Information Security
CS 526

Topic 8: Operating Systems Security Basics & Unix Access Control

Readings for This Lecture

- Wikipedia
  - CPU modes
  - System call
  - Filesystem Permissions
- Other readings
  - UNIX File and Directory Permissions and Modes
    - http://www.hccfl.edu/pollock/AUnix1/FilePermissions.htm
  - Unix file permissions
    - http://www.unix.com/tips-tutorials/19060-unix-file-permissions.html

Announcements and Outline

- Outline of this topic
  – Brief overview of the goals of OS security
  – Memory protection, CPU modes, and system calls
  – Access control basic concepts
  – UNIX File System permissions
  – UNIX processes

What Security Goals Does Operating System Provide?

- Originally: time-sharing computers: enabling multiple users to securely share a computer
  - Separation and sharing of processes, memory, files, devices, etc.
- What is the threat model?
  - Users may be malicious, users have terminal access to computers, software may be malicious/buggy, and so on
- Security mechanisms
  - Memory protection
  - Processor modes
  - User authentication
  - File access control

What Security Goals Does Operating System Provide?

- More recent past and present: Networked desktop computers: ensure secure operation in networked environment
- New threat?
  - Attackers coming from the network. Network-facing programs on computers may be buggy. Users may be hurt via online communication.
- Security mechanisms
  - Authentication; Access Control
  - Secure Communication (using cryptography)
  - Logging & Auditing
  - Intrusion Prevention and Detection
  - Recovery

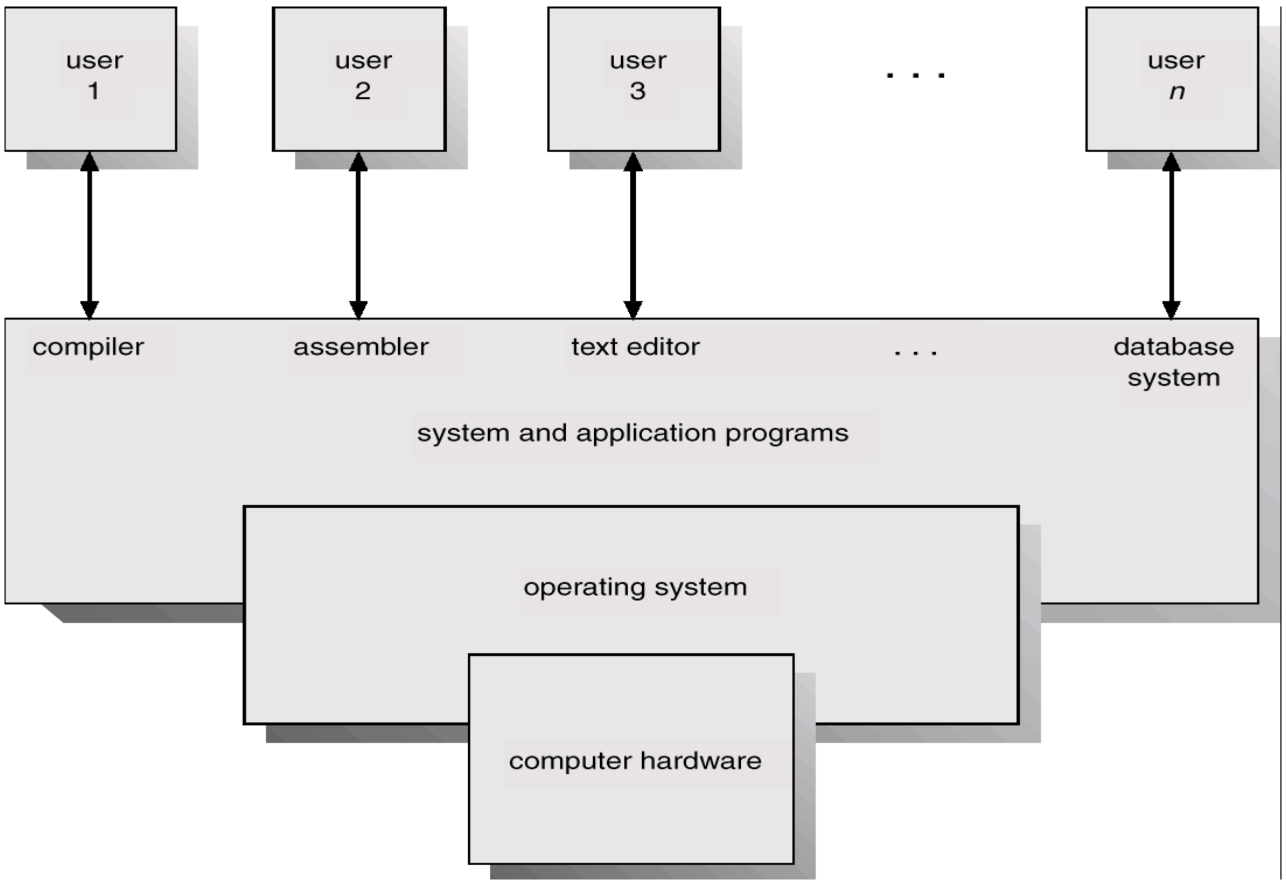
What Security Goals Does Operating System Provide?

