Access Control for Online Social Networks using Relationship Type Patterns

Dissertation Defense

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## Roadmap

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World-Leading Research with Real-World Impact!
World-Leading Research with Real-World Impact!

Outline

• Introduction
• UURAC
• UURAC_A
• URRAC
• Conclusion
Background

• Security issues in OSNs can be organized into at least four categories
  – Privacy breaches (focus of this work)
  – Spam and phishing attacks
  – Sybil attacks
  – Malware attacks

• Privacy breaches
  – Easy to happen from OSN providers, other users, and 3rd party applications
  – OSN providers store user data
  – 3rd party applications provide extra functionalities
  – Major threats are from peer users
  • Not aware of who they share with and how much
  • Have difficulty in managing privacy controls
Why Privacy is Hard to Protect in OSNs

• Users tend to give out too much information
  – Unaware of privacy issues
  – Promote sharing vs. Protect privacy

• Users tend to be Reactive rather than Proactive

• Privacy policies
  – Changing over time
  – Confusing
  – Privacy thresholds vary by individuals
The Challenges of OSN Access Control

• Lack of a Central Administrator
  – Traditional access control mechanisms, such as RBAC, requires an administrator to manage access control
  – No such administrator exists in OSNs

• Dynamic Changing Environment
  – Frequent content updates and volatile nature of relationships
  – Identity and attribute-based access control are not effective for OSNs
Relationship-based Access Control

• Users in OSNs are connected by social relationships (user-to-user relationships)

• Owner of the resource can control its release based on such relationships between the access requester and the owner
Motivating Examples

- Related User’s Control
  - There exist several different types of relationships in addition to ownership
  - e.g., Alice and Carol want to control the release of Bob’s photo which contains Alice and Carol’s image.

- Administrative Control
  - A change of relationship may result in a change of authorization
  - Treat administrative activities different from normal activities
    - Policy specifying, relationship invitation and relationship recommendation
  - e.g., Bob’s mother Carol may not want Bob to become a friend with her colleagues, to access any violent content or to share personal information with others.

- Attribute-aware ReBAC
  - Exploit more complicated topological information
  - Utilize attributes of users and relationships
  - e.g., common friends, duration of friendship, minimum age, etc.
Problem Statement

• Traditional access control mechanisms are not suitable for OSNs
  – OSNs keep massive resources and change dynamically

• Existing relationship-based access control approaches are coarse-grained and limited
  – Commercial systems support either limited types or limited depth of U2U relationships
  – Academic works are also not flexible and expressive enough in relationship composition

• Policy administration and conflict resolution are missing
  – Multiple users can specify policies for the same resource

• Using relationships alone does not meet users’ expectations

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Thesis

• Users and resources are interconnected through U2U, U2R and R2R relationships, which form the basis of an OSN system, the social graph.
• By utilizing regular expression notation for policy specification, it is efficient and effective to regulate access in OSNs in terms of the pattern of relationship path on the social graph and the hopcount limit on the path.
• Integrating attribute-based policies further enables finer-grained controls that are not available in ReBAC alone.
Scope and Assumptions

• Assumptions
  – The threat model does not include OSN providers
  – Users’ computers are not compromised by malicious intruders or malwares
  – Do not consider the case when a hacker gains unauthorized access to a site’s code and logic

• Scope
  – Aim to improve the access control mechanism
    • ReBAC
Contributions

- Identified access control characteristics for OSNs based on relationships
  - Supporting essential characteristics that need to be addressed by OSN access control
- Further built two ReBAC models that utilize different kinds of relationships, using regular expression notation.
  - Greater generality and flexibility of path patterns in policy specifications
  - Addressed administrative control and policy conflict resolution
- Integrated attribute-based policies into ReBAC.
- Provided two effective path checking algorithms for access control policy evaluation.
  - With proof of correctness and complexity analysis
  - Enhanced the algorithms for attribute-aware ReBAC
- Implemented the algorithms and evaluated the performance.

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Social Networks

- 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
Characteristics of 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, etc.

