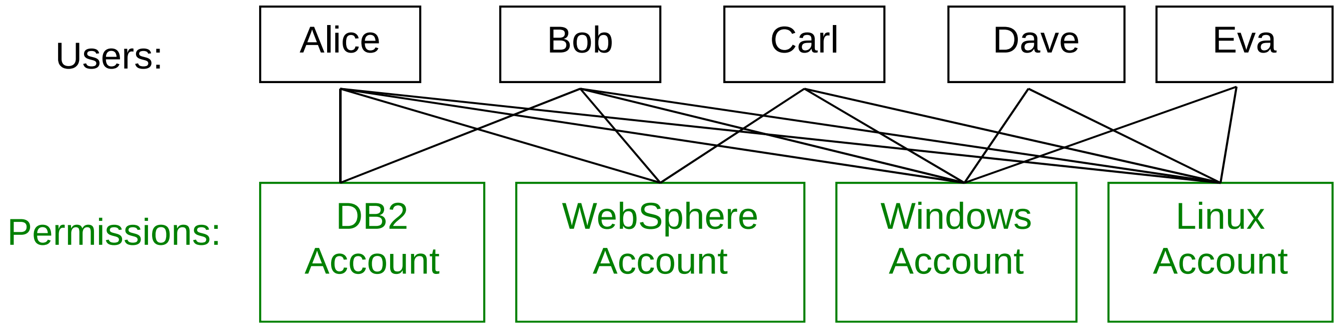
Role-based access control

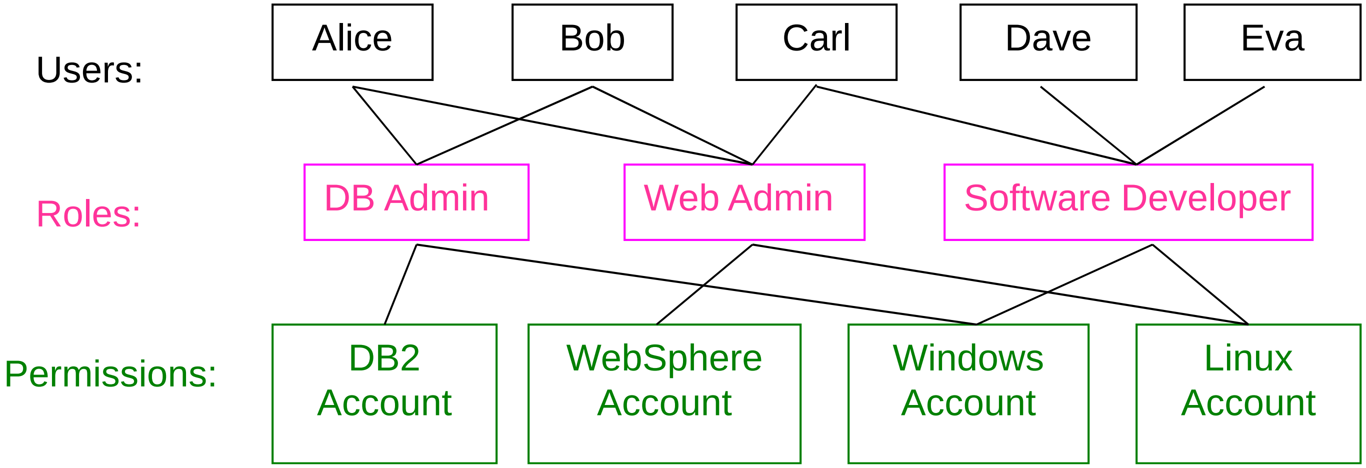
RBAC: Motivations

- Complexity of security administration
  - For large number of subjects and objects, the number of authorizations can become extremely large
  - For dynamic user population, the number of grant and revoke operations to be performed can become very difficult to manage



RBAC: Motivations

- Organizations operate based on roles
  - Roles add a useful level of abstraction
- RBAC assigns permissions to roles in the organization, rather than directly to users
- With roles, there are fewer relationships to manage
  - possibly from O(mn) to O(m+n), where m is the number of users and n is the number of permissions



RBAC: Motivations

- Roles is more stable
  - Users can be easily reassigned from one role to another.
  - Roles can be granted new permissions as new applications and systems are incorporated, and permissions can be revoked from roles as needed
  - Permissions assigned to roles tend to change relatively slowly
- Let administrators confer and revoke user membership in existing roles without authorizing them to create new roles or change role-permission
  - Assigning users to roles requires less technical skill than assigning permissions to roles.

Groups vs. Roles

- Some differences
  - Sets of users vs. sets of users as well as permissions
  - Roles can be activated and deactivated, groups cannot
    - Groups can be used to prevent access with negative authorization.
    - Roles can be deactivated for least privilege
  - Can easily enumerate permissions that a role has, but not for groups
    - Roles are associated with a function, groups not necessarily
  - Roles form a hierarchy, groups don’t

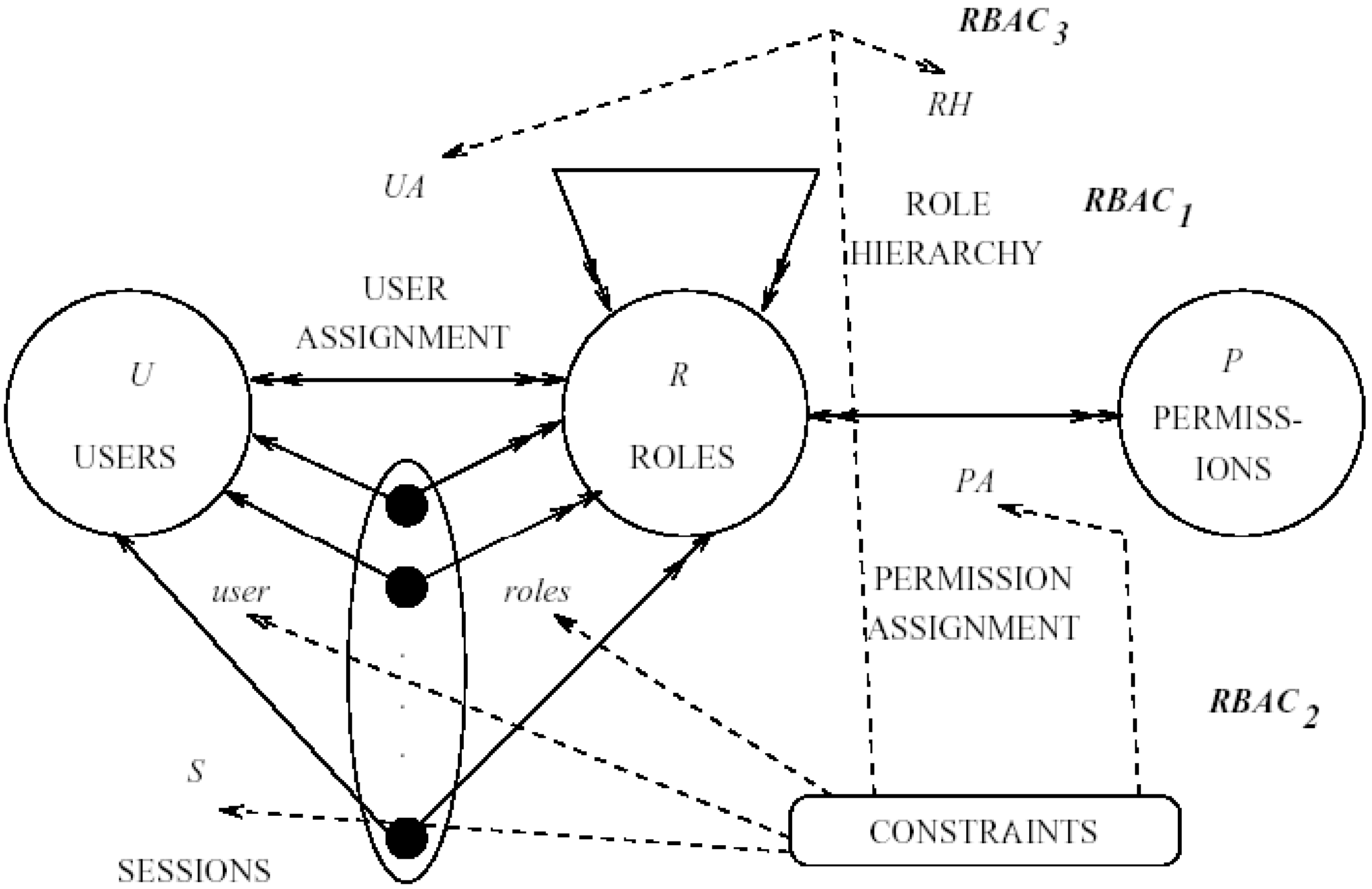
Role-Based Access Control - RBAC

- Simplify authorization management
  - Subject-role-object (role-object is persistent) rather than subject-object
  - Roles are created for various job functions
  - Users are assigned roles based on responsibility
- Express organizational policies
  - Separation of duties (SoD)
    - Define conflicting roles that cannot be executed by the same user
  - Delegation of authority
- Supports
  - Least-privilege
  - SoD
  - Data abstraction

