Computer Security

04. Injection Attacks & application confinement

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Last week, we looked at …

Attacks

• Buffer overflows
  – Stack overflow & return address override
  – Off-by-one overflow & frame pointer override
  – Heap overflow & data or function pointer corruption

• printf attacks
  – If you have the ability to set the format string
Defenses

- **Programming languages with bounds checks & strong typing**
  - Use "safe" functions in C/C++
  - Java, C# – Python is vulnerable in some areas
    - But native methods might be vulnerable

- **Data execution protection (DEP)**
  no-execute memory pages for stack & heap
  - Attacks: return-to-libc or Return-Oriented-Programming attacks

- **Address Space Layout Randomization (ASLR)**
  - Attacks:
    - not all programs or libraries use ASLR
    - **NOP sled** – create a huge block of NOPs to increase chance of jumping to exploit
    - Try and try again if there isn’t much entropy in the randomization

- **Stack canaries**
  - Attack: if canary is modified, the compiler causes an exception. If you can modify the exception handler, it can point to your code: *Structured Exception Handling* (SEH) exploit.
Security-Sensitive Programs

• Control hijacking isn’t interesting for regular programs on your system
  – You might as well run commands from the shell

• It *is* interesting if the program
  – Has escalated privileges (*setuid*), especially root
  – Runs on a system you don’t have access to (most servers)

Privileged programs are more sensitive & more useful targets
Injection attacks

• Injection is rated as the #1 software vulnerability in 2017 by the Open Web Application Security Project (OWASP)

• Allows an attacker to inject code into a program or query to
  – Execute commands
  – Modify a database
  – Change data on a website

• We looked at buffer overflows and format strings … but there are other forms too

Bad Input: SQL Injection

• Let’s create an SQL query in our program

```c
sprintf(buf,
    "SELECT * WHERE user=\"%s\" AND query=\"%s\";\",
    uname, query);
```

• You’re careful to limit your queries to a specific user

• But suppose `query` comes from user input and is:

```sql
foo' OR user='root
```

• The command we create is:

```sql
SELECT * WHERE user='paul' AND query='foo' OR user='root';
```
What’s wrong?

• We should have used `snprintf` to avoid buffer overflow (but that's not the problem here)

• We didn’t validate our input
  – And ended up creating a query that we did not intend to create!
Another example: password validation

• Suppose we’re validating a user’s password:

```c
sprintf(buf,
"SELECT * from logininfo WHERE username = '%s' AND password = '%s';",
uname, passwd);
```

• But suppose the user entered this for a password:

```sql
' OR 1=1 --
```

• The command we create is:

```sql
SELECT * from logininfo WHERE username = paul AND password = '' OR 1=1 -- ;
```

1=1 is always true!
Opportunities for destructive operations

Most databases support a batched SQL statement: multiple statements separated by a semicolon

```
SELECT * FROM students WHERE name = 'Robert';DROP TABLE Students;--
```
Protection from SQL Injection

• SQL injection attacks are incredibly common because most web services are front ends to database systems
  – Input from web forms becomes part of the command

• Type checking is difficult
  – SQL contains too many words and symbols that may be legitimate in other contexts
  – Use **escaping** for special characters
    • Replace single quotes with two single quotes
    • Prepend backslashes for embedded potentially dangerous characters (newlines, returns, nuls
  – Escaping is error-prone
    • Rules differ for different databases (MySQL, PostgreSQL, dashDB, SQL Server, …)

Don’t create commands with user substrings added into them
Protection from SQL Injection

• Use parameterized SQL queries or stored procedures
  – Keeps query consistent: parameter data never becomes part of the query string

uname = getResourceString("username");
passwd = getResourceString("password");
query = "SELECT * FROM users WHERE username = @0 AND password = @1";
db.Execute(query, uname, passwd);
General Rule

• If you invoke \textit{any} external program, know its parsing rules

• Converting data to statements that get executed is common in some interpreted languages
  – Shell, Perl, PHP, Python
IFS

