HA NOI UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF INFORMATION AND COMMUNICATION TECHNOLOGY

# Access Control

# Topics

- Overview
- Access Control Matrix model
- Discretionary Access Control (DAC)
- Mandatory Access Control (MAC) and an example model
- Role Based Access Control (RBAC)
- Access Control in Unix

# What is AC

- Quote from Ross Anderson (text “Security Engineering”)
  - Its function is to control which principals (persons, processes, machines, …) have access to which resources in the system -- which files they can read, which programs they can execute, and how they share data with other principals, and so on.

# Access Control is Pervasive

- Application
  - business applications
- Middleware
  - DBMS
- Operating System
  - controlling access to files, ports
- Hardware
  - memory protection, privilege levels

# Access Control Matrix – A general model for protection systems

- Lampson'1971
  - "Protection"
- Refined by Graham and Denning'1972
  - "Protection---Principles and Practice"
- Harrison, Ruzzo, and Ullman'1976
  - "Protection in Operating Systems"

# Overview

- Protection state of system
  - Describes current settings, values of system relevant to protection
- Access control matrix
  - Describes protection state precisely
  - Matrix describing rights of subjects
  - State transitions change elements of matrix

# Access Matrix

- A set of subjects S
- A set of objects O
- A set of rights R
- An access control matrix
  - one row for each subject
  - one column for each subject/object
  - elements are right of subject on another subject or object

# Description

objects (entities)

subjects

| | $o_1$ | … | $o_m$ | $s_1$ | … | $s_n$ |
|---|---|---|---|---|---|---|
| $s_1$ | | | | | | |
| $s_2$ | | | | | | |
| … | | | | | | |
| $s_n$ | | | | | | |

- Subjects $S = \{ s_1,\ldots,s_n \}$
- Objects $O = \{ o_1,\ldots,o_m \}$
- Rights $R = \{ r_1,\ldots,r_k \}$
- Entries $A[s_i, o_j] \subseteq R$
- $A[s_i, o_j] = \{ r_x, \ldots, r_y \}$ means subject $s_i$ has rights $r_x, \ldots, r_y$ over object $o_j$

# Example 1

- Processes *p*, *q*
- Files *f*, *g*
- Rights *r*, *w*, *x*, *a*, *o*

| | *f* | *g* | *p* | *q* |
|---|---|---|---|---|
| *p* | *rwo* | *r* | *rwxo* | *w* |
| *q* | *a* | *ro* | *r* | *rwxo* |

# Example 2

- Procedures *inc_ctr*, *dec_ctr*, *manage*
- Variable *counter*
- Rights +, –, *call*

| | *counter* | *inc_ctr* | *dec_ctr* | *manage* |
|---|---|---|---|---|
| *inc_ctr* | + | | | |
| *dec_ctr* | – | | | |
| *manage* | | *call* | *call* | *call* |

# Implementation

- Storing the access matrix
  - by rows: capability lists
  - by column: access control lists
  - through indirection:
    - e.g., key and lock list
    - e.g., groups, roles, multiple level of indirections, multiple locks
- How to do indirection correctly and conveniently is the key to management of access control.

# Implementation

**Access Control List** (column) (ACL)

| **File 1** | **File 2** |
|---|---|
| Joe:Read | Joe:Read |
| Joe:Write | Sam:Read |
| Joe:Own | Sam:Write |
| | Sam:Own |

**Capability List** (row)

Joe: File 1/Read, File 1/Write, File 1/Own, File 2/Read
Sam: File 2/Read, File 2/Write, File 2/Own

**Access Control Triples**

| Subject | Access | Object |
|---|---|---|
| Joe | Read | File 1 |
| Joe | Write | File 1 |
| Joe | Own | File 1 |
| Joe | Read | File 2 |
| Sam | Read | File 2 |
| Sam | Write | File 2 |
| Sam | Own | File 2 |

# Access control lists

| Object F | Object G |
|---|---|
| U: r,w, own | S: r,w, own |
| V: w | T: r,w |
| S: r | U: r |

- ACL is a list of permissions attached to an object
  - Who can modify the object's ACL?
  - What changes are allowed?
  - How are contradictory permissions handled?
  - How is revocation handled?