• 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
Outline

• Introduction
• UURAC
• $\text{UURAC}_A$
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U2U Relationship-based Access Control (UURAC) Model

- **Uₐ**: Accessing User
- **Uₜ**: Target User
- **Uₖ**: Controlling User
- **Rₜ**: 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., \(<uₐ, (f*c,3)⟩>\)

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Access Request and Evaluation

• Access Request \(<u_a, \text{action}, \text{target}>\)
  – \(u_a\) tries to perform \text{action} on \text{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

<table>
<thead>
<tr>
<th>Accessing User Policy</th>
<th>$&lt;\text{action, (start, path rule)}&gt;\text{,}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target User Policy</td>
<td>$&lt;\text{action}^{-1}, (\text{start, path rule})&gt;$</td>
</tr>
<tr>
<td>Target Resource Policy</td>
<td>$&lt;\text{action}^{-1}, \text{uc, (start, path rule)}&gt;\text{,}$</td>
</tr>
<tr>
<td>System Policy for User</td>
<td>$&lt;\text{action, (start, path rule)}&gt;\text{,}$</td>
</tr>
<tr>
<td>System Policy for Resource</td>
<td>$&lt;\text{action, (r.typename, r.typevalue), (start, path rule)}&gt;\text{,}$</td>
</tr>
</tbody>
</table>

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

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

- “Only Me”
  - $<\text{poke}, (u_a, (\emptyset, 0))>$ says that $u_a$ can only poke herself
  - $<\text{poke}^{-1}, (u_t, (\emptyset, 0))>$ specifies that $u_t$ can only be poked by herself

- The Use of Negation Notation
  - $(fffc \land \neg fc)$ allows the coworkers of the user’s distant friends to see, while keeping away the coworkers of the user’s direct friends
Policy Extraction

- Policy: \( \langle \text{action}, \text{r.type}, \text{graph rule} \rangle \)

- Graph Rule: \( \text{start}, \text{path rule} \)

- Path Rule: \( \text{path spec} \land | \lor \text{path spec} \)

- Path Spec: \( \text{path}, \text{hopcount} \)

It determines the starting node, where the evaluation starts.

The other user involved in access becomes the evaluating node.

Path-check each path spec using Algorithm 2 (introduced in detail later).

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Path Checking Algorithms

• Two strategies: DFS and BFS

• Parameters: $G$, path, hopcount, $s$, $t$

Access Request: (Alice, read, $r_t$)

Policy: (read^{-1}, $r_t$, (f*cf*, 3))

Path pattern: f*cf*
Hopcount: 3

DFA for f*cf*
Path pattern: f*cf*
Hopcount: 3

Case 1: next node is already visited, thus creates a self loop

Case 2: found a matching path but DFA not at an accepting state

Case 3: currentPath matches the prefix of the pattern, but DFA not at an accepting state

\[ d: \emptyset \]

currentPath: \( (H,D,f)(D,B,c)(B,A,f) \)

stateHistory: 0123
Complexity

- Time complexity is bounded between $[O(d_{min}^{Hopcount}), O(d_{max}^{Hopcount})]$, where $d_{max}$ and $d_{min}$ are maximum and minimum out-degree of node
  
  - Users in OSNs usually connect with a small group of users directly, the social graph is very sparse
  
  - Given the constraints on the relationship types and hopcount limit, the size of the graph to be explored can be dramatically reduced
Evaluation

• Experiment 1 examines the performance w.r.t policies with different hopcount limit
  – 1000 users, single relationship type
  – *-pattern and enumeration path
• Experiment 2 studies the performance w.r.t different node degrees
  – 1000 users, two relationship types
  – Various density: 100, 200, 500 and 1000
  – Enumeration path
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(a) True-case scenarios: *-patterns

(b) True-case scenarios: enum-patterns

(c) False-case scenarios
(a) True-case scenarios: hopcount 1

(b) True-case scenarios: hopcount 2

(c) True-case scenarios: hopcount 3

(d) False-case scenarios

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Observations

• Exp. 1:
  – 1) For *-pattern, a qualified path can be always found within 4 hops; BFS outplays DFS for large hopcount in sparse graph
  – 2) For enum-path, time cost of BFS leaps

• Exp. 2:
  – 1) Hopcount increases, search space expands
  – 2) It’s more likely to find a path at a shorter time in denser graphs when hopcount is 2
  – 3) BFS suffers from the increase of search space

• In false cases, both are exhaustive search. But large hopcount is barely seen in practical OSN scenarios.

• BFS vs DFS:
  – Similar for 1, 2-hop, but DFS in general better for intermediate hopcount values (3, 4, 5, etc.)
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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

- \(<\text{quantifier}, f(\text{ATTR}(N), \text{ATTR}(E)), \text{count} \geq i>\)

∀ [+1, -2], age(u) > 18
∃ [+1, -1], weight(e) > 0.5
∃ [+1, +2, -1], gender = “male”
Example: Node Attributes

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

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Example: Edge Attributes

<read, Photo1, (u_a, ((f*, 3): ∀[+1, -1], duration ≥ 3 month, _)))>

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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
URRAC Model Components

