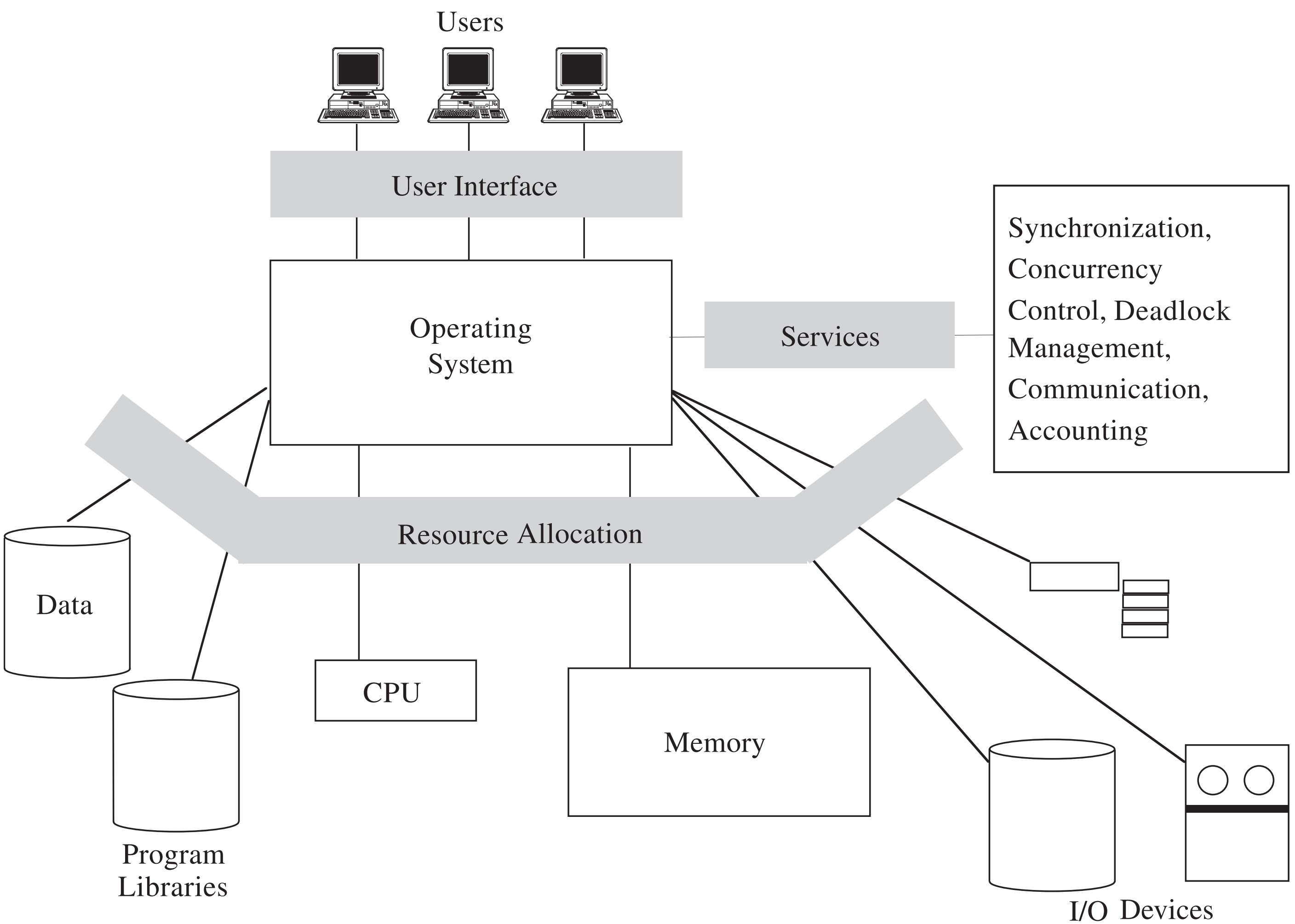
CISC 3325- INFORMATION SECURITY

Chapter 5 - Operating Systems

Chapter 5 Objectives

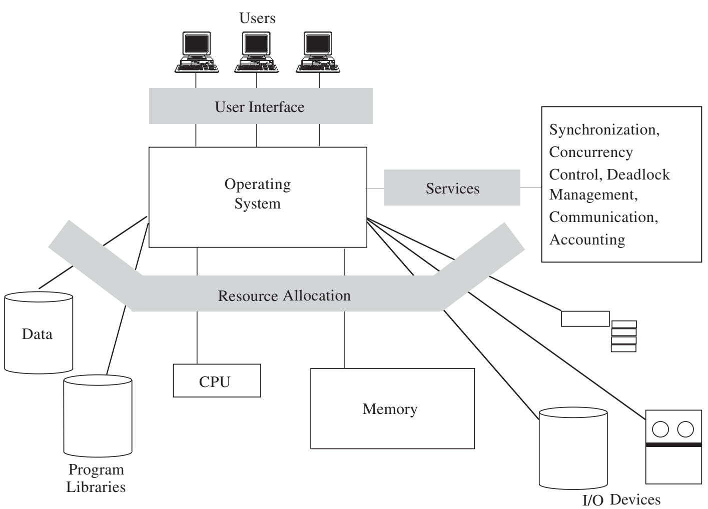
- Basic security functions provided by operating systems
- System resources that require operating system protection
- Operating system design principles
- How operating systems control access to resources
- The history of trusted computing
- Characteristics of operating system rootkits

Operating System Functions



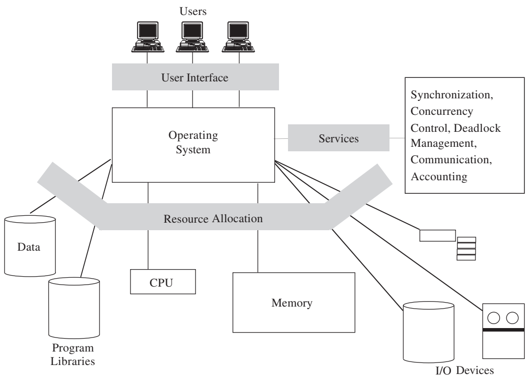
Operating System Functions

- Security-relevant features:
  - Enforced sharing
  - Inter-process communication and synchronization
  - Protection of critical data
  - Guaranteed fair service
  - Interface to hardware
  - User authentication
  - Memory protection



Operating System Functions

- Enforced sharing:
  - Resources should be made available to users
  - appropriate sharing brings about the need to guarantee integrity and consistency.
  - Controlled sharing is supported
    - though table lookup, combined with integrity controls such as monitors or transaction processors



Operating System Functions

- Inter-process communication and synchronization:
  - Executing processes sometimes need to communicate with other processes
    - or to synchronize their accesses to shared resources.
  - Operating systems act as a bridge between processes
    - responding to process requests for asynchronous communication with other processes or synchronization.
  - Interprocess communication is mediated by access control tables.

Operating System Functions

- Protection of critical data:
  - The operating system must maintain data by which it can enforce security
    - if these data are not protected against unauthorized access the operating system cannot provide enforcement.
      - Protect against unauthorized read, modify, and delete
  - Various techniques support protection of operating system security data
    - encryption, hardware control, and isolation

Operating System Functions

- Guaranteed fair service:
  - CPU usage and other service should ensure no user is indefinitely starved from receiving service
  - Hardware clocks combine with scheduling disciplines to provide fairness.
  - Hardware facilities and data tables combine to provide control

History of Operating Systems

- Single-user systems, no OS
- Multiprogrammed OS, aka monitors
  - Multiple users
  - Multiple programs
  - Scheduling, sharing, concurrent use
- Personal computers

History of Operating Systems

- First, an entire computer was dedicated to one program at a time
  - but this approach proved wasteful
- The first operating systems saved startup, loading, and shutdown time
  - made much better use of limited resources

History of Operating Systems

- The first personal computers took a major step back, as they were dedicated to single users
  - effectively one program at a time
- Multitasking returned to the mainstream in the 1990s
  - With all the lessons of the early shared computers

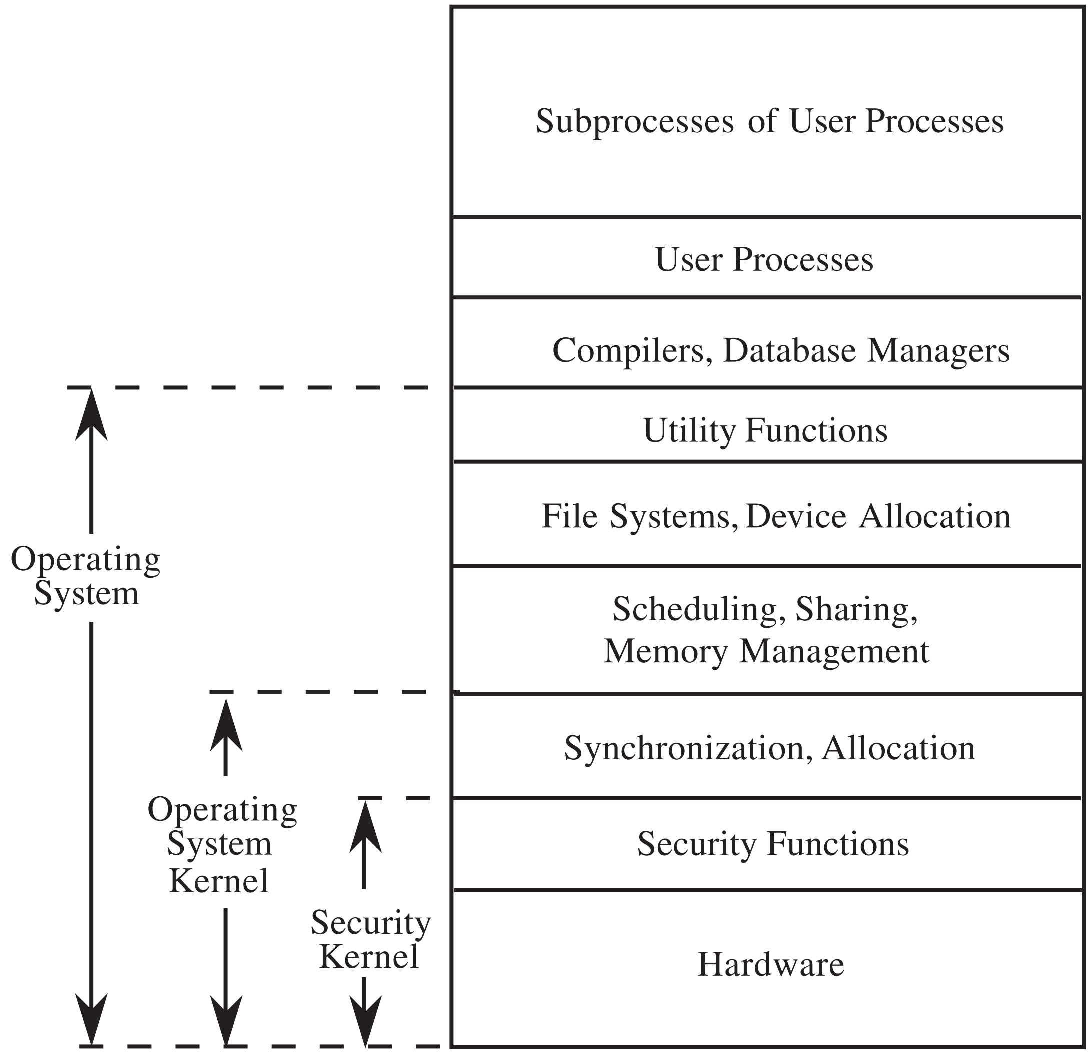
Protected Objects

- Memory
- Sharable I/O devices, such as disks
- Serially reusable I/O devices, such as printers
- Sharable programs and subprocedures
- Networks
- Sharable data

OS Layered Design

- OS can be visualized in layers,
- From most critical (bottom) to least critical

