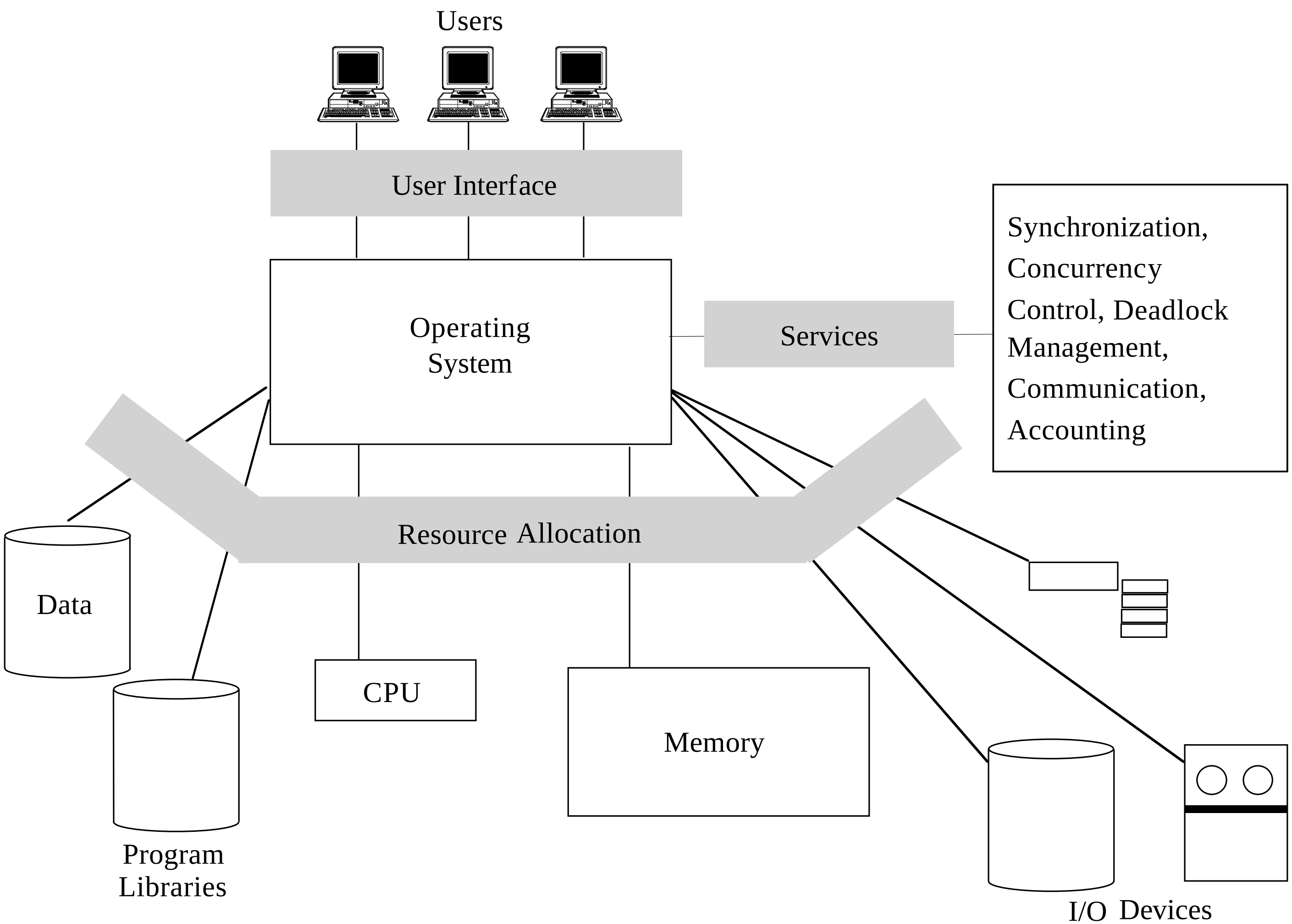
SECURITY IN COMPUTING, FIFTH EDITION

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



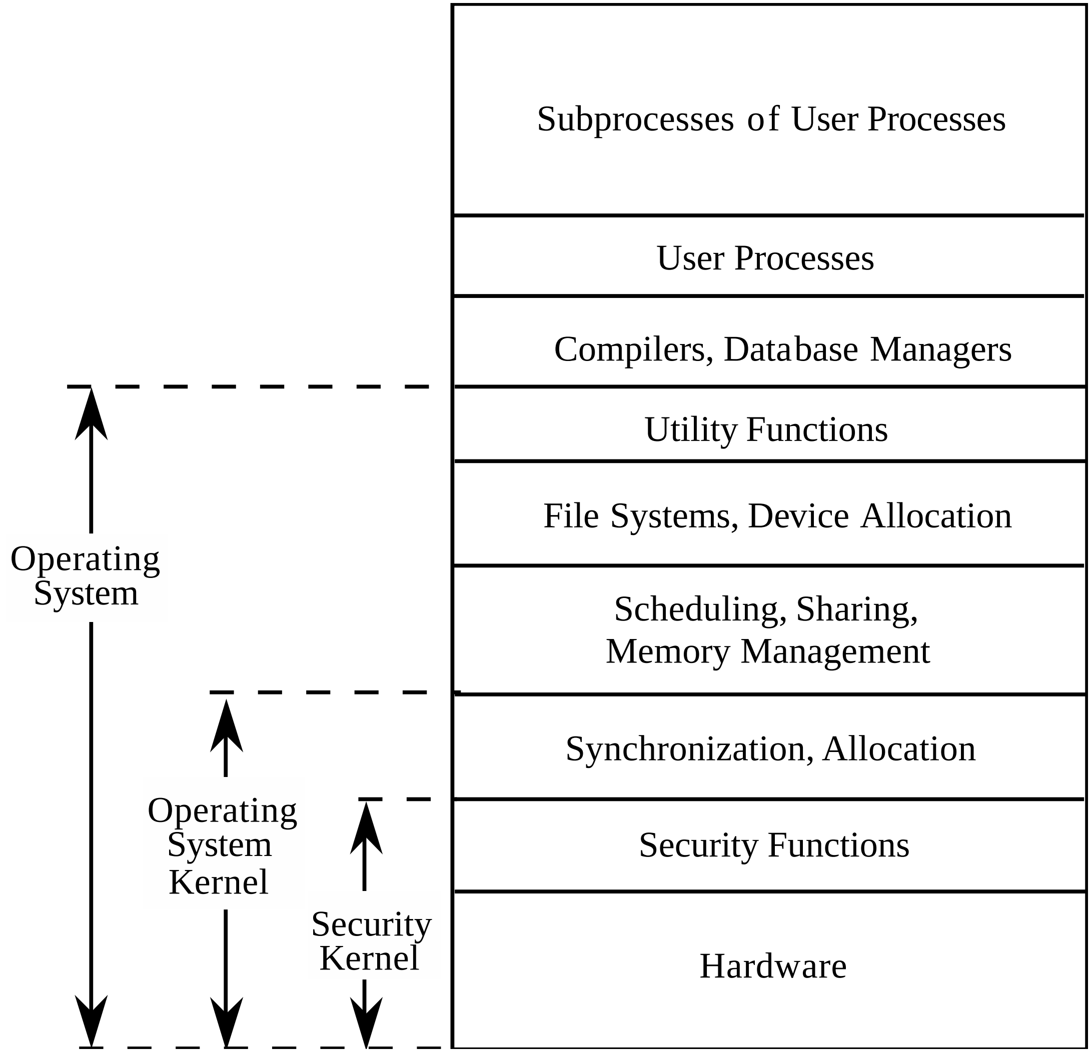
History of Operating Systems

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

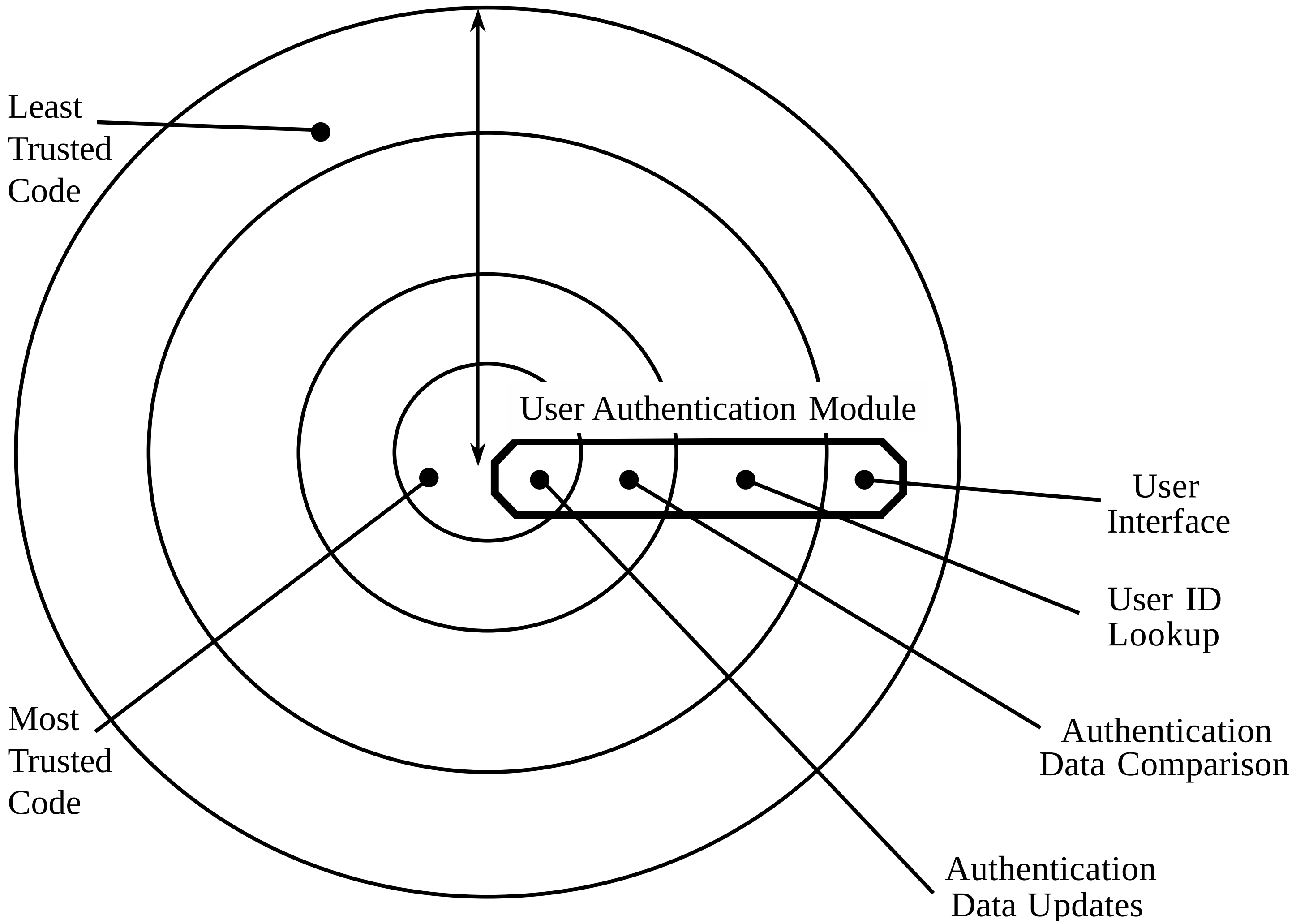
Protected Objects

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

