OS Security

Authentication and Authorization

Radboud University, Nijmegen, The Netherlands

Winter 2016/2017

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Examples of shared resources

- Memory
- Input and Output (I/O) including
  - Files on the hard drive
  - Network
- Computation cycles on the processor(s)
- Peripheral hardware (keyboard, screen, ...)

What does that mean for security?

- Operating system needs to decide whether processes are allowed to perform certain operations
- Obvious security disasters:
  - One process reading the memory of another process
  - A process reading a "secret" file
  - A process preventing other processes from operating
  - One process reading (keyboard) input meant for another process

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- Worst-case authentication failure: impersonation

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- **Security nightmare:** an attacker who gets `root` access

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- Init process starts `login` (runs as root)
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- Comparison of *password hash* against info stored in `/etc/shadow` (originally `/etc/passwd`)

Password hashing algorithms

- Traditionally Linux used `crypt` for password hashing
- Truncate the password to 8 characters, 7 bits each
- Encrypt the all-zero string with modified DES with this 56-bit key
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- Better algorithm through https://password-hashing.net/
- Winner announced on Nov 2, 2015: ARGON2

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  6. Encrypt the fixed ASCII string `KGS!@#$%`
  7. Concatenate the two ciphertexts to obtain the LM hash

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- Passwords shorter than 8 characters produce hash ending in `0xAAD3B435B51404EE`
- Cracking LM hashes is fairly easy, there are even online services, e.g., http://rainbowtables.it64.com/

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- Today, Windows uses multiple different approaches for passwords

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- Most common passwords in 2014 (SplashData list):
  - Place 3: **12345**
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- Exercises in 1st semester course include breaking (unsalted) hash of a 7-character random password.
- Some students typically manage to do that in a week!

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- **Replay attack:** device-dependent, use challenge-response

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When a password is compromised, change your password. What if your fingerprint is compromised?

Compromising fingerprints. . .

Politician’s fingerprint reproduced using photos of her hands

At a Chaos Computer Club convention, hacker Starbug suggests notable people wear gloves.

by **Megan Geuss** - Dec 30, 2014 2:05am CET

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Pluggable authentication modules

- Local login is not the only program that needs user authentication:
  - SSH (remote login)
  - Graphical login (GDM, LightDM)
  - Screen locks (screensaver)
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- This is handled by Pluggable Authentication Modules (PAM)
- Add a new module (e.g., for fingerprint authentication), directly available to all PAM enabled programs

PAM design

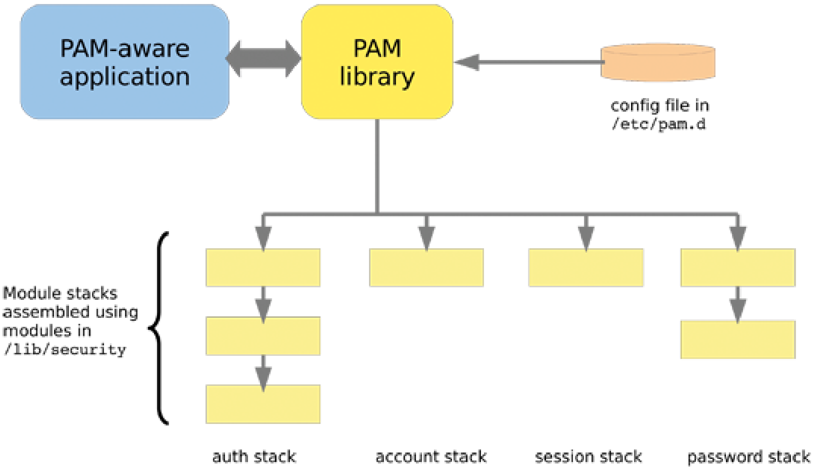


Image from http://www.tuxradar.com/content/how-pam-works

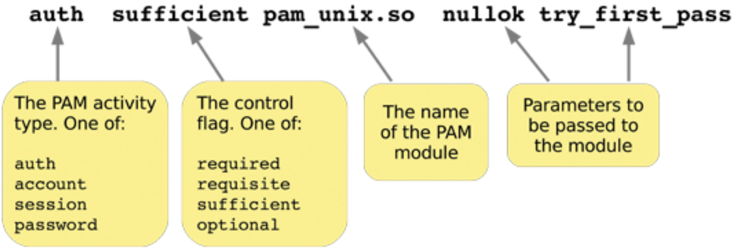
PAM activities

PAM knows 4 different authentication-related *activities*:

- **auth:** The activity of user authentication; typically by password, but can also use tokens, fingerprints etc.
- **account:** After a user is identified, decide whether he is allowed to log in. For example, can restrict login times.
- **session:** Allocates resources, for example mount home directory, set resource usage limits, print greeting message with information.
- **password:** Update the user's credentials (typically the password)

PAM configuration syntax

Configuration for program `progname` is in `/etc/pam.d/progname`



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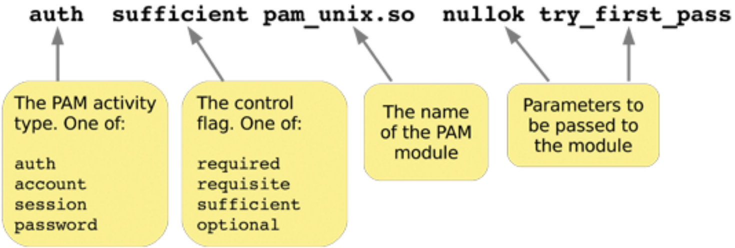

