COMPSCI4062&5063: Cyber Security Fundamentals

# Topic 3: Access Control

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# Quiz Time

- Active 24 hours (unless you have a proof of absence)

# Written Assignment for COMPSCI5063

Literature Review  Due: 17 March 4 PM

Marking Criteria

- Meet the number of words and references (at least 800 words, and 10 state-of-the-art/latest cybersecurity publications)  25%
- Discuss advantages 25% (easy to be found in the section of contribution)
- Discuss disadvantages  30%
- Discuss connections among different papers  10%
- Propose future research directions  10%

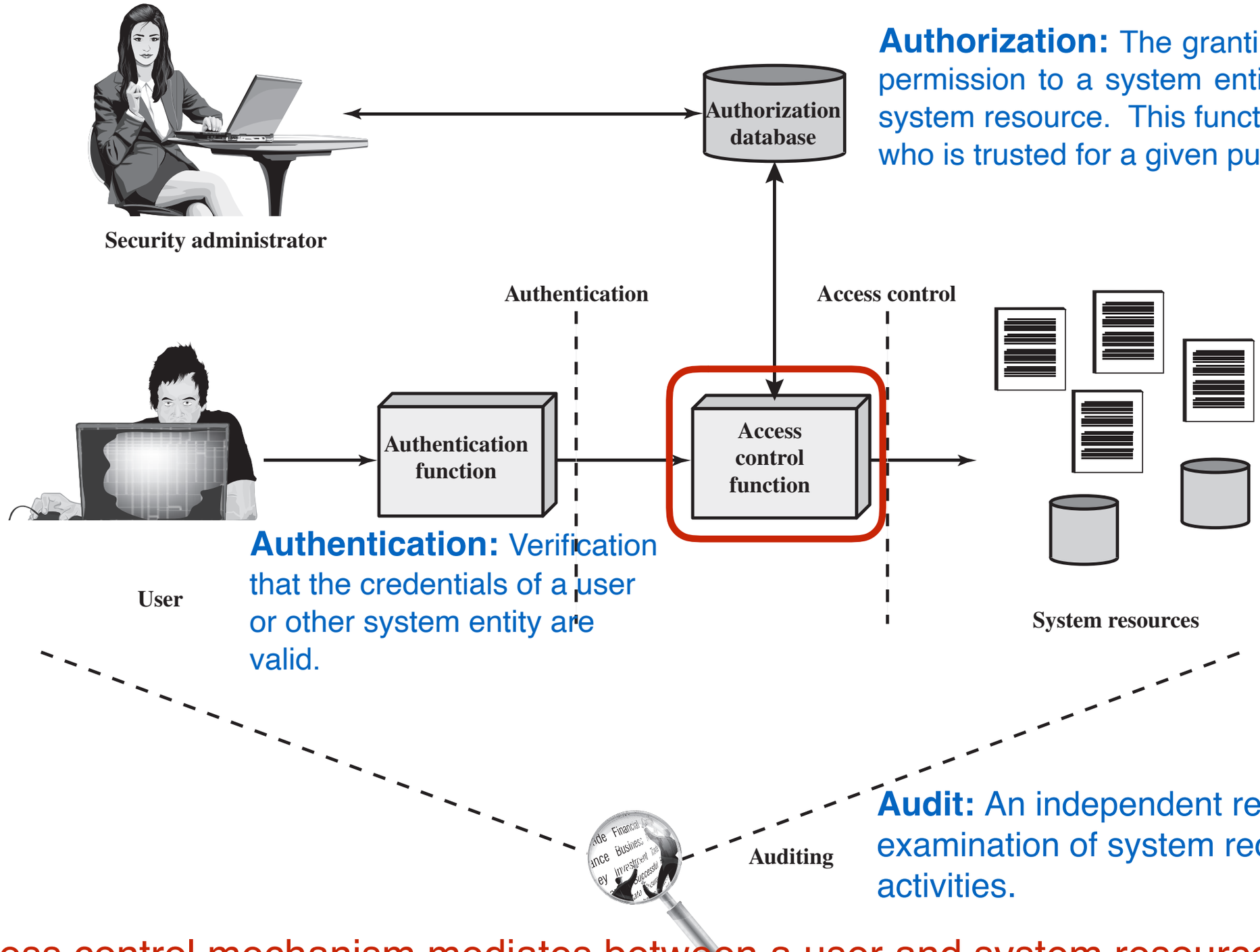
# Overview

- Concept of Access Control
  - Definition
  - Access control in a broader context
  - Basic elements
- Access Control Policies
  - Discretionary access control (DAC)
  - Role-based access control (RBAM)
  - Attribute-based access control (ABAC)

# Concept of Access Control

- Access control implements a security policy that specifies who or what (e.g., in the case of a process) may have access to each specific system resource and the type of access that is permitted in each instance.

# Access control in a broader context




**Authorization:** The granting of a right or permission to a system entity to access a system resource. This function determines who is trusted for a given purpose.

**Authentication:** Verification that the credentials of a user or other system entity are valid.

**Audit:** An independent review and examination of system records and activities.

An access control mechanism mediates between a user and system resources such as applications, operating systems, firewalls, routers, files, and database.

# Basic Elements of Access Control

- **Object:** a resource to which access is controlled; an entity used to contain and/or receive information (e.g., pages, files, mailboxes…)
- **Subject:** an entity capable accessing objects
  - Owner (e.g., creator of a resource, system administrator)
  - Group (membership in the group is sufficient to exercise the access rights)
  - World (granted the least amount of access, not included in owner/group)
- **Access right:** describes the way in which a subject may access an object
  - Read: view information in a system resources, including ability to copy or print
  - Write: add, modify, or delete data; including read access
  - Execute: execute specified programs
  - Delete: delete certain system resources (e.g., files, records, programs)
  - Create: create new files, records, or fields
  - Search: list the files in a directory or otherwise search the directory

# Access Control Policies

- Discretionary access control (DAC)
- Mandatory access control (MAC)
- Role-based access control (RBAM)
- Attribute-based access control (ABAC)

Not mutually exclusive.
An access control mechanism can employ two or even all three of these policies to cover different classes of system resources.

# Discretionary Access Control (DAC)

- DAC controls access based on the identity of the requestor and on access rules (authorizations) stating what requestors are (or are not) allowed to do.

- An entity may be granted access rights that permit the entity, by its own volition, to enable another entity to access some resources.

# DAC: Access Matrix

Dimension 1: Identified subjects that may attempt data access to the resources

Dimension 2: objectives that may be accessed

| | | OBJECTS | | | |
|---|---|---|---|---|---|
| | | File 1 | File 2 | File 3 | File 4 |
| SUBJECTS | User A | Own<br>Read<br>Write | | Own<br>Read<br>Write | |
| | User B | Read | Own<br>Read<br>Write | Write | Read |
| | User C | Read<br>Write | Read | | Own<br>Read<br>Write |

