Security in and for Operating Systems

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Learning Objectives

- Security methods of ordinary OS
  - Memory and address protection
  - Control of access to general objects
  - File protection
  - User authentication
- Trusted OS
  - Concepts
  - Security policies and models
  - Trusted OS design:
    - kernelized design, separation/isolation, virtualization

Security Methods of Ordinary OS

Protected Objects

- Memory
- I/O devices (sharable, serially usable)
- Networks
- Sharable programs and subprocedures
- Sharable data

Security Methods of OS

- Separation: One user's objects separate from other users
- Physical separation
  - E.g., separate printers
- Temporal separation
  - Processes executing at different times
- Logical separation
  - Users operate under the illusion that no other processes exist
- Cryptographic separation
  - Data and computations unintelligible to outside processes

Levels of Separation

more difficult

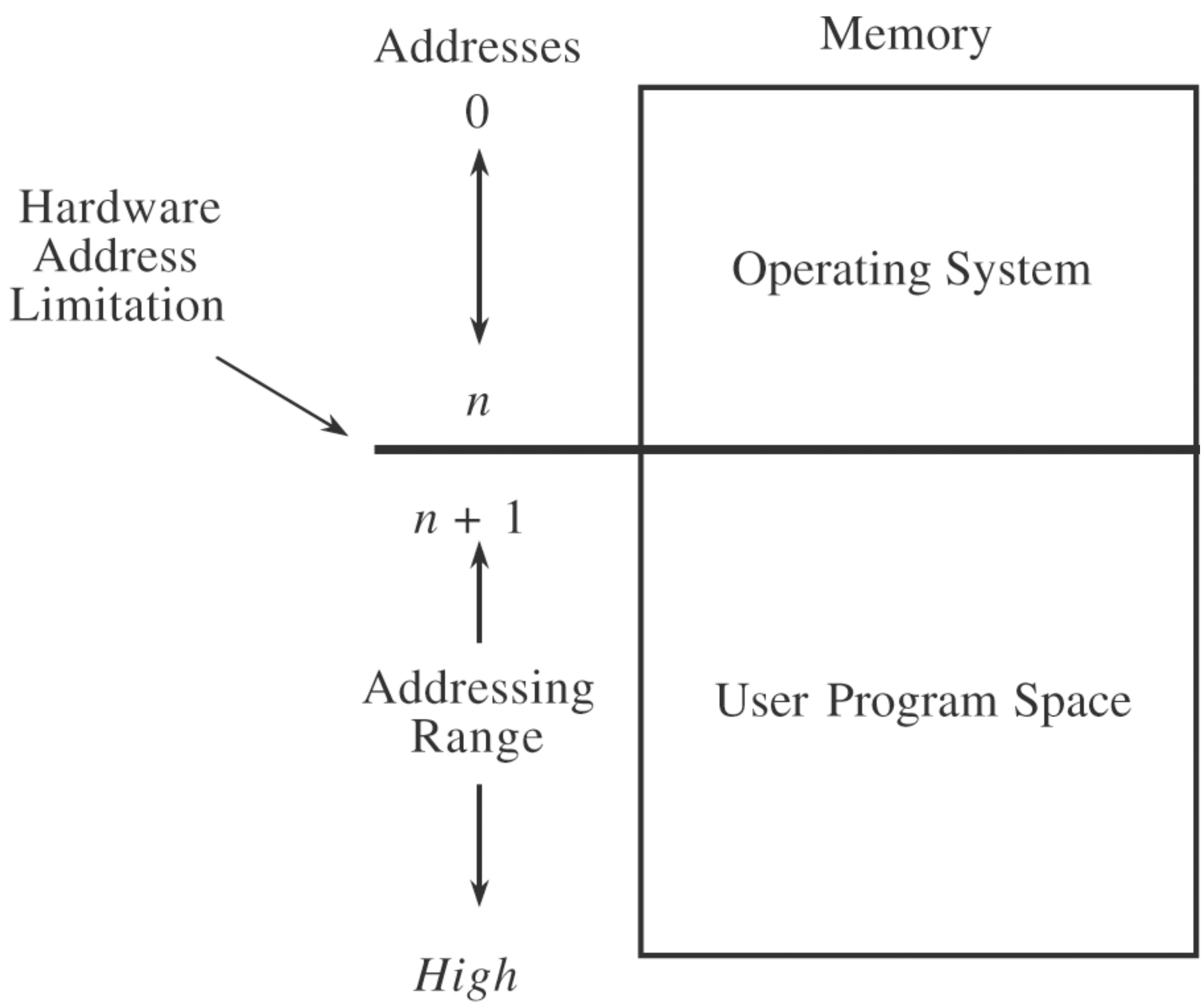
- Do not protect
- Isolate: Processes are unaware of each other
  - Each has its own address space, files, and other objects
- Share all or nothing
  - The owner of an object make it either public or private
- Discretionary access control
  - The owner controls the access to its objects
- Mandatory access control
  - The O.S. controls the access to objects
- Limit use of an object
  - Not just the access, but also the usage made after access

