

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

- 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

- 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

- 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.)

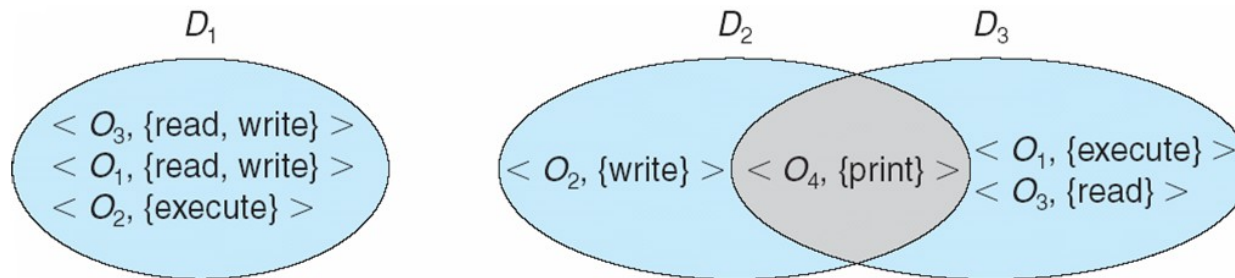
- Must consider “grain” aspect
 - Rough-grained privilege management easier, simpler, but least privilege now done in large chunks
 - ▶ For example, traditional Unix processes either have abilities of the associated user, or of root
 - Fine-grained management more complex, more overhead, but more protective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

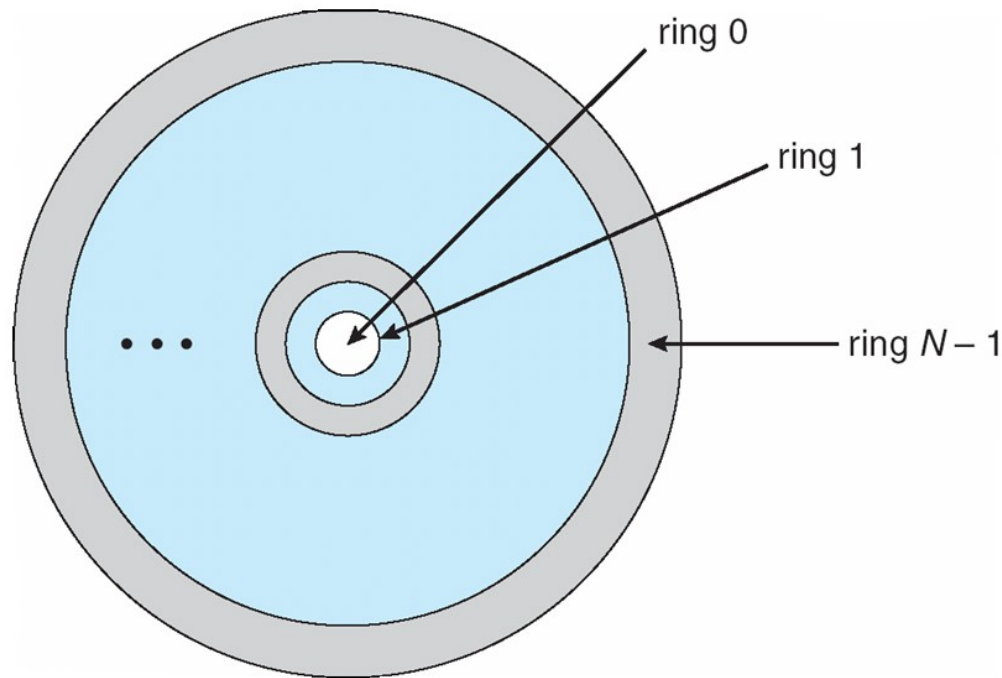
- Domain = user-id
- Domain switch accomplished via file system
 - ▶ Each file has associated with it a domain bit (setuid bit)
 - ▶ When file is executed and setuid = on, then user-id is set to owner of the file being executed
 - ▶ When execution completes user-id is reset
- Domain switch accomplished 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

- 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 Domain $_i$ can invoke on 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.)

- **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

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

(a)

domain \ object	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 $D_i \rightarrow$ search table for $\langle D_i, O_j, R_k \rangle$
 - ▶ with $M \in R_k$
 - But table could be large \rightarrow 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.)

- 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.)

- 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

- 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.)

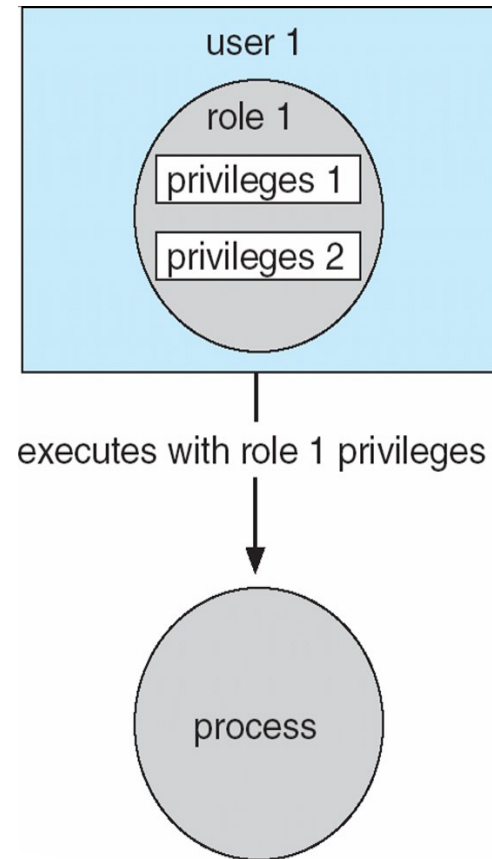
- Most systems use combination of access lists and capabilities
 - First access to an object -> access list searched
 - ▶ If allowed, capability created and attached to process
 - Additional accesses need not be checked
 - ▶ After last access, capability destroyed
 - ▶ Consider file system with ACLs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

- 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

- 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

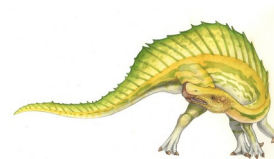
- Protection is handled by the Java Virtual Machine (JVM)
- A **class** is assigned a protection domain when it is loaded by the JVM
- The protection domain indicates what operations the class can (and cannot) perform
- If a library **method** is invoked that performs a privileged operation, the stack 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