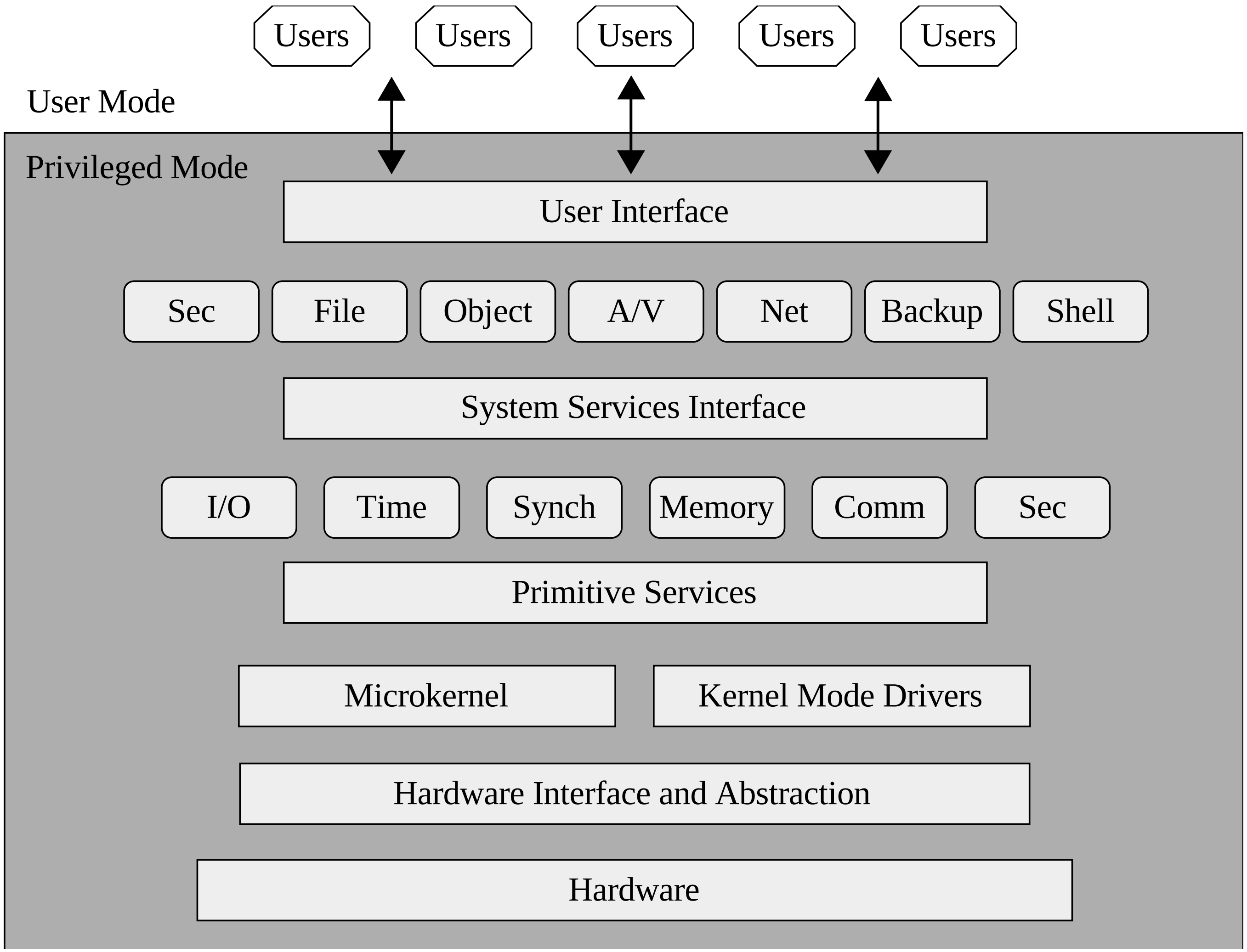
OS Layered Design



Functions Spanning Layers



Modular OS Design



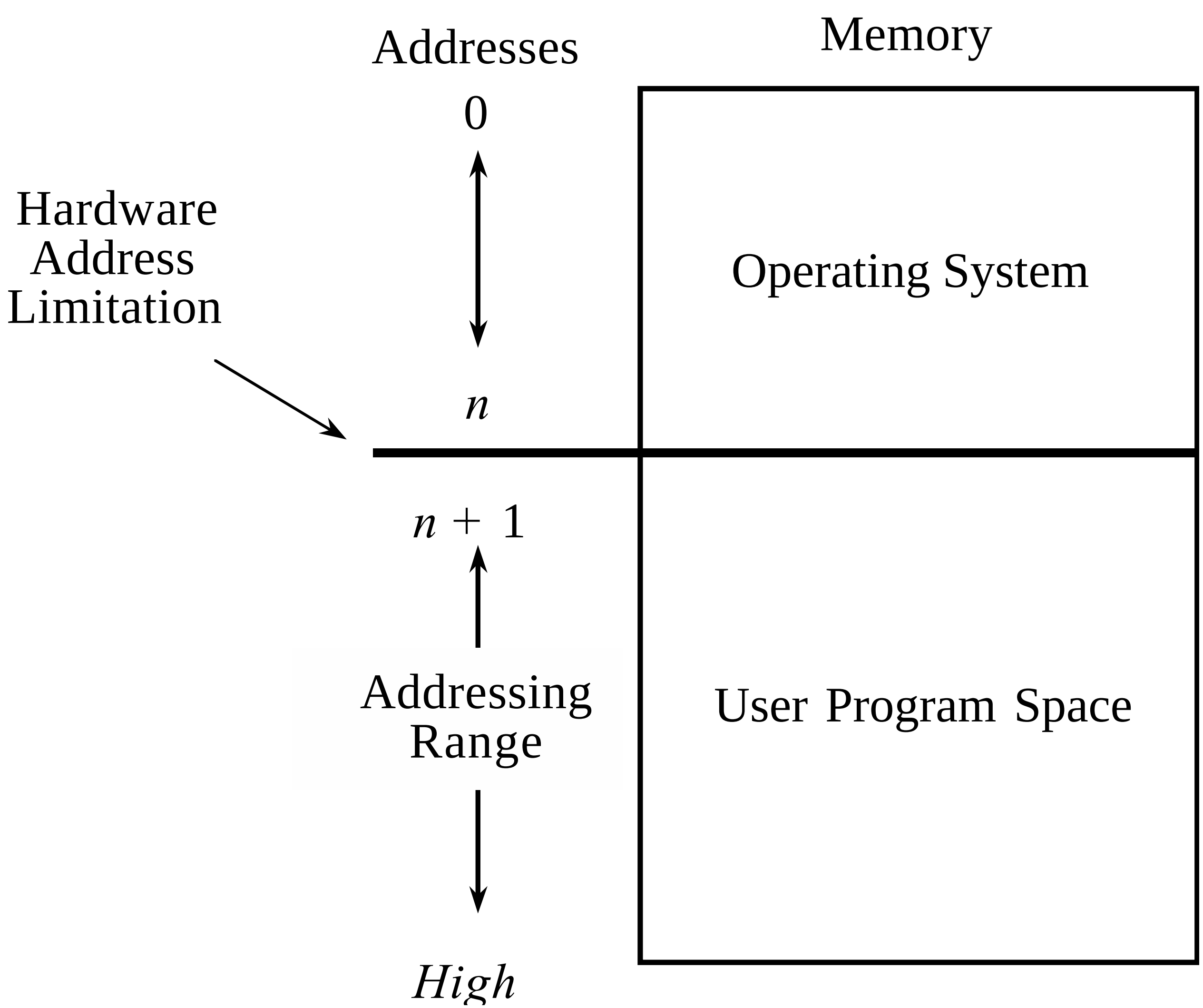
Virtualization

- 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
- 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
- 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