RBAC – Basic Concepts

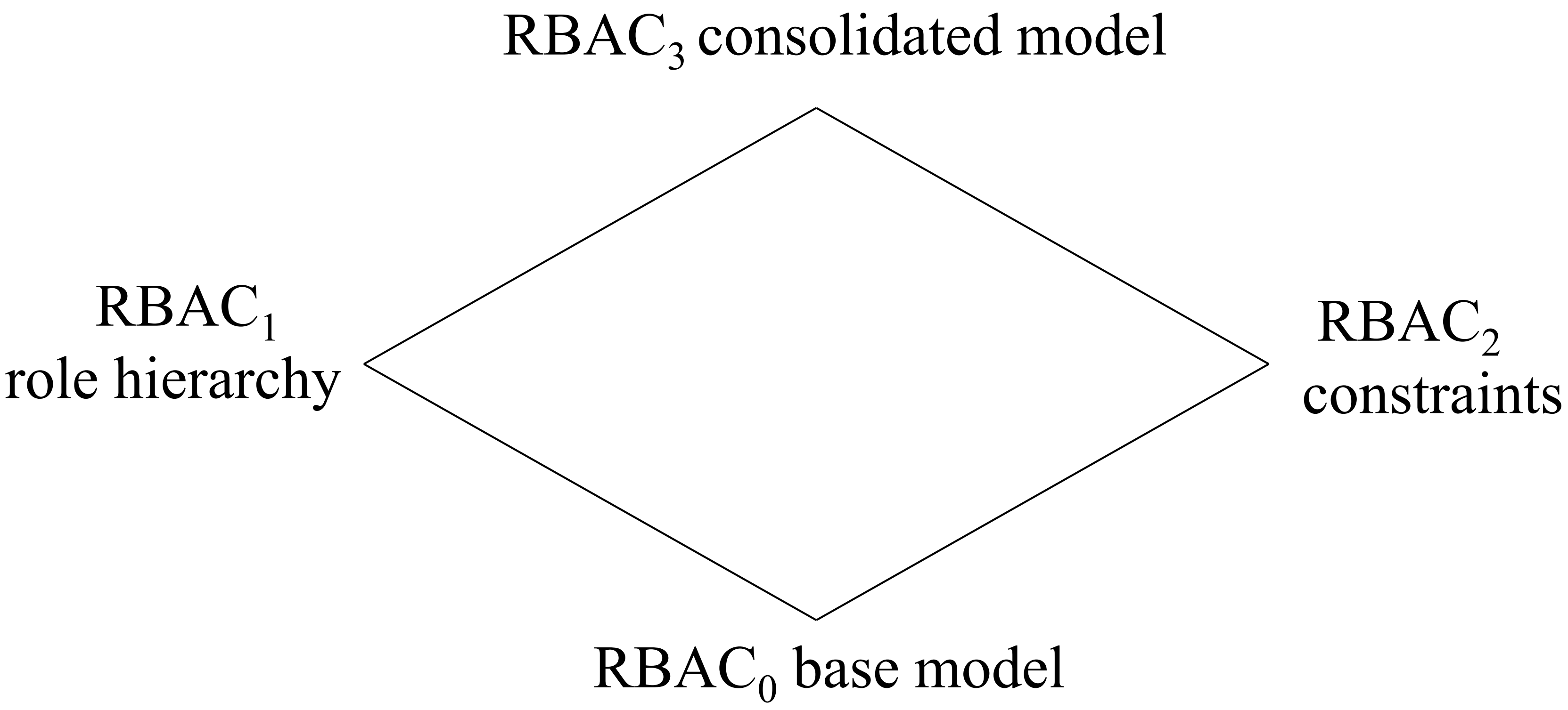
- User – a human being, a machine, a process, or an intelligent autonomous agent, etc.
- Permission: Approval of particular mode of access to an object
  - Access modes and objects are domain dependent
    - OS objects: Files, directories, devices, ports; Access: Read, Write, Execute
    - DB objects: Relation, tuple, attribute, views; Access: Insert, Delete, Update
- Role – job function within the context of an organization with an associated semantics regarding its authority and responsibility
  - mediator between collection of users and collection of permissions
- Permission assignment (PA): role-permission
- User assignment (UA): user-role
- Session: Dynamically activate subset of roles that user is a member of

RBAC Models



R.S. Sandhu, E.J. Coyne, H.L. Feinstein, and C.E. Youman. *Role-based Access Control Models.*
IEEE Computer, 29(2):38--47, February 1996

RBAC



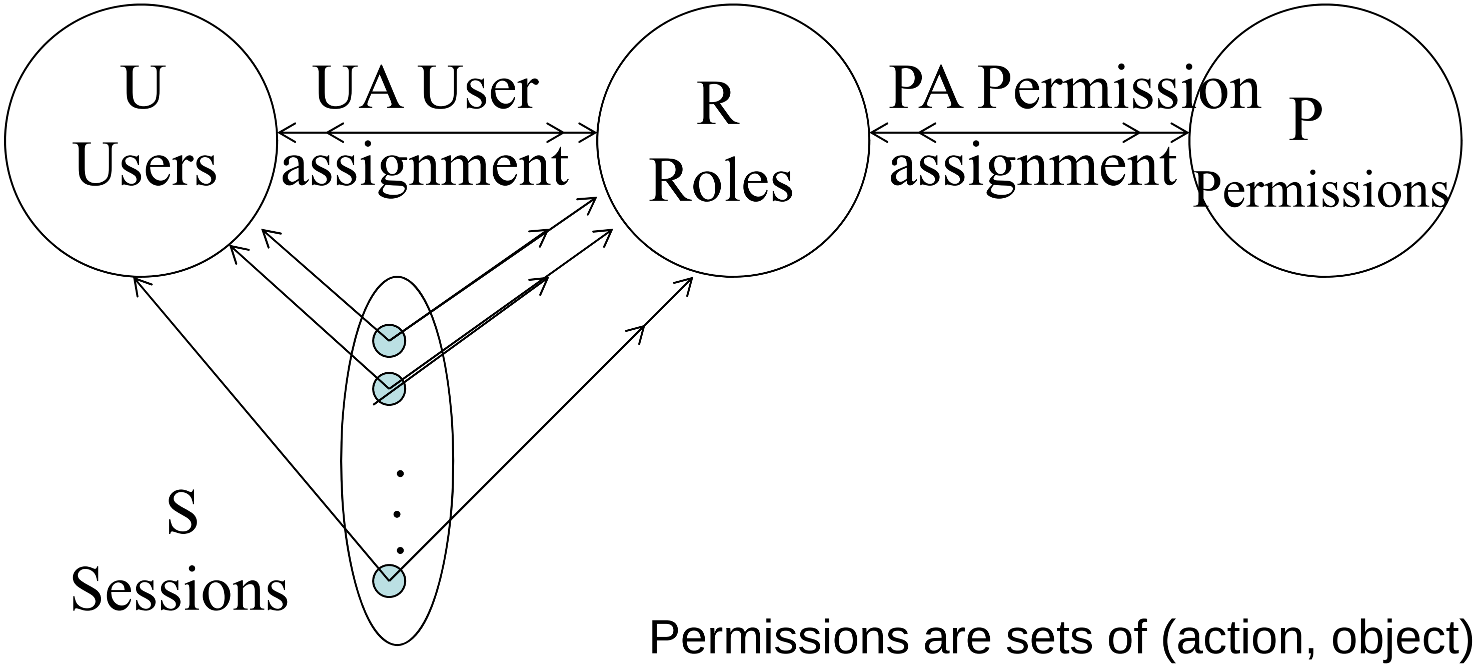
RBAC$_3$ consolidated model

RBAC$_1$
role hierarchy

RBAC$_2$
constraints

RBAC$_0$ base model

$RBAC_0$



Permissions are sets of (action, object) pairs, e.g., (read, Table1), (write, Table2), etc.

RBAC$_0$

- UA: user assignments
  - Many-to-many
- PA: Permission assignment
  - Many-to-many mapping
- 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