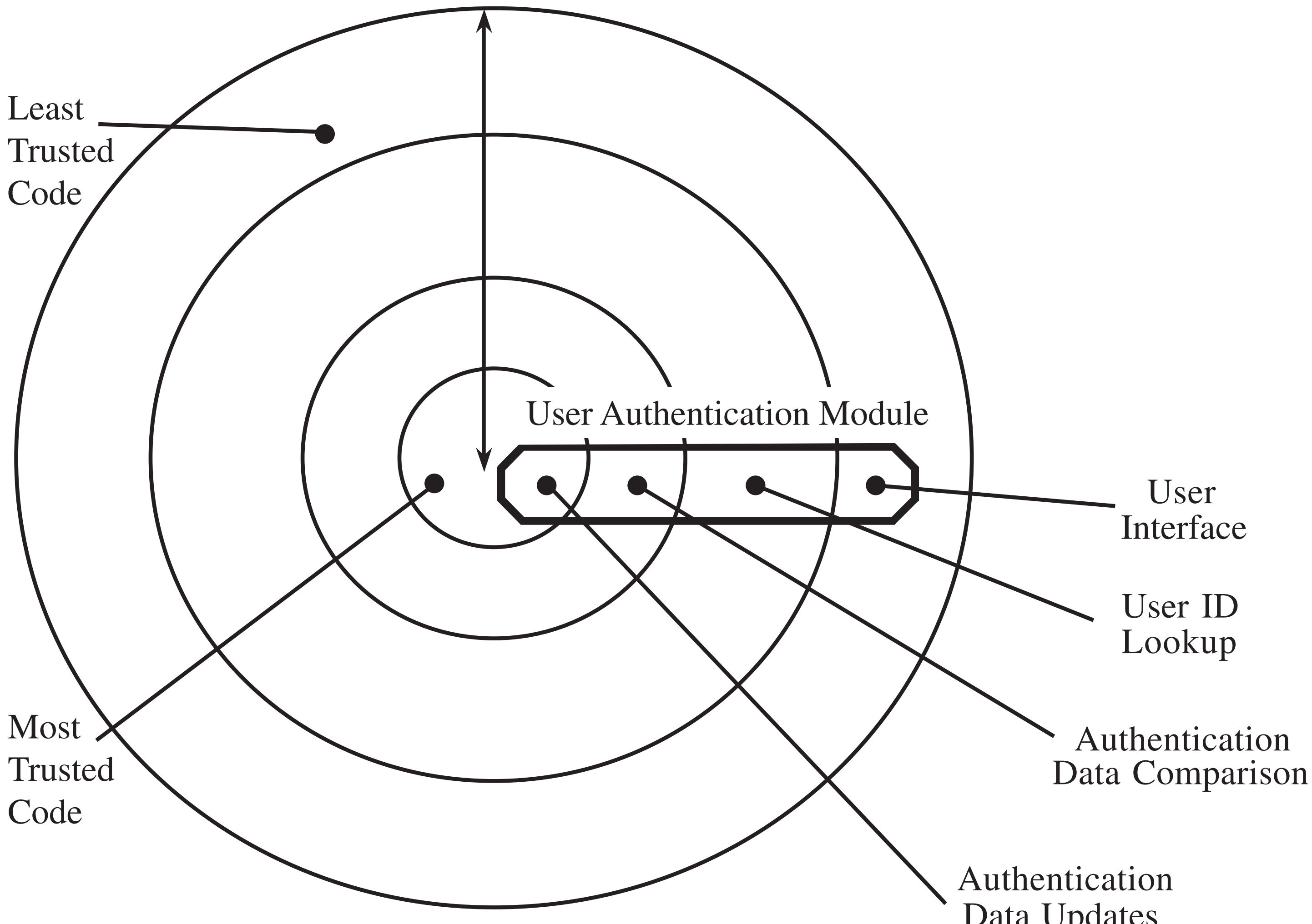
OS Layered Design



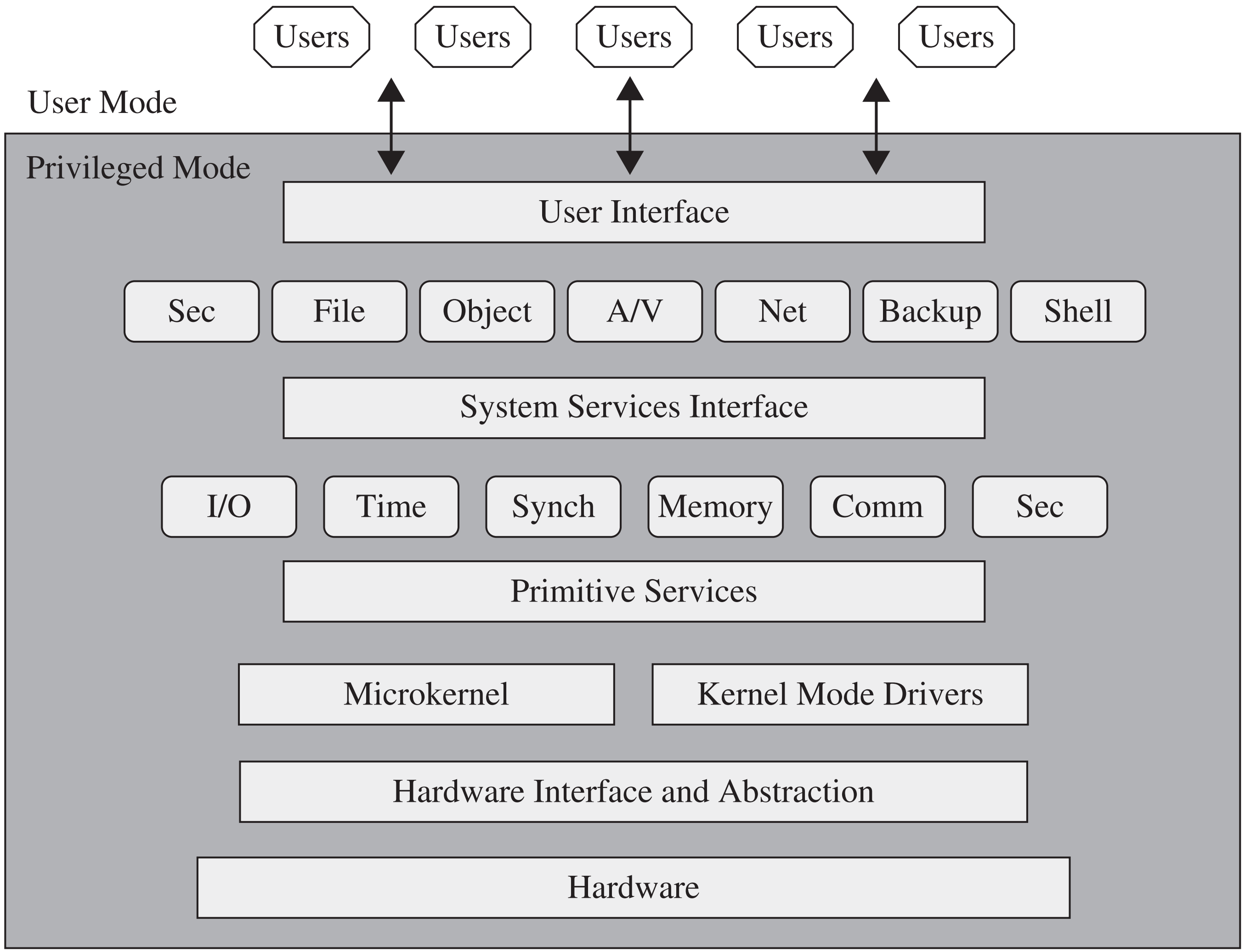
OS Layered Design

- OS can be visualized in layers,
- From most critical (bottom) to least critical
- Authentication is a good example of a function that needs to span the layers
    - in the layered model

Functions Spanning Layers



Modular OS Design



Modular OS Design

- Modern OSs are built from discrete modules
- These modules generally come from a variety of sources
  - are subject to updating/overwriting
    - => so they cannot trust one another.

Virtualization

- With virtualization, the OS presents each user with just the resources that user should see
- The user has access to a virtual machine (VM), which contains those resources
- The user cannot access resources that are available to the OS but exist outside the VM
- By acting as a sandbox, virtualization is a robust form of access control

Virtualization

- A hypervisor, or VM monitor, is the software that implements a VM
  - Translates access requests between the VM and the OS
  - Can support multiple OSs in VMs simultaneously
- Honeypot: A VM meant to lure an attacker into an environment that can be both controlled and monitored

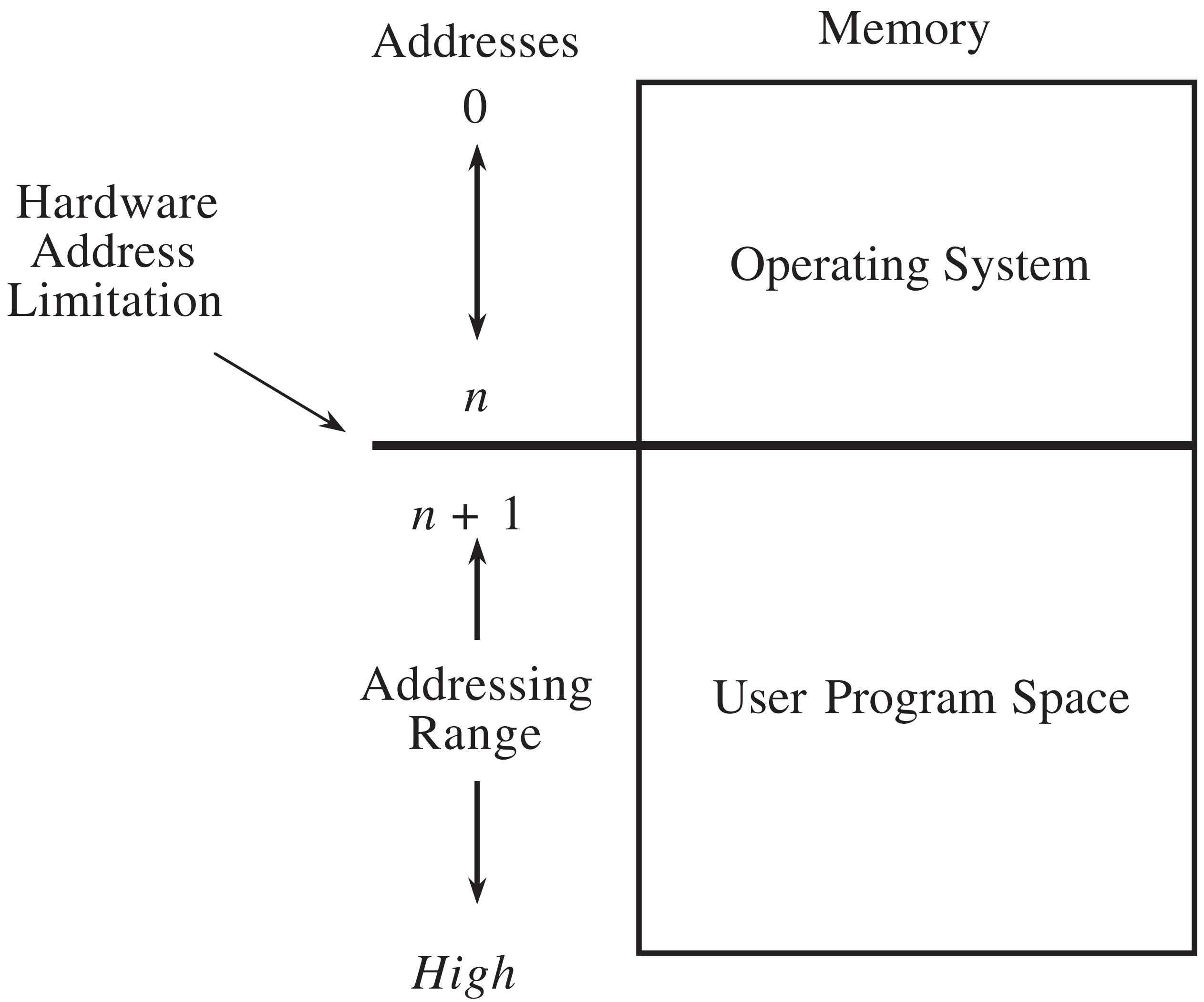
Separation and Sharing

- Methods of separation:
  - Physical
  - Temporal
  - Logical
  - Cryptographic

Separation and Sharing

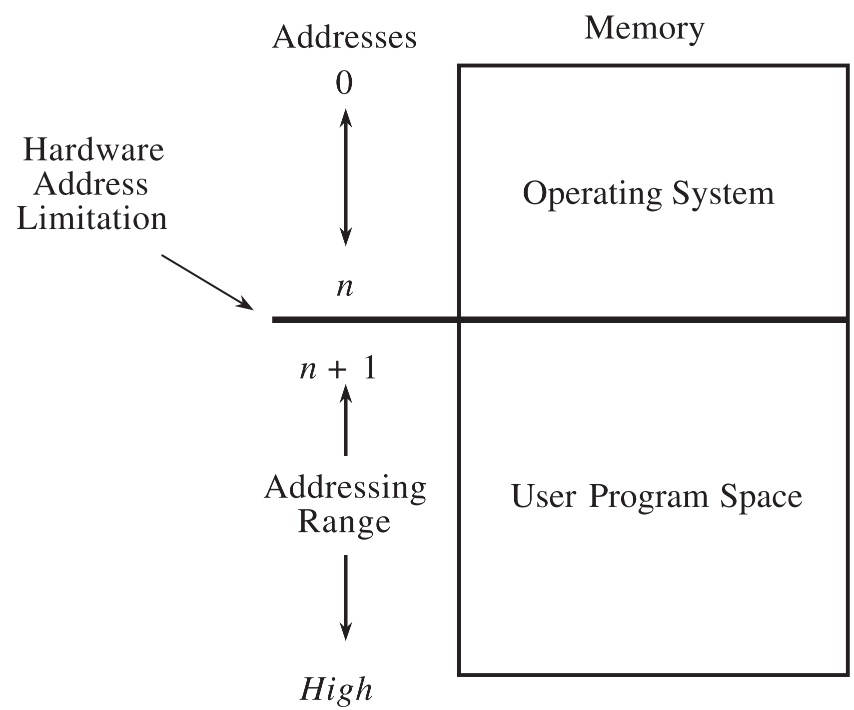
- Methods of supporting separation/sharing:
  - Do not protect
  - Isolate
  - Share all or share nothing
  - Share but limit access
  - Limit use of an object

Hardware Protection of Memory



Hardware Protection of Memory

- A fence defined by a fixed memory address
- Users have access only to memory above a certain address.