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

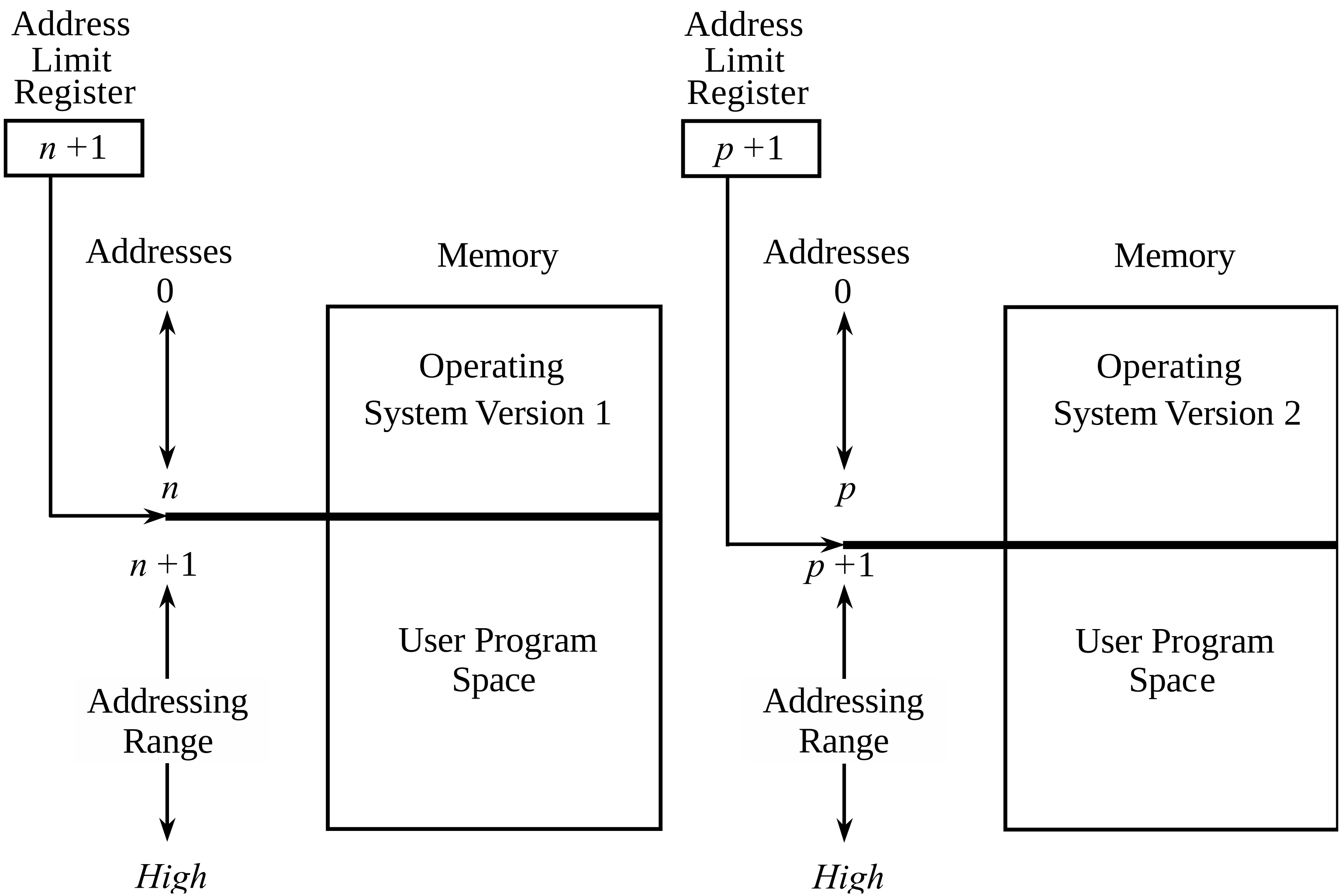
Fence Registers

- 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



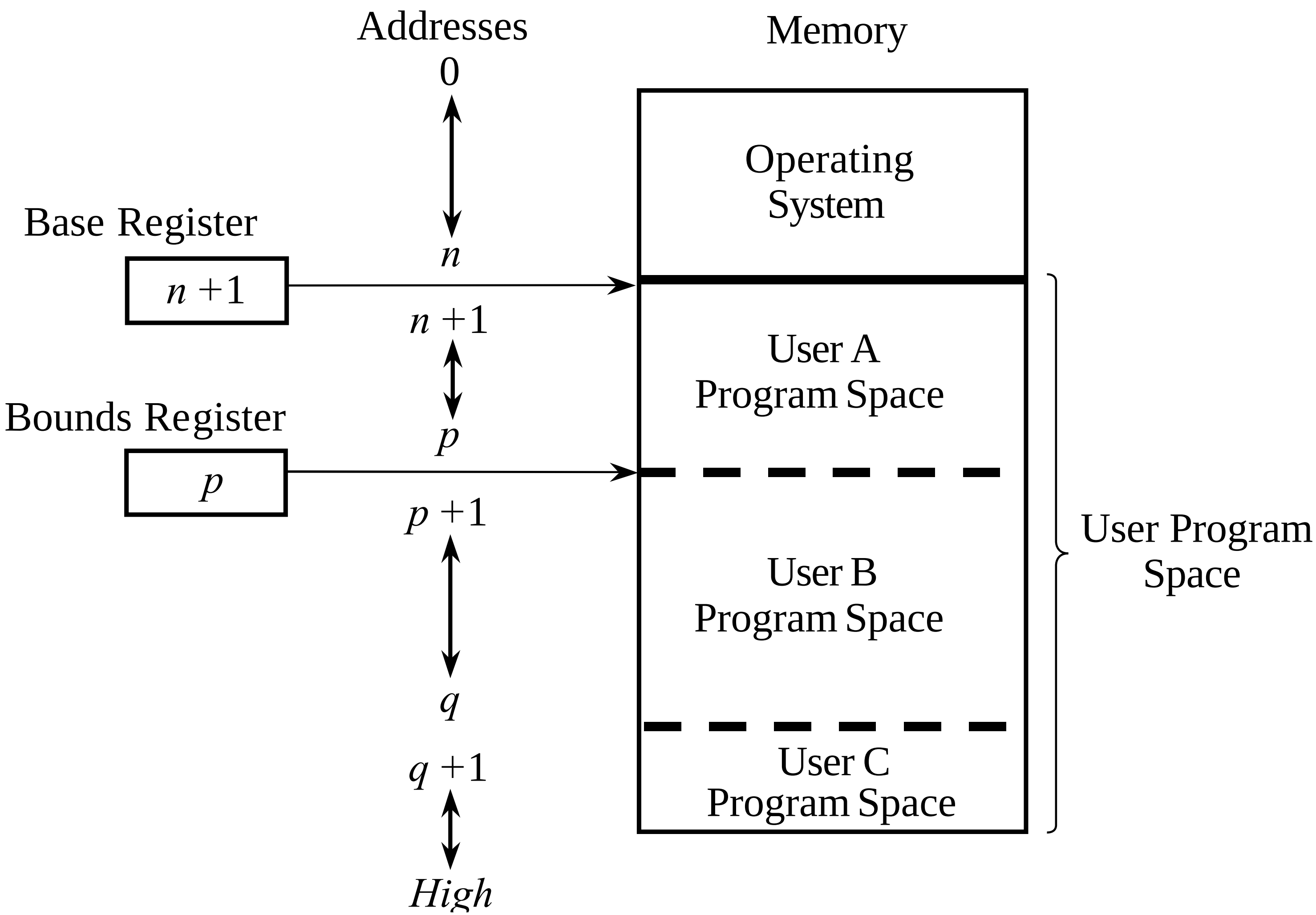
Base/Bounds Registers

- 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*

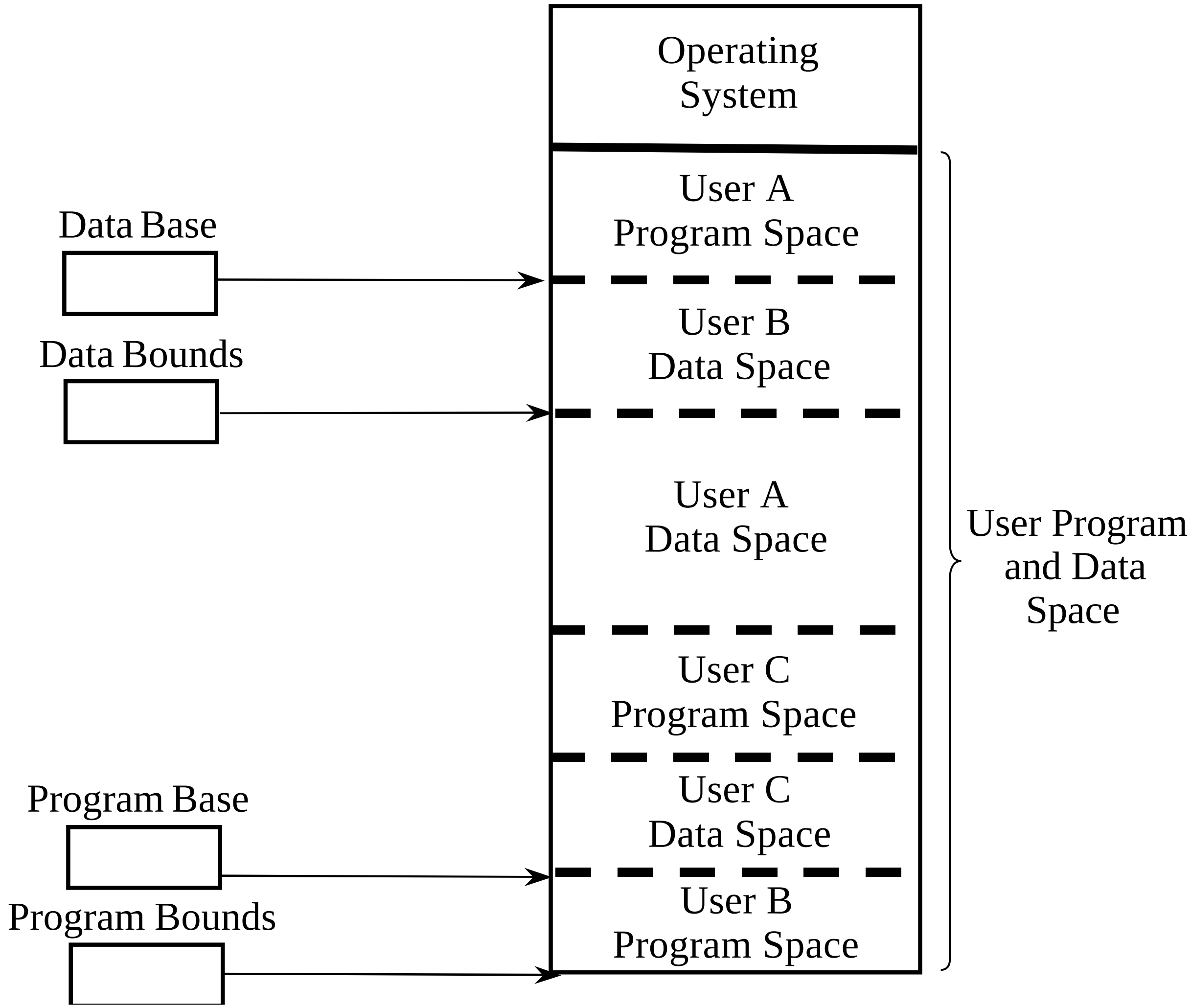
Base/Bounds Registers

- 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 and 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.
- 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