Memory and Address Protection

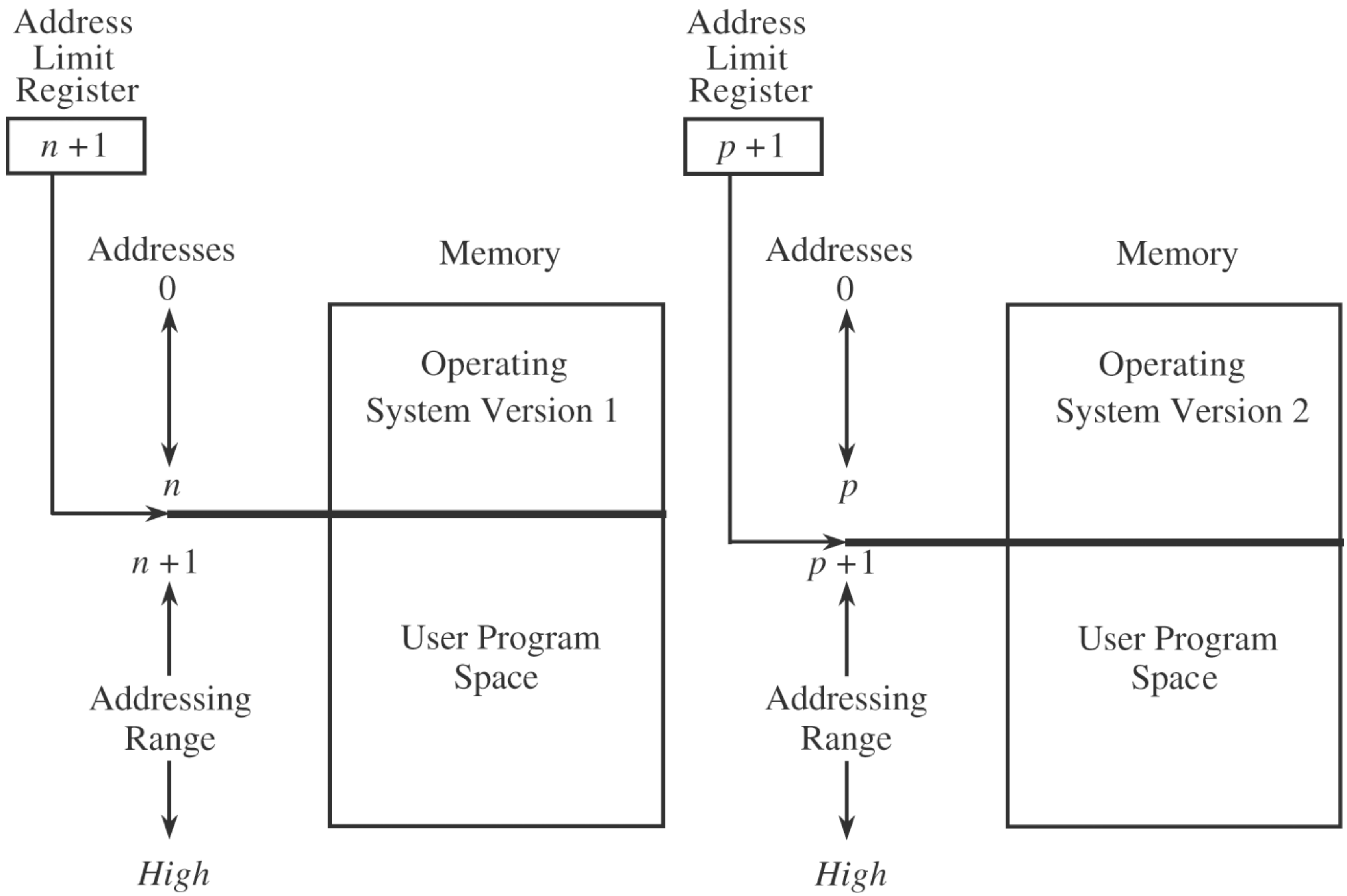
Every access goes through certain HW points

- Fence
- Relocation
- Base/Bound Registers
- Tagged Architecture
- Segmentation
- Paging
- Combined Paging with Segmentation

