# 02. Protection

9th ed: Ch. 2.7+, 14, 15, 16

10th ed: Ch. 2.7+, 16, 17, 19

# Objectives

- To describe the evolution of the operating system
- To understand how the OS protects itself from user programs
- To understand how the OS protects user programs from each other
- To know some different ways the OS can be structured
- To be aware of some security considerations

# Outline

- OS evolution
- Kernels
- Security

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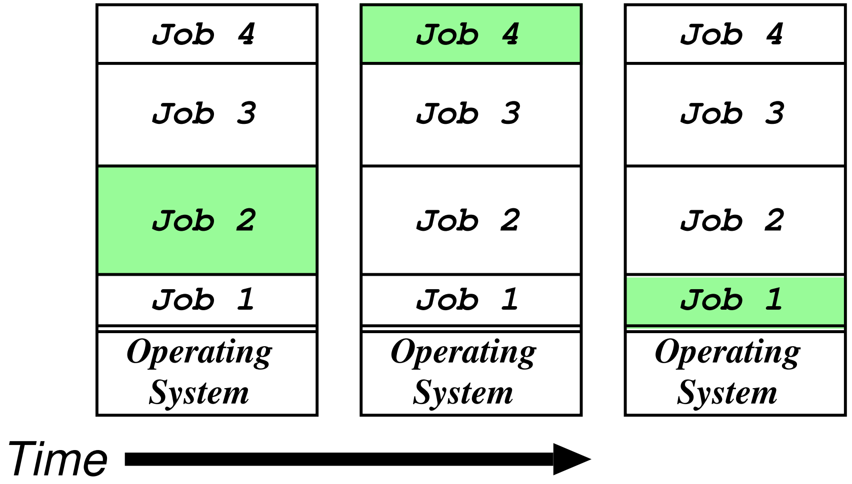
- OS evolution
  - Single-tasking
  - Dual-mode operation
- Kernels
- Security

# Operating system evolution

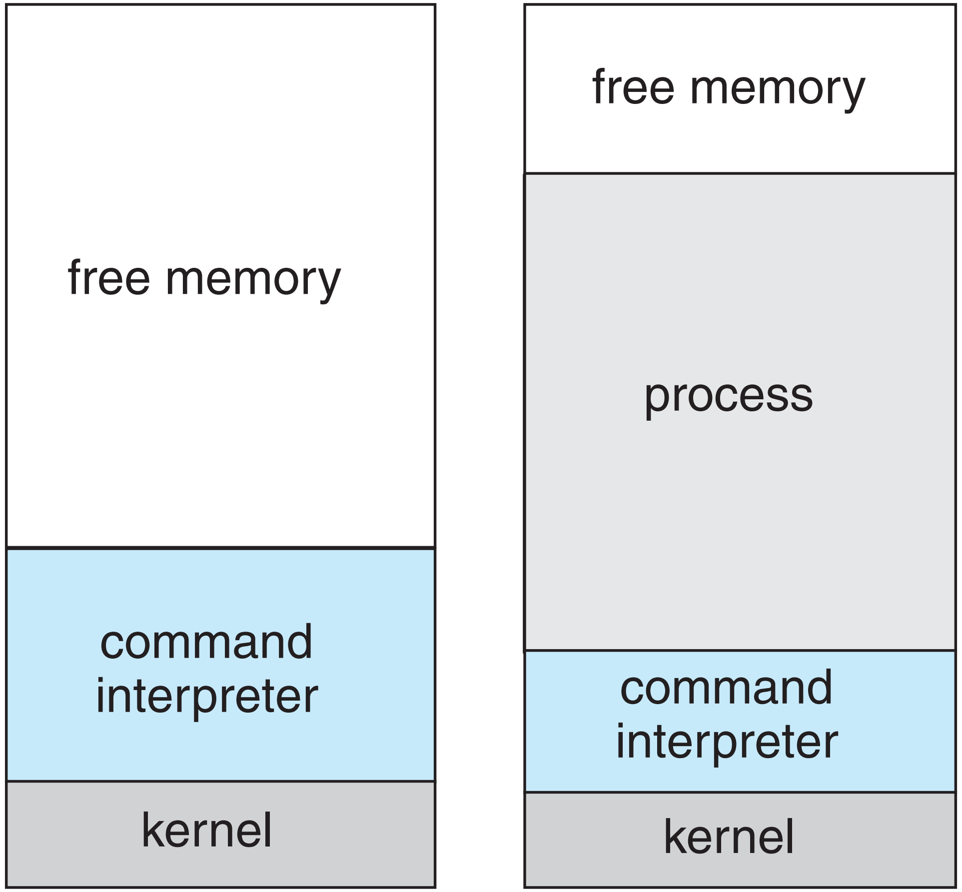
- **Open shop**: One machine, one CPU, one user, one program – the user is the programmer is the operator, all programming is in machine code
  - E.g., EDSAC, 1947—1955
- **Batch systems**: tape drives collate and run a set of programs in a batch, increasing efficiency
  - Spooling allowed overlap of I/O with computation
- **Multiprogramming**: one machine, one CPU, one running program but many loaded programs
  - **Job scheduling**: select jobs to load and then which resident job to run