# Owners and Groups

- Who can modify the object's ACL?
  - One way is by introducing owners of objects
- With ACLs we can define any combination of access, but that makes them difficult to manage
  - Group allow relatively fine-grained access control while making ACLs easier to manage
- Owners and groups can change

# Capability lists

- One way to partition the matrix is by rows.
  - All access rights of one user together, stored in a data structure called a **capability list**
    - Lists all the access rights or capabilities that a user has.
    - E.g. Fred --> /dev/console(RW)--> fred/prog.c(RW)--> fred/letter(RW) --> /usr/ucb/vi(X) Jane --> /dev/console(RW)--> fred/prog.c(R)--> fred/letter() --> /usr/ucb/vi(X)

# Capability lists

- All access to objects is done through capabilities
  - Every program holds a set of capabilities
  - Each program holds a small number of capabilities
  - The only way a program can obtain capabilities is to have them granted as a result of some communication
  - The set of capabilities held by each program must be as small as possible (*principle of least privilege)*
- Example: EROS Operating System
  - http://www.eros-os.org/eros.html

# Harrison-Ruzzo-Ullman model

- **Discretionary Access Control**
  - Rights defined on specific (subject, object), decided by individual owners (as oppose to **Mandatory Access Control**, decided by system policies)
- HRU work
  - Formulating access matrices, towards Operating Systems
  - Provide a model that is sufficiently powerful to encode several access control approaches, and precise enough so that security properties can be analyzed
  - Introduce the "safety problem"
  - Show that the safety problem
    - is decidable in certain cases
    - is undecidable in general
    - is undecidable in monotonic case

# Primitive Operations

- **create subject** *s*; **create object** *o*
  - Creates new row, column in ACM; creates new column in ACM
- **destroy subject** *s*; **destroy object** *o*
  - Deletes row, column from ACM; deletes column from ACM
- **enter** *r* **into** *A*[*s*, *o*]
  - Adds *r* rights for subject *s* over object *o*
- **delete** *r* **from** *A*[*s*, *o*]
  - Removes *r* rights from subject *s* over object *o*

# Creating File

- Process *p* creates file *f* with *r* and *w* permission

```
command create•file(p, f)
    create object f;
    enter own into A[p, f];
    enter r into A[p, f];
    enter w into A[p, f];
end
```

# Mono-Operational Commands

- Make process *p* the owner of file *g*

```
command make•owner(p, g)
    enter own into A[p, g];
end
```

- Mono-operational command
  - Single primitive operation in this command

# Conditional Commands

- Let *p* give *q r* rights over *f*, if *p* owns *f*

```
command grant•read•file•1(p, f, q)
    if own in A[p, f]
    then
            enter r into A[q, f];
end
```

- Mono-conditional command
  - Single condition in this command

# Discretionary Access Control (DAC)

- No precise definition
- Widely used in modern operating systems
- Often has the notion of owner of an object
- The owner controls other users' accesses to the object
- Allows access rights to be propagated to other subjects

# Drawbacks in DAC

- DAC cannot protect against
  - Trojan horse
  - Malware
  - Software bugs
  - Malicious local users
- Cannot control information flow

# Mandatory Access Control (MAC)

# Mandatory Access Control

- *Objects:* security classification

  e.g., grades=(confidential, {student-info})

- *Subjects:* security clearances

  e.g., Joe=(confidential, {student-info})

- *Access rules:* defined by comparing the security classification of the requested objects with the security clearance of the subject

  e.g., subject can read object only if label(subject) dominates label(object)

# Mandatory Access Control

- If *access control rules* are satisfied, access is permitted

  e.g., Joe wants to read grades.

  label(Joe)=(confidential,{student-info})

  label(grades)=(confidential,{student-info})

  Joe is permitted to read grades

- *Granularity* of access rights!