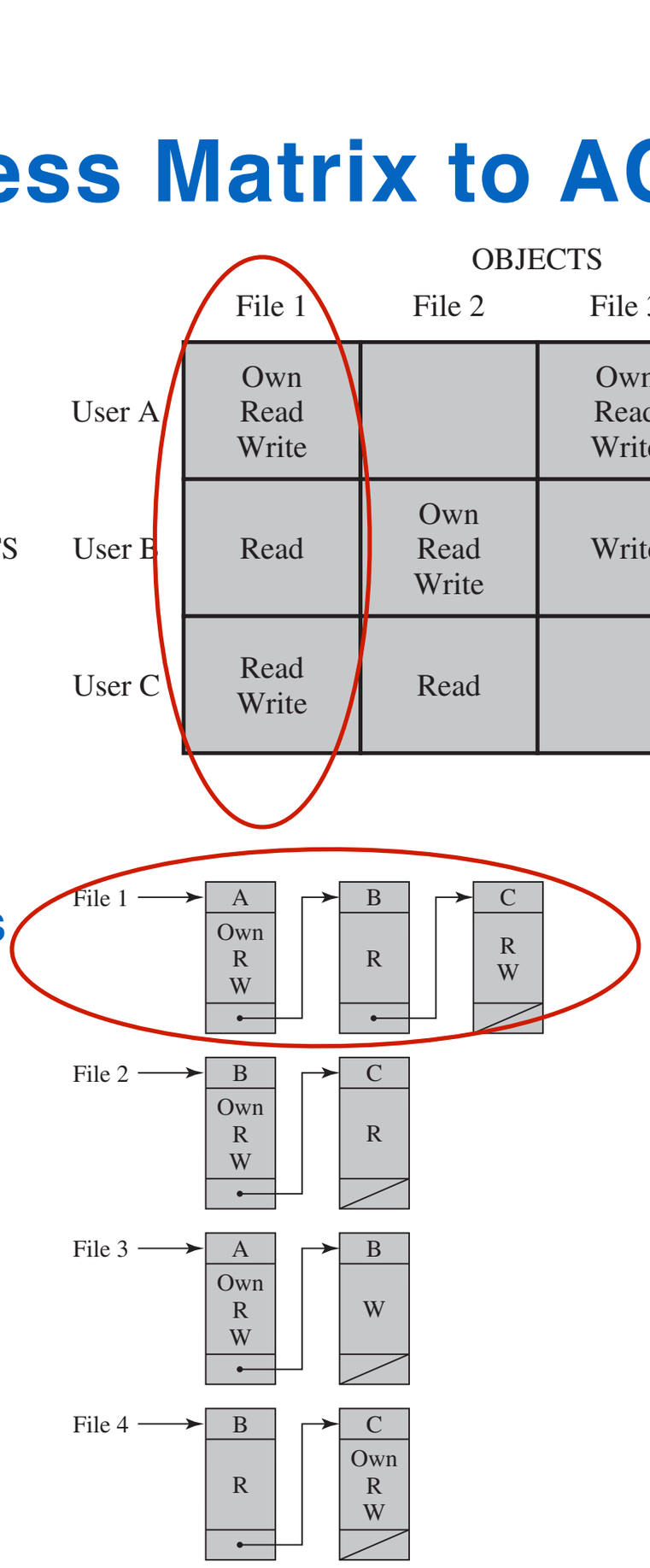
Access Matrix (sparse)

# DAC: Access Matrix to ACL

## Access Matrix

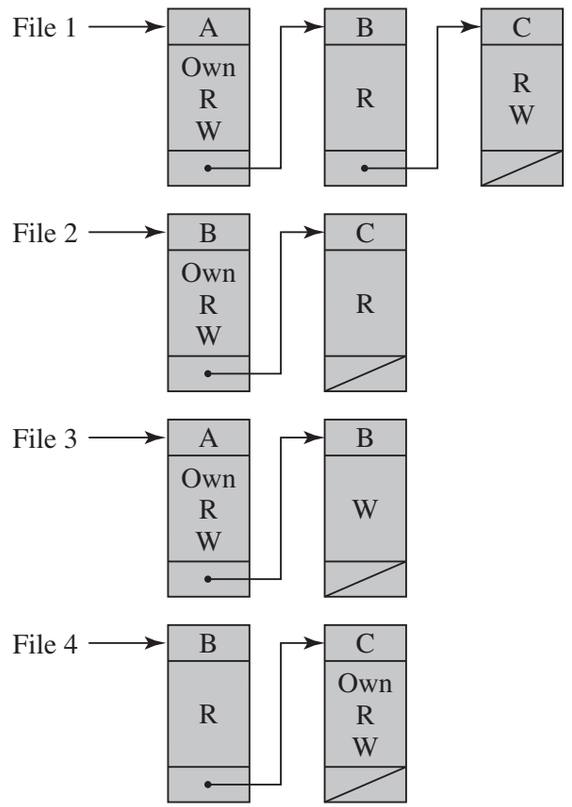
| SUBJECTS | OBJECTS: File 1 | File 2 | File 3 | File 4 |
|---|---|---|---|---|
| User A | Own Read Write | | Own Read Write | |
| User B | Read | Own Read Write | Write | Read |
| User C | Read Write | Read | | Own Read Write |

## Access control lists (Columns)




ACL lists users and their permitted access rights

# DAC: Access Control List



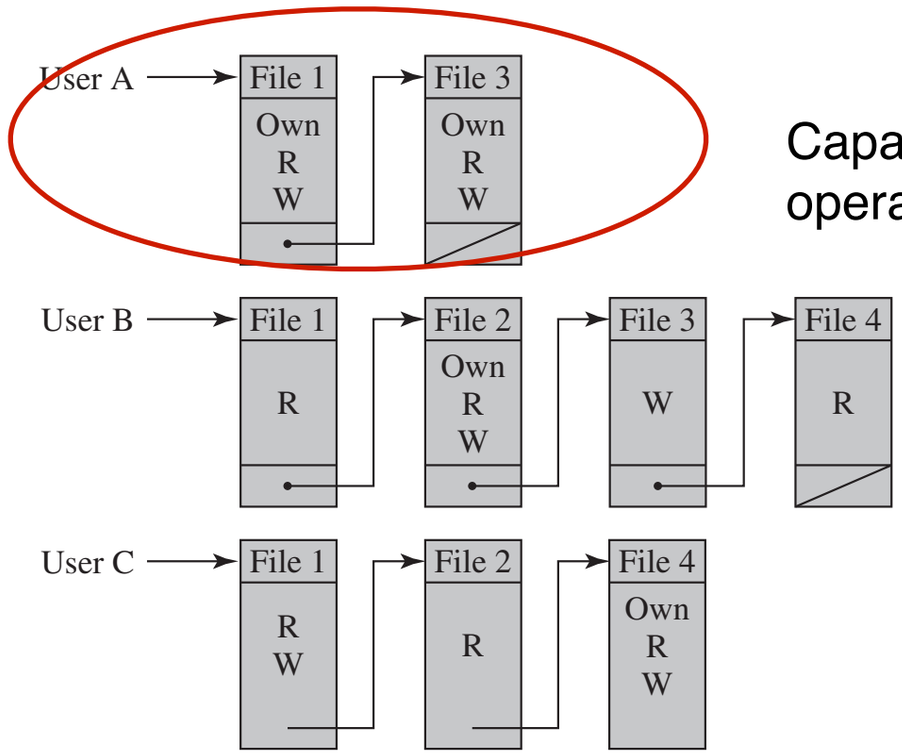

- Advantage
  - Contain a default, or public, entry (e.g. read-only access) that users are not explicitly listed
  - For a given resources, it is convenient for determining which subjects have which rights
- Disadvantage
  - Not convenient for determining the access rights available to a specific user

# DAC: Access Matrix to Capability Tickets

## Access Matrix

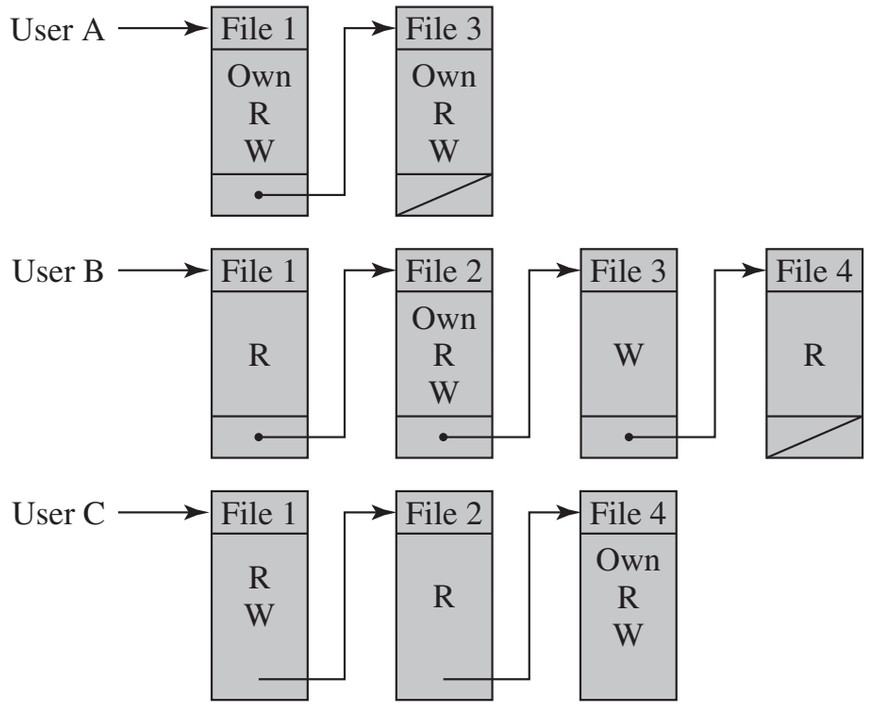
| | | OBJECTS File 1 | File 2 | File 3 | File 4 |
|---|---|---|---|---|---|
| SUBJECTS | User A | Own Read Write | | Own Read Write | |
| | User B | Read | Own Read Write | Write | Read |
| | User C | Read Write | Read | | Own Read Write |