- Present and near future: mobile computing devices:
- New threat?
  - Apps (programs) may be malicious.
  - More tightly connected with personal life of the owner.
- Security mechanisms?
  - Isolation of each app.
  - Help users assess risks of apps.
  - Risk communication.

Computer System Components

- Hardware
  - Provides basic computing resources (CPU, memory, I/O devices).
- Operating system
  - Controls and coordinates the use of the hardware among the various application programs.
- Applications programs
  - Define the ways in which the system resources are used to solve the computing problems of the users.
- Users
  - E.g., people, machines, other computers.

Abstract View of System Components



Memory Protection: Access Control to Memory

- Ensures that one user's process cannot access other's memory
  - fence
  - relocation
  - base/bounds register
  - segmentation
  - paging
  - …
- Operating system and user processes need to have different privileges

CPU Modes (a.k.a. processor modes or privilege

- System mode (privileged mode, master mode, supervisor mode, kernel mode)
  - Can execute any instruction
  - Can access any memory locations, e.g., accessing hardware devices,
  - Can enable and disable interrupts,
  - Can change privileged processor state,
  - Can access memory management units,
  - Can modify registers for various descriptor tables .

Reading: http://en.wikipedia.org/wiki/CPU_modes

User Mode

- User mode
  - Access to memory is limited,
  - Cannot execute some instructions
  - Cannot disable interrupts,
  - Cannot change arbitrary processor state,
  - Cannot access memory management units
- Transition from user mode to system mode can only happen via well defined entry points, i.e., through system calls

Reading: http://en.wikipedia.org/wiki/CPU_modes

System Calls

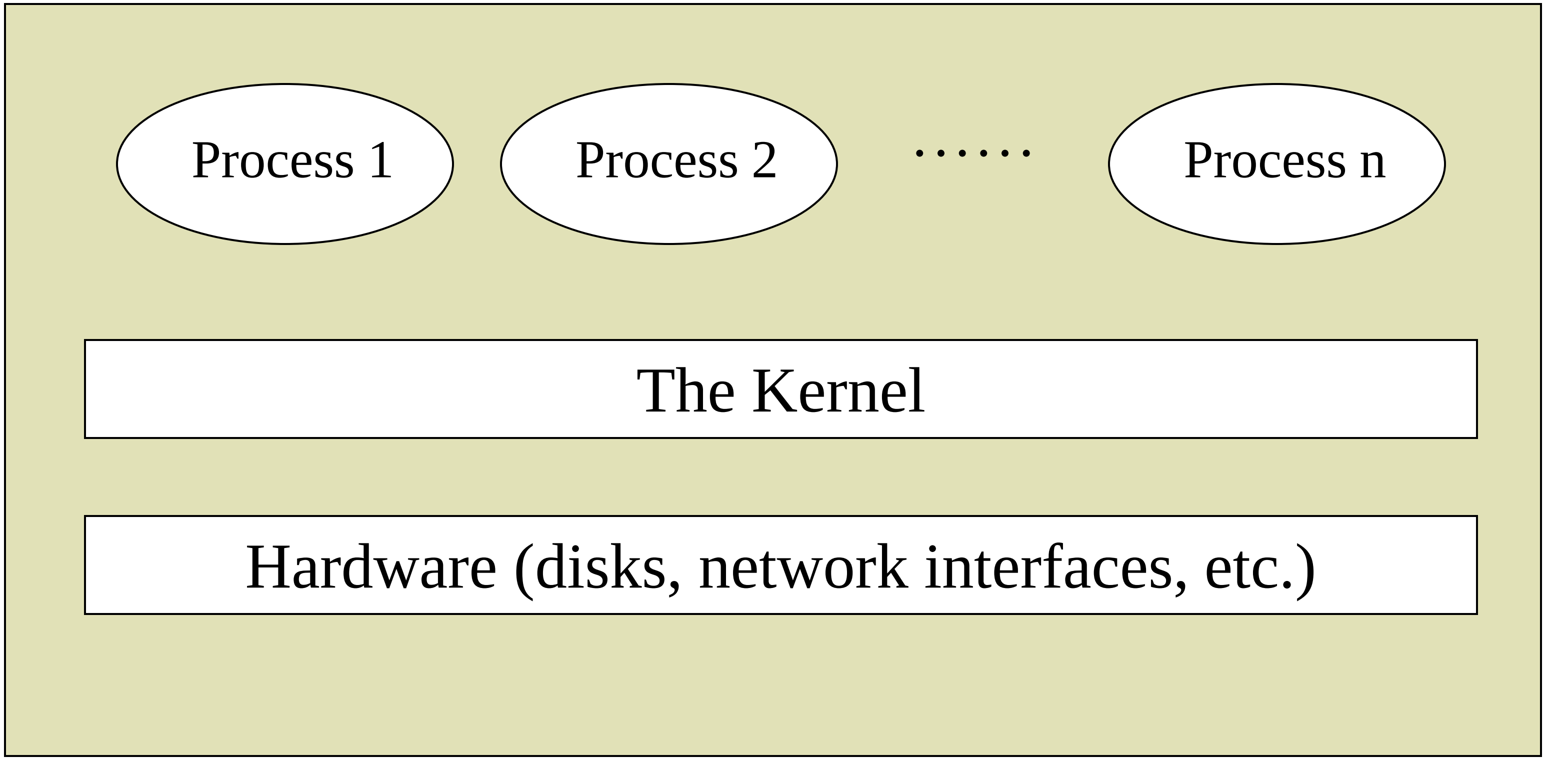
- Guarded gates from user mode (space, land) into kernel mode (space, land)
  - use a special CPU instruction (often an interruption), transfers control to predefined entry point in more privileged code; allows the more privileged code to specify where it will be entered as well as important processor state at the time of entry.
  - the higher privileged code, by examining processor state set by the less privileged code and/or its stack, determines what is being requested and whether to allow it.

