CISC 3320

C30a Protection: Domain and Access Matrix

Hui Chen

Department of Computer & Information Science

CUNY Brooklyn College

Acknowledgement

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Outline

- Goals of Protection
- Principles of Protection
- Domain of Protection
- Access Matrix
- Implementation of Access Matrix
- Revocation of Access Rights

Security and Protection

- Security systems
  - authenticate system users to protect the integrity of program code, data, and the physical resources of the computer system.
  - prevent unauthorized access, malicious destruction or alteration of data, and accidental introduction of inconsistency.
- Protection mechanisms
  - controls the access of programs, processes, or users to the resources defined by a computer system.

Protection Model: Process & Objects

- A 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
  - Processes carry out the operations
  - Hardware objects (such as devices)
  - Software objects (such as files, programs, semaphores)
- Process should only have *currently required types of access* to *currently required objects* to complete its task
  - the least-privilege principle
  - the need-to-know principle

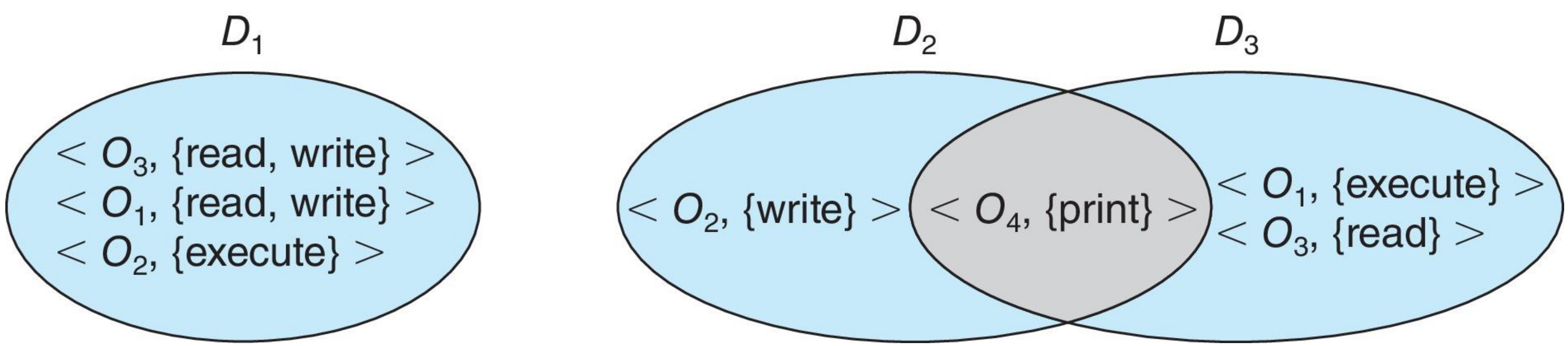
Domain of Protection

- A process may operate within a protection domain that specifies the resources that the process may access.
- Example
  - Ability to execute an operation on an object is an access right
    - Example operation: read, write, execute, list
  - A domain can be defined as a collection of access rights
    - each of which is an ordered pair <object-name, rights-set>.
  - A process is associated with a domain
    - Associations can be **static** or **dynamic**
    - If dynamic, processes can **switch domains**

Examples of Protection Domain

- Domain = set of access-rights
- *Access-right = <object-name, rights-set>*
- *Rights-set* is a subset of all valid operations that can be performed on the object
- Example
    - 3 domains below

Example: 3 Domains



Representing Protection Domain: Access Matrix

- View protection as a matrix, called Access Matrix or Access Control 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 $Object_j$
- A domain is associated with a process in the process-object model

Access Matrix: Example

- A process associated with D_i will have the specified rights for the specified objects

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

- Associate a process with a domain (a process is in/is executing in/enters the domain)
- 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

Access Matrix: Policy & Mechanism

- 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

Access Matrix: Dynamic Protection

- Can be expanded to dynamic protection (domain switch)
  - Operations to add, delete access rights
  - Special access rights:
    - *transfer – switch from domain D_i to D_j*
    - *owner of O_i*
    - *copy op from O_i to O_j (denoted by "*")*
    - *control – D_i can modify D_j access rights*
  - *Copy* and *Owner* applicable to an object
  - *Control* applicable to domain object

Access Matrix Domain Switch: Example

- A process in D_2 can enter/switch to D_3 or D_4

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			

Copy Right

- The ability to copy an access right from one domain (or row) of the access matrix to another
- denoted by an asterisk (*) appended to the access right.
- The copy right allows the access right to be copied only within the column (that is, for the object) for which the right is defined.

