OS Security

Authorization

Radboud University Nijmegen, The Netherlands

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- Flexible mechanism for managing authentication: PAM
  - Authentication modules in `/lib/security/`
  - Per-application configuration files in `/etc/pam.d/`
  - Library `libpam` as easy mechanism for applications to use PAM

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  - Authentication modules in `/lib/security/`
  - Per-application configuration files in `/etc/pam.d/`
  - Library `libpam` as easy mechanism for applications to use PAM
- Authentication even more tricky in networked environments
- State of the art: LDAP and Kerberos

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- Non-priveleged code needs to ask the OS to perform operations on resources
- Separate code in *protection rings*
- Ring 0: OS *kernel*
- Outer rings: less privileged software (drivers, userspace programs)

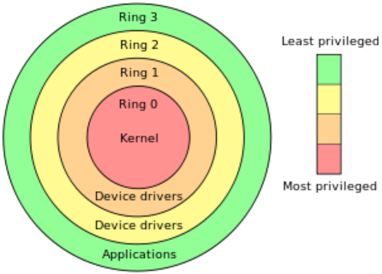

Image source: http://en.wikipedia.org/wiki/Protection_ring

Protection rings in Linux

- Protection rings are supported by hardware
- Certain instructions can only be executed by privileged (ring-0) code
- X86 and AMD64 support 4 different rings (ring 0–3)
- Trying to execute a ring-0 instruction from ring-3 results in SIGILL (illegal instruction)
- Idea:
  - OS kernel (memory and process management) run in ring 0
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  - Operating system runs with supervisor flag enabled (ring 0)
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  - Call ring-0 code *kernel space*
  - Call ring-3 code *user space*

System calls and `strace`

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- Sometimes don't use system calls that directly, e.g., `printf` also calls `write`
- Can print (trace) all syscalls of a program: `strace`
- Very helpful for understanding what's happening "behind the scenes"

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- Example: enable userspace access to hardware cycle counter on ARM processors
- Answer: Modify OS kernel (add syscall), reboot
- Better answer: Modify OS kernel *at runtime*
- Linux kernel typically allows to load *kernel modules*
- Modules run in kernel space (ring 0)
- Load module into kernel with program `insmod`

A kernel module example

```
#include <linux/module.h>
#include <linux/kernel.h>
MODULE_LICENSE("Dual BSD/GPL");

#define DEVICE_NAME "enableccnt"

static int enableccnt_init(void)
{
  printk(KERN_INFO DEVICE_NAME " starting\n");
  asm volatile("mcr p15, 0, %0, c9, c14, 0" :: "r"(1));
  return 0;
}

static void enableccnt_exit(void)
{
  asm volatile("mcr p15, 0, %0, c9, c14, 0" :: "r"(0));
  printk(KERN_INFO DEVICE_NAME " stopping\n");
}

module_init(enableccnt_init);
module_exit(enableccnt_exit);
```

Files

- Persistent data on background storage is organized in *files*
- Files are logical units of information organized by a *file system*
- Files have names and additional associated information:
  - Date and time of last access
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  - Access-permission-related information

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- Files are logically organized in a tree hierarchy of *directories*
- The file system maps logical information to bits and bytes on the storage device
- The file system runs in kernel space (typically through device drivers)
- Access to files goes through system calls

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  - (User-space programs also operate on memory, but that’s for next lecture)

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- `lseek()`: Change position in the file handle
- `access()`: Check access rights based on real user ID (more later)

Pseudo filesystems proc and sys

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  - echo 1 > /proc/sys/net/ipv4/ip_forward: Enable IP forwarding
  - echo powersave > /sys/.../cpu0/cpufreq/scaling_governor: Switch CPU0 to "powersave" mode

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- Important for access control: reading/writing those parameters is implemented through operations on (pseudo-)files

Device files

- Hardware devices are represented as files in `/dev/`
- Examples:
  - `/dev/sda`: First hard drive
  - `/dev/sda1`: First partition on first hard drive
  - `/dev/tty*`: Serial devices and terminals
  - `/dev/input/*`: Input devices
  - `/dev/zero`: Pseudo-devices that prints zeros
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Symbolic links and pipes

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- Accessing a symbolic link really accesses the file it points to
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- Pipes for inter-process communication are also implemented through file handles

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- Show all currently defined environment variables: `export`
- Important system-wide variables:
  - `PATH`: colon-separated list of directories to search for programs
  - `LD_LIBRARY_PATH`: colon-separated list of directories to search for libraries
  - `IFS`: "Internal Field Separator", character to be used to separate fields in a list (more later)

MAC and DAC

Protection system

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Discretionary Access Control

A system implements *discritionary access control* (DAC) if the protection state can be modified by untrusted users. The protection of a user's files is then "at the discretion of the user".

Access Matrix

An *access matrix* is a set of subjects S, a set of objects O, a set of operations X and a function $op : S \times O \to \mathcal{P}(X)$. Given $s \in S$ and $o \in O$, the function op returns the set of operations that s is allowed to perform on o.