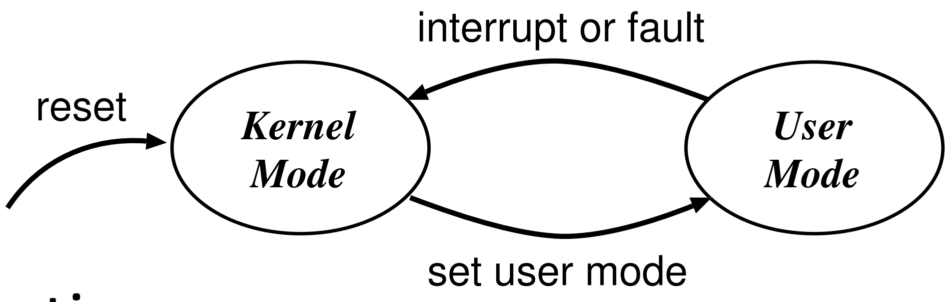

- **Timesharing**: switching jobs so frequently that users have the illusion many jobs are running simultaneously
  - **CPU scheduling**: select which job to run from many that are ready
  - Enables interactive computing

# Single-tasking OS: MS-DOS

- Command interpreter receives input from user
  - Program is loaded, overwriting much of the command interpreter
  - Instruction pointer set to start of program
- Once finished, termination causes command interpreter stub to reload command interpreter
  - Exit error code available to user



# Dual-mode operation



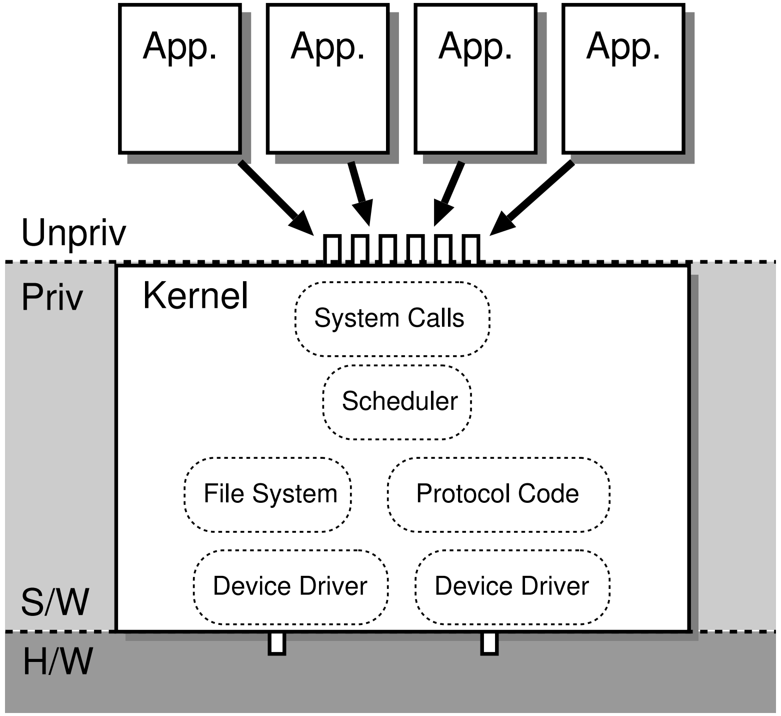

- Allows OS to stop malicious or buggy code from doing bad things
- Use hardware – a **mode bit** – to distinguish (at least) two modes of operation
  - **User mode** when executing on behalf of a user (i.e. application programs)
  - **Kernel mode** when executing on behalf of the OS
  - Some instructions designated as privileged, only executable in kernel mode
- Increasingly CPUs support multi-mode operations
  - i.e. virtual machine manager (VMM) mode for guest VMs
- Often "nested" e.g., x86 rings 0—3; further inside can do strictly more
  - Not ideal, but disjoint/overlapping permissions is complex