Access Matrix with Copy Rights: Example

- A process executing in domain D_2 can copy the read operation into any entry associated with file F_2.

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)

Owner Right

- If access(i,j) includes the owner right, then a process executing in domain D_i can add and remove any right in any entry in column j.

Access Matrix with Owner Rights: Example

- the access matrix of (a) can be modified to the access matrix (b).

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

(a)

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

(b)

Control Right

- The copy and owner rights allow a process to change the entries in a column.
- The control right is applicable only to domain objects, i.e., to change the entries in a row (or a domain)
- Example
  - See below
    - A process is executing in domain D_2 can change D_4

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	read write		read write		switch			

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
  - How much memory do we need to naively/directly implement an access matrix?
- Examples
  - Global table
  - Access list (access-control list)
  - Capability list
  - Lock key

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
  - How big?
- Difficult to group objects (consider an object that all domains can read)

Global Table: Example

- Given 3 domains and 3 files:
  - r,w,x,o = read, write, execute, own

	File1	File2	File3
D1	rx	r	rwo
D2	rwxo	r	
D3	rx	rwo	w

  - Q: how to store this as a global table?

Global Table: Example

- Given 3 domains and 3 files:
  - r,w,x,o = read, write, execute, own

	File1	File2	File3
D1	rx	r	rwo
D2	rwxo	r	
D3	rx	rwo	w

  - Global table (3 columns, 6 rows)
    - <D1, File1, rx>, <D1, File2, r>, <D1, File3, rwo>, <D2, File1, rwxo>, <D2, File2, r>, <D3, File1, rx>, <D3, File2, rwo>, <D3, File3, w>

Access Lists (Access-Control 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

Access Lists: Example

- Each column implemented as an access list for one object

	File1	File2	File3
D1	rx	r	rwo
D2	rwxo	r	
D3	rx	rwo	w

- File1: {<D1, rx>, <D2, rwxo>, <D3, rx>}
- File2: {<D1, r>, <D2, r>, <D3, rwo>}
- File3: {<D1, rwo>, <D3, w>}

Access List and Capability List

- Access list for objects
  - Each column = Access list for one object
    Defines who can perform what operation
    - Domain 1 = Read, Write
    - Domain 2 = Read
    - Domain 3 = Read
- Capability list
  - Each Row = Capability List for each domain, what operations allowed on what objects
    - Object F1 – Read
    - Object F4 – Read, Write, Execute
    - Object F5 – Read, Write, Delete, Copy

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

Capability Lists: Example

- Capability list for domain is list of objects together with operations allows on them

	File1	File2	File3
D1	rx	r	rwo
D2	rwxo	r	
D3	rx	rwo	w

- D1: { <file1, rx>, <file2, r>, <file3, rwo> }
- D2: { <file1, rwxo>, <file2, r> }
- D3: { <file1, rx>, <file2, rwo>, <file3, w> }

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

Implementation

- 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

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

Revocation of Access Rights in Access List

- **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 in Capability List

- **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?