AU: Accessing User
AS: Accessing Session
TU: Target User
TS: Target Session
O: Object
P: Policy
PAU: Accessing User Policy
PAS: Accessing Session Policy
PTU: Target User Policy
PTS: Target Session Policy
PO: Object Policy
PP: Policy for Policy
PSys: System Policy

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Differences with UURAC

• U2R Relationship-based Access Control

• Access Request
  – \((s, \text{act}, T)\) 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 \lor tag \lor share)>\>
  - \(<read^{-1}, (own \land tag)>\>
  - \(<friend_request, (parent > @)>\>
Example

- View a photo where a friend is tagged. *Bob and Ed are friends of Alice, but not friends of each other. Alice posted a photo and tagged Ed on it. Later, Bob sees the activity from his news feed and decides to view the photo: (Bob, read, Photo2)*
  
  - Bob’s $P_{AS}(read)$: $<read,(u_a,([\Sigma_{u_u}*,2][[\Sigma_{u_r},1]],2))>$
  
  - Photo2’s $P_O(read^{-1})$ by Alice:
    
    $<read^{-1},(t,([post^{1},1][friend*,3],4))>$
  
  - Photo2’s $P_O(read^{-1})$ by Ed: $<read^{-1},(u_e,([friend],1))>$
  
  - $AP_{Sys}(read)$: $<read,(ua,([\Sigma_{u_u}*,5][[\Sigma_{u_r},1]],5))>$
  
  - $CRP_{Sys}(read)$: $<read^{-1},(own\wedge tag)>$
**Example**

- **Parental control of policies.** *The system features parental control such as allowing parents to configure their children’s policies. The policies are used to control the incoming or outgoing activities of children, but are subject to the parents’ will. For instance, Bob’s mother Carol requests to set some policy, say Policy1 for Bob: *(Carol, specify policy, Policy1)*
  - Carol’s $P_{AS}(\text{specify} \_ \text{policy})$: $<\text{specify} \_ \text{policy}, (u_\alpha([\text{own}], 1) \lor ([\text{child} \cdot \text{own}], 2))>$
  - Policy1’s $P_{p}(\text{specify} \_ \text{policy}^{-1})$ by Bob: $<\text{specify} \_ \text{policy}^{-1}, (t, ([\text{own}^{-1}], 1))>$
  - $P_{sys}(\text{specify} \_ \text{policy})$: $<\text{specify} \_ \text{policy}, (u_\alpha([\text{own}], 1) \lor ([\text{child} \cdot \text{own}], 2))>$
  - $CRP_{sys}(\text{specify} \_ \text{policy})$: $<\text{specify} \_ \text{policy}, (\text{parent} \land @)>$
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## Comparison with Our Approach

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- Passive form of action allows **outgoing** and **incoming** action policy
- **Path pattern of different relationship types** and hopcount skipping make policy specification more expressive
- **Attribute-aware** access control based on attributes of users and relationships
- System-level **conflict resolution** policy
Publications


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Summary

- **UURAC**
  - Proposed a U2U relationship-based model and a regular expression-based policy specification language for OSNs
  - Provided a DFS-based path checking algorithm

- **URRAC**
  - Proposed a U2U, U2R and R2R relationship-based access control model for users’ usage and administrative access in OSNs
    - Access control policies are based on regular expression-based path patterns
    - Hopcount skipping for more expressiveness
  - Provided a system-level conflict resolution policies based on relationship precedence

- **UURAC\textsubscript{A}**
  - Incorporated attribute-awareness to UURAC model
  - Enhanced the path checking algorithm
Future Research

• Access control for 3rd party applications
  – Current strategy: all-or-nothing
  – Apps often gain much more rights than necessary

• User-specified conflict resolution policy
  – Specified by users
  – Applies to a smaller context
  – Raises ambiguity

• Unconventional relationships
Questions/Comments
Numbers and Facts

• **Survey Data from PEW Internet (2011)**
  – 47% of American adults use at least one OSN.
  – close to double the 26% of adults who used an OSN in 2008.

• **Statistics from Facebook**
  – One billion monthly active users as of Oct 2012.
  – 552 million daily active users on average in June 2012.
  – 600 million monthly active users who used Facebook mobile products in Sep 2012.
Control on Social Interactions

• A user wants to control other users’ access to her own shared information
  – Only friends can read my post
• A user wants to control other users’ activities who are related to the user
  – My children cannot be a friend of my co-workers
  – My activities should not be notified to my co-workers
• A user wants to control her outgoing/incoming activities
  – No accidental access to violent contents
  – Do not poke me
• A user’s activity influences access control decisions
  – Once Alice sends a friend request to Bob, Bob can see Alice’s profile
Privacy Breaches