Fence - Predefined



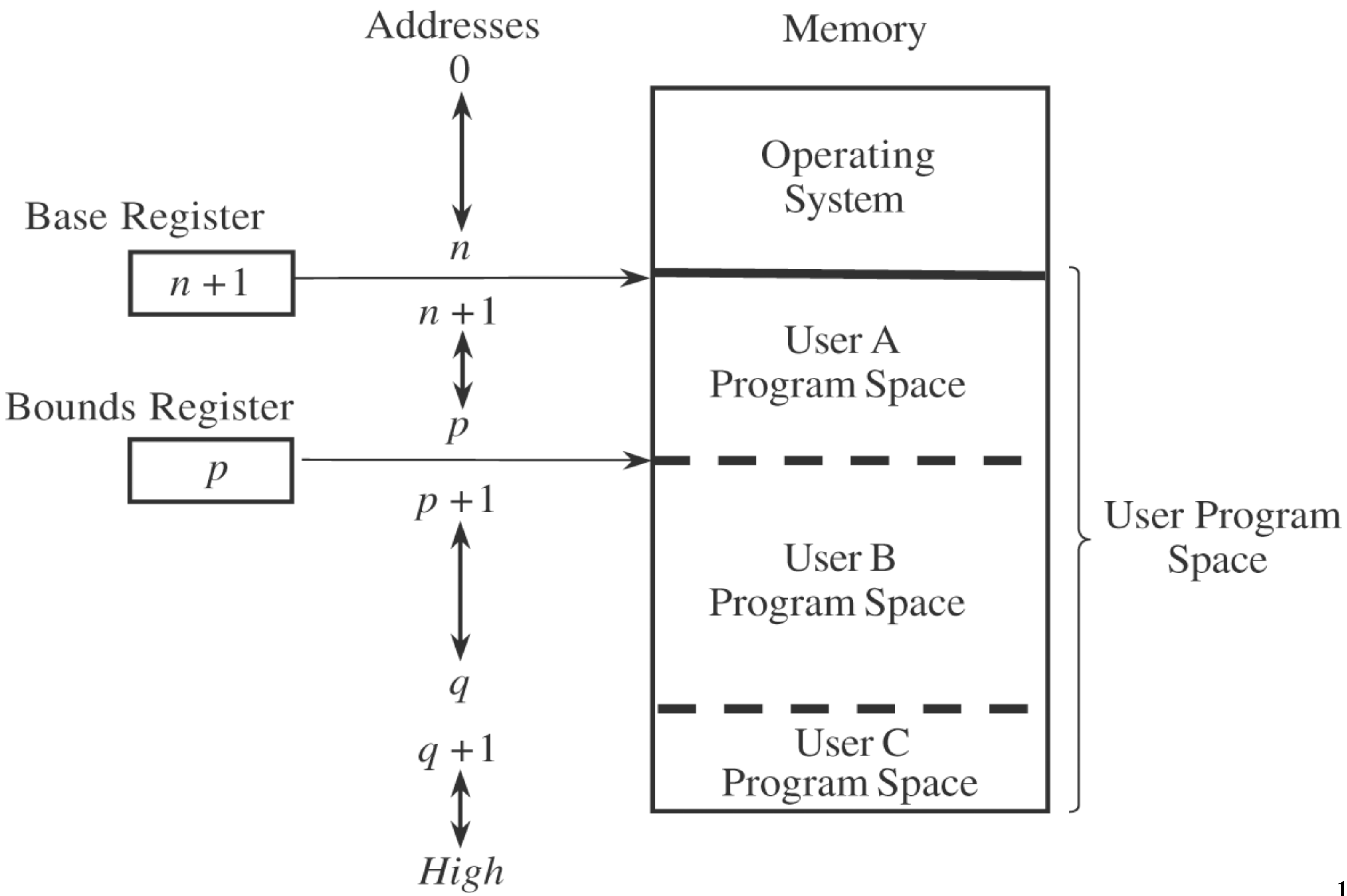
Fence – Fence Register

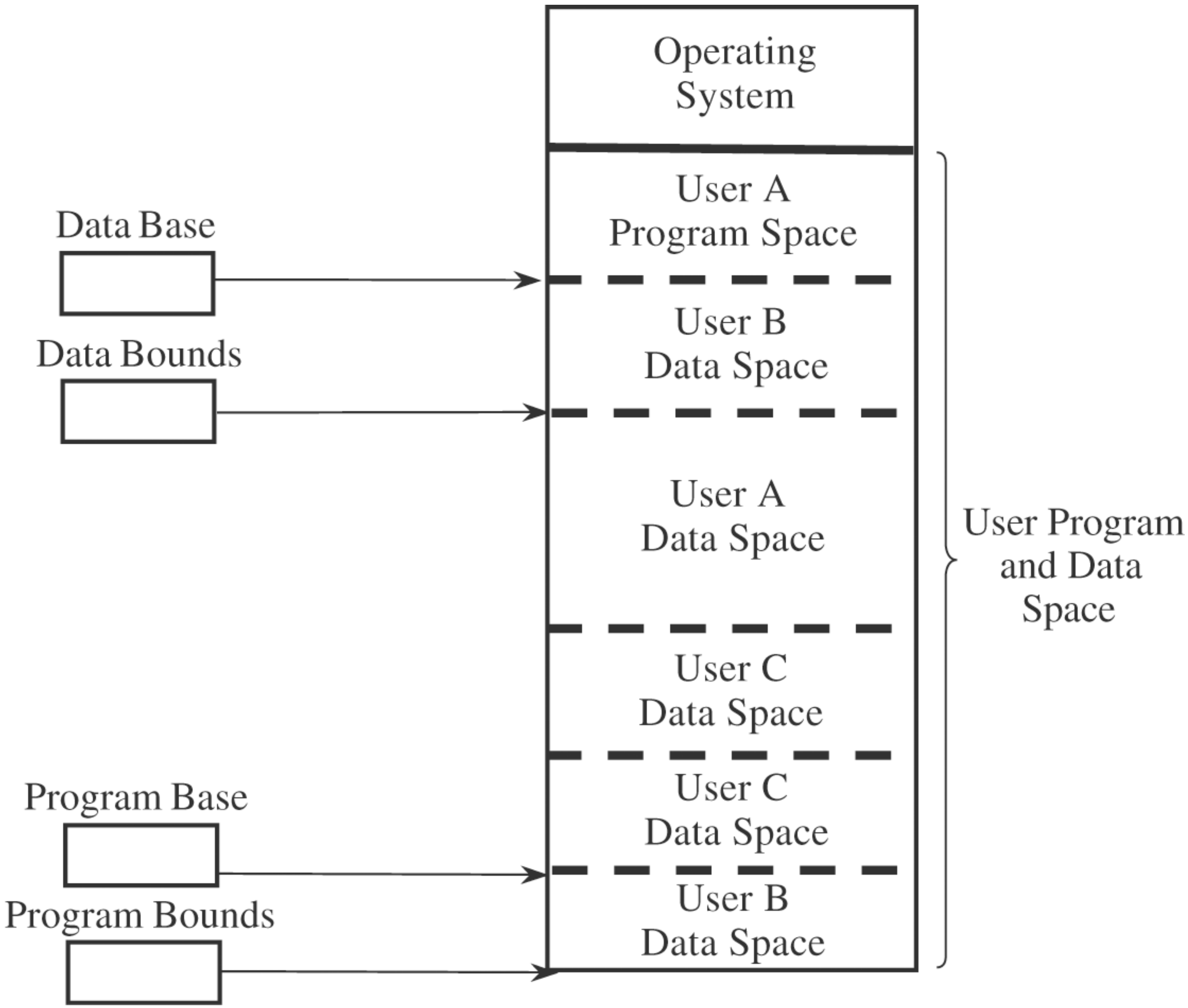


Relocation

- Program written as if it began at address 0
- Adding a constant relocation factor when loading the program into memory
- The fence register can be a hardware relocation device

Base/Bounds Registers



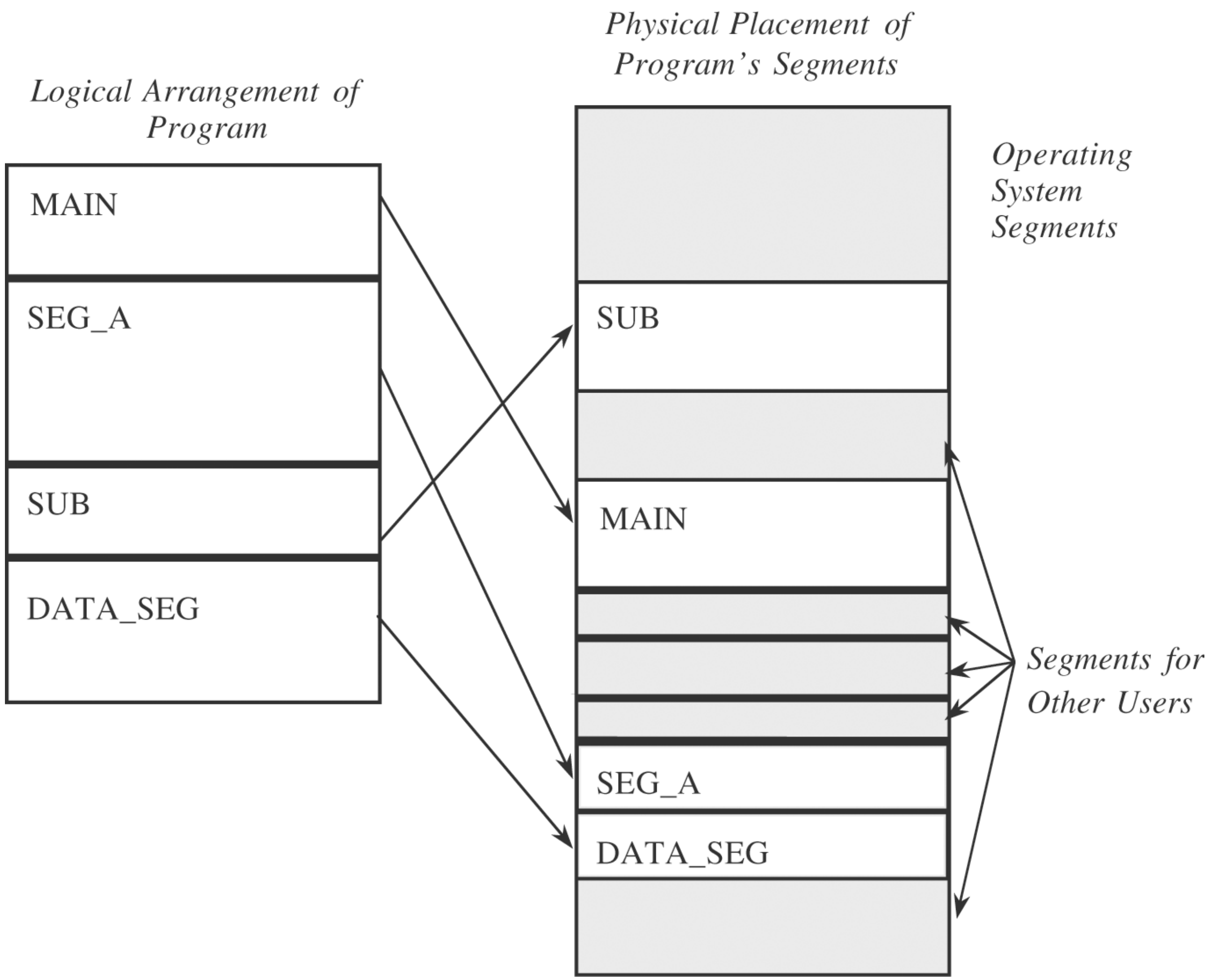

Operating
System
User A
Program Space
Data Base
User B
Data Space
Data Bounds
User A
Data Space
User Program
and Data
Space
User C
Data Space
User C
Data Space
Program Base
User B
Data Space
Program Bounds