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

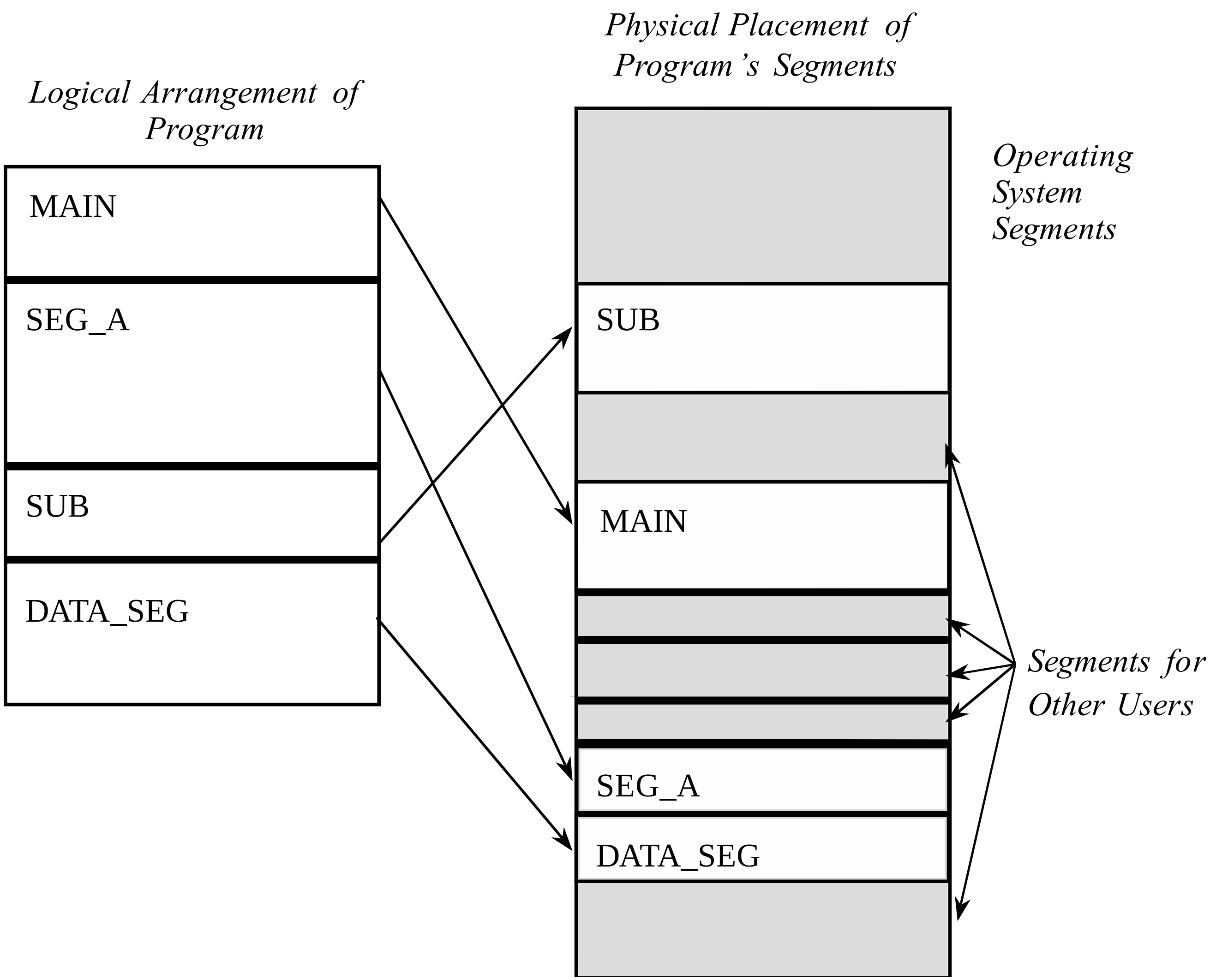
Segmentation

- 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 and 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

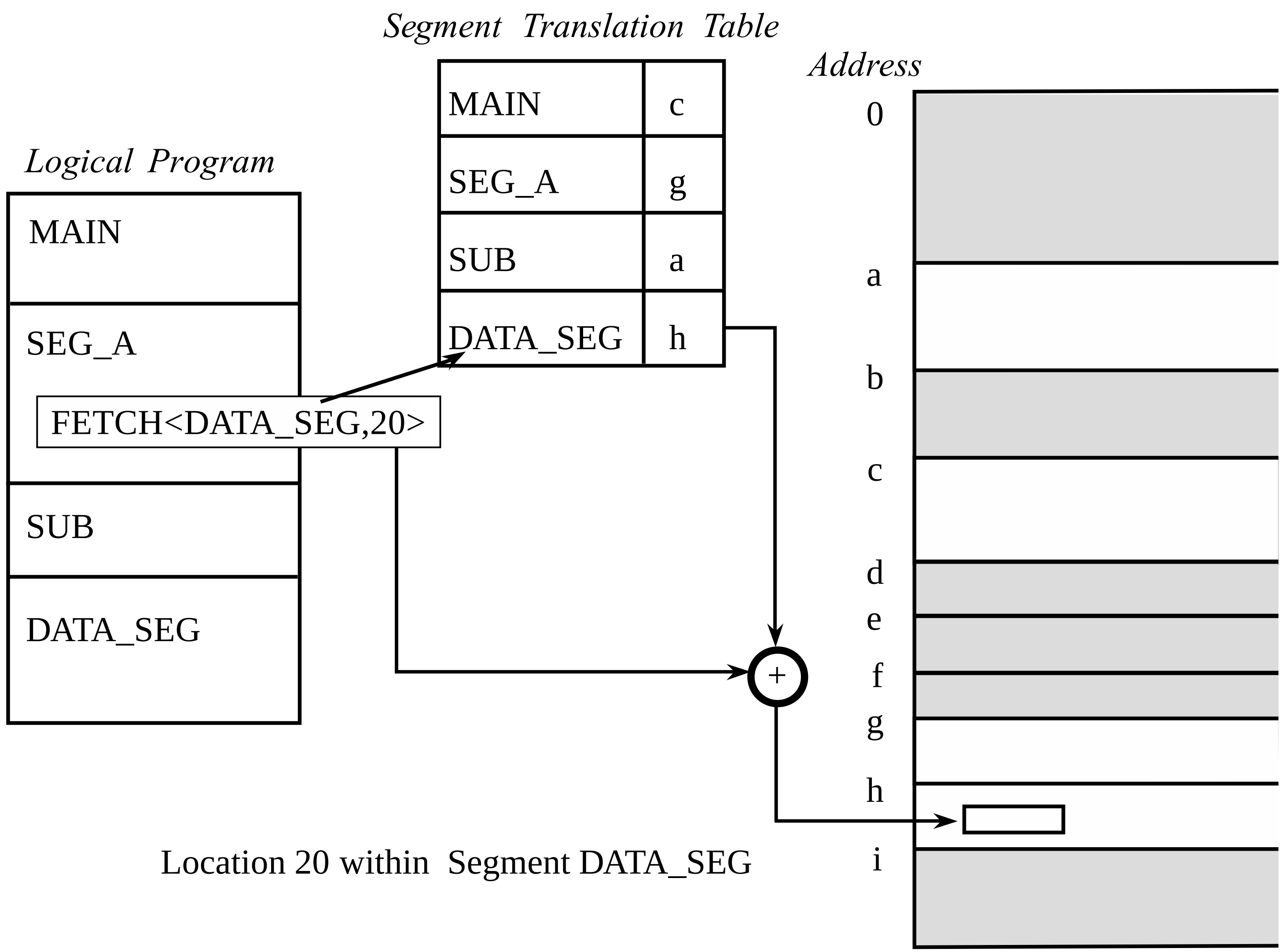
Segmentation

- 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
- 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