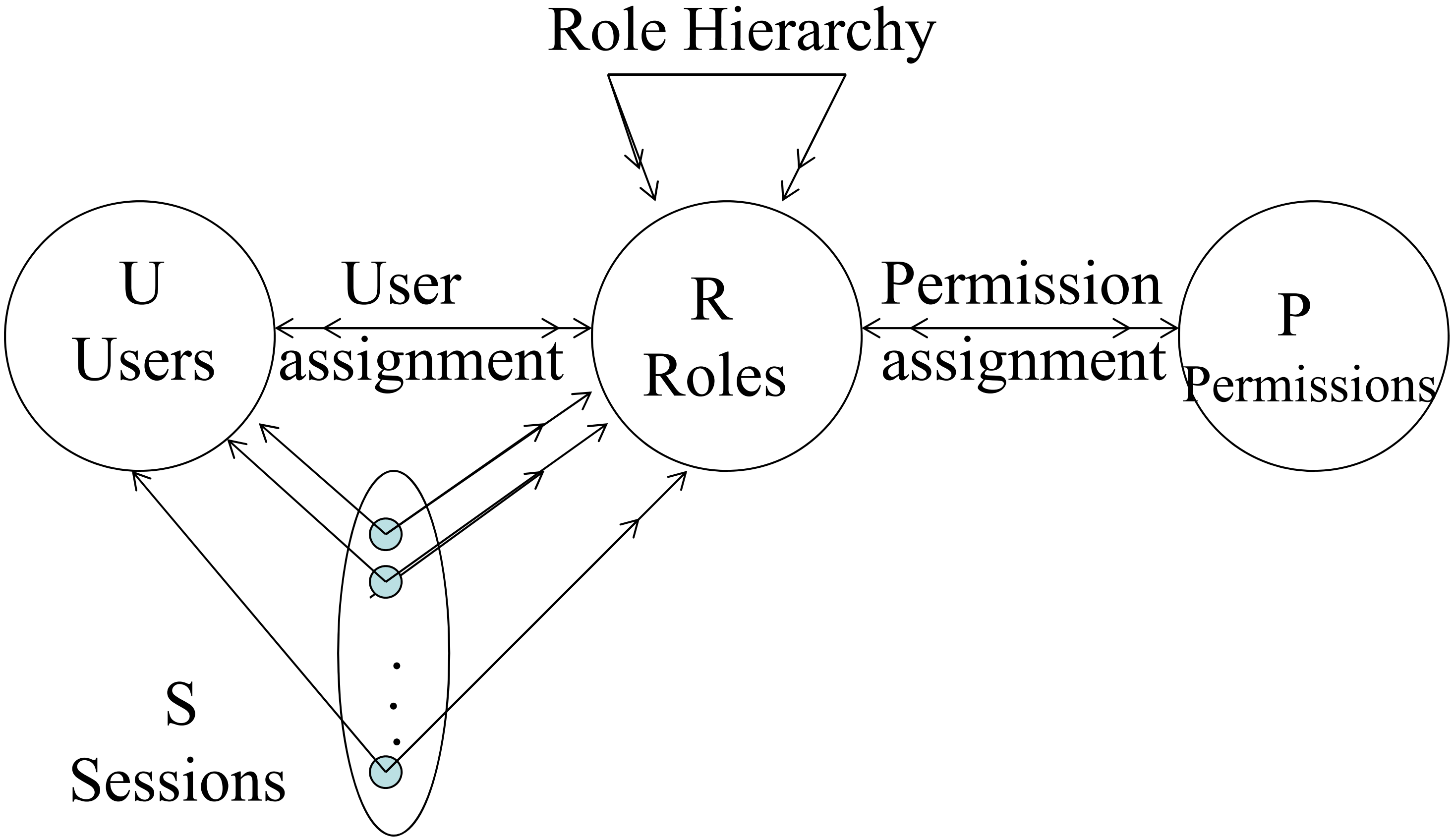
RBAC$_0$ Components

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

RBAC$_0$

- Permissions apply to data and resource objects only
  - 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 – RBAC_0 + Role Hierarchy



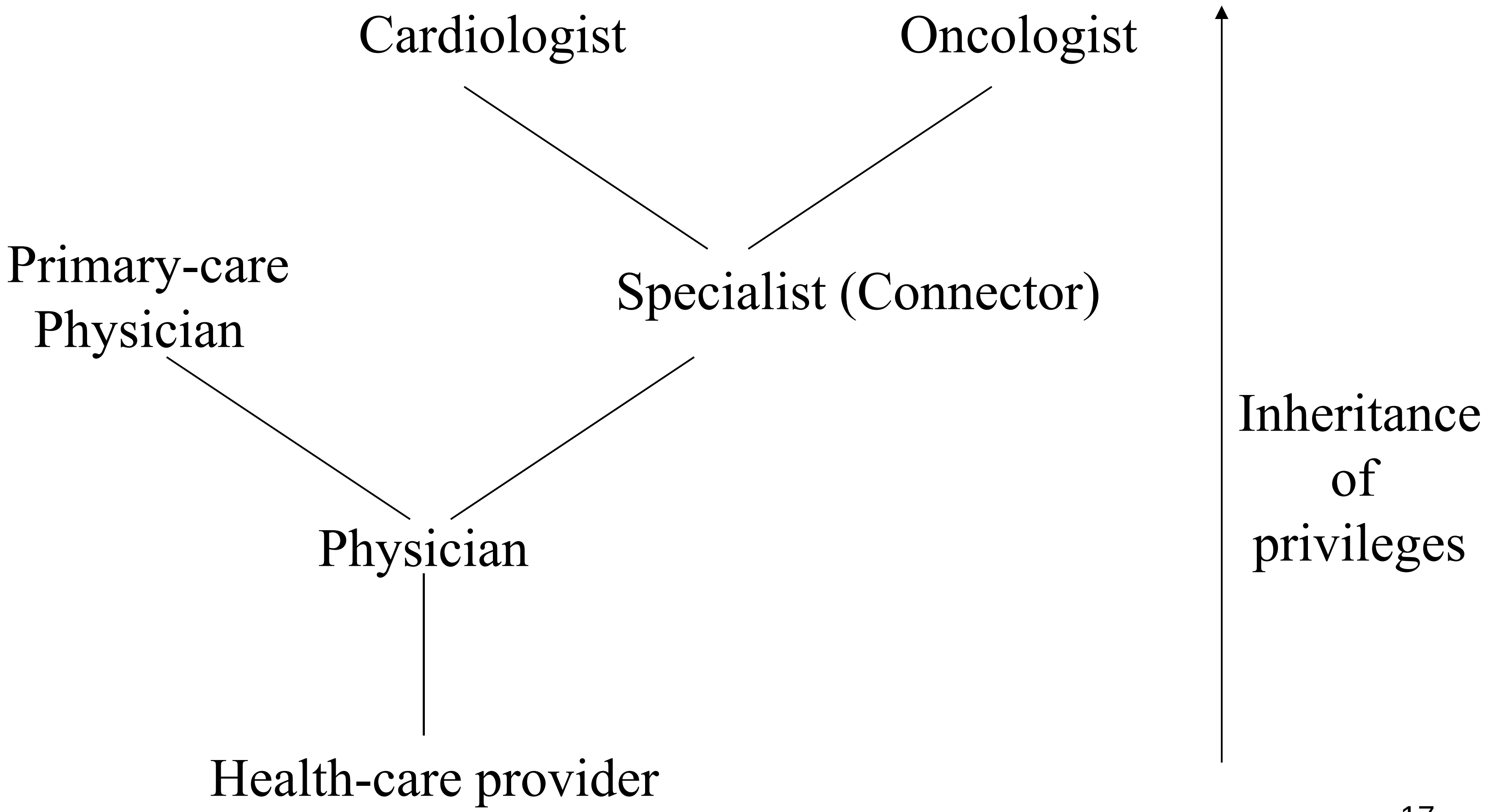
$RBAC_1$

- Role hierarchies for structuring roles to reflect an organization’s line of authority and responsibility
- Inheritance of permission from junior role (bottom) to senior role (top)
- Partial order
  - Reflexive
  - Transitive
  - Anti-symmetric

RBAC_1 Components

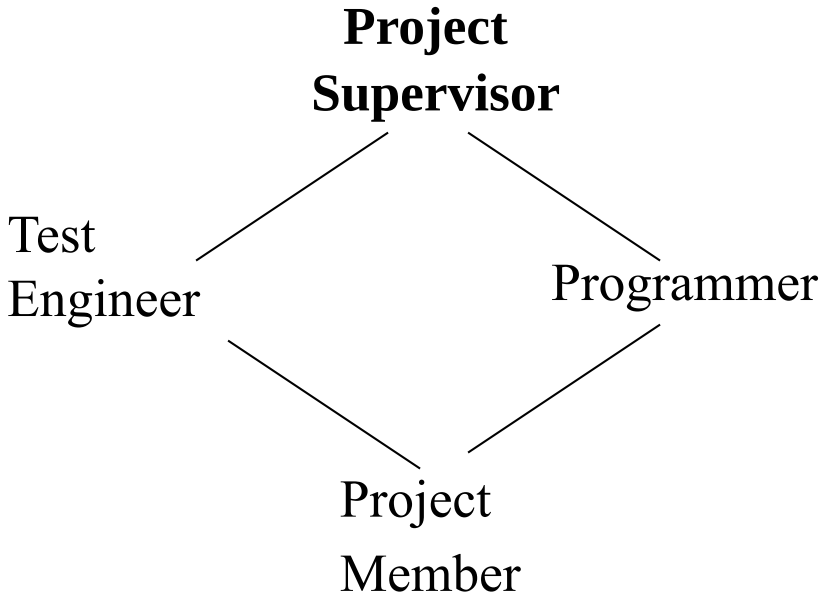
- Same as RBAC_0: **U**sers, **R**oles, **P**ermissions, **S**essions, $PA \subseteq P \times R$, $UA \subseteq U \times R$, user: $S \rightarrow U$, mapping each session s_i to a single user user(s_i)
- $RH \subseteq R \times R$, partial order ($\geq$ dominance)
- roles: $S \rightarrow 2^R$, mapping each session s_i to a set of roles roles(s_i) $\subseteq \{r \mid (\exists r' \geq r)\ [(\text{user}(s_i), r') \in UA]\}$ and s_i has permissions $\cup_{r \in \text{roles(si)}} \{p \mid (\exists r'' \leq r)\ [(p, r'') \in PA]\}$