Fence Registers

- Hardware registers used in low-level OS memory management techniques
  - to confine users to one side of a boundary
- Contain the address of the end of the operating system
  - the location of the fence could be changed in time

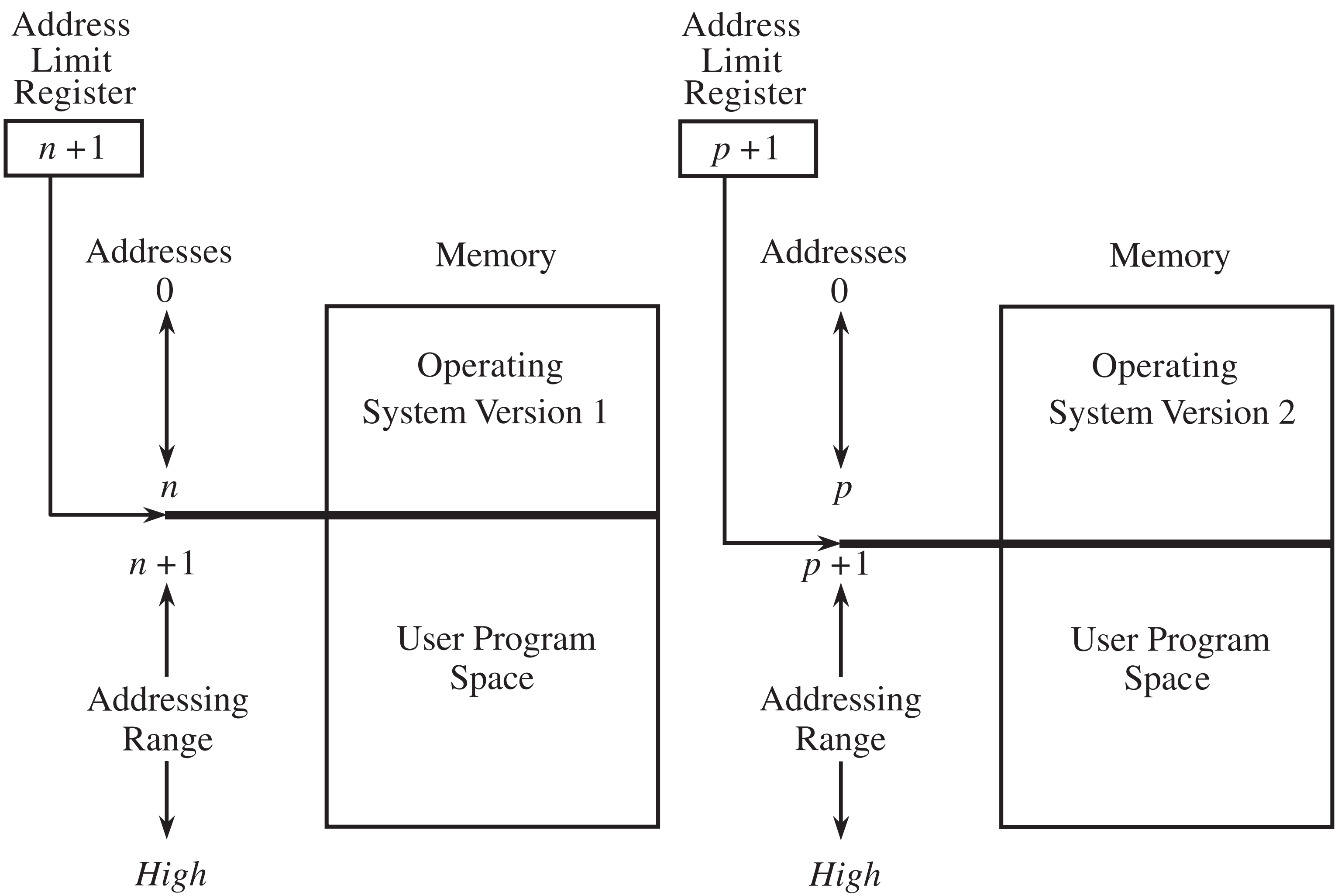
Fence Registers

- A user program generates addresses for data modification
- Each address is automatically compared with the fence address.
- If the address is greater than the fence address (that is, in the user area), the instruction is executed;
  - Otherwise, an error condition is raised

Fence Registers

- Fence Registers protect only in one direction:
  - An operating system can be protected from a single user
    - but the fence cannot protect one user from another user
  - Similarly, a user cannot identify certain areas of the program as inviolable
    - such as the code of the program itself or a read-only data area

Fence Registers



Fence Registers

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  - Similarly, a user cannot identify certain areas of the program as inviolable
    - such as the code of the program itself or a read-only data area
- Like fences, but fence registers allow for the boundary to change

Base/Bounds Registers

- A simple form of virtual memory
- Access to computer memory is controlled by one or a small number of sets of processor registers
  - called *base and bounds registers*

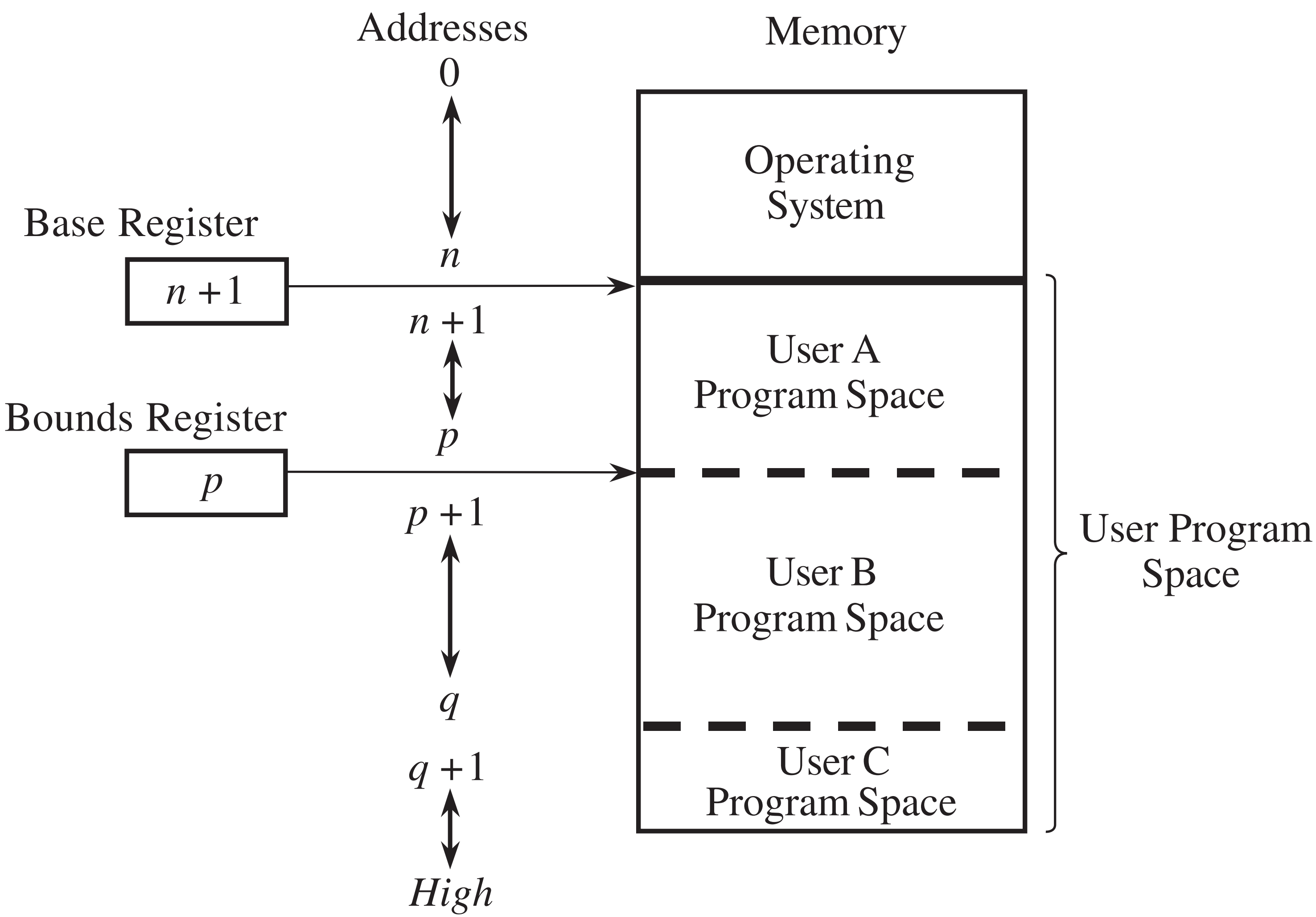
Base/Bounds Registers

- Each user process is assigned a single contiguous segment of main memory.
- The operating system:
  - Loads the physical address of this segment into a base register
  - Loads its size into a bound register.
- Virtual addresses seen by the program are added to the contents of the base register
  - to generate the physical address
- .

Base/Bounds Registers

- The address is checked against the contents of the bounds register
  - to prevent a process from accessing memory beyond its assigned segment.

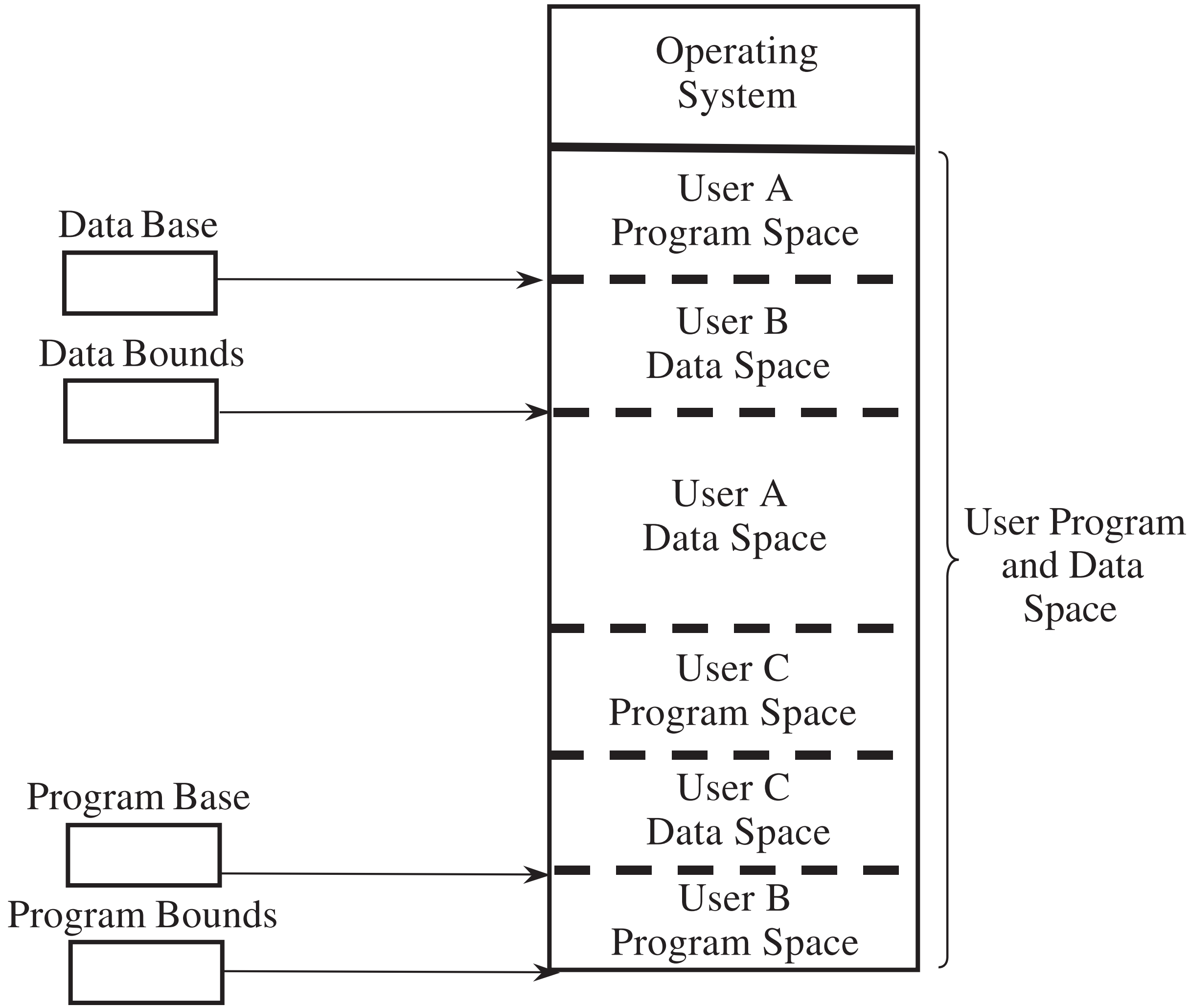
Base/Bounds Registers



Base/Bounds Registers

- With base and bounds registers, memory space can be broken into more than two sections
  - allowing for multiple users