Implementing Protection Domain: UNIX

- Domain = user-id (or group-id, or "public")
- 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)

A Sample UNIX Directory Listing

-rw-rw-r--	1	pbg	staff	31200	Sep 3 08:30	intro.ps
drwx------	5	pbg	staff	512	Jul 8 09.33	private/
drwxrwxr-x	2	pbg	staff	512	Jul 8 09:35	doc/
drwxrwx---	2	pbg	student	512	Aug 3 14:13	student-proj/
-rw-r--r--	1	pbg	staff	9423	Feb 24 2003	program.c
-rwxr-xr-x	1	pbg	staff	20471	Feb 24 2003	program
drwx--x--x	4	pbg	faculty	512	Jul 31 10:31	lib/
drwx------	3	pbg	staff	1024	Aug 29 06:52	mail/
drwxrwxrwx	3	pbg	staff	512	Jul 8 09:35	test/

Permissions

number of hardlinks

user & group

size

modify time

name

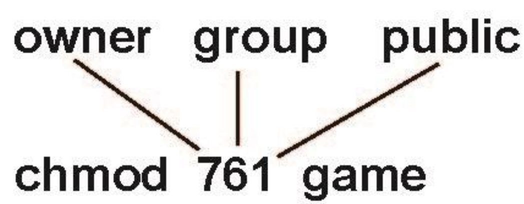
Access Lists in UNIX

- Mode of access: read, write, execute
- Three classes of users on Unix / Linux

			RWX
a) **owner access**	7	⇒	1 1 1
			RWX
b) **group access**	6	⇒	1 1 0
			RWX
c) **public access**	1	⇒	0 0 1

Access Groups in UNIX

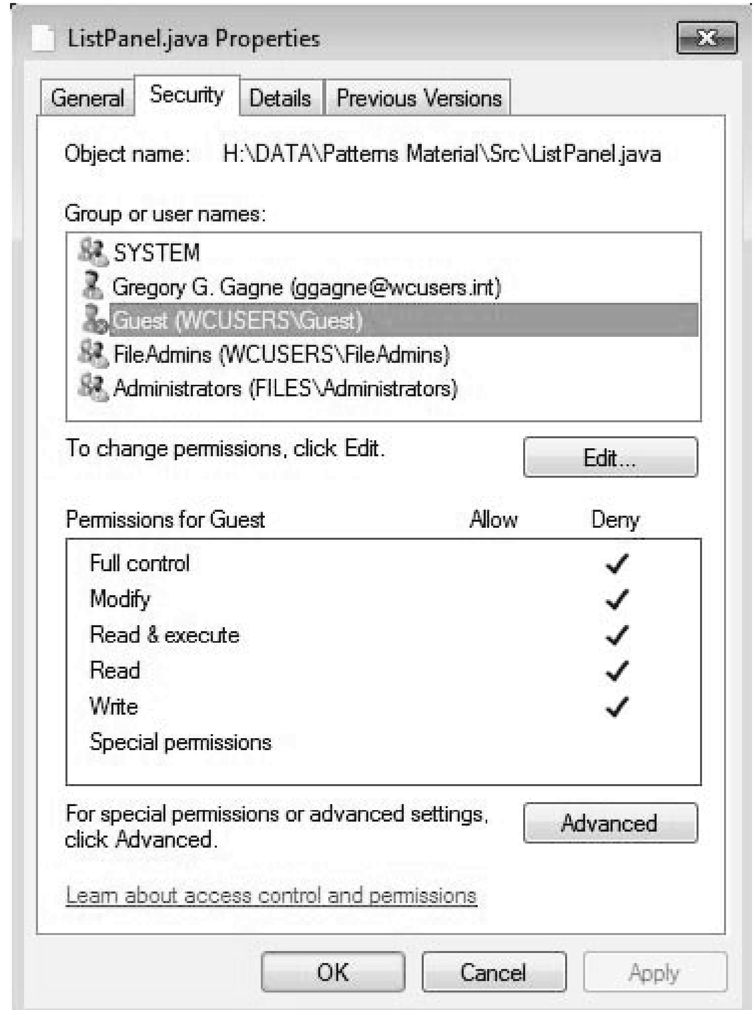
- Ask administrator/manager to create a group (unique name), say *G*, and add some users to the group.
- For a particular file (say *game*) or subdirectory, define an appropriate access.



Attach a group to a file

`chgrp G game`

Windows Access-Control List Management



Questions?

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- Principles of Protection
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- Access Matrix
- Implementation of Access Matrix
- Revocation of Access Rights