RBAC$_1$: Role Hierarchy

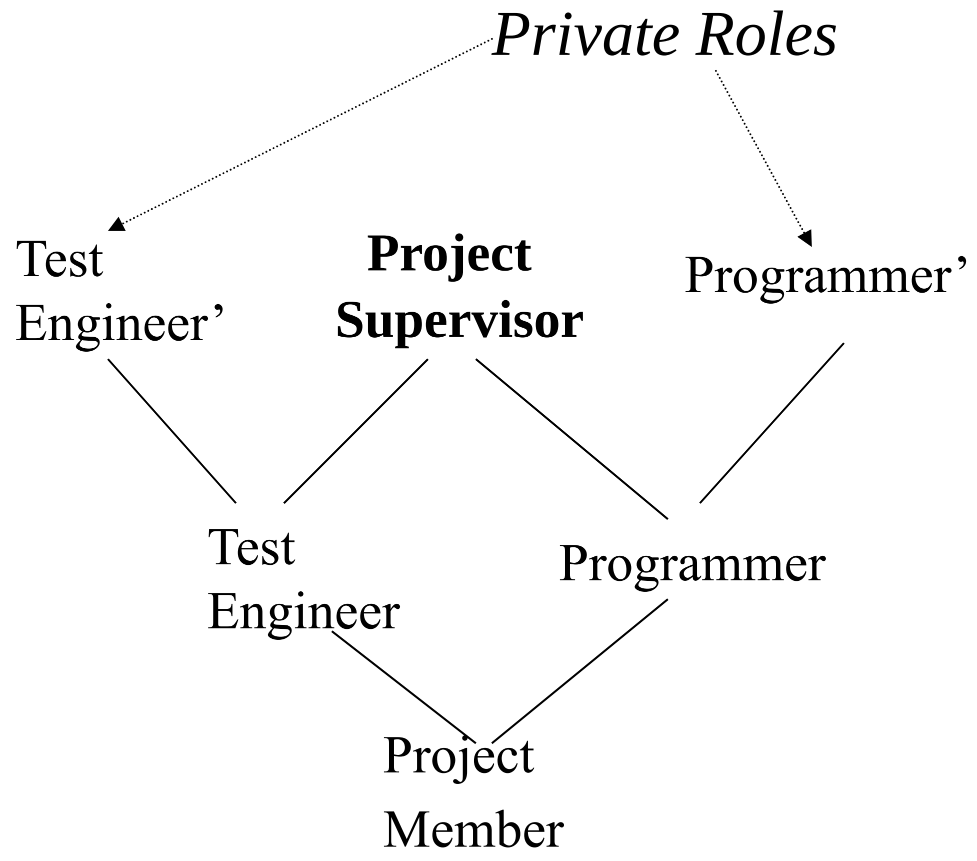


How to limit the scope of inheritance?

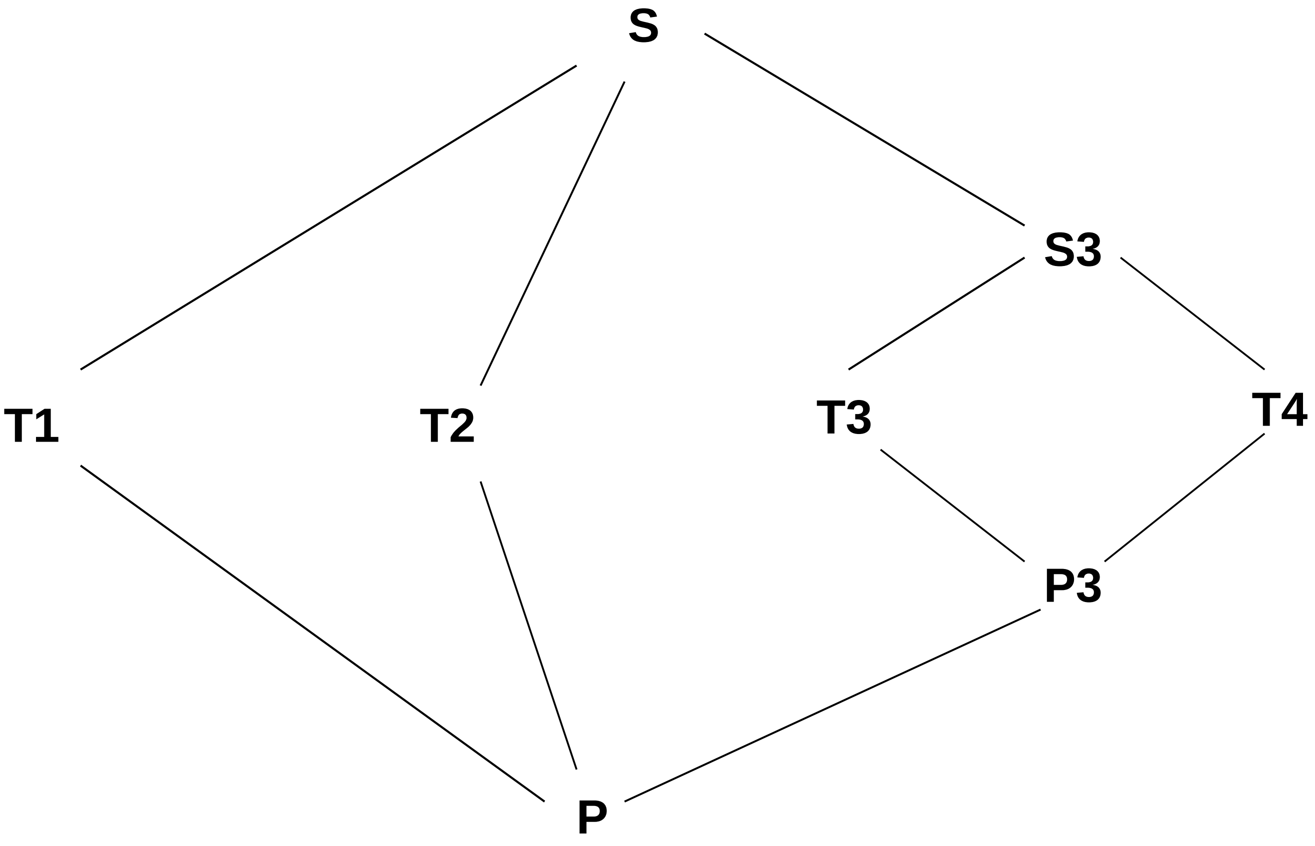
- E.g. do not let boss see incomplete work in progress?



