A Provenance-based Access Control Model for Dynamic Separation of Duties

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Separation of Duties (SoD)

• Duties
  – The responsibilities required for accomplishing a certain task
  – Example: washing dishes, flying airplane, saving the world, etc.
  – Responsibilities are assigned to people (or users)

• Conflicting Duties
  – Too many responsibilities = corrupted power
  – Example: “One Ring to rule them all”

• Essentially an Access Control Problem
  – Who can have which responsibility?
RBAC Approach for SoD

• Roles as semantic constructs
  – Various responsibilities can be encapsulated within a specific role.
  – Example: Professor is responsible for assigning and grading homework.
  – Responsibilities are mapped to roles, which are then assigned to users.

• Conflicting Roles
  – Two main approaches: Static and Dynamic.
Static Separation of Duties

- Mainly deals with role assignment
  - No two conflicting roles can be assigned to the same user.
  - Example: A user should not be assigned both police and thief roles.

- Narrow scope
  - Unable to address SoD concerns in dynamic environment.
Dynamic Separation of Duties

• Utilizes the Role Activation concept
  – Two conflicting roles can be assigned to the same user, just not activated at the same time (or under other constraints).

• Variations of DSOD
  – Expressing different concerns.
  – Each concern features unique characteristic.
# DSOD Variations + Features

## Features

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<th>Feature</th>
<th>Simple DSOD</th>
<th>Obj-DSOD</th>
<th>Ops-DSOD</th>
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DSOD Examples

- **Scenario: Homework Grading System**
  - Students can **upload/replace/submit** a homework to the system.
  - Once it is **submitted**, the homework can be **reviewed** by other students or designated graders until it is **graded** by the teaching assistant (TA).
  - The Professor holds the highest authority.

- **Variations of DSOD constraints:**
  - Cannot activate roles *Reviewer* and *Student* at the same time – **Simple DSOD**
  - Can activate roles *Reviewer* and *Student*, but cannot **review** the homework **submitted** – **Object-based DSOD**
  - Cannot activate roles *TA* and *Student*, if permitted actions cover Professor’s – **Operational DSOD**
  - Cannot **grade** a homework before it is **submitted** – **History-based DSOD**
  - Cannot **grade** a homework unless reviews’ combined **weights** exceeds 3 – **TCE**
PBAC Approach to DSOD
PBAC Approach to DSOD

• Naturally provide history information
  – Existing approaches assume ready availability for usages.

• Expressive control unit (dependency names)
  – Facilitate policy specification and convenient enforcement.

• Enables new DSOD concerns
  – Capable of capturing more interesting behavior from system events.

• Easily incorporated with other AC mechanisms
  – RBAC and more
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Provenance Data

- Information of operations/transactions performed against data objects and versions
  - Actions that were performed against data
  - Acting Users/Subjects who performed actions on data
  - Data Objects used for actions
  - Data Objects generated from actions
  - Additional Contextual Information of the above entities

- Directed Acyclic Graph (DAG)
- Causality dependencies between entities (acting users / subjects, action processes and data objects)

- Dependency graph can be traced for the discovery of Origin, usage, versioning info, etc.
Provenance-aware Systems

- Capturing provenance data
- Storing provenance data
- Querying provenance data
- Using provenance data
- Securing provenance data

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From Open Provenance Model (OPM)

• 3 Node Types
  – Object (Artifact)
  – Action (Process)
  – User/Subject (Agent)

• 5 Causality dependency edge Types (not a dataflow)

• Provenance data: a set of 2 entities & 1 dependency

  • E.g., (ag,p1,a1,a2): <p1,ag,c>,<p1,a1,u>,<a2,p1,g>
OPM Example

100g Sugar
100g Flour
100g Butter
Two Eggs
John
Bake
Cake

wasDerivedFrom
wasGeneratedBy
used
wasControlledBy

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Provenance Data Model

Subject (agent) → Action (process) → Object1 (artifact)

- c: wasControlledby
- u: type
- t: type
- g: type

Attribute

hasAttributeOf

→ Attrb. edge
→ Dep. edge

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Capturing Provenance Data

(Subject1, Grade1, HW1, GradedHW1, ContextualInfoSet-Grade1)

(Grade1, u, HW1)
(Grade1, c, Subject1)
(GradedHW1, g, Grade1)

(Grade1, t[actingUser], Alice)
(Grade1, t[activeRole], TA)
(Grade1, t[weight], 2)
(Grade1, t[object-size], 10MB)
Provenance Graph

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Storing and Querying Provenance Data

- **Resource Description Framework (RDF)** provides natural representation of triples.

- **RDF-format triples** can be stored in databases.

- Utilizes **SPARQL Protocol and RDF Query Language** for extracting useful provenance information.
  - Starting Node: any entities (not attribute nodes)
  - A matching path pattern: combination of dependency edges
Provenance Graph

Sub1

HW1

Grade1

HW1_G

u

c

g

t(actUser)

t(...)

t(...)
Provenance Graph

SELECT ?agent WHERE { HW1_G [g:c] ?agent }
Provenance Graph

SELECT ?user WHERE { HW1_G [g:t[actUser]] ?user }

Sub1

SELECT ?user WHERE { HW1_G [g:t[actUser]] ?user }

Alice

TA

2

10MB

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Provenance Graph
Provenance Graph

SELECT ?user
WHERE
{ HW1_G’ [g:u:g:c] ?user }

{ HW1_G’ [[g:u]*:g:c] ?user }

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Provenance-aware Systems

Using provenance data

Securing provenance data
PBAC Model Components
Dependency List

- **Object Dependency List (DL$_o$):** A set of identified dependencies that consists of pairs of
  - Dependency Name: abstracted dependency names (DNAME) and
  - regular expression-based object dependency path pattern (DPATH)