# Outline

- OS evolution
- Kernels
    - System calls
    - Microkernels
    - Virtualisation
- Security

# Kernels

- Protection prevents applications doing IO – kernel does it for them
  - Thus we need an unprivileged instruction to transition from user to kernel mode
  - Generally called a **trap** or a **software interrupt** since operates similarly to (hardware) interrupt
- OS services are accessible via **system calls**
  - Invoked by a trap with OS having vectors to handle
  - Vector enforces code run when mode switch occurs
  - Prevents application from switching to kernel mode and then just doing whatever it likes
- Alternative is for OS to emulate for application, and check every instruction before execution as used in some virtualisation systems, e.g., QEMU

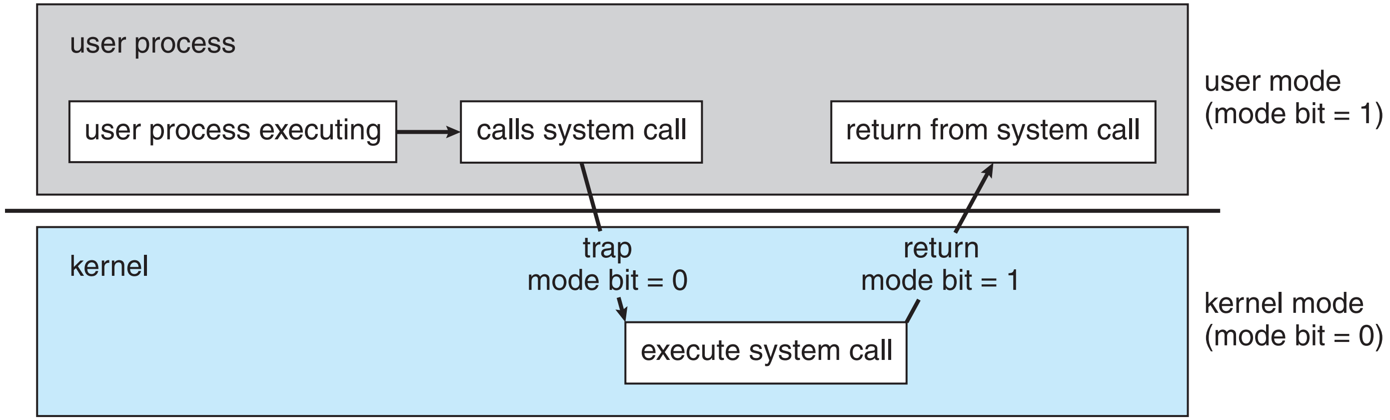


# System calls

- Provide a (language agnostic) standard interface to the OS services
- Accessed via a high-level (language specific) Application Programming Interface (API) rather than called directly
  - E.g., glibc

