

# Chapter 14: Protection

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- Goals of Protection
- Principles of Protection
- Domain of Protection
- Access Matrix
- Implementation of Access Matrix
- Access Control
- Revocation of Access Rights
- Capability-Based Systems
- Language-Based Protection





# Objectives

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- Discuss the goals and principles of protection in a modern computer system
- Explain how protection domains combined with an access matrix are used to specify the resources a process may access
- Examine capability and language-based protection systems





# Goals of Protection

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- In one protection model, computer consists of a collection of objects, hardware or software
- Each object has a unique name and can be accessed through a well-defined set of operations
- Protection problem - ensure that each object is accessed correctly and only by those processes that are allowed to do so





# Principles of Protection

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- Guiding principle – **principle of least privilege**
  - Programs, users and systems should be given just enough **privileges** to perform their tasks
  - Limits damage if entity has a bug, gets abused
  - Can be static (during life of system, during life of process)
  - Or dynamic (changed by process as needed) – **domain switching, privilege escalation**
  - “Need to know” a similar concept regarding access to data





# Principles of Protection (Cont.)

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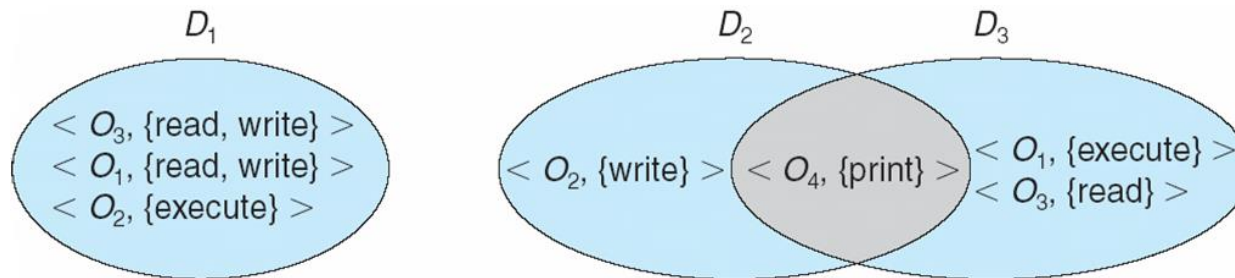
- Must consider “grain” aspect
  - Rough-grained privilege management easier, simpler, but least privilege now done in large chunks
    - ▶ For example, traditional Unix processes either have abilities of the associated user, or of root
  - Fine-grained management more complex, more overhead, but more protective
    - ▶ File ACL lists, RBAC
- Domain can be user, process, procedure





# Domain Structure

- Access-right =  $\langle \text{object-name}, \text{rights-set} \rangle$   
where *rights-set* is a subset of all valid operations that can be performed on the object
- Domain = set of access-rights





# Domain Implementation (UNIX)

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- Domain = user-id
- Domain switch accomplished via file system
  - ▶ Each file has associated with it a domain bit (setuid bit)
  - ▶ When file is executed and setuid = on, then user-id is set to owner of the file being executed
  - ▶ When execution completes user-id is reset
- Domain switch accomplished via passwords
  - `su` command temporarily switches to another user's domain when other domain's password provided
- Domain switching via commands
  - `sudo` command prefix executes specified command in another domain (if original domain has privilege or password given)