http://en.wikipedia.org/wiki/System_call

Kernel space vs User space

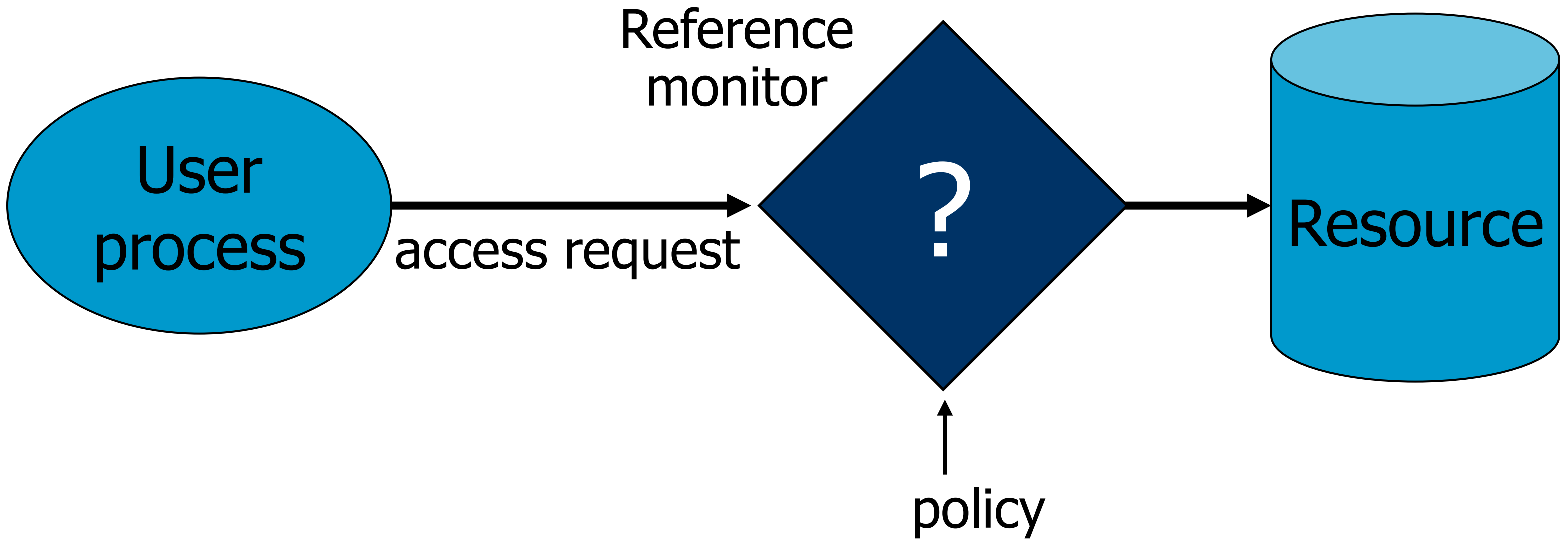
- Part of the OS runs in the kernel model
  - known as the OS kernel
- Other parts of the OS run in the user mode, including service programs (daemon programs), user applications, etc.
  - they run as processes
  - they form the user space (or the user land)
- What is the difference between kernel mode and processes running as root (or superuser, administrator)?