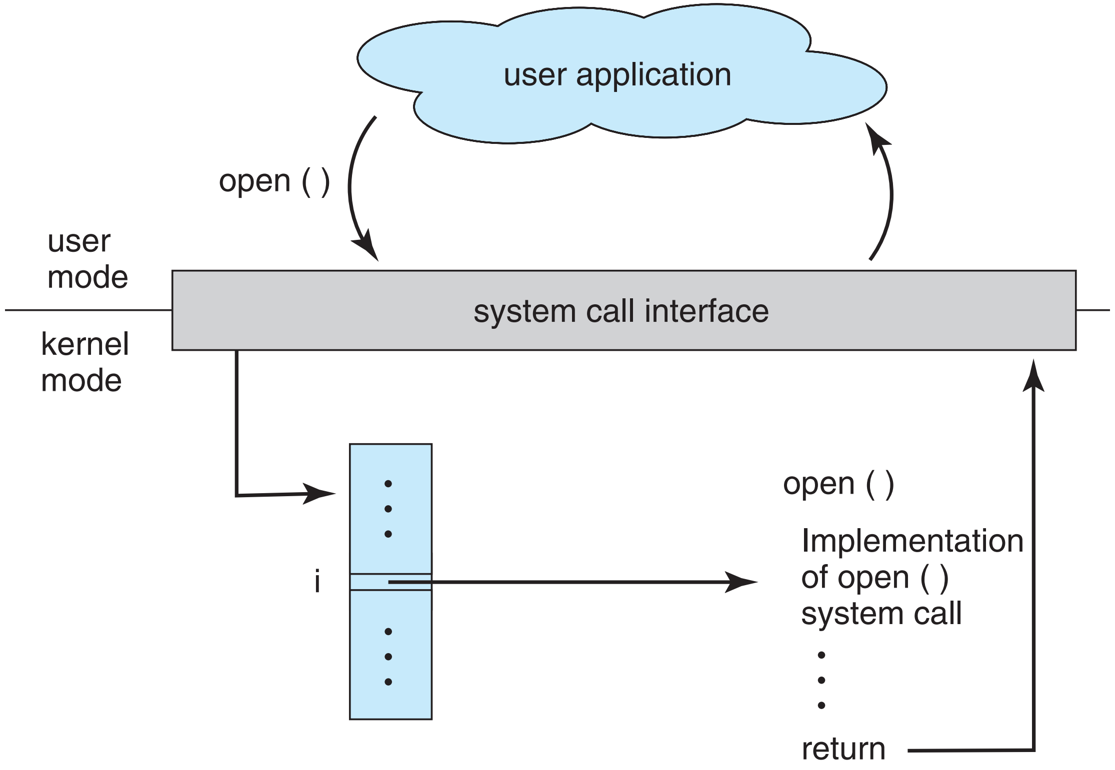
```rust
#[inline(always)]
pub unsafe fn syscall4(mut n: usize,
                       a1: usize,
                       a2: usize,
                       a3: usize,
                       a4: usize)
                       -> usize
{
    llvm_asm!("int $$0x80"
         : "+{eax}"(n)
         : "{ebx}"(a1) "{ecx}"(a2) "{edx}"(a3) "{esi}"(a4)
         : "memory" "cc"
         : "volatile");
    n
}
```

Raw system calls in Rust
https://github.com/strake/system-call.rs/



# System call invocation

- Typically each system call is associated by a number that indexes a **system call table**
  - Invoked by putting the relevant number and any required parameters in the right places and trapping
  - Return status and any values made available to application in user space
- Usually managed by run-time support library, a set of functions built into libraries automatically linked by your compiler

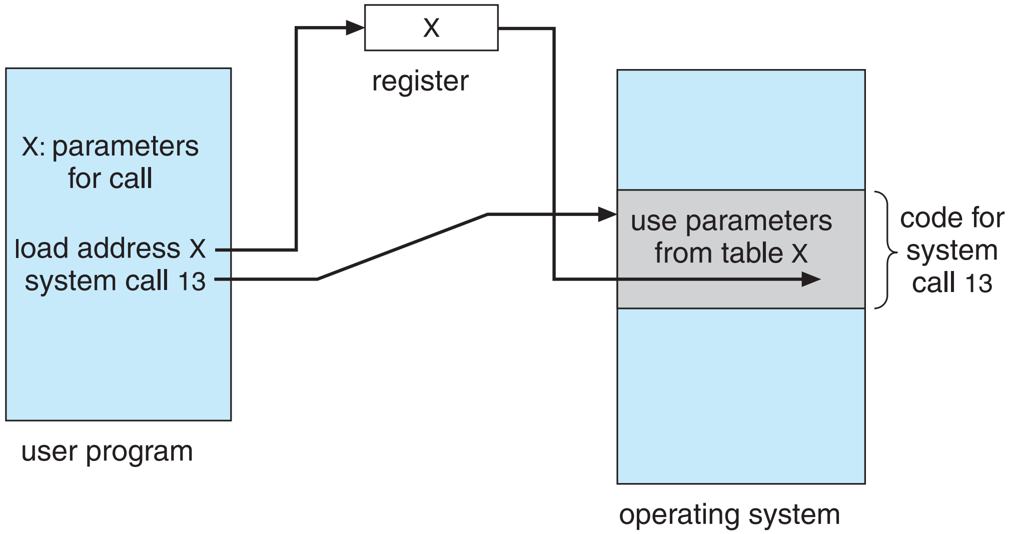


# System call parameters

- Three main ways to pass parameters:
    1. Load into registers
    2. Place onto stack for the kernel to pop off
    3. Place into a block of memory and put the block's address into a register
- One of the latter two usually preferred
    - Registers limited in number and size