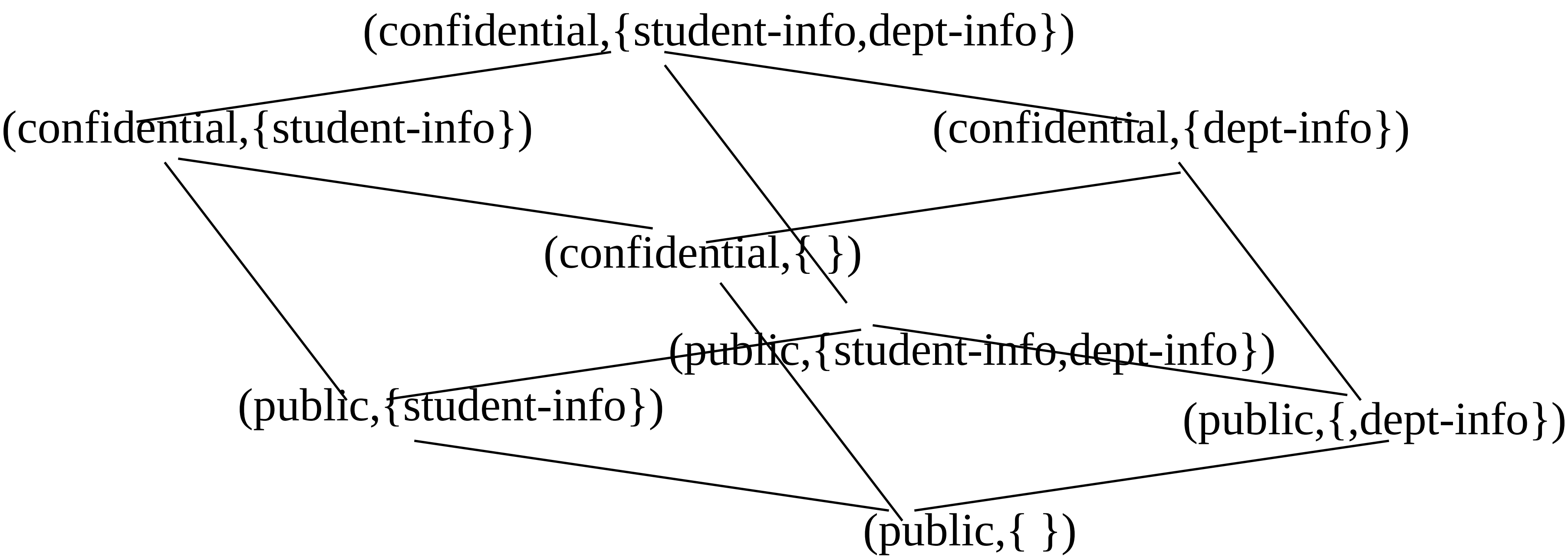
# Mandatory Access Control

*Security Classes* (labels): (A,C)

A – total order authority level

C – set of categories

e.g., A = confidential > public , C = {student-info, dept-info}



# Mandatory Access Control

- *Dominance* ($\geq$): label l=(A,C) dominates l'=(A',C') iff A $\geq$ A' and C $\supseteq$ C'

  e.g., (confidential,{student-info}) ≥ (public,{student-info})

  BUT NOT

  (confidential, {student-info}) ≥ (public,{student-info, department-info})

# Bell- LaPadula (BLP) Model

- Confidentiality protection
- Lattice-based access control
  - Subjects
  - Objects
  - Security labels
- Supports decentralized administration

# BLP Reference Monitor

- All accesses are controlled by the reference monitor
- Cannot be bypassed
- Access is allowed iff the resulting system state satisfies all security properties
- *Trusted subjects*: subjects trusted not to compromise security

# BLP Axioms 1.

*Simple-security property*: a subject *s* is allowed to read an object *o* *only if* the security label of *s* dominates the security label of *o*

- No read up
- Applies to *all subjects*

Subject *s* can read object *o* iff $L(o) \le L(s)$ and *s* has permission to read *o*

- Note: combines mandatory control (relationship of security levels) and discretionary control (the required permission)

# BLP Axioms 2.

**-property*: a subject *s* is allowed to write an object *o* *only if* the security label of *o* dominates the security label of *s*

- No write down
- Applies to *un-trusted subjects* only
- Subject *s* can write object *o* iff $L(s) \le L(o)$ and *s* has permission to write *o*
- Note: combines mandatory control (relationship of security levels) and discretionary control (the required permission)

# Example

| *security level* | *subject* | *object* |
|---|---|---|
| Top Secret | Tamara | Personnel Files |
| Secret | Samuel | E-Mail Files |
| Confidential | Claire | Activity Logs |
| Unclassified | Ulaley | Telephone Lists |

- Tamara can read all files
- Claire cannot read Personnel or E-Mail Files
- Ulaley can only read Telephone Lists