High-level View of Kernel Space vs. User Space

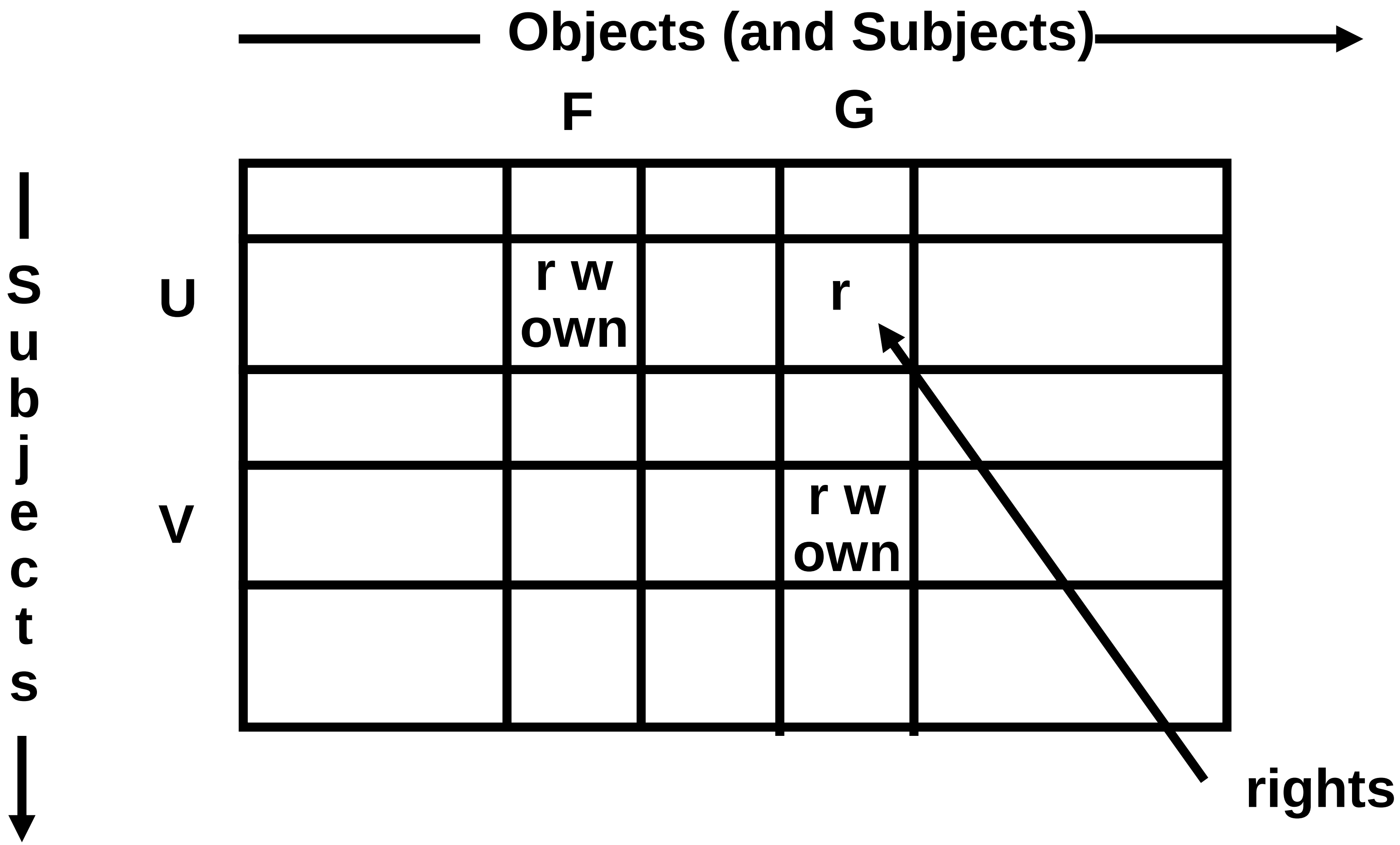


Access control

- A reference monitor mediates all access to resources
  - Principle: Complete mediation: control **all** accesses to resources



ACCESS MATRIX MODEL



ACCESS MATRIX MODEL

- Basic Abstractions
  - Subjects
  - Objects
  - Rights
- The rights in a cell specify the access of the subject (row) to the object (column)

PRINCIPALS AND SUBJECTS

- A subject is a program (application) executing on behalf of some principal(s)
- A principal may at any time be idle, or have one or more subjects executing on its behalf

What are subjects in UNIX?

What are principals in UNIX?

