Data Security and Privacy

Unix Discretionary Access Control

Readings for This Lecture

- Wikipedia
  - 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

What Security Goals Does Operating System Provide (Past)?

- 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 (Recent Past and Current)?

- More recent past and present: Networked 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 (Current and Near Future)?

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

What is Access Control?

- Build a wall to prevent access, and then design a guarded gate to decide what access should be allowed.

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: A chip-enforced Wall

- 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)

- 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

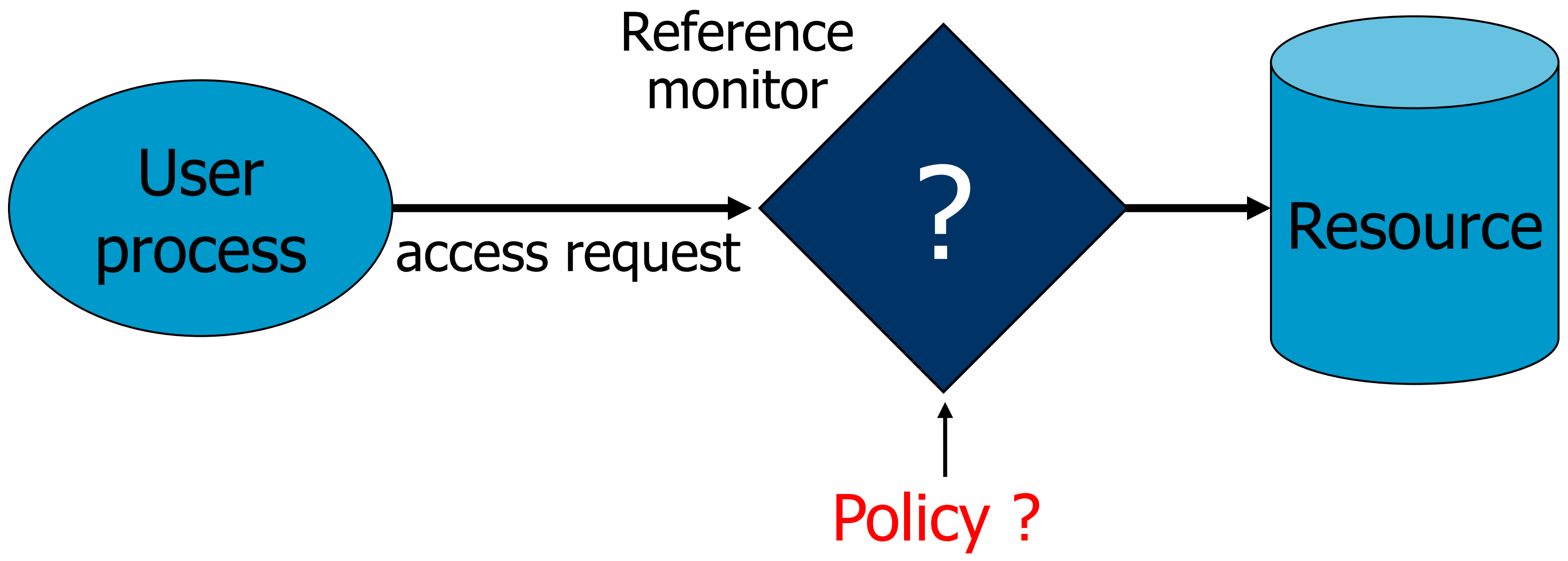
- Part of the OS runs in the kernel model
  - known as the OS kernel
- Other parts of the OS run in the user mode, including service programs (daemon programs), user applications, etc.
  - they run as processes
  - they form the user space (or the user land)
- When they need privileged access that only kernel can provide, they issue system calls.

Privilege Levels

- Security is often achieved by running control/protection code at a higher privilege level
- Components running at the same level can be isolated by a higher-privilege component
- If attack and defense are at the same level, then it is an arms’ race and there can be no guarantee

