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

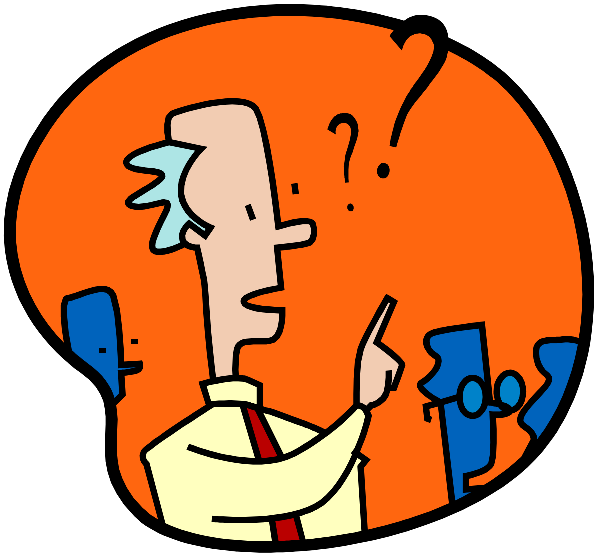
Features	Simple DSOD	Obj-DSOD	Ops-DSOD	HDSOD	TCE
Per Role	√	√	√	√	√
Per Action		√	√	√	√
Per Object		√		√	√
Task-aware			√	√	√
Order-aware				√	√
Weighted Action-aware					√

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

DSOD Variations + Features

Features	Simple DSOD	Obj-DSOD	Ops-DSOD	HDSOD	TCE	DSOD in PBAC
Per Role	√	√	√	√	√	√
Per Action		√	√	√	√	√
Per Object		√		√	√	√
Task-aware				√	√	√
Order-aware			√	√	√	√
Weighted Action-aware					√	√

DSOD Variations + Features

Features	Simple DSOD	Obj-DSOD	Ops-DSOD	HDSOD	TCE	DSOD in PBAC
Per Role	√	√	√	√	√	√
Per Action		√	√	√	√	√
Per Object		√		√	√	√
Task-aware				√	√	√
Order-aware			√	√	√	√
Weighted Action-aware					√	√
Dependency Path Patterns- aware						√

DSOD Variations + Features

Features	Simple DSOD	Obj-DSOD	Ops-DSOD	HDSOD	TCE	DSOD in PBAC
Per Role	√	√	√	√	√	√
Per Action		√	√	√	√	√
Per Object		√		√	√	√
Task-aware				√	√	√
Order-aware			√	√	√	√
Weighted Action-aware					√	√
Dependency Path Patterns- aware						√
Past Attribute-aware						√

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

Provenance Data Model

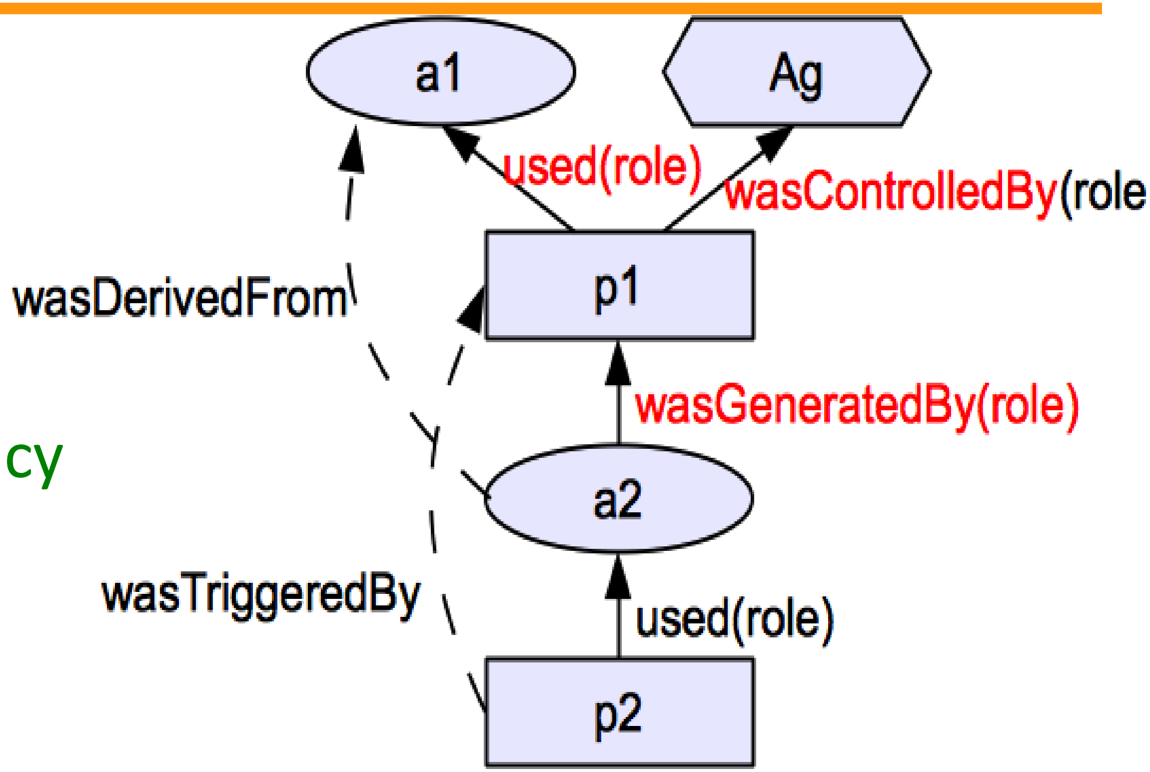
- Using provenance data
- Securing provenance data

Access Control

From Open Provenance Model (OPM)

