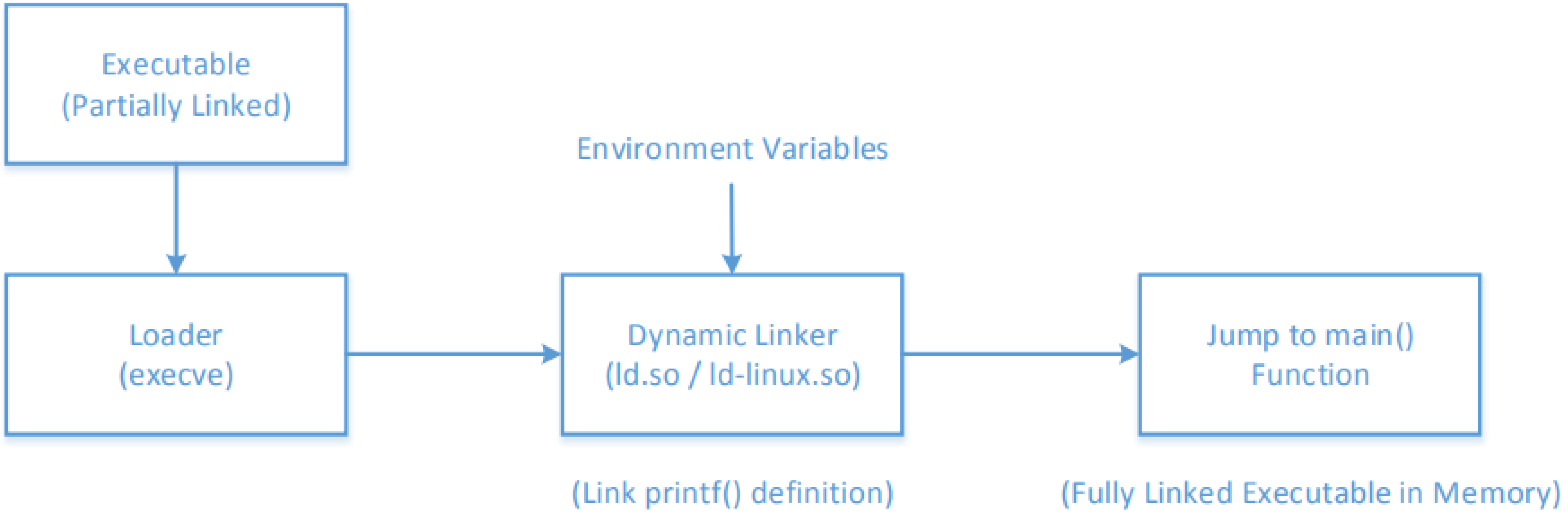
- We can notice that the size of a static compiled program is 100 times larger than a dynamic program

```
seed@ubuntu:$ gcc -o hello_dynamic hello.c
seed@ubuntu:$ gcc -static -o hello_static hello.c
seed@ubuntu:$ 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
```

Attacks via Dynamic Linker

Dynamic Linking

- **The linking is done during runtime**
  - Shared libraries (DLL in windows)
- **Before a program compiled with dynamic linking is run, its executable is loaded into the memory first**



Attacks via Dynamic Linker

Dynamic Linking:

- **We can use “ldd” command to see what shared libraries a program depends on :**

```
$ ldd hello_static
   not a dynamic executable
$ ldd hello_dynamic
   linux-gate.so.1 =>  (0xb774b000)
   libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb758e000)
   /lib/ld-linux.so.2 (0xb774c000)
```

for system calls

The dynamic linker itself is in a shared library. It is invoked before the main function gets invoked.

The libc library (contains functions like printf() and sleep())

Attacks via Dynamic Linker: the Risk

- **Dynamic linking saves memory**
- **This means that a part of the program’s code is undecided during the compilation time**
- **If the user can influence the missing code, they can compromise the integrity of the program**

Attacks via Dynamic Linker: Case Study 1

- **LD_PRELOAD contains a list of shared libraries which will be searched first by the linker**
- **If not all functions are found, the linker will search among several lists of folder including the one specified by LD_LIBRARY_PATH**
- **Both variables can be set by users, so it gives them an opportunity to control the outcome of the linking process**
- **If that program were a Set-UID program, it may lead to security breaches**

Attacks via Dynamic Linker: Case Study 1

Example 1 – Normal Programs:

- **Program calls sleep function which is dynamically linked:**

```
/* mytest.c */
int main()
{
  sleep(1);
  return 0;
}
```

```
seed@ubuntu:$ gcc mytest.c -o mytest
seed@ubuntu:$ ./mytest
seed@ubuntu:$
```