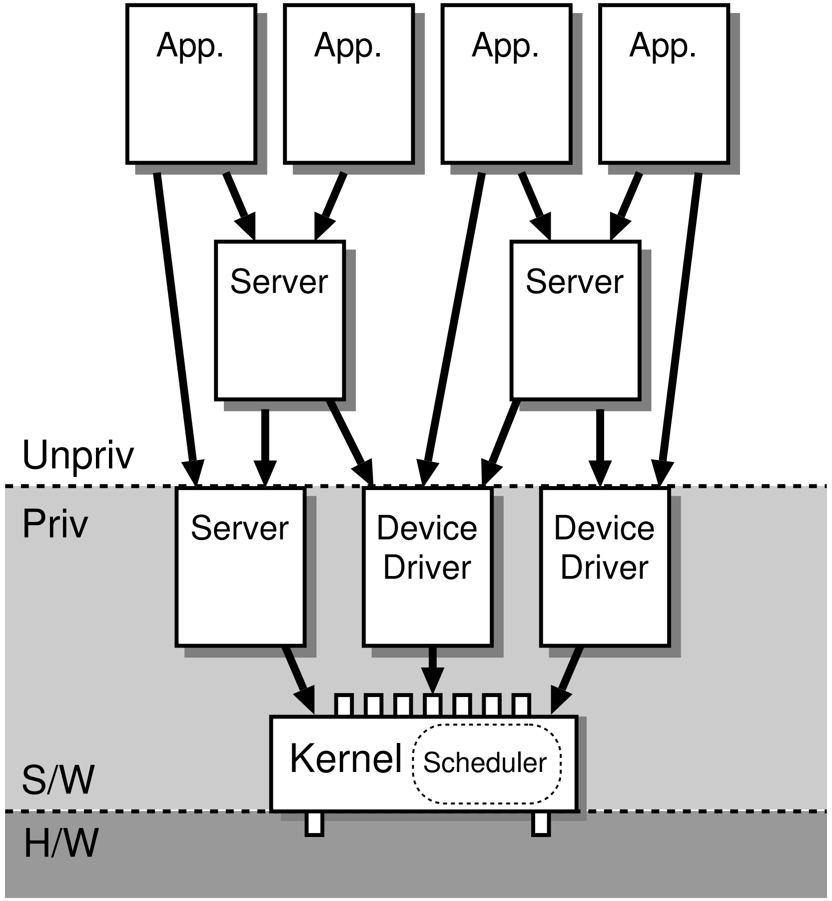
```
int
open(const char *path, int oflag, ...);

ssize_t
read(int fildes, void *buf, size_t nbyte);
```