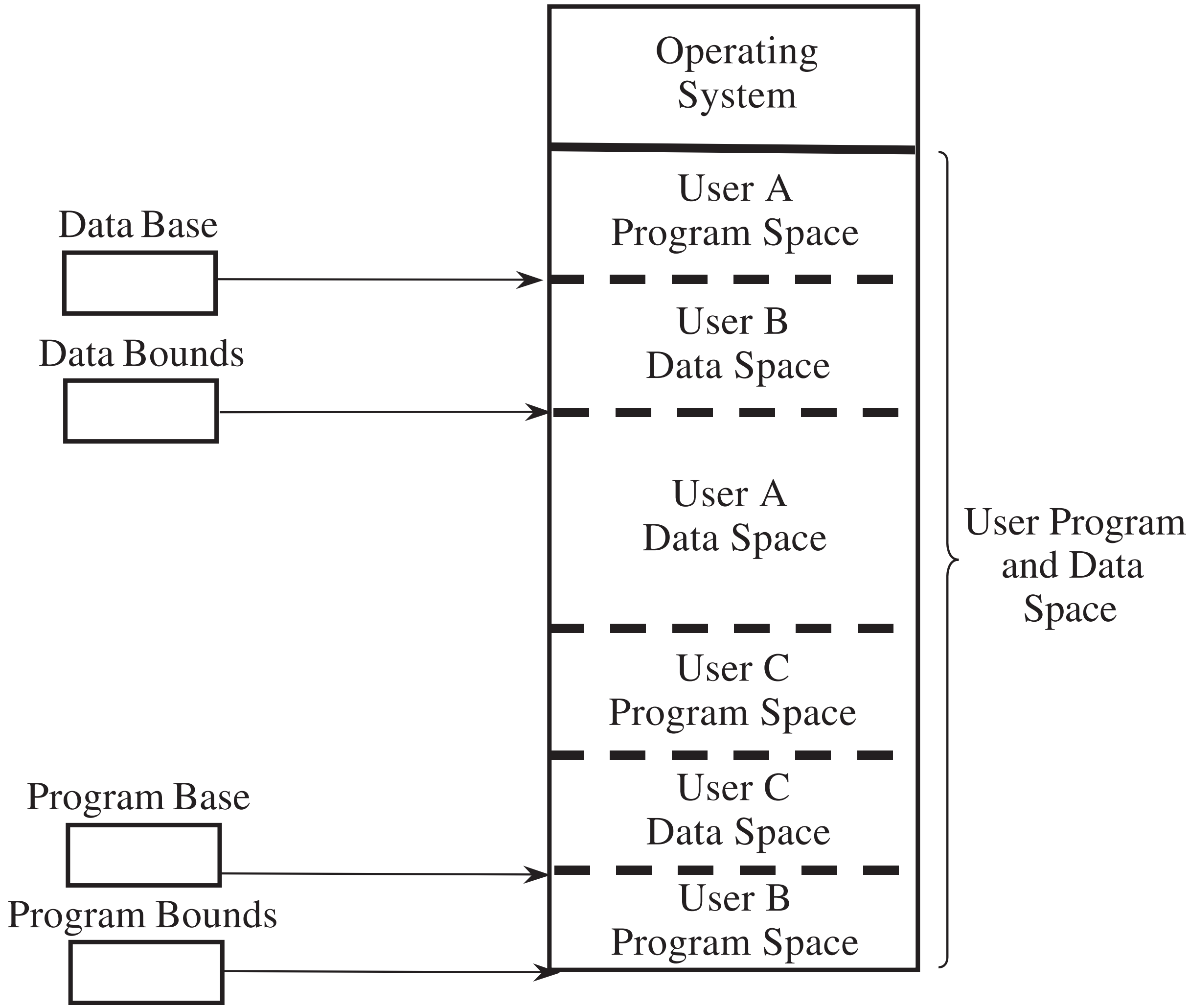
Two Pairs of Base/Bounds Registers



Two Pairs of Base/Bounds Registers

- This separates executable memory from data memory for each user
- making it harder for bugs/attacks to overwrite code

Two Pairs of Base/Bounds Registers



Tagged Architecture

- A particular type of computer architecture
- Extra data bits are attached to each word
  - to denote the data type, the function of the word, or both
- Each tagged union is divided into two sections:
  - Data (a number of bits)
  - A tag section that describes the type of the data:
    - how it is to be interpreted, and, if it is a reference, the type of the object that it points to

Tagged Architecture

Tag	Memory Word
R	0001
RW	0137
R	0099
X	
X	
X	
X	
X	
X	
R	4091
RW	0002

Code: R = Read-only RW = Read/Write
X = Execute-only

Tagged Architecture

- In a tagged architecture, each word of machine memory has one or more extra bits
  - to identify its access rights
- The big benefit is that access rights aren’t based on contiguous memory locations
- Tagged architecture has not been widely adopted

Segmentation

- Dividing the computer's primary memory into segments or sections.
- If segmentation is used, a reference to a memory location includes:
    - a value that identifies a segment
    - an offset (memory location) within that segment.
- Segments or sections are also used in object files of compiled programs
  - Segments are linked together into a program image

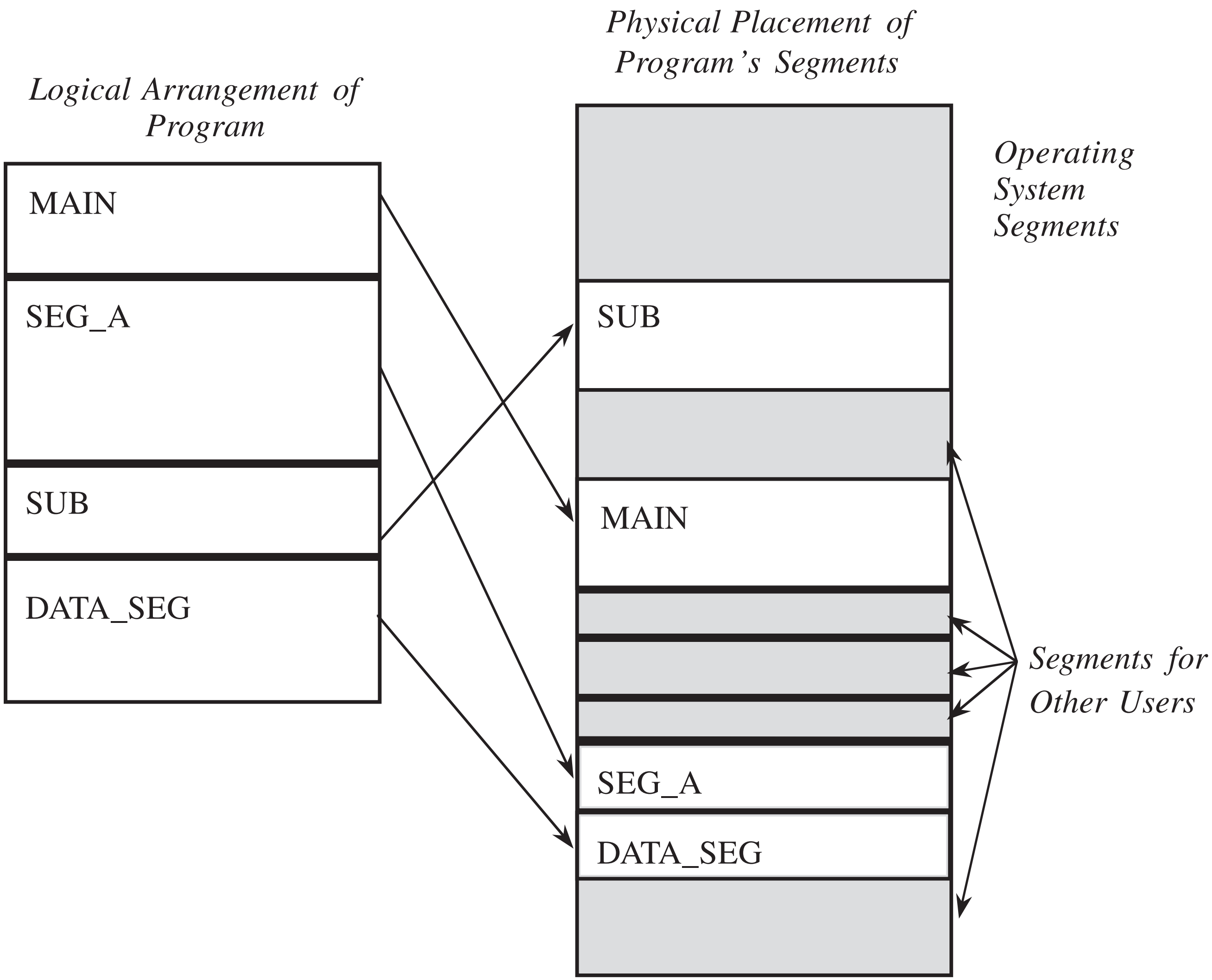
Segmentation

- Segments usually correspond to natural divisions of a program
  - such as individual routines or data tables
- segmentation is generally more visible to the programmer than paging alone

Segmentation

- Different segments may be created for different program modules
  - or for different classes of memory usage such as code and data segments.
- Certain segments may be shared between programs.

Segmentation



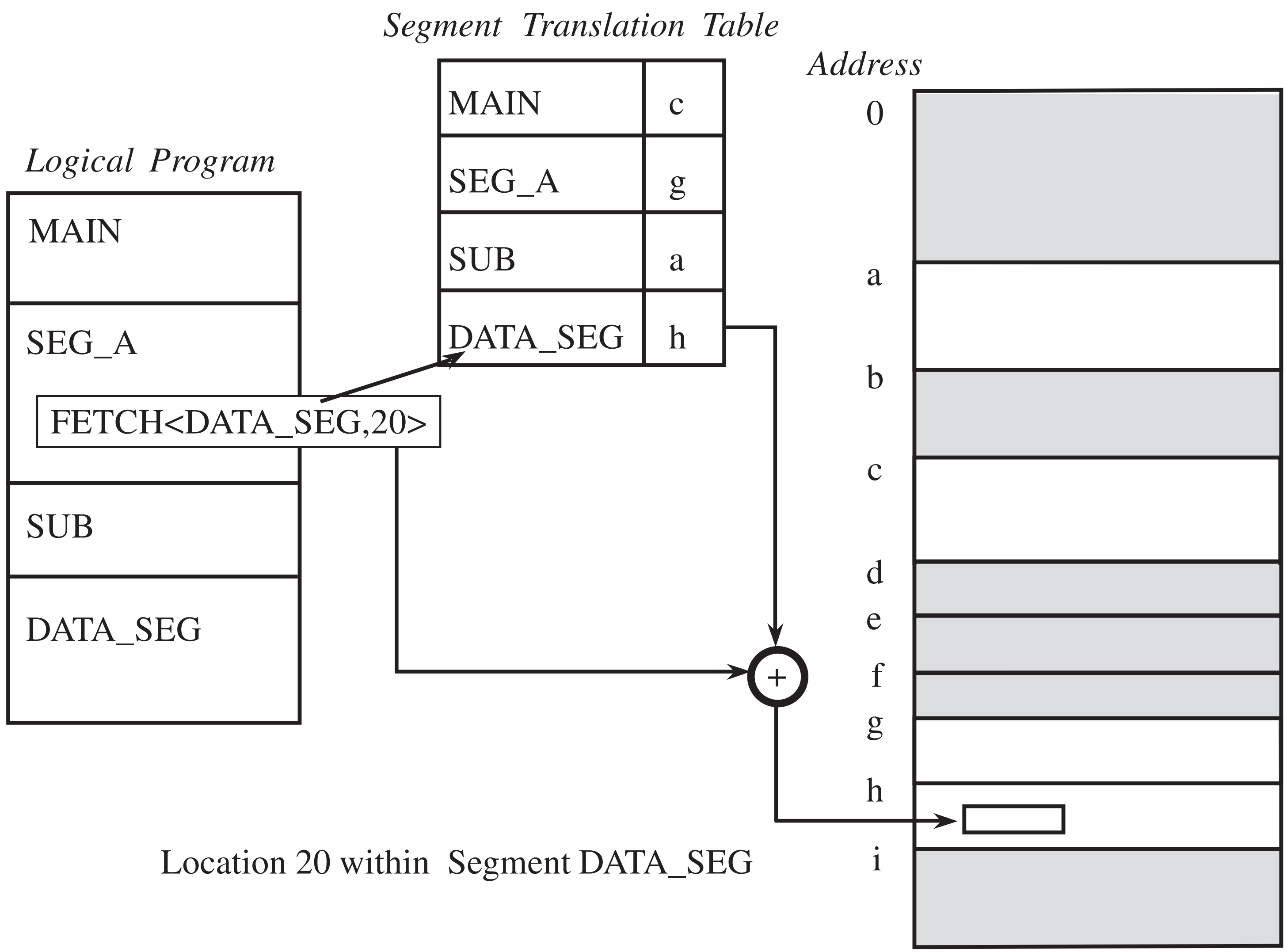
Segmentation

- A program is divided into separate, logical pieces (e.g., an array, a procedure).
- Each segment has ***its own set of access rights***
- The operating system maintains a table of each segment and its true memory address
  - it translates calls to each segment using that table

