A Provenance-based Access Control Model (PBAC)

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Jaehong Park, Dang Nguyen and Ravi Sandhu
Institute for Cyber Security
University of Texas at San Antonio

Provenance Data

- Information of operations/transactions performed against data objects and versions
  - Actions that were performed against data
  - Agents who performed actions on data
  - Data used for actions
  - Data generated from actions

Provenance-aware Systems

- Capturing/expressing provenance data
- Storing provenance data
- Querying provenance data

- Using provenance data 

- Securing provenance data 

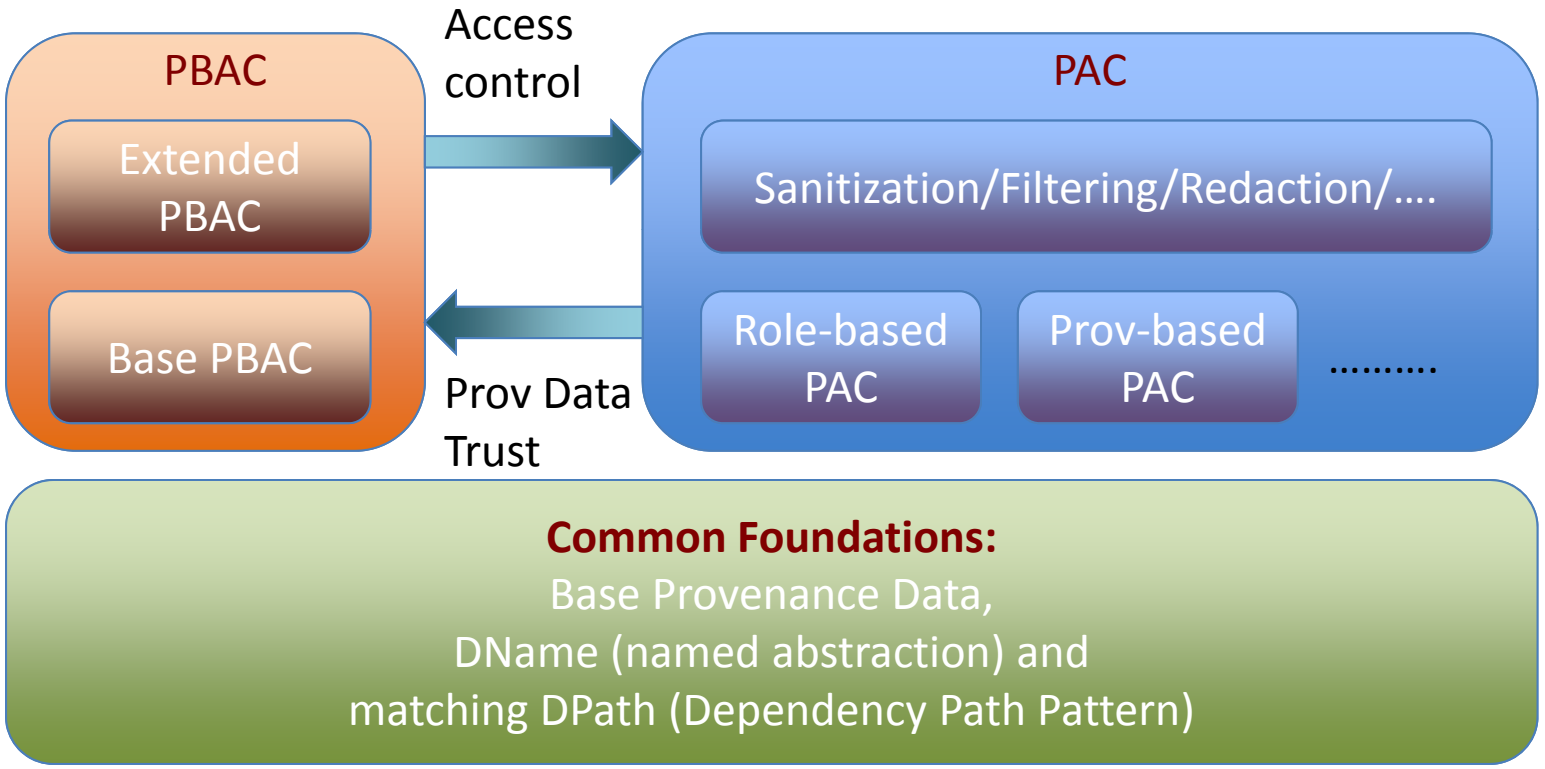
Access control in Provenance-aware Systems

- Provenance Access Control (PAC)
  - Controlling access to provenance data which could be more sensitive than the underlying data
  - Needs access control models/mechanisms (e.g, RBAC)
  - (Meaningful) control granularity? Right level of abstraction?

