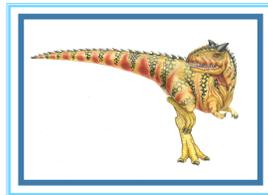# Chapter 14: Protection

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Chapter 14: Protection

- 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
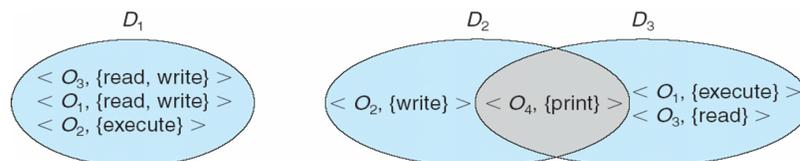
Principles of Protection

- 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

- 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 = *<object-name, rights-set>*
  where *rights-set* is a subset of all valid operations that can be performed on the object

- Domain = set of access-rights

$$D_1$$
$< O_3, \{read, write\} >$
$< O_1, \{read, write\} >$
$< O_2, \{execute\} >$

$$D_2 \qquad D_3$$
$< O_2, \{write\} > \quad < O_4, \{print\} > \quad < O_1, \{execute\} >$
$< O_3, \{read\} >$

3

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 $j < I \Rightarrow D_i \subseteq D_j$
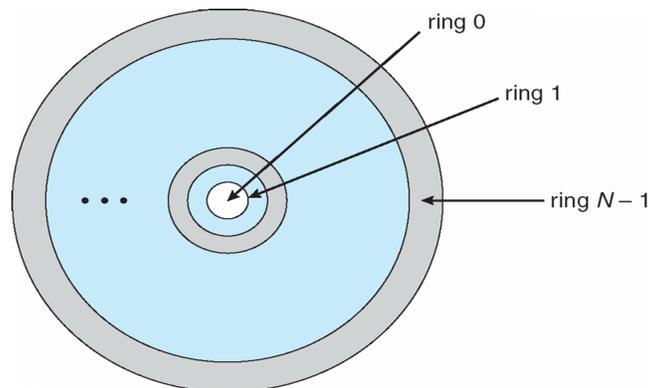
Multics Benefits and Limits

- 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$_j$

Access Matrix

object → domain ↓	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

object \\ domain	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			

7

Access Matrix with *Copy* Rights

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

(a)

object domain	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)

8
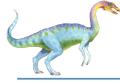
Modified Access Matrix of Figure B

object domain	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 < D_i, O_j, R_k >
    - 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)

- 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 $\in$ default set, also allow access

■ 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

■ 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

- 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

- 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

Role-based Access Control in Solaris 10
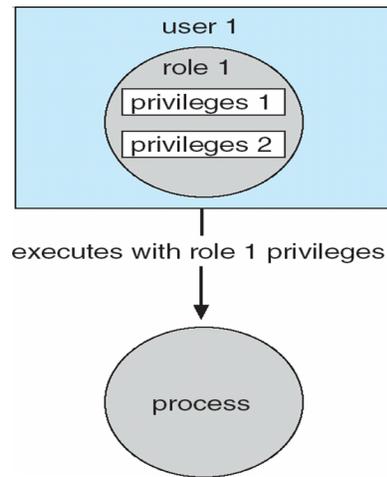
Revocation of Access Rights

- 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
- **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
- 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

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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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