Segmentation

- Advantages:
  - The OS can move segments around as necessary
    - very helpful as segments grow and shrink.
  - Segments can be removed from memory if they aren’t being used currently
  - Every legitimate address reference must pass through the OS
    - providing an opportunity for access control

Segment Address Translation



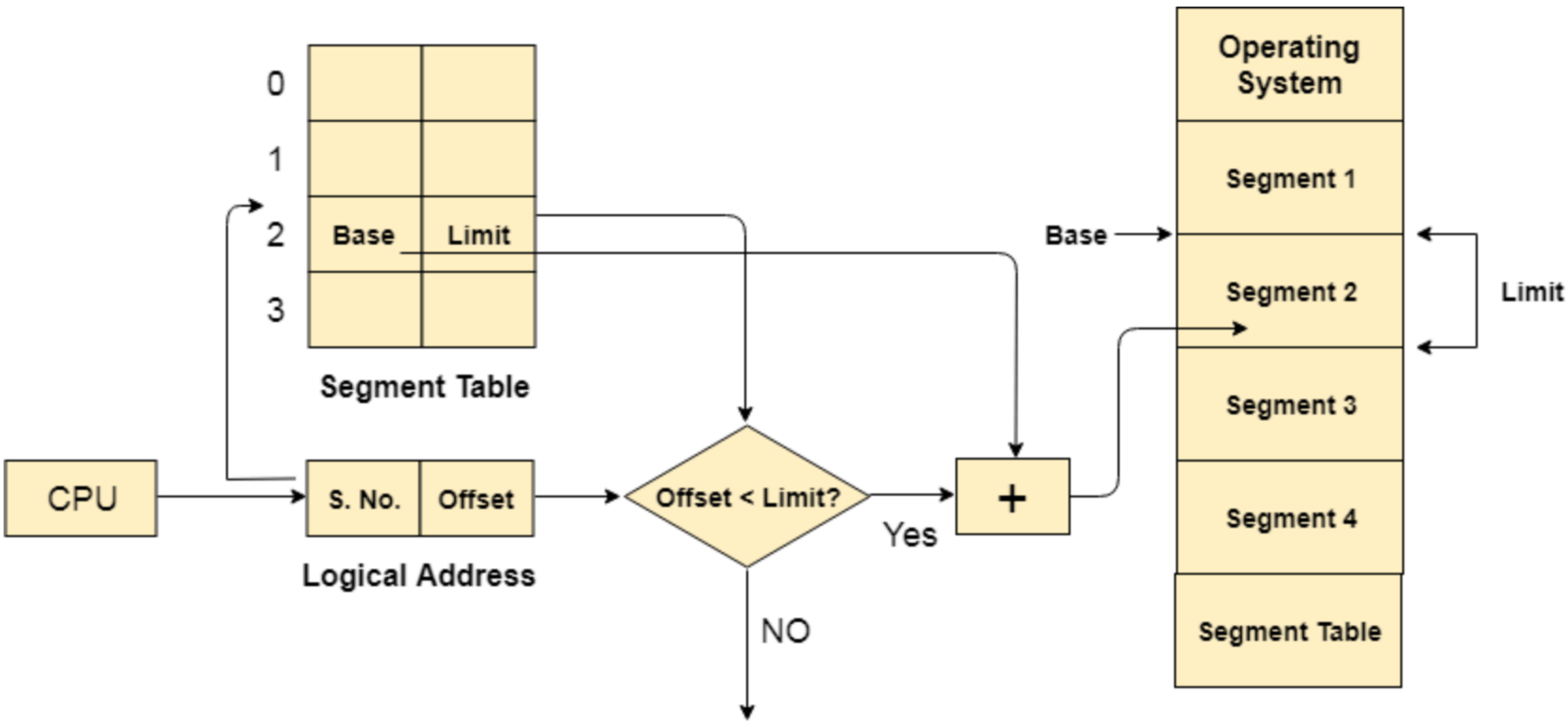
Translation of Logical address into physical address by segment table

- CPU generates a logical address which contains two parts:
  - Segment Number
  - Offset
- Segment number is mapped to segment table
  - The limit of the respective segment is compared with offset.
    - If the offset is less than the limit then address is valid
    - otherwise it throws an error as the address is invalid.

Translation of Logical address into physical address by segment table

- If valid address:
  - The base address of the segment is added to the offset
    - to get the physical address of actual word in the main memory.

Segmentation



https://www.javatpoint.com/os-segmentation

Segmentation Advantages

- No internal fragmentation
- Average Segment Size is larger than the actual page size.
- Less overhead
- It is easier to relocate segments than entire address space.
- The segment table is of lesser size as compare to the page table in paging.

Segmentation Disadvantages

- It can have external fragmentation.
- It is difficult to allocate contiguous memory to variable sized partition.
- Costly memory management algorithms.

Paging

- Paging is a memory management scheme by which a computer stores and retrieves data from secondary storage
  - for use in main memory.
- In this scheme, the operating system retrieves data from secondary storage in same-size blocks called pages.

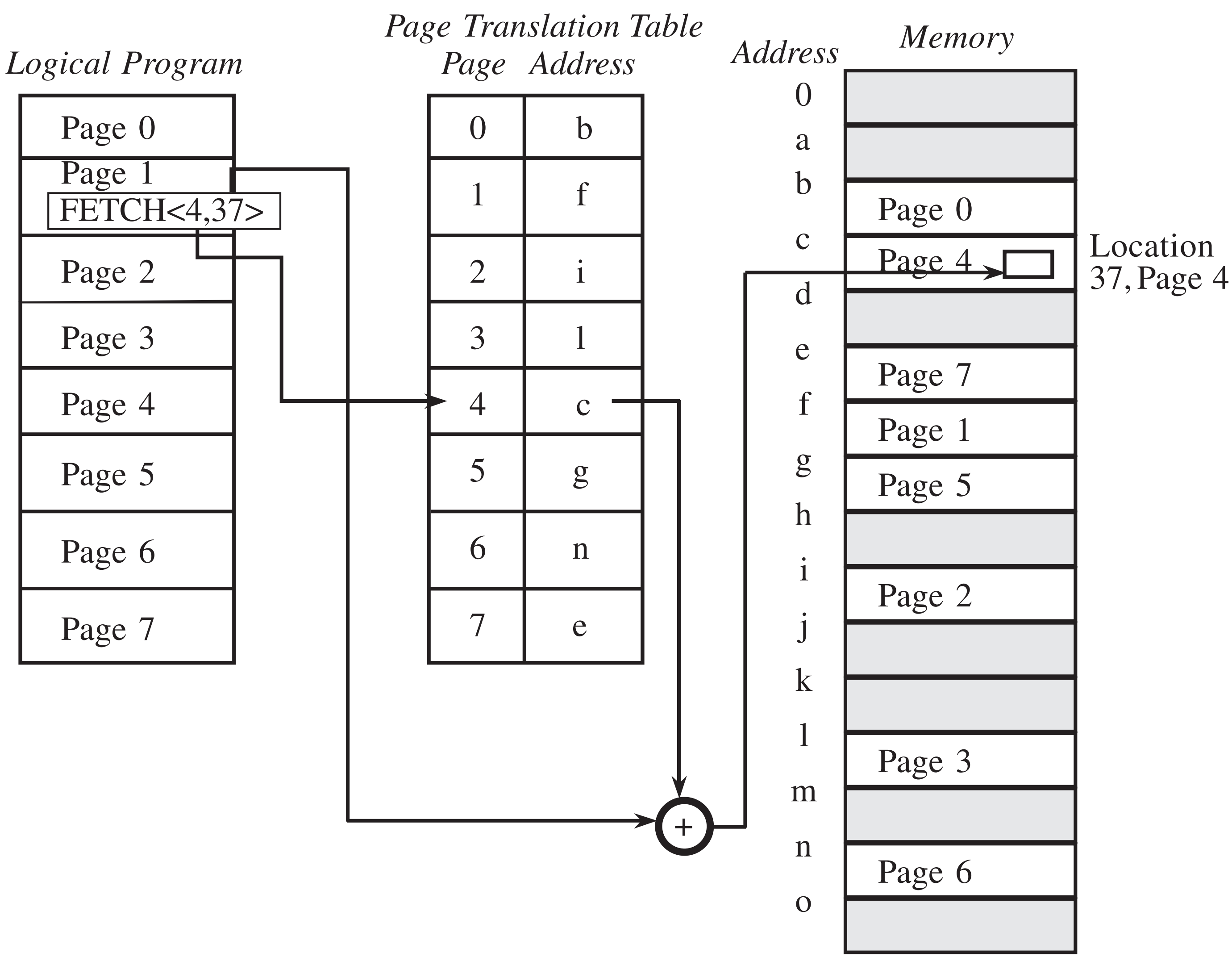
Paging

- Paging is an important part of virtual memory implementations in modern operating systems,
  - using secondary storage to let programs exceed the size of available physical memory.

Paging

- Typically, the main memory is called "RAM" (an acronym of "random-access memory")
- The secondary storage is called "disk" (a shorthand for "hard disk drive")
- The concepts do not depend on whether these terms apply literally to a specific computer system

Paging



Logical Program
Page 0
Page 1
FETCH<4,37>
Page 2
Page 3
Page 4
Page 5
Page 6
Page 7
Page Translation Table
Page Address
0 b
1 f
2 i
3 l
4 c
5 g
6 n
7 e
+
Address
0
a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
Memory
Page 0
Page 4
Page 7
Page 1
Page 5
Page 2
Page 3
Page 6
Location
37, Page 4

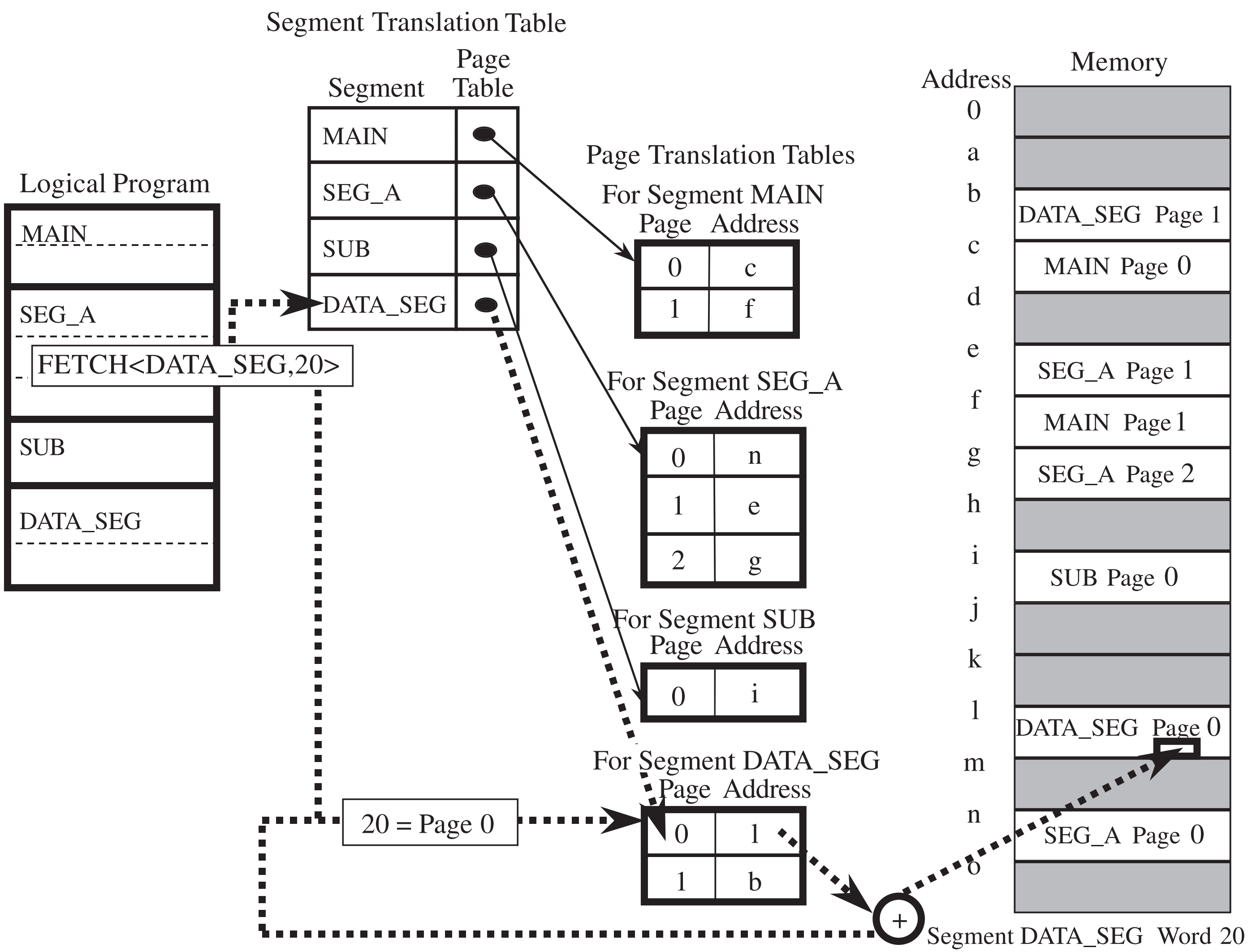
Paging

- Similar to segmentation
  - but programs are broken into fixed-size fragments (pages) rather than being broken down by logical unit
- Programs aren’t broken into logical units
  - => paging doesn’t allow different parts of a program to have different access rights

