Linux security mechanisms

Mechanisms

- Capabilities
- cgroups (control groups)
- LSM (Linux Security Modules)

Linux management privileges

- ▷ Initial UNIX philosophy
  - Privileged processes (UID = 0)
    - Bypass all kernel permission checks
  - Unprivileged processes (UID ≠ 0)
    - Subject to permission checking based on their credentials
    - Effective UID, effective GID, secondary group list

Unix file protection ACLs: Special protection bits

- ▷ Set-UID bit

```
creator:Pictures$ ls -la /usr/bin/passwd
-rwsr-xr-x 1 root root 59640 Mar 22  2019 /usr/bin/passwd
```

  - Is used to change the UID of processes executing the file
- ▷ Set-GID bit

```
creator:Pictures$ ls -la /usr/bin/at
-rwsr-sr-x 1 daemon daemon 51464 Feb 20  2018 /usr/bin/at
```

  - Is used to change the UID of processes executing the file
- ▷ Sticky bit

```
creator:Pictures$ ls -la /tmp
total 108
drwxrwxrwt 25 root    root    4096 Dec 15 13:12 .
```

  - Hint to keep the file/directory as much as possible in memory cache

Privilege elevation: Set-UID mechanism

- It is used to change the UID of a process running a program stored on a Set-UID file
  - If a program file is owned by UID X and the set-UID bit of its ACL is set, then it will be executed in a process with UID X
    - Independently of the UID of the subject that executed the program
- Used to allow normal users to execute privileged tasks encapsulated in administration programs
  - Change the user's password (passwd)
  - Change to super-user mode (su, sudo)
  - Mount devices (mount)

Privilege elevation: Set-UID mechanism (cont.)

- Effective UID / Real UID
  - Real UID is the UID of the process creator
    - App launcher
  - Effective UID is the UID of the process
    - The one that really matters for defining the rights of the process
- UID change
  - Ordinary application
    - eUID = rUID = UID of process that executed **exec**
    - eUID cannot be changed (unless = 0)
  - Set-UID application
    - eUID = UID of **exec**'d application file, rUID = initial process UID
    - eUID can revert to rUID
  - rUID cannot change

Privilege elevation: Set-UID/Set-GID decision flowchart

- exec (path, ...)
  - File referred by path has Set-UID?
  - Yes
    - ID = path owner
    - Change the process effective UID to ID
  - No
    - Do nothing
  - File referred by path has Set-GID?
  - Yes
    - ID = path GID
    - Change the process GIDs to ID only
  - No
    - Do nothing

Capabilities

- Protection mechanism introduced in Kernel 2.2
- They allow to divide the traditional super-user privileges into distinct units
  - That can be independently enabled and disabled
- Capabilities are a per-thread attribute
  - Propagated through forks
  - Changed explicitly of by execs

List of capabilities: Examples (small sample ...)

- CAP_CHOWN
  - Make arbitrary changes to file UIDs and GIDs
- CAP_DAC_OVERRIDE / CAP_DAC_READ_SEARCH
  - Bypass file permission / directory transversal checks
- CAP_KILL
  - Bypass permission checks for sending signals
- CAP_NET_ADMIN
  - Perform various network-related operations
- CAP_SYS_ADMIN
  - Overloaded general-purpose administration capability

Capability management

- Per-thread capabilities
  - They define the privileges of the thread
  - Divided in sets
- Sets
  - Effective
  - Inheritable
  - Permitted
  - Bounding
  - Ambient

Thread capability sets: Effective

- Set of capabilities used by the kernel to perform permission checks for the thread

Thread capability sets: Inheritable

- Set of capabilities preserved across an exec
  - Remain inheritable for any program
- Are added to the permitted set when executing a program that has the corresponding bits set in the file inheritable set

Thread capability sets: Permitted

- ▷ Limiting superset
  - For the effective capabilities that the thread may assume
  - For the capabilities that may be added to the inheritable set
    - Except for threads w/ CAP_SETPCAP in their effective set
- ▷ Once dropped, it can never be reacquired
  - Except upon executing a file with special capabilities

Thread capability sets: Bounding

- ▷ Set used to limit the capabilities that are gained during an exec
  - From a file with capabilities set
- ▷ Was previously a system-wide attribute
  - Now is a per-thread attribute

Thread capability sets: Ambient

▷ Set of capabilities that are preserved across an exec of an unprivileged program
- No set-UID or set-GID
- No capabilities set

▷ Executing a privileged program will clear the ambient set

Thread capability sets: Ambient

▷ No capability can ever be ambient if it is not both permitted and inheritable
- One cannot preserve something one cannot have
- One cannot preserve something one cannot inherit
- Automatically lowered if either of the corresponding permitted or inheritable capabilities is lowered

▷ Ambient capabilities are added to the permitted set and assigned to the effective set upon a exec