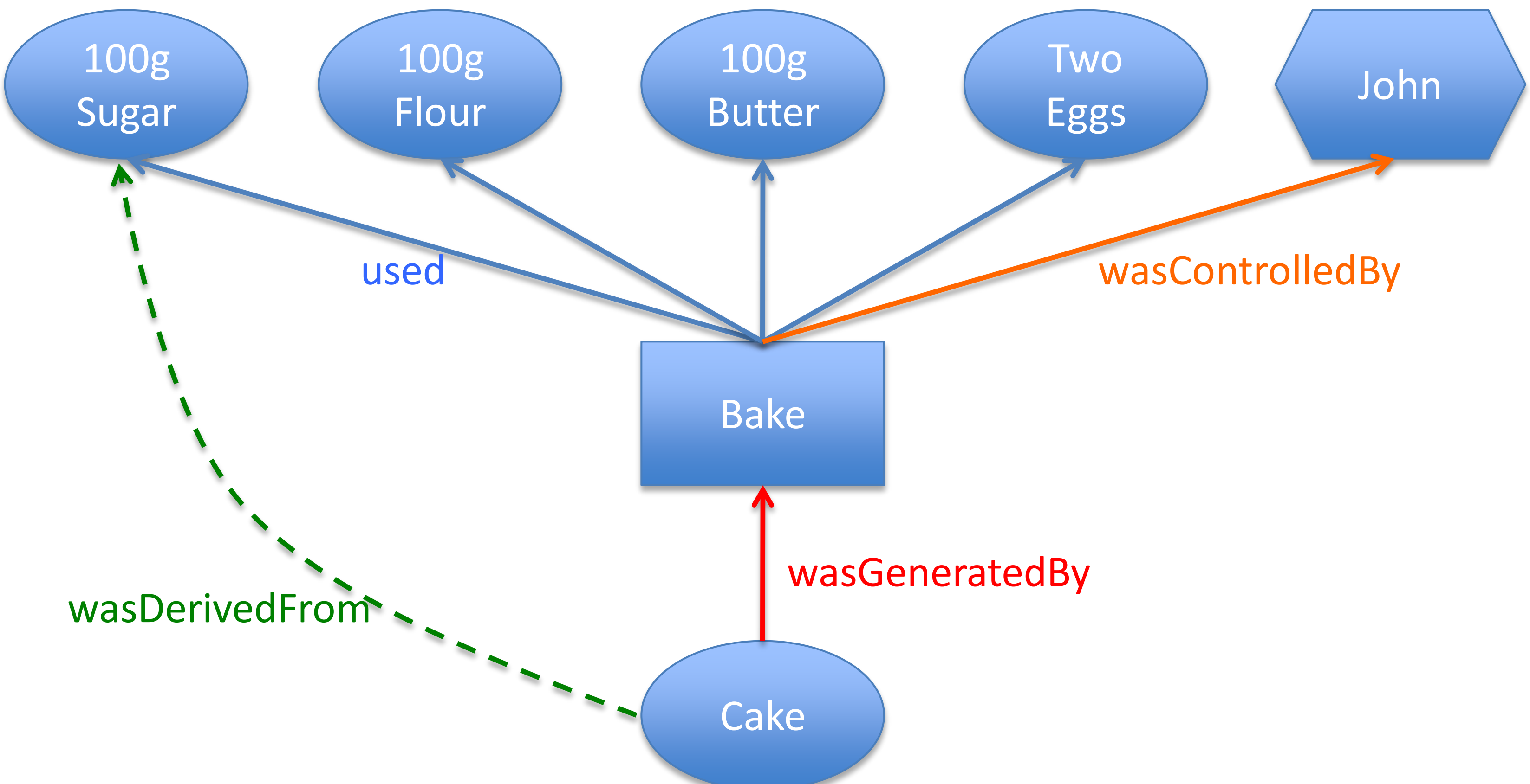
- 3 Node Types
  - Object (Artifact)
  - Action (Process)
  - User/Subject (Agent)

- 5 Causality dependency edge Types (not a dataflow)

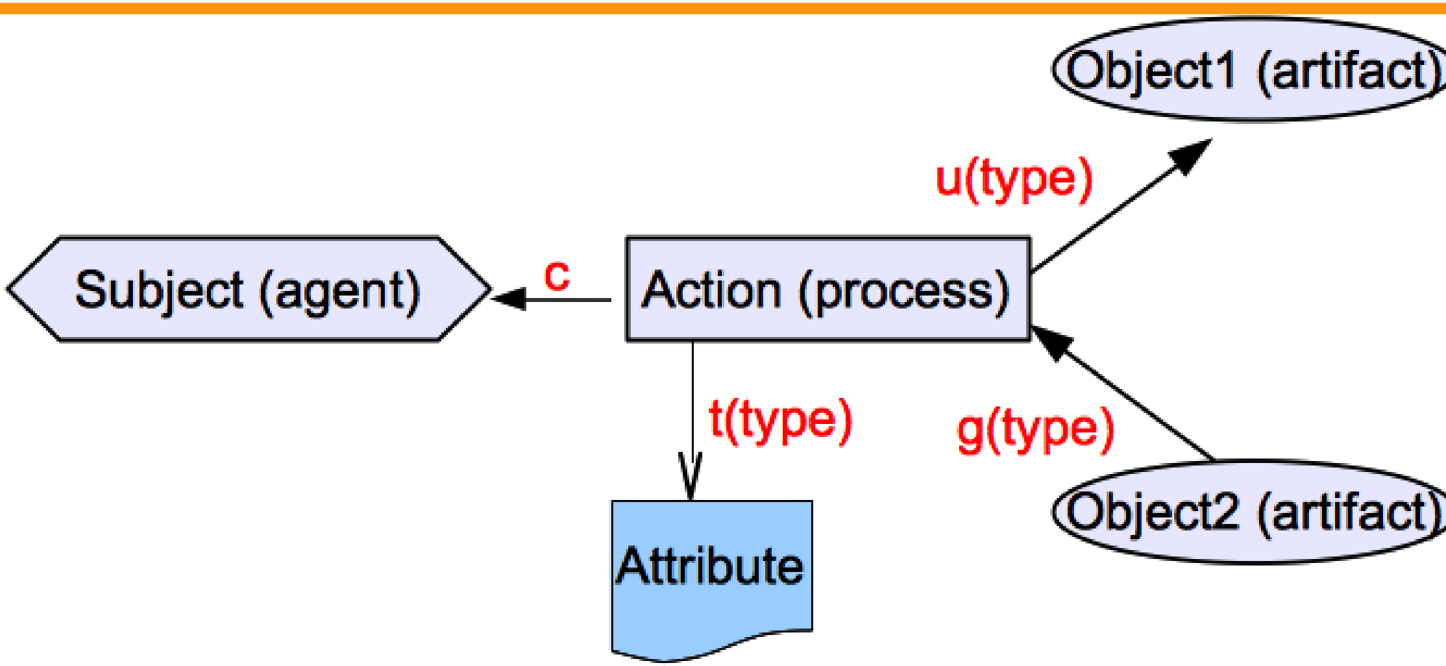


- Provenance data: a set of 2 entities & 1 dependency
  - E.g., (ag,p1,a1,a2): <p1,ag,c>,<p1,a1,u>,<a2,p1,g>

