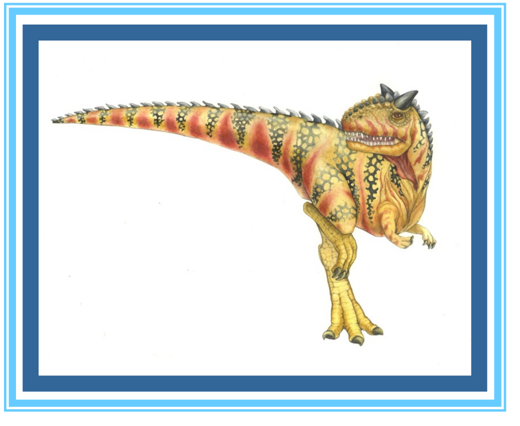
Chapter 17: Protection



Chapter 17: Protection

- Goals of Protection
- Principles of Protection
- Protection Rings
- Domain of Protection
- Access Matrix
- Implementation of Access Matrix

Objectives

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

Goals of Protection

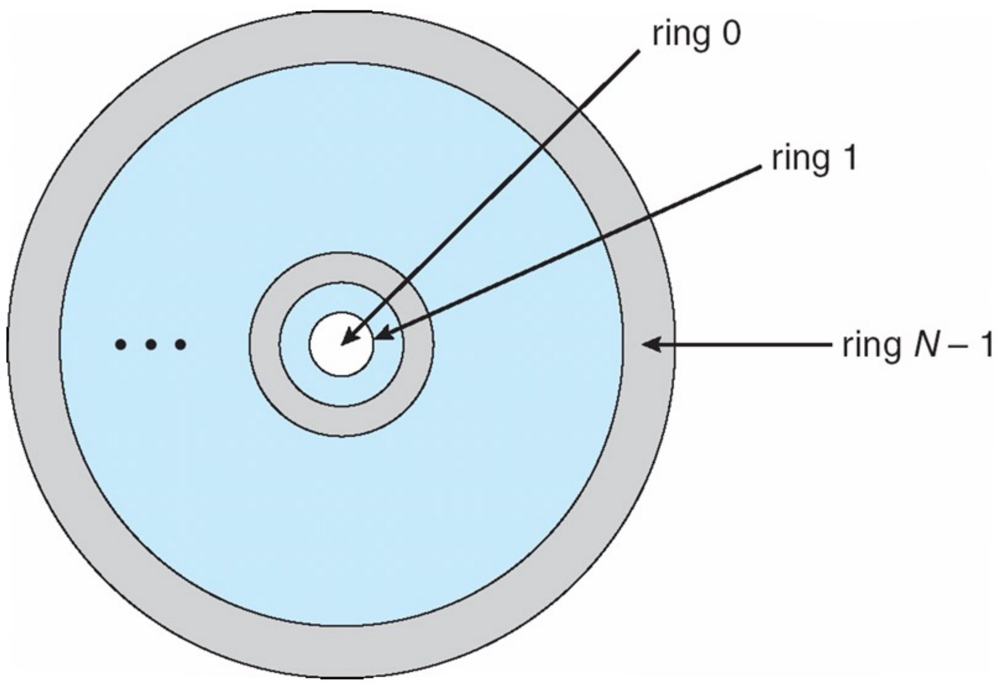
- In a protection model, computer system consists of a collection of **objects**, hardware or software
  - Hardware objects: CPU, memory segments, printers, disks, and tape
  - Software objects: files, programs, and semaphores
- Each object has a unique name and can be accessed through a well-defined set of operations
- **Protection problem** is to ensure that each object is accessed correctly and only by those processes allowed to do so
- Mechanisms are distinct from policies, in which mechanisms determine how something will be done, and policies decide what will be done.
  - The separation is important for **flexibility**, as policies are likely to change from place to place or from time to time.
  - The separation ensures that not every change in policy would require a change in the underlying mechanism.