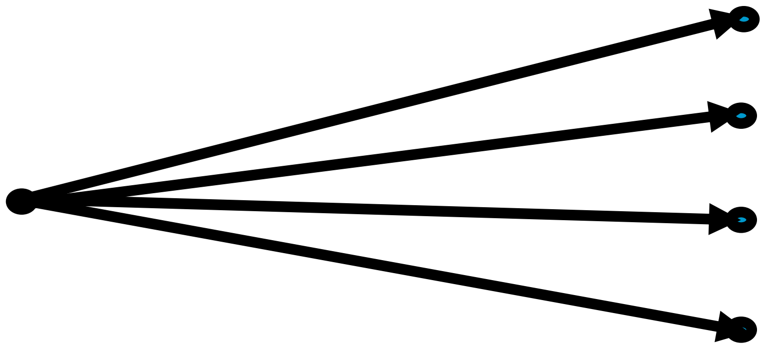
OBJECTS

- An object is anything on which a subject can perform operations (mediated by rights)
- Usually objects are passive, for example:
  - File
  - Directory (or Folder)
  - Memory segment
- But, subjects (i.e. processes) can also be objects, with operations performed on them
  - kill, suspend, resume, send interprocess communication, etc.

Basic Concepts of UNIX Access Control: Users, Groups, Files, Processes

- Each user account has a unique UID
  - The UID 0 means the super user (system admin)
- A user account belongs to multiple groups
- Subjects are processes
  - associated with uid/gid pairs, e.g., (euid, egid), (ruid, rgid), (suid, sgid)
- Objects are files

USERS AND PRINCIPALS



USERS | **PRINCIPALS**

Real World User

Unit of Access Control and Authorization

the system authenticates the human user to a particular principal

USERS AND PRINCIPALS

- There should be a one-to-many mapping from users to principals
  - a user may have many principals, but
  - each principal is associated with an unique user
- This ensures accountability of a user's actions

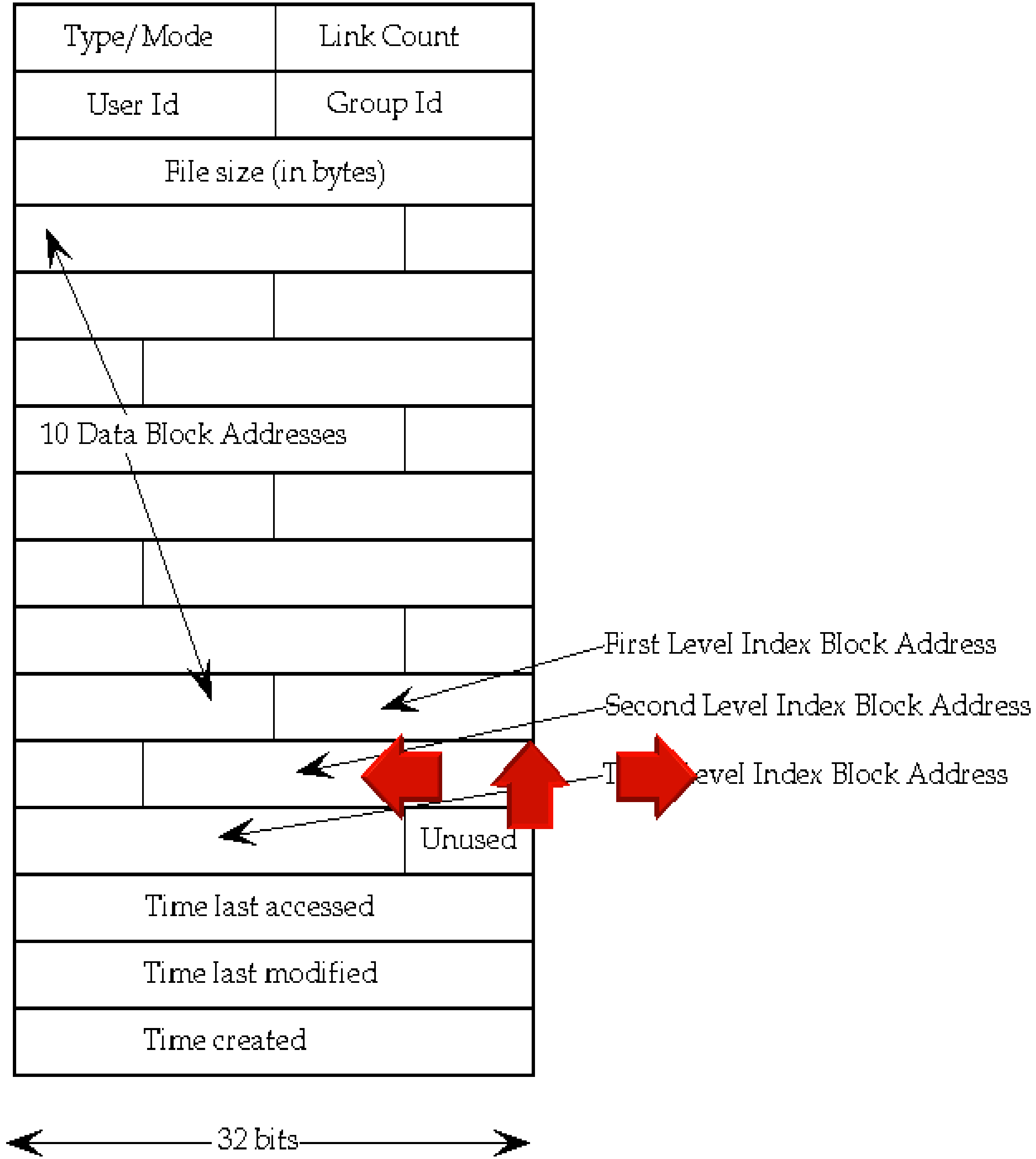
What does the above imply in UNIX?