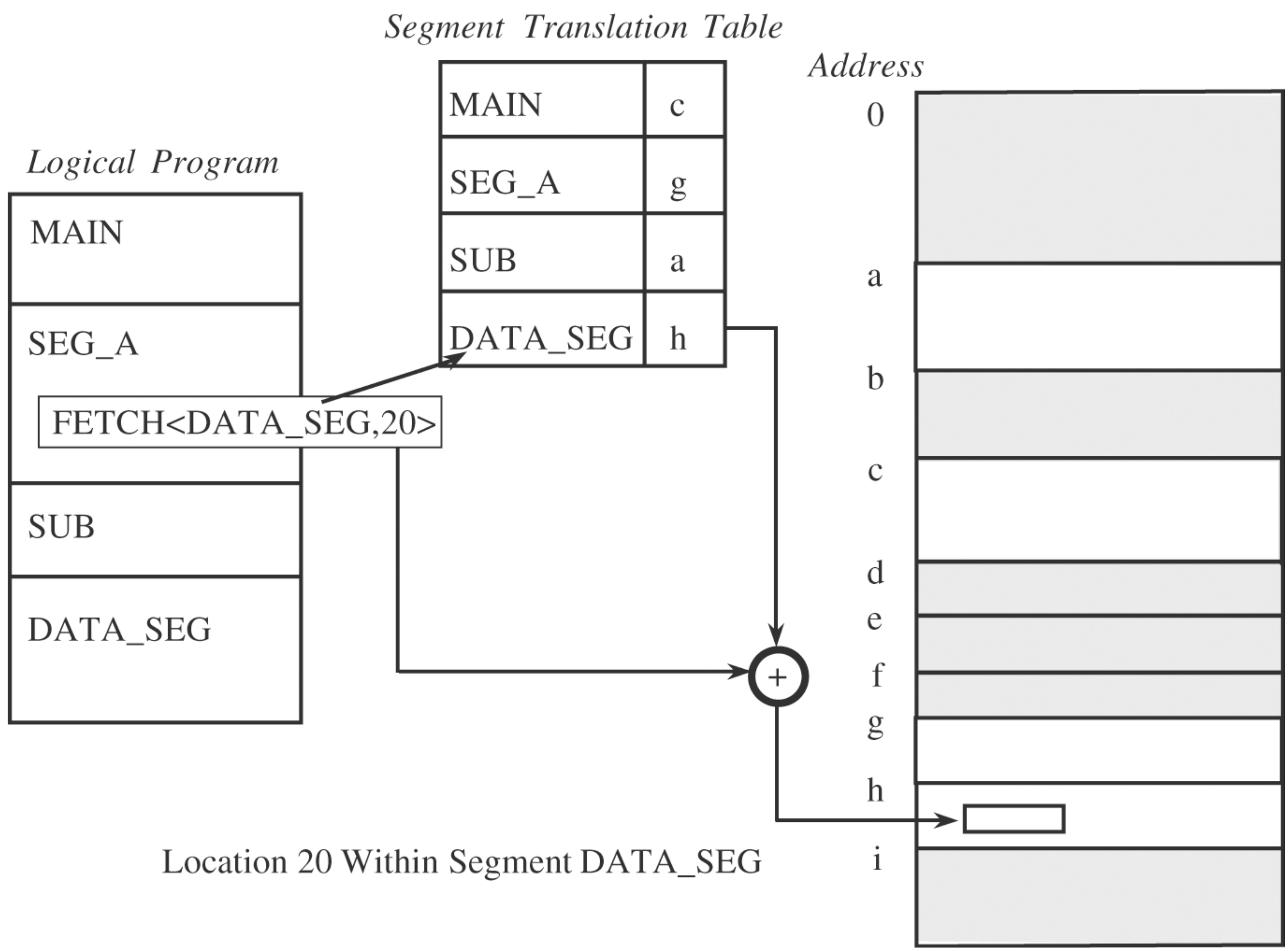
Tagged Architecture

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

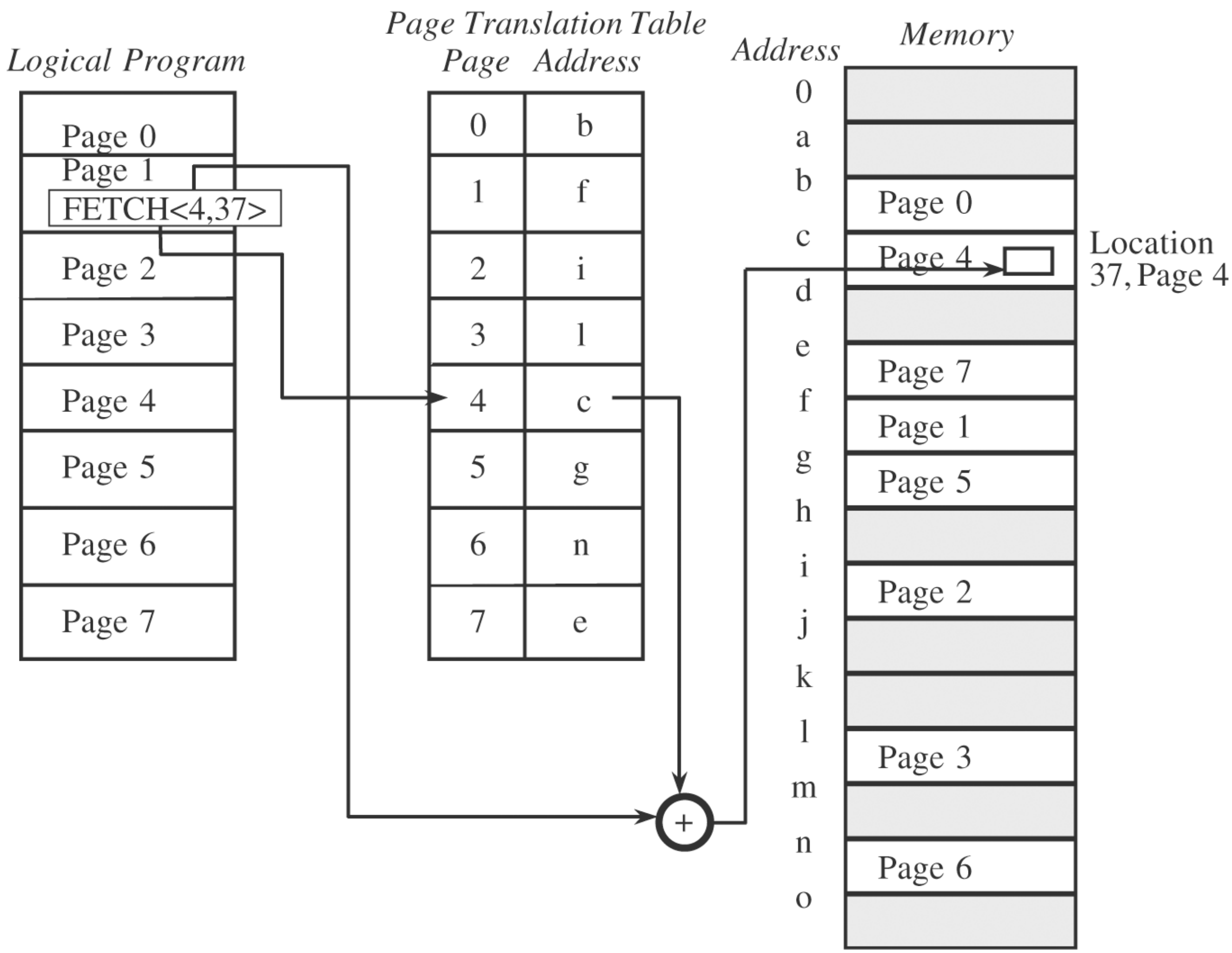
Code: R = Read-only RW = Read/Write
X = Execute-only