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

- **Now we implement our own sleep() function:**

Attacks via Dynamic Linker: Case Study 1

Example 1 – Normal Programs (continued):

- **We need to compile the above code, create a shared library and add the shared library to the LD_PRELOAD environment variable**

```
seed@ubuntu:$ gcc -c sleep.c
seed@ubuntu:$ gcc -shared -o libmylib.so.1.0.1 sleep.o
seed@ubuntu:$ ls -l
-rwxrwxr-x 1 seed seed 6750 Dec 27 08:54 libmylib.so.1.0.1
-rwxrwxr-x 1 seed seed 7161 Dec 27 08:35 mytest
-rw-rw-r-- 1 seed seed   41 Dec 27 08:34 mytest.c
-rw-rw-r-- 1 seed seed   78 Dec 27 08:31 sleep.c
-rw-rw-r-- 1 seed seed 1028 Dec 27 08:54 sleep.o
seed@ubuntu:$ export LD_PRELOAD=./libmylib.so.1.0.1
seed@ubuntu:$ ./mytest
I am not sleeping!    ← Our library function got invoked!
seed@ubuntu:$ unset LD_PRELOAD
seed@ubuntu:$ ./mytest
seed@ubuntu:$
```

Attacks via Dynamic Linker: Case Study

Example 2 – Set-UID Programs:

- **If the technique in example 1 works for Set-UID program, it can be very dangerous. Lets convert the above program into Set-UID :**

```
seed@ubuntu:$ sudo chown root mytest
seed@ubuntu:$ sudo chmod 4755 mytest
seed@ubuntu:$ ls -l mytest
-rwsr-xr-x 1 root seed 7161 Dec 27 08:35 mytest
seed@ubuntu:$ export LD_PRELOAD=./libmylib.so.1.0.1
seed@ubuntu:$ ./mytest
seed@ubuntu:$
```

- **Our sleep() function was not invoked.**
  - This is due to a **countermeasure** implemented by the dynamic linker. It ignores the LD_PRELOAD and LD_LIBRARY_PATH environment variables when the **EUID** and **RUID differ**.

- **Lets verify this countermeasure with an example in the next slide.**

Attacks via Dynamic Linker

Let's verify the countermeasure

- **Make a copy of the `env` program and make it a Set-UID program :**

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

- **Export LD_LIBRARY_PATH and LD_PRELOAD and run both the programs:**

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

Run the original `env` program

Run our `env` program

Attacks via External Program

- **An application may invoke an external program.**
- **The application itself may not use environment variables, but the invoked external program might.**
- **Typical ways of invoking external programs:**
  - `exec()` family of function which call `execve()`: runs the program directly
  - `system()`
    - The `system()` function calls `execl()`
    - `execl()` eventually calls `execve()` to run `/bin/sh`
    - The shell program then runs the program
- **Attack surfaces differ for these two approaches**

Attacks via External Program: Case Study

- **Shell programs behavior is affected by many environment variables, the most common of which is the PATH variable.**

- **When a shell program runs a command and the absolute path is not provided, it uses the PATH variable to locate the command.**

- **Consider the following code:**

```
/* The vulnerable program (vul.c) */
#include <stdlib.h>
int main()
{
    system("cal");
}
```

Full path not provided. We can use this to manipulate the path variable

- **We will force the above program to execute the following program :**

```
/* our malicious "calendar" program */
int main()
{
    system("/bin/dash");
}
```

Attacks via External Program: Attack Surfaces

- **Compared to system(), execve()'s attack surface is smaller**
- **execve() does not invoke shell, and thus is not affected by environment variables**
- **When invoking external programs in privileged programs, we should use execve()**

Attacks via Application Code

```
/* prog.c */

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

int main(void)
{
   char arr[64];
   char *ptr;

   ptr = getenv("PWD");
   if(ptr != NULL) {
       sprintf(arr, "Present working directory is: %s", ptr);
       printf("%s\n", arr);
   }
   return 0;
}
```

- **Programs may directly use environment variables. If these are privileged programs, it may result in untrusted inputs.**

Attacks via Application Code

- **The program uses getenv() to know its current directory from the PWD environment variable**
- **The program then copies this into an array “arr”, but forgets to check the length of the input. This results in a potential buffer overflow.**
- **Value of PWD comes from the shell program, so every time we change our folder the shell program updates its shell variable.**
- **We can change the shell variable ourselves.**

```
$ pwd
/home/seed/temp
$ echo $PWD
/home/seed/temp
$ cd ..
$ echo $PWD
/home/seed
$ cd /
$ echo $PWD
/
$ PWD=xyz
$ pwd
/
$ echo $PWD
xyz
```