Organization of Objects

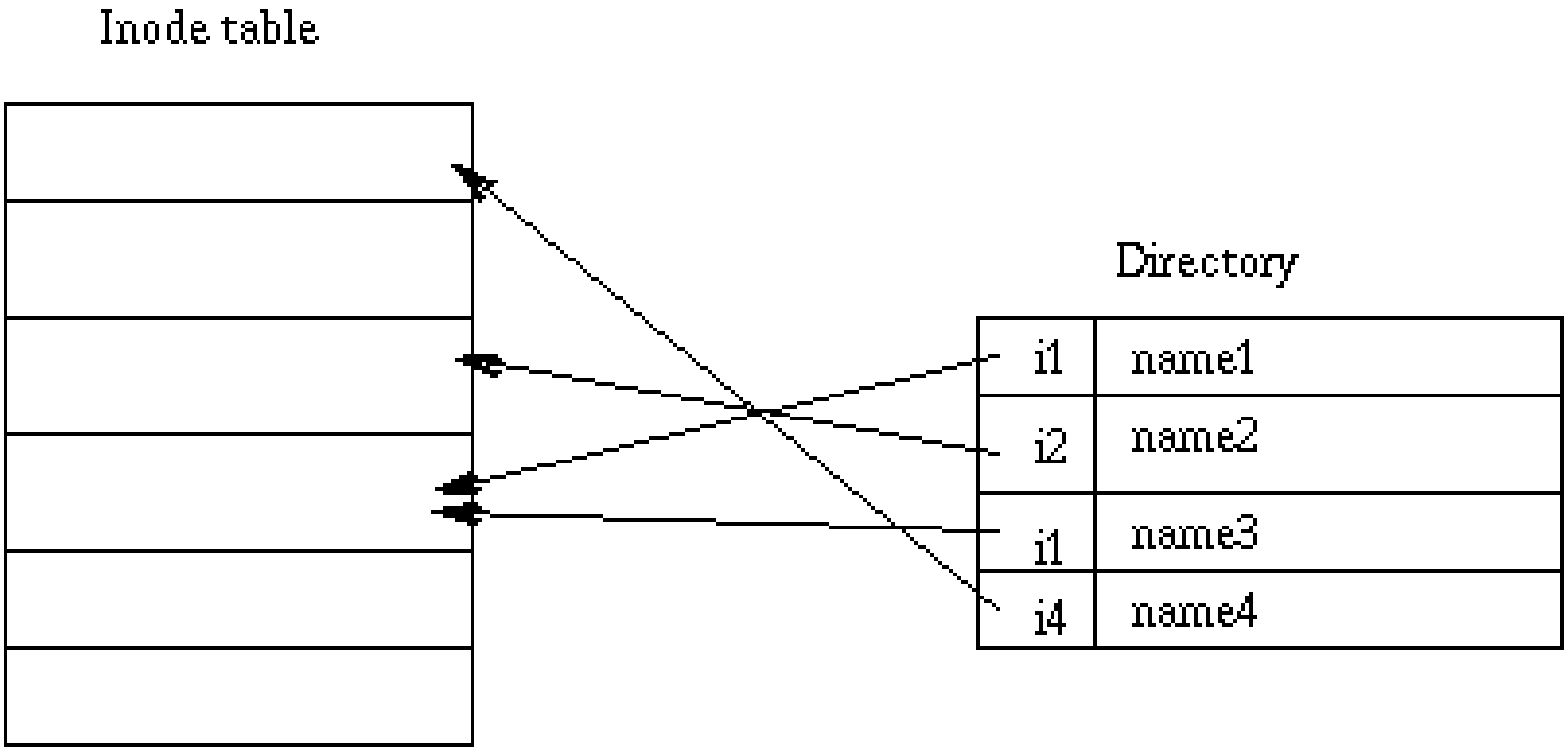
- In UNIX, almost all objects are modeled as files
  - Files are arranged in a hierarchy
  - Files exist in directories
  - Directories are also one kind of files
- Each object has
  - owner
  - group
  - 12 permission bits
    - rwx for owner, rwx for group, and rwx for others
    - suid, sgid, sticky

UNIX inodes:

Each file corresponds to an inode



UNIX Directories



Basic Permissions Bits on Files (Non-directories)