# Levels and Lattices

- Security level is (*clearance*, *category set*)
  - ( Top Secret, { NUC, EUR, ASI } )
  - ( Confidential, { EUR, ASI } )
  - ( Secret, { NUC, ASI } )
- $(A, C)$ *dom* $(A', C')$ iff $A' \leq A$ and $C' \subseteq C$
  - (Top Secret, {NUC, ASI}) *dom* (Secret, {NUC})
  - (Secret, {NUC, EUR}) *dom* (Confidential,{NUC, EUR})
  - (Top Secret, {NUC}) $\neg$*dom* (Confidential, {EUR})

# MAC Overview

- Advantages:
  - Very secure
  - Centralized enforcement
- Disadvantages:
  - May be too restrictive
  - Need additional mechanisms to implement multi-level security system
  - Security administration is difficult

# Role-Based Access Control (RBAC)

# RBAC Motivation

- Multi-user systems
- Multi-application systems
- Permissions are associated with roles
- Role-permission assignments are persistent v.s. user-permission assignments
- Intuitive: competency, authority and responsibility

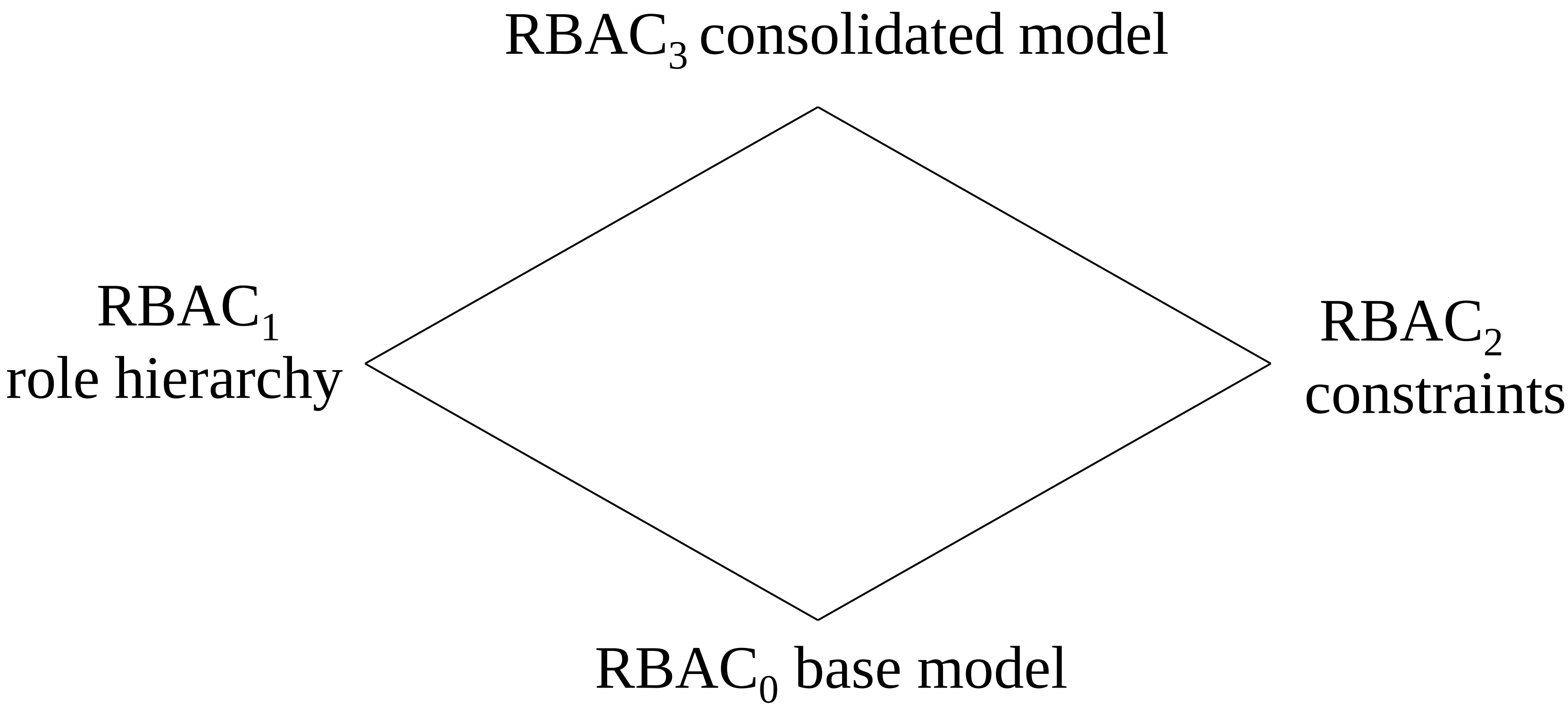
# Motivation

- Express organizational policies
  - Separation of duties
  - Delegation of authority
- Flexible: easy to modify to meet new security requirements
- Supports
  - Least-privilege
  - Separation of duties
  - Data abstraction