## Capability tickets/lists (Rows)



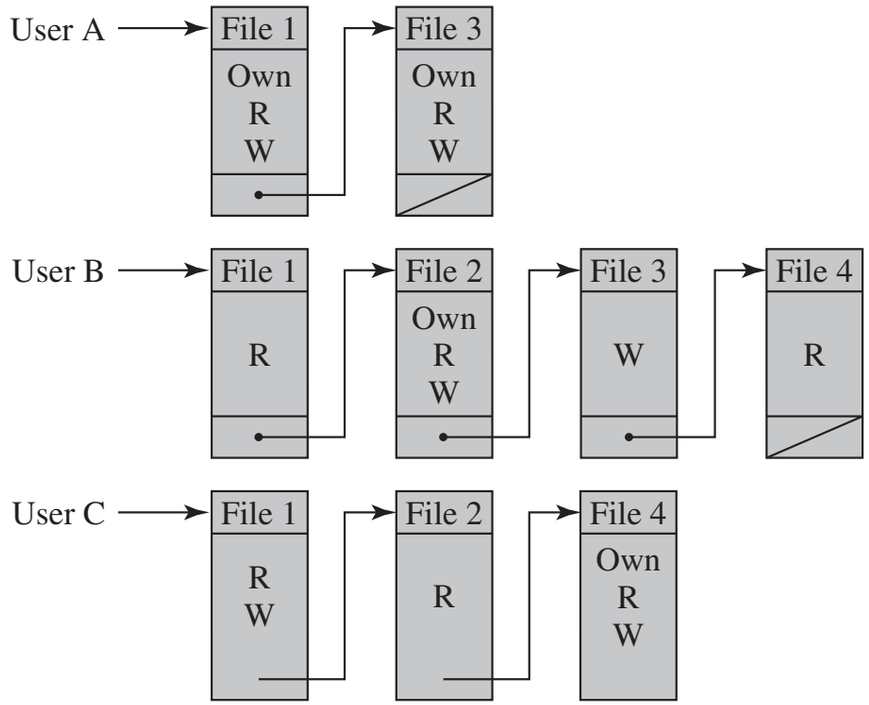

Capability tickets specifies authorized objects and operations for a particular user

# DAC: Capability Tickets




- Advantages
  - Given a user, it is easy to determine the set of access rights
- Disadvantages
  - Given a specific resource, it is difficult to determine the list of users with specific access rights
  - Tickets may be authorized to loan or given to others, dispersed around the system —> security problem

# DAC: Capability Tickets




- Advantages
  - Given a user, it is easy to determine the set of access rights
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**Solution**

Key idea: Make the ticket protected, guaranteed, and unforgeable

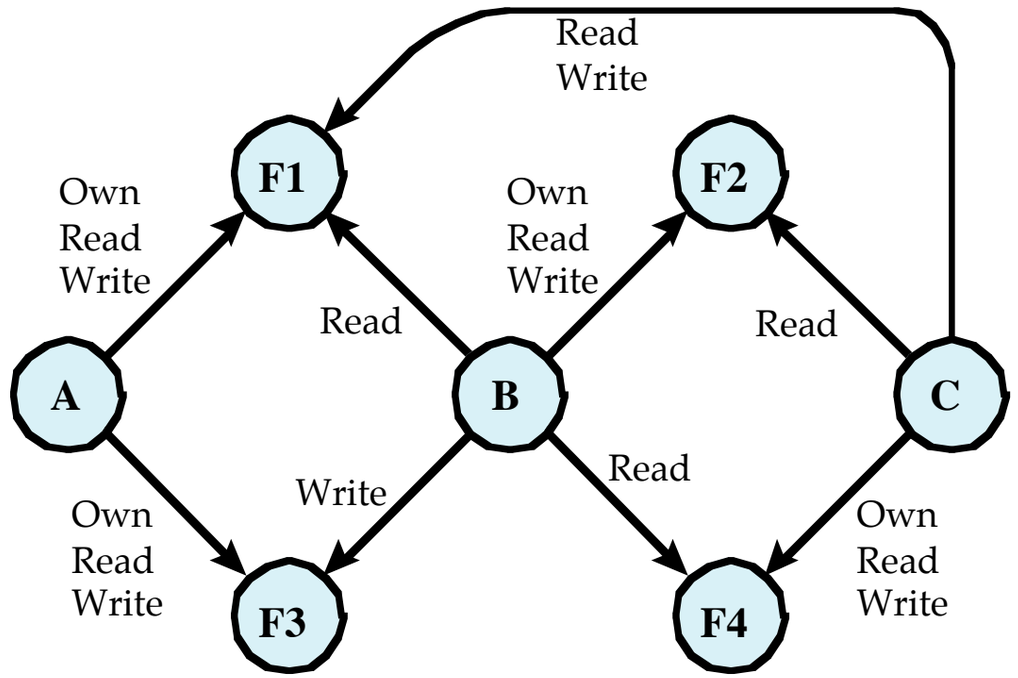
Solution 1: The operating system hold all tickets on behalf of users, but in a region of memory inaccessible to users

Solution 2: Include an unforgeable token (e.g., a large random pass word, or a cryptographic message authentication code) in the capability

# DAC: Other Forms

| Subject | Access Mode | Object |
|---|---|---|
| A | Own | File 1 |
| A | Read | File 1 |
| A | Write | File 1 |
| A | Own | File 3 |
| A | Read | File 3 |
| A | Write | File 3 |
| B | Read | File 1 |
| B | Own | File 2 |
| B | Read | File 2 |
| B | Write | File 2 |
| B | Write | File 3 |
| B | Read | File 4 |
| C | Read | File 1 |
| C | Write | File 1 |
| C | Read | File 2 |
| C | Own | File 4 |
| C | Read | File 4 |
| C | Write | File 4 |

Authorization Table




Directed Graph

# DAC: Model

- Subjects, Objects, Rules
- Protection state: set of information, at a given point in time, that specifies the access rights for each subject with respect to each object.
- Three requirements
  - Representing the protection state
  - Enforcing access rights
  - Allowing subjects to alter the protection state in certain ways.

# DAC: Model

- How to represent the protection state?
  - Extended access control matrix

| SUBJECTS | OBJECTS: Subjects $S_1$ | Subjects $S_2$ | Subjects $S_3$ | Files $F_1$ | Files $F_2$ | Processes $P_1$ | Processes $P_2$ | Disk drives $D_1$ | Disk drives $D_2$ |
|---|---|---|---|---|---|---|---|---|---|
| $S_1$ | control | owner | owner control | read* | read owner | wakeup | wakeup | seek | owner |
| $S_2$ | | control | | write* | execute | | | owner | seek* |
| $S_3$ | | | control | | write | stop | | | |

* = copy flag set

**Extended**

-Processes: The ability to delete, stop(block), and wake up a process

-Devices: The ability to read/write the devices, to control its operation, and to block/unblock the device for use

-Memory locations/regions: The ability to read/write certain regions of memory that are protected such that the default is to disallow access

-Subjects: The ability to grant or delete rights of that subject to other objects