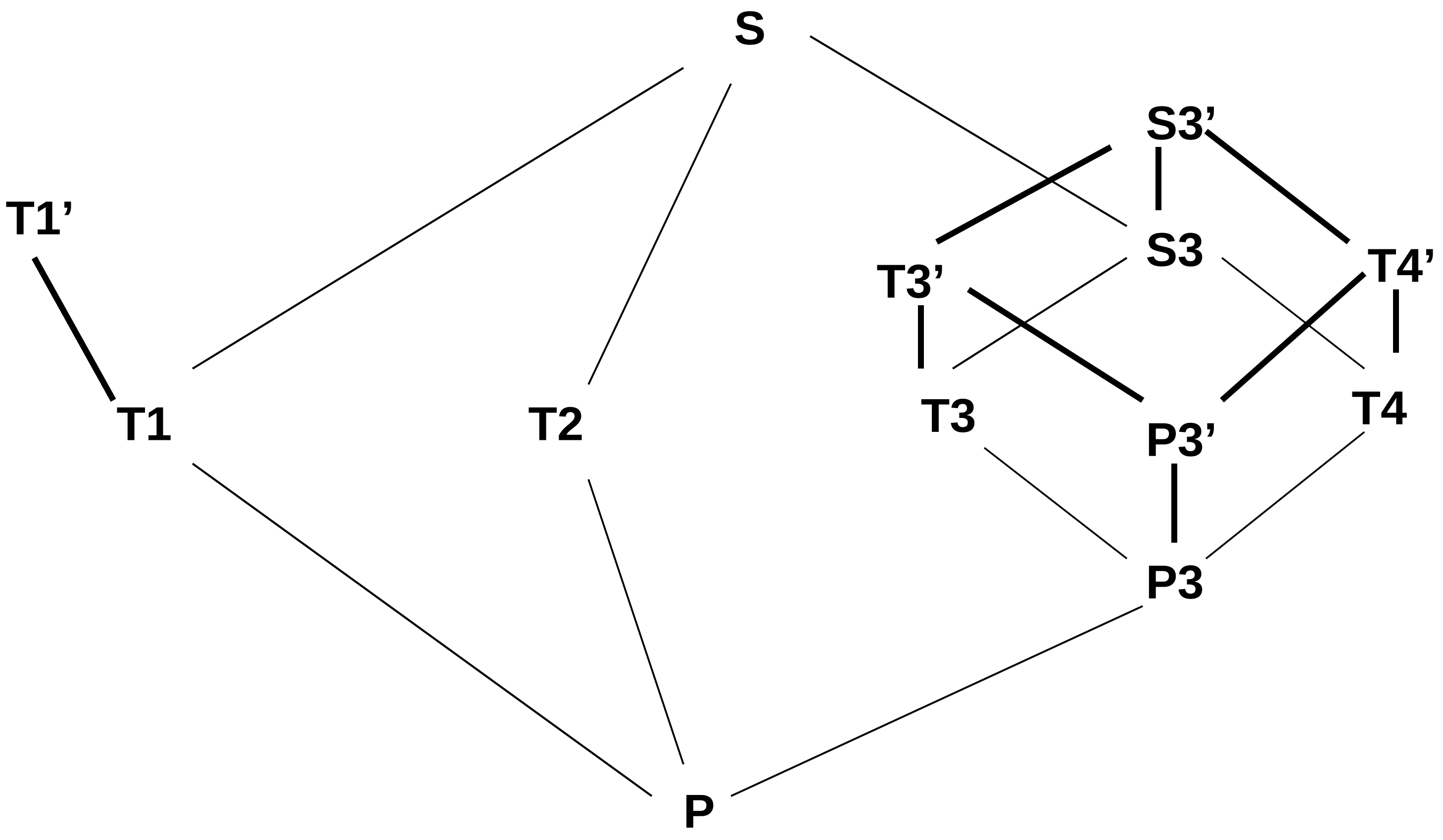
RBAC$_1$ – Limit Scope of Inheritance



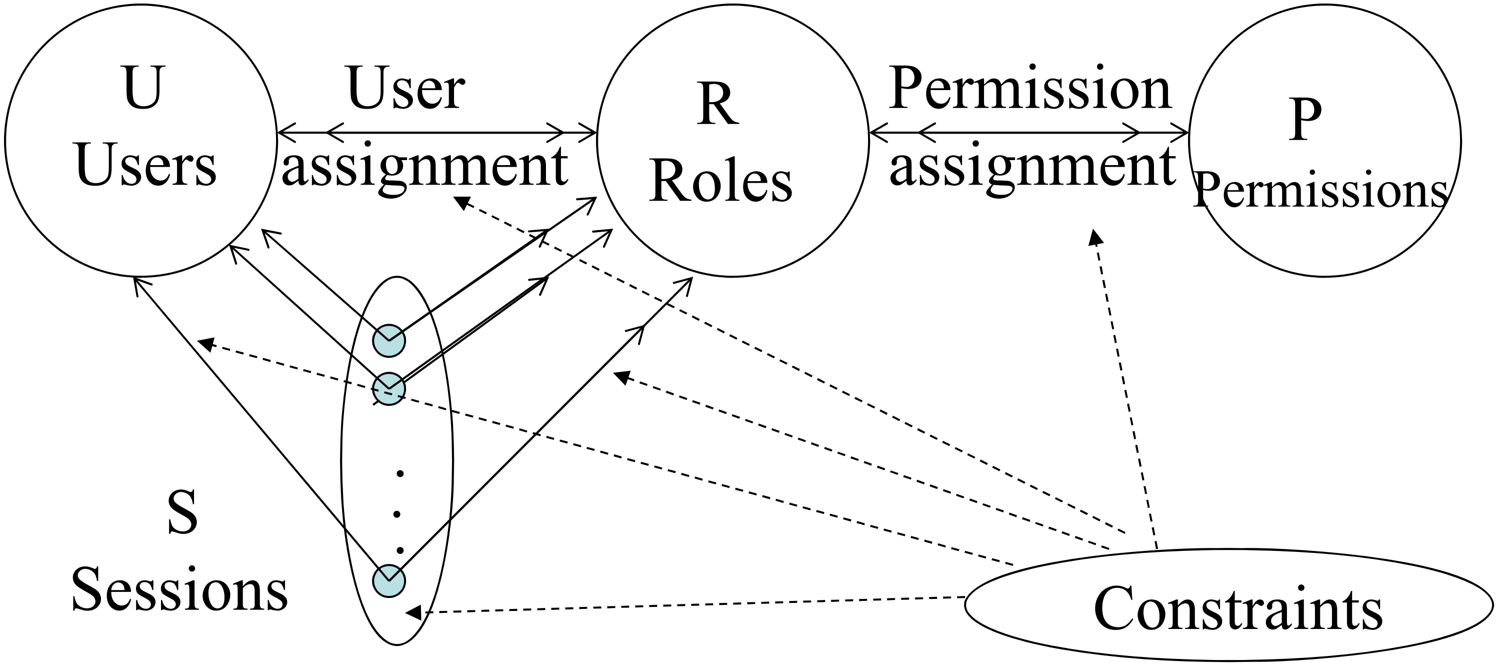
Role Hierarchies with Private Roles



Role Hierarchies with Private Roles



$RBAC_2$ – $RBAC_0$ + Constraints



$RBAC_2$ – $RBAC_0$ + Constraints

- Enforce high-level organizational policies
  - Mutually disjoint roles: Separation of duties
    - UA: Same user cannot be both accounts manager and purchasing manager
    - Violation is caused only as a result of collusion
  - Dual constraint of permission assignment
    - PA: Permission to issue checks cannot be assigned to both accounts & purchasing managers (**limit distribution of powerful permissions**)
  - Cardinality:
    - A role can have maximum number of members
    - Maximum number of roles to each user
    - Any problem in enforcing minimum number?
    - Can also apply to PA
  - Others: Limit number of roles at runtime (per session) or based on history or pre-requisite (e.g., user can only be assigned to the testing role if assigned to project role already; permission to read a file is assigned to a role if permission has been granted to read the directory)
- Any problem if one user has multiple user ids?

RBAC – Static SoD Constraints

- SSoD places restrictions on the set of roles
- No user is assigned to *t* or more roles in a set of *m* roles
- Prevents a person being authorized to use too many roles
- These constraints can be enforced based on the users assigned to each role

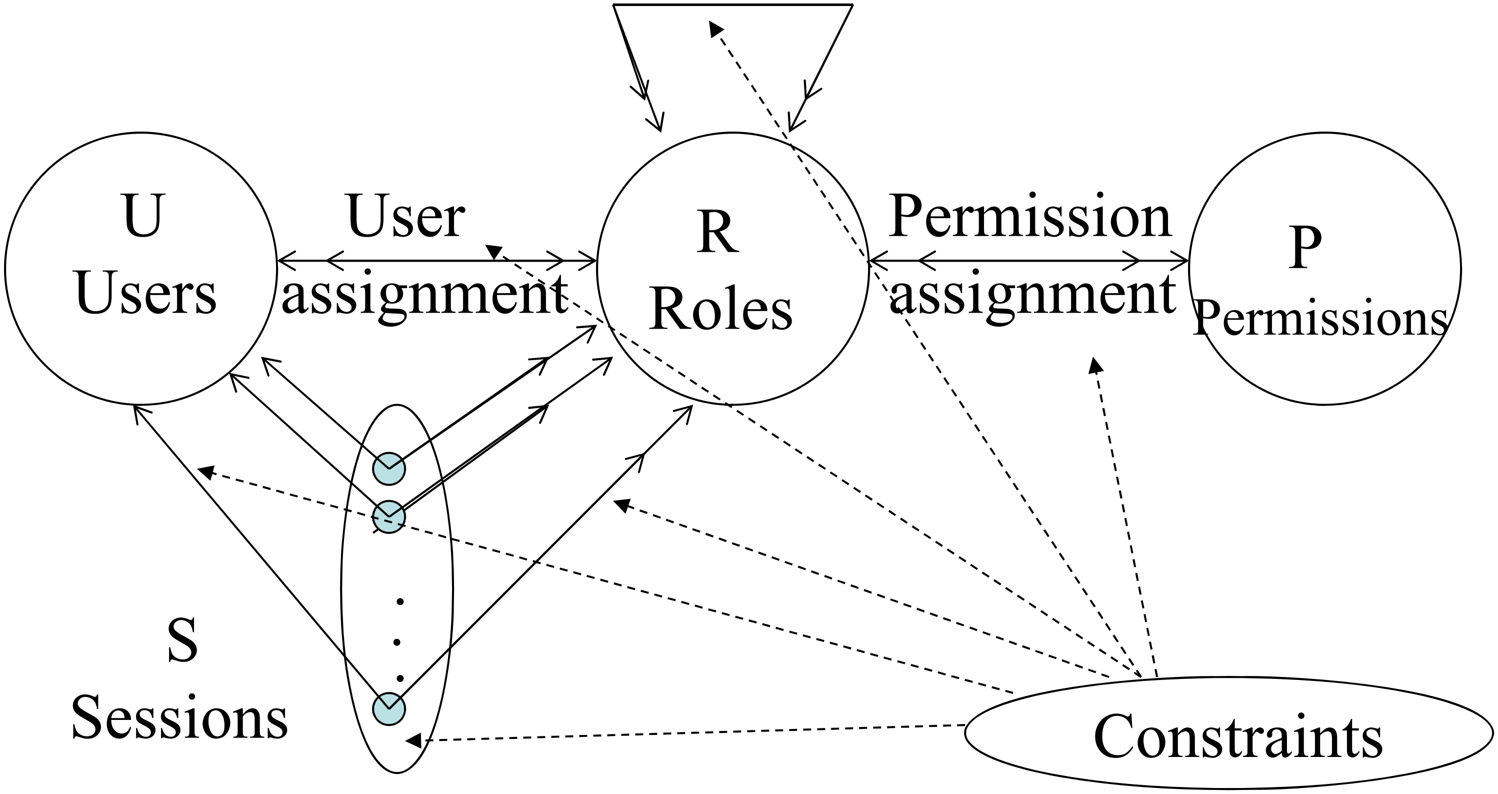
RBAC – Dynamic SoD Constraints

- These constraints limit the number of roles a user can activate in a single session
- Examples of constraints:
  - No user may activate *t* or more roles from the roles set in each user session.
  - If a user has used role *r*1 in a session, he/she cannot use role *r*2 in the same session
    - What if user terminates one session in one role and logs in with another role?
- Enforcement of these roles requires keeping the history of the user access to roles within a session