Shell variable IFS (Internal Field Separator) defines delimiters used in parsing arguments
- If you can change IFS, you may change how the shell parses data
- The default is space, tab, newline

```
#!/bin/bash
while read name password; do
    echo name="$name", password="$password"
done
```

```
james password
mary 123456
john qwerty
patricia letmein
robert shadow
jennifer harley
```

```
$ ./try1.sh <names
name="james", password="password"
name="mary", password="123456"
name="john", password="qwerty"
name="patricia", password="letmein"
name="robert", password="shadow"
name="jennifer", password="harley"
```
One small change: \texttt{IFS=}+

```
#!/bin/bash
IFS=+
while read name password; do
echo name="\$name\", password="\$password\"
done
```

```
names
james password
mary 123456
john qwerty
patricia letmein
robert shadow
jennifer harley
```

```
output
$ ./try1.sh <names
name="james password", password=""
name="mary 123456", password=""
name="john qwerty", password=""
name="patricia letmein", password=""
name="robert shadow", password=""
name="jennifer harley", password=""
```
It gets tricky for output

```
#!/bin/bash

IFS='+

echo ""$@"" expansion
echo "$@"

echo ""$*"" expansion
echo "$*"
```

```
$ ./try.sh sleepy sneezy grumpy dopey doc
"$@" expansion
sleepy sneezy grumpy dopey doc
"$*" expansion
sleepy+sneezy+grumpy+dopey+doc
```

You really have to know what you're dealing with!

Suppose a program wants to send mail. It might call:

```
FILE *fp = popen("/usr/bin/mail -s subject user", "w")
```

If `IFS` is set to `"/"` then the shell will try to execute `usr bin mail`...

An attacker needs to plant a program named “usr” anywhere in the search path...
system() and popen()

- These library functions make it easy to execute programs
  - `system`: execute a shell command
  - `popen`: execute a shell command and get a file descriptor to send output to the command or read input from the command

- These both run `sh -c command`

- Vulnerabilities include
  - Altering the search path if the full path is not specified
  - Changing IFS to change the definition of separators
  - Using user input as part of the command

```c
snprintf(cmd, "/usr/bin/mail -s alert %s", bsize, user);
f = popen(cmd, "w");
What if user = "paul; rm -fr /home/*"
sh -c "/usr/bin/mail -s alert paul; rm -fr /home/*"
```
Other environment variables

• **PATH**: search path for commands
  – If untrusted directories are in the search path before trusted ones (/bin, /usr/bin), you might execute a command there.
  • Users sometimes place the current directory (.) at the start of their search path
  • What if the command is a booby-trap?
    – If shell scripts use commands, they’re vulnerable to the user’s path settings
    – Use absolute paths in commands or set PATH explicitly in a script

• **ENV, BASH_ENV**
  – Set to a file name that some shells execute when a shell starts
Other environment variables

**LD_LIBRARY_PATH**
- Search path for shared libraries
- If you change this, you can replace parts of the C library by custom versions
  - Redefine system calls, `printf`, whatever…

**LD_PRELOAD**
- Forces a list of libraries to be loaded for a program, even if the program does not ask for them
- If we preload our libraries, they get used instead of standard ones

You won’t get root access with this but you can change the behavior of programs
- Change random numbers, key generation, time-related functions in games
- List files or network connections that a program does
- Modify features or behavior of a program
Example of LD_PRELOAD

random.c

```c
#include <time.h>
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char **argv)
{
    int i;

    srand(time(NULL));
    for (i=0; i < 10; i++)
    {
        printf("%d\n", rand()%100);
    }
    return 0;
}
```

$ gcc -o random random.c
$ ./random
9
57
13
1
83
86
45
63
51
5
Let’s create a replacement for \texttt{rand()}

\begin{verbatim}
int rand() {
    return 42;
}
\end{verbatim}

\begin{verbatim}
$ gcc -shared -fPIC rand.c -o newrandom.so  # compile
$ export LD_PRELOAD=$PWD/newrandom.so    # preload
$ ./random
42
42
42
42
42
42
42
42
42
42
\end{verbatim}

We didn’t have to recompile \textit{random}!
Function interposition

**interpose**
(ˈɪnˈtər-pəz′)

1. Verb (transitive)
   to put someone or something in a position between two other people or things
   *He swiftly interposed himself between his visitor and the door.*
2. To say something that interrupts a conversation

