Relationship-Based Access Control (ReBAC)

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Lecture 6

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Access Control

Fixed policy

Discretionary Access Control (DAC), 1970

Mandatory Access Control (MAC), 1970

Role Based Access Control (RBAC), 1995

Attribute Based Access Control (ABAC), ????

Flexible policy

Access Control

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Flexible policy

ReBAC Models

Online Social Networks (OSNs)

- Social graph is modeled as a directed labeled simple graph $G=<U, E, \Sigma>$
  - Nodes U as users
  - Edges E as relationships
  - $\Sigma=\{\sigma_1, \sigma_2, \ldots, \sigma_n, \sigma_1^{-1}, \sigma_2^{-1}, \ldots, \sigma_n^{-1}\}$

  as relationship types supported

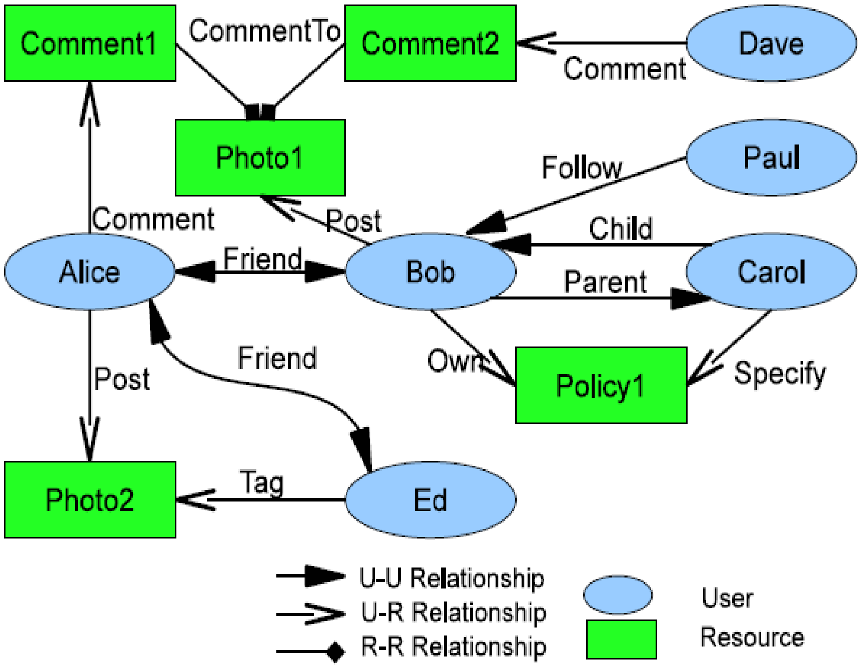
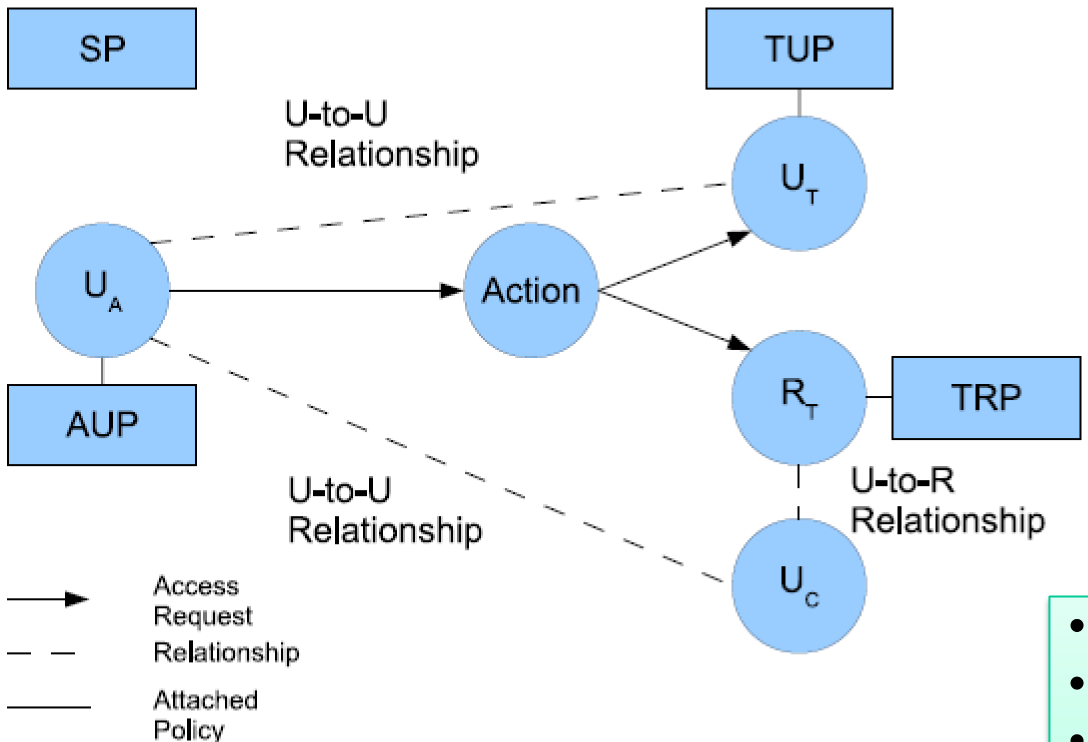


Fig. 3. A Sample Social Graph

Access Control in OSNs

- Policy Individualization
  - Users define their own privacy and activity preferences
  - Related users can configure policies too
  - Collectively used by the system for control decision
- User and Resource as a Target
  - e.g., poke, messaging, friendship invitation
- User Policies for Outgoing and Incoming Actions
  - User can be either requester or target of activity
  - Allows control on 1) activities w/o knowing a particular resource and 2) activities against the user w/o knowing a particular access requestor
  - e.g., block notification of friend's activities; restrict from viewing violent contents

U2U ReBAC (UURAC) Model



U_A: Accessing User
U_T: Target User
U_C: Controlling User
R_T: Target Resource
AUP: Accessing User Policy
TUP: Target User Policy
TRP: Target Resource Policy
SP: System Policy

- Policy Individualization
- User and Resource as a Target
- Separation of user policies for incoming and outgoing actions
- Regular Expression based path pattern w/ max hopcounts (e.g., <u_a, (f*c,3)>)

Access Request and Evaluation

- Access Request <u_a, *action*, *target*>
  - u_a tries to perform *action* on *target*
  - Target can be either user u_t or resource r_t

- Policies and Relationships used for Access Evaluation
  - When u_a requests to access a user u_t
    - u_a's AUP, u_t's TUP, SP
    - U2U relationships between u_a and u_t
  - When u_a requests to access a resource r_t
    - u_a's AUP, r_t's TRP, SP
    - U2U relationships between u_a and u_c

Policy Representations

Accessing User Policy	$< action, (start, path\ rule) >$
Target User Policy	$< action^{-1}, (start, path\ rule) >$
Target Resource Policy	$< action^{-1}, u_c, (start, path\ rule) >$
System Policy for User	$< action, (start, path\ rule) >$
System Policy for Resource	$< action, (r.typename, r.typevalue), (start, path\ rule) >$

- *$action^{-1}$* in TUP and TRP is the passive form since it applies to the recipient of action
- TRP has an extra parameter u_c to specify the controlling user
  - U2U relationships between u_a and u_c
- SP does not differentiate the active and passive forms
- SP for resource needs *r.typename, r.typevalue* to refine the scope of the resource

Example

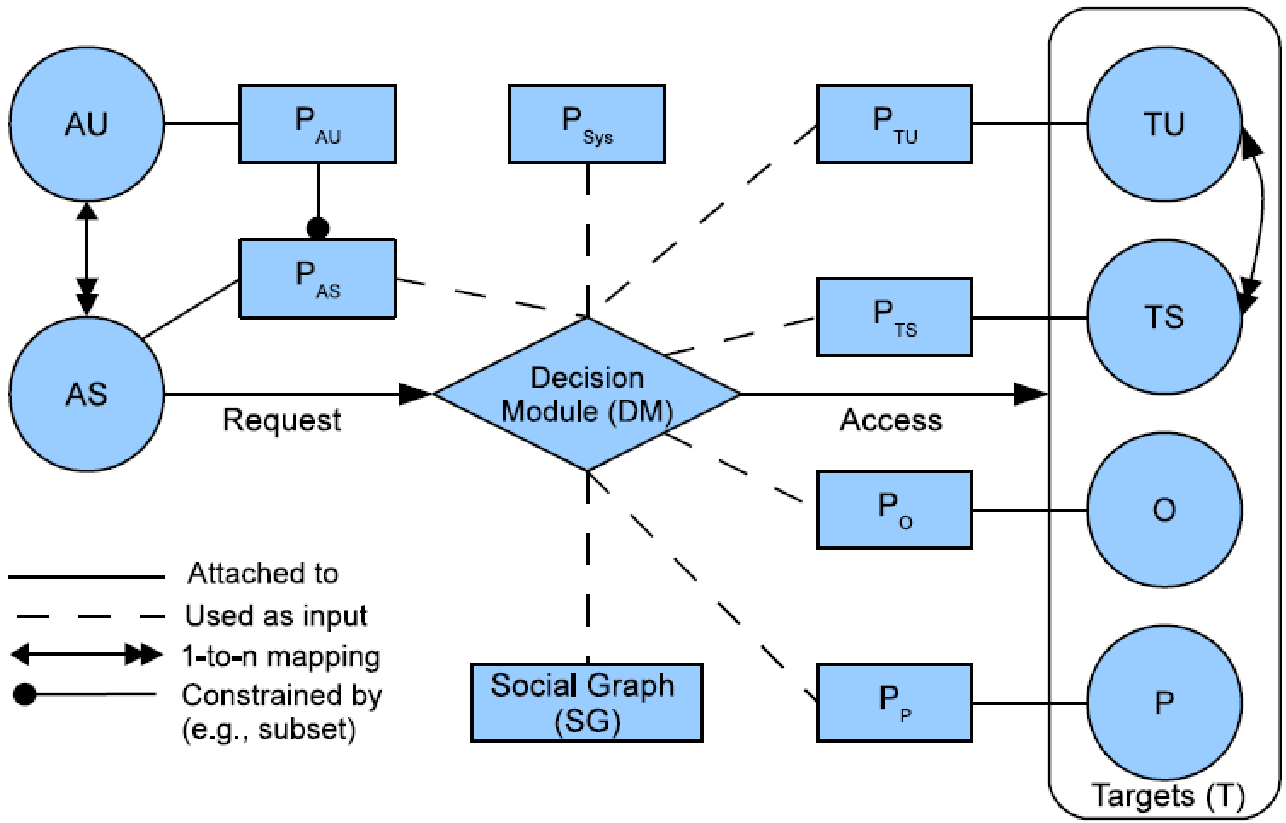
- Alice's policy P_{Alice}:
  - $< poke, \left(u_a, (f*,3)\right) >, < poke^{-1}, \left(u_t, (f,1)\right) >,$
  - $< read, \left(u_a, (\Sigma*,5)\right) >$
- Harry's policy P_{Harry}:
  - $< poke, \left(u_a, (cf*,5) \vee (f*,5)\right) >, < poke^{-1}, \left(u_t, (f*,2)\right) >$
- Policy of file2 P_{file2}:
  - $< read^{-1}, Harry, (uc, \neg(p+,2) >$
- System's policy P_{Sys}:
  - $< poke, \left(u_a, (\Sigma*,5)\right) >$
  - $< read, (filetype, photo), \left(u_a, (\Sigma*,5)\right) >$

- "Only Me"
  - $< poke, \left(u_a, (\emptyset, 0)\right) >$ says that ua can only poke herself
  - $< poke^{-1}, \left(u_t, (\emptyset, 0)\right) >$ specifies that ut can only be poked by herself
- The Use of Negation Notation
  - $(fffc \wedge \neg fc)$ allows the coworkers of the user's distant friends to see, while keeping away the coworkers of the user's direct friends

Beyond U2U Relationships

- There are various types of relationships between users and resources in addition to U2U relationships and ownership
  - e.g., share, like, comment, tag, etc
- U2U, U2R and R2R
- U2R further enables relationship and policy administration

U2U, U2R & R2R ReBAC (URRAC) Model



AU: Accessing User
AS: Accessing Session
TU: Target User
TS: Target Session
O: Object
P: Policy
P_{AU}: Accessing User Policy
P_{AS}: Accessing Session Policy
P_{TU}: Target User Policy
P_{TS}: Target Session Policy
P_{O}: Object Policy
P_{P}: Policy for Policy
P_{Sys}: System Policy

Differences with UURAC

- Access Request
  - (s, act, T) where T may contain multiple objects
- Policy Administration
- User-session Distinction
- Hopcount Skipping
  - Local hopcount stated inside “[[]]” will not be counted in global hopcount.
  - E.g., “([f*,3][[c*, 2]],3)”, the local hopcount 2 for c* does not apply to the global hopcount 3, thus allowing f* to have up to 3 hops.

Policy Conflict Resolution

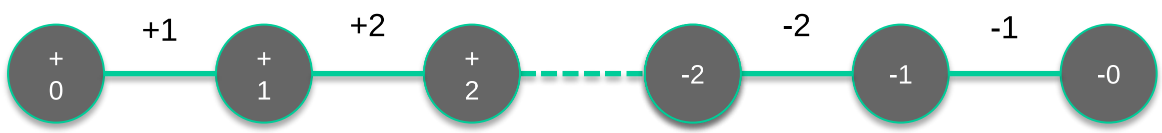
- System-defined conflict resolution for potential conflicts among user-specified policies
- Disjunctive, conjunctive and prioritized order between relationship types
  - <share-1, (own ∨ tag ∨ share)>
  - <read-1, (own ∧ tag)>
  - <friend_request, (parent > @)>

Beyond Relationships

- ReBAC usually relies on type, depth, or strength of relationships, but cannot express more complicated topological information
- ReBAC lacks support for attributes of users, resources, and relationships
- Useful examples include common friends, duration of friendship, minimum age, etc.

Attribute-based Policy

- $<quantifier, f(ATTR(N), ATTR(E)), count \geq i>$

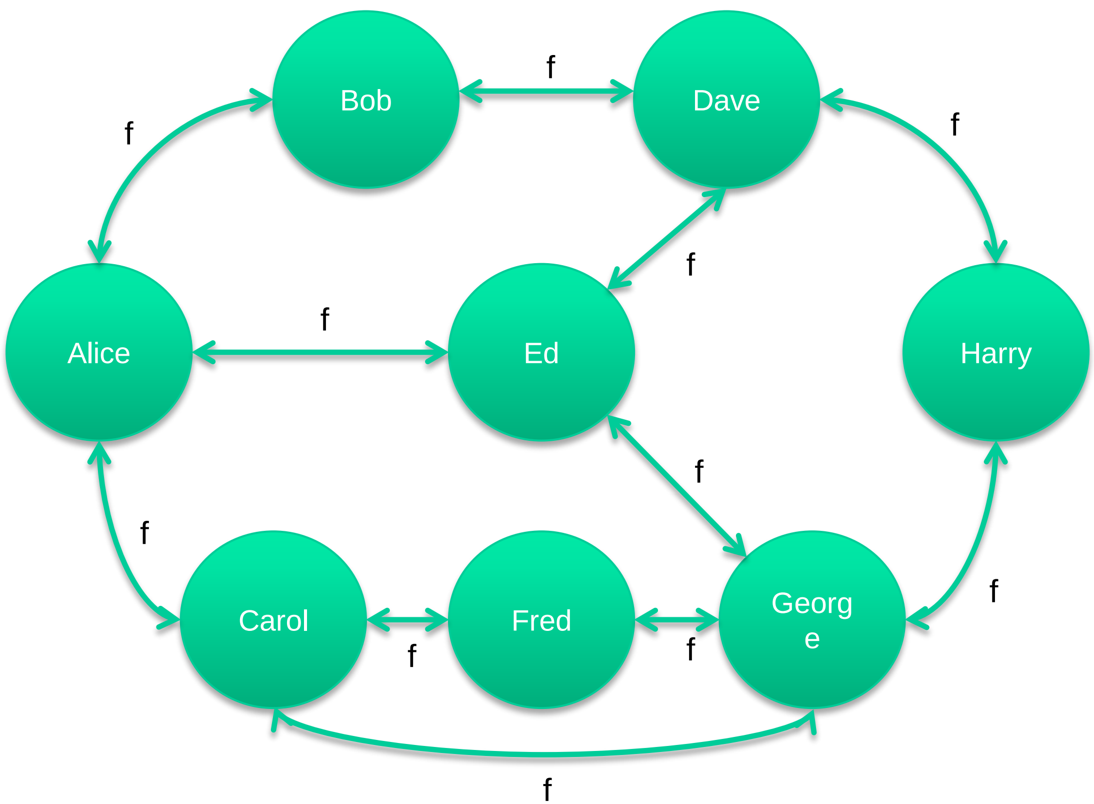


∀[+1, -2], age(u) > 18
∃[+1, -1], weight(e) > 0.5
∃{+1, +2, -1}, gender(u) = “male”

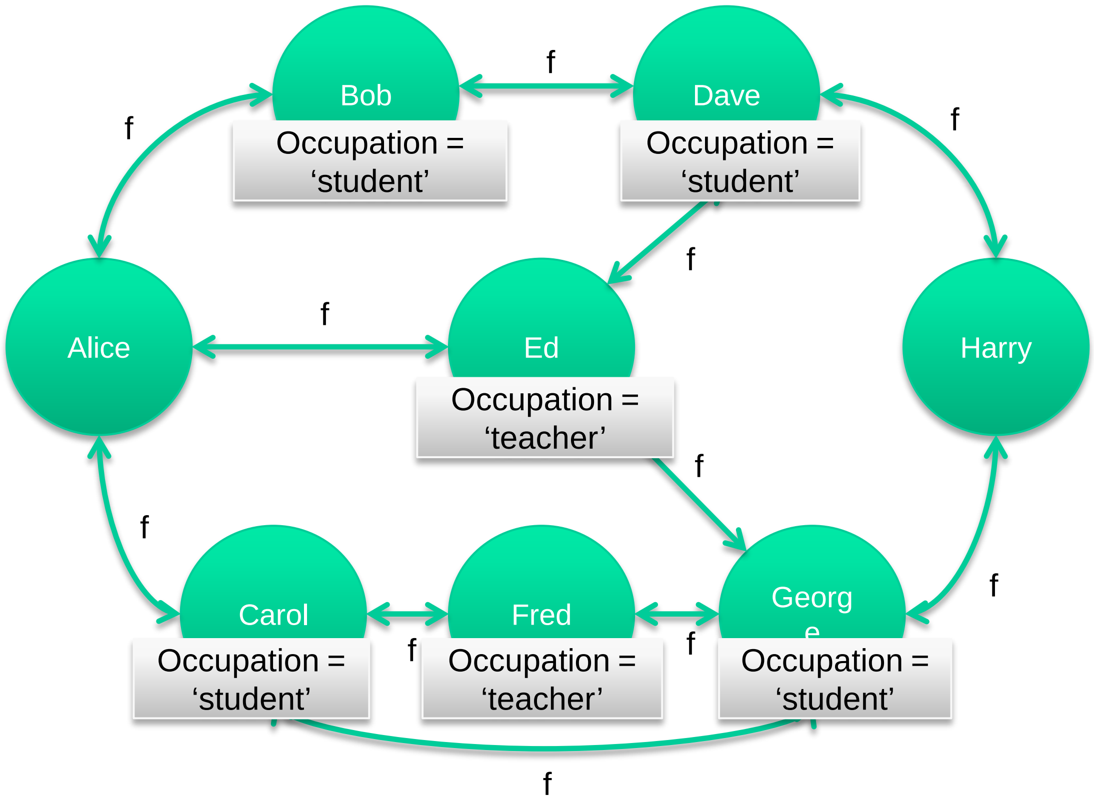
Attribute-based Policy

- Node attributes
  - Define user's identity and characteristics: e.g., name, age, gender, etc.
- Edge attributes
  - Describe the characteristics of the relationship: e.g., weight, type, duration, etc.
- Count attributes
  - Occurrence requirements for the attribute-based path specification, specifying the minimum

Example: No Attributes

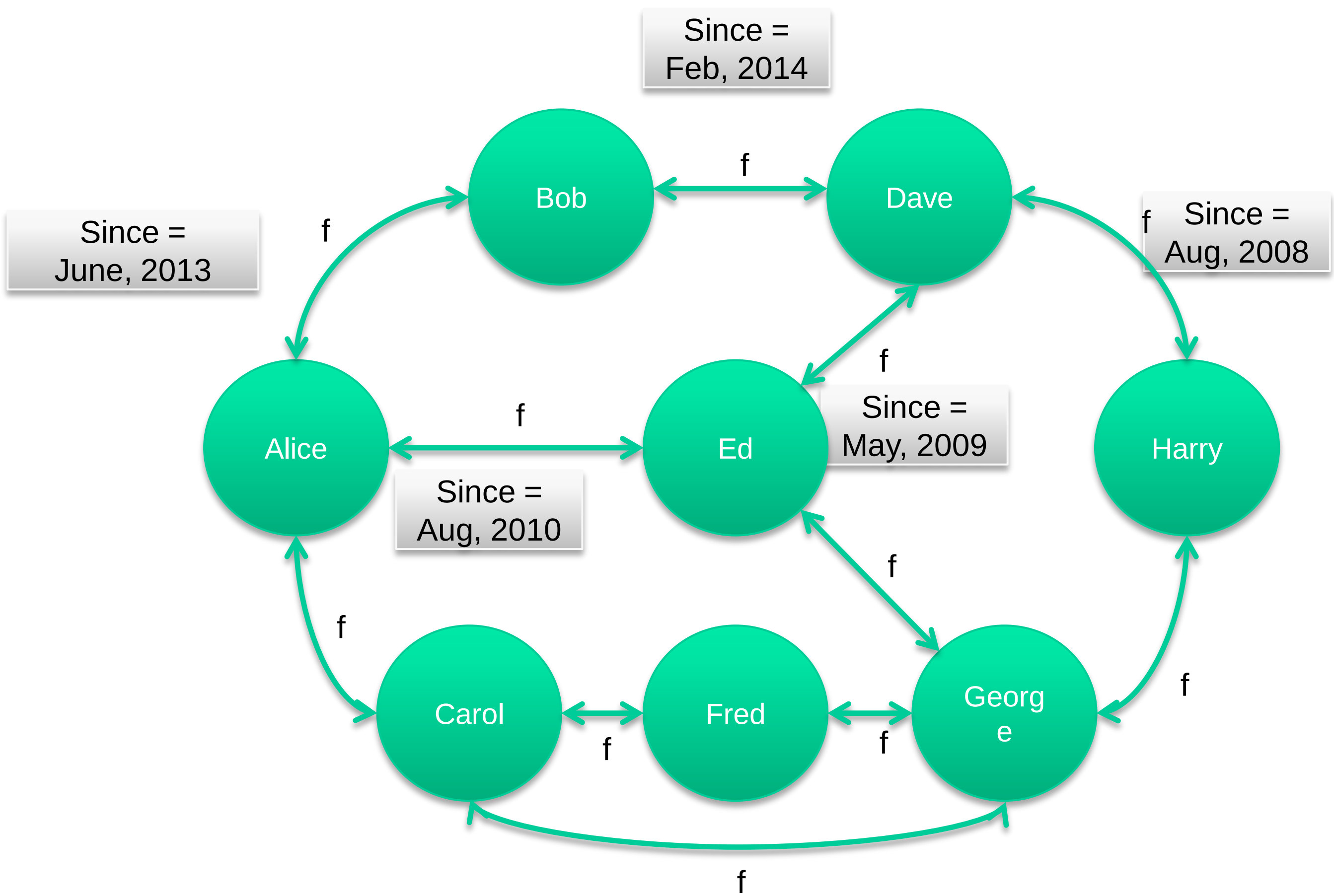


Example: Node Attributes



$<$access, (u_a, ((f*, 4): ∃[+1, -1], occupation = 'student', count ≥ 3)))$>$

Example: Edge Attributes

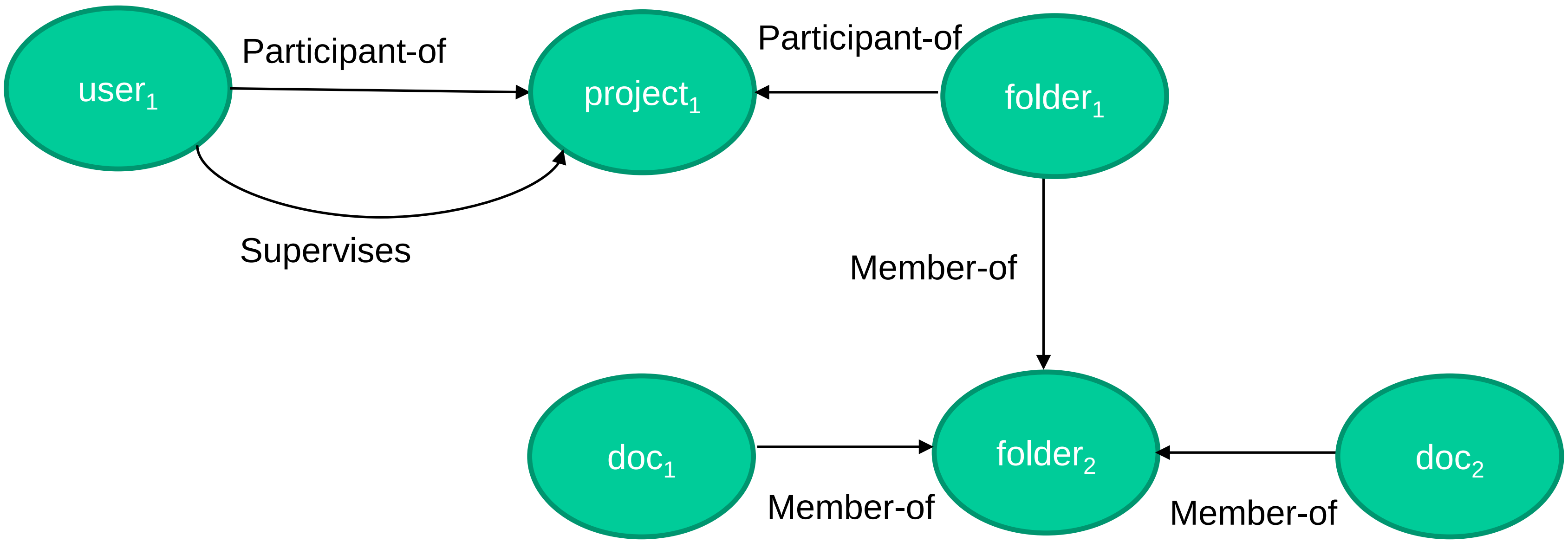


<read, Photo1, (u_a, ((f*, 3): $\forall$[+1, -1], duration $\geq$ 3 month, _)))>

ReBAC Models
Object-to-Object

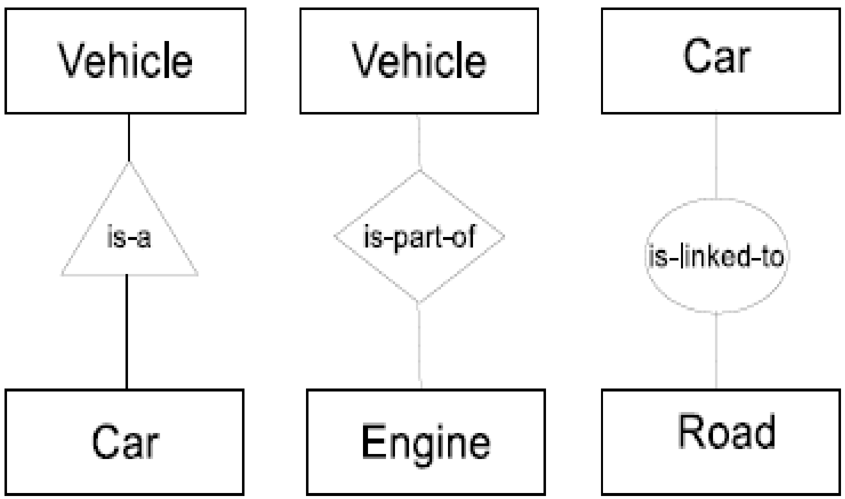
Object Relationships in ReBAC

- ReBAC for OSN generally considers only user to user relationship
- OSN has very specific types of resources – photos, notes, comments, which are strongly tied to users.
- Even though some ReBAC models consider general computing systems beyond OSNs they still need users/subjects existence in relationship graph.

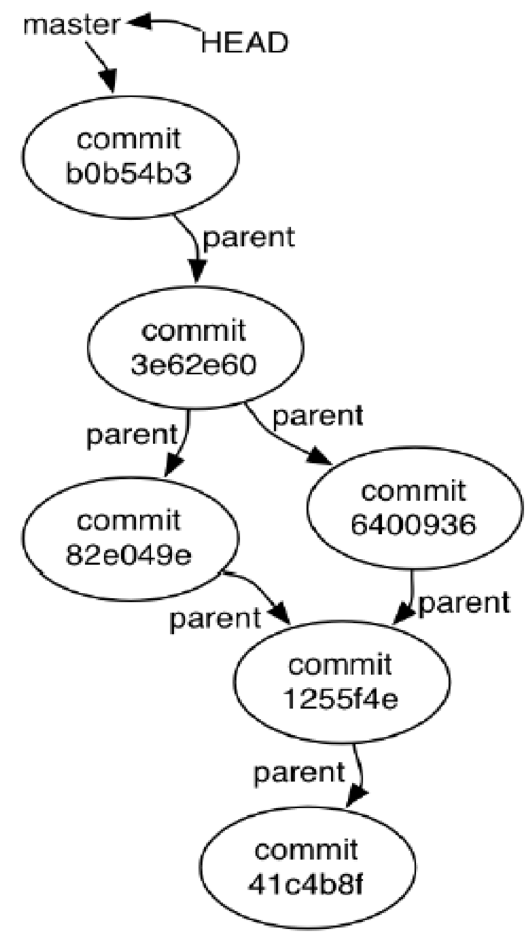


A sample Relationship Graph for Organizational Environment
[RPPM, Crampton et al. ,2014]

Existence of Object Relationship Independent of User



Object Relationship in Object –Oriented System (Inheritance, Composition and Association)



History of a Git Project (Version Control System) is a DAG

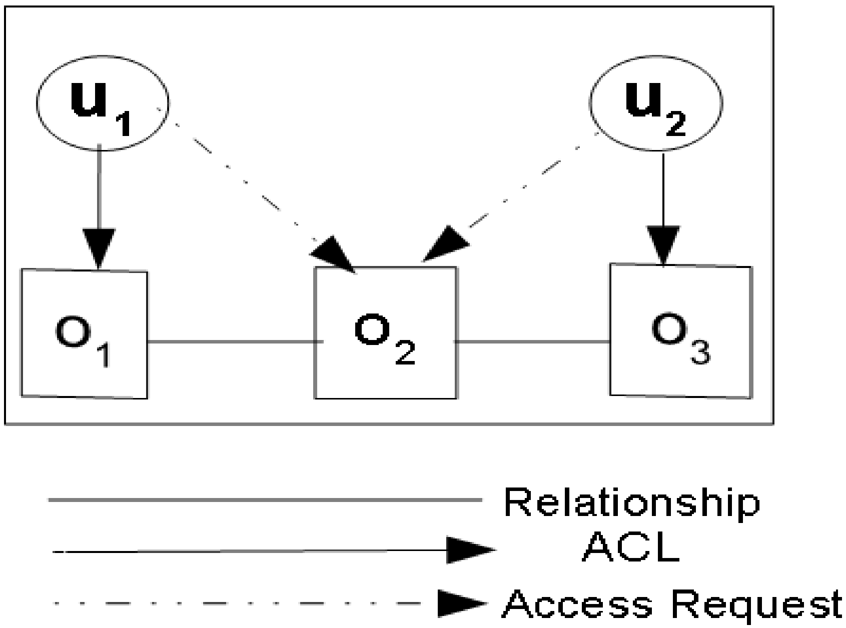
Limitations of Existing ReBAC Models

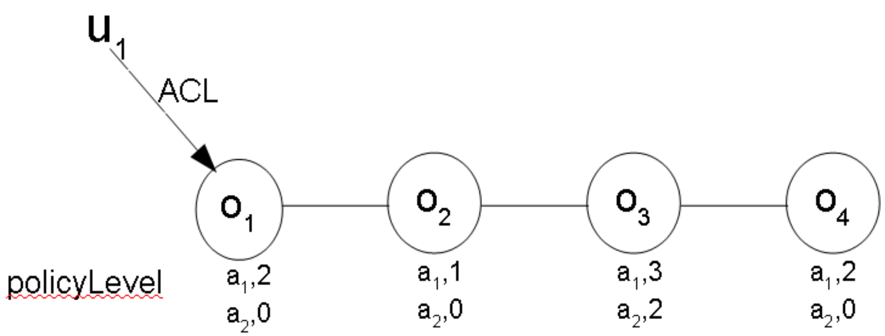
- Cannot configure relationship between objects independent of user.
- Cannot express authorization policy solely considering object relationship.

How the model would look like?

Object to Object Relationship Based Access Control

Policy Level Example

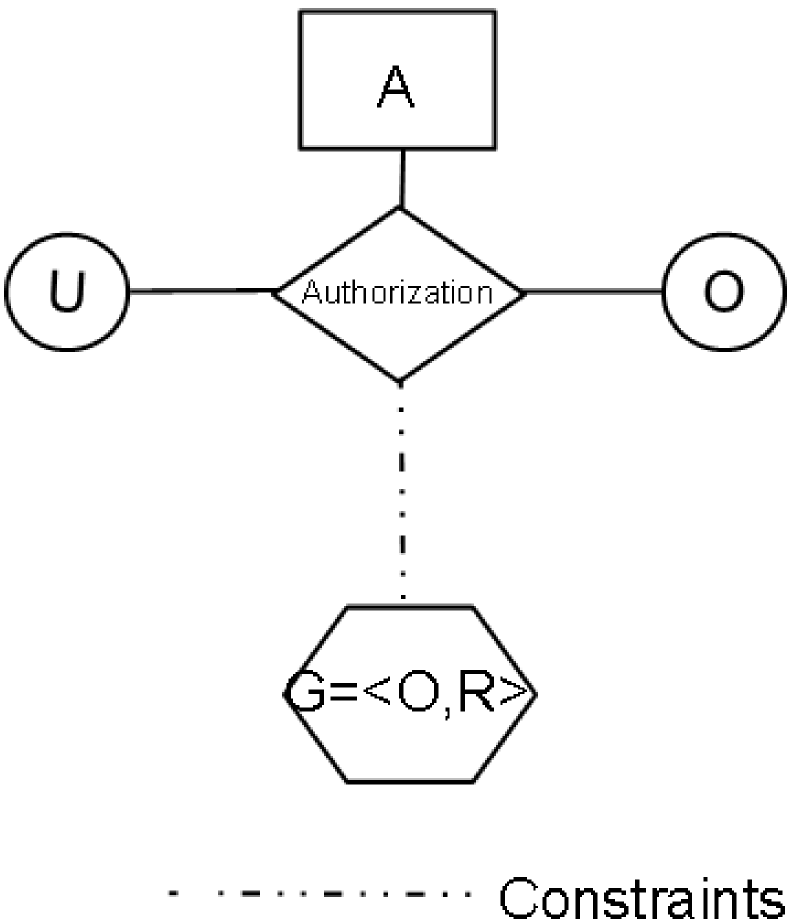




$ACL(o_1) = \{u_1\}$
$ACL(o_2) = \{\}$
$ACL(o_3) = \{u_2\}$

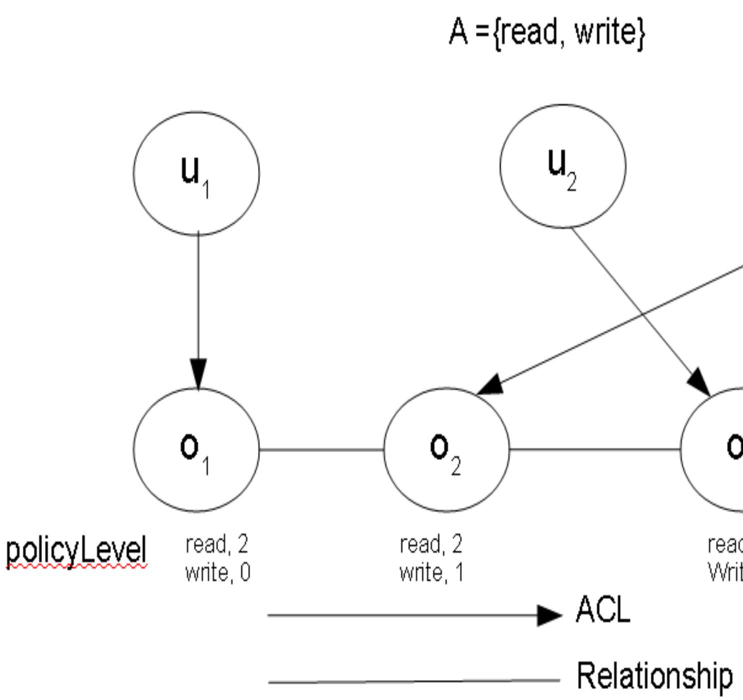
$policyLevel(a_1, o_1) = 2$
$policyLevel(a_2, o_1) = 0$
$policyLevel(a_1, o_2) = 1$
$policyLevel(a_2, o_2) = 0$
$policyLevel(a_1, o_3) = 3$
$policyLevel(a_2, o_3) = 2$
$policyLevel(a_1, o_4) = 2$
$policyLevel(a_2, o_4) = 0$

OOReBAC: Model Components and Definition



- U is a set of users
- O is a set of objects
- $R \subseteq \{z \mid z \subset O \wedge |z| = 2\}$
- $G = \langle O, R\rangle$ is an undirected relationship graph with vertices O and edges R
- A is a set of actions
- $P^i(o_1) = \{ o_2 \mid$ there exists a simple path of length p in graph G from o_1 to $o_2 \}$
- policyLevel: $O \times A \rightarrow \mathbb{N}$
- ACL: $O \rightarrow 2^U$ which returns the Access control List of a particular object.
- There is a single policy configuration point. Authorization Policy. for each action $a \in A$, $Authz_a(u{:}U, o{:}O)$ is a boolean function which returns true or false and u and o are formal parameters.
- Authorization Policy Language:
  Each action "a" has a single authorization policy $Authz_a(u{:}U, o{:}O)$ specified using the following language.
  $\phi ::= u \in PATH_i$
  $PATH_i ::= ACL(P^0(o)) \cup \ldots \cup ACL(P^i(o))$ where $i = \min(|O| - 1, \text{policyLevel}(a, o))$
  where for any set X, $ACL(X) = \bigcup_{x \in X} ACL(x)$

OOReBAC: An Example



Sequence of operations and its outcome:

- $U = \{u_1, u_2, u_3\}$
- $O = \{o_1, o_2, o_3, o_4\}$
- $R = \{\{o_1, o_2\}, \{o_2, o_3\}, \{o_3, o_4\}\}$
- $ACL(o_1) = \{u_1\}$
  $ACL(o_2) = \{u_3\}$
  $ACL(o_3) = \{u_2\}$
  $ACL(o_4) = \{u_3\}$
- policyLevel(read, o_1) = 2
  policyLevel(write, o_1) = 0
  policyLevel(read, o_2)= 2
  policyLevel(write,o_2) = 1
  policyLevel(read,o_3) = 0
  policyLevel(write,o_3) = 0
  policyLevel(read,o_4) = 2
  policyLevel(write,o_4) = 1

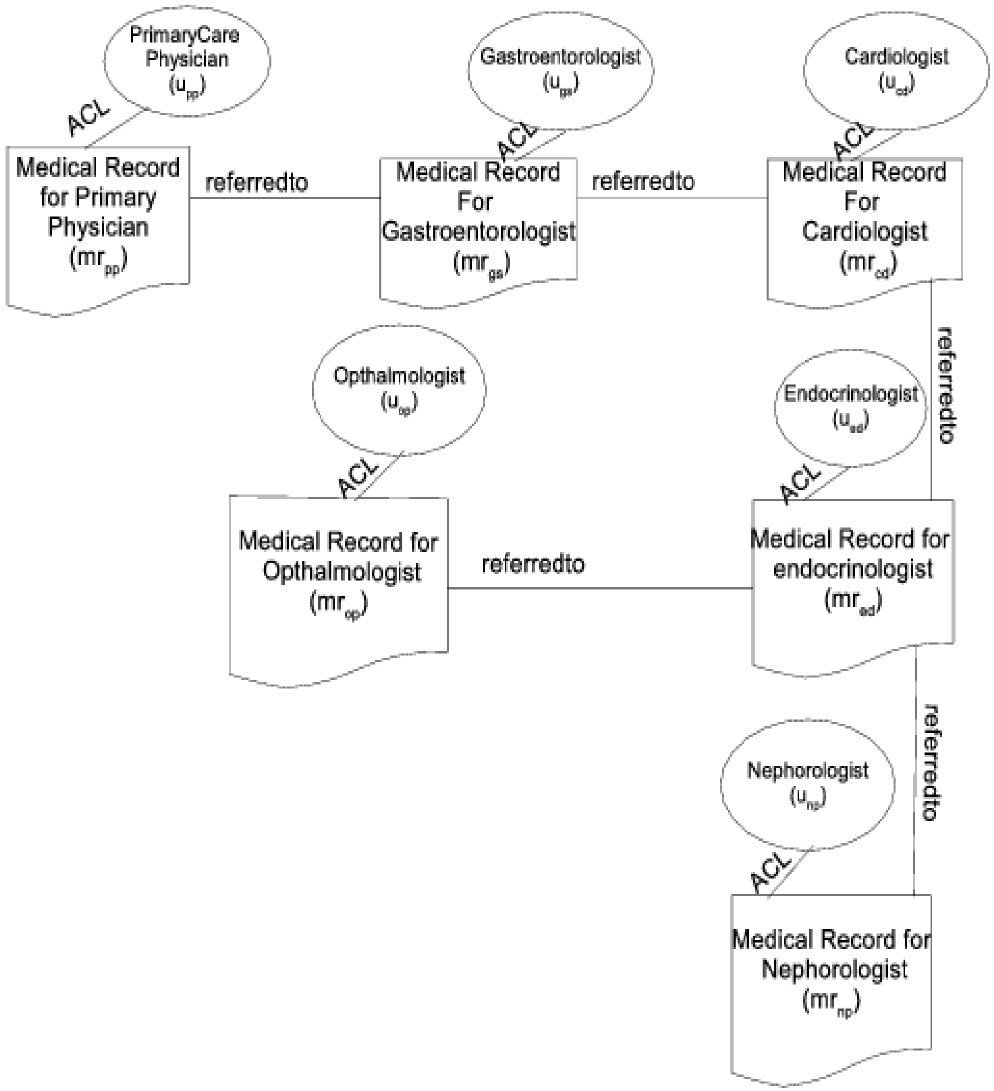
Configuration:

- $A = \{read, write\}$
- $Authz_{read}(u{:}U, o{:}O) \equiv u \in P^{policyLevel(read,o)}$
- $Authz_{write}(u{:}U, o{:}O) \equiv u \in P^{policyLevel(write,o)}$

Sequence of operations and its outcome:

- read(u_1,o_3), write(u_1,o_3) are denied
- read(u_2, o_1) is allowed, write(u_2, o_1) is denied
- read(u_1,o_4, write(u_1,o_4) are denied

OOReBAC: Application



An OOReBAC Instantiation

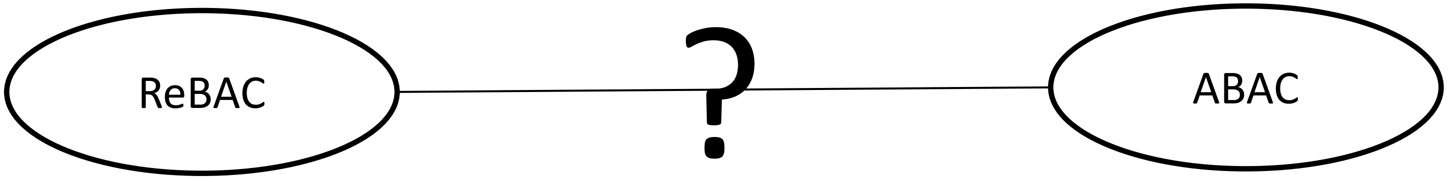
- $U = \{ u_{pp}, u_{gs}, u_{cd}, u_{op}, u_{ed}, u_{np} \}$
- $O = \{ mr_{pp}, mr_{gs}, mr_{cd}, mr_{op}, mr_{ed}, mr_{np} \}$
- $R = \{\{mr_{pp}, mr_{gs}\}, \{mr_{gs}, mr_{cd}\}, \{mr_{cd}, mr_{ed}\}, \{mr_{op}\ mr_{ed}\},\{mr_{np}, mr_{ed}\}\}$
- $ACL(mr_{pp}) = \{u_{pp}\}$,
  $ACL(mr_{gs}) = \{u_{gs}\}$,
  $ACL(mr_{cd}) = \{u_{cd}\}$,
  $ACL(mr_{op}) = \{u_{op}\}$,
  $ACL(mr_{ed}) = \{u_{ed}\}$,
  $ACL(mr_{np}) = \{u_{np}\}$
- Action $=\{$read, write$\}$
- $policyLevel(read,mr_{pp})=\infty$, $policyLevel(write,mr_{pp})=0$,
  $policyLevel(read,mr_{gs})=\infty$, $policyLevel(write,mr_{gs})=0$,
  $policyLevel(read,mr_{cd})=\infty$, $policyLevel(write,mr_{cd})=0$,
  $policyLevel(read,mr_{op})=\infty$, $policyLevel(write,mr_{op})=0$,
  $policyLevel(read,mr_{ed})=\infty$, $policyLevel(write,mr_{ed})=0$,
  $policyLevel(read,mr_{np})=\infty$, $policyLevel(write,mr_{np})=0$
- Authorization policy:
  $Authz_{read}(u,o) \equiv u \in P^{policyLevel(read,o)}$
  $Authz_{write}(u,o) \equiv u \in P^{policyLevel(write,o)}$

Sequence of Operations and Outcomes

1) $read(u_{np}, mr_{pp})$: authorized
2) $read(u_{cd}, mr_{np})$: authorized
3) $write(u_{np}, mr_{np})$: authorized
4) $write(u_{np}, mr_{pp})$: denied
5) $write(u_{np}, mr_{pp})$: denied

ABAC-ReBAC Comparison

ReBAC Vs. ABAC



- Are they Comparable ?
- Can Attributes Express Relationships?
- Can ReBAC Configure ABAC? Vice versa?
- Do they have equal expressive power?

If not

- Which one is more expressive?

Attribute Types

1. Attribute Value Structure
   - Atomic-valued or Single-valued Attribute (e.g. gender)
   - Set-valued or Multi-valued Attribute (e.g. phoneNumber)
   - Structured Attribute (e.g person-Info (name, age, phoneNumber))
2. Attribute Value Scope
   - Entity Attribute (e.g. friend)
   - Non-entity Attribute (e.g. age)
3. Boundedness of attribute range
   - Finite Domain Attribute (e.g. gender)
   - Infinite Domain Attribute (e.g. time)
4. Attribute association
   - Contextual or Environmental Attribute (e.g. currentTime)
   - Meta Attribute (e.g. role(user) = manager , task(manager) = supervise)
5. Attribute mutability
   - Mutable Attribute
   - Immutable Attribute

Attribute Function Composition

$$f : X \rightarrow Y$$

$$g : Y \rightarrow Z$$

$$x \in X \text{ , } g\big(f(x)\big) \in Z$$

Assumptions

- All non entity attribute are finite domain
- Entity attribute functions are partial functions defined on existing entities only
- Inner attribute function in an attribute function composition should always be entity attributes
- Structured attribute is a multivalued tuple of atomic or set-valued attributes. So it is more expressive than atomic or set-valued attribute.

ReBAC Classification

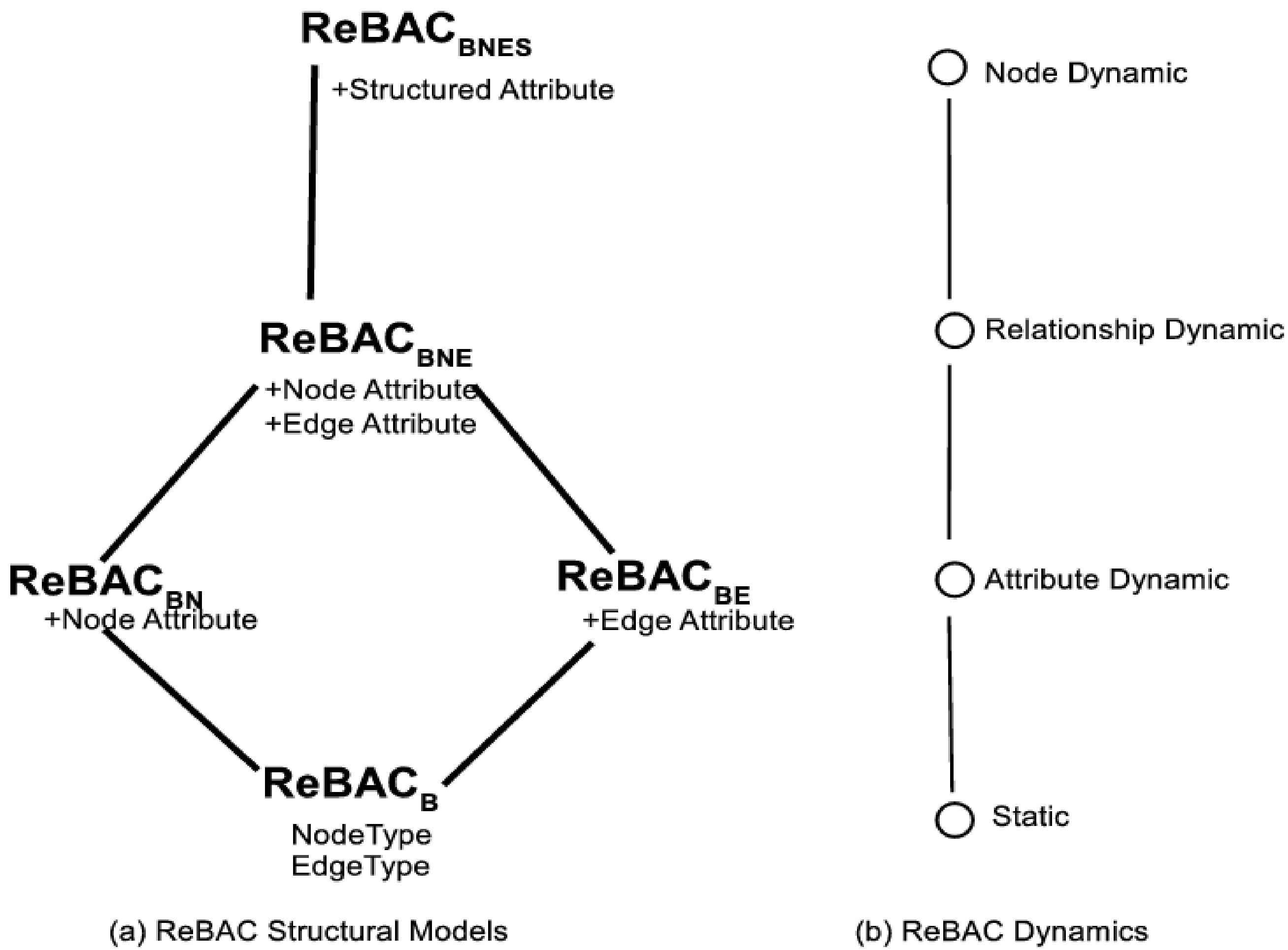


Figure 3.: ReBAC Framework

Example

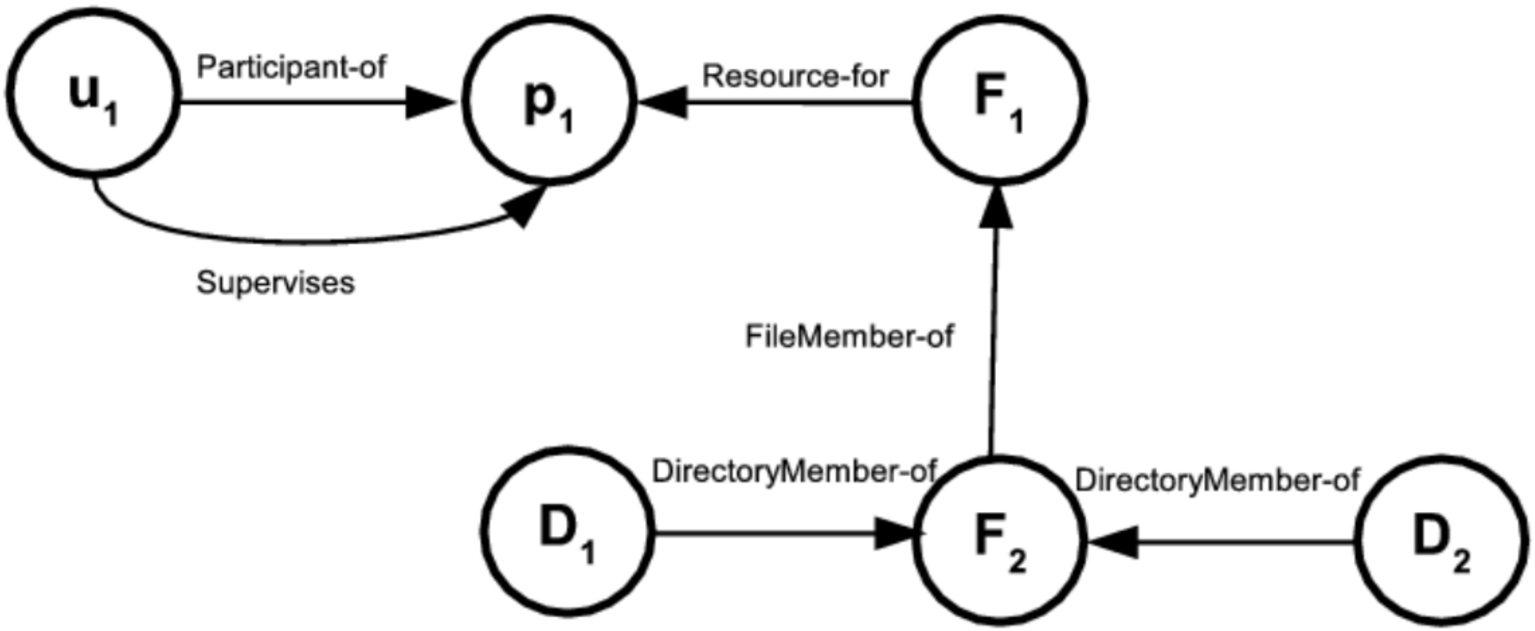


Figure 4.: A Simple Relationship Graph Expressible in $ReBAC_B$ [Crampton et al. 2014]

Example (Continued…)

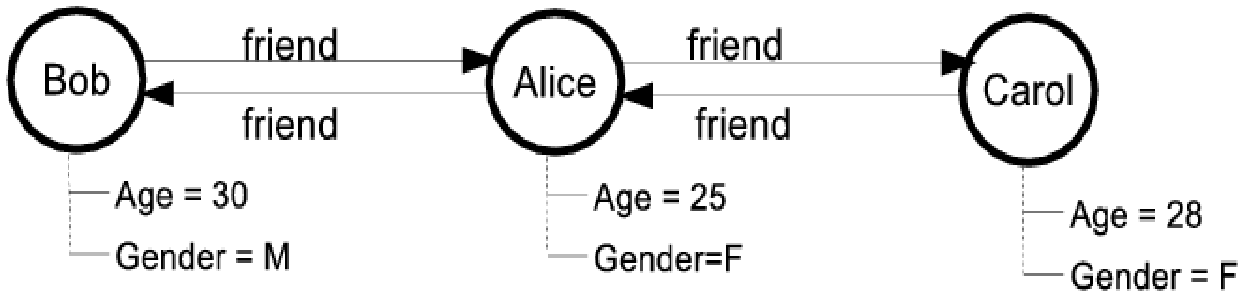


Figure 5: An Example of Node Attributes in Relationship Graph Expressible in $ReBAC_{BN}$

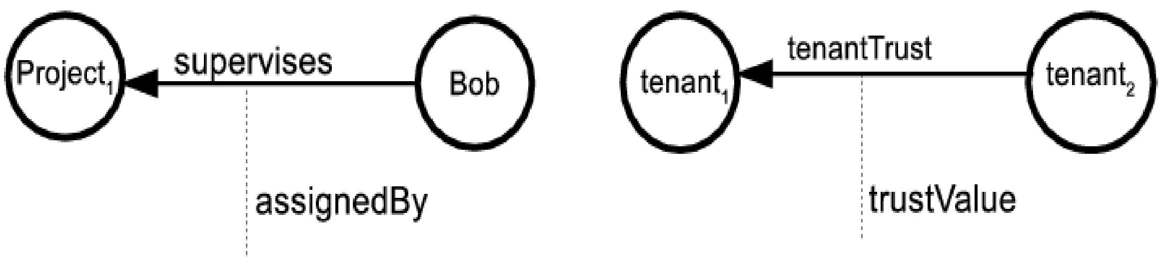
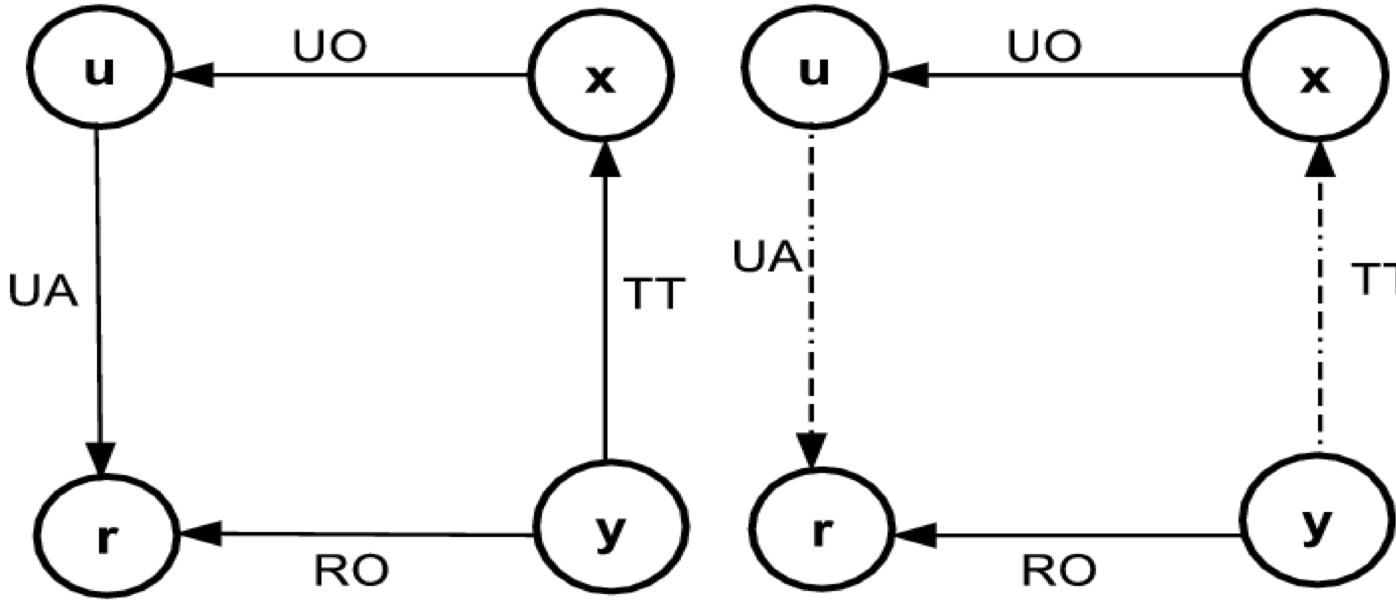


Figure 6: An Example of Edge Attributes in Relationship Graph Expressible in $ReBAC_{BE}$

Example (Continued…)



Structure Edge Attribute:
dependsOn

Sub Attributes of dependsON
Source Node
Target Node
RelationshipType

dependsOn (u,r,UA) = (y,x,TT)

Figure 7: An Example of Node Attributes in Relationship Graph Expressible in $\text{ReBAC}_{\text{BNES}}$ [Cheng et al. 2016]

ABAC Classification

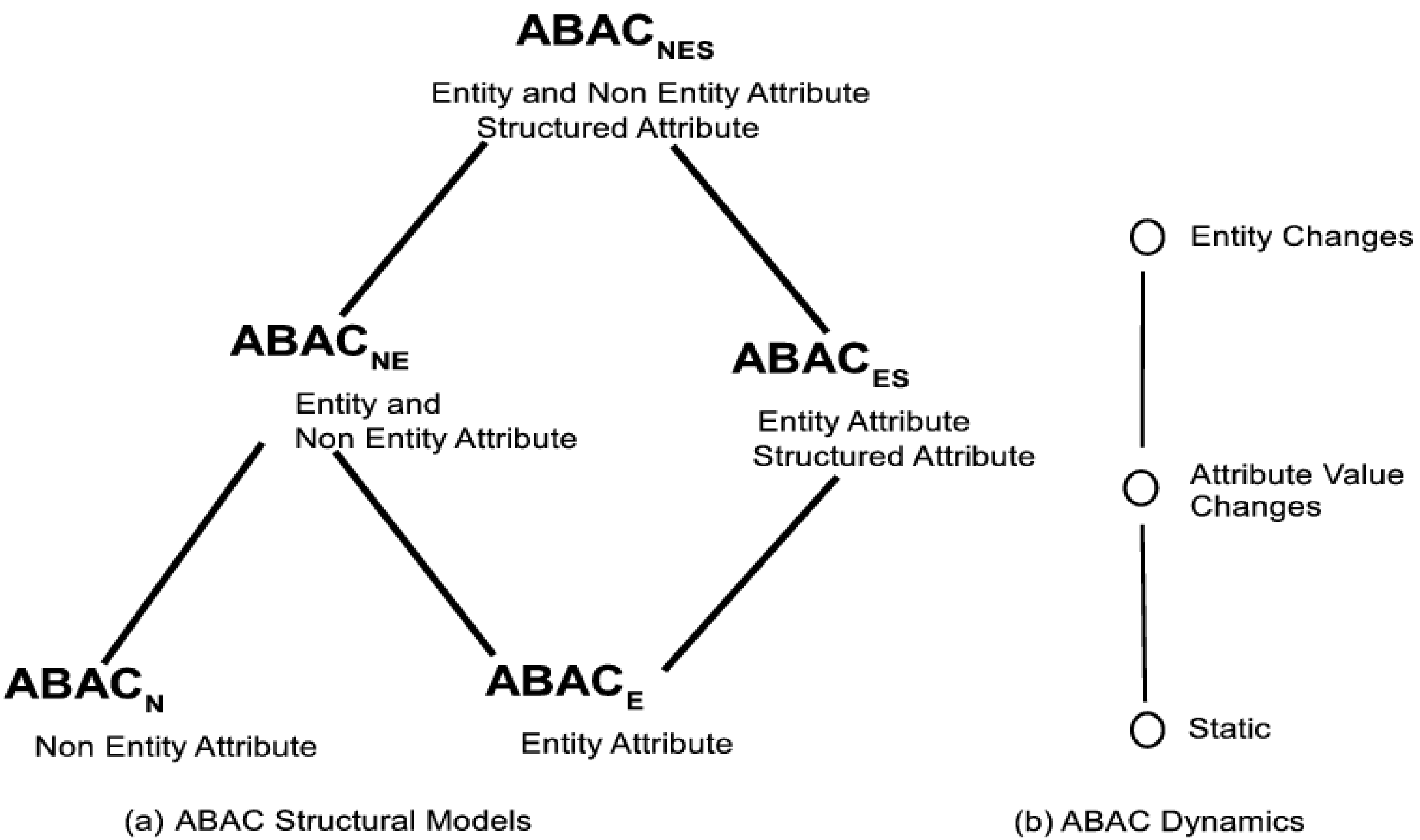
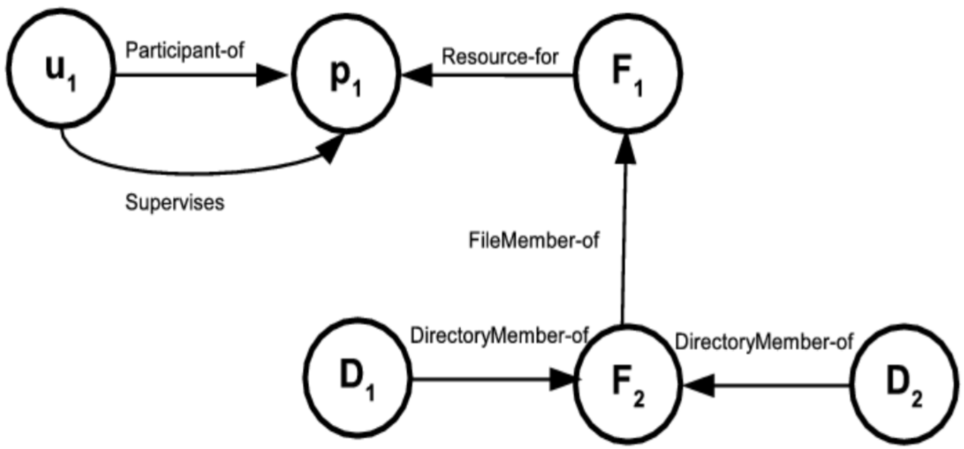


Figure 8: ABAC Framework

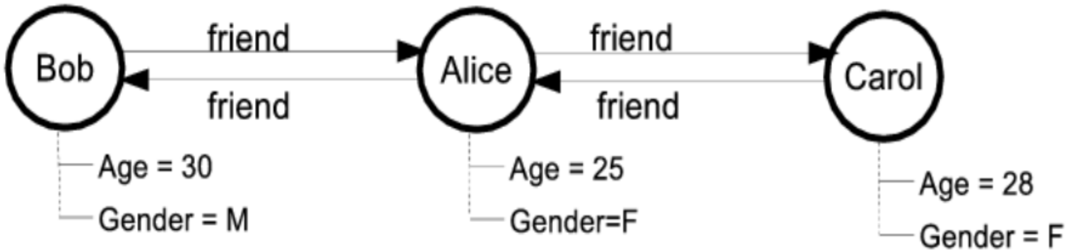
Expressing Relationship Graph with Attributes



- Entity types = {user, project, file , directory}
- Attributes:
  - User attributes ={Participant-of, Supervises}
  - File attributes = {Resource-for, FileMember-of}
  - Project attributes = {}
  - Directory attributes ={DirectoryMember-of}

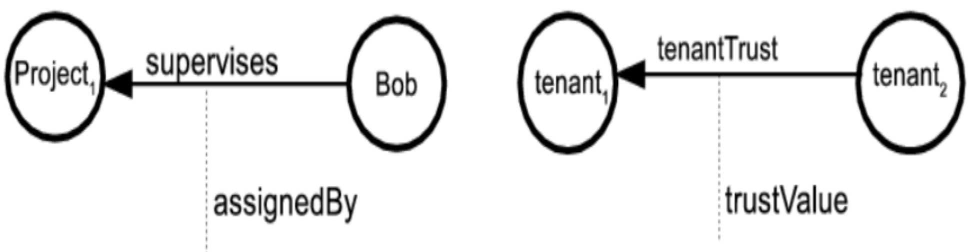
Relationship Graph in Figure 4 is Expressible with $ABAC_E$

Expressing Relationship Graph with Attributes (Continued…)



- entityType = {user}
- Attribute:
  - ❑ user's entity attribute ={friend}
  - ❑ User's Non Entity Attribute ={Name, Age, Gender}

Relationship Graph in Figure 5 is Expressible with $ABAC_E$

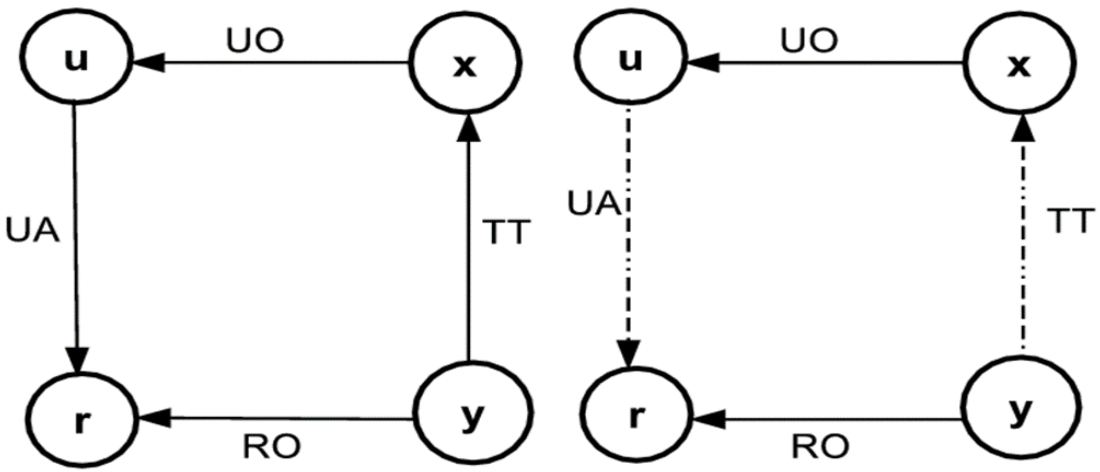


- entityType = {user, project, tenant}
- Attribute:
  - ❑ user's atomic entity attribute ={supervises}
  - ❑ User's structured entity Attribute ={assignedBy}

  e.g. assignedBy(Bob) = ("Project1", "supervises", "Alice")

Relationship Graph in Figure 6 is Expressible with $ABAC_{ES}$

Expressing Relationship Graph with Attributes (Continued…)



- Entity types: {user, tenant, role}
- Attribute:
  - User's atomic entity attribute: {UO,UA}
  - Users Structured Entity Attribute: {dependentEdge}

  dependentEdge(u) = ("r","UA", {(y,x,TT)})

Relationship Graph in Figure 7 is Expressible with $ABAC_{ES}$

Expressing Multilevel Relationship With Attributes

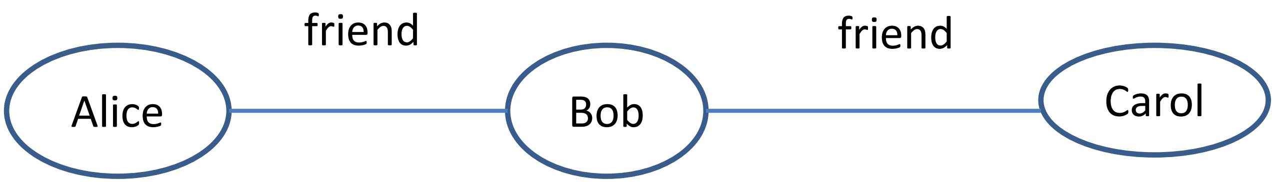


Figure 9. A simple Relationship Graph

Attribute Composition

- ❑ Needs one attribute: friend
- ❑ Policy Expression uses Attribute composition

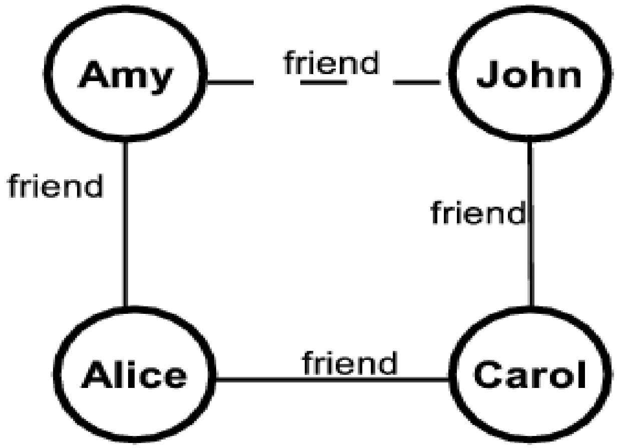
friend(Alice)={Bob}
friend(friend(Alice))={Carol}

Composite Attribute

- ❑ Needs two attribute
  1. friend
  2. friendoffriend
- ❑ Policy Expression uses direct attributes

friend(Alice) ={Bob}
friendoffriend(Alice)={Carol}

Example:



friend(Alice) = {Amy, Carol}
friendoffriend(Alice) = {John}

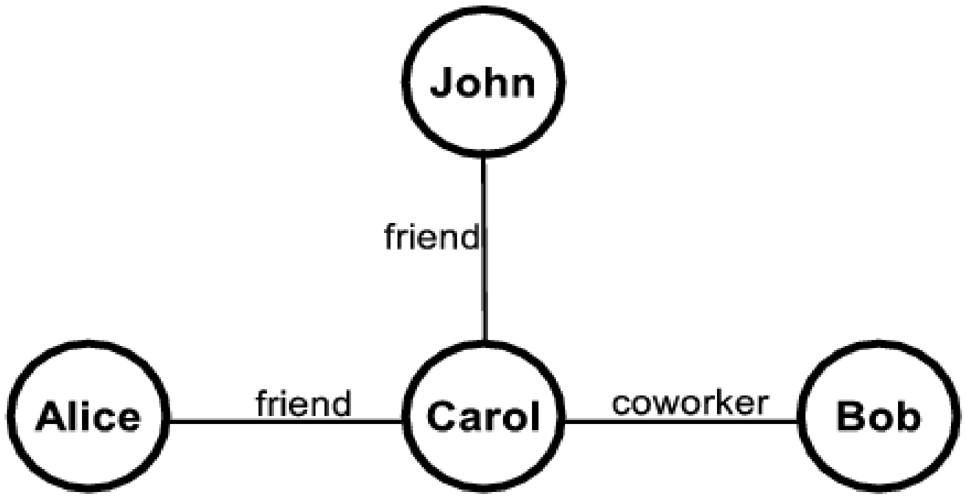
Figure 10. A simple Relationship Graph

If the friend relationship between Amy and John deleted

friendoffriend(Alice) = ?

Instead of keeping the end user as attribute value we have to keep the exact path information.

Example



Attribute Composition:

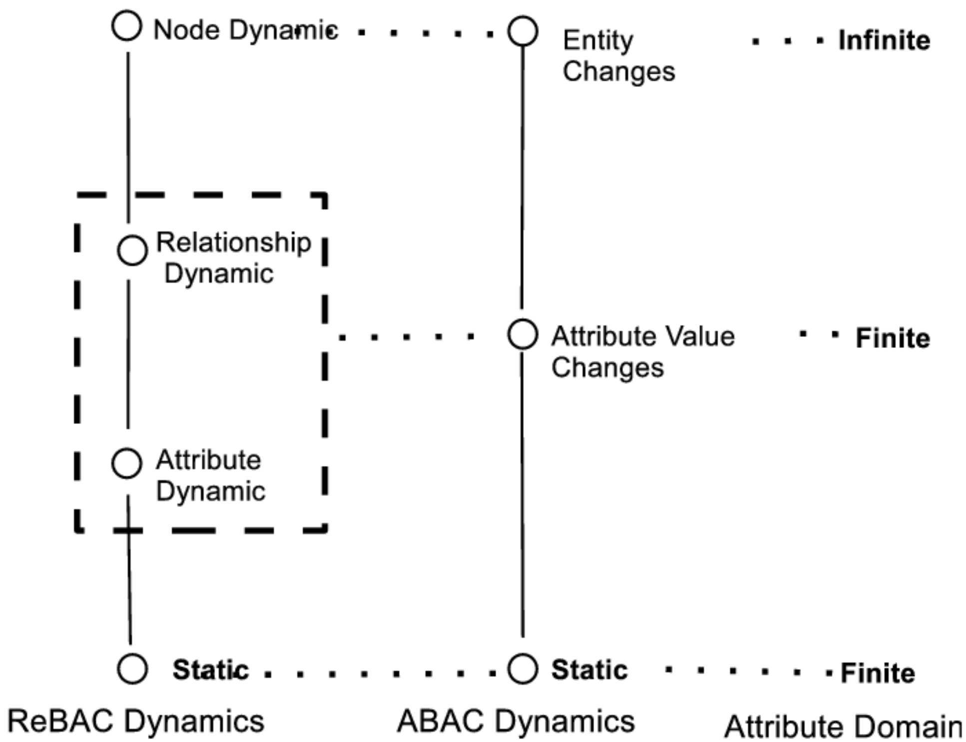
friend (“Alice”) = {“Carol”}
coworker (“Alice”) = { }
friend (friend(“Alice”)) = { “John”}
coworker(coworker(“Alice”)) = { }
friend (coworker(“Alice”)) = { }
coworker (friend(“Alice”)) = {“Bob”}

Composite Attribute:

friend (“Alice”) = {“Carol”}
coworker (“Alice”) = { }
friendOfFriend(“Alice”) = { “Carol.John”}
coworkerOfCoworker(“Alice”)) = { }
friendOfCoworker(“Alice”) = { }
coworkerOfFriend(“Alice”)) = {“Carol.Bob”}

Figure 12: Multilevel Relationship Expression with Attribute

Comparison: On Dynamics



$ABAC_X \equiv ReBAC_Y\ Means$

- Static and finite attribute domain $ABAC_X \equiv Static\ ReBAC_Y$
- $ABAC_X\ Attribute\ value\ changes\ with\ finite\ domain \equiv Relationship\ Dynamic\ ReBAC_Y$
- $ABAC_X\ with\ entity\ changes\ and\ infinite\ domin\ entity\ attribute \equiv node\ dynamic\ ReBAC_Y$

Figure 12: ReBAC Dynamics, ABAC Dynamics and Attribute Domain wise Comparison between ReBAC and ABAC

Comparison: Equivalent Structural Models for ReBAC and ABAC

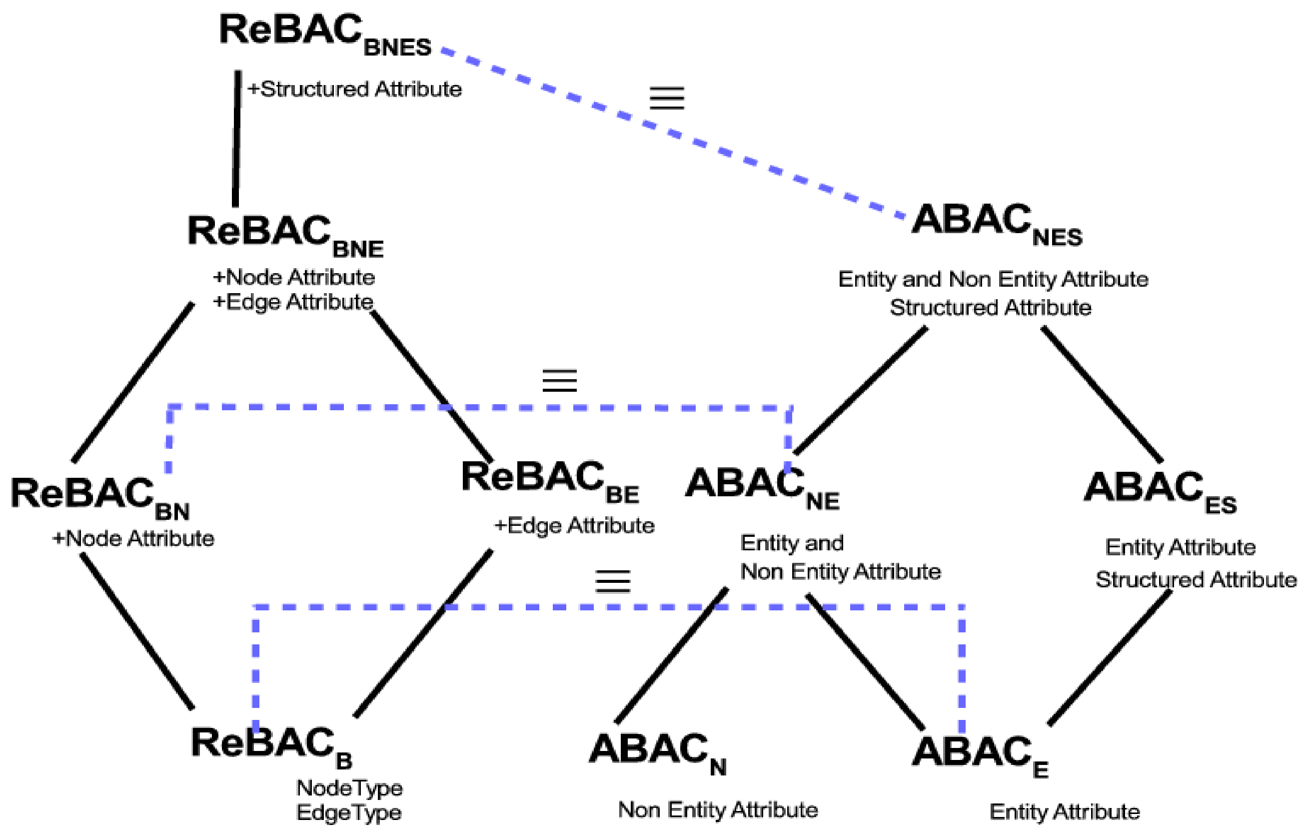


Figure 13: Equivalence of ReBAC and ABAC Structural Classification

Comparison: Non-Equivalent Structural models for ReBAC and ABAC

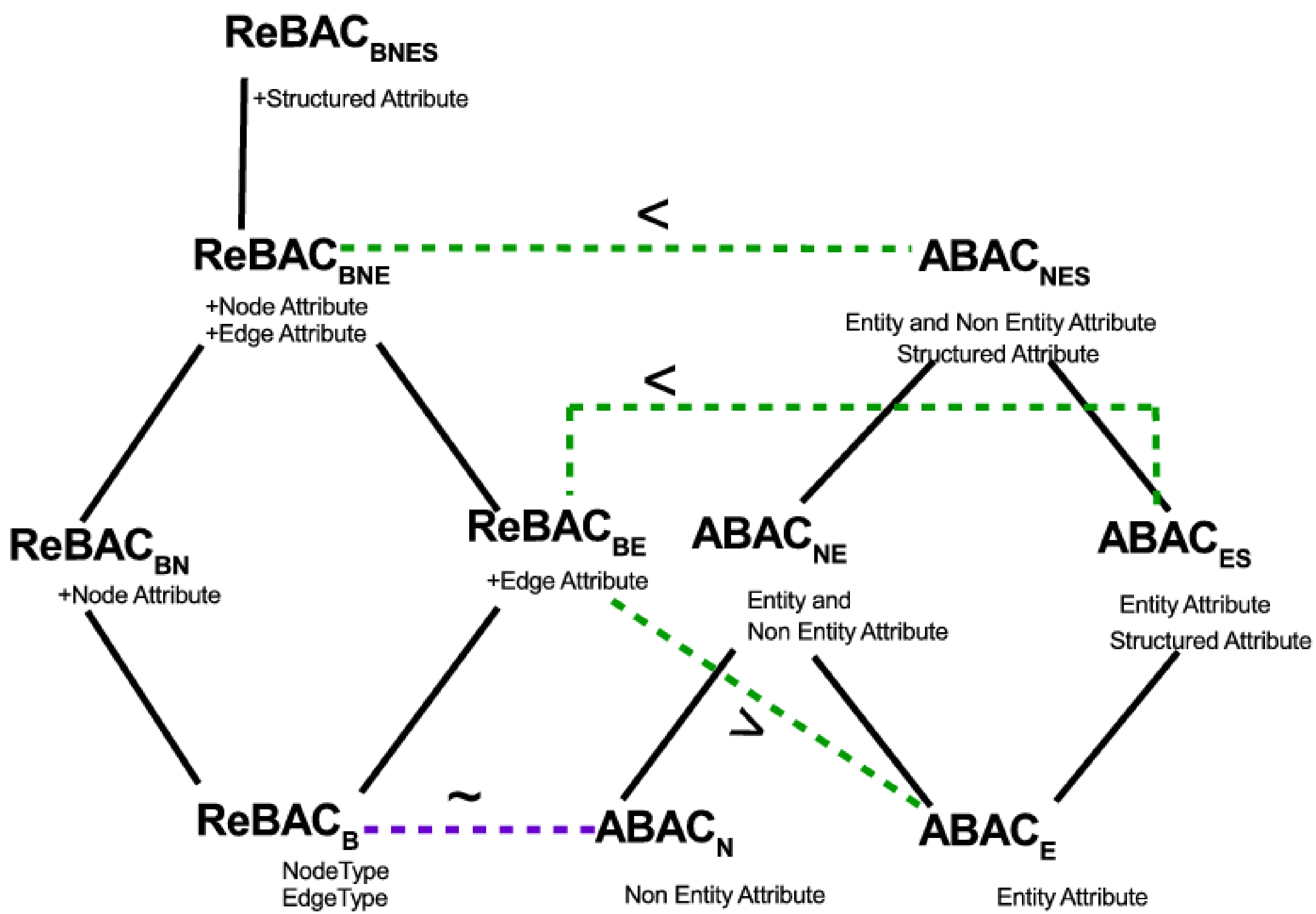


Figure 14: Non-Equivalence of ReBAC and ABAC Structural Classification

Comparison: On Performance

- Attribute Composition is similar to ReBAC and Both have polynomial complexity for authorization policy and constant complexity on update
- Composite attribute has constant complexity on authorization policy and polynomial complexity on update to maintain relationship changes.
- Performance Depends on :
  - Node Dynamics
  - Relationship Dynamics
  - Density of the Relationship Graph

Comparison: Choice of Models

- For static system or only change or non entity attribute------Composite attribute is the best approach
- System with huge node dynamics, relationship dynamics and high relationship density----- Attribute composition is the best option
- If the system is in the middle between two extremes ---- A hybrid approach where both composite attribute and attribute composition is used.
- Hybrid Approach:

To achieve p level relationship composition it uses m level composite attribute and n level attribute composition where p = n X m.

Comparison: In Respect of PEI Framework

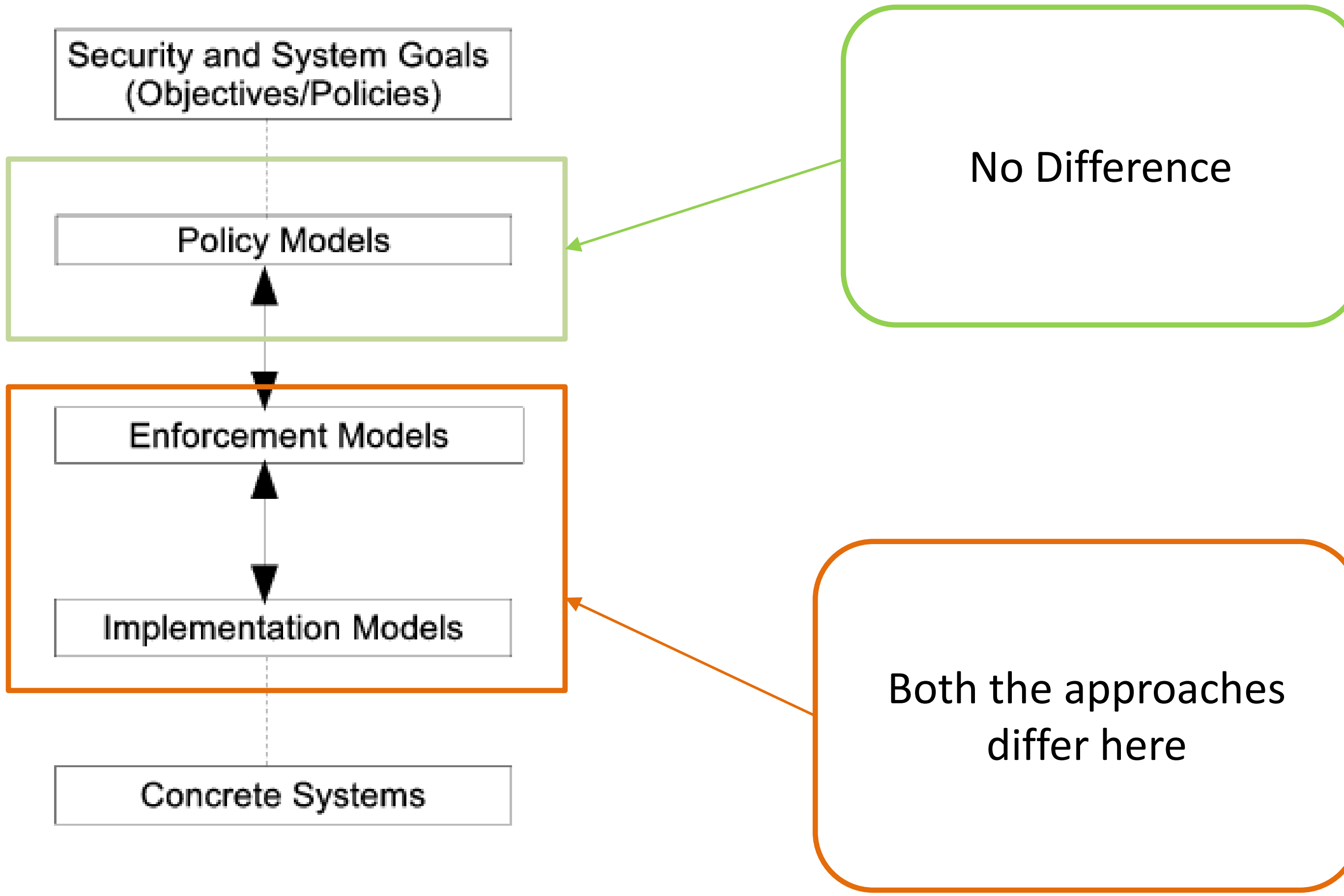


Figure 15: PEI Framework