Segmentation



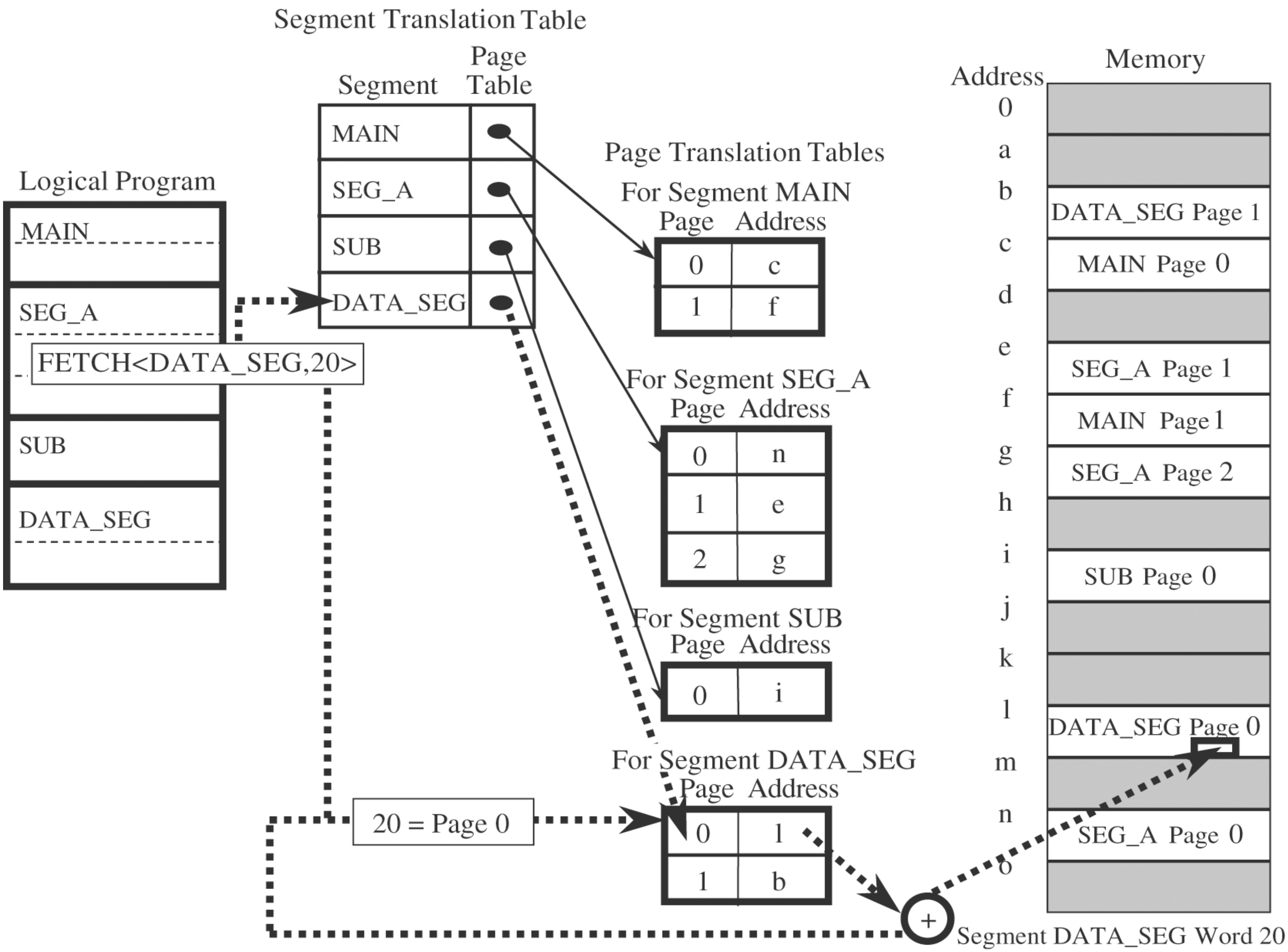

Segment Translation Table
MAIN c
SEG_A g
SUB a
DATA_SEG h
Address
0
a
b
c
d
e
f
g
h
i
Logical Program
MAIN
SEG_A
FETCH<DATA_SEG,20>
SUB
DATA_SEG
+
Location 20 Within Segment DATA_SEG

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

Combined Paging with Segmentation



Control of Access to General Objects

- Memory is a special object
- Objects can be:
  - A memory space
  - A file or data set on an auxiliary storage device
  - An executing program in memory
  - A directory of files
  - A hardware device
  - A data structure, such as a stack
  - A table of the operating system
  - Privileged instructions
  - Passwords and user authentication mechanism
  - The protection mechanism itself
- Refer to Chapter 2 on Authentication and Access Control

Designing Trusted Operating Systems

4 Underpinnings of a *Trusted* OS

- **Security policy**: requirement statements of what an OS should do and how it should do it, usually a set of rules on what to be secured and why.
- **Model**: a representation of the policy the OS will enforce (and compared with the security policy to ensure the security needs are met)
- **Design**: design/implement the OS w.r.t the model
- **Trust**: *features* (the OS has all the functionalities to enforce the security policy) and *assurance* (it will do so correctly and effectively)

Secure vs. Trusted

- *Either-or*: something either is or is not secure
- Property of *presenter*
- *Asserted* based on product characteristics
- *Absolute*: not qualified as to how used, where, when, or by whom
- A *goal*

- *Graded*: degrees of trustworthiness
- Property of *receiver*
- *Judged* based on evidence and analysis
- *Relative*: viewed in context of use
- A *characteristic*

Security Policies

- Military Security Policy
- Commercial Security Policies
  - Clark-Wilson
  - Separation of Duty
  - Chinese Wall

Military Security Policy: object

- Each piece of information is ranked at a sensitivity level: *unclassified, restricted, confidential, secret, top secret*
- Each piece of information is also associated with *compartments*
  - Need-to-know principle
- **class** or **classification** of a piece of information: <*rank; compartments*>