- Change the way library functions work without recompiling programs
- Create wrappers for existing functions
File Descriptors

• On POSIX systems
  – File descriptor 0 = standard input (stdin)
  – File descriptor 1 = standard output (stdout)
  – File descriptor 2 = standard error (stderr)

• open() returns the first available file descriptor

Vulnerability
  – Suppose you close file descriptor 1
  – Invoke a setuid root program that will open some sensitive file for output
  – Anything the program prints to stdout (e.g., via printf) will write into that file, corrupting it
# File Descriptors - example

files.c

```c
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <unistd.h>
#include <stdio.h>

int main(int argc, char **argv)
{
    int fd = open("secretfile", O_WRONLY|O_CREAT, 0600);

    fprintf(stderr, "fd = %d\n", fd);
    printf("hello!\n");
    fflush(stdout); close(fd);
    return 0;
}
```

$ ./files
fd = 3
hello!
$ ./files >&-
fd = 1

Bash command to close a file descriptor
We close the standard output
Obscurity

Windows CreateProcess function

BOOL WINAPI CreateProcess(
    _In_opt_    LPCTSTR               lpApplicationName,
    _Inout_opt_ LPTSTR                lpCommandLine,
    _In_opt_    LPSECURITY_ATTRIBUTES lpProcessAttributes,
    _In_opt_    LPSECURITY_ATTRIBUTES lpThreadAttributes,
    _In_        BOOL                  bInheritHandles,
    _In_        DWORD                 dwCreationFlags,
    _In_opt_    LPVOID                lpEnvironment,
    _In_        LPCTSTR               lpCurrentDirectory,
    _In_opt_    LPSTARTUPINFO         lpStartupInfo,
    _Out_       LPPROCESS_INFORMATION lpProcessInformation);

• 10 parameters that define window creation, security attributes, file inheritance, and others…

• It gives you a lot of control but do most programmers know what they’re doing?
App-level access control: filenames

• If we allow users to supply filenames, we need to check them
• App admin may specify acceptable pathnames & directories
• Parsing is tricky
  – Particularly if wildcards are permitted (*, ?)
  – And if subdirectories are permitted
Parsing directories

• Suppose you want to restrict access outside a specified directory
  – Example, ensure a web server stays within `/home/httpd/html`

• Attackers might want to get other files
  – They’ll put `..` in the pathnaame
  – `..` is a link to the parent directory
  – For example:
    ```
    http://poopybrain.com/../../../etc/passwd
    ```
  – The `..` does not have to be at the start of the name – could be anywhere
    ```
    http://poopybrain.com/419/notes/../../../416/../../../../../../etc/passwd
    ```
  – But you can’t just search for `..` because an embedded `..` is valid
    ```
    http://poopybrain.com/419/notes/some..junk..goes..here/
    ```
  – Also, extra slashes are fine
    ```
    http://poopybrain.com/419/////notes///some..junk..goes///here////
    ```

Basically, it’s easy to make mistakes!
Application-Specific Syntax: Unicode

Here’s what Microsoft IIS did

• Checked URLs to make sure the request did not use . . / to get outside the inetpub web folder
  – Prevents http://www.poopybrain.com/scripts/../../../winnt/system32/cmd.exe

• Then it passed the URL through a decode routine to decode extended Unicode characters

• Then it processed the web request

What went wrong?
Application-Specific Syntax: Unicode

• What’s the problem?
  – / could be encoded as unicode `%c0%af`

• UTF-8
  – If the first bit is a 0, we have a one-byte ASCII character
    • Range 0..127
      / = 47 = 0x2f = 0010 0111
  – If the first bit is 1, we have a multi-byte character
    • If the leading bits are 110, we have a 2-byte character
    • If the leading bits are 1110, we have a 3-byte character, and so on...
  – 2-byte Unicode is in the form \texttt{110a bcde 10fg hijk}
    • 11 bits for the character # (codepoint), range 0 .. 2047
    • C0 = 1100 0000, AF = 1010 1111 which represents 0x2f = 47
  – Technically, two-byte characters should not process # < 128
    • … but programmers are sloppy … and we want the code to be fast
Application-Specific Syntax: Unicode