Paged Segmentation

- Memory management mechanism:
  - Partition segments into fixed-size pages
  - Allocate and deallocate pages
- Individual segments can be implemented as a paged, virtual address space

Paged Segmentation



Paged Segmentation

- Programs can be broken into segments, and the segments are then combined to fill pages
- This approach creates an extra layer of translation
  - allows for the benefits of both paging and segmentation

WINDOWS OS DESIGN

User and Kernel Modes

- User mode handles user applications
- Kernel mode handles low-level library that communicate with the hardware
- Drivers call routines exported by kernel components
- Drivers must respond to certain operating system calls

User Mode

- Applications are segmented from each other
  - Private
  - If one application crashes, not affecting another app

Kernel Mode

- All code shares a virtual address space
- If a kernel mode driver writes to the wrong virtual address, data belonging to another driver may be compromised
- If kernel-mode driver crashes, entire operating system crashes

SECURE OS DESIGN

Access Control

Principles of Secure OS Design

- Simplicity of design
  - OSs are inherently complex, and any unnecessary complexity only makes them harder to understand and secure
- Layered design
  - Enables layered trust

Principles of Secure OS Design

- Layered trust
  - Layering is both a way to keep a design logical and understandable and a way to limit risk
- Examples:
  - very tight access controls on critical OS functions
  - fewer access controls on important noncritical functions
  - few if any access controls on functions that aren’t important to the OS

OS Security

- It is the responsibility of the Operating System to create a protection system
- Ensure that a user who is running a particular program is authentic
  - Identify/authenticate the user as part of access control

Complete Mediation Principle

- Every access to every object must be checked for authority
  - Ensures that all access to data is mediated by something that checks access control policy.
    - Therefore, the access checks can’t be bypassed
  - Forces a system-wide view of access control
    - Includes normal operation, initialization, recovery, shutdown, and maintenance
    - If a change in authority occurs, system must be updated

https://twitter.com/com_mediation

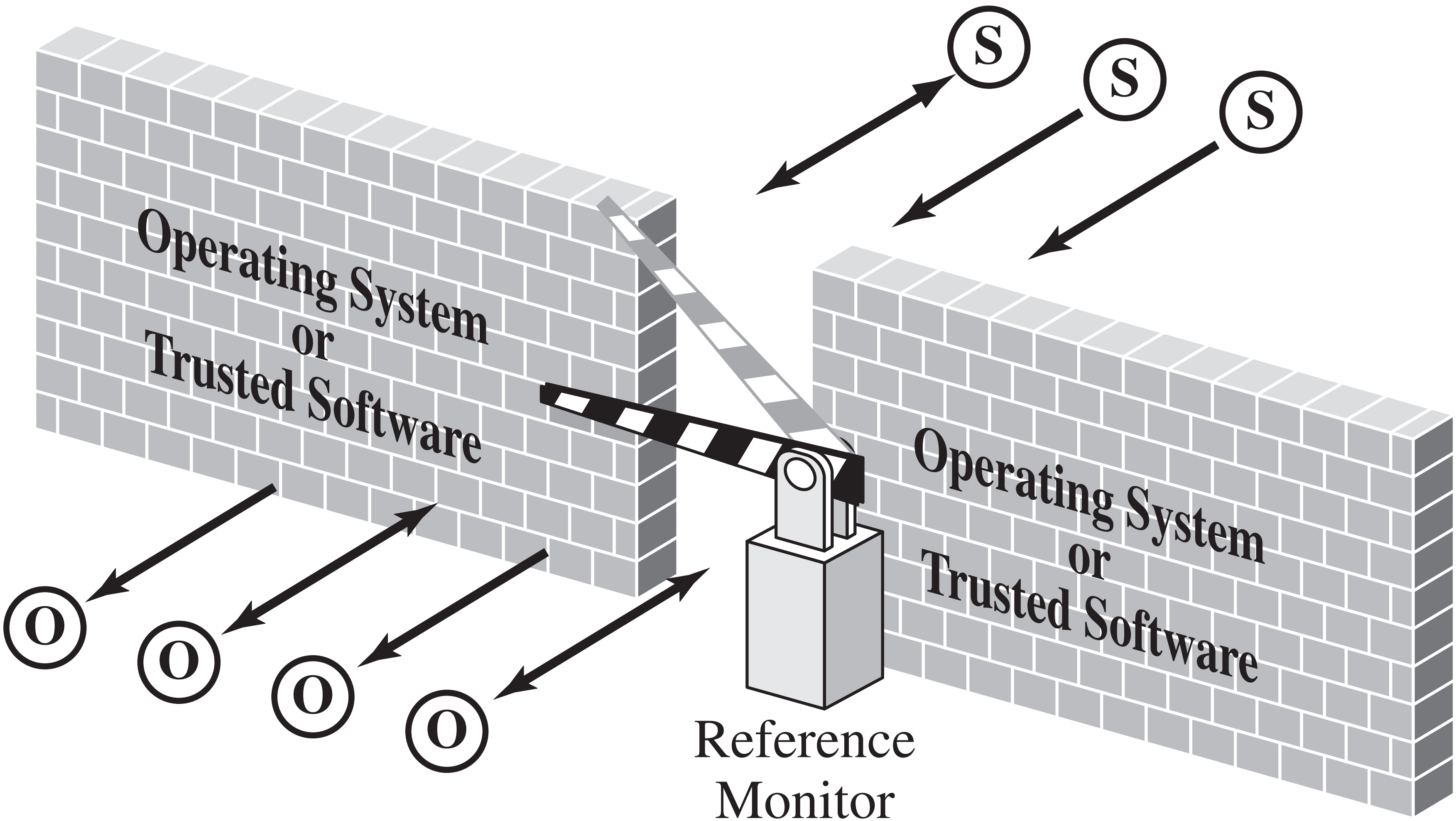
Kernelized Design

- A kernel is the part of the OS that performs the lowest-level functions
  - Synchronization
  - Inter-process communication
  - Message passing
  - Interrupt handling
- A security kernel is responsible for enforcing the security mechanisms of the entire OS
  - Typically contained within the kernel

Reference Monitor

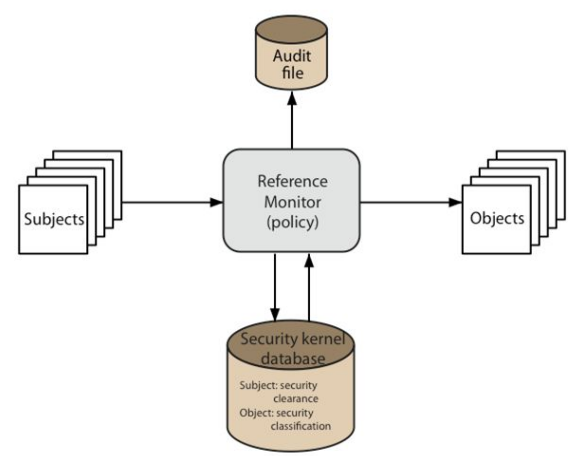
- The most important part of a security kernel is the **reference monitor**
  - the portion that controls accesses to objects

Reference Monitor



Reference Monitor

- Defines a set of design requirements on a reference validation mechanism
- Enforces an access control policy over subjects ability to perform operations on objects
  - Subjects, e.g., processes and users
  - Operations, e.g. read and write
  - Users, e.g. files, etc.

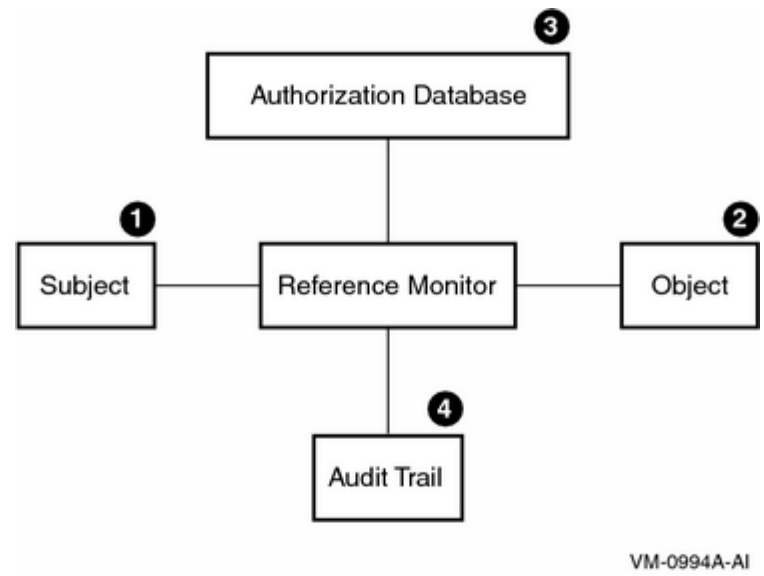


http://slideplayer.com/slide/697485/

Reference Monitor

- A reference monitor is responsible for mediating all access to data
- Subject cannot access data directly; operations must go through the reference monitor, which checks whether they're OK

Reference Monitor



- Authorization Database: Repository for the security attributes of subjects and objects
- Audit trail: Record of all security-relevant events

Criteria for a Reference Monitor

- Ideally, a reference monitor should be:
  - Non-bypassable: mediate every attempt by a subject to gain access to an object
  - Tamper-resistant: Provide a tamperproof database and audit trail
    - that are thoroughly protected from attackers
  - Verifiable: should be simple and well-structured software
    - so that it is effective in enforcing security requirements
    - Unlikely to have bugs

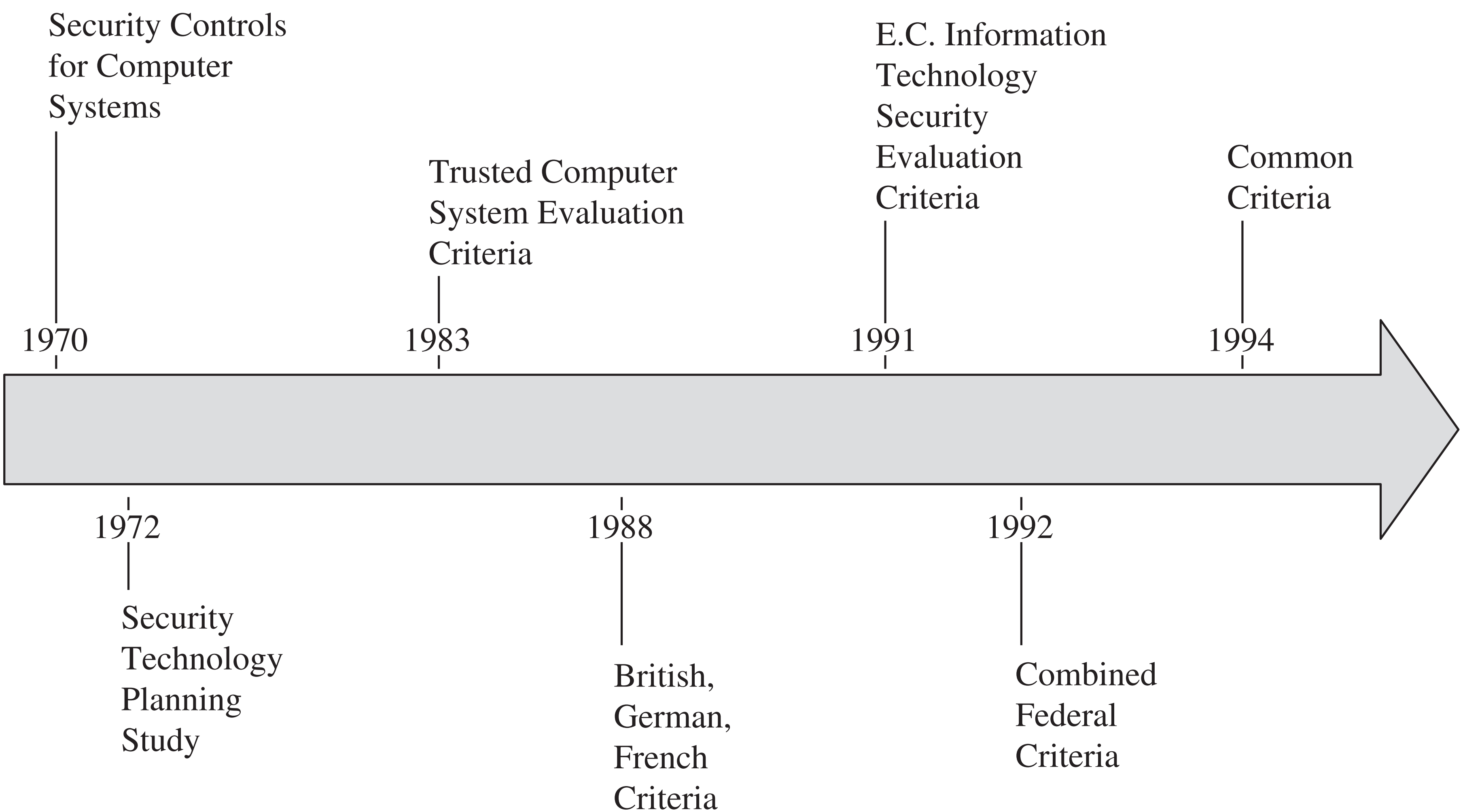
Example: **Windows Kernel-Mode Protection**