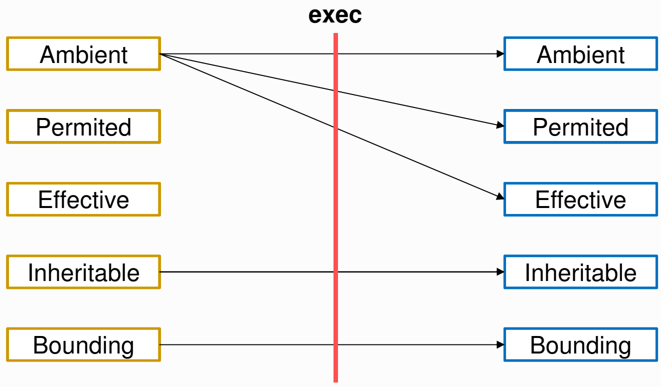
Files extended attributes (xattr)

- Files' metadata in UNIX-like systems
  - Some not interpreted by kernels
- Linux: key-value pairs
  - Keys can be defined or undefined
  - If defined, their value can be empty or not
  - Key's namespaces
    - namespace.attr_name[.attr_name]
- Namespace classes
  - Security
    - For files' capabilities
    - setcap / getcap
  - System
    - ACL
  - Trusted
    - Protected metadata
  - User
    - setfattr / lsattr / getfattr

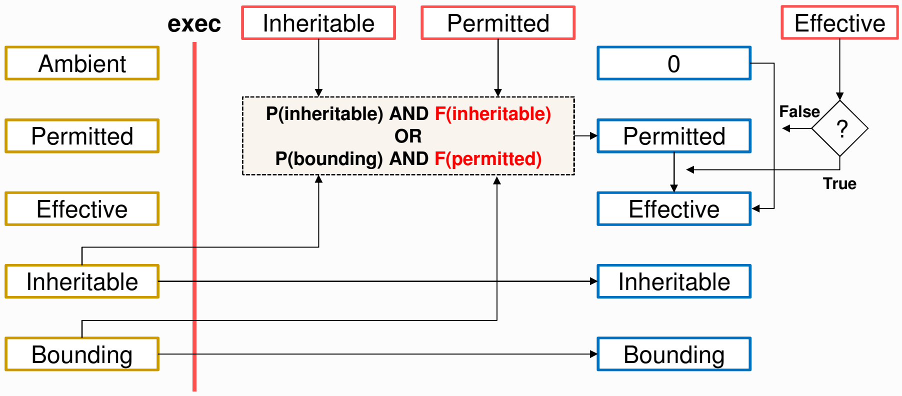
File capabilities

- Stored in the security.capability attribute
- Specify capabilities for threads that exec a file
  - Permitted set
    - Immediately forced into the permitted set
    - Previous AND with the thread's bounding set
  - Inheritable set
    - To AND with the threads' inheritable set
    - Can be used to reduce the effective set upon the exec
  - Effective bit
    - Enforce all new capabilities into the thread's effective set

Capability transfer across exec: No privileged files



Capability transfer across exec (non-root) Privileged files



Capability transfer across exec (root)

- EUID = 0 or RUID = 0
  - File sets are considered to be all 1's
- EUID = 0
  - File effective bit considered 1
- Exception: EUID = 0, RUID ≠ 0
  - File capabilities are honored if present

Control groups (cgroups)

- Collection of processes bound by the same criteria and associated with a set of parameters or limits
- cgroups are organized hierarchically
  - cgroup file system
  - Limits can be defined at each hierarchical level
    - Affecting the sub-hierarchy underneath
- Subsystems
  - Kernel component that modifies the behavior of cgroup processes
  - Resource controllers (or simply controllers)

cgroups file system

- This file system is created by mounting several controllers as cgroup-type file system entities
  - Usually /sys/fs/cgroup

- Each controller defines a tree of cgroups below the mount point
  - e.g. memory controller → /sys/fs/cgroup/memory

cgroups v1 and v2

- Currently two versions coexist
  - But controllers can only be used in on of them

cgroup controllers

- cpu, cpuacct
  - CPU usage & accounting
- cpuset
  - CPU bounding
- memory
  - Memory usage & accounting
- devices
  - Device creation & usage
- freezer
  - Suspend/resume groups of processes
- net_cls
  - Outbound packet classification
- blkio
  - Block I/O management
- perf_event
  - Performance monitoring
- net_prio
  - Network interfaces priorities
- hugelb
  - Huge pages management
- pids
  - # of processes in cgroup
- rdma
  - RDMA / IB resources' management

cgroups v1: Common files

- cgroup.procs
  - The processes in the cgroup

cgroups of a process

- A process can be controlled by an arbitrary number of cgroups
- The list of a process' cgroups is given by the /proc file system
  - /proc/[PID]/cgroup

Linux Security Modules (LSM)

- Framework to add new Mandatory Access Control (MAC) extensions to the kernel
- Those extensions are not kernel modules
  - They are embedded in the kernel code
  - They can be activated or not at boot time
  - List of extensions given by /sys/kernel/security/lsm

LSM extensions

- Capabilities (default)
- AppArmor
- LoadPin
- SELinux
- Smack
- TOMOYO
- Yama

AppArmor

- Enables the definition of per-application MAC policies
  - Profiles
  - Applications are identified by their path
    - Instead of i-node
- Profiles restrict applications' actions to the required set
  - All other actions will be denied
- Profiles define
  - Actions white-listed
  - Logging actions

AppArmor: profiles

- Profiles are loaded into the kernel
  - Upon compilation from textual files
  - apparmor_parser
- Profiles can be used on a voluntary basis
  - aa-exec