- Parsing ignored %c0%af as / because it shouldn’t have been one
- So intruders could use IIS to access ANY file in the system
- IIS ran under an IUSR account
  - Anonymous account used by IIS to access the system
  - IUSER is a member of Everyone and Users groups
  - Has access to execute most system files, including cmd.exe and command.com
- A malicious user had the ability to execute any commands on the web server
  - Delete files, create new network connections
Parsings escaped characters

Even after Microsoft fixed the Unicode bug, another problem came up

- If you encoded the backslash (\) character
  (Microsoft uses backslashes for filenames & accepts either in URLs
- … and then encoded the encoded version of the \, you could bypass the security check

\ = %5c
- % = %25
- 5 = %35
- c = %63

For example, we can also write:
- %35c => %5c => \n- %25%35%63 => %5c => \n- %255c => %5c => \n
Yuck!
These are application problems

• The OS uses what the application gives it
  – It traverses the directory tree and checks access rights as it goes along
    • “x” (search) permissions in directories
    • Read or write permissions for the file

• The application is trying to parse a pathname and map it onto a subtree
More Unicode issues

Unicode represents virtually all the world's glyphs

- Some symbols look the same (or similar) but have different values
  - `/` = solidus (slash) = U+002F
  - `/` = fraction slash = U+2044
  - `/` = division slash = U+2215
  - `/` = combining short solidus overlay = U+0337
  - `/` = combining long solidus overlay = U+0338
  - `/` = fullwidth solidus = U+FF0F

- Like the slash, other characters may have multiple representations
  - `á` = U+00C1 = U+0041,U+0301

- Comparison rules have to be application dependent

Yuck!
Paul ≠ Paul
Paul ≠ Paul

This is an uppercase i
This is an Greek u (upsilon)
This is an Cyrillic a
This is an Greek P
Homograph (Homoglyph) Attacks

• Some characters may look alike:
  – 1 (one), l (L), l (i)
  – 0 (zero), O

• Homograph attack = deception
  – paypal.com vs. paypaI.com (I instead of L)

• It got worse with internationalized domain names (IDN)
  – wikipedia.org
    • Cyrillic a (U+0430), e (U+435), p (U+0440)
    • Belarusian-Ukrainian i (U+0456)
  – Paypal
    • Cyrillic P, a, y, p, a; ASCII l

Check out the Homoglyph Attack Generator at
https://www.irongeek.com/homoglyph-attack-generator.php
Setuid file access

Some commands may need to write to restricted directories or files but also access user’s files

- Example: some versions of `lpr` (print spooler)
  - Read users’ files and write them to the spool directory

- Let’s run the program as setuid to root
  - But we will check file permissions first to make sure the user has read access

```c
if (access(file, R_OK) == 0) {
    fd = open(file, O_RDONLY);
    ret = read(fd, buf, sizeof buf);
    ...
}
else {
    perror(file);
    return -1;
}
```
Problem: TOCTTOU

if (access(file, R_OK) == 0) {
    fd = open(file, O_RDONLY);
    ret = read(fd, buf, sizeof buf);
    ...
} 
else {
    perror(file);
    return -1;
}

• Race condition:
  TOCTTOU: Time of Check to Time of Use

• Window of time between access check & open
  – Attacker can create a link to a readable file
  – Run lpr in the background
  – Remove the link and replace it with a link to the protected file
  – The protected file will get printed
`mktemp` is also affected by this race condition

Create a temporary file to store received data

```c
if (tmpnam_r(filename)) {
    FILE* tmp = fopen(filename, "wb+");
    while((recv(sock, recvbuf, DATA_SIZE, 0) > 0) && (amt != 0))
        amt = fwrite(recvbuf, 1, DATA_SIZE, tmp);
}
```

- API functions to create a temporary filename
  - C library: `tmpnam`, `tempnam`, `mktemp`
  - C++: `_tempnam`, `_tempnam`, `_mktemp`
  - Windows API: `GetTempFileName`

- They create a unique name when called
  - But no guarantee that an attacker doesn’t create the same name before the filename is used
  - Name often isn’t very random: high chance of attacker constructing it