PAM control flags

- **requisite:** if module fails, immediately return failure and stop
- **required:** if module fails, return failure but continue
- **sufficient:** if module passes, return pass and stop
- **optional:** pass/fail result is ignored

Image source: http://www.tuxradar.com/content/how-pam-works

Examples of PAM modules

Name	Activities	Description
pam_unix	auth, session, password	Standard UNIX authentication through /etc/shadow passwords
pam_permit	auth, account, session, password	Always returns true
pam_deny	auth, account, session, password	Always returns false
pam_rootok	auth	Returns true iff you're root
pam_warn	auth, account, session, password	Write a log message to the system log
pam_cracklib	password	Perform checks of the password strength

Some PAM config examples

- Prevent all users from using su (/etc/pam.d/su)

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- Prevent all users from using `su` (`/etc/pam.d/su`)

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- Enforce passwords with at least 10 characters and at least 2 special characters, use SHA-512 for password hash (`/etc/pam.d/passwd`):

```
password    required   pam_cracklib.so minlen=10 ocredit=-2
password    required   pam_unix.so     sha512
```

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- Possible disadvantage of central login server: single point of failure
- Different common protocols (NIS, LDAP, Kerberos)

NTLM and "pass the hash"

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- Attacker only needs to obtain the password *hash*
- The whole point of storing password hashes is gone
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- Conveniently automated in `metasploit`
- Almost any larger Windows network still has NTLM somewhere

Part II

Authorization

Protection rings

- OS needs to control access to resources
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- Separate code in *protection rings*
- Ring 0: OS *kernel*
- Outer rings: less privileged software (drivers, userspace programs)

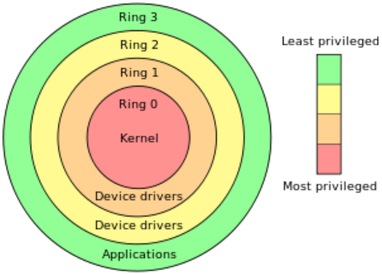

Image source: http://en.wikipedia.org/wiki/Protection_ring

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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- Linux (and Windows) use a simpler *supervisor-mode* model:
  - Operating system runs with supervisor flag enabled (ring 0)
  - Userspace programs run with supervisor flag disabled (ring 3)

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  - OS kernel (memory and process management) run in ring 0
  - Device drivers run in ring 1 and 2
  - Userspace software runs in ring 3
- Linux (and Windows) use a simpler *supervisor-mode* model:
  - Operating system runs with supervisor flag enabled (ring 0)
  - Userspace programs run with supervisor flag disabled (ring 3)
  - Call ring-0 code *kernel space*
  - Call ring-3 code *user space*

System calls and `strace`

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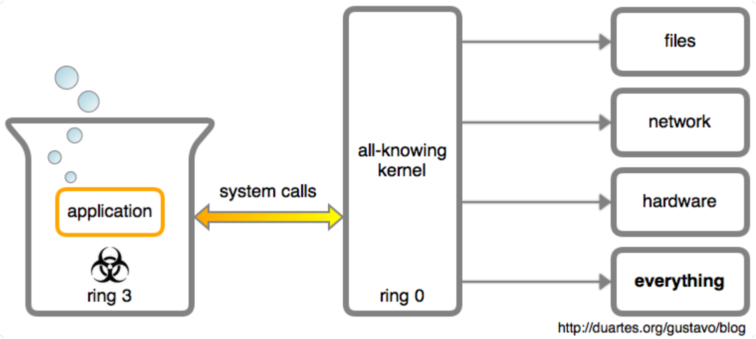
- Sometimes don't use system calls that directly, e.g., `printf` also calls `write`
- Can print (trace) all syscalls of a program: `strace`
- Very helpful for understanding what's happening "behind the scenes"

Applications and the OS



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- 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
  - Date and time of last modification
  - 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

"Everything is a file"

- Design principle of UNIX (and Linux): every persistent resource is accessed through a file handle
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  - (User-space programs also operate on memory, but that’s for next lecture)

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- `access()`: Check access rights based on real user ID (more later)

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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

MAC and DAC

Protection system

A *protection system* consists of a *protection state*, which describes what operations subjects (processes) may perform on objects (files) together with a set of *protection state operations* that enable modification of the state.

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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 $op : S \times O \to \mathcal{P}(X)$. 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 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

UNIX/Linux protection model: subjects

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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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- 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
```

UNIX/Linux protection model: matching

- When a process wants to access a file, check the following
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- `execute`: Can traverse the directory (`cd` into or across the directory)

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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!

setuid example: `su`

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

Privilege escalation

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- 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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- 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"

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:
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  - process operates on maliciously crafted input (in particular network processes)
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- Ideal situation: OS enforces security:
  - Clearly defined security goals (confidentiality, integrity)
  - All software outside the TBC can be arbitrarily malicious
  - OS still enforces the security goals

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 accidentally runs malware (more later in the lecture)
  - process operates on maliciously crafted input (in particular network processes)
- This is a problem of all mainstream "classical" operating systems!
- Ideal situation: OS enforces security:
  - Clearly defined security goals (confidentiality, integrity)
  - 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