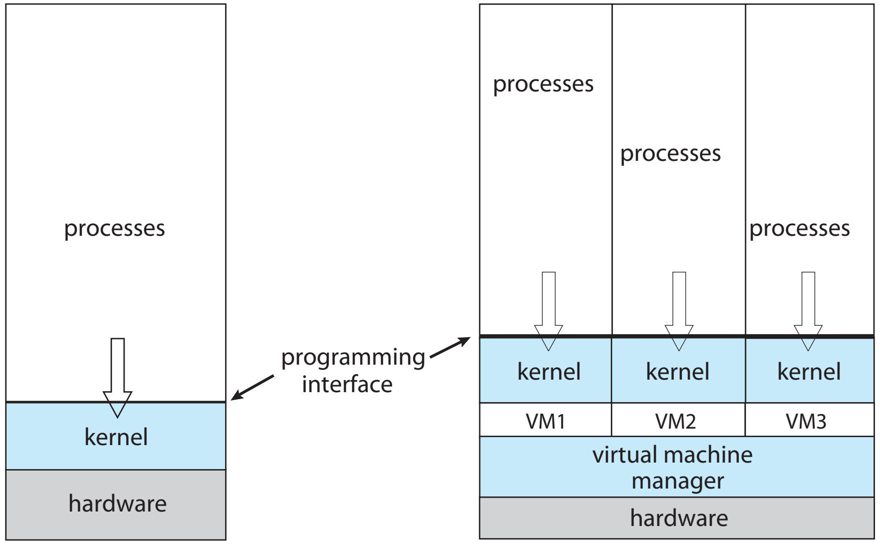
# Microkernels

- OS interfaces must be extremely stable
  - Makes them difficult to extend with new calls
  - Even more difficult to remove calls
- Alternative is **microkernels**
  - Move OS services into local, sometimes privileged, servers
  - Increases modularity and extensibility
- **Message passing** used to access servers
  - Replaces trapping so must be extremely efficient
- Many common OSs blur the distinction between kernel and microkernel, e.g.,
  - Linux has kernel modules and some servers
  - Windows NT 3.5 originally a microkernel but performance concerns caused NT 4.0 to move services back into the kernel



# Virtualisation

- More recently, trend towards encapsulating applications differently
  - Make the system appear to be supporting just one application
  - Particularly relevant when building systems using microservices
  - Protection, or isolation at a different level




- **Virtualisation**: allows operating systems to be run alongside each other above a **hypervisor**
  - Type 1 runs directly on the host hardware, possibly using hardware extensions (VT-x)
  - Type 2 runs above a full OS kernel
  - Can support cross-architecture using **emulation** (slow) or **interpretation** (if not natively compiled)

# Virtual machines, containers

- Virtual Machines encapsulate an entire running system, including the OS, and then boot the VM over a hypervisor
  - E.g., Xen, VMWareESX, Hyper-V
- Containers expose functionality in the OS so that each container acts as a separate entity even though they all share the same underlying OS functionality
  - E.g., Linux Containers, FreeBSD Jails, Solaris Zones
- Use cases include
  - Laptops and desktops running multiple OSes for exploration or compatibility
  - Developing apps for multiple OSes without having multiple systems
  - QA testing applications without having multiple systems
  - Executing and managing compute environments within datacenters

# Outline

- OS evolution
- Kernels
- Security
    - Principle of least privilege
    - Domain of protection
    - Access matrix
    - Access Control Lists (ACLs)
    - Capabilities
    - Authentication

# Security

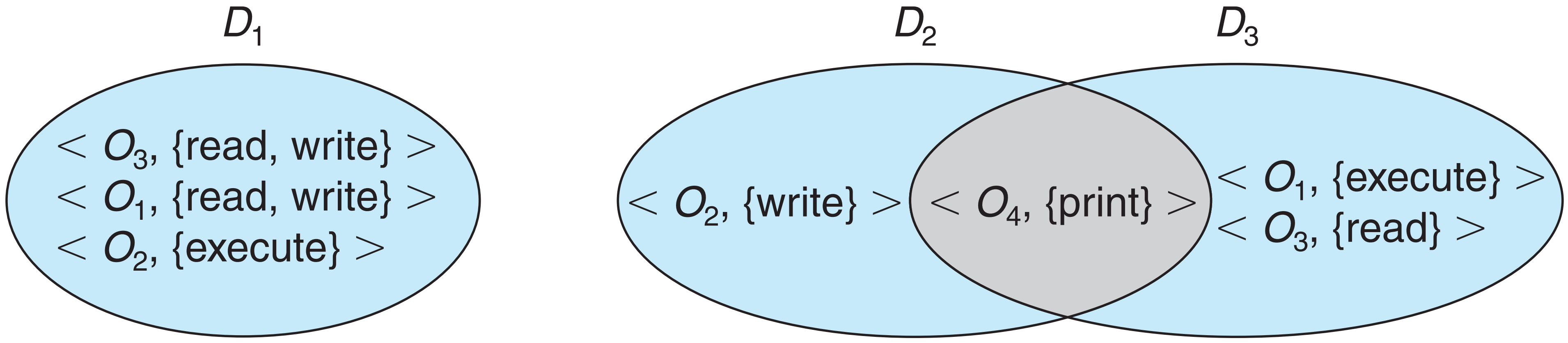
- Defence of the system against internal and external attacks
  - Huge range of attacks, including denial-of-service, worms, viruses, identity theft, theft of service
- Systems generally first distinguish among users, to determine who can do what
  - User identities (user IDs, security IDs) include name and associated number, one per user
  - User ID then associated with all files, processes of that user to determine access control
  - Group identifier (group ID) allows set of users to be defined and controls managed, then also associated with each process, file
- **Privilege escalation** allows user to change to effective ID with more rights