From https://www.owasp.org/index.php/Insecure_Temporary_File
**mktemp is also affected by this race condition**

If an attacker creates that file first:
- Access permissions may remain unchanged
  - Attacker may access the file later and read its contents

- Legitimate code may append content, leaving attacker’s content in place
  - Which may be read later as legitimate content

- Attacker may create the file as a link to an important file
  - The application may end up corrupting that file

- The program may be smart and call `open` with `O_CREAT | O_EXCL`
  - Or, in Windows: `CreateFile` with the `CREATE_NEW` attribute
  - Create a new file with exclusive access
  - But if the attacker creates a file with that name, the `open` will fail
    - Denial of service

From https://www.owasp.org/index.php/Insecure_Temporary_File
Defense against mktemp attacks

Use `mkstemp`

- It will attempt to create & open a unique file

- You supply a template
  - A name of your choosing with `XXXXXX` that will be replaced to make the name unique
  - `mkstemp("/tmp/secretfileXXXXXX")`

- File is opened with mode 0600: `r--` `---` `---`

- If unable to create a file, it will fail and return -1
  - You should test for failure and be prepared to work around it.
The main problem: interaction

• To increase security, a program must minimize interactions with the outside
  – Users, files, sockets

• All interactions may be attack targets

• Must be controlled, inspected, monitored
Relative Attack Surface Quotient (RASQ)

- Microsoft metric of application vulnerability
  - Attempts to mathematically quantify the attackability of software

- Roughly, measures # of input channels
  - Some channels are easier to exploit
  - Some channels are more accessible to others

- Sum of “effective attack surface values” for all “root attack vectors”
  - Root attack vector: feature that can positively or negatively affect the security of a product
  - Attack bias: value representing risk of compromise for an attack
    - Subjective measure: 0=no threat, 1=maximum threat
  - Attackable surface: target for an attacker
  - Effective attack surface value: Product of the {# of attack surfaces within a root attack vector} and the {attack bias}

### RASQ Sample root vectors & bias values

<table>
<thead>
<tr>
<th>Root vector</th>
<th>Bias value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open sockets</td>
<td>1.0</td>
<td>Every open &amp; listening socket is a potential target</td>
</tr>
<tr>
<td>Open RPC endpoints</td>
<td>0.9</td>
<td>Like sockets but require more skill</td>
</tr>
<tr>
<td>Enabled accounts</td>
<td>0.7</td>
<td>Default accounts simplify brute-force password attacks</td>
</tr>
<tr>
<td>Enabled accounts in the Administrator group</td>
<td>0.9</td>
<td>Admin accounts are higher risk</td>
</tr>
<tr>
<td>Weak ACLs in file system</td>
<td>0.2</td>
<td>Most files in the system are targeted after a system is compromised</td>
</tr>
<tr>
<td>Weak ACLs on file shares</td>
<td>0.9</td>
<td>Default shares are commonly known and often targeted</td>
</tr>
</tbody>
</table>

Summary

• Better OSes and strict access controls would be nice
  – A secure OS will make it easy to write security-sensitive programs
  – Enforce principle of least privilege
  – Validate user inputs … and try to avoid using user input in commands

• Minimize chances of errors
  – Eliminate unnecessary interactions (files, users, network, devices)
  – User per-process or per-user /tmp
  – Avoid error-prone system calls and libraries
    • Or study the detailed behavior and past exploits
    • Minimize comprehension mistakes
  – Specify the operating environment & all inputs
    • And validate it at runtime
      – PATH, LD_LIBRARY_PATH, user input, …
    • Don’t make user input a part of executed commands
App Confinement
Confinement

• We realize that an application may be compromised
  – We want to run applications we may not completely trust

• Not always possible

• Limit an application use a subset of the system’s resources

• Make sure a misbehaving application cannot harm the rest of the system
How about access control

• Limit damage via access control
  – E.g., run servers as a low-privilege user
  – Proper read/write/search controls on files … or role-based policies

• ACLs don't address applications (users)
  – Cannot set permissions for a process: “don’t allow access to anything else”
  – At the mercy of default (other) permissions