# DAC: Model

OBJECTS

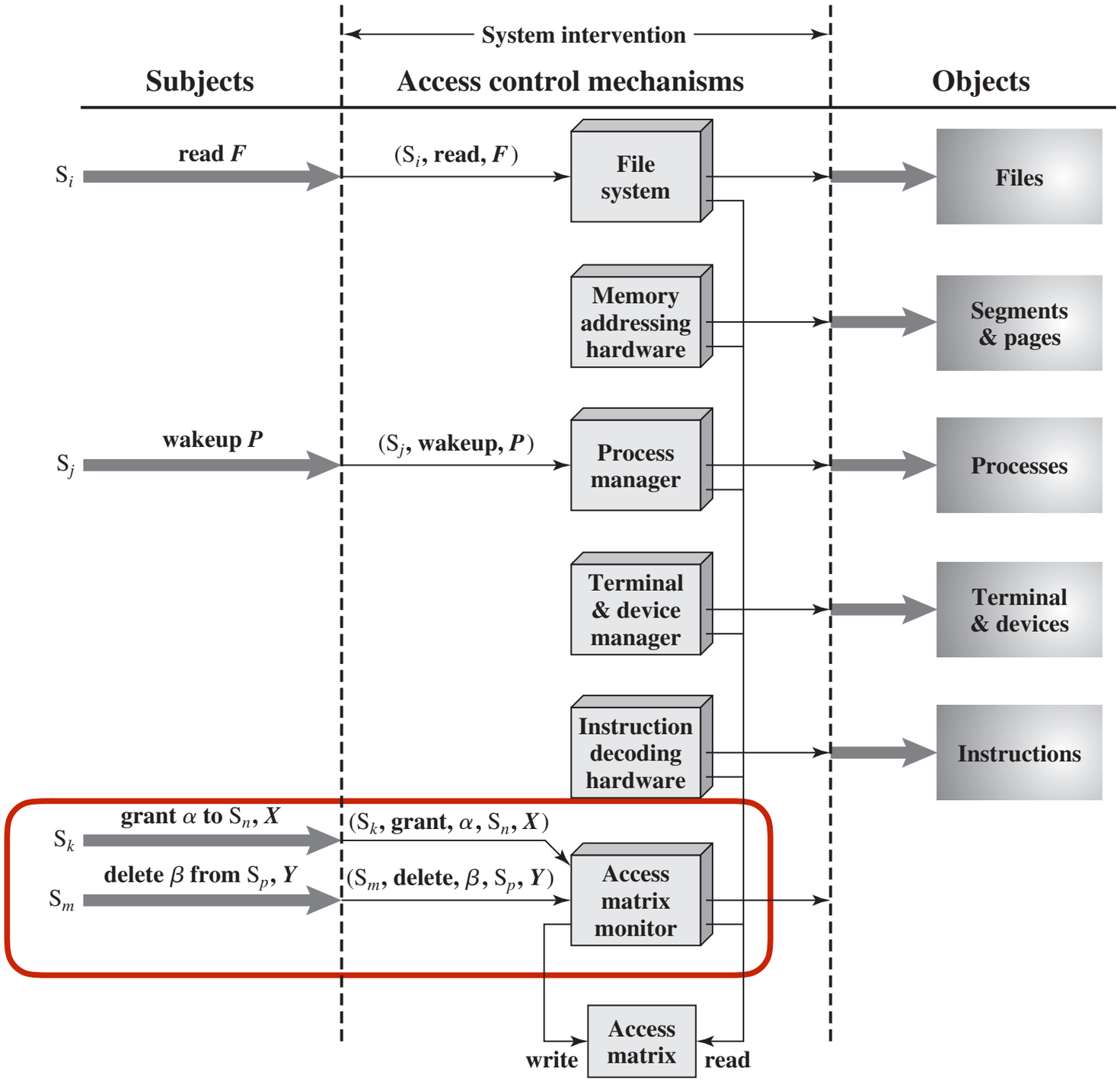
| SUBJECTS | Subjects | | | Files | | Processes | | Disk drives | |
|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $F_1$ | $F_2$ | $P_1$ | $P_2$ | $D_1$ | $D_2$ |
| $S_1$ | control | owner | owner control | read∗ | read owner | wakeup | wakeup | seek | owner |
| $S_2$ | | control | | write∗ | execute | | | owner | seek∗ |
| $S_3$ | | | control | | write | stop | | | |

∗ = copy flag set

For an access control matrix A, each entry $A[S, X]$ contains strings, called access attributes, that specify the access rights of subject S to object X.

Example: $A[S_1, F_1]$. —> ‘read’ , that is S1 may read file F1.

# DAC: Model




An Organization of the Access Control Function

# DAC: Model

- A separate access control module is associated with each the of objects
- The module evaluates each request by the following steps

1. A subject $S_0$ issues a request of type $\alpha$ for object $X$.
2. The request causes the system (the operating system or an access control interface module of some sort) to generate a message of the form ($S_0$, $\alpha$, $X$) to the controller for $X$.
3. The controller interrogates the access matrix $A$ to determine if $\alpha$ is in $A[S_0, X]$. If so, the access is allowed; if not, the access is denied and a protection violation occurs. The violation should trigger a warning and appropriate action.

# DAC: Model

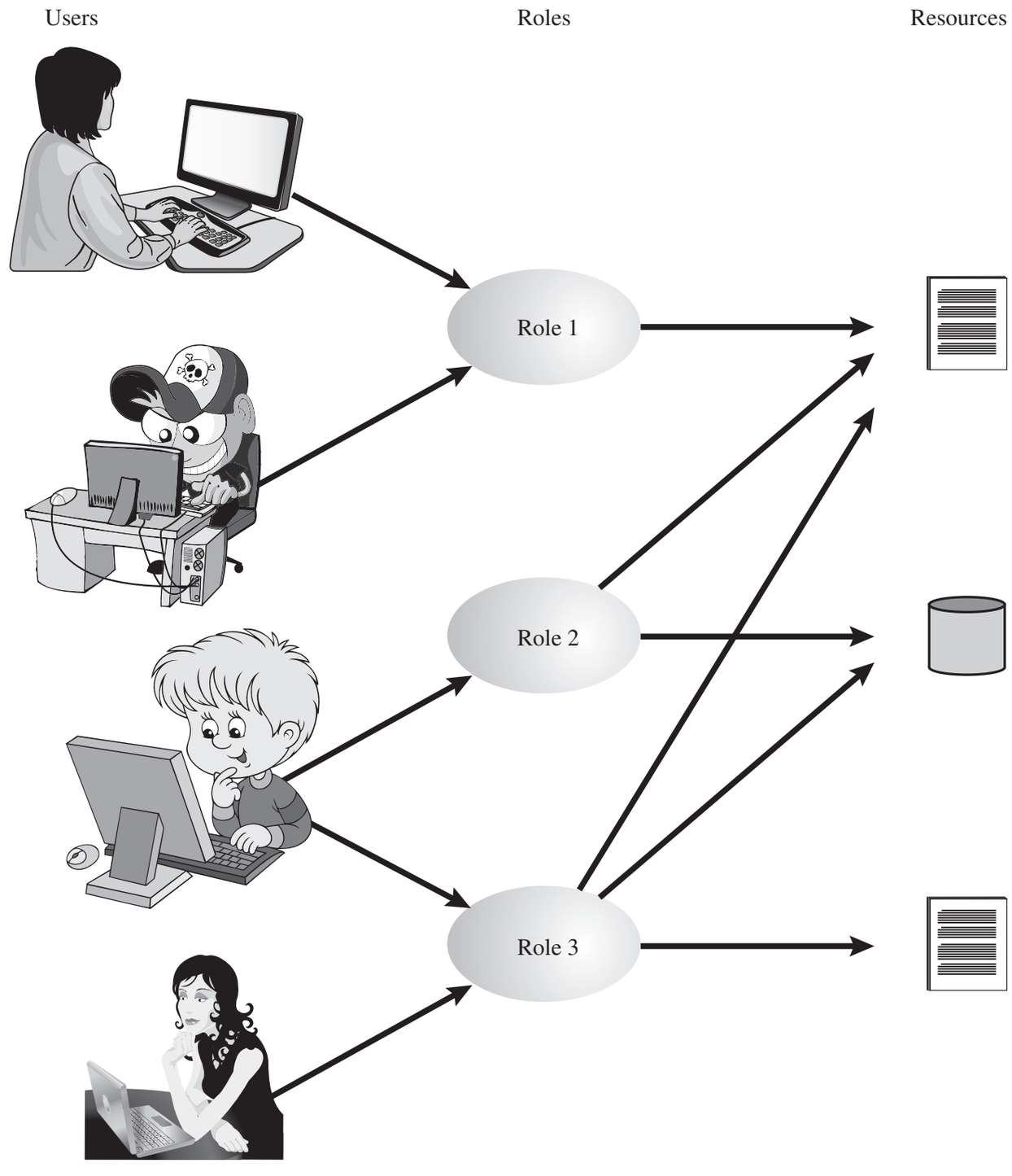
- How to modify the access matrix?
  - Access control system commands