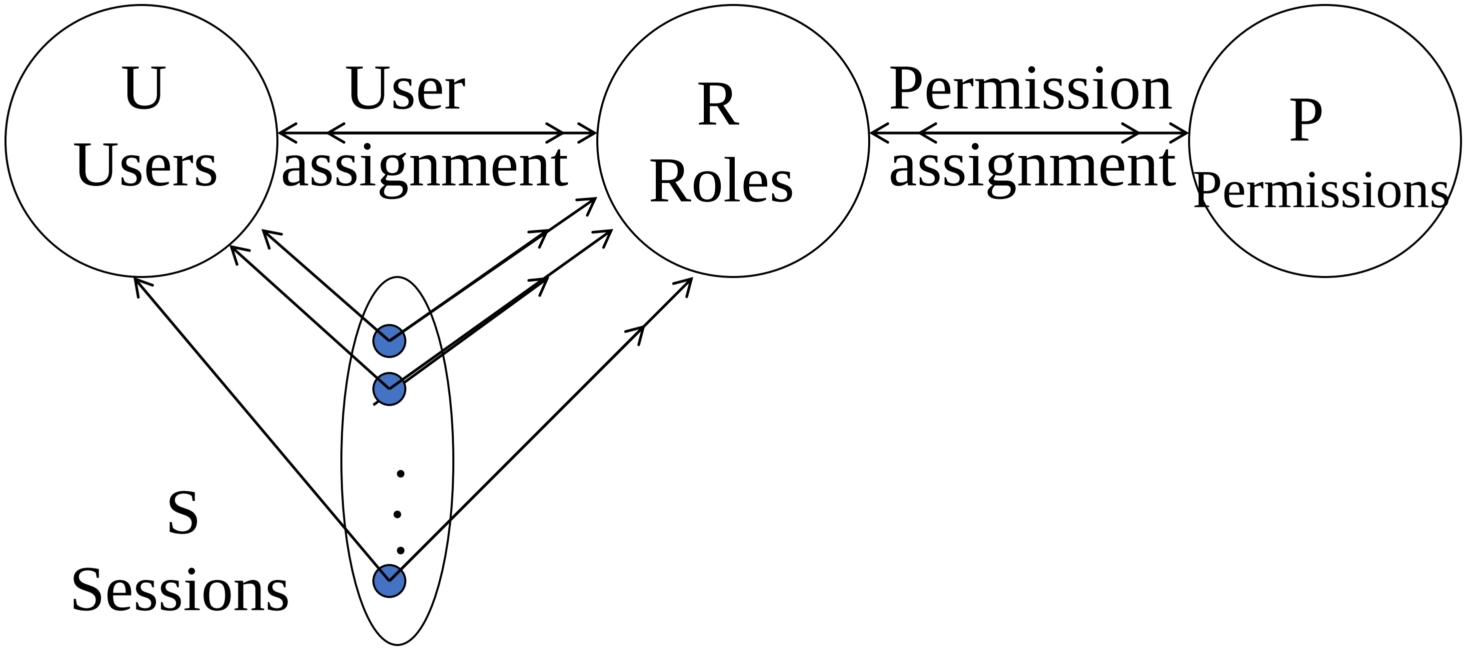
# Roles

- **User group**: collection of user with possibly different permissions
- **Role**: mediator between collection of users and collection of permissions
- **RBAC** independent from DAC and MAC (they may coexist)
- RBAC is **policy neutral**: configuration of RBAC determines the policy to be enforced

# RBAC


$RBAC_3$ consolidated model
$RBAC_1$
role hierarchy
$RBAC_2$
constraints
$RBAC_0$ base model

# $RBAC_0$


U
Users
User
assignment
R
Roles
Permission
assignment
P
Permissions
S
Sessions

# $RBAC_0$

- User: human beings
- Role: job function (title)
- Permission: approval of a mode of access
  - Always positive
  - Abstract representation
  - Can apply to single object or to many