Segment Address Translation



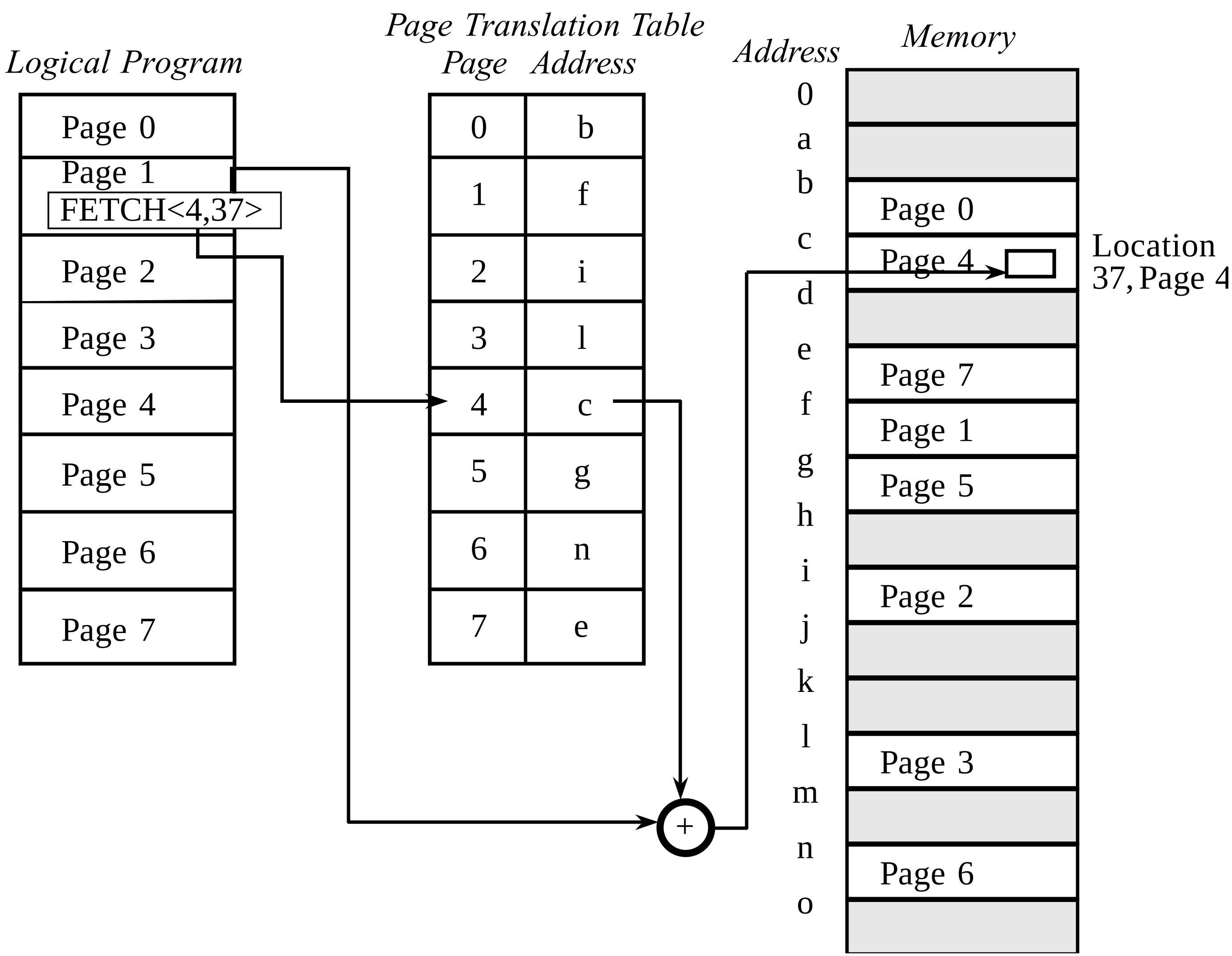
Paging

- 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 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")

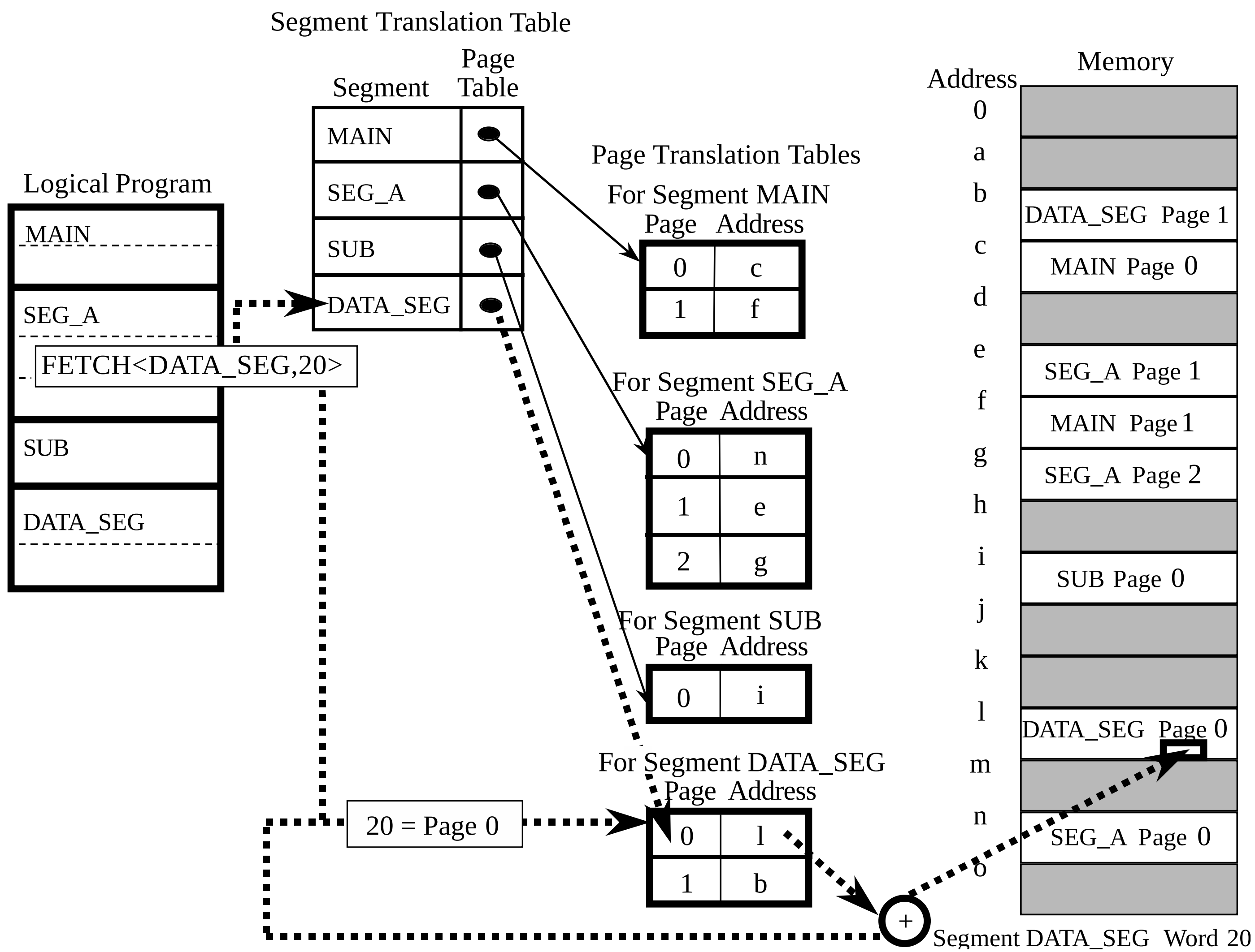
Paging


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

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



SECURE OS DESIGN

Access Control

Principles of Secure OS Design

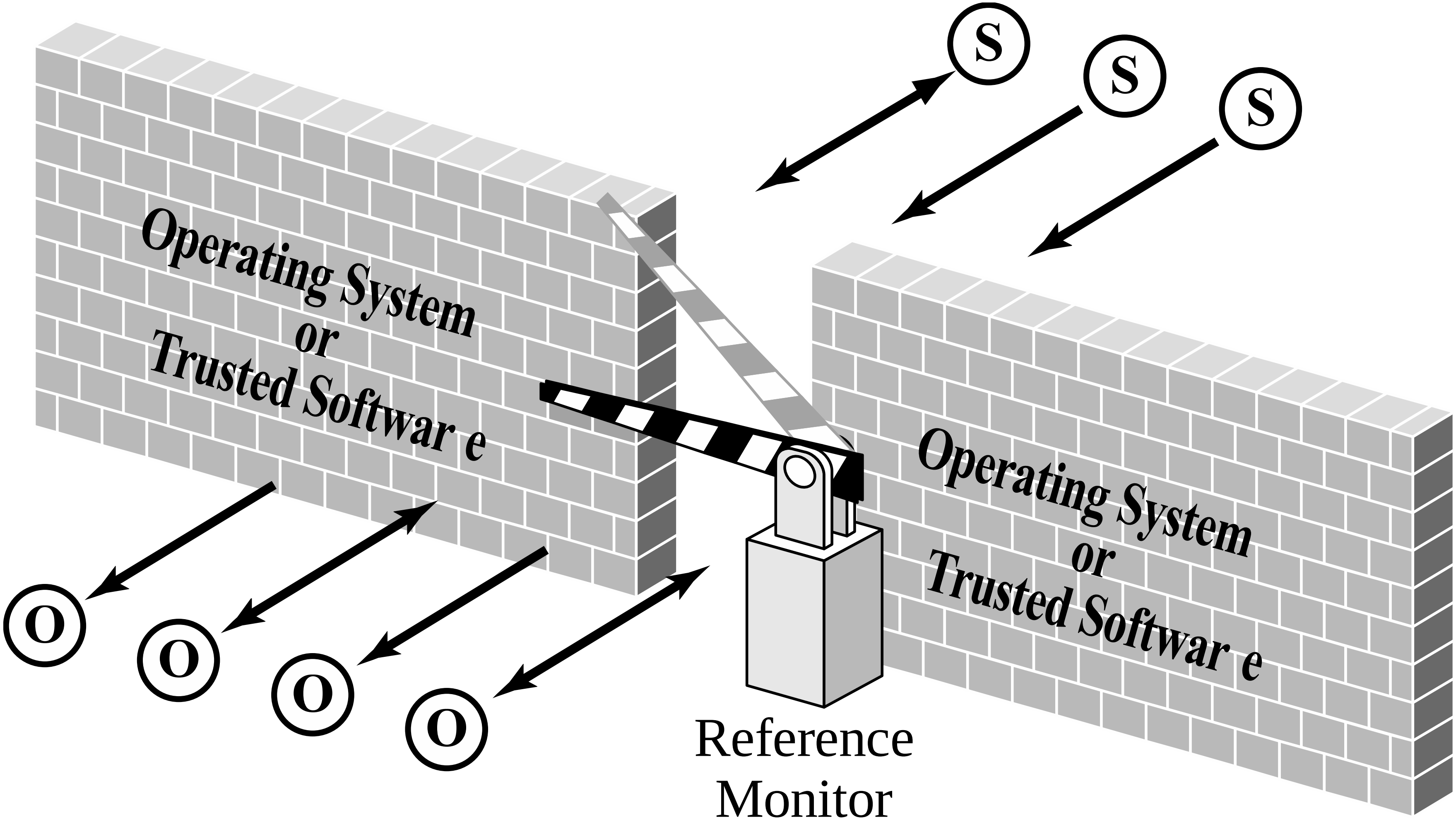
- Simplicity of design
  - OSs are inherently complex, and any unnecessary complexity only makes them harder to understand and secure
- Layered design
  - Enables layered trust
- Layered trust
  - Layering is both a way to keep a design logical and understandable and a way to limit risk
  - Example: very tight access controls on critical OS functions, fewer access controls on important noncritical functions, and few if any access controls on functions that aren't important to the OS