| Rule | Command (by $S_0$) | Authorization | Operation |
|---|---|---|---|
| R1 | **transfer** $\left\{\begin{matrix}\alpha^* \\ \alpha\end{matrix}\right\}$ **to** $S, X$ | '$\alpha^*$' in $A[S_0, X]$ | store $\left\{\begin{matrix}\alpha^* \\ \alpha\end{matrix}\right\}$ in $A[S, X]$ |
| R2 | **grant** $\left\{\begin{matrix}\alpha^* \\ \alpha\end{matrix}\right\}$ **to** $S, X$ | 'owner' in $A[S_0, X]$ | store $\left\{\begin{matrix}\alpha^* \\ \alpha\end{matrix}\right\}$ in $A[S, X]$ |
| R3 | **delete** α **from** $S, X$ | 'control' in $A[S_0, S]$<br>or<br>'owner' in $A[S_0, X]$ | delete α from $A[S, X]$ |
| R4 | $w \leftarrow$ **read** $S, X$ | 'control' in $A[S_0, S]$<br>or<br>'owner' in $A[S_0, X]$ | copy $A[S, X]$ into $w$ |
| R5 | **create object** $X$ | None | add column for $X$ to $A$; store 'owner' in $A[S_0, X]$ |
| R6 | **destroy object** $X$ | 'owner' in $A[S_0, X]$ | delete column for $X$ from $A$ |
| R7 | **create subject** $S$ | none | add row for $S$ to $A$; execute **create object** $S$; store 'control' in $A[S, S]$ |
| R8 | **destroy subject** $S$ | 'owner' in $A[S_0, S]$ | delete row for $S$ from $A$; execute **destroy object** $S$ |

-R1: With a copy flag $\alpha^*$, $S_0$ can transfer this right with/without copy flag to another subject.

-R4: Permits a subject to read that portion of the matrix that it owns or controls

# Role-Based Access Control (RBAC)

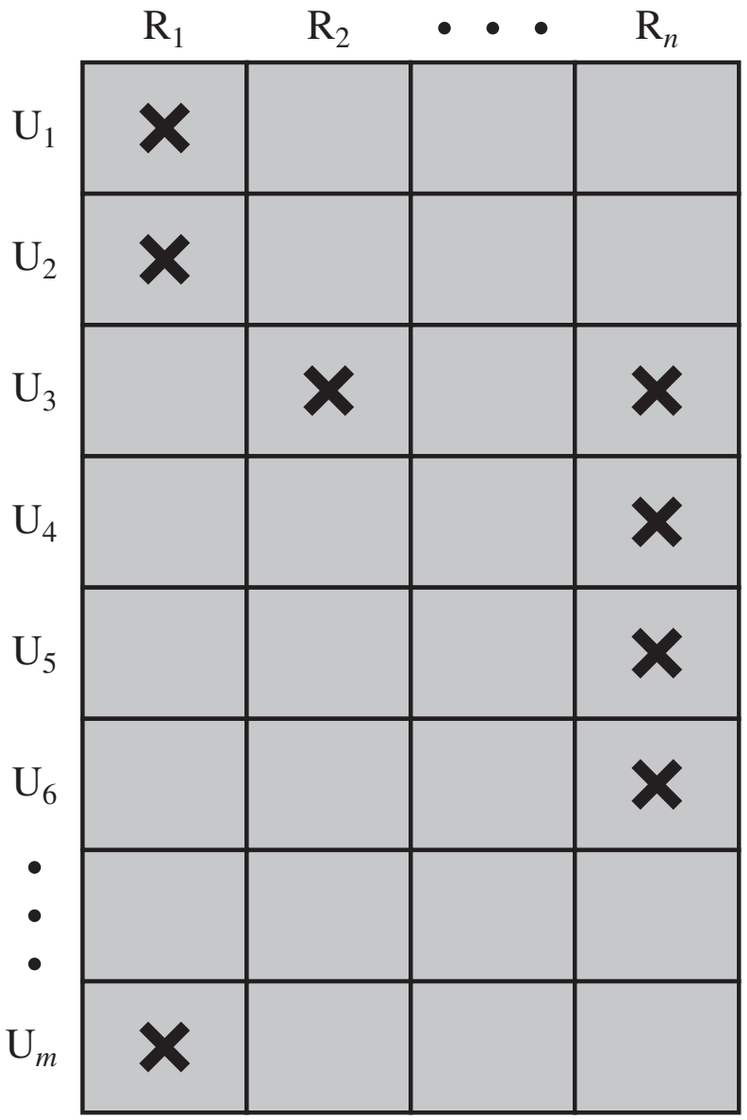


# Role-Based Access Control (RBAC)

- RBAC controls access based on the **roles** that users have within the system and on rules stating what accesses are allowed to users in given roles (rather than user's identity in DAC).
- Users are assigned to different roles, either statically or dynamically, according to their responsibilities.
- The relationship of users to roles is many to many, as is the relationship of roles to resources, or system objects.

RBAC is active in commercial use and research :)