OPM Example


100g
Sugar
100g
Flour
100g
Butter
Two
Eggs
John
used
wasControlledBy
Bake
wasGeneratedBy
wasDerivedFrom
Cake

Provenance Data Model



c wasControlledby
u used
g wasGeneratedBy
t hasAttributeOf

Attrb. edge
Dep. edge

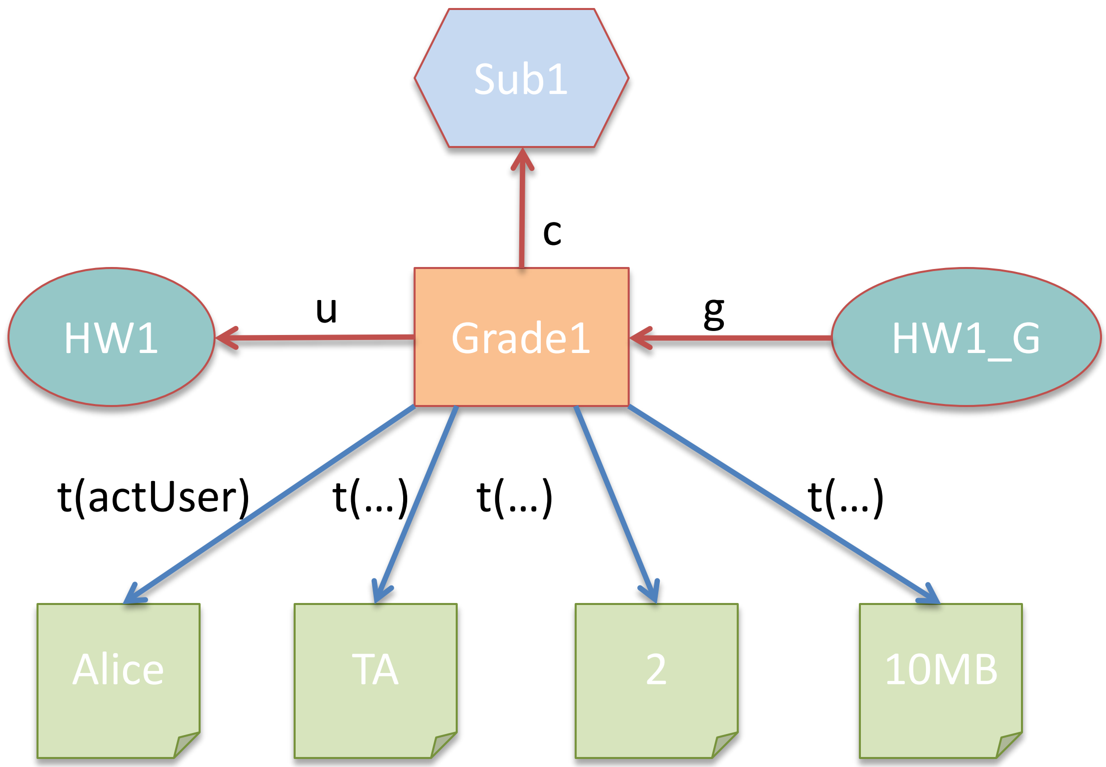
Capturing Provenance Data

(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)