$RBAC_2$

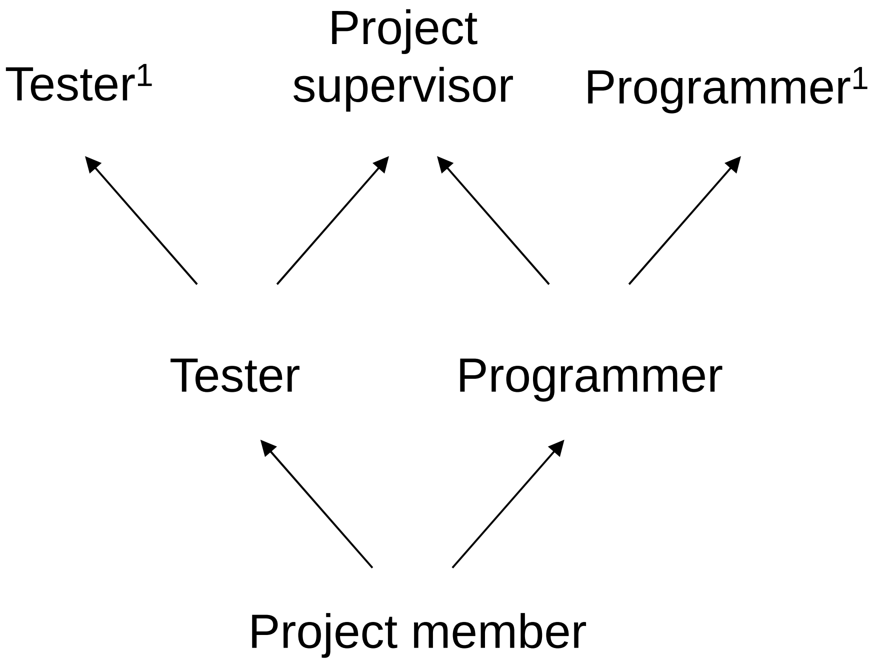
- How to implement role hierarchy with constraints?
  - Specify a constraint that a permission assigned to a (junior) role must also be assigned to an inherited (senior) role
  - Specify a constraint that a user assigned to a (senior) role must also be assigned to any parent (junior) role
- $RBAC_1$ is redundant (?)

RBAC_3 – RBAC_1 + RBAC_2

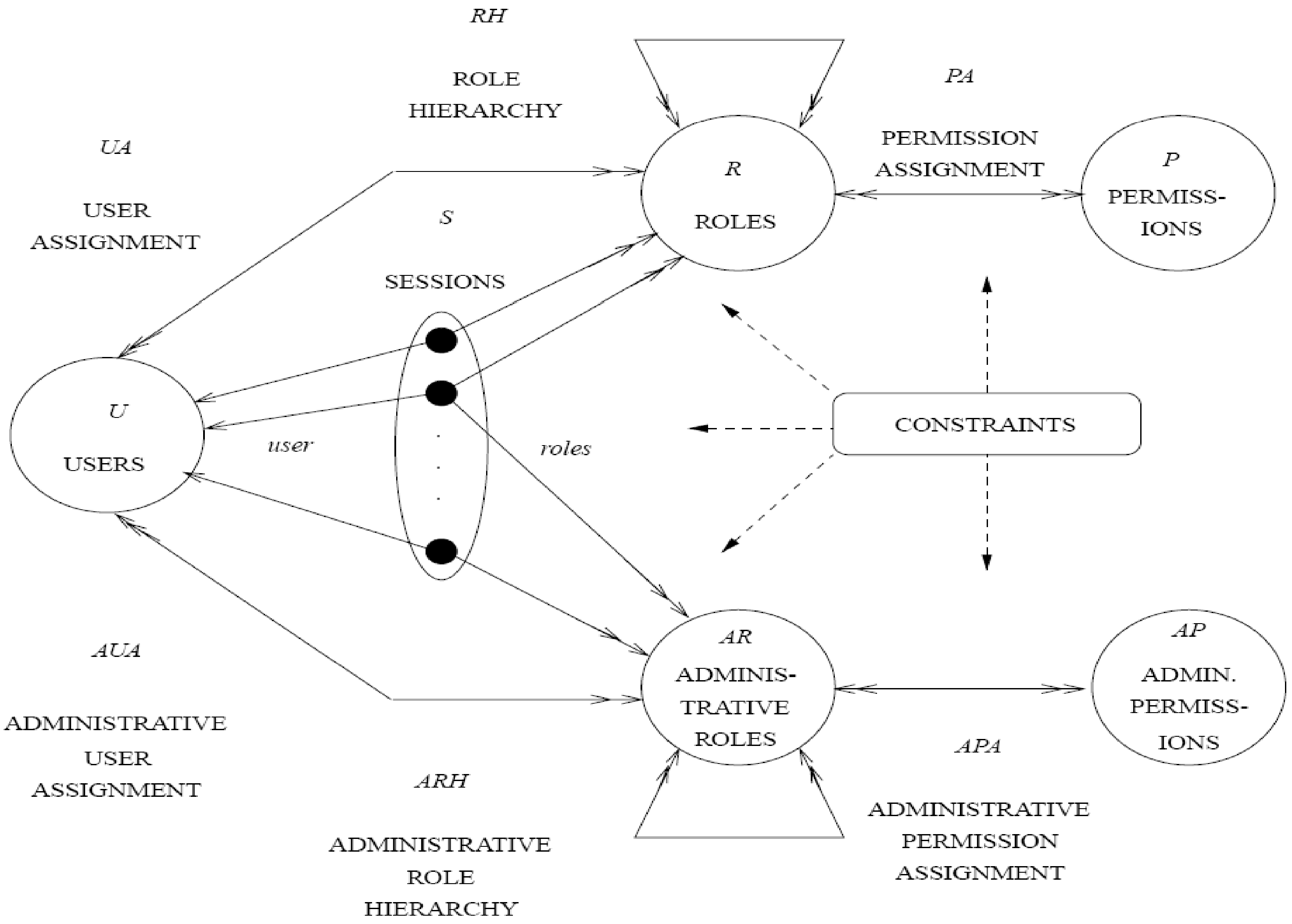


$RBAC_3$ – $RBAC_1$ + $RBAC_2$

- Constraints can apply to role hierarchy
  - E.g. 2 or more roles cannot have common senior/junior role
  - E.g. limit the number of senior/junior roles that a given role may have
- Interactions between RH and constraints
  - E.g. Programmer & tester are mutually exclusive. Project supervisor inherits both sets of permissions. How?
  - E.g., Cardinality constraint – a user can be assigned to at most one role. How about Tester? Do cardinality constraint applies to only direct membership or they also carry on to inherited membership?
- Private roles
  - E.g., setting Tester to (max) cardinality of zero means supervisor and Tester (aka Tester1) are mutually exclusive



RBAC Models (+ Administrative Roles)



RBAC System and Administrative Functional Specification

- Administrative Operations
  - Create, Delete, Maintain elements and relations
- Administrative Reviews
  - Query operations
- System Level Functions
  - Creation of user sessions
  - Role activation/deactivation
  - Constraint enforcement
  - Access Decision Calculation

Case Study: Oracle Enterprise Server

- Create password-protected role for update
  - Create role update_role identified by passwd;
- Grant update privileges to protected role
  - Grant insert, update on app.table1 to update_role;
- Create non-password protected role for query
  - Create role query_role;
- Grant select privileges to unprotected role
  - Grant select on app.table1 to query_role;
- Grant both roles to users
  - Grant update_role, query_role to user1;

Case Study: Oracle Enterprise Server

- User1 activates the roles
  - Set role update_role identified by passwd, query_role;
- Set default active role for User1
  - Alter user user1 default role query_role;
- Assignable privileges
  - System: create session, create table, select any table
  - Object:
    - Table: select, update, insert, delete, alter, create index
    - View: select, update, insert, delete
    - Procedures & functions: execute

Comparison of DBMSs

Item	Feature	Informix	Sybase	Oracle
1	Ability for a role grantee to grant that role to other users	Yes	No	Yes
2	Multiple active roles for a user session	No	Yes	Yes
3	Specify a default active role set for a user session	No	Yes	Yes
4	Build a role hierarchy	Yes	Yes	Yes
5	Specify static separation of duty constraints on roles	No	Yes	No
6	Specify dynamic separation of duty constraints on roles	(Yes)	Yes	No
7	Specify maximum or minimum cardinality for role memberships	No	No	No
8	Grant DBMS system privileges to a role	No	Yes	Yes
9	Grant DBMS object privileges to a role	Yes	Yes	Yes

Source: Role-Based Access Control Features in Commercial Database Management Systems, C. Ramaswamy, R. Sandhu

Configuring RBAC to Enforce MAC and DAC

S. Osborn, R. Sandhu and Q. Munawer. ***Configuring Role-based Access Control to Enforce Mandatory and Discretionary Access Control Policies*. ACM Trans. Information and Systems Security. 3, 2 (May 2000), Pages 85-106.**

Configuring RBAC for MAC

- *Construction (Liberal *-Property) (write-up)*

  R = {L1R. . . LnR, L1W. . . LnW} where Li denote label i

  RH which consists of two disjoint role hierarchies. The first role hierarchy consists of the "read" roles *{L1R. . . LnR}* and has the same partial order as $\geq_{MAC}$; the second partial consists of the "write" roles *{L1W. . . LnW}* and has a partial order which is the inverse of $\geq_{MAC}$.