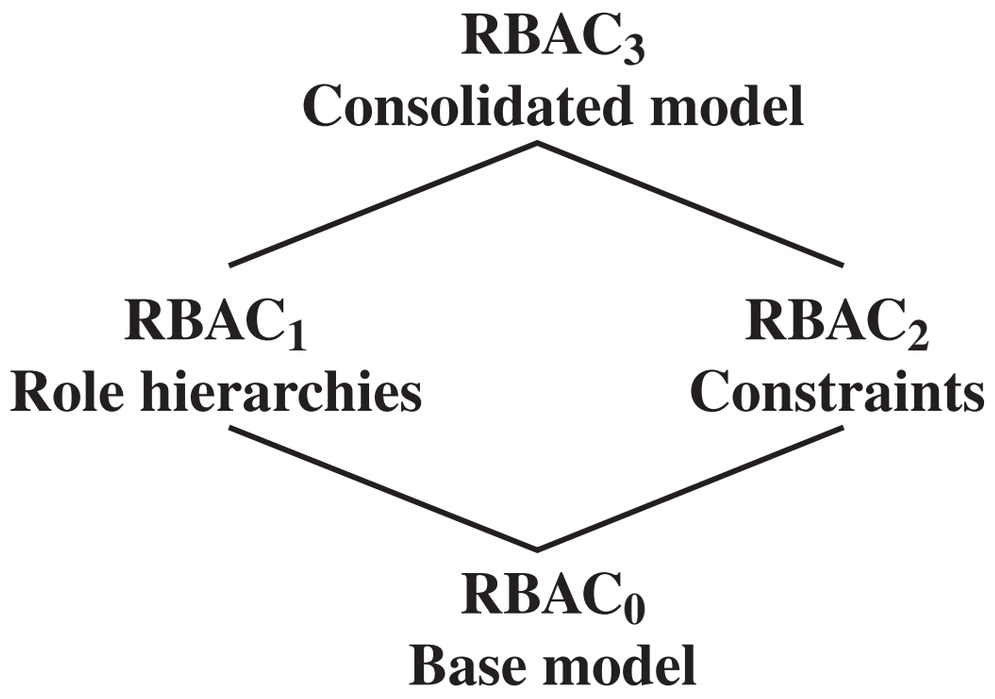
# RBAC: Access Control Matrix



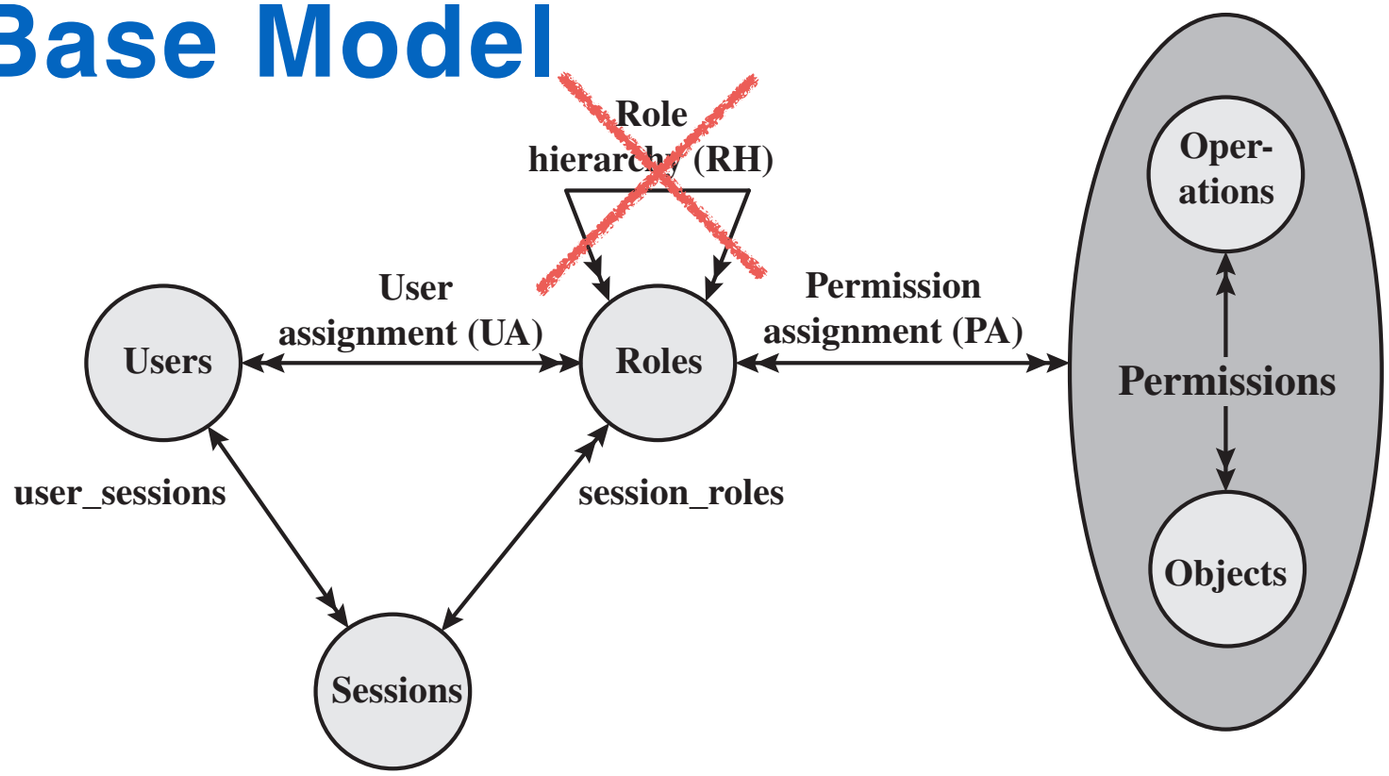

OBJECTS

| ROLES | $R_1$ | $R_2$ | $R_n$ | $F_1$ | $F_2$ | $P_1$ | $P_2$ | $D_1$ | $D_2$ |
|---|---|---|---|---|---|---|---|---|---|
| $R_1$ | control | owner | owner control | read * | read owner | wakeup | wakeup | seek | owner |
| $R_2$ | | control | | write * | execute | | | owner | seek * |
| • • • | | | | | | | | | |
| $R_n$ | | | control | | write | stop | | | |

# RBAC: Models

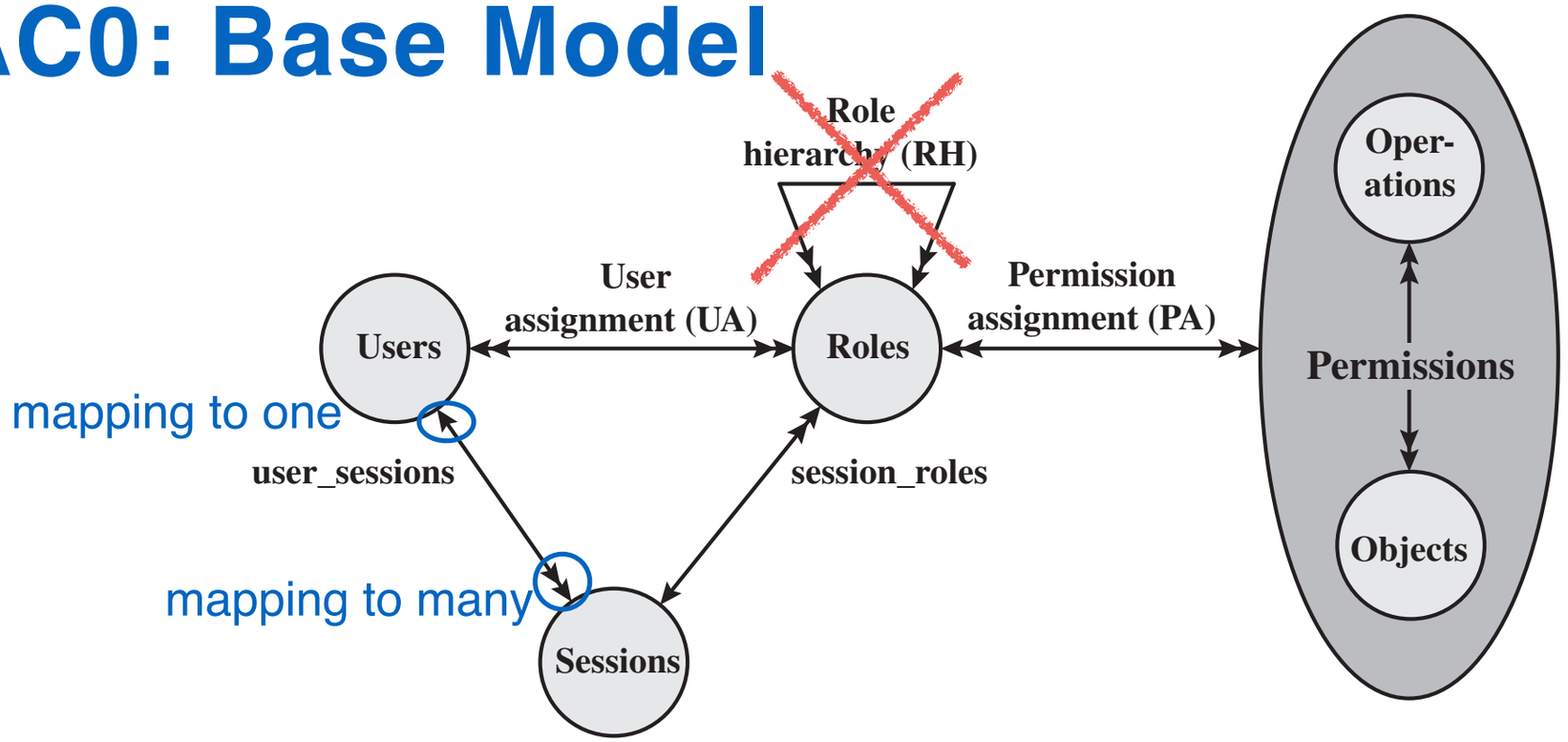

RBAC3
Consolidated model
RBAC1
Role hierarchies
RBAC2
Constraints
RBAC0
Base model

# RBAC0: Base Model




- User: An individual that has access to this computer system. Each individual has an associated user ID.
- Role: A name of job function within the organization that controls this computer system. Typically, associated with each role is a description if the authority and responsibility conferred on this role, and on any user who assumes this role.
- Permission: An approval of a particular mode of access to one or more objects. Equivalent terms are access right, privilege, and authorization.
- Session: A mapping between a user and an activated subset of the set of roles to which the user is assigned.