# $RBAC_0$

- UA: user assignments
  - Many-to-many
- PA: Permission assignment
  - Many-to-many
- Session: mapping of a user to possibly many roles
  - Multiple roles can be activated simultaneously
  - Permissions: union of permissions from all roles
  - Each session is associated with a single user
  - User may have multiple sessions at the same time

# $RBAC_0$ Components

- **U**sers, **R**oles, **P**ermissions, **S**essions
- $PA \subseteq P \times R$ (many-to-many)
- $UA \subseteq U \times R$ (many-to-many)
- user: $S \rightarrow U$, mapping each session $s_i$ to a single user $user(s_i)$
- roles: $S \rightarrow 2^R$, mapping each session $s_i$ to a set of roles:
  - $roles(s_i) \subseteq \{r \mid (user(s_i),r) \in UA\}$ and $s_i$ has permissions $\bigcup_{r \in roles(s_i)} \{p \mid (p,r) \in PA\}$

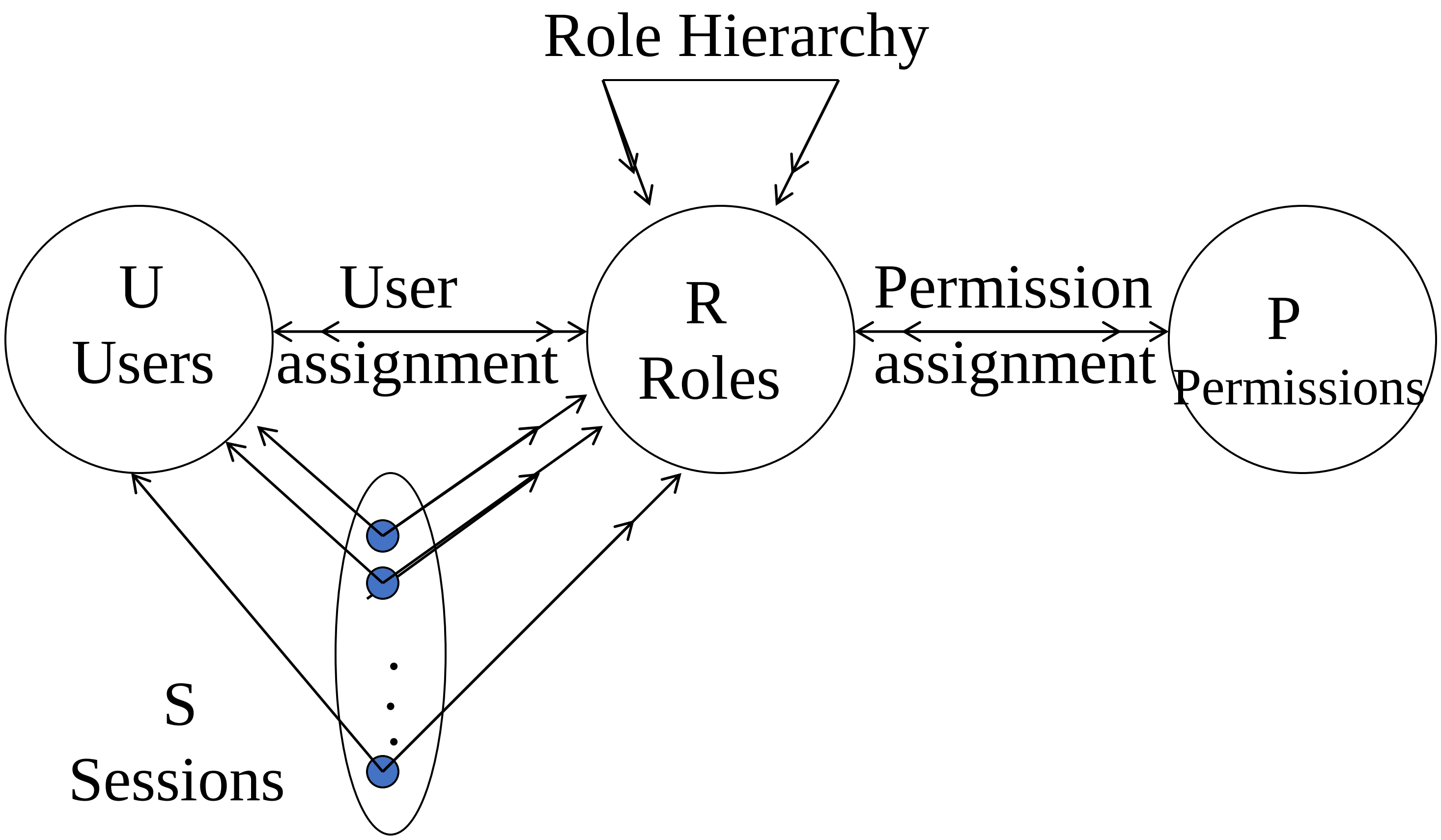
# $RBAC_0$

- Permissions apply to data and resource objects only
- Permissions do NOT apply to RBAC components
- Administrative permissions: modify U,R,S,P
- Session: under the control of user to
  - Activate any subset of permitted roles
  - Change roles within a session

# $RBAC_1$

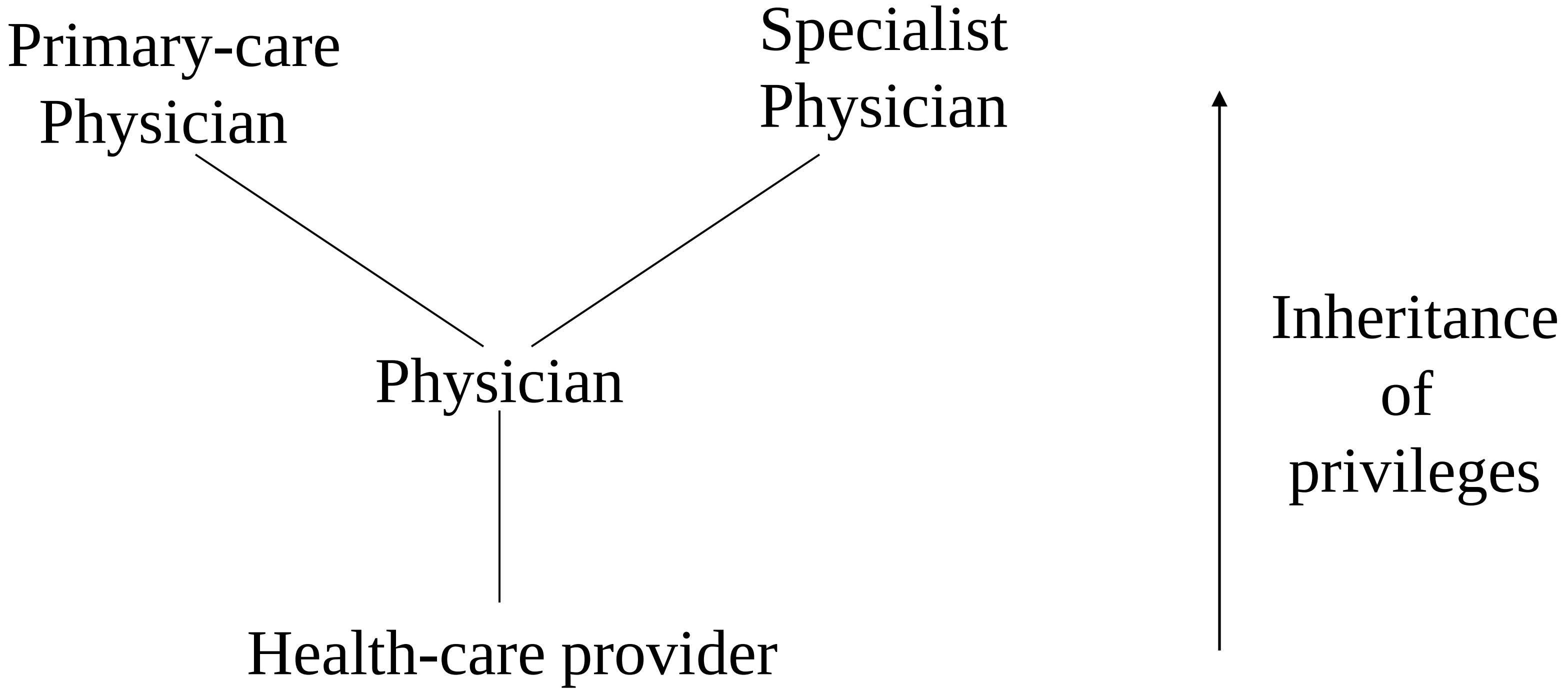
- Structuring roles
- Inheritance of permission from junior role (bottom) to senior role (top)
- Partial order
  - Reflexive
  - Transitive
  - Anti-symmetric

