# OS Security

## Authorization

Radboud University Nijmegen, The Netherlands

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- Typical approach: user authentication:
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- Classical UNIX/Linux authentication through user data in `/etc/passwd` and `/etc/shadow`
- 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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- Separate code in *protection rings*
- Ring 0: OS *kernel*
- Outer rings: less privileged software (drivers, userspace programs)

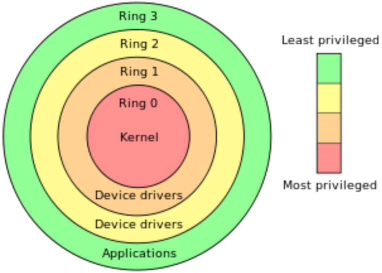


Image source: http://en.wikipedia.org/wiki/Protection_ring

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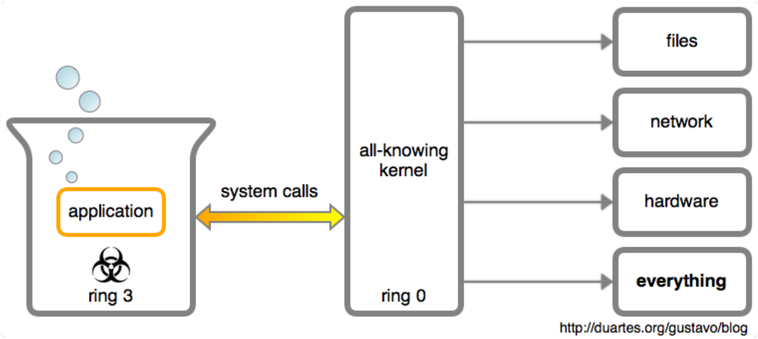
- Sometimes don't use system calls that directly, e.g., `printf` also calls `write`
- Can print (trace) all syscalls of a program: `strace`
- Very helpful for understanding what's happening "behind the scenes"

# Applications and the OS



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- What if there is no syscall for a certain operation?
- 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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| **Integer value** | **Name/Meaning** | **<stdio.h> file stream** |
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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

- A *symbolic link* is a special file that “links” to another file
- Accessing a symbolic link really accesses the file it points to
- Create a symbolic link to /home/peter/teaching/ with name /home/peter/ru:

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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 *discretionary 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 $op : S \times O \rightarrow \mathcal{P}(X)$. 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 running with `root` permissions, e.g.:
  - `init` 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
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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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- When a process wants to access a file, check the following
  1. Does the effective user ID of the process match the owner of the file? If so, use the owner permissions.
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- `write`: Can rename and delete content of the directory and create new content

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- When a process wants to access a file, check the following
  1. Does the effective user ID of the process match the owner of the file? If so, use the owner permissions.
  2. Does one of the group IDs of the process match the group of the file? If so, use the group permissions.
  3. Otherwise, use the "other" permissions
- Note: if the owner matches, the group permissions don't matter.

## Directory permissions

- `read`: Can see content (files and subdirectories) of the directory
- `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 veelasha:dialout test.txt` changes
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  - the group of test.txt to dialout
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  - `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-----`

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  - chmod 640: set permissions to rw-r-----
- 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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- User IDs of a suid program:
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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!

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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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  `%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
  - vertical: obtain privileges of root (or the kernel), "privilege elevation"

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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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  1. `export PATH=.:$PATH`
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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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- `PATH` variable is still inherited
- Custom variables are still inherited
- Can try all this easily with a C program using `getenv`
- Cannot try this with a shell script
- Shell scripts won't execute setuid (even if you set the bit)

# Shellshock

- Environment variables can be dangerous because they allow (potentially unintended) data flow
- Even worse if environment variables are badly parsed: http://digg.com/video/the-shellshock-bug-explained-in-about-four-minutes

# More Shellshock background

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- We can define functions: `hello() { echo "Hello World"; }`
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- The bash is not just a command line but also a programming language
- We can define functions: `hello() { echo "Hello World"; }`
- We can also `export` functions with `export -f`
- Environment variables do not support functions, just strings
- The newly launched bash looks for variables that “look like a function”
- Parsing things that “look like a function” goes wrong

# Shellshock test

```
env x='() { :;}; echo vulnerable' bash -c "echo this is a test"
```

# Access control lists

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  ```
  mount -o remount,acl /
  ```

- 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

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- Grant read and execute rights for members of the group `dialout`:
  `setfacl -m group:dialout:r-x test.txt`
- 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)
  - process operates on maliciously crafted input (in particular network processes)

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  - All software outside the TBC can be arbitrarily malicious
  - OS still enforces the security goals
- No current mainstream OS achieves this goal
- Requires mandatory access control

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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