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

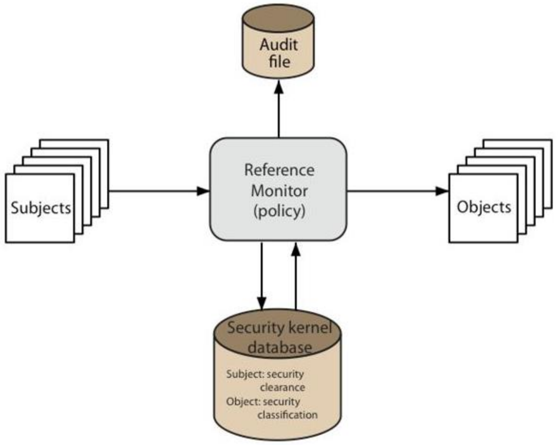
https://twitter.com/com_mediation

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.

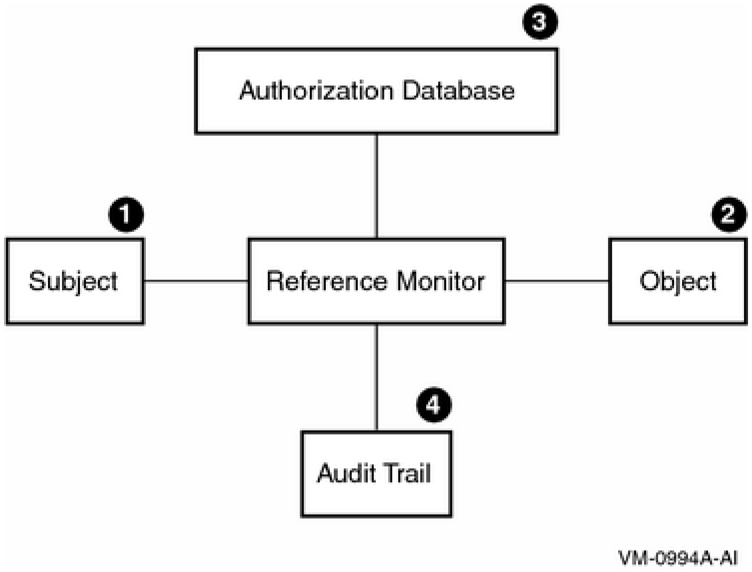


http://slideplayer.com/slide/697485/

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

Kernelized Design

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

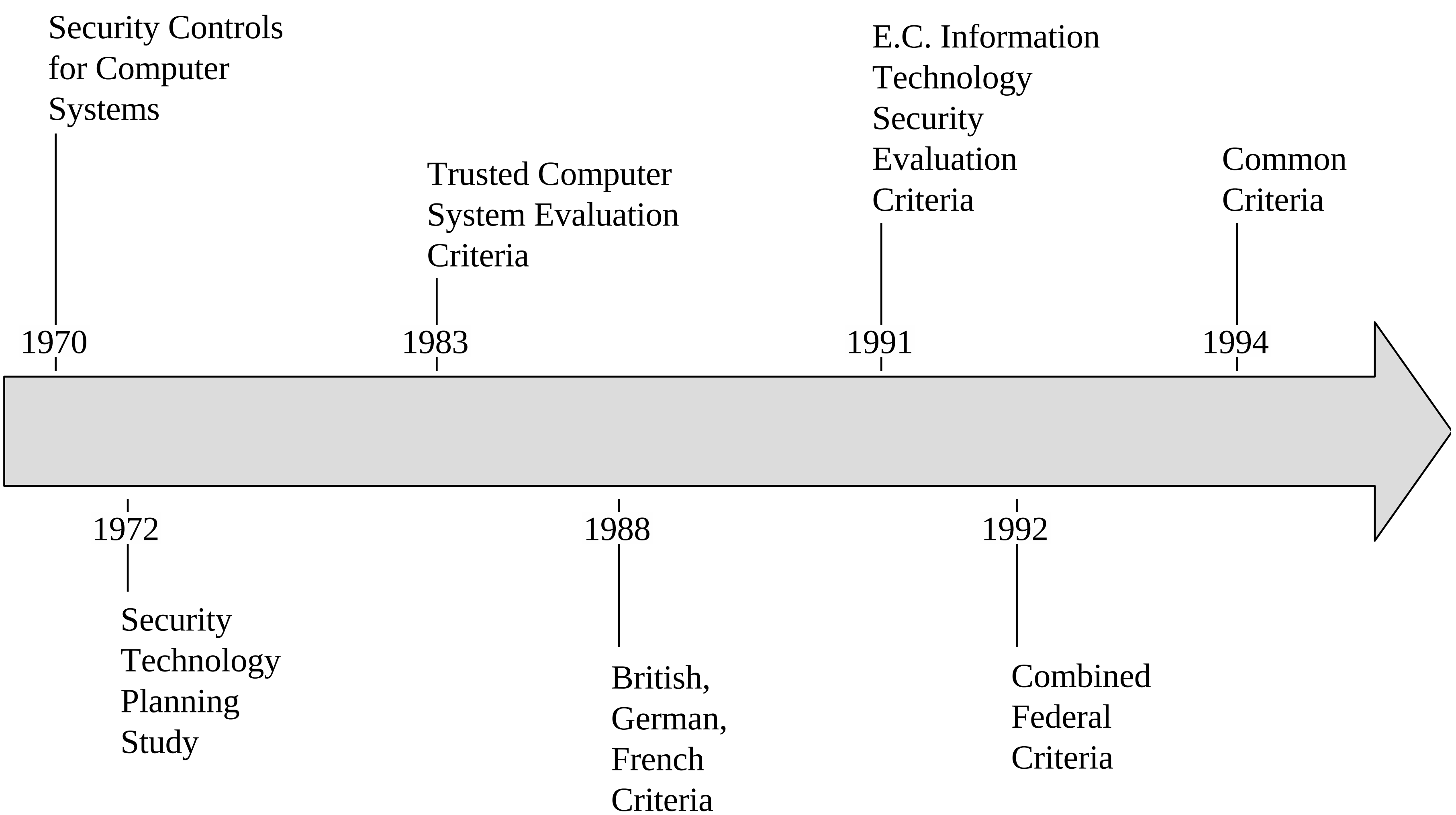
Example: **Windows Kernel-Mode Protection**