  P = { (o,r),(o,w) | o is an object in the system}

  Constraint on *UA*: Each user is assigned to exactly two roles xR and LW where x is the label assigned to the user and LW is the write role corresponding to the lowermost security level according to $\geq_{MAC}$

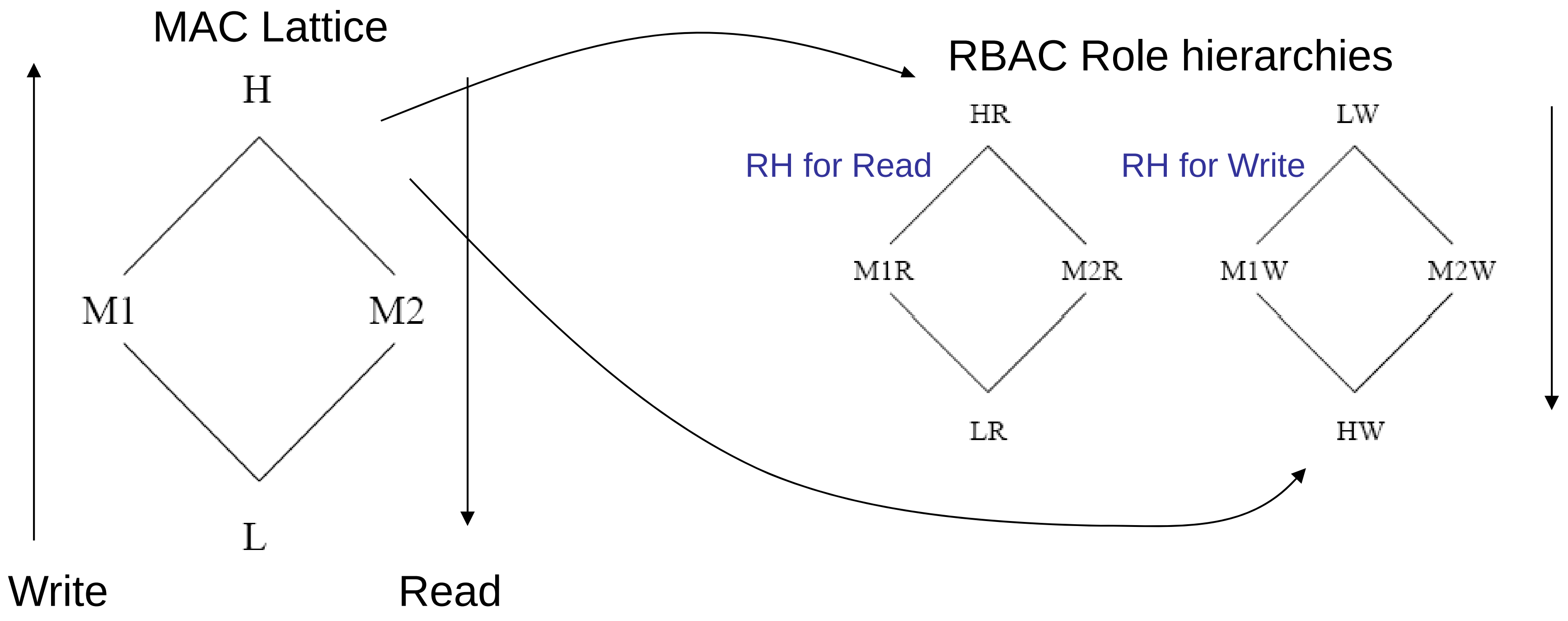
  Constraint on sessions: Each session has exactly two roles yR and yW (x ≥ y)

  Constraints on *PA*:

  (o,r) is assigned to xR iff (o,w) is assigned to xW

  (o,r) is assigned to exactly one role xR such that x is the label of o

Configuring RBAC for MAC



Each user with label x is assigned roles xR & LW (why?)

Additional Constraints:

- Each session has exactly two matching roles yR and yW ($x \geq y$)
- For each object with label x, a pair of permissions (o,r) & (o,w) is assigned to exactly one matching pair of xR and xW roles

Traditional MAC

H
|
M
|
L

Privileges at logon

	H	M	L
H	R/W	R	R
M	W	R/W	R
L	W	W	R/W

Overall privileges

	H	M	L
H	R/W	R/W	R/W
M	W	R/W	R/W
L	W	W	R/W

RBAC simulation of MAC: Case 1

Login mismatch

	H	M	L
(H, H)	R/W	R/W	R/W
(M, M)		R/W	R/W
(L, L)			R/W

Overall mismatch

H
|
M
|
L

	H	M	L
H	R	R	R
M		R	R
L			R

	H	M	L
H	W	W	W
M		W	W
L			W

H
|
M
|
L

Traditional MAC

H
|
M
|
L

Privileges at logon

	H	M	L
H	R/W	R	R
M	W	R/W	R
L	W	W	R/W

Overall privileges

	H	M	L
H	R/W	R/W	R/W
M	W	R/W	R/W
L	W	W	R/W

Logon match

RBAC simulation of MAC: Case 2

	H	M	L
(H, H)	R/W	R	R
(M, M)	W	R/W	R
(L, L)	W	W	R/W

Match??

H
|
M
|
L

	H	M	L
H	R	R	R
M		R	R
L			R

	H	M	L
L	W	W	W
M	W	W	
H	W		

L
|
M
|
H

Traditional MAC

H
|
M
|
L

Privileges at logon

	H	M	L
H	R/W	R	R
M	W	R/W	R
L	W	W	R/W

Overall privileges

	H	M	L
H	R/W	R/W	R/W
M	W	R/W	R/W
L	W	W	R/W

Logon match

RBAC simulation of MAC: Case 2

	H	M	L
(H, H)	R/W	R	R
(M, M)	W	R/W	R
(L, L)	W	W	R/W

Problem?
User with (H, H) cannot
“logon as” (inherit) (M, M) since H
for write is junior to M!

H
|
M
|
L

	H	M	L
H	R	R	R
M		R	R
L			R

	H	M	L
L	W	W	W
M	W	W	
H	W		

L
|
M
|
H

Traditional MAC

H
|
M
|
L

Privileges at logon

	H	M	L
H	R/W	R	R
M	W	R/W	R
L	W	W	R/W

Overall privileges

	H	M	L
H	R/W	R/W	R/W
M	W	R/W	R/W
L	W	W	R/W

Logon match

Overall match

Restrict at runtime

RBAC simulation of MAC: Case 3

Static

	H	M	L
(H, L)	R/W	R/W	R/W
(M, L)	W	R/W	R/W
(L, L)	W	W	R/W

	H	M	L
(H, H)	R/W	R	R
(M, M)	W	R/W	R
(L, L)	W	W	R/W

H
|
M
|
L

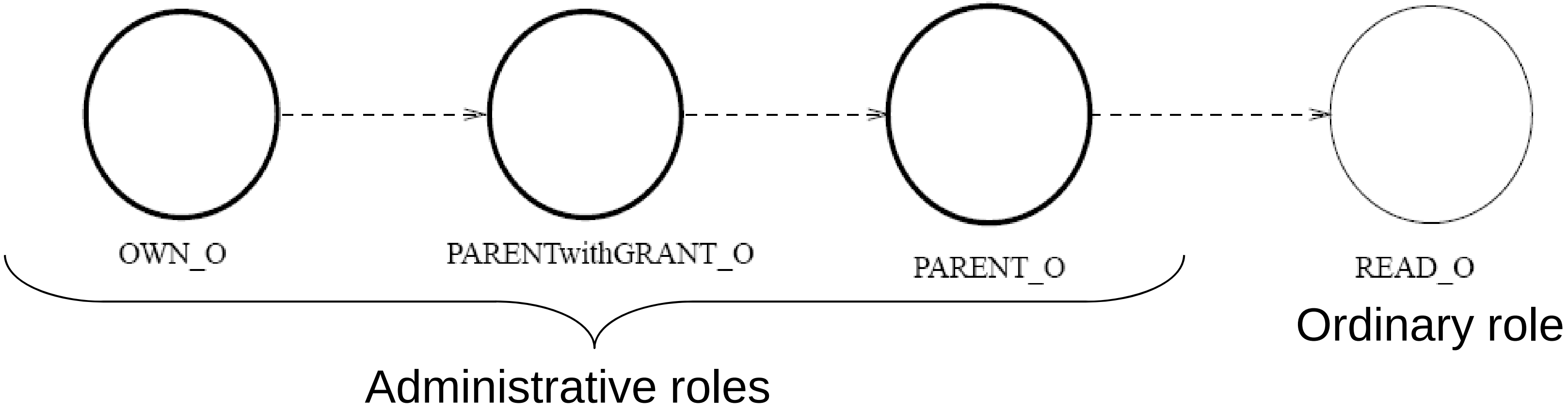
	H	M	L
H	R	R	R
M		R	R
L			R

	H	M	L
L	W	W	W
M	W	W	
H	W		

L
|
M
|
H

Configuring RBAC for DAC

- The basic idea is to simulate the owner-centric policies of DAC using roles that are associated with each object.
  - Strict DAC – only owner can grant access
  - Liberal DAC – owner can delegate discretionary authority for granting access to an object to other users
- *Create an Object*. For every object O that is created, three administrative roles and one regular role are also created (we show only Read operation)