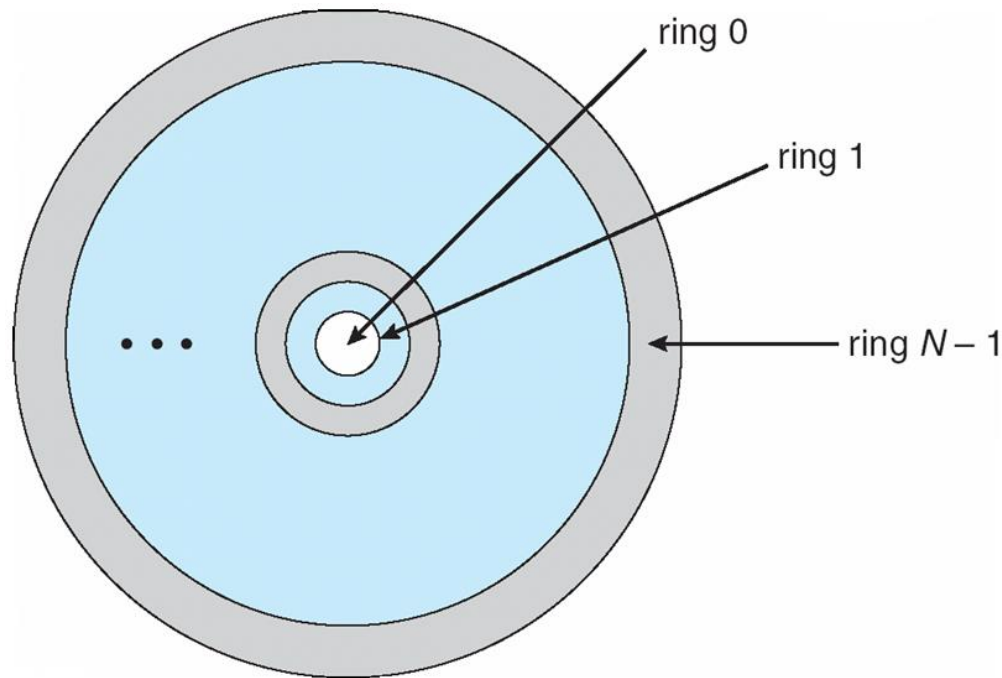






# Domain Implementation (MULTICS)

- Let  $D_i$  and  $D_j$  be any two domain rings
- If  $j < i \Rightarrow D_i \subseteq D_j$





# Multics Benefits and Limits

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- Ring / hierarchical structure provided more than the basic kernel / user or root / normal user design
- Fairly complex -> more overhead
- But does not allow strict need-to-know
  - Object accessible in  $D_j$  but not in  $D_i$ , then  $j$  must be  $< i$
  - But then every segment accessible in  $D_i$  also accessible in  $D_j$





# Access Matrix

- View protection as a matrix (**access matrix**)
- Rows represent domains
- Columns represent objects
- **Access**( $i, j$ ) is the set of operations that a process executing in  $\text{Domain}_i$  can invoke on  $\text{Object}_j$

domain \ object	$F_1$	$F_2$	$F_3$	printer
$D_1$	read		read	
$D_2$				print
$D_3$		read	execute	
$D_4$	read write		read write	





# Use of Access Matrix

- If a process in Domain  $D_i$  tries to do “op” on object  $O_j$ , then “op” must be in the access matrix
- User who creates object can define access column for that object
- Can be expanded to dynamic protection
  - Operations to add, delete access rights
  - Special access rights:
    - ▶ *owner of  $O_i$*
    - ▶ *copy op from  $O_i$  to  $O_j$  (denoted by “\*”)*
    - ▶ *control –  $D_i$  can modify  $D_j$  access rights*
    - ▶ *transfer – switch from domain  $D_i$  to  $D_j$*
  - *Copy and Owner* applicable to an object
  - *Control* applicable to domain object





# Use of Access Matrix (Cont.)

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- **Access matrix** design separates mechanism from policy
  - Mechanism
    - ▶ Operating system provides access-matrix + rules
    - ▶ If ensures that the matrix is only manipulated by authorized agents and that rules are strictly enforced
  - Policy
    - ▶ User dictates policy
    - ▶ Who can access what object and in what mode
- But doesn't solve the general confinement problem





# Access Matrix of Figure A with Domains as Objects

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
$D_3$		read	execute					
$D_4$	read write		read write		switch			





# Access Matrix with Copy Rights

<div>object</div> <div>domain</div>	$F_1$	$F_2$	$F_3$
$D_1$	execute		write*
$D_2$	execute	read*	execute
$D_3$	execute		

(a)

<div>object</div> <div>domain</div>	$F_1$	$F_2$	$F_3$
$D_1$	execute		write*
$D_2$	execute	read*	execute
$D_3$	execute	read	

(b)