- Read controls reading the content of a file
  - i.e., the read system call
- Write controls changing the content of a file
  - i.e., the write system call
- Execute controls loading the file in memory and execute
  - i.e., the execve system call

Permission Bits on Directories

- Read bit allows one to show file names in a directory
- The execution bit controls traversing a directory
  - does a lookup, allows one to find inode # from file name
  - chdir to a directory requires execution
- Write + execution control creating/deleting files in the directory
  - Deleting a file under a directory requires no permission on the file
- Accessing a file identified by a path name requires execution to all directories along the path

The suid, sgid, sticky bits

	suid	sgid	sticky bit
non-executable files	no effect	affect locking (unimportant for us)	not used anymore
executable files	change euid when executing the file	change egid when executing the file	not used anymore
directories	no effect	new files inherit group of the directory	only the owner of a file can delete

Some Examples

- What permissions are needed to access a file/directory?
  - read a file: /d1/d2/f3
  - write a file: /d1/d2/f3
  - delete a file: /d1/d2/f3
  - rename a file: from /d1/d2/f3 to /d1/d2/f4
  - …
- File/Directory Access Control is by System Calls
  - e.g., open(2), stat(2), read(2), write(2), chmod(2), opendir(2), readdir(2), readlink(2), chdir(2), …

The Three Sets of Permission Bits

- Intuition:
  - if the user is the owner of a file, then the r/w/x bits for owner apply
  - otherwise, if the user belongs to the group the file belongs to, then the r/w/x bits for group apply
  - otherwise, the r/w/x bits for others apply

Other Issues On Objects in UNIX

- Accesses other than read/write/execute
  - Who can change the permission bits?
    - The owner can
  - Who can change the owner?
    - Only the superuser
- Rights not related to a file
  - Affecting another process
  - Operations such as shutting down the system, mounting a new file system, listening on a low port
    - traditionally reserved for the root user

Security Principles Related to Access Control

- Psychological acceptability is related to configuring access control policies.

- Fail-safe defaults
- Least privilege
- Complete mediation

Principle of Fail-safe defaults

- Base access decisions on permission rather than exclusion. This principle[…] means that the default situation is lack of access, and the protection scheme identifies conditions under which access is permitted. The alternative, in which mechanisms attempt to identify conditions under which access should be refused, presents the wrong psychological base for secure system design. A conservative design must be based on arguments why objects should be accessible, rather than why they should not.
- E.g., whitelisting instead of black listing.

Principle of Least Privilege

- Every program and every user of the system should operate using the least set of privileges necessary to complete the job. Primarily, this principle limits the damage that can result from an accident or error. It also reduces the number of potential interactions among privileged programs to the minimum for correct operation, so that unintentional, unwanted, or improper uses of privilege are less likely to occur. [……] The military security rule of "need-to-know" is an example of this principle.

Principle of Complete mediation

- Every access to every object must be checked for authority. This principle, when systematically applied, is the primary underpinning of the protection system. It forces a system-wide view of access control, which in addition to normal operation includes initialization, recovery, shutdown, and maintenance. It implies that a foolproof method of identifying the source of every request must be devised. It also requires that proposals to gain performance by remembering the result of an authority check be examined skeptically. If a change in authority occurs, such remembered results must be systematically updated.

Subjects vs. Principals

- Access rights are specified for user accounts (principals).
- Accesses are performed by processes (subjects)
- The OS needs to know on which user accounts' behalf a process is executing

- How is this done in Unix?

Process User ID Model in Modern UNIX Systems

- Each process has three user IDs
  - real user ID (ruid) — owner of the process
  - effective user ID (euid) — used in most access control decisions
  - saved user ID (suid)
- and three group IDs
  - real group ID
  - effective group ID
  - saved group ID

Process User ID Model in Modern UNIX Systems

- When a process is created by *fork*
  - it inherits all three users IDs from its parent process
- When a process executes a file by *exec*
  - it keeps its three user IDs unless the set-user-ID bit of the file is set, in which case the effective uid and saved uid are assigned the user ID of the owner of the file
- A process may change the user ids via system calls

The Need for suid/sgid Bits

- Some operations are not modeled as files and require user id = 0
  - halting the system
  - bind/listen on “privileged ports” (TCP/UDP ports below 1024)
  - non-root users need these privileges
- File level access control is not fine-grained enough
- System integrity requires more than controlling who can write, but also how it is written

Security Problems of Programs with suid/sgid

- These programs are typically setuid root
- Violates the least privilege principle
  - every program and every user should operate using the least privilege necessary to complete the job
- Why violating least privilege is bad?
- How would an attacker exploit this problem?
- How to solve this problem?