• We are responsible for changing protections of every file on the system that could be accessed by other
  – And hope users don’t change that
  – Or use more complex mandatory access control mechanisms … if available

Not high assurance
Other resources to protect

- CPU time
- Amount of memory used: physical & virtual
- Disk space
- Network identity & access
We can regulate access to some resources

POSIX `setrlimit()`

- Maximum CPU time that can be used
- Maximum data size
- Maximum file that can be created
- Maximum memory a process can lock
- Maximum # of open files
- Maximum # of processes for a user
- Maximum amount of physical memory used
- Maximum stack size
Network identity

• Each system has an IP address unique to the network

• Compromised application can exploit address-based access control
  – E.g., log in to remote machines that think you’re trusted

• Intrusion detection systems can get confused
Compromised applications

• Some services run as root

• What if an attacker compromises the app and gets root access?
  – Change resource limits
  – Change file permissions (or ignore them!)
  – Change the IP address of the system
Application confinement goals

• Enforce security – broad access restrictions
• High assurance – know it works
• Simple setup – minimize comprehension errors
• General purpose – works with any (most) applications

We can’t get all of this…
chroot: the granddaddy of confinement

- Oldest confinement mechanism
- Make a subtree of the file system the root for a process
- Anything outside of that subtree doesn’t exist
chroot: the granddaddy of confinement

• Only root can run *chroot*
  
  `chroot /local/httpd`
  
  `su httpuser`

• The root directory is now `/local/httpd`
  – Anything above it is not accessible

“chroot jail”
Jailkits

• If programs within the jail need any utilities, they won’t be visible
  – They’re outside the jail
  – Need to be copied
  – Ditto for shared libraries

• Jailkit (https://olivier.sessink.nl/jailkit/)
  – Set of utilities that build a chroot jail
  – Automatically assembles a collection of directories, files, & libraries
  – Place the **bare minimum** set of supporting commands & libraries
    • The fewer executables live in a jail, the less tools an attacker will have to use
  – Contents
    • jk_init: create a jail using a predefined configuration
    • jk_cp: copy files or devices into a jail
    • jk_chrootsh: places a user into a chroot jail upon login
    • jk_lsh: limited shell that allows the execution only of commands in its config file
    • ...

https://olivier.sessink.nl/jailkit/
Problems?

• Does not limit network access
• Does not protect network identity
• Applications are still vulnerable to root compromise
• `chroot` must be available only to root
  – If not...
  – Create a jail directory       `mkdir /tmp/jail`
  – Create a link to the su command  `ln /bin/su /tmp/jail/su`
  – Copy or link libraries & shell       `...`
  – Create an `/etc` directory        `mkdir /tmp/jail/etc`
  – Create password file(s) with a known password for root
  – Enter the jail                  `chroot /tmp/jail`
  – `su root` – su will validate against the password file in the jail!
Escaping a chroot jail

If you can become root in a jail, you have access to all system calls

• Create a device file
  – On Linux/Unix/BSD, all non-network devices have filenames
  – Even memory has a filename (/dev/mem)

1. Create a memory device (*mknod* system call)
   – Change kernel data structures to remove your jail

2. Create a disk device to access your raw disk
   – Mount it within your jail and you have access to the whole file system
   – Get what you want, change the admin password, …

3. Send signals to kill other processes
   (doesn’t escape the jail but causes harm to others)

4. Reboot the system
chroot summary

• Good confinement
• Imperfect solution
• Useless against root
• Setting up a working environment takes some work (or use jailkit)
FreeBSD Jails

• Enhancement to chroot

• Run via
  
  
jail jail_path hostname ip_addr command

• Main ideas:
  – Confine an application, just like chroot
  – Restrict what operations a process within a jail can perform, even if root

FreeBSD Jails: Differences from chroot

• Network restrictions
  – Jail has its own IP address
  – Can only bind to sockets with a specified IP address and authorized ports

• Processes can only communicate with processes inside the jail
  – No visibility into unjailed processes

• Hierarchical: create jails within jails

• Root power is limited
  – Cannot load kernel modules
  – Ability to disallow certain system calls
    • Raw sockets
    • Device creation
    • Modifying network configuration
    • Mounting/unmounting file systems
    • set_hostname