# Access Matrix With Owner Rights

object domain	$F_1$	$F_2$	$F_3$
$D_1$	owner execute		write
$D_2$		read* owner	read* owner write
$D_3$	execute		

(a)

object domain	$F_1$	$F_2$	$F_3$
$D_1$	owner execute		write
$D_2$		owner read* write*	read* owner write
$D_3$		write	write

(b)







# Modified Access Matrix of Figure B

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			





# Implementation of Access Matrix

- Generally, a sparse matrix
- Option 1 – Global table
  - Store ordered triples **<domain, object, rights-set>** in table
  - A requested operation  $M$  on object  $O_j$  within domain  $D_i$  -> search table for  $\langle D_i, O_j, R_k \rangle$ 
    - ▶ with  $M \in R_k$
  - But table could be large -> won't fit in main memory
  - Difficult to group objects (consider an object that all domains can read)





# Implementation of Access Matrix (Cont.)

- Option 2 – Access lists for objects
  - Each column implemented as an access list for one object
  - Resulting per-object list consists of ordered pairs **<domain, rights-set>** defining all domains with non-empty set of access rights for the object
  - Easily extended to contain default set -> If  $M \in \text{default set}$ , also allow access





# Implementation of Access Matrix (Cont.)

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- Each column = Access-control list for one object  
Defines who can perform what operation

Domain 1 = Read, Write  
Domain 2 = Read  
Domain 3 = Read

- Each Row = Capability List (like a key)  
For each domain, what operations allowed on what objects
  - Object F1 – Read
  - Object F4 – Read, Write, Execute
  - Object F5 – Read, Write, Delete, Copy





# Implementation of Access Matrix (Cont.)

- Option 3 – Capability list for domains
  - Instead of object-based, list is domain based
  - **Capability list** for domain is list of objects together with operations allows on them
  - Object represented by its name or address, called a **capability**
  - Execute operation  $M$  on object  $O_j$ , process requests operation and specifies capability as parameter
    - ▶ Possession of capability means access is allowed
  - Capability list associated with domain but never directly accessible by domain
    - ▶ Rather, protected object, maintained by OS and accessed indirectly
    - ▶ Like a “secure pointer”
    - ▶ Idea can be extended up to applications





# Implementation of Access Matrix (Cont.)

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- Option 4 – Lock-key
  - Compromise between access lists and capability lists
  - Each object has list of unique bit patterns, called **locks**
  - Each domain as list of unique bit patterns called **keys**
  - Process in a domain can only access object if domain has key that matches one of the locks





# Comparison of Implementations

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- Many trade-offs to consider
  - Global table is simple, but can be large
  - Access lists correspond to needs of users
    - ▶ Determining set of access rights for domain non-localized so difficult
    - ▶ Every access to an object must be checked
      - Many objects and access rights -> slow
  - Capability lists useful for localizing information for a given process
    - ▶ But revocation capabilities can be inefficient
  - Lock-key effective and flexible, keys can be passed freely from domain to domain, easy revocation





# Comparison of Implementations (Cont.)

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- Most systems use combination of access lists and capabilities
  - First access to an object -> access list searched
    - ▶ If allowed, capability created and attached to process
      - Additional accesses need not be checked
    - ▶ After last access, capability destroyed
    - ▶ Consider file system with ACLs per file