Changing effective user IDs

- A process that executes a set-uid program can drop its privilege; it can
  - drop privilege permanently
    - removes the privileged user id from all three user IDs
  - drop privilege temporarily
    - removes the privileged user ID from its effective uid but stores it in its saved uid, later the process may restore privilege by restoring privileged user ID in its effective uid

What Happens during Logging in

login	
pid	2235
euid	0
ruid	0
suid	0

setuid(500) →

login	
pid	2235
euid	500
ruid	500
suid	500

exec("bash") →

bash	
pid	2235
euid	500
ruid	500
suid	500

fork() →

After the login process verifies that the entered password is correct, it issues a setuid system call.

The login process then loads the shell, giving the user a login shell.

The user types in the passwd command to change his password.

bash	
pid	2235
euid	500
ruid	500
suid	500

bash	
pid	2297
euid	500
ruid	500
suid	500

exec("passwd")

passwd	
pid	2297
euid	0
ruid	500
suid	0

Drop privilege permanently

passwd	
pid	2297
euid	500
ruid	500
suid	500

Drop privilege temporarily

passwd	
pid	2297
euid	500
ruid	500
suid	0

The fork call creates a new process, which loads "passwd", which is owned by root user, and has setuid bit set.

Mechanism versus Policy

- "Separation of mechanism and policy" as a design principle
  - Roughly, implements a mechanism that is flexible and can be configured to support different policies, instead of hardcoding the policy in the implementation.
  - Delay decisions as much as possible, leave decisions to users
- Examples:
  - "Mechanism, not policy" made explicit initially by the designers of X windowing system
    - X provide primitives, and Interface and look-and-feel up to application level
  - UNIX's philosophy in general, simple flexible tools
  - Linux security module as another example

Case Against "Mechanism, no Policy"

- Eric Steven Raymond in The Art of Unix Programming, the "What Unix Gets Wrong" section
  - "But the cost of the mechanism-not-policy approach is that when the user *can* set policy, the user *must* set policy. Nontechnical end-users frequently find Unix's profusion of options and interface styles overwhelming and retreat to systems that at least pretend to offer them simplicity."
  - "In the short term, Unix's laissez-faire approach may lose it a good many nontechnical users. In the long term, however, it may turn out that this 'mistake' confers a critical advantage — because policy tends to have a short lifetime, mechanism a long one. So the flip side of the flip side is that the "mechanism, not policy" philosophy may enable Unix to renew its relevance long after competitors more tied to one set of policy or interface choices have faded from view."

Case Against "Mechanism, no Policy", My View

- Especially problematic for security.
  - "A security mechanism that is very flexible and can be extensively configured is not just overwhelming for end users, it is also highly error-prone. While there are right ways to configure the mechanism to enforce some desirable security policies, there are often many more incorrect ways to configure a system. And the complexity often overwhelms users so that the mechanism is simply not enabled. […] While a mechanism is absolutely necessary for implementing a protection system, having only a low-level mechanism is not enough."
  - In Li et al. "Usable Mandatory Integrity Protection for Operating Systems", IEEE SSP 2007.

For security, needs to provide right tradeoff of flexibility versus rigitity.

A Case Study of “Mechanism vs. Policy” in UNIX Access Control

- The policy: a process that executes a set-uid program can drop its privilege; it can
  - drop privilege permanently
  - drop privilege temporarily
- The mechanism: setuid system calls

“Setuid Demystified”, In USENIX Security ‘ 02

Access Control in Early UNIX

- A process has two user IDs: real uid and effective uid and one system call setuid
- The system call setuid(id)
  - when euid is 0, setuid set both the ruid and the euid to the parameter
  - otherwise, the setuid could only set effective uid to real uid
    - Permanently drops privileges
- A process cannot temporarily drop privilege

System V

- To enable temporarily drop privilege, added saved uid & a new system call
- The system call seteuid
  - if euid is 0, seteuid could set euid to any user ID
  - otherwise, could set euid to ruid or suid
    - Setting euid to ruid temp. drops privilege
- The system call setuid is also changed
  - if euid is 0, setuid functions as seteuid
  - otherwise, setuid sets all three user IDs to real uid

BSD

- Uses ruid & euid, change the system call from setuid to setreuid
  - if euid is 0, then the ruid and euid could be set to any user ID
  - otherwise, either the ruid or the euid could be set to value of the other one
    - enables a process to swap ruid & euid

Modern UNIX

- System V & BSD affect each other, both implemented setuid, seteuid, setreuid, with different semantics
  - some modern UNIX introduced setresuid
- Things get messy, complicated, inconsistent, and buggy
  - POSIX standard, Solaris, FreeBSD, Linux

Suggested Improved API

- Three method calls
  - drop_priv_temp
  - drop_priv_perm
  - restore_priv
- Lessons from this?
  - "Mechanism, not policy" not necessarily a good idea for security (flexibility not always a good thing)
  - Psychological acceptability principle
    - "human interface should be designed for ease of use"
    - the user's mental image of his protection goals should match the mechanism

Coming Attractions …

- Software Vulnerabilities