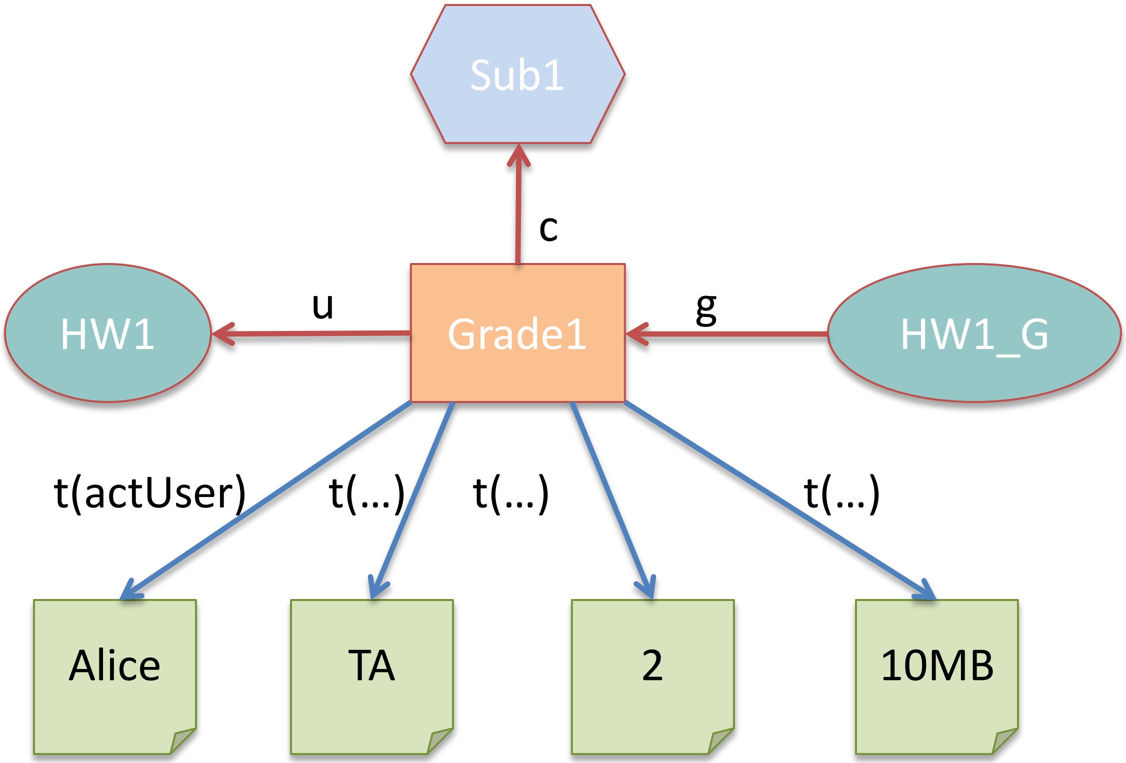
Provenance Graph



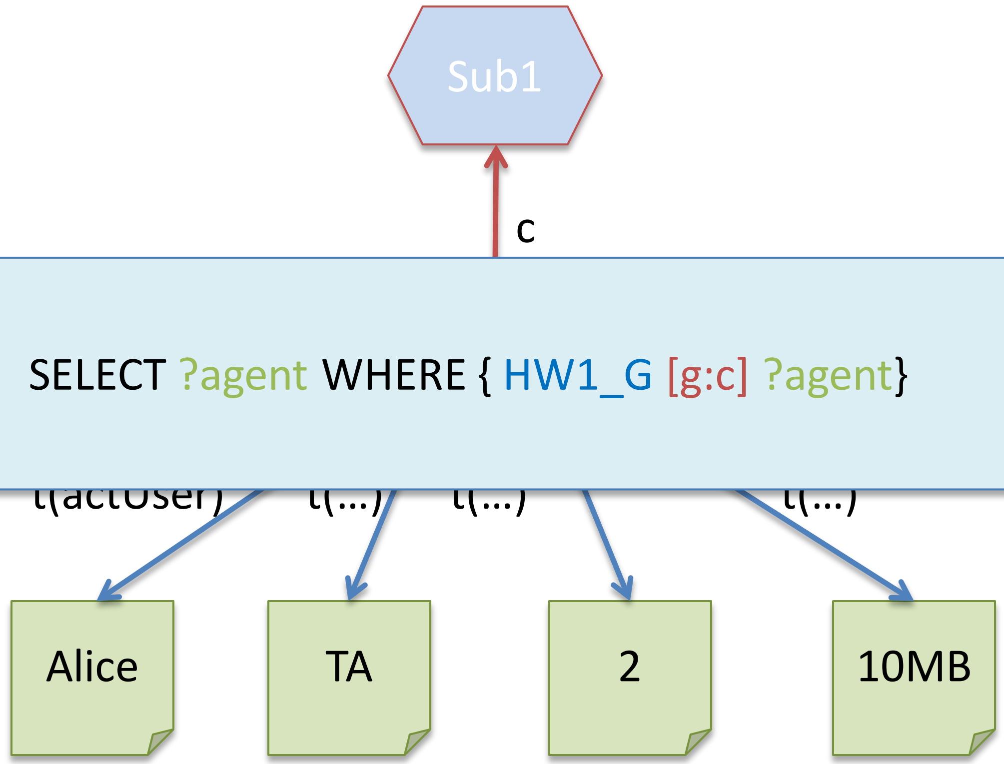
Storing and Querying Provenance Data

- 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

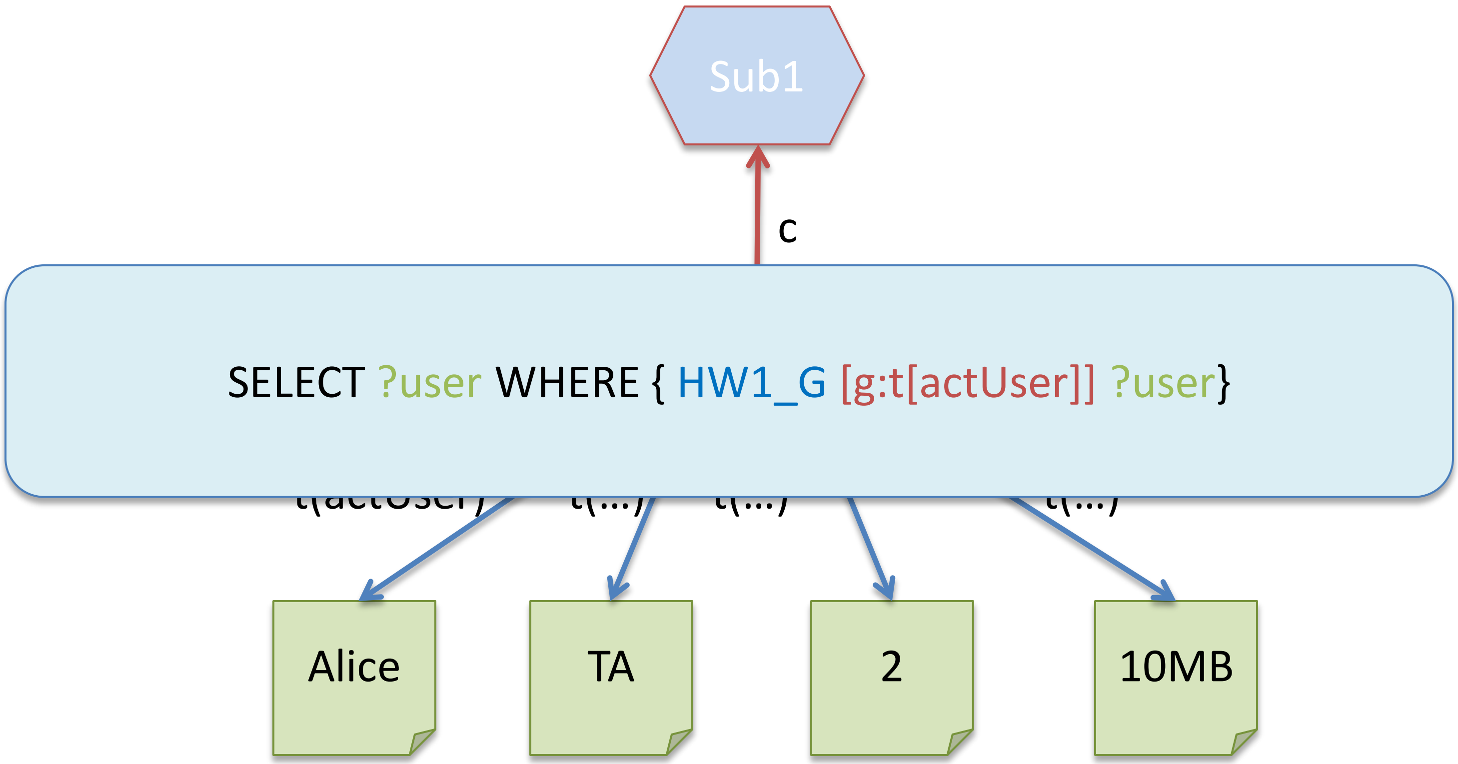


Provenance Graph

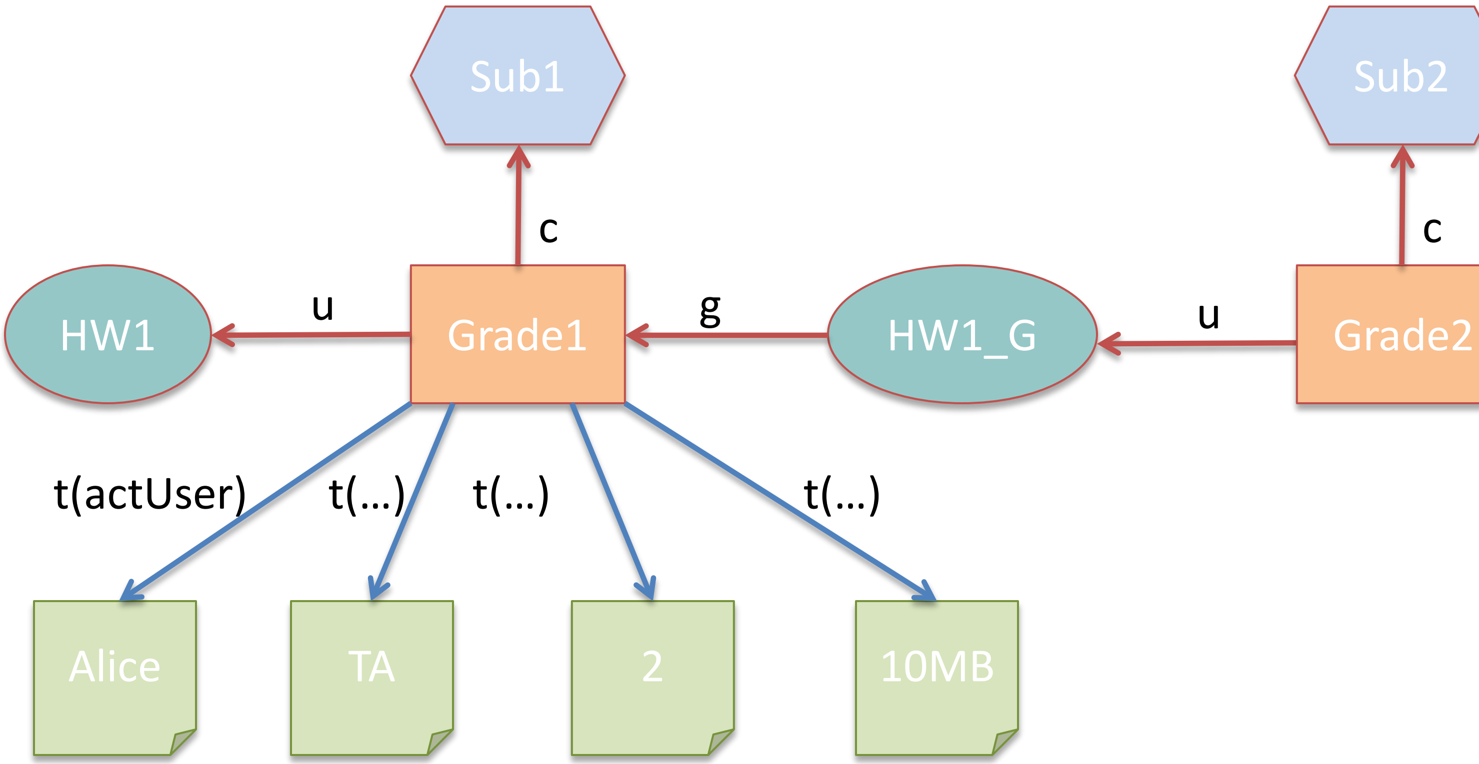


SELECT ?agent WHERE { HW1_G [g:c] ?agent}

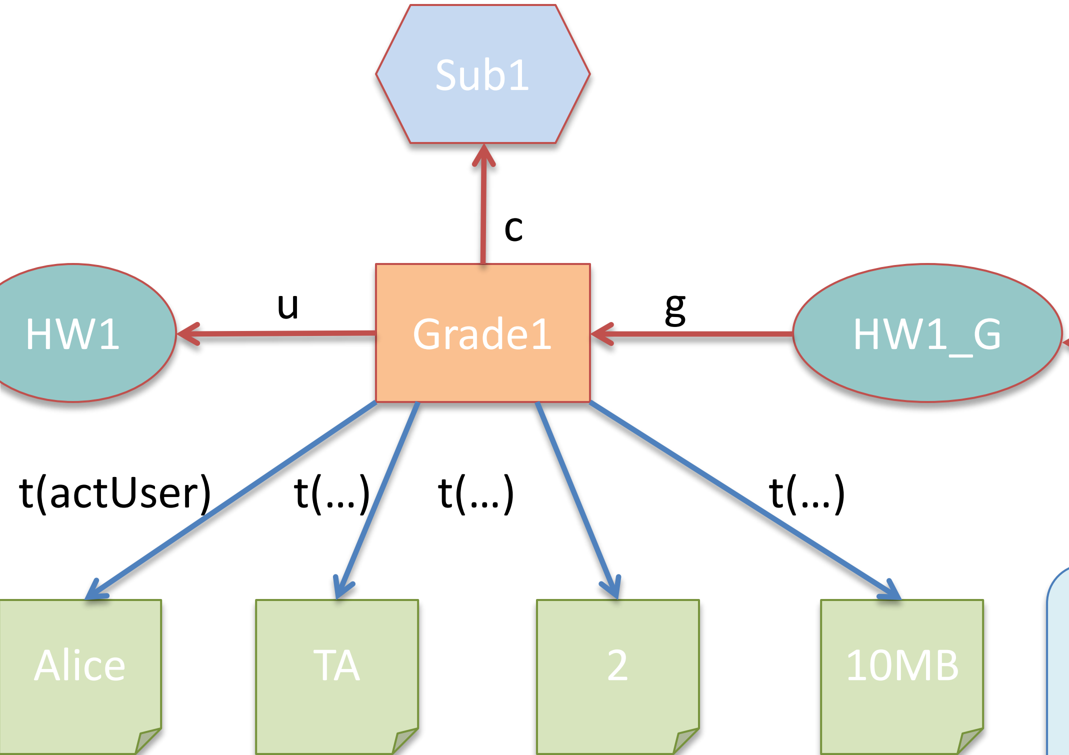
