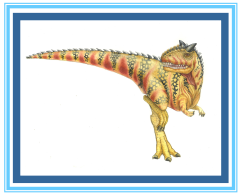
# Chapter 17: Protection





## 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



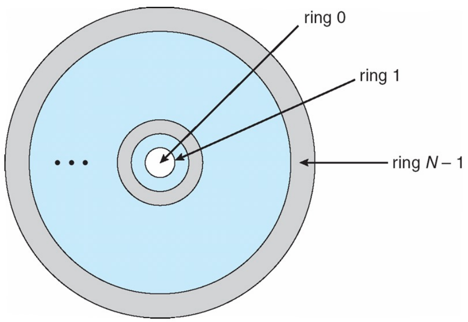
# Principles of Protection (Cont.)

- **Audit trail** –the collection of activities in a log for monitoring review
  - An audit trail is a record in the system logs
  - It can reveal early warnings of an attack or provide clues as to which attack were used and assess the damage caused
- No single principle is a panacea for security vulnerabilities – need **defense in depth**
  - The theory states more layers of defense provide stronger defense than fewer layers



# 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

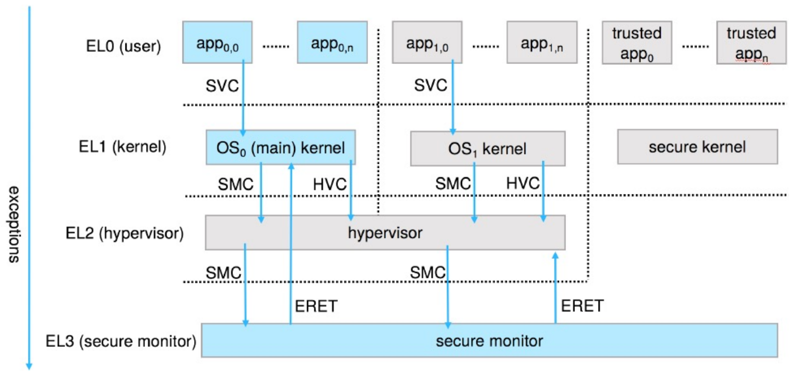





# Protection Rings (Cont.)

- 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



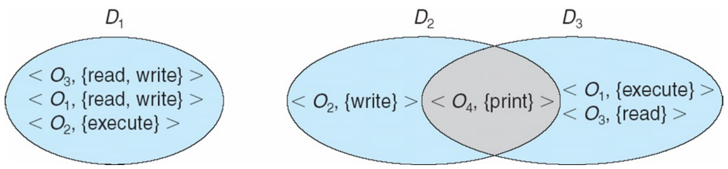
# Domain of Protection (Cont.)

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 $\text{Domain}_i$ 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<br>write | | read<br>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<br>write | | read<br>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

| domain \ object | $F_1$ | $F_2$ | $F_3$ |
|---|---|---|---|
| $D_1$ | owner<br>execute | | write |
| $D_2$ | | read*<br>owner | read*<br>owner<br>write |
| $D_3$ | execute | | |

(a)

| domain \ object | $F_1$ | $F_2$ | $F_3$ |
|---|---|---|---|
| $D_1$ | owner<br>execute | | write |
| $D_2$ | | owner<br>read*<br>write* | read*<br>owner<br>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<br>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 $M \in$ 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