# Principle of least privilege

- Objects should be given just enough privileges to perform their tasks
  - **Hardware objects** (e.g., devices) and **software objects** (e.g., files, programs, semaphores)
- Properly set permissions can limit damage if object has a bug and gets abused
  - Can be **static** (during life of system, during life of process)
  - Or **dynamic** (changed by process as needed) by domain switching, privilege escalation
- Compartmentalization a derivative concept regarding access to data
  - Process of protecting each individual system component through the use of specific permissions and access restrictions
  - More granular, more complex, more protective
- **Covert channels** leak information using side-effects
  - Hardware include wire tapping or receiving electromagnetic radiation from devices
  - Software include page fault statistics or input-dependent timing
  - E.g., lowest layer of recent OCaml TLS library had to be written in C to avoid the garbage collector becoming a covert channel

# Domain of protection

- Domain limits access to (and operations on) objects
  - *access-right* = < *object-name*, *rights-set* > where *rights-set* is a subset of all valid operations that can be performed on *object-name*
  - A domain is then a set of *access-rights*
  - In UNIX a domain is a user id



# Access matrix

- A matrix of **domains** (**subjects**, **principals**) against **objects**
  - Rows represent domains, columns represent objects
  - $M_{i,j}$ = operations a process in domain $i$ can invoke on object $j$
  - Operations can include adding/deleting entries in matrix
- Example of separation of policy from mechanism

| domain \ object | $F_1$ | $F_2$ | $F_3$ | laser printer | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
|---|---|---|---|---|---|---|---|---|
| $D_1$ | read | | read | | | switch | | |
| $D_2$ | | | | print | | | switch | switch control |
| $D_3$ | | read | execute | | | | | |
| $D_4$ | write | | write | | switch | | | |

# Implementing the access matrix

- The access matrix is a table of triples < *domain, object, rights-set* >
  - For a domain to invoke an operation on an object involves searching to see if that operation is in any *rights-set* for the pair < *domain*, *object* >
- Table is large so may not fit in memory – but sparse
- Two common representations
  1. By **object**, storing list of subjects and rights with each object – **Access Control List** (**ACL**)
  2. By **subject**, storing list of objects and rights with each subject – **Capabilities**

# Access Control Lists (ACLs)

- Each column is an access list for one object
    - Results in a per-object ordered list of < *domain*, *rights-set* >
- Often used in storage systems
    - System naming scheme provides for ACL to be inserted in naming path, e.g., files
- If ACLs stored on disk, check is in software so use only on low duty cycle – for higher duty cycle must cache results of check
    - E.g., ACL checked when file opened for read or write, or when code file is to be executed
- In (e.g.) UNIX, access control is by program, allowing arbitrary policies

# Capabilities

- Each row is a capability for one domain
  - Indicates operations permitted on a set of objects
- To execute operation $M$ on object $O_j$, process requests operation and passes capability as parameter
  - Possession of capability means access is allowed
  - Capability is a protected object, maintained by the OS and unmodifiable by the application – like a “secure pointer”
- Hardware capabilities, e.g., CHERI
  - Have special machine instructions to modify (restrict) capabilities
  - Support passing of capabilities on procedure (program) call
- Software capabilities
  - Protected by encryption
  - Nice for distributed systems

# Authentication

- User to system: required as protection systems depend on user ID
  - Typically established through use of *password* (or passphrase or key)
  - Need to be managed, kept secure
  - Hashed with a salt (easy to compute, hard to invert)
  - Multi-factor authentication adds a second (or more) component
  - Failed access attempts usually logged
- System to user: avoid user talking to the wrong computer / program
  - In the old days with directly wired terminals, make login character same as terminal attention, or always do a terminal attention before trying login
  - E.g., Windows NT’s Ctrl-Alt-Del to login — no-one else can trap it
  - (When your bank phones, how do you know it’s them?)

# Summary

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