Provenance Graph



Provenance Graph



Provenance Graph



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

{ HW1_G’ ***[[g:u]*:g:c]*** ?user}

Provenance-aware Systems

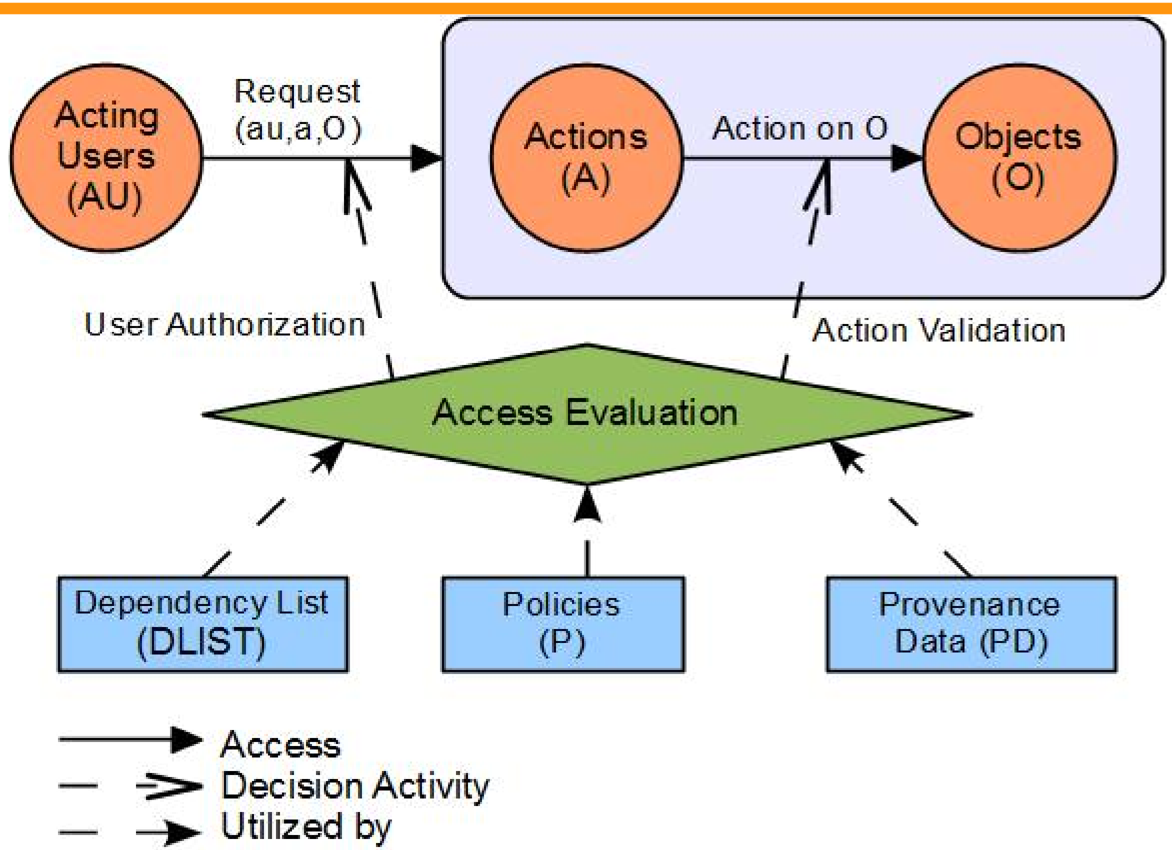
Using provenance data

PBAC

PAC

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 $*.g_{upload}.c$ >

$PBAC_B$: A Base Model