Current directory with unmodified shell variable

Current directory with modified shell variable

Attacks via Application Code - Countermeasures

- **When environment variables are used by privileged Set-UID programs, they must be sanitized properly.**

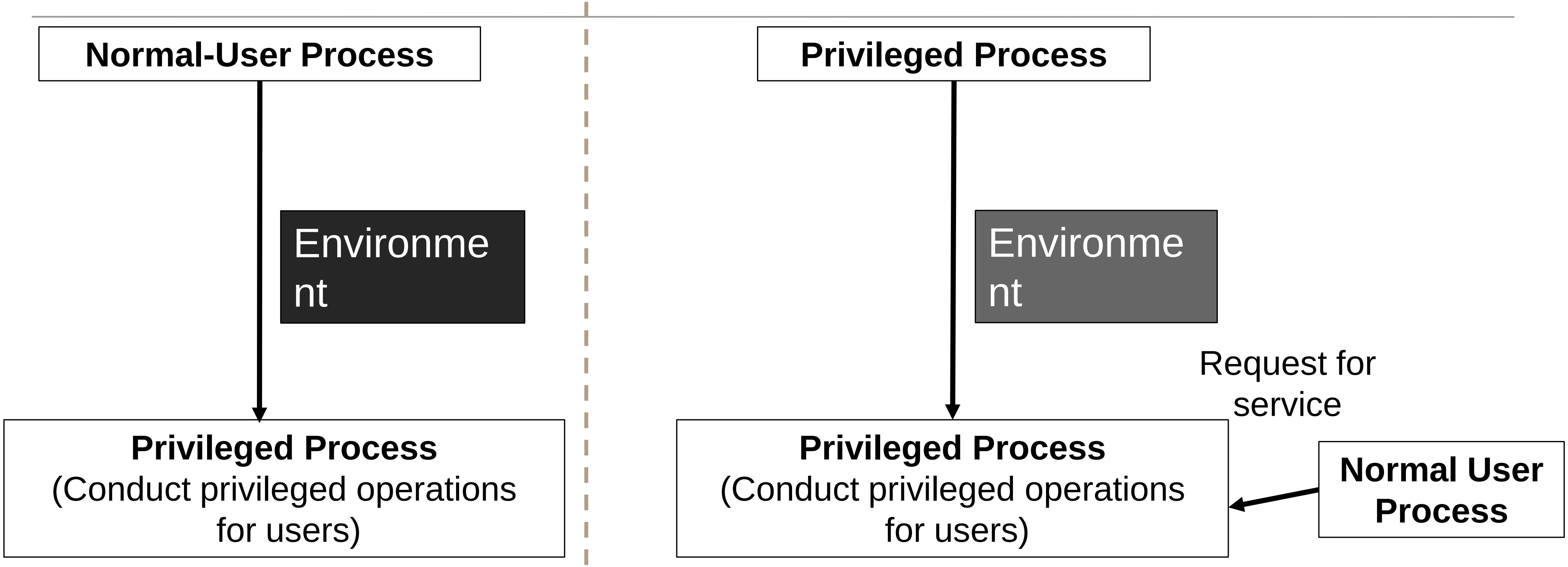
- **Developers may choose to use a secure version of getenv(), such as secure_getenv().**

  - getenv() works by searching the environment variable list and returning a pointer to the string found, when used to retrieve a environment variable.

  - secure_getenv() works the exact same way, except it returns NULL when “secure execution” is required.

  - Secure execution is defined by conditions like when the process’s user/group EUID and RUID don’t match

Set-UID Approach VS Service Approach



(a) Set-UID Approach

(b) Service Approach

Set-UID Approach VS Service Approach

- **Most operating systems follow two approaches to allow normal users to perform privileged operations**
  - Set-UID approach: Normal users have to run a special program to gain root privileges temporarily
  - Service approach: Normal users have to have to request a privileged service to perform the actions for them. Figure in the earlier slide depicts these two approaches
- **Set-UID has a much broader attack surface, which is caused by environment variables**
  - Environment variables cannot be trusted in Set-UID approach
  - Environment variables can be trusted in Service approach
- **Although, the other attack surfaces still apply to Service approach, it is considered safer than Set-UID approach**
- **Due to this reason, the Android operating system completely removed the Set-UID and Set-GID mechanism**

Summary

- **What are environment variables**
- **How they get passed from one process to its children**
- **How environment variables affect the behaviors of programs**
- **Risks introduced by environment variables**
- **Case studies**
- **Attack surface comparison between Set-UID and service approaches**