Access control

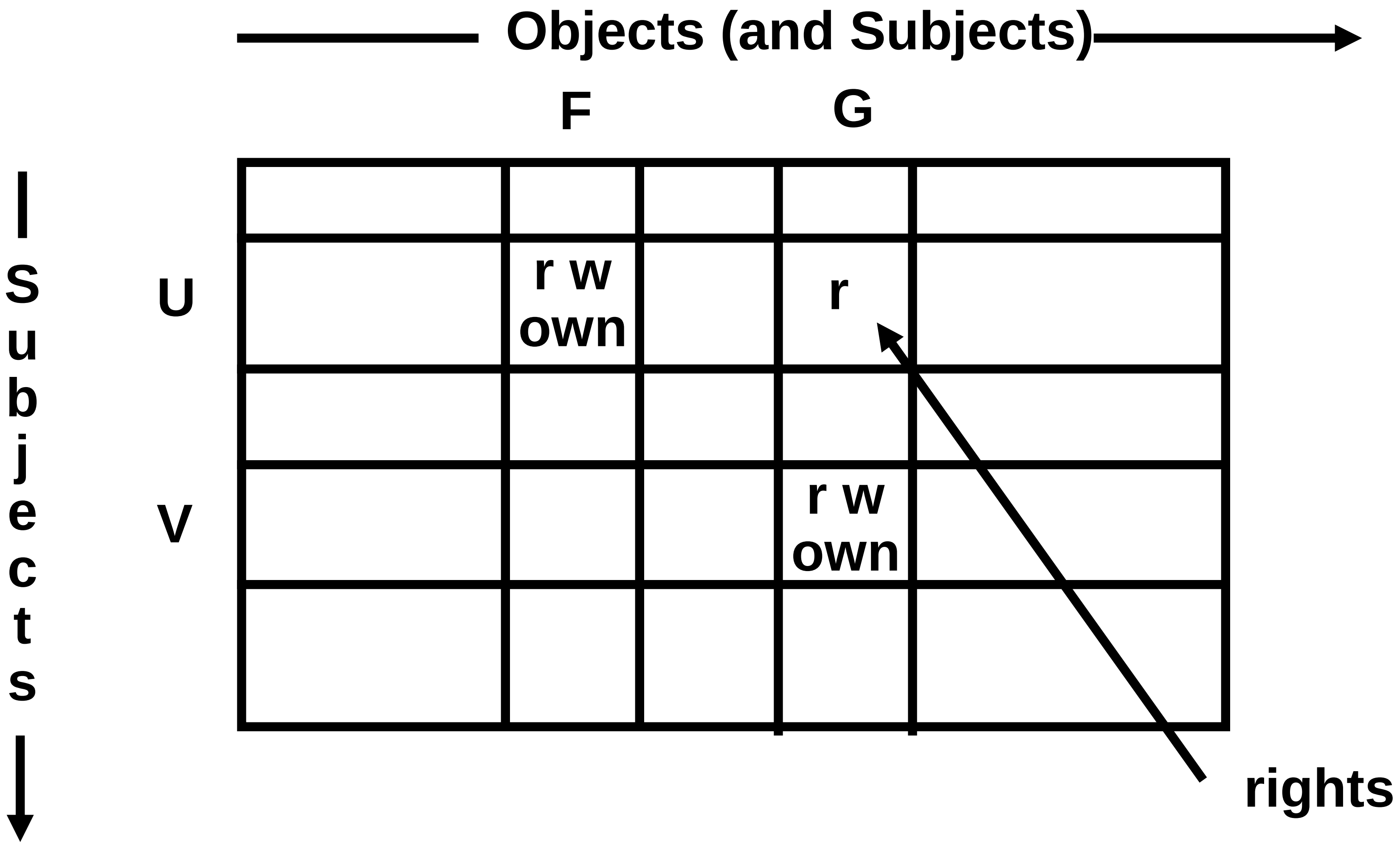
- A reference monitor mediates all access to resources
  - Principle: Complete mediation: control **all** accesses to resources



A Motivating Example

- In Linux/Unix, a process calls the system call
  remove(“/d1/d2/f3”)
- How does the system decides whether to allow it or not?

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)

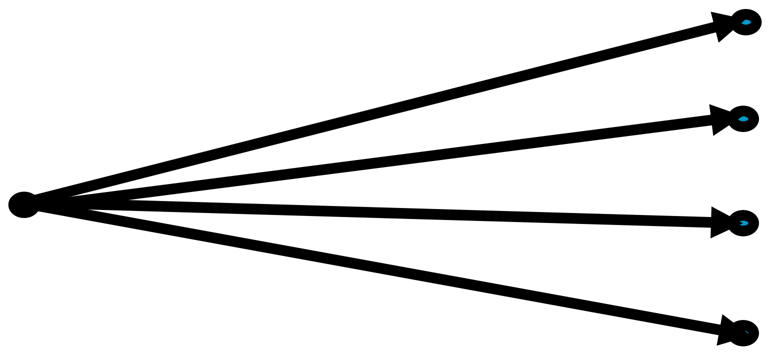
The Need for PRINCIPALS: Beyond SUBJECTS

- A subject is a program (application) executing on behalf of some principal(s)
- A principal is an entity to which the policy grants access rights
- 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?