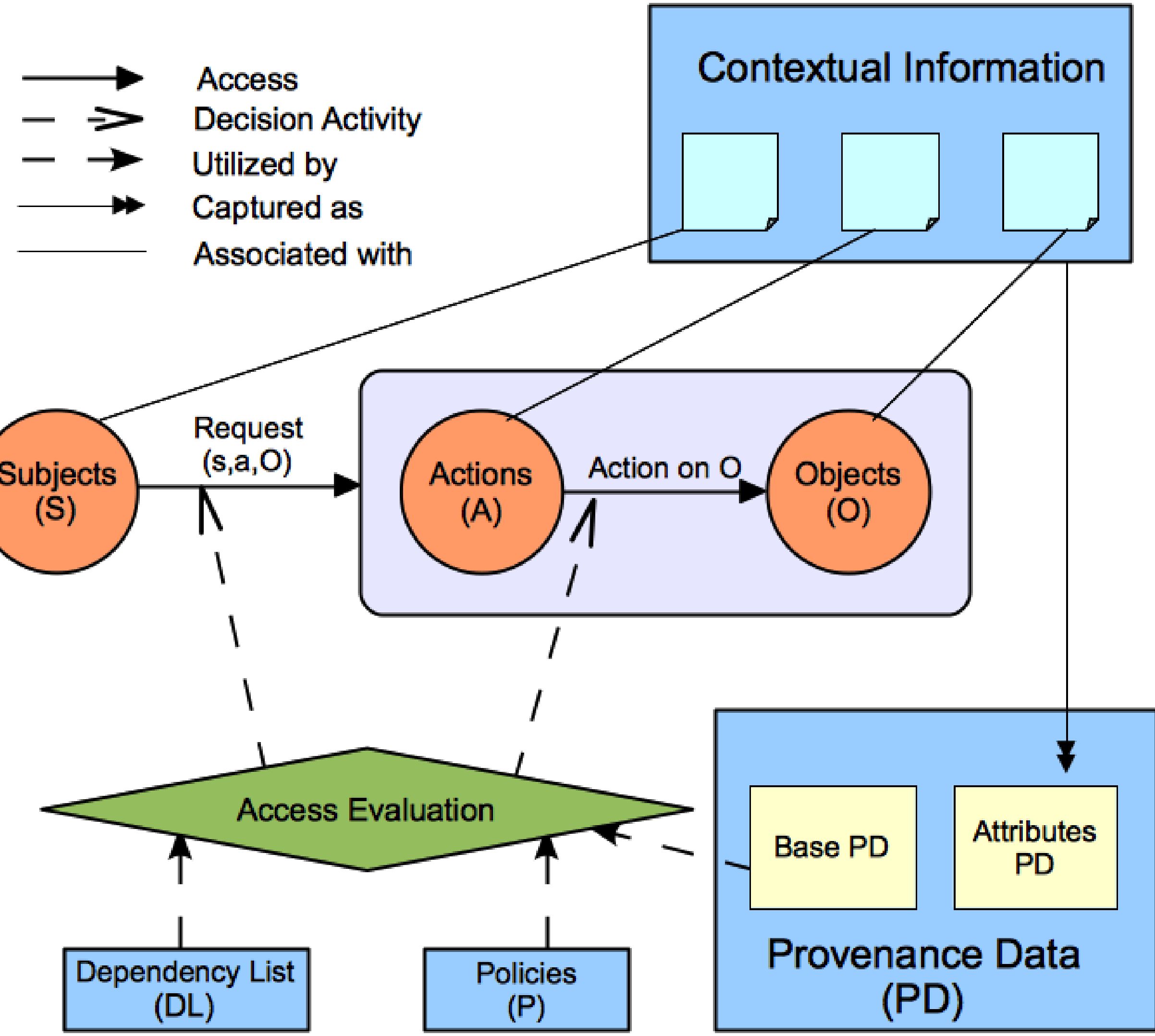
- System-captured Base Provenance Data only
  - Using sub-types of 3 direct dependencies (u, g, c)
  - No user-declared provenance data
- Object dependency only
- Supports Simple and effective policy specification and access control management
- Supports DSOD, workflow control, origin-based control,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