- Windows uses an access control list (ACL) to determine which objects have what security
- The reference monitor provides routines for your driver to work with access control
- Ensures that drivers can only access devices available to them.
  - enforces limits on what resources each process can access

Trusted Systems

- A trusted system is one that has been shown to warrant some degree of trust that it will perform certain activities faithfully
- Characteristics of a trusted system:
  - A defined policy that details what security qualities it enforces
  - Appropriate measures and mechanisms by which it can enforce security adequately
  - Independent scrutiny or evaluation to ensure that the mechanisms have been selected and implemented properly

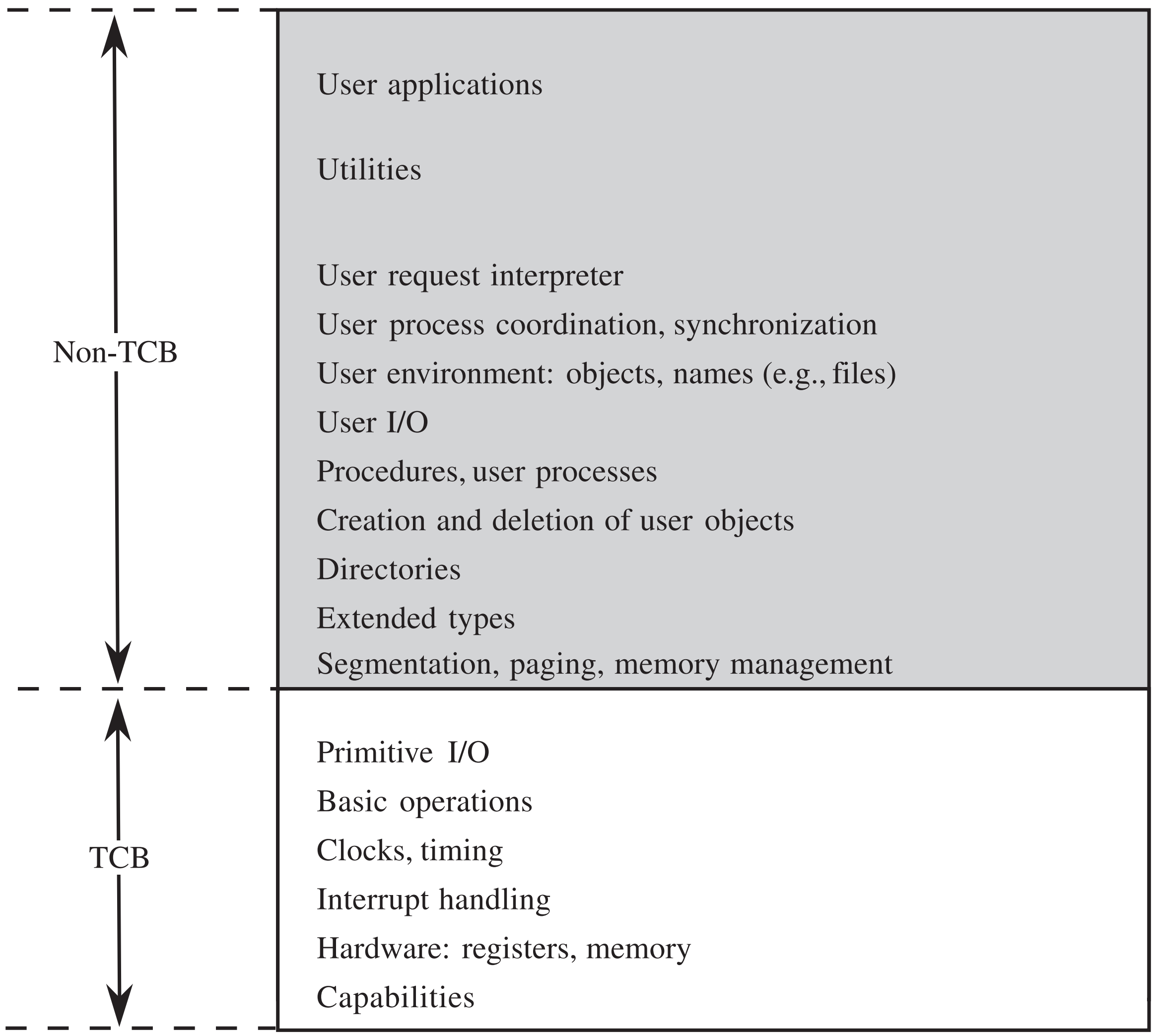
History of Trusted Systems



Trusted Systems

- Attempts to declare computers trustworthy go back almost 50 years
- Over the years, changes in technology have resulted in new requirements
- the explosion of new devices and software have made it challenging to impossible to keep up

Trusted Computing Base (TCB)



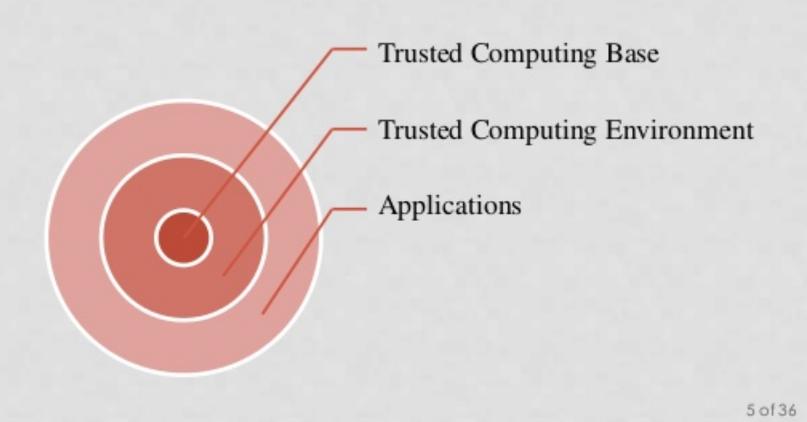
Trusted Computing Base (TCB)

- The TCB portion of the OS is the part we depend on for enforcement of security policy
- The TCB monitors and protects the secrecy and integrity of four basic interactions:
  - process activation
  - execution domain switching
  - memory protection
  - I/O operation

Trusted Computing Base (TCB)

- TCB is the set of all hardware, firmware, and/or software components critical to its security
- Example:
  - TCB for enforcing file access permissions
    - includes the OS kernel and filesystem drivers
- Ideally, TCBs should be non-bypassable, tamper-resistant, and verifiable

Trusted Computing Base (TCB)



https://www.slideshare.net/k33a/trusted-platform-module-tpm

Trusted Computing Base (TCB)

- Every system has a TCB:
  - Your reference monitor
  - Compiler
  - OS
  - CPU
  - Memory
  - Keyboard.....

Trusted Computing Base (TCB)

- Security requires the TCB be
  - Correct
  - Complete (can’t be bypassed)
  - Secure (can’t be tampered with)
- How can we improve the security of software, so security bugs are less likely to be catastrophic?

Trusted Computing Base (TCB)

- Two key principles behind a good TCB:
  - Keep it small and simple
    - To reduce overall susceptibility to compromise
  - Use Privilege Separation: A technique in which a program is divided into parts which are limited to the specific privileges
    - Don't give a part of the system more privileges than it needs to do its job ("need to know")
    - Principle of "least privilege"

Trusted Computing Base (TCB)

- How can we improve the security of software, so security bugs are less likely to be catastrophic?
  - Design the software so it has a separate, small TCB.
    - Isolate privileged operations to as small a module as possible
    - any bugs outside the TCB will not be catastrophic

Other Trusted System Characteristics

- Secure startup
  - System startup is a tricky time for security, as most systems load basic I/O functionality before being able to load security functions
- Trusted path
  - An unforgeable connection by which the user can be confident of communicating directly with the OS

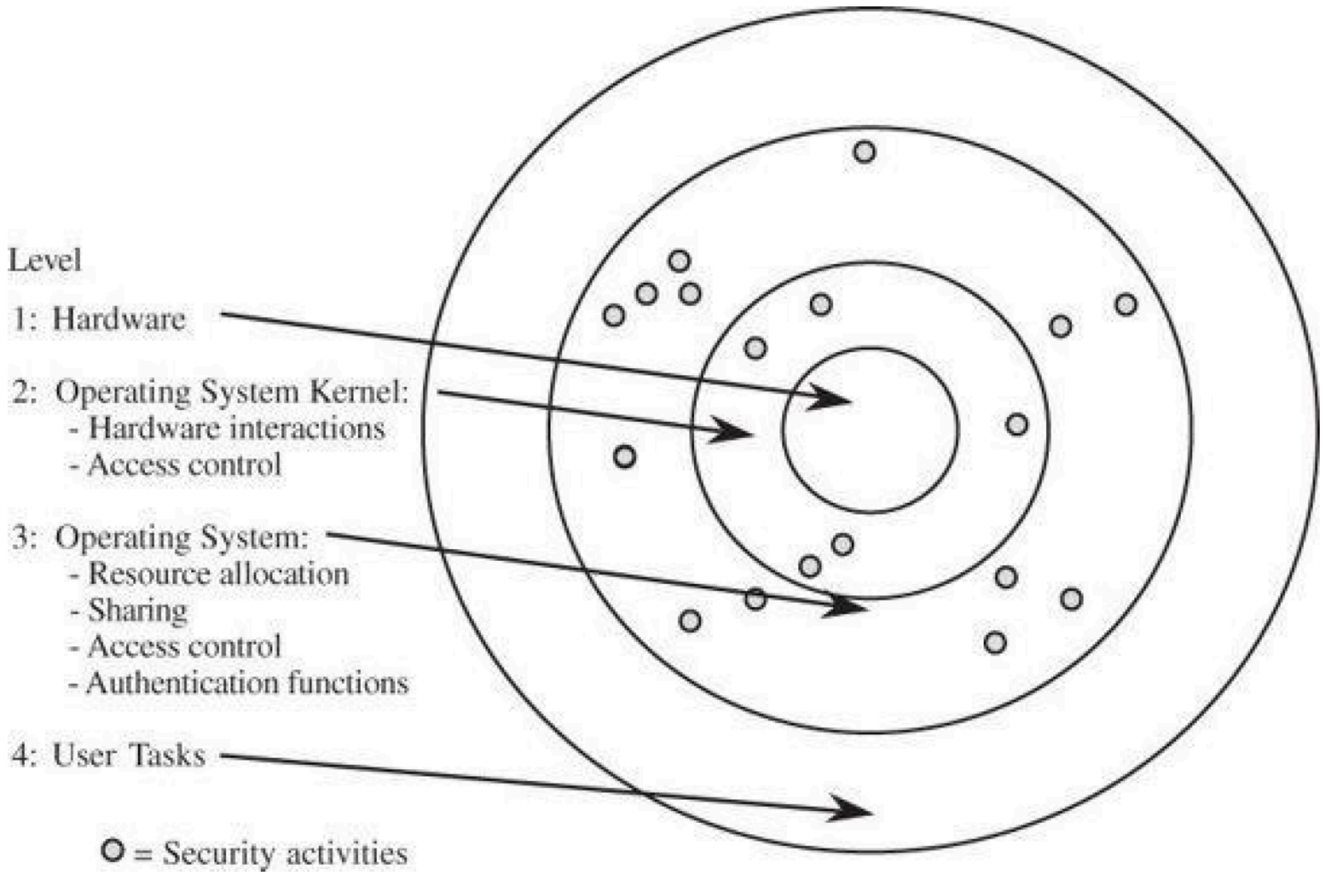
Other Trusted System Characteristics

- Object reuse control
  - OS clears memory before reassigning it to ensure that leftover data doesn't become compromised
- Audit
  - Trusted systems track security-relevant changes, such as installation of new programs or OS modification
  - Audit logs must be protected against tampering and deletion

Security Kernel

- Security functions of the OS may be separated from the rest of the OS
- Creating a ***Security Kernel***

Security Kernel



Boot-Time

- OS initializes at system boot-time
- Initializes tasks at an orderly fashion
  - Device drivers, primitive functions
    - Including inter-process communications, input and outpu
  - Process controls
  - File and memory management routines
  - User interface

Boot-Time

- Anti-virus are initiated late!
  - As they are an add-on to OS
  - However, has to be in control before OS allows access to new objects that may contain viruses

Boot-Time

- What if malware embeds itself in the OS
  - such that it is active before operating system components that might detect or block it?
- What if the malware can circumvent or take over other parts of the operating system?