USERS AND PRINCIPALS



USERS

Real World User

PRINCIPALS

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?

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

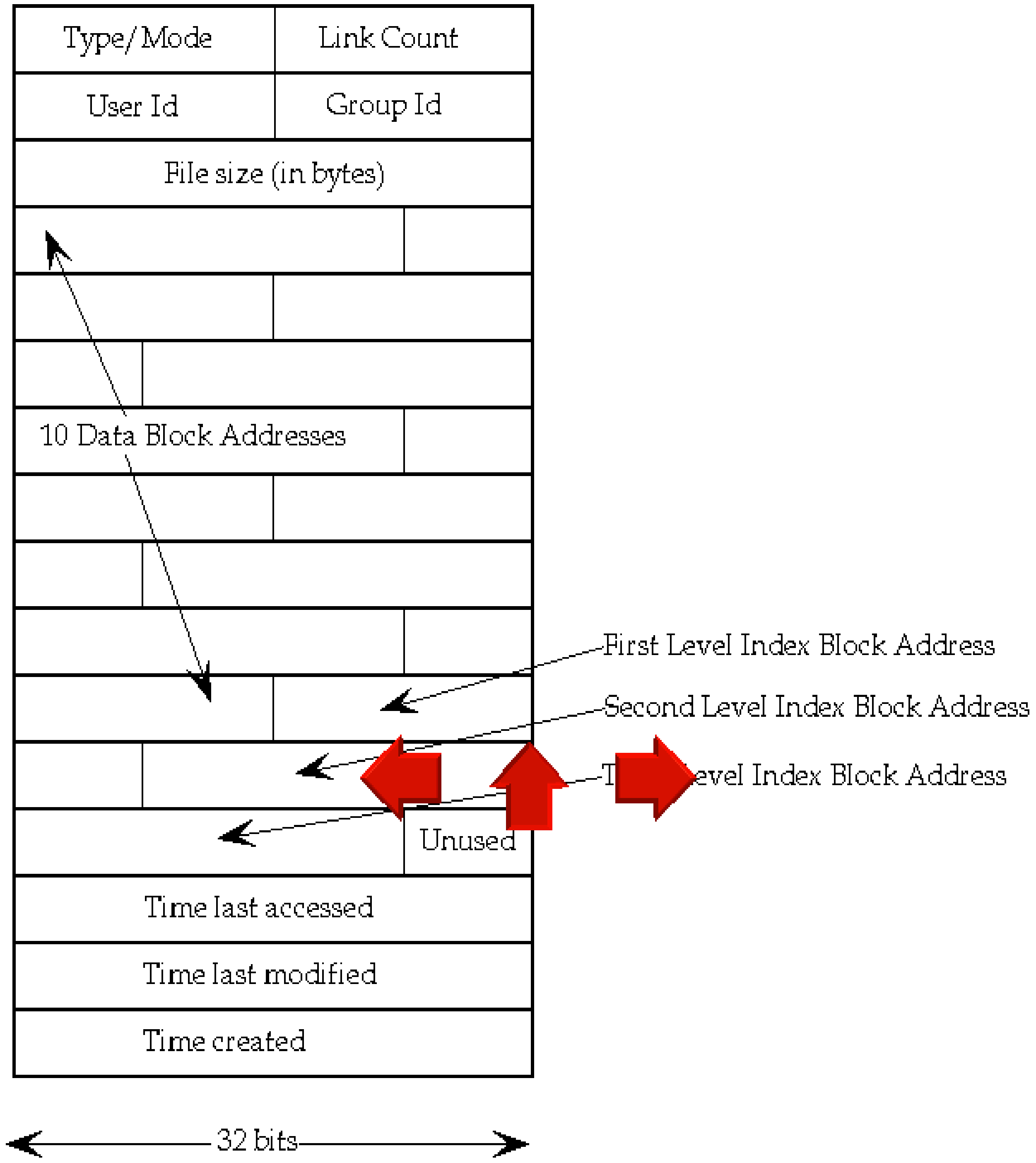
Organization of Objects

- 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

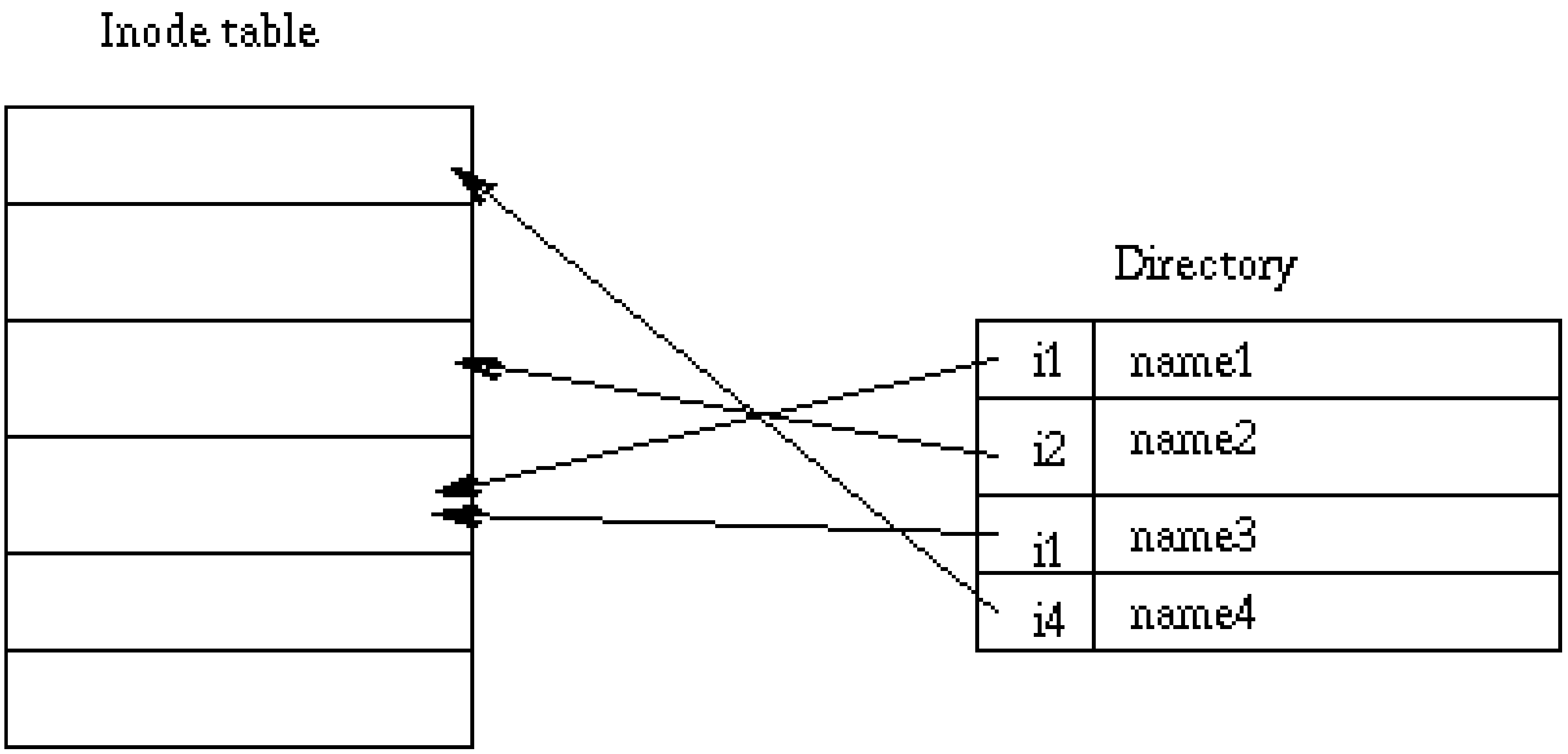
- Each object has
  - owner
  - group
  - 12 permission bits
    - rwx for owner, rwx for group, and rwx for others
    - suid, sgid, sticky

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

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

- What are the other 3 bits? What do they control?

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

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

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?