- 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

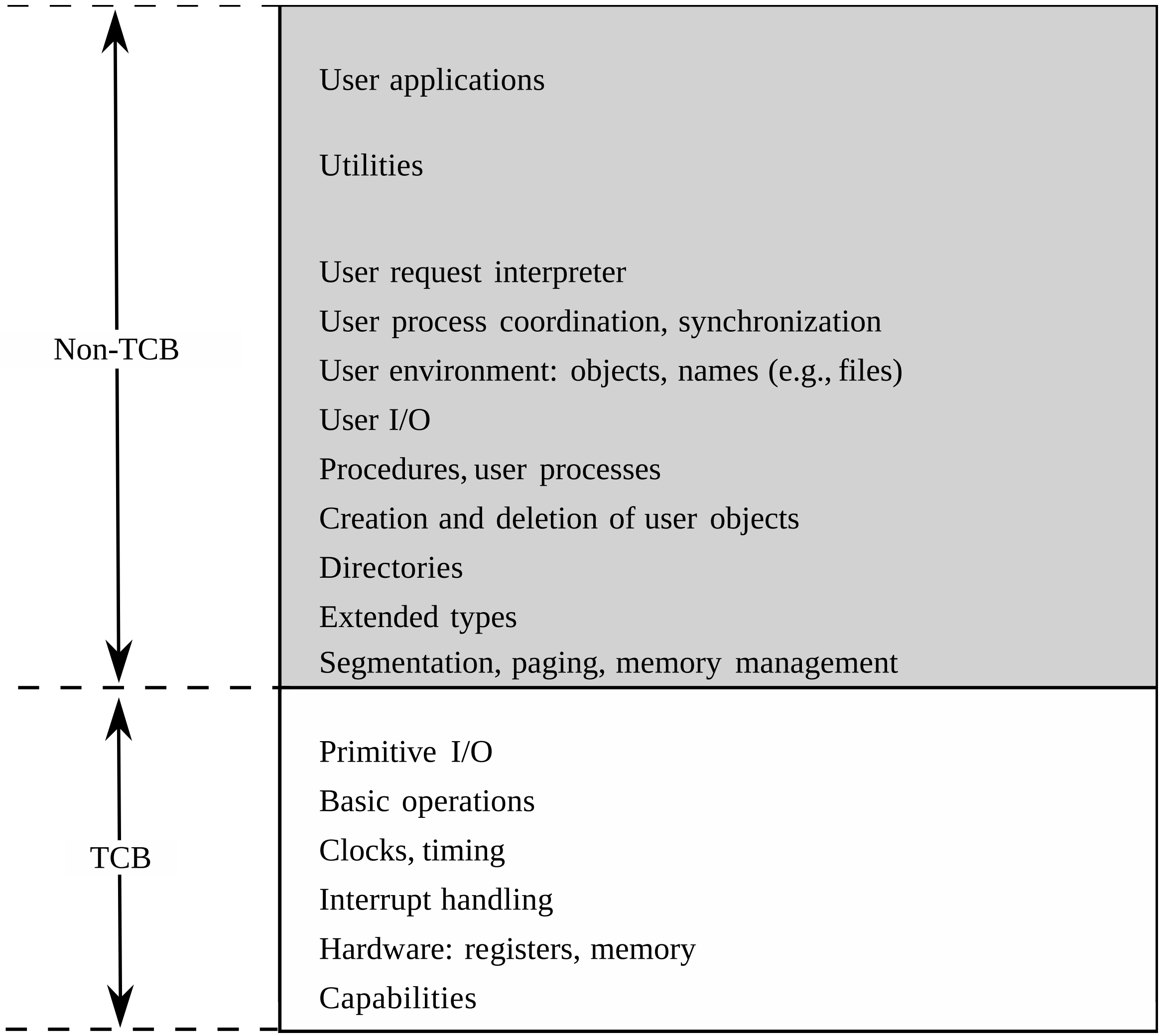
Trusted Systems

- 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



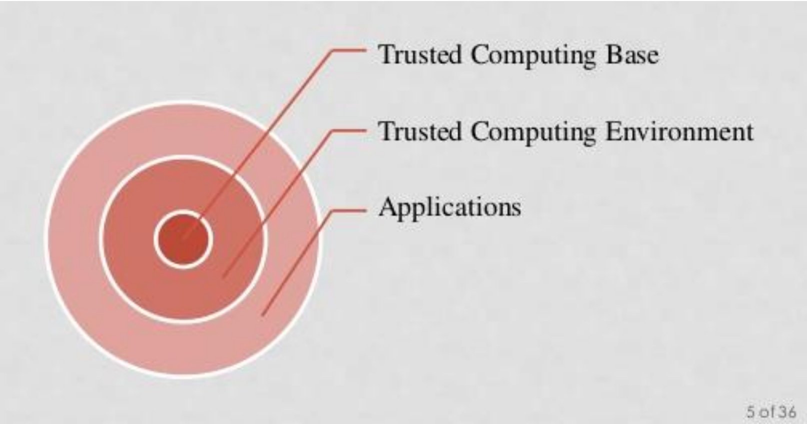
Trusted Computing Base (TCB)



Trusted Computing Base (TCB)

- TCB is the set of all hardware, firmware, and/or software components that are critical to its security
- Example: the 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

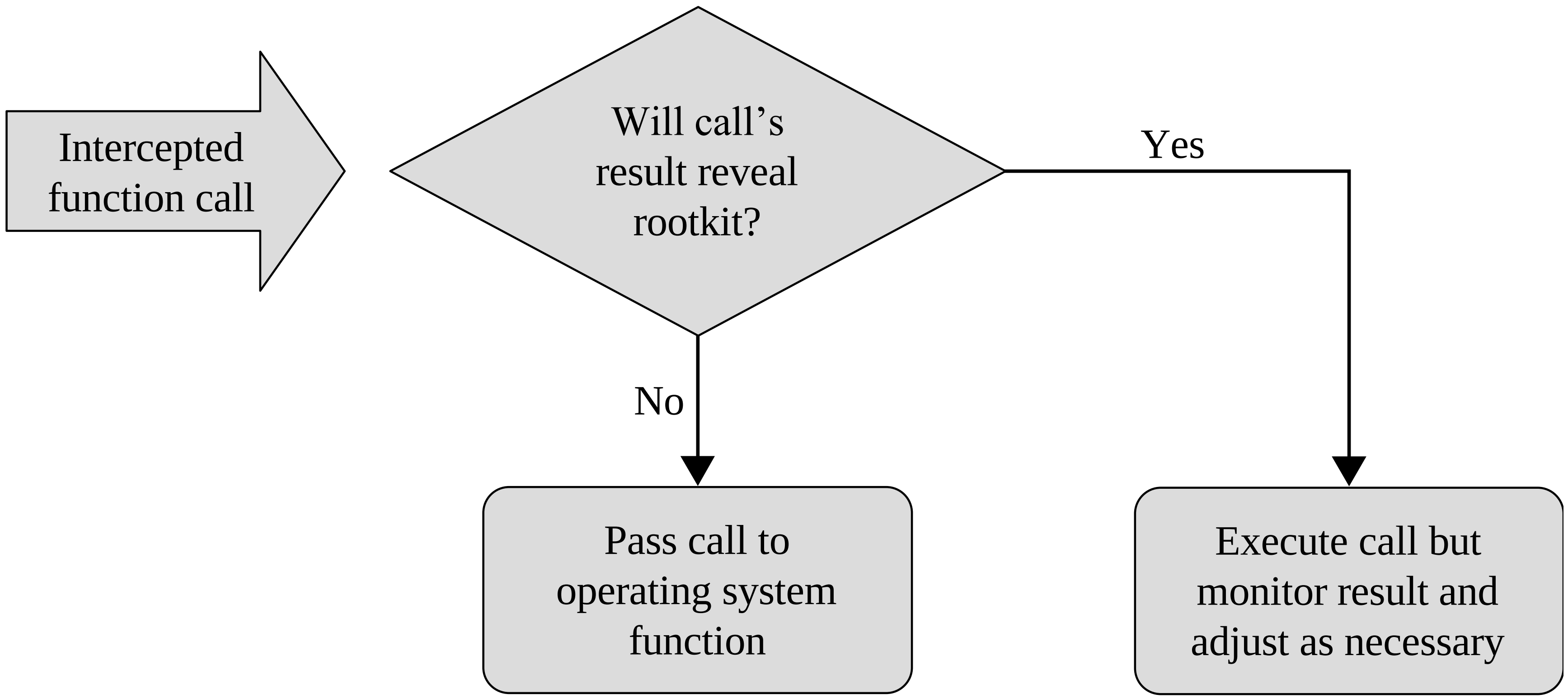
Other Trusted System Characteristics

- 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
- 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

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 or, if discovered and partially removed, to reestablish themselves
  - This can include intercepting or modifying basic OS functions

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 and to separate critical functions from noncritical ones
- 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?