- **System-computable (complex) dependency instances**
  - using pre-defined dependency names and matching dependency path patterns in DL (and querying base provenance data)

- **User-declared (complex) dependency instances**
  - using pre-defined dependency names in DL

- **Examples**
  - `< wasSubmittedVof, g_submit.u_input >`
  - `< wasAuthoredBy, wasSubmittedVof?.wasReplacedVof *.g_upload.c >`

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PBAC\textsubscript{B}: A Base Model

- System-captured Base Provenance Data only
  - Using sub-types of 3 direct dependencies (u, g, c)
  - No user-declared provenance data
- Object dependency only
- Supports Simple and effective policy specification and access control management
- Supports DSOD, workflow control, origin-based control, usage-based control, object versioning, etc.
Limitations of $\text{PBAC}_B$

• Simplified data model
  – Does not capture contextual information
  – Unable to address advanced DSOD
  – Access evaluation restrained to User Verification and Action Validation

• $\text{PBAC}_C$: extending the base model
PBAC_C : PBAC_B + Contextual Info.
Provenance Data Model
Provenance Data Model

• A new type of entity, **Attribute**, to capture all contextual information.

• A new type of edge (can be considered dependency), \( t \), that connects an entity and the associated attribute.

• Notice all attribute types (regardless of association) is concentrated in **Action** entities.
  – Action instances define system events.
PBAC\textsubscript{C} : PBAC\textsubscript{B} + Contextual Info.

• Introduce **Subject** entities
• Incorporate *contextual information* associated with the main entities (*Users*, *Subjects*, etc.)
• Enable more variations of *dependency*
• **Access evaluation** now utilizes attributes
• Enable enhanced *traditional* and *new* features of DSOD
• More **flexible policy specification** (*startNode = (S, A, or O)*)

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Enhanced DSOD Features

• **Awareness of Past-Action attribute.**
  – Context information of action varies in different states in time
  – Past context information may potentially be significant for current state
  – Example: policy can specify decision rules based on either past or current assigned weight to action types

• **Dependency Path Pattern-based DSOD.**
  – More **expressive control units**
  – Can achieve **wide variety of path patterns**
  – Combinations of actions, versioning, etc.
Policies

• An *informal policy language* is used to specify access decision rules based on dependency name control units

• Example ObjDSOD:
  – **English Policy**: requires the requesting subject on replacing a homework object to be activated by the same acting user who activated the subject on uploading it.
  – **Informal Policy**:
    
    \[
    \text{allow}(\text{sub}, \text{replace}, o) \Rightarrow
    (\text{sub}, \text{hasPerforme}\text{dActions:hasAttributeOf(actingUser)}) \in
    (o, \text{wasUploadedBy}) \text{ and count}(o, \text{wasSubm}i\text{ttedVof}) = 0.
    \]

• Smooth conversion to XACML policy language
  – Can be easily enforced
  – A proof-of-concept prototype is implemented
Sample XACML policy

<Policy PolicyId="replacePolicy"
RuleCombiningAlgId="urn:oasis:names:tc:xacml:1.0:rulecombining-algorithm:ordered-permit-overrides">
<Target>
...
<Actions>
  <Action>
    <ActionMatch MatchId="urn:oasis:names:tc:xacml:1.0 :function:string-equal">
      <AttributeValue
        DataType="http://www.w3.org/2001/XMLSchema#string">replace</AttributeValue>
    </ActionMatch>
    <ActionAttributeDesignator
      AttributeId="urn:oasis:names:tc:xacml:1.0:action:action-id"
      DataType="http://www.w3.org/2001/XMLSchema#string" />
  </Action>
</Actions>
Sample XACML policy

...<Rule RuleId="ReplaceRule" Effect="Permit">
  <Condition FunctionId="urn:oasis:names:tc:xacml:1.0:function:and">
    <Apply FunctionId="urn:oasis:names:tc:xacml:1.0:function:string-is-in">
      <Apply FunctionId="provenance-query-SPARQL">
        <Apply FunctionId="urn:oasis:names:tc:xacml:1.0:function:string-one-and-only">
          <SubjectAttributeDesignator AttributeId="urn:oasis:names:tc:xacml:1.0:subject:subject-id" DataType="http://www.w3.org/2001/XMLSchema#string"/>
          <AttributeValue DataType="http://www.w3.org/2001/XMLSchema#string">hasPerformedActions:hasAttributeOf(actingUser)</AttributeValue>
        </Apply>
      </Apply>
    </Apply>
  </Condition>
</Rule>
Extended XACML Architecture
PBAC Reasoner Implementation

- Dependency Repository
- Provenance Data Repository
- Query Engine

- Extend OASIS XACML
  - Utilize top-of-the-shelf toolkits

MySQL
Jena
ARQ

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Experiment and Performance

- **System**
  - Ubuntu 12.10 image with 4GB Memory and 2.5 GHz quad-core CPU running on a Joyent SmartData center (ICS Private Cloud).

- **Mock Data simulating HGS scenario**
  - Different shapes of provenance graph
  - Extreme depth and width settings

- **Results for tracing 2k/12k edges**
  - 0.017/0.718 second per deep request
  - 0.014/0.069 second per wide request
Throughput Evaluation

• Results for tracing 2k/12k edges
  – 0.0096/0.154 second per deep request
  – 0.035/0.04 second per wide request

FEASIBLE !!!
Conclusion

• Propose a PBAC approach for traditional and enhanced DSOD variations
• Extend the base PBAC model to capture contextual information
• Proof-of-concept prototype on XACML architecture extension
• An access control foundation for secure provenance computing!
Thank you!!!

• Questions and Comments?