UNIX Access Control Overview

• Three concepts	Our terminology
– Human Users	Humans
– User Accounts	Users/accounts/principals
– Process	Processes/subjects

- UNIX Access Control System has
  - A discretionary policy specification
    - determines which user accounts have access to which objects
  - A policy enforcement component
    - determines on which user’s behalf a subject (process) is acting upon

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
- In addition, 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”) →

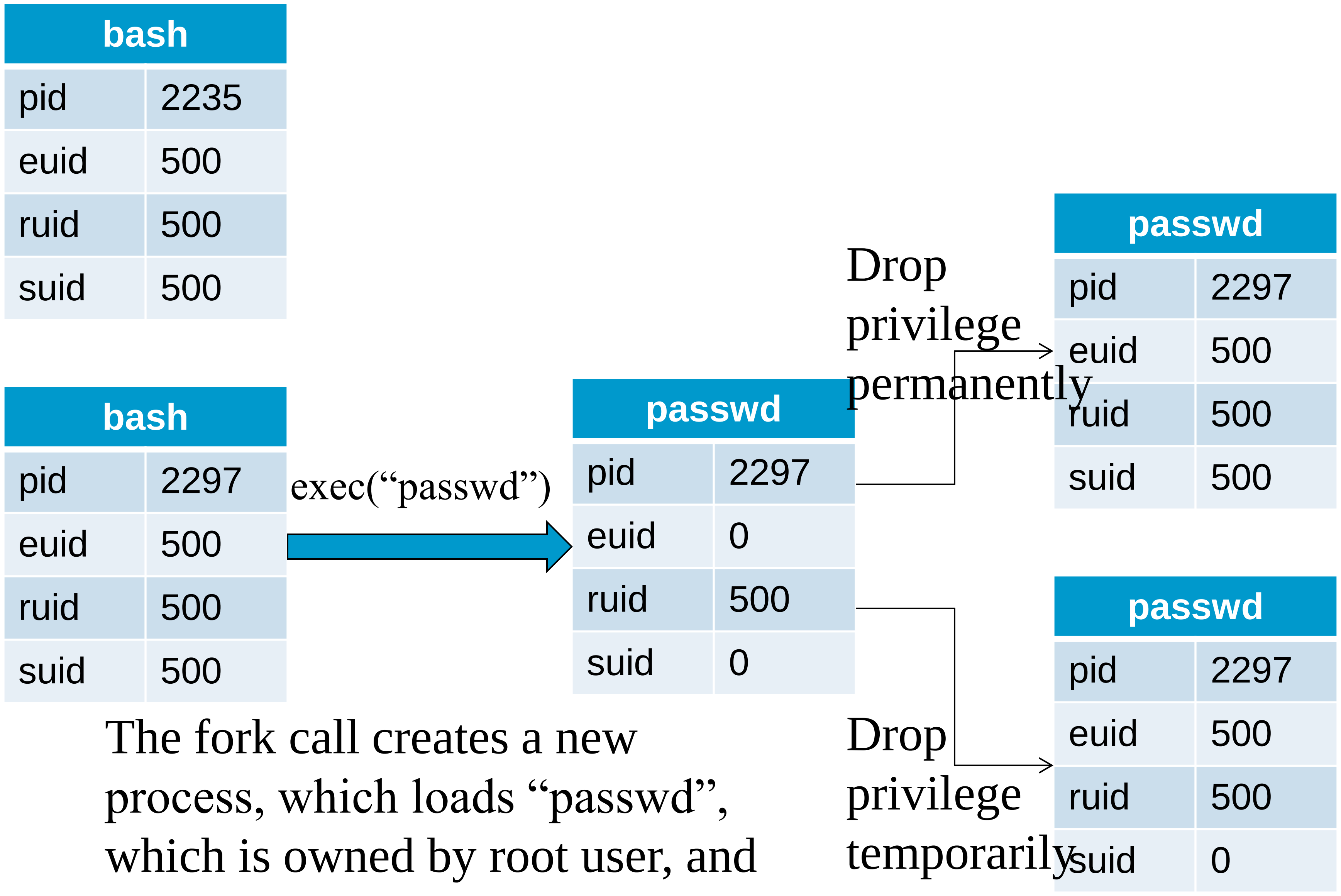
bash	
pid	2235
euid	500
ruid	500
suid	500

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.

Issues to Consider in Designing an Access Control System

- What are the objects? How are they organized?
- What are the subjects? What are the principals?
- How to relate subjects to principals?
- Whether/how to map human users to principals?
- What kinds of operations subjects can perform on objects?
- Where to store the access control policy data?
- How can access control policy data be updated? How to control the update operation?
- How to intercept access to perform the check? Are all access path covered?
- What are the limitations of the protection, i.e., what does it take to break the protection? How to deal with such residue threats?

Coming Attractions …

- How to deal with the threat of malicious and/or buggy software to enforcing access control policies?