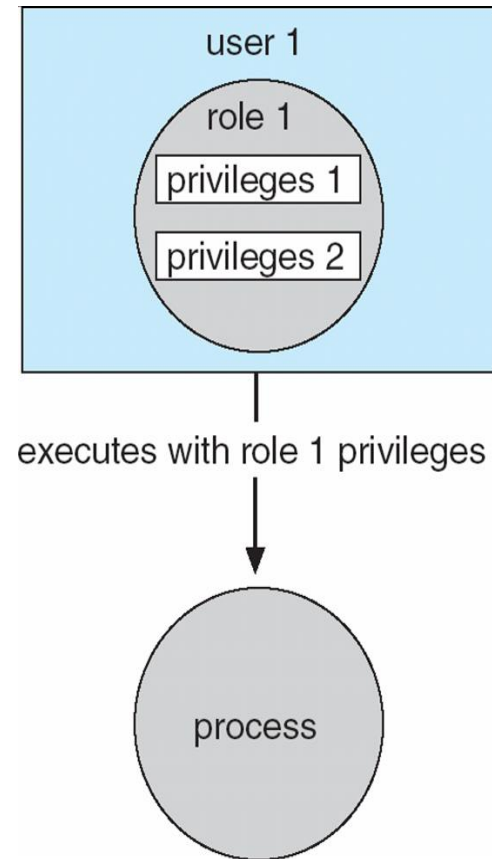






# Access Control

- Protection can be applied to non-file resources
- Oracle Solaris 10 provides **role-based access control (RBAC)** to implement least privilege
  - **Privilege** is right to execute system call or use an option within a system call
  - Can be assigned to processes
  - Users assigned **roles** granting access to privileges and programs
    - ▶ Enable role via password to gain its privileges
  - Similar to access matrix





# Revocation of Access Rights

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- Various options to remove the access right of a domain to an object
  - Immediate vs. delayed
  - Selective vs. general
  - Partial vs. total
  - Temporary vs. permanent
- **Access List** – Delete access rights from access list
  - **Simple** – search access list and remove entry
  - **Immediate, general or selective, total or partial, permanent or temporary**





# Revocation of Access Rights (Cont.)

- **Capability List** – Scheme required to locate capability in the system before capability can be revoked
  - **Reacquisition** – periodic delete, with require and denial if revoked
  - **Back-pointers** – set of pointers from each object to all capabilities of that object (Multics)
  - **Indirection** – capability points to global table entry which points to object – delete entry from global table, not selective (CAL)
  - **Keys** – unique bits associated with capability, generated when capability created
    - ▶ Master key associated with object, key matches master key for access
    - ▶ Revocation – create new master key
    - ▶ Policy decision of who can create and modify keys – object owner or others?





# Capability-Based Systems

- Hydra
  - Fixed set of access rights known to and interpreted by the system
    - ▶ i.e. read, write, or execute each memory segment
    - ▶ User can declare other **auxiliary rights** and register those with protection system
    - ▶ Accessing process must hold capability and know name of operation
    - ▶ **Rights amplification** allowed by trustworthy procedures for a specific type
  - Interpretation of user-defined rights performed solely by user's program; system provides access protection for use of these rights
  - Operations on objects defined procedurally – procedures are objects accessed indirectly by capabilities
  - Solves the *problem of mutually suspicious subsystems*
  - Includes library of prewritten security routines





# Capability-Based Systems (Cont.)

- Cambridge CAP System
  - Simpler but powerful
  - **Data capability** - provides standard read, write, execute of individual storage segments associated with object – implemented in microcode
  - **Software capability** -interpretation left to the subsystem, through its protected procedures
    - ▶ Only has access to its own subsystem
    - ▶ Programmers must learn principles and techniques of protection





# Language-Based Protection

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- Specification of protection in a programming language allows the high-level description of policies for the allocation and use of resources
- Language implementation can provide software for protection enforcement when automatic hardware-supported checking is unavailable
- Interpret protection specifications to generate calls on whatever protection system is provided by the hardware and the operating system





# Protection in Java 2

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- Protection is handled by the Java Virtual Machine (JVM)
- A **class** is assigned a protection domain when it is loaded by the JVM
- The protection domain indicates what operations the class can (and cannot) perform
- If a library **method** is invoked that performs a privileged operation, the stack is **inspected** to ensure the operation can be performed by the library
- Generally, Java's load-time and run-time checks enforce **type safety**
- Classes effectively **encapsulate** and protect data and methods from other classes





# Stack Inspection

protection domain:	untrusted applet	URL loader	networking
socket permission:	none	*.lucent.com:80, connect	any
class:	gui: ... get(url); open(addr); ...	get(URL u): ... doPrivileged { open('proxy.lucent.com:80'); } <request u from proxy> ...	open(Addr a): ... checkPermission (a, connect); connect (a); ...





# End of Chapter 14

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