# RBAC0: Base Model



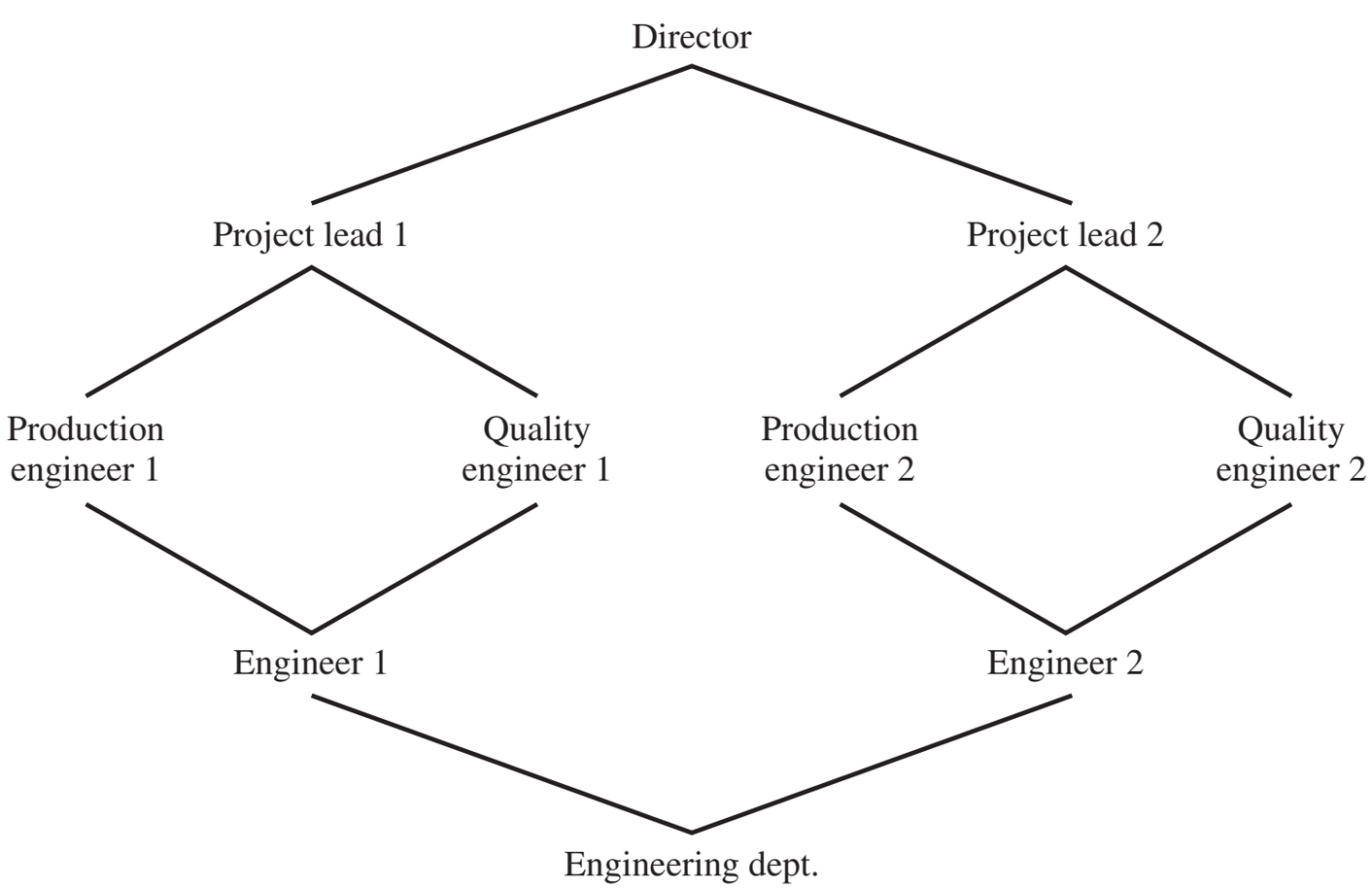

- Many-to-many between users and roles
- Many-to-many between roles and permissions

## Flexibility and Granularity

Without flexibility and granularity, there is a greater risk that a user may be granted more access to resources than is needed because of the limited control over the types of access that can be allowed.

# RBAC1: Role Hierarchies

- Job functions with greater responsibility have greater authority to access resources
- Role hierarchies make use of the concept of inheritance to enable one role to implicitly include access rights associated with a subordinate role



# RBAC2: Constraints

- Constraints provide a means of adapting RBAC to the specifics of administrative and security policies in an organization.
  - Mutually Exclusive Roles
  - Cardinality
  - Prerequisite Roles

# RBAC2: Constraints

- Mutually Exclusive Roles

  Separation of duties and capabilities within an organization

  - A user can only be assigned to one role in the set
  - Any permission (access right) can be granted to only one role in the set

Purpose:  To increase difficulty of collusion among individuals of different skills or divergent job functions to thwart security policies

# RBAC2: Constraints

- Cardinality

  Set a maximum number with respect to roles

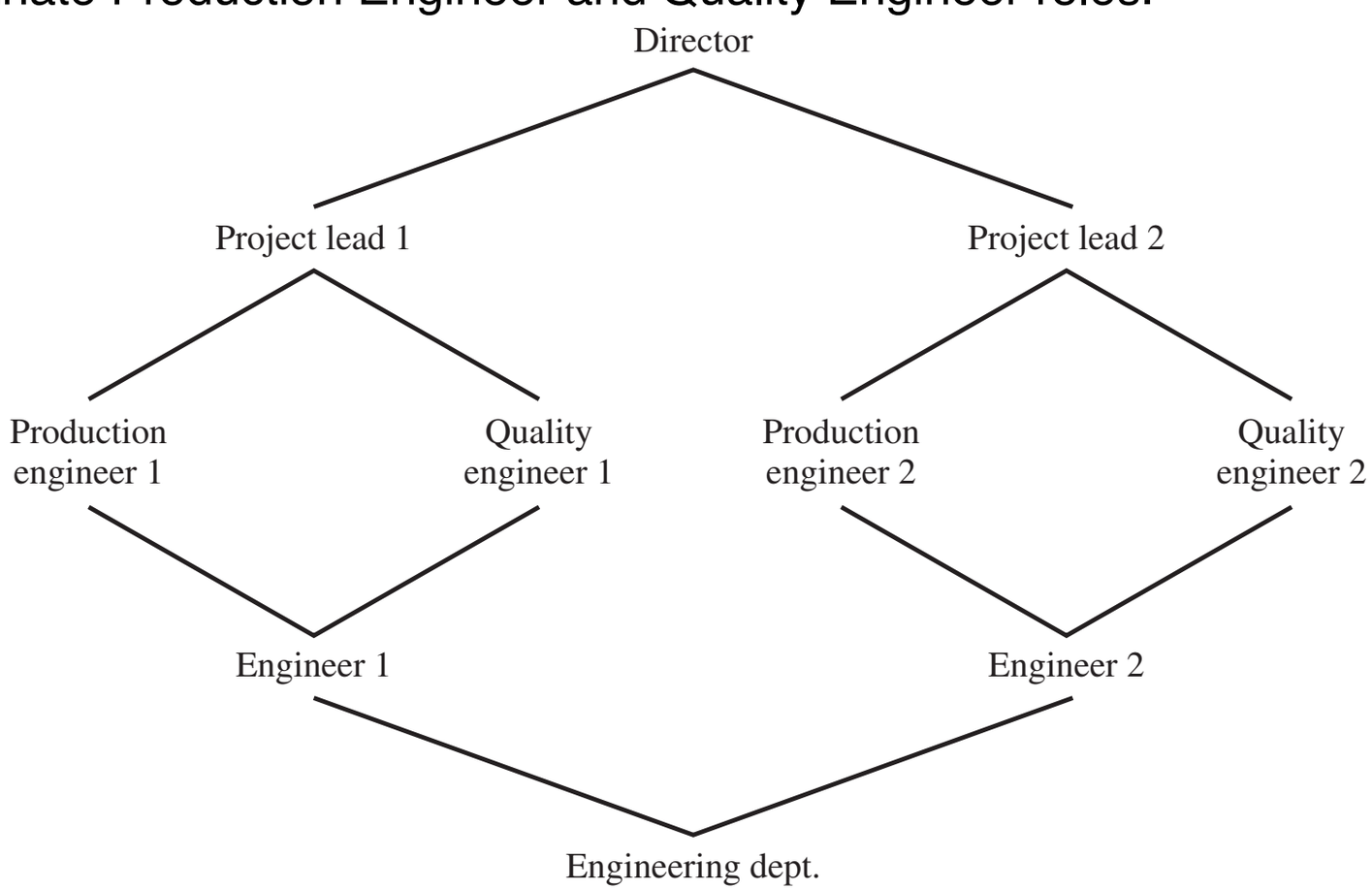
  - Set a maximum number of users that can be assigned to a given role
  - Constraint on the number of roles that is a user assigned to
  - Set a maximum number of roles that can be granted  a particular permission

# RBAC2: Constraints

- Prerequisite role

  A user can only be assigned to a particular role if it is already assigned to some other specified roles

  Example: In a hierarchy, a user assigned to a Project Lead role must also be assigned to at the subordinate Production Engineer and Quality Engineer roles.