Problems

• Coarse policies
  – All or nothing access to parts of the file system
  – Does not work for apps like a web browser
    • Needs access to files outside the jail (e.g., saving files, uploading attachments)

• Does not prevent malicious apps from
  – Accessing the network & other machines
  – Trying to crash the host OS

• BSD Jails is a BSD-only solution

• Pretty good for running things like DNS servers and web servers

• Not all that useful for user applications
Linux namespaces

- *chroot* only changed the root of the filesystem namespace
- Linux provides control over the following namespaces:

<table>
<thead>
<tr>
<th>IPC</th>
<th>System V IPC, POSIX message queues</th>
<th>Objects created in an IPC namespace are visible to all other processes <em>only</em> in that namespace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network</td>
<td>Network devices, stacks, ports</td>
<td>Isolates IP protocol stacks, IP routing tables, firewalls, socket port #s</td>
</tr>
<tr>
<td>Mount</td>
<td>Mount points</td>
<td>Mount points can be different in different processes</td>
</tr>
<tr>
<td>PID</td>
<td>Process IDs</td>
<td>Different PID namespaces can have the same PID – child cannot see parent processes or other namespaces</td>
</tr>
<tr>
<td>User</td>
<td>User &amp; group IDs</td>
<td>Per-namespace user/group IDs. You can be root in a namespace with restricted privileges</td>
</tr>
<tr>
<td>UTS</td>
<td>Hostname and NIS domain name</td>
<td><em>sethostname</em> and <em>setdomainname</em> affect only the namespace</td>
</tr>
</tbody>
</table>
Linux namespaces

Unlike chroot, unprivileged users can create namespaces

- **unshare()**
  - System call that dissociates parts of the process execution context
  - Examples
    - Unshare IPC namespace, so it’s separate from other processes
    - Unshare PID namespace, so the thread gets its own PID namespace for its children

- **clone()** – system call to create a child process
  - Like fork() but allows you to control what is shared with the parent
    - Open files, root of the file system, current working directory, IPC namespace, network namespace, memory, etc.

- **setns()** – system call to associate a thread with a namespace
  - A thread can associate itself with an existing namespace in /proc/[pid]/ns
Linux capabilities

How do we restrict what root can do in a namespace?

• UNIX systems distinguished privileged vs. unprivileged processes
  – Privileged = UID 0 = root ⇒ kernel bypasses all permission checks

• If we can provide limited elevation of privileges to a process:
  – If a process becomes root, it would be limited in what it could do
  – E.g., no ability to set UID to root, no ability to mount filesystems

N.B.: These capabilities have nothing to do with capability lists
Linux capabilities

- Linux divides privileges into 38 distinct controls, including:
  - CAP_CHOWN: make arbitrary changes to file owner and group IDs
  - CAP_DAC_OVERRIDE: bypass read/write/execute checks
  - CAP_KILL: bypass permission checks for sending signals
  - CAP_NET_ADMIN: network management operations
  - CAP_NET_RAW: allow RAW sockets
  - CAP_SETUID: arbitrary manipulation of process UIDs
  - CAP_SYS_CHROOT: enable chroot

- These are per-thread attributes
  - Can be set via the prctl system call
Linux Control Groups (cgroups)

- Limit the amount of resources a process tree can use
  - CPU, memory, block device I/O, network
    - E.g., a process tree can use at most 25% of the CPU
    - Limit # of processes within a group
  - Interface = cgroup file system: /sys/fs/cgroup

- Namespaces + cgroups = lightweight process virtualization
  - Process gets the illusion that it is running on its own Linux system, isolated from other processes
Vulnerabilities

• Bugs have been found
  – User namespace: unprivileged user was able to get full privileges

• But comprehension is a bigger problem
  – Namespaces do not prohibit a process from making privileged system calls
    • They control resources that those calls can manage
    • The system will see only the resources that belong to that namespace
  – User namespaces grant non-root users increased access to system capabilities
    • Design concept: instead of dropping privileges from root, provide limited elevation to non-root users
  – If a real root process has its admin capability removed
    • If it creates a user namespace, the capability is restored to the root user in that namespace – although limited in function
Next time:
Containers & Virtual Machines