# RBAC$_1$


Role Hierarchy
U
Users
User
assignment
R
Roles
Permission
assignment
P
Permissions
S
Sessions

# $RBAC_1$

Role Hierarchy



# RBAC$_1$ Components

- Same as RBAC$_0$: **U**sers, **R**oles, **P**ermissions, **S**essions, PA $\subseteq$ P x R, UA $\subseteq$ U x R, user: S $\rightarrow$ U, mapping each session $s_i$ to a single user user($s_i$)
- RH $\subseteq$ R x R, partial order ($\geq$ dominance)
- roles: S $\rightarrow$ $2^R$, mapping each session $s_i$ to a set of roles
  - roles($s_i$) $\subseteq$ $\{r \mid (\exists r' \geq r)\, [(user(s_i), r') \in UA]\}$ and $s_i$ has permissions $\cup_{r \in roles(s_i)} \{p \mid (\exists r'' \leq r)\, [(p, r'') \in PA]\}$

# Access Control in Unix

# General Concepts

- Users, Groups, Processes, Files
  - Each user has a unique UID
  - Each group has a unique GID
  - Each process has a unique PID
  - Users belong to multiple groups GID
  - Objects whose access is controlled
    - Files
    - Directories
- Organization of Objects
  - Files are arranged in a hierarchy
  - Files exist in directories
  - Directories are one type of files
  - In UNIX, access on directories are not inherited

# Basic Permissions Bits on Files

- Permission:
  - Read:  control reading the content of a file
  - Write: controls changing the content of a file
  - Execute: controls loading the file then execute
- Many operations can be performed only by the owner of the file
- Where are Permission Bits Kept?
  - Each file/directory has associated an i-node.
  - The file type, permissions, owner UID and owner GID are save on disk in the inode of a file or directory

# Permission Bits on Directories

- Read:  for showing file names in a directory
- Execution: for traversing a directory
  - does a lookup, allows one to find inode # from file name
  - 'chdir' to a directory requires execution
- Write + execution: for creating/deleting files in the directory
  - requires no permission on the file
- Accessing a file a path name: need execution permission to all directories along the path

# The Three Sets of Permission Bits

- Permission example

  drwxr-xr-x

  - First: directory or not
  - Next three: owner permission
    - if the user is the owner of a file then the r/w/x bits for owner apply
  - Next three: group permission
    - if the user belongs to the group the file belongs to then the r/w/x bits for group apply
  - Next three: others permission
    - Apply when not the owner  or belong to the group
- Where are Permission Bits Kept?
  - Each file/directory has associated an inode.
  - The file type, permissions, owner UID and owner GID are save on disk in the inode of a file or directory

# Users vs. Subjects

- Permission bits talk about what users can access a file
  - ➔ but it is subjects (processes) to perform actions on files
  - When a subject accesses a file, the system check which user it is acting on behalf of
- Problem: what if an executable need stronger permission than the subject calling it
  - The **passwd** program needs to update a system-wide password file, which ordinary users should not be able to modify, but only root can modify
  - But remember, it needs to be run by ordinary users

# Real User ID vs. Effective User ID

- Each process has three user IDs
  - real user ID (ruid): owner of the process
  - effective user ID (euid): used in most access control decisions, often the same as ruid unless there is a change
  - saved user ID (suid): keeps the previous euid if it was a change
- and three group IDs
  - real group ID
  - effective group ID
  - saved group ID

# The setuid flag

- When used for a file
  - allows certain processes to have more than ordinary privileges while still being executable by ordinary users
  - When set, the effective uid of the calling process takes the value of the owner of the file

# How the process user IDs work

- When a process is created by *fork*
  - it inherits all three UIDs from its parent process
- When a process executes a file by *exec*

  if (the setuid bit of the file is off)

  it keeps its three user IDs

  otherwise // the setuid is set

  euid of the process = ruid of the file

  suid = previous euid
- How to solve the passwd problem and the likes?
  - Passwd is owned by root and setuid is set
  - When a process executes it, then effective user becomes root, so the program runs as root on behalf of the user (only within the passwd work)
- Can be a security flaw if the mechanism for temporary higher privilege is abused

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# Thank you for your attentions!