Military Security Policy: subject

- **clearance** of a subject: <*rank; compartments*>
  - The subject is trusted to access information up to a certain level of sensitivity (*rank*)
  - The subject needs to know certain categories of information (compartments)
- A subject ***s*** dominates an object ***o*** (***s*** $\geq$ ***o***) *iff*

  rank(***s***) >= rank(***o***) *and*

  Compartments(***s***) $\geq$ Compartments(***o***)

Military Security Policy

- A subject ***s*** can read an object ***o*** only if ***s*** dominates ***o*** ($s \geq o$)
- Appropriate for a setting in which access is rigidly controlled by <u>a central authority</u>

Models of Security

- Test a particular policy
  - Completeness
  - Consistency
- Document a policy
- Help conceptualize and design an implementation
- Check whether an implementation meets its requirements

Models

- Models for multilevel security
  - Bell-La Padula Confidentiality Model
  - Biba Integrity Model
- Models proving theoretical limitations of security systems
  - Graham-Denning
  - Harrison-Ruzzo-Ullman
  - Take-Grant
- We focus on models for multilevel security

Bell-La Padula Confidentiality Model

- The system has a set of subjects $S=\{s\}$ and a set of objects $O=\{o\}$
- Each subject s or object o has a **security class** $C(s)$, $C(o)$
- Enforces two properties on the secure flow of information

Properties

- **Simple Security Property.** A subject *s* can <u>read</u> an object *o* only if $\underline{C(s) \geq C(o)}$.
  - Prevents *read-up*
- ***-property** (called "star property"). A subject *s* who can read an object *o* can <u>write</u> to *p* only if $\underline{C(o) \leq C(p)}$.
  - Prevents *write-down*

Biba Integrity Model

- To prevent inappropriate modification of data
- Subjects and objects are ordered by an integrity classification scheme. $I(s)$, $I(o)$.
- **Simple integrity property.** Subject s can modify (write) object o only if $I(s) \geq I(o)$.
- **Integrity *-property.** If subject s has *read* access to object o with integrity level $I(o)$, s can write object p only if $I(o) \geq I(p)$.

Graham-Denning Model

- Model the access control mechanisms of a protection system
- A set of subjects S, a set of objects O, a set of rights R, and an access control matrix A.
- 8 primitive protection rights
  - Create object, create subject, delete object, delete subject
  - Read access right, grant access right, delete access right, transfer access right

Harrison-Ruzzo-Ullman

- A variation of the Graham-Denning model
- Based on **commands** with conditions and primitive operations

command *name*($o_1, o_2, \ldots, o_k$)
    if r_1 in $A[s_1, o_1]$ and
        …
        r_m in $A[s_m, o_m]$
    then
        op_1
        …
        op_n
end

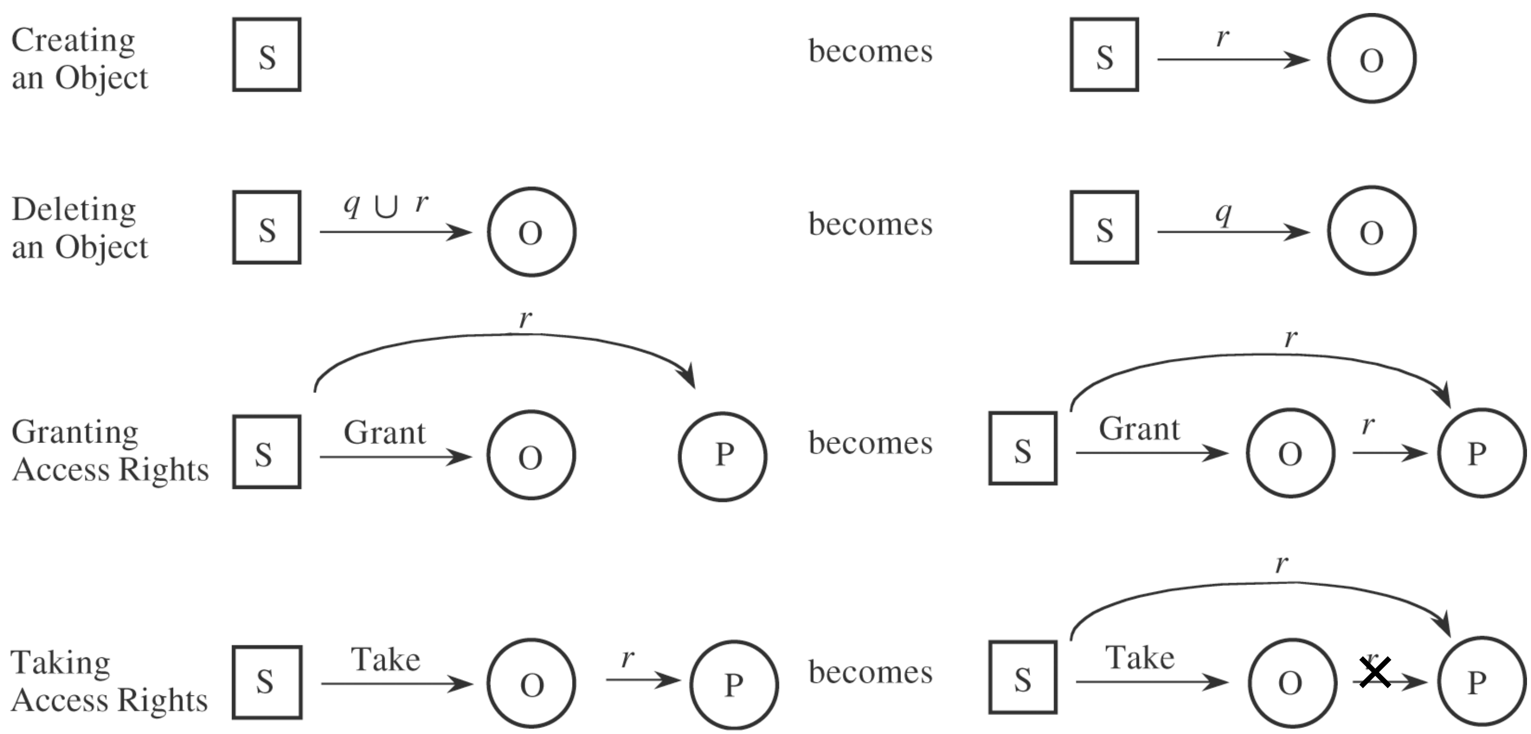
- Primitive operations:
  - –create/destroy subject/object
  - –enter/delete right r into/from $A[s,o]$

HRU Results

- In the modeled system, in which commands are restricted to a single operation each, it *is* possible to decide whether a given subject can even obtain a particular right to an object.
- If commands are not restricted to one operation each, it is *not* always decidable whether a given protection system can confer a given right.

Take-Grant Model

- 4 primitive operations by a subject *s*: create(*o*, *r*), revoke(*o*, *r*), grant (*o*, *p*, *r*), take(*o*, *p*, *r*).