Boot-Time

- Leads to an important vulnerability:
  - Gaining control before the protector means that the protector’s power is limited.
    - The attacker has near-complete control of the system
    - The malicious code is undetectable and unstoppable
      - Because the malware operates with the privileges of the root of the operating system, it is called a rootkit.
- Embedding a rootkit within the operating system is difficult
  - However, a successful effort is certainly worth it.

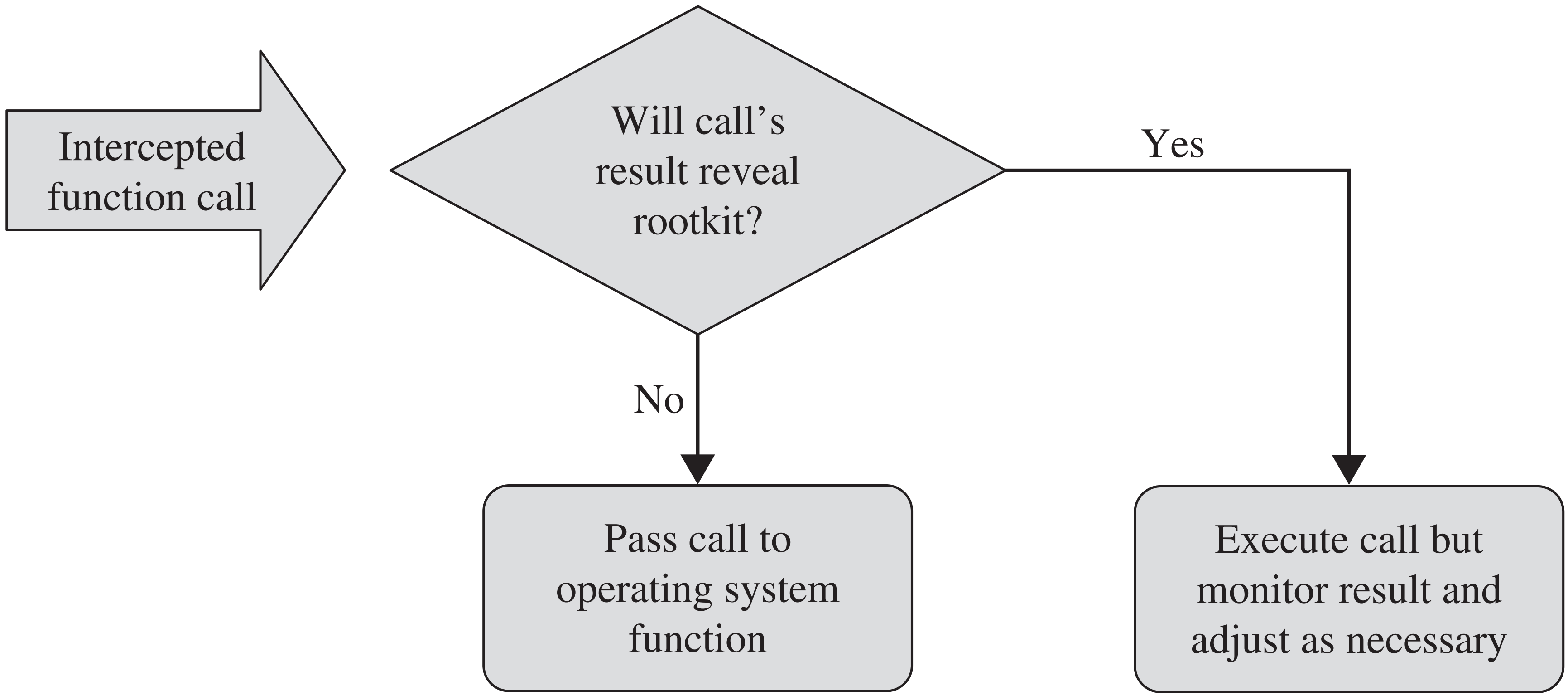
Rootkits

- A rootkit is a malicious software package that attains and takes advantage of root status
  - or effectively becomes part of the OS
- Rootkits often go to great length to:
  - avoid being discovered
  - if discovered and partially removed, reestablish themselves
  - This can include intercepting or modifying basic OS functions

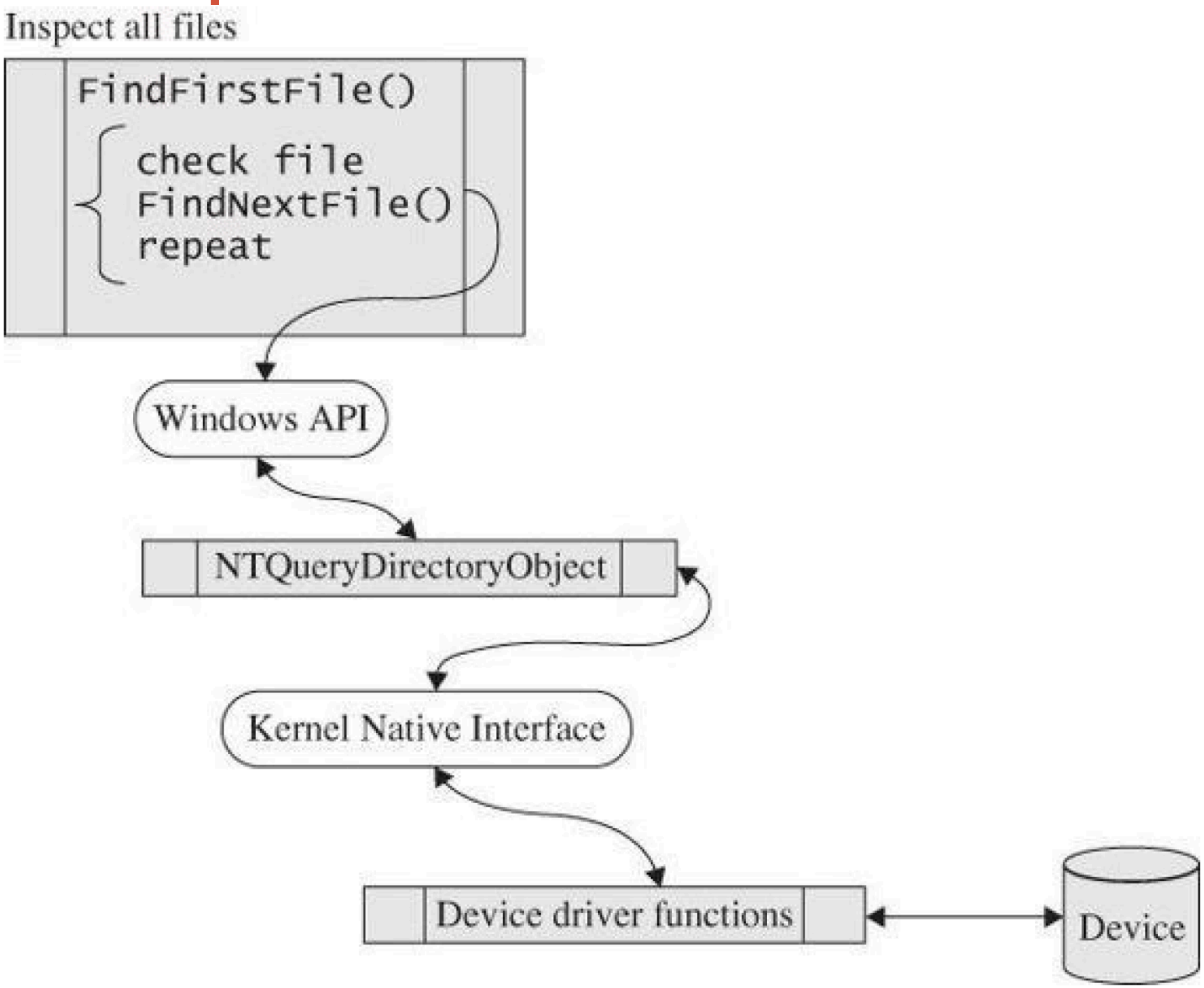
Rootkit Evading Detection

- Example: a rootkit may monitor a system call in order to intercept potentially threatening results

Rootkit Evading Detection



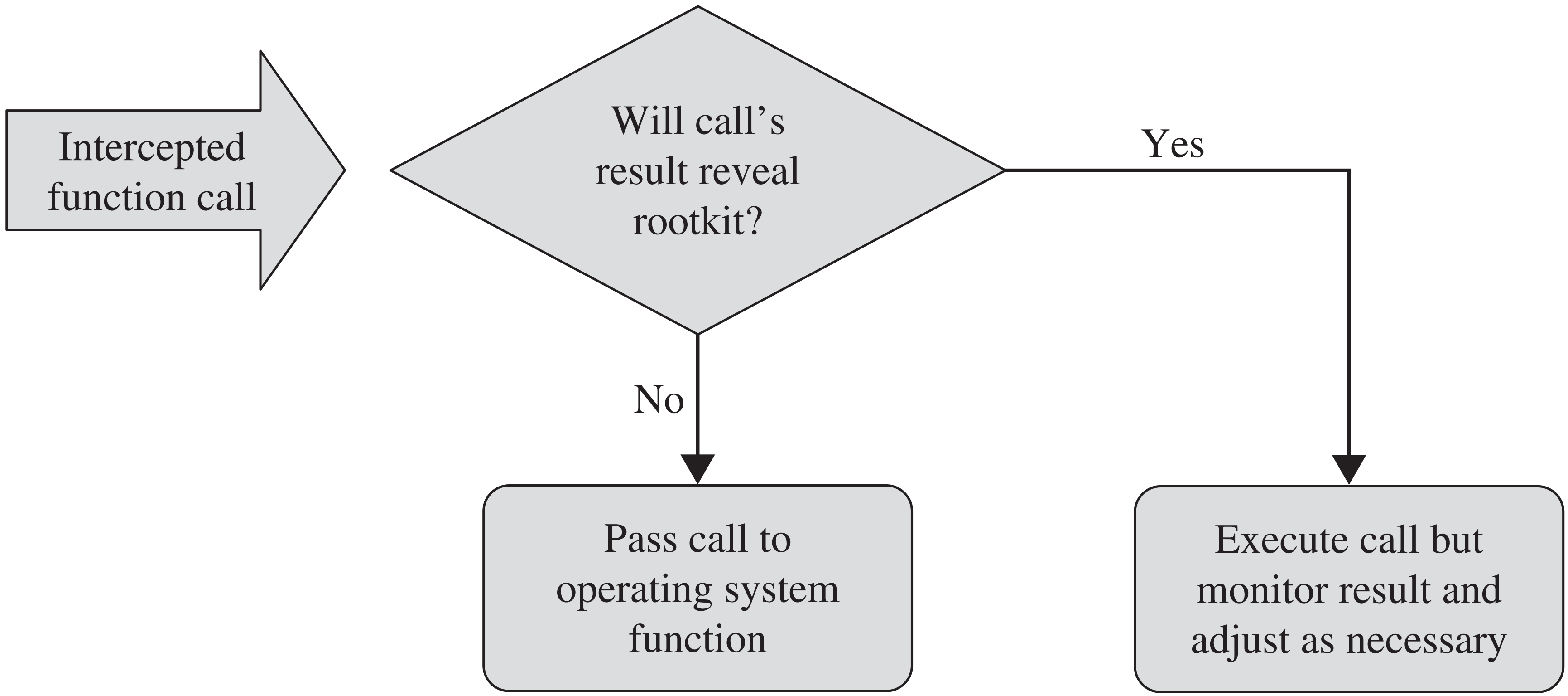
Example - Windows



Example - Windows

- A malicious file, named “mal_code.exe’ may exist
- To remain invisible, the rootkit intercepts OS calls
- If the result from FindNextFile() points to mal_code.exe:
  - Rootkit skips that file and executes FindNextFile() again
  - Finds the next file after mal_code.exe
  - The higher-level utility keeps the running total of file sizes for the files of which it receives information
    - so total in listing correctly reports all files except mal_code.exe

Rootkit Evading Detection



Summary

- OSs have evolved
  - from supporting single users and single programs to many users and programs at once
- Resources that require OS protection:
  - memory, I/O devices, programs, and networks
- OSs use layered and modular designs
  - for simplification
  - to separate critical functions from noncritical ones

Summary

- Resource access control can be enforced in a number of ways
  - including virtualization, segmentation, hardware memory protection, and reference monitors
- Rootkits are malicious software packages that attain root status
  - or effectively become part of the OS

- Questions?