Principles of Protection

- The guiding principle – **principle of least privilege**
  - Programs, users and systems should be given just enough privileges to perform their tasks - mitigate the attack
  - In file permissions, this principle dictates that a user have read access but not write or execute access to a file. The principle of least privilege would require that the OS provides a mechanism to only allow read access but not write or execute access
- Properly set permissions (i.e., the access rights to an object) can limit damage if entity has a bug or gets abused

Protection Rings

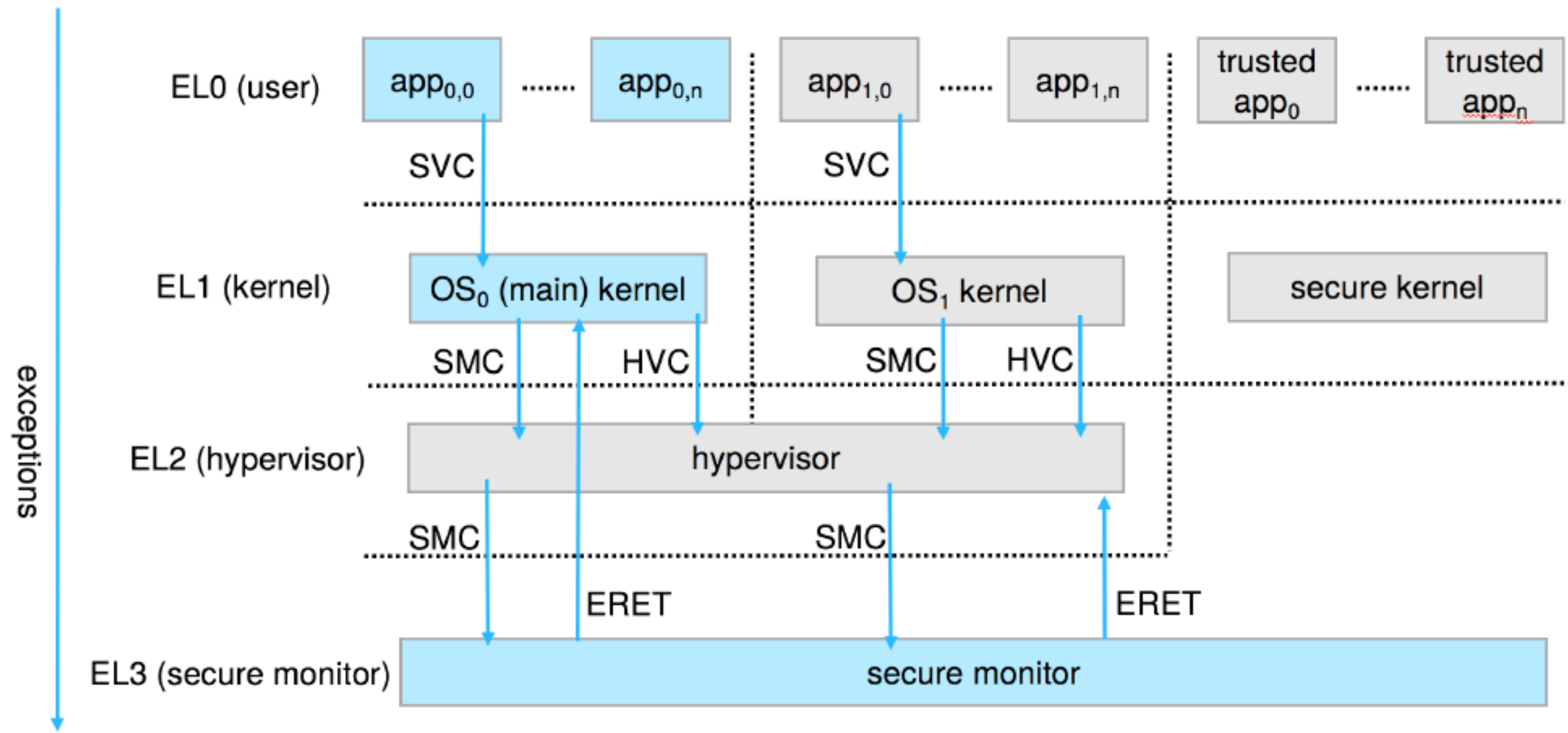
- **User mode** and **kernel mode** – privilege separation
- Hardware support required to support the notion of separate execution
- Let D_i and D_j be any two domain rings
- If $j < i \Rightarrow D_i \subseteq D_j$
- The innermost ring, ring 0, provides the full set of privileges



Protection Rings (Cont.)