• Easy to happen from OSN providers, other users, and 3rd party applications
• OSN providers store user data
  – Users have to trust OSNs to protect and not to misuse the data
  – OSNs can benefit from analyzing and sharing the data (e.g., targeted advertisement)
• 3rd party applications provide extra functionalities
  – Simply all-or-nothing control
  – Access to more information than actual need
  – Be able to post or access user data without user’s knowledge
• Another major threats are from peer users
  – Not aware of who they share with and how much
  – Have difficulty in managing privacy controls
Limitation of U2U Relationships

• We rely on the controlling user and ownership to regulate access to resources in UURAC (U2U Relationship-based-based AC)

• Needs more flexible control
  – Parental control, related user’s control (e.g., tagged user)
  – User relationships to resources (e.g., U-U-R)
  – User relationships via resources (e.g., U-R-U)
Motivating Examples

• Related User’s Control
  – There exist several different types of relationships in addition to *ownership*
  – e.g., Alice and Carol want to control the release of Bob’s photo which contains Alice and Carol’s image.
  – e.g., Betty shares Ed’s original post and acquires the ability to decide how the shared post can be available to others.
Motivating Examples (cont.)

• Administrative Control
  – Policy administration is important
  – A change of relationship may result in a change of authorization
  – Treat *administrative activities* different from normal activities
    • Policy specifying, relationship invitation and relationship recommendation
  – e.g., Bob’s mother Carol may not want Bob to become a friend with her colleagues, to access any violent content or to share personal information with others.
Policy Taxonomy

Access Control Policy

User-specified Policy
- Policy for Resource
  - Incoming Action Policy (Target Resource Policy)
- Policy for User
  - Outgoing Action Policy (Accessing User Policy)

System-specified Policy
- Policy for Resource
- Policy for User
  - Incoming Action Policy (Target User Policy)
UURAC Graph Rule Grammar

GraphRule ::= "(" <StartingNode> "," <PathRule> ")"
PathRule ::= <PathSpecExp> | <PathSpecExp><Connective><PathRule>
Connective ::= \lor\land
PathSpecExp ::= <PathSpec> | ¬<PathSpec>
PathSpec ::= "(" <Path> "," <HopCount> ")"| "(" <EmptySet> "," <Hopcount> ")"
HopCount ::= <Number>
Path ::= <TypeExp> | <TypeExp><Path>
EmptySet ::= {}
TypeExp ::= <TypeSpecifier> | <TypeSpecifier><Wildcard>
StartingNode ::= u_a|u_t|u_c
TypeSpecifier ::= σ₁|σ₂|...|σₙ|σ⁻¹|σ⁻¹|...|σ⁻¹|Σ where Σ = {σ₁, σ₂,..., σₙ, σ⁻¹, σ⁻¹,..., σ⁻¹}
Wildcard ::= "*"|"?"|"+"
Number ::= [0, 9]⁺
Policy Evaluation

• Evaluate a combined result based on conjunctive or disjunctive connectives between path specs
• Make a collective result for multiple policies in each policy set.
  – Policy conflicts may arise. We assume system level conflict resolution strategy is available (e.g., disjunctive, conjunctive, prioritized).
• Compose the final result from the result of each policy set (AUP, TUP/TRP, SP)
Policy Collecting

- To authorize \((u_a, \text{action}, \text{target})\) if \(\text{target} = u_t\)
  - E.g., \((\text{Alice}, \text{poke}, \text{Harry})\)

```
<\text{poke}, (\text{ua}, (f^*,3))>
<\text{poke}^{-1}, (\text{ua}, (f^*,3))>
<\text{poke}, (\text{ua}, (\Sigma^*,5))>
<\text{poke}^{-1}, (\text{ut}, (f^*,2))>
```
Policy Collecting

• To authorize \((u_a, \text{action}, \text{target})\) if \(\text{target} = r_t\)
  
  – Determine the controlling user for \(r_t\):
    • \(u_c \leftarrow \text{owner}(r_t)\)
  
  – E.g., \((\text{Alice}, \text{read}, \text{file2})\)

World-Leading Research with Real-World Impact!
Additional Characteristics of URRAC

• **Policy Administration**
  – Policy and Relationship Management
  – Users specify policies for other users and resources

• **User-session Distinction**
  – A user can have multiple sessions with different sets of privileges
  – Especially useful in mobile and location-based applications
URRAC Action and Access Request

- $ACT = \{act_1, act_2, \ldots, act_n\}$ is the set of OSN supported actions

- Access Request $<s, act, T>$
  - $s$ tries to perform $act$ on $T$
  - Target $T \subseteq (2^{TU \cup R} - \emptyset)$ is a non-empty set of users and resources
    - $T$ may contain multiple targets
### URRAC Authorization Policy