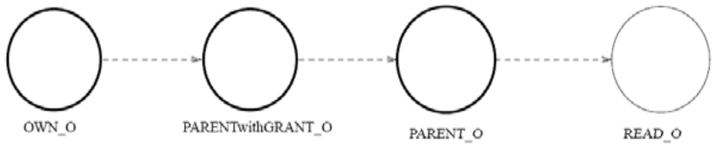
Eight Permissions

- The following eight permissions are also created along with creation of each object O.
  - canRead_O: assigned to the role READ_O (authorizes read operation on object O)
  - destroyObject_O: assigned to the role OWN_O (authorizes deletion of the object)
  - addReadUser_O, deleteReadUser_O: assigned to the role PARENT_O (add/remove users to/from role READ_O)
  - addParent_O, deleteParent_O: assigned to the role PARENTwithGRANT_O (add/remove users to/from role PARENT_O)
  - addParentWithGrant_O, deleteParentWithGrant_O: assigned to the role OWN_O (add/remove users to/from PARENTwithGRANT_O)
- Object deletion removes the roles OWN_O, PARENT_O, PARENTwithGRANT_O and READ_O along with the 8 permissions

Roles and associated Permissions

- OWN_O
  - destroyObject_O, addParentWithGrant_O, deleteParentWithgrant_O
- PARENTwithGRANT_O
  - addParent_O, deleteParent_O
- PARENT_O
  - addReadUser_O, deleteReadUser_O
- READ_O
  - canRead_O

Strict DAC

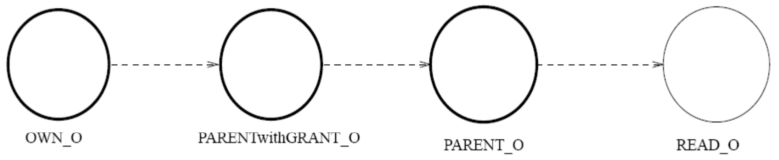


- Only owner has discretionary authority to grant access to an object.
- Example:
  - Alice has created an object (she is owner) and grants access to Bob. Now Bob cannot propagate the access to another user.
- Cardinality constraints on roles:
  - OWN_O = 1
  - PARENT_O = 0
  - PARENTwithGRANT_O = 0
- By virtue of the role hierarchy, owner can change assignments of the role READ_O

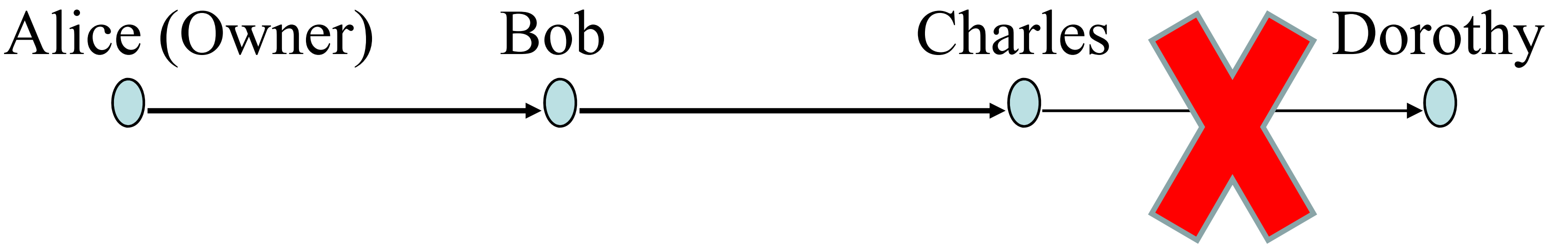
Liberal DAC

- Owner can delegate discretionary authority for granting access to other users.
  - One Level grant
  - Two Level Grant
  - Multilevel Grant

One Level Grant

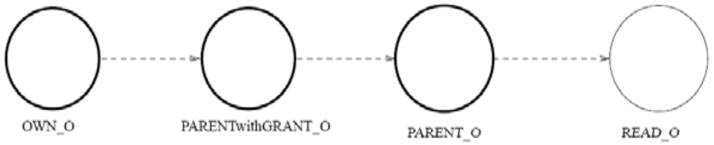


- Owner can delegate authority to another user but they *cannot* further delegate this power.

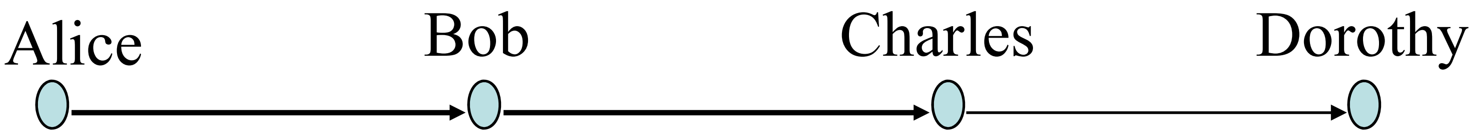


- Cardinality constraints as:
  - Role OWN_O = 1
  - Role PARENTwithGRANT_O = 0
  - No restriction on Parent_O

Two Level Grant

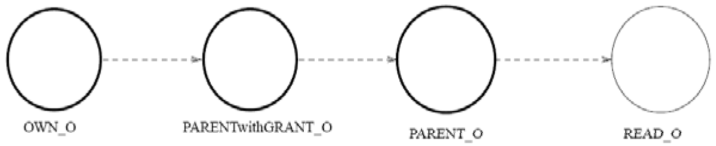


- In addition to a one level grant *the owner* can allow some users to delegate grant authority to other users.



- Cardinality constraints as:
  - Role OWN_O = 1

Multi-Level Grant

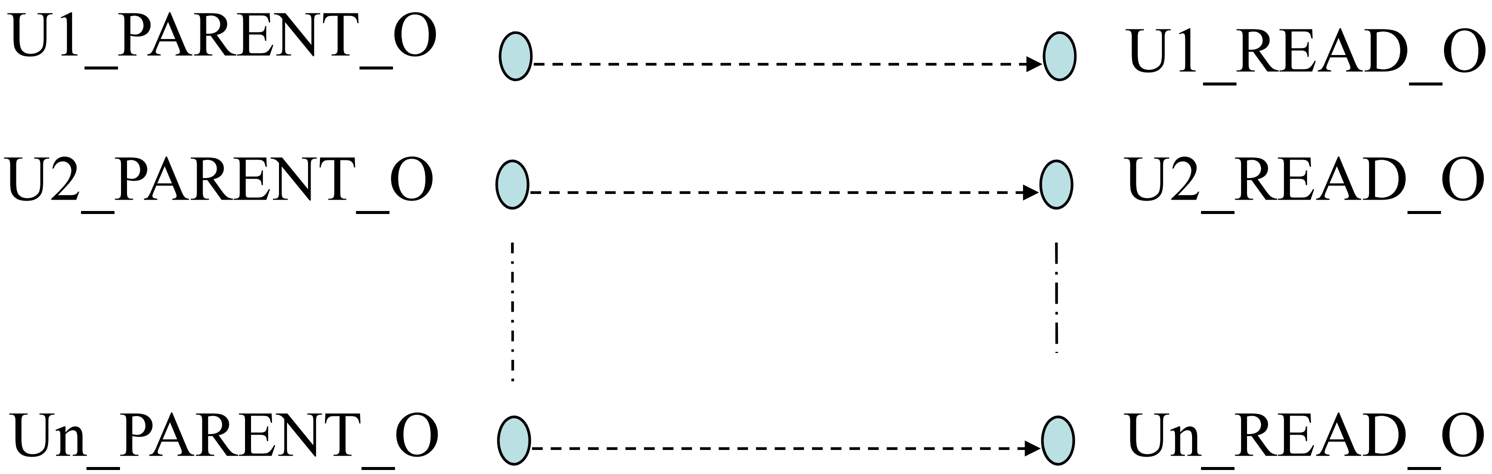


- In addition to a one level grant the owner can allow *some users* to delegate grant authority to other users.
- Cardinality constraints as:
  - Role OWN_O = 1
- Additional permission
  - PARENTwithGRANT_O
    - AddParentWithGrant_O
    - DeleteParentWithGrant_O
      - Grant independent revocation
      - Alternatively, leave delete with OWN_O

Revocation

- Grant-Independent Revocation
  - Grant may be revoked by anyone (not necessarily the granter)
  - Alice grants Bob access, but Bob’s access may be revoked by Charles
- Grant-Dependent Revocation
  - Revocation is tied to the granter
  - Alice grants Bob access, and only Alice can revoke Bob’s access

Grant-Dependent Revocation (One-level grant)



READ_O role associated with members of PARENT_O

We need a different administrative role U_PARENT_O and a regular role U_READ_O *for each user* U authorized to do a one-level grant by owner. We also need two new administrative permissions

- addU_ReadUser_O, deleteU_ReadUser_O: assigned to U_PARENT_O
- authorize the operations to add users to role U_Read_O and delete users from U_Read_O
- cardinality of U_PARENT_O = 1

Summary

- Group is NOT the same as Role
- Role hierarchy is NOT the same as company (report-to) hierarchy
- RBAC can support SoD, data abstraction and least privilege
- RBAC can be used to configure DAC and MAC