# Attribute-Based Access Control (ABAC)

- ABAC controls access based on attributes of the users, the resources to be accessed, and current environmental conditions.
- Flexibility and expressive power

- Three key elements
  - Attributes
  - Architecture Model
  - Policies

# ABAC: Attributes

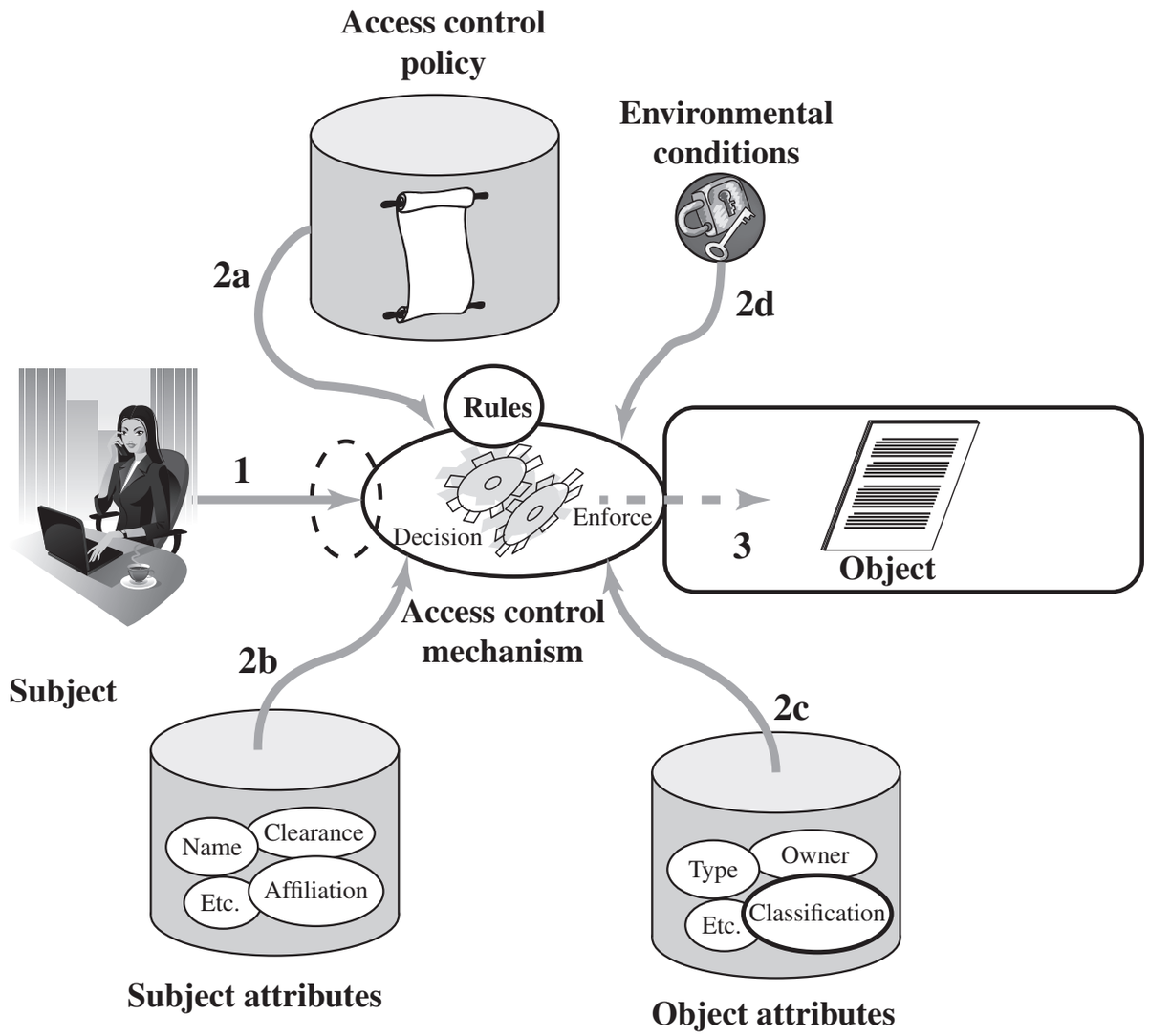
It defines specific aspects of the subject, object, environment conditions, and/or requested operations that are predefined or preassigned by an authority.

- Subject attributes: Define the identity and characteristics of the subject (e.g., the subject's identifier, name, organization, job titles…)
- Object attributes: Can be extracted from the metadata of the object and leveraged to make access control decisions (e.g. title, date, author of a Microsoft Word document )
- Environment attributes (ignored in most access control policies): Describe the operational, technical, and even situational environment or context in which the information access occurs; not associated with a particular subject nor a object/resource (e.g., current data and time, virus/hacker activities, and the network's security level)

# ABAC: Logical Architecture

- Use four independent sources for the access control decision — powerful and flexible

Complexity and Performance Tradeoff



# ABAC: Policies

1. S, O, and E are subjects, objects, and environments, respectively;
2. $SA_k$ $(1 \leq k \leq K)$, $OA_m$ $(1 \leq m \leq M)$, and $EA_n$ $(1 \leq n \leq N)$ are the pre-defined attributes for subjects, objects, and environments, respectively;
3. ATTR($s$), ATTR($o$), and ATTR($e$) are attribute assignment relations for subject $s$, object $o$, and environment $e$, respectively:

$$\texttt{ATTR}(s) \subseteq SA_1 \times SA_2 \times \ldots \times SA_K$$
$$\texttt{ATTR}(o) \subseteq OA_1 \times OA_2 \times \ldots \times OA_M$$
$$\texttt{ATTR}(e) \subseteq EA_1 \times EA_2 \times \ldots \times EA_N$$

4. In the most general form, a Policy Rule, which decides on whether a subject $s$ can access an object $o$ in a particular environment $e$, is a Boolean function of the attributes of $s$, $o$, and $e$:

   $$\texttt{Rule: can\_access } (s, o, e) \leftarrow f(\texttt{ATTR}(s), \texttt{ATTR}(o), \texttt{ATTR}(e))$$

   Given all the attribute assignments of $s$, $o$, and $e$, if the function's evaluation is true, then the access to the resource is granted; otherwise the access is denied.
5. A policy rule base or policy store may consist of a number of policy rules, covering many subjects and objects within a security domain. The access control decision process in essence amounts to the evaluation of applicable policy rules in the policy store.

# ABAC: Example

- An online entertainment store enforces the following access control policy based on the user's age and the movie content rating:

| Movie Rating | Users Allowed Access |
|---|---|
| R | Age 17 and older |
| PG-13 | Age 13 and older |
| G | Everyone |

-RBAC: Three roles (Adult, Juvenile, Child), Tree Permissions (can view R-rated movies, can view PG-13-rated movies, and can view G-rated movies). User-to-role assignment and the permission-to-tole assignment are manual admin tasks.

-ABAC: Without explicitly defining roles! Whether a user u can access a movie m (in a security environment e which is ignored here) would be resolved by evaluating a policy rule below.

$$
\begin{aligned}
&\text{R1:}\mathtt{can\_access}(u,\ m,\ e) \leftarrow \\
&\quad (\mathtt{Age}(u) \geq 17 \wedge \mathtt{Rating}(m) \in \{\mathtt{R},\ \mathtt{PG\text{-}13},\ \mathtt{G}\}) \vee \\
&\quad (\mathtt{Age}(u) \geq 13 \wedge \mathtt{Age}(u) < 17 \wedge \mathtt{Rating(m)} \in \{\mathtt{PG\text{-}13},\ \mathtt{G}\}) \vee \\
&\quad (\mathtt{Age}(u) < 13 \wedge \mathtt{Rating}(m) \in \{\mathtt{G}\})
\end{aligned}
$$