Limitations of $PBAC_B$

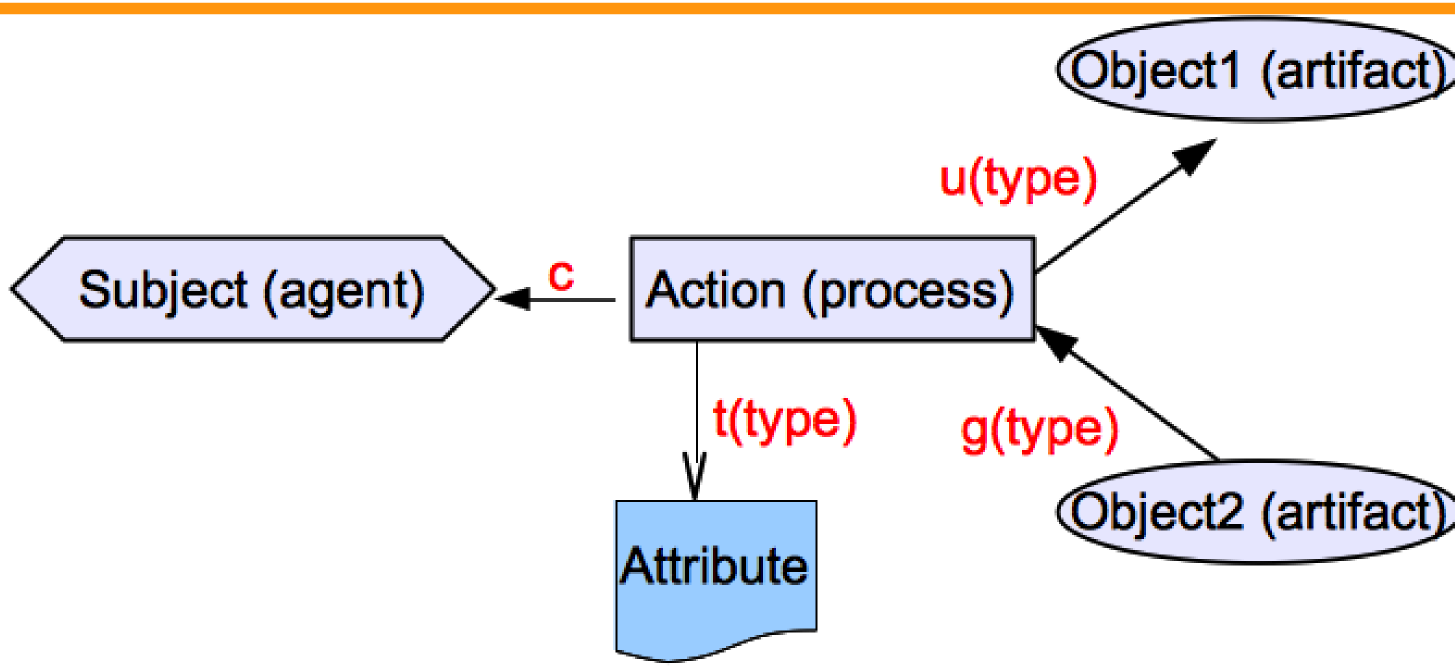
- Simplified data model
  - Does not capture contextual information
  - Unable to address advanced DSOD
  - Access evaluation restrained to User Verification and Action Validation

- $PBAC_C$: extending the base model

$PBAC_C$: $PBAC_B$ + Contextual Info.



Provenance Data Model



c wasControlledby
u used
g wasGeneratedBy
t hasAttributeOf

→ Attrb. edge
→ Dep. edge

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.

$PBAC_C$: $PBAC_B$ + 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))

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**:

    allow(sub,replace,o) =>
    (sub,hasPerformedActions:hasAttributeOf(actingUser)) ϵ (o,wasUploadedBy) *and* count(o,wasSubmittedVof) = 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</AttributeValu
    e>
    <ActionAttributeDesignator
    AttributeId="urn:oasis:names:tc:xacml:1.0:action:action-id“
    DataType="http://www.w3.org/2001/XMLSchema#string" />
    </ActionMatch>
    </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" /></Apply>

<AttributeValue DataType="http://www.w3.org/2001/XMLSchema#string">**hasPerformedActions:hasAttributeOf(actingUser)**

</AttributeValue>

</Apply>

<Apply FunctionId="**provenance-query-SPARQL">**

<Apply FunctionId="urn:oasis:names:tc:xacml:1.0:function:string-one-and-only">

<ResourceAttributeDesignator AttributeId="urn:oasis:names:tc:xacml:1.0:resource:resourceid" DataType="http://www.w3.org/2001/XMLSchema#string" />