- Provenance-based Access Control (PBAC)
  - Using provenance data to control access to the underlying data
  - Provenance-based policy specification

Meaningful granularity of provenance data?

Access Controls in Provenance-aware Systems



PAC & PBAC in Applications

- Common Foundation
  - Base provenance data
  - Dependency list
    - Dependency Name: meaningful, named abstraction
    - matching regular expression-based causality dependency path pattern
- PAC and PBAC are complementary
  - In PAC, control decision can be based on provenance data (PB-PAC)
  - In PBAC, PAC can be used for added trustworthiness on provenance data

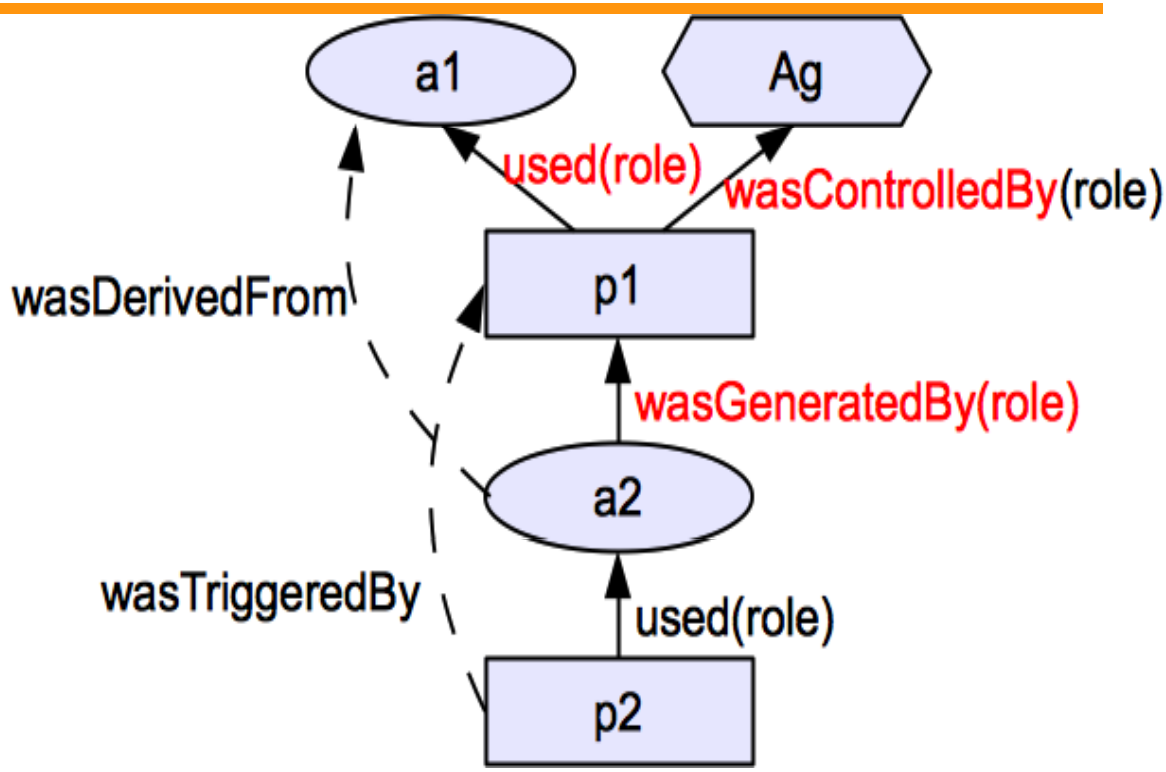
Provenance Data

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

- Dependency graph can be traced for extracting Origin, usage, versioning information, etc.
  - PBAC can support origin/usage-based control, Dynamic Separation of Duty (DSOD), workflow control, etc.

From Open Provenance Model (OPM)

- 3 Nodes
  - Artifact (ellipse)
  - Process (Rectangle)
  - Agent (Hexagon)
- 5 Causality dependency edges (not 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>

Direct vs. Indirect Dependencies

