Protection
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

- Operating system 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 privilege to perform their tasks
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
Domain Implementation (UNIX)

- System consists of 2 domains:
  - User
  - Supervisor

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

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

- View protection as a matrix (*access matrix*), $\text{Access}[i,j]$

- Rows represent domains

- Columns represent objects

- $\text{Access}[i, j]$ is the set of operations that a process executing in Domain$_i$ can invoke on Object$_j$
## Access Matrix

<table>
<thead>
<tr>
<th>domain</th>
<th>object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
<th>printer</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td></td>
<td>read</td>
<td></td>
<td>read</td>
<td></td>
</tr>
<tr>
<td>$D_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>print</td>
</tr>
<tr>
<td>$D_3$</td>
<td></td>
<td></td>
<td>read</td>
<td>execute</td>
<td></td>
</tr>
<tr>
<td>$D_4$</td>
<td></td>
<td>read write</td>
<td></td>
<td>read write</td>
<td></td>
</tr>
</tbody>
</table>

**Figure A**
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.

- 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 $O_j$
    - control – $D_i$ can modify $D_j$‘s access rights
    - transfer – switch from domain $D_i$ to $D_j$
Use of Access Matrix (Cont.)

- Access matrix design separates mechanism from policy.
  - **Mechanism**
    - Operating system provides access-matrix + rules.
    - It 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.
Implementation of Access Matrix

• Each column is an **Access-control list** for one object

  Defines who can perform what operation on that object.
  
  Domain 1 = Read, Write  
  Domain 2 = Read  
  Domain 3 = Read  
  ...  

• Each Row is a **Capability List** for one domain

  For a given domain, what operations are allowed on each object.
  
  Object 1 – Read  
  Object 4 – Read, Write, Execute  
  Object 5 – Read, Write, Delete, Copy
### Access Matrix of Figure A With Domains as Objects

<table>
<thead>
<tr>
<th>Domain</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
<th>Laser Printer</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>read</td>
<td>read</td>
<td></td>
<td></td>
<td>switch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_2$</td>
<td></td>
<td></td>
<td></td>
<td>print</td>
<td>switch</td>
<td>switch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_3$</td>
<td></td>
<td>read</td>
<td>execute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D_4$</td>
<td>read</td>
<td>write</td>
<td>read</td>
<td>write</td>
<td>switch</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure B**
## Access Matrix with Copy Rights

<table>
<thead>
<tr>
<th>domain</th>
<th>object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>execute</td>
<td></td>
<td>write*</td>
<td></td>
</tr>
<tr>
<td>$D_2$</td>
<td>execute</td>
<td>read*</td>
<td>execute</td>
<td></td>
</tr>
<tr>
<td>$D_3$</td>
<td>execute</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D2 has copy rights to F2 and can add this right (without the copy right) for any other domain in this column.

<table>
<thead>
<tr>
<th>domain</th>
<th>object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>execute</td>
<td></td>
<td>write*</td>
<td></td>
</tr>
<tr>
<td>$D_2$</td>
<td>execute</td>
<td>read*</td>
<td>execute</td>
<td></td>
</tr>
<tr>
<td>$D_3$</td>
<td>execute</td>
<td>read</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a)

(b)
### Access Matrix With Owner Rights

**Table (a):**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td></td>
<td>owner execute</td>
<td></td>
<td>write</td>
</tr>
<tr>
<td>$D_2$</td>
<td></td>
<td>read* owner</td>
<td>read* owner</td>
<td>write</td>
</tr>
<tr>
<td>$D_3$</td>
<td></td>
<td>execute</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table (b):**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td></td>
<td>owner execute</td>
<td></td>
<td>write</td>
</tr>
<tr>
<td>$D_2$</td>
<td></td>
<td>owner read* write*</td>
<td>read* owner</td>
<td>write</td>
</tr>
<tr>
<td>$D_3$</td>
<td></td>
<td>write</td>
<td></td>
<td>write</td>
</tr>
</tbody>
</table>

D$_2$ is owner of F$_2$ and F$_3$ and can add or remove any valid right within these two columns.
### Modified Access Matrix of Figure B

<table>
<thead>
<tr>
<th></th>
<th>object</th>
<th>$F_1$</th>
<th>$F_2$</th>
<th>$F_3$</th>
<th>laser printer</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>domain</td>
<td>$D_1$</td>
<td>read</td>
<td>read</td>
<td></td>
<td></td>
<td>switch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$D_2$</td>
<td></td>
<td></td>
<td>print</td>
<td></td>
<td></td>
<td>switch</td>
<td>switch</td>
<td>control</td>
</tr>
<tr>
<td></td>
<td>$D_3$</td>
<td>read</td>
<td>execute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$D_4$</td>
<td>write</td>
<td>write</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Process executing in $D_2$ has modified $D_4$’s rights to $F_1$ and $F_3$
Access Control

- Protection can be applied to non-file resources
- Solaris 10 provides role-based access control 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
Role-based Access Control in Solaris 10

user 1

role 1

privileges 1

privileges 2

executes with role 1 privileges

process
Revocation of Access Rights

- **Access List** – Delete access rights from access list.
  - Simple
  - Immediate

- **Capability List** – Scheme required to locate capability in the system before capability can be revoked.
  - Reacquisition
  - Back-pointers
  - Indirection
  - Keys
Capability-Based Systems

- Hydra
  - Fixed set of access rights known to and interpreted by the system.
  - Interpretation of user-defined rights performed solely by user's program; system provides access protection for use of these rights.

- Cambridge CAP System
  - Data capability - provides standard read, write, execute of individual storage segments associated with object.
  - Software capability - interpretation left to the subsystem, through its protected procedures.
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.