Take-Grant Results

Decidable on certain protection questions in reasonable time:

1. Can we decide whether a given subject can share an object with another subject?
2. Can we decide whether a given subject can steal access to an object from another subject?

Design of a Trusted OS

- Principles
- Security features of an ordinary OS
- Security features of a trusted OS
- Kernelized design
- Separation/Isolation
- Virtualization
- (Layered design)

Design Principles by Saltzer & Schroeder

- Least privilege
- Economy of mechanism (small, simple, straightforward)
- Open design
- Complete mediation
- Permission based (default is denial of access)
- Separation of privilege
- Least common mechanism (minimal sharing)
- Ease of use

Security Features of a Trusted OS

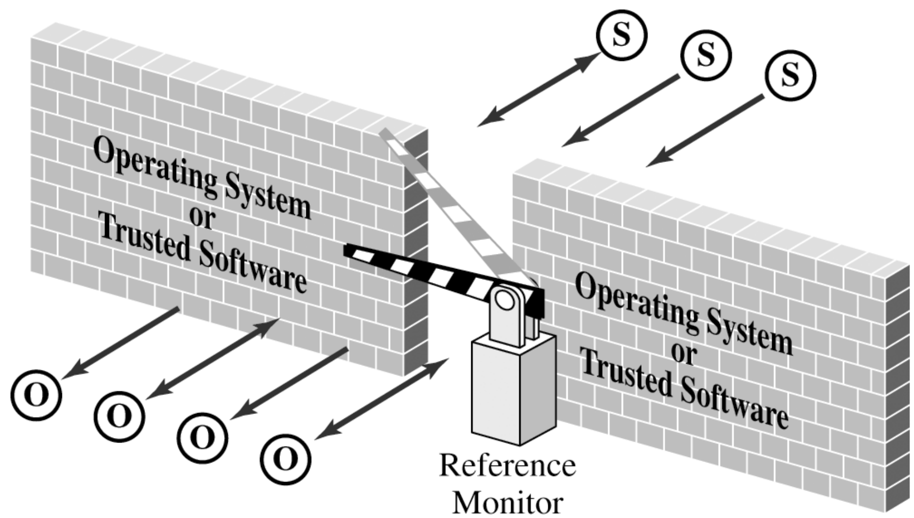
- User identification and authentication
- Mandatory access control (MAC)
- Discretionary access control (DAC)
- Object reuse protection
- Complete mediation
- Trusted path
- Audit
- Intrusion detection

Kernelized Design

- A **security kernel** is responsible for enforcing the security mechanisms of the entire OS
  - Coverage (<u>complete mediation</u>)
  - Separation (from the rest of OS and applications)
  - Unity (a single set of code thus easier to debug)
  - Modifiability (easy to modify)
  - Compactness (small)
  - Verifiability (friendly to rigorous analysis)

Reference Monitor

- The most important part of a security kernel
- It must be:
  - Tamperproof
  - <u>Unbypassable</u>
  - analyzable

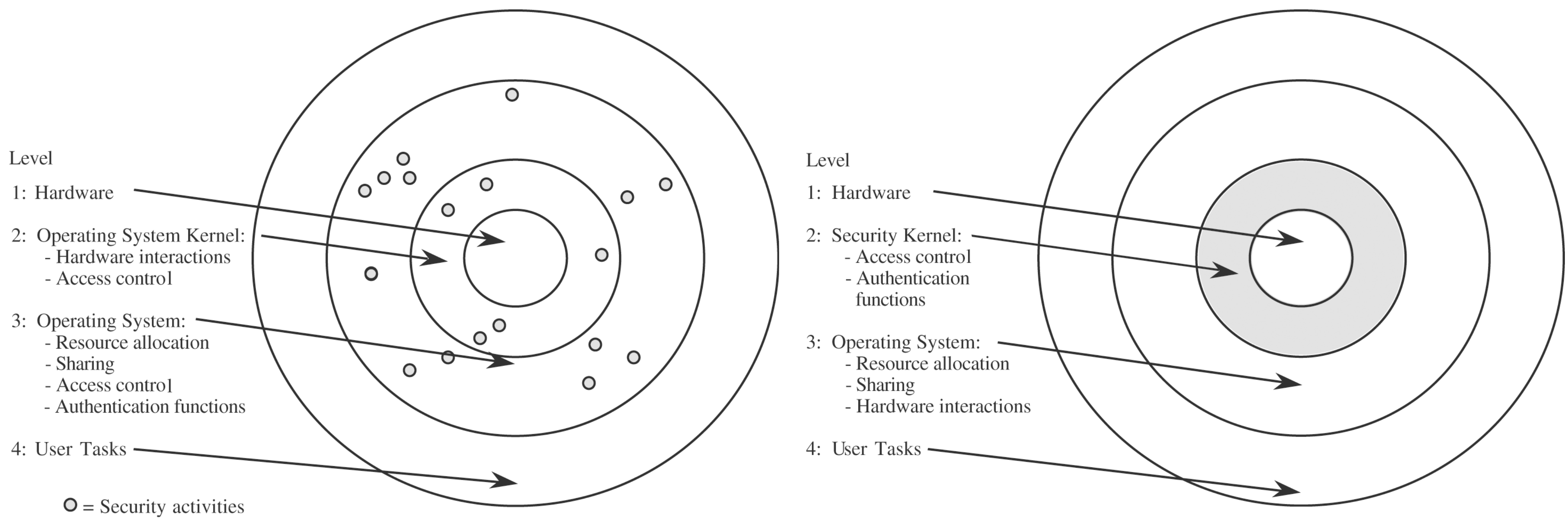


Pfleeger/Pfleeger Fig. 05-12 rev 9/30/02

Trusted Computing Base (TCB)

- Everything in a trusted OS necessary to enforce the security policy
  - Trust in the security of the whole system depends on the TCB
  - Non-TCB part can be malicious w/o affecting security enforcement
- Usually include:
  - Hardware
  - Protected memory
  - Some notion of processes and IPC
  - Primitive files (security-related)