</Apply>

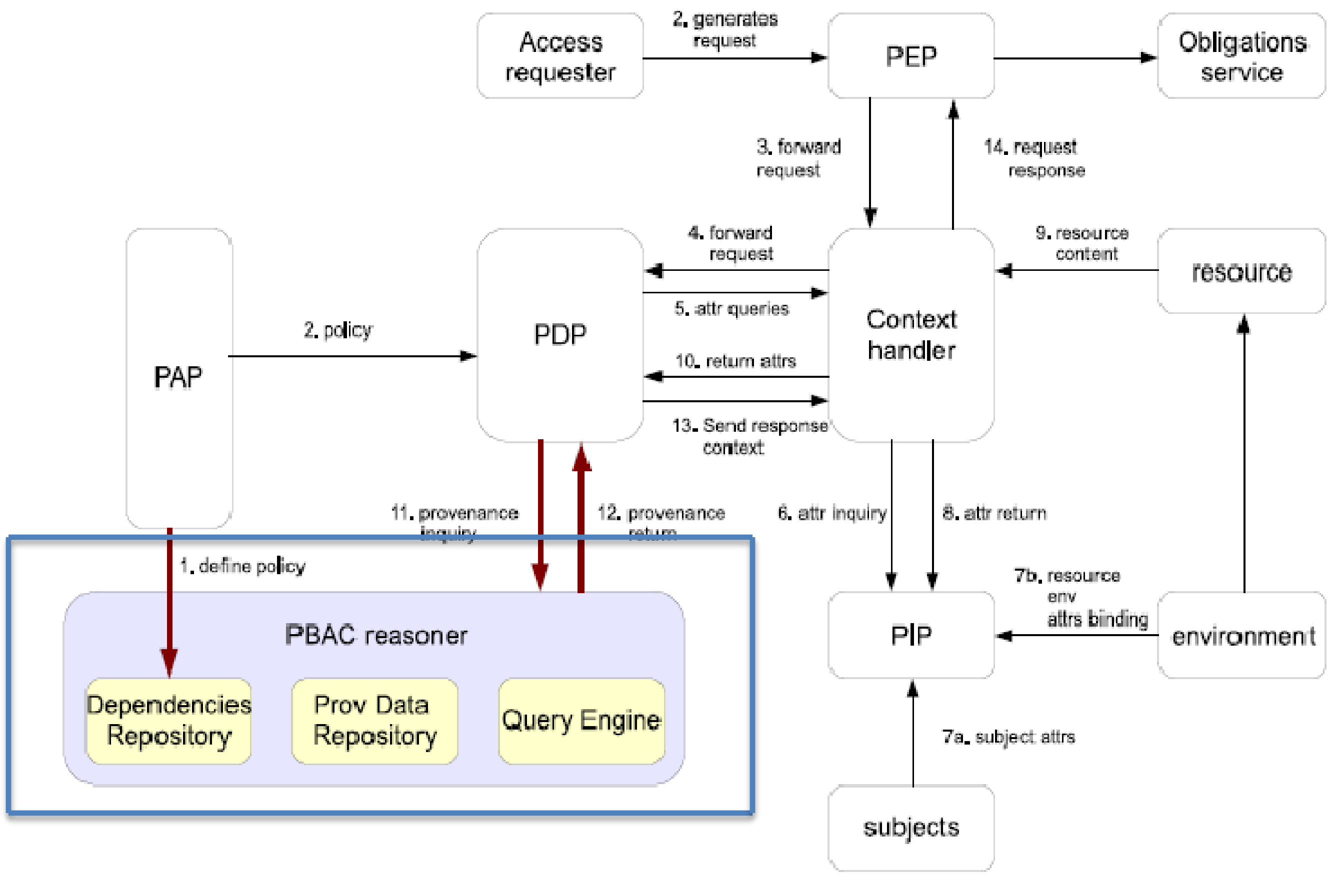
<AttributeValue DataType="http://www.w3.org/2001/XMLSchema#string">**wasUploadedBy**</AttributeValue>

</Apply>

</Apply>

…

Extended XACML Architecture



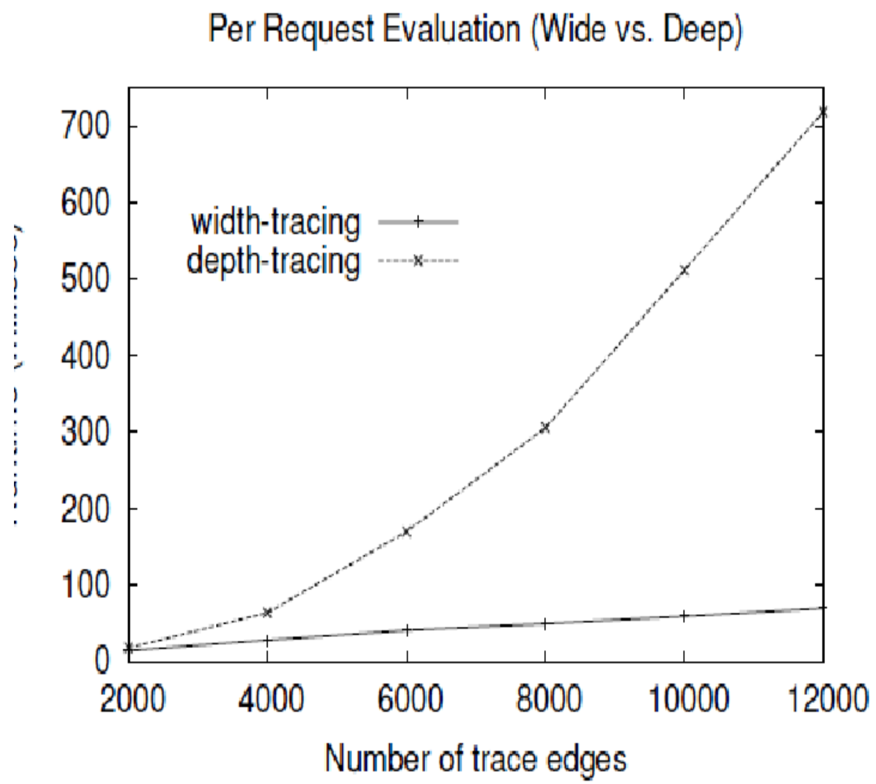
PBAC Reasoner Implementation

- Dependency Repository ← MySQL
- Provenance Data Repository ← Jena
- Query Engine ← ARQ

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

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?