Access Matrix

	File 1	File 2	File 3	File 4
Process 1	read	read	read,write	
Process 2		read		
Process 3	read,write	read		

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- When a user creates a file, she adds a column to the table
- Adding a column means modifying the protection state
- The access-matrix model leads to a DAC system

UNIX/Linux protection model

- *Trusted code base* (TCB) of Linux is all code running in kernel space and several processes run with `root` permissions, e.g.:
  - boot process
  - login (user authentication)
  - network services
- Goal: protect users' processes from each other and the TCB from all user processes

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- Each process has associated three user IDs:
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- Each process also has associated a set of *group IDs*
- The groups of all users are defined in `/etc/group`
- Each user has a primary group defined in `/etc/passwd`
- When you are logged in, you can see your groups with the command `groups`

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  - 750: owner may read, write, and execute; group may read and execute, others may nothing
  - 644: owner may read and write; group and others may read

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- Command `ls -l` shows files with corresponding permissions, e.g.

```
peter@tyrion:/etc$ ls -l passwd shadow
-rw-r--r-- 1 root root   2217 Nov 16 18:13 passwd
-rw-r----- 1 root shadow 1454 Nov 16 18:13 shadow
```

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- `write`: Can rename and delete content of the directory and create new content
- `execute`: Can traverse the directory (`cd` into or across the directory)

chown, chmod and umask

- `chown` changes owner and group of a file
- Example: `chown anna:dialout test.txt` changes
  - the owner of `test.txt` to `anna` and
  - the group of `test.txt` to `dialout`
- Only root can change ownership; owner can change group to any group he's member of

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- Only root can change ownership; owner can change group to any group he's member of
- `chmod` changes permissions of a file, e.g.:
  - `chmod g+w`: grant write permissions to group
  - `chmod o-x`: remove execute permissions from other
  - `chmod a+rw`: grant read and write permissions to owner, group, and other
  - `chmod 640`: set permissions to `rw-r-----`

chown, chmod and umask

- `chown` changes owner and group of a file
- Example: `chown anna:dialout test.txt` changes
  - the owner of `test.txt` to `anna` and
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- Default permissions for files are 666 and for directories 777
- `umask` influences default permissions
- The `umask` is subtracted from permissions
- Example: a `umask` of 022 removes write permissions for group and other by default

The setuid bit

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- Most important application: setuid root
- Setuid root process can drop privileges (effective ID)
- Can regain root rights as long as saved ID is still 0!

The setgid and sticky bit

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Sticky bit

- Another "special" permission bit is the *sticky bit*
- On directories: allow only owner of contained files to rename or delete the file
- Important, for example, for `/tmp/`
- On executables: keep in swap space (faster loading)
- Not really used anymore today
- Set sticky bit with `chmod +t`

setuid example: `su`

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- Other prominent example: passwd (needs write access to /etc/shadow)
- Again, authenticate against PAM before doing anything

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- Instead use the following rule in etc/sudoers:

  `%sudo ALL=(ALL:ALL) ALL`
- Allows members of the group sudo to run any program as root
- With this rule, run sudo su to obtain a root shell

Privilege escalation

- Attack that expands attacker's privileges is called *privilege escalation*
- Two types of privilege escalation:
  - horizontal: obtain privileges of another un-privileged user
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- An exploit that lets an unprivileged (logged in, local) user gain root rights is called *local root exploit*

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  4. Run the suid program `stupid`

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  4. Run the suid program `stupid`
- `stupid` launches a shell, which is handed `/bin/date`
- Shell looks at variable `IFS` to parse this string
- Shell calls program `bin` with argument `date`

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- Set ACL entries with the program `setfacl` (set file access control lists)
- Read ACL entries with `getfacl` (get file access control lists)
- Note: `ls -l` will not show ACLs, only a '+' to indicate that "there's more"

Linux ACL examples

- Grant user `anna` read,write execute rights on file `test.txt`:

  ```
  setfacl -m user:anna:rwx test.txt
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- Grant read and execute rights for members of the group `dialout`:
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- Read and set permissions for `test.txt` from file `test.perm`:
  `setfacl -M test.perm test.txt`

UNIX weaknesses: assuming benign processes

- UNIX and Linux are built on the assumption that user processes behave benignly
- A malicious process can easily violate a user's security goals
- Mainly two ways why processes may be malicious:
  - user accidently runs malware (more later in the lecture)
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  - OS still enforces the security goals
- No current mainstream OS achieves this goal
- Requires mandatory access control

UNIX weaknesses: TOCTTOU

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if (access("file", W_OK) != 0) {
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- Attacker attempts to run `symlink("/etc/shadow", "file");` between `access()` and `open()`
- This is an example for a *race condition*
- Generally, a *race condition bug* is a bug where software behaviour depends on uncontrollable timing behavior in an unintended way

The safety problem

Safe systems

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- The safety problem is undecidable for *compound* protection state operations
- Example of *compound state operation*: create a file and set the owner
- Safety problem is undecidable for (a formal version) of the UNIX protection system