TCB Implementation



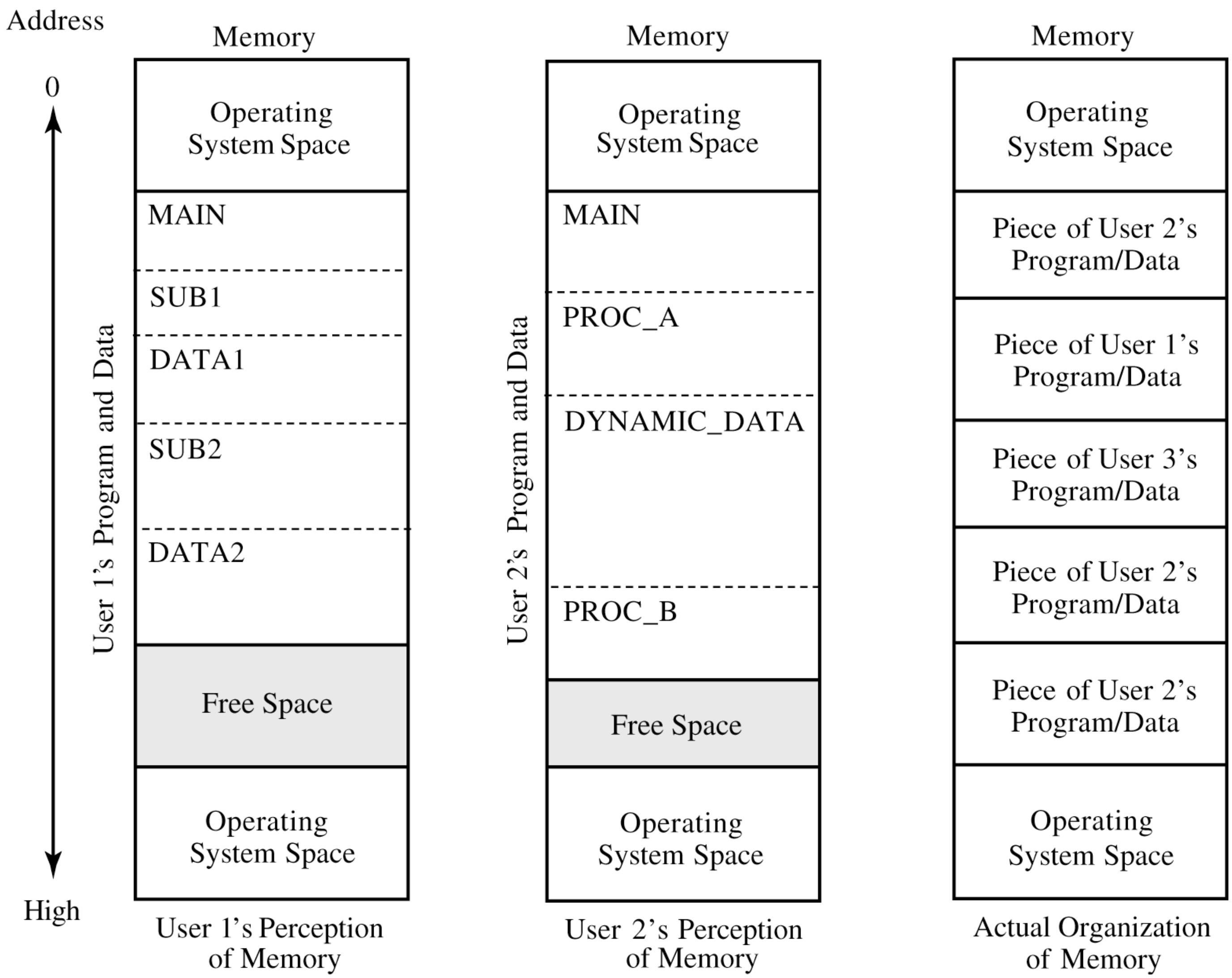
Separation

- Physical separation
- Temporal separation
- Cryptographic separation
- Logical separation

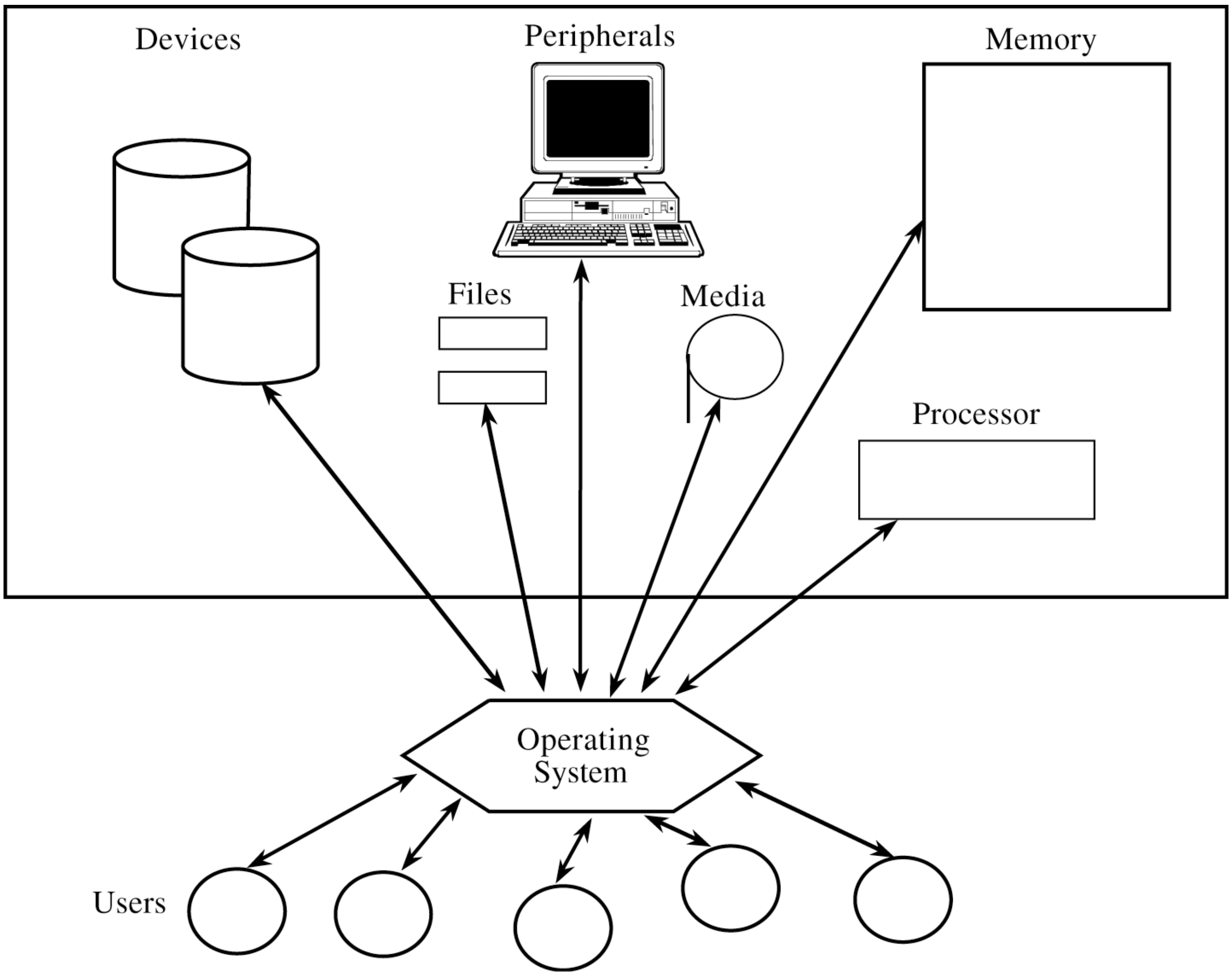
Virtualization

- Multiple Virtual Memory Spaces
- Virtual Machines

Multiple Virtual Memory Spaces



Virtual Machines



Virtual Machines