- Components ordered by amount of privilege and protected from each other
  - For example, the kernel is in one ring and user applications in another
  - This privilege separation requires hardware support
  - "Gates" used to transfer between rings, for example the syscall Intel instruction, also traps and interrupts
- **Hypervisors** (Intel) is introduced (another ring) - virtual machine managers, which create and run virtual machines, and have more capabilities than the kernels of the guest operating systems
- ARM processors added **TrustZone** or **TZ** ring to protect crypto functions with access (more privileged than kernel)
  - This most privileged execution environment has exclusive access to hardware-backed cryptographic features, such as the NFC Secure Element and an on-chip cryptographic key, that make handling passwords and sensitive information more secure.

ARM CPU Architecture



Domain of Protection

- Protection rings separate functions into different domains and order them hierarchically
- **Domain** can be considered as a generalization of rings without a **hierarchy**
- A computer system can be treated as processes and objects
  - Hardware objects (such as CPU, memory, disk) and software objects (such as files, programs, semaphores)
- Process for example should only have access to objects it currently requires to complete its task – the need-to-know principle (policy)
- Implementation can be via process operating in a protection domain
  - Protection domain specifies the set of resources a process may access
  - Each domain specifies set of objects and types of operations may be invoked on each object

Domain of Protection (Cont.)

- Ability to execute an operation on an object is an **access right**
- A domain is a collection of access rights, each of which is an ordered pair <object-name, rights-set>
  - An example: if domain D has the access right <file F, {read,write}>, then a process executing in domain D can both read and write file F. It cannot, however, perform any other operation on that object.
- Domains may share access rights
- Associations between processes and domains can be static if the set of resources available to the process is fixed throughout the process's lifetime, or can be dynamic
- If dynamic, a mechanism is available to allow domain switching, enabling the process to switch from one domain to another during different stage of execution

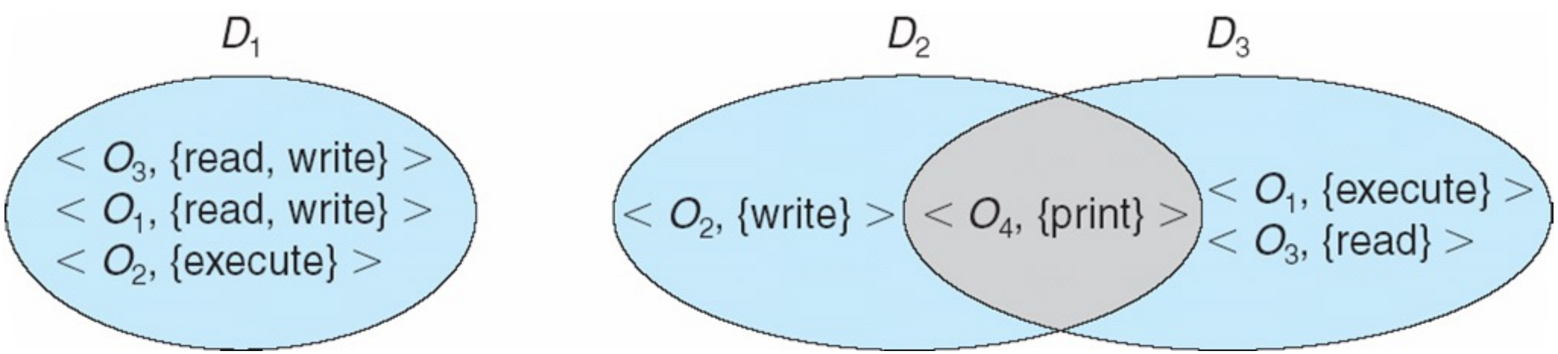
Domain of Protection (Cont.)

Domain can be realized in a variety of ways:

- Each user may be a domain - the set of objects that can be accessed depends on the identity of the user. Domain switching occurs when the user is changed
- Each process may be a domain - the set of objects that can be accessed depends on the identity of the process. Domain switching occurs when one process sends a message to another process and then waits for a response.
- Each procedure may be a domain - the set of objects that can be accessed corresponds to the local variables defined within the procedure. Domain switching occurs when a procedure call is made

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
- The access right <O4, {print}> shared by domains D2 and D3, thus, a process executing in either of these two domains can print object O4.



Access Matrix

- View protection as a matrix (**access matrix**)
- **Rows** represent domains, and **columns** represent objects
- **Access(i,j)** consists of a set of access rights - 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

- The **access matrix** scheme provides the mechanism for specifying a variety of policies - mechanism and policy separation
- The mechanism consists of implementing the access matrix and ensuring that the semantic properties hold.
  - To ensure that a process executing in domain D_i can access only those objects specified in row i.
- The policy decisions specify which rights should be included in the (i,j)th entry, and determine the domain in which each process executes
- 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 an object can define access column for that object
  - When a user creates a new object O_j , the column O_j is added to the access matrix with the appropriate initialization entries, as dictated by the creator. The user may decide to enter some rights in some entries in column j and other rights in other entries, as needed.

Use of Access Matrix (Cont.)

This can be expanded to dynamic protection

- Operations to add, delete access rights
- Special access rights:
  - owner of O_i - can add and remove any right in any entry in column
  - copy op from O_i to O_j (denoted by "*") - only within the column (that is, for the object)
  - control – D_i can modify D_j access rights – modify domain objects (a row)
  - transfer – switch from domain D_i to D_j
- Copy and Owner applicable to an object - change the entries in a column
- Control applicable to domain object - change the entries in a row
- New objects and new domains can be created dynamically and included in the access-matrix model
- In a dynamic protection system, we may sometimes need to revoke access rights to objects shared by different users – revocation of access right

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

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)

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

- In general, the access matrix is sparse; that is, most of the entries will be empty
- **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 the table could be large -> might not fit in main memory, requires additional I/O – virtual memory techniques are often used
  - Difficult to group objects - For example, if everyone can read a particular object, this object must have a separate entry in every domain.

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 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
  - Obviously, the empty entries can be discarded.
  - This can be easily extended to define **default** set of access rights -> If M ∈ default set, also allow access (for all domains)

Implementation of Access Matrix (Cont.)

- **Option 3** – **Capability list for domains**
  - Instead of object-based, list is domain-based
  - A capability list for domain is a list of objects together with operations allowed on them
  - An object represented by its name or address, called a **capability**
  - To execute operation M on object O_j, a process requests operation M, specifying the capability (or pointer) for object O_j as a parameter
  - Possession of capability means access is allowed
- Capability list associated with a domain, but never directly accessible by a process executing in that domain
  - Rather, the capability list itself is a protected object, maintained by OS and accessed by users only indirectly
  - This avoids the possibility of capability list modification by users
  - If all capabilities are secure, the object they protect is also secure against unauthorized access

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 of the object
  - As with capability lists, the list of keys for a domain must be managed by the operating system on behalf of the domain.
  - Users are not allowed to examine or modify the list of keys (or locks) directly.

Comparison of Implementations

Choosing a technique for implementing an access matrix involves various trade-offs.

- Global table is simple, but large, lack of grouping of objects or domains
- Access lists correspond directly to the needs of users
  - An access list on an object is specified when a user creates the object
  - Determining set of access rights for each domain is difficult - every access to the object must be checked, requiring a search of the access list.
- Capability lists useful for localizing information for a given process
  - But revocation capabilities can be inefficient
- Lock-key can be effective and flexible depending on the length of the keys
  - Keys can be passed freely from domain to domain, easy revocation
- Most systems use combination of access lists and capabilities

End of Chapter 17