<table>
<thead>
<tr>
<th>Policy Type</th>
<th>Action Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessing User Policy</td>
<td><code>&lt;act, graphrule&gt;</code></td>
</tr>
<tr>
<td>Accessing Session Policy</td>
<td><code>&lt;act, graphrule&gt;</code></td>
</tr>
<tr>
<td>Target User Policy</td>
<td><code>&lt;act^{-1}, graphrule&gt;</code></td>
</tr>
<tr>
<td>Target Session Policy</td>
<td><code>&lt;act^{-1}, graphrule&gt;</code></td>
</tr>
<tr>
<td>Object Policy</td>
<td><code>&lt;act^{-1}, graphrule&gt;</code></td>
</tr>
<tr>
<td>Policy for Policy</td>
<td><code>&lt;act^{-1}, graphrule&gt;</code></td>
</tr>
<tr>
<td>System Policy for User</td>
<td><code>&lt;act, graphrule&gt;</code></td>
</tr>
<tr>
<td>System Policy for Resource</td>
<td><code>&lt;act, o.type, graphrule&gt;</code></td>
</tr>
<tr>
<td></td>
<td>where <code>o.type</code> is optional</td>
</tr>
</tbody>
</table>

- *action*\(^{-1}\) in TUP, TSP, OP and PP is the passive form since it applies to the recipient of action.
- SP does not differentiate the active and passive forms.
- SP for resource needs *o.type* to refine the scope of the resource.
URRAC Graph Rule Grammar

GraphRule → "(" StartingNode"," PathRule")"
PathRule → PathSpecExp | PathSpecExp Connective PathRule
Connective → ∨ | ∧
PathSpecExp → PathSpec | "¬" PathSpec
PathSpec → "(" Path"," HopCount")" | "(" EmptySet"," HopCount")"
HopCount → Number
Path → ["" TypeSeq""] | "" TypeSeq"," HopCount"" | "" TypeSeq"," HopCount""
EmptySet → ∅
TypeSeq → TypeExp {} "." TypeExp
TypeExp → TypeSpecifier | TypeSpecifier Wildcard
StartingNode → u_a | u_c | t
TypeSpecifier → σ_1 | σ_2 | ... | σ_n | σ_1⁻¹ | σ_2⁻¹ | ... | σ_n⁻¹ | Σ where Σ={σ_1,σ_2,...,σ_n,σ_1⁻¹,σ_2⁻¹,...,σ_n⁻¹}
Wildcard → "*" | "?" | "+"
Number → [0-9]+
Hopcount Skipping

• U2R and R2R relationships may form a long sequence
  – Omit the distance created by resources
  – 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.
• \(<\text{read}^{-1}, (\text{own} \land \text{tag})>\>
  – The more rigid one between the owner’s and the tagged users’ “read-1” policies over the photo is honored.

• \(<\text{friend\_request}, (\text{parent} > @)>\>
  – When child attempts friendship request to someone, parents’ policies get precedence over child’s own will.

• \(<\text{share}^{-1}, (\text{own} \lor \text{tag} \lor \text{share})>\>
  – A weblink is sharable if either the original owner, or any of the tagged users or shared users allows.
## Attribute Policy Taxonomy

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\forall [+m, -n]$</td>
<td>All entities from the $m^{th}$ to the $n^{th}$ last, $m + n \leq h$ where $m$ and $n$ are non-negative integers and $h$ is a hopcount limit</td>
</tr>
<tr>
<td>$\forall [+m, +n]$</td>
<td>All entities from the $m^{th}$ to the $n^{th}$, $m \leq n \leq h$</td>
</tr>
<tr>
<td>$\forall [-m, -n]$</td>
<td>All entities from the $m^{th}$ last to the $n^{th}$ last, $h \geq m \geq n$</td>
</tr>
<tr>
<td>$\exists [+m, -n]$</td>
<td>One entity from the $m^{th}$ to the $n^{th}$ last, $m + n \leq h$</td>
</tr>
<tr>
<td>$\exists [+m, +n]$</td>
<td>One entity from the $m^{th}$ to the $n^{th}$, $m \leq n \leq h$</td>
</tr>
<tr>
<td>$\exists [-m, -n]$</td>
<td>One entity from the $m^{th}$ last to the $n^{th}$ last, $h \geq m \geq n$</td>
</tr>
<tr>
<td>$\forall {2^{\pm N}}$</td>
<td>All entities in this set</td>
</tr>
<tr>
<td>$\exists {2^{\pm N}}$</td>
<td>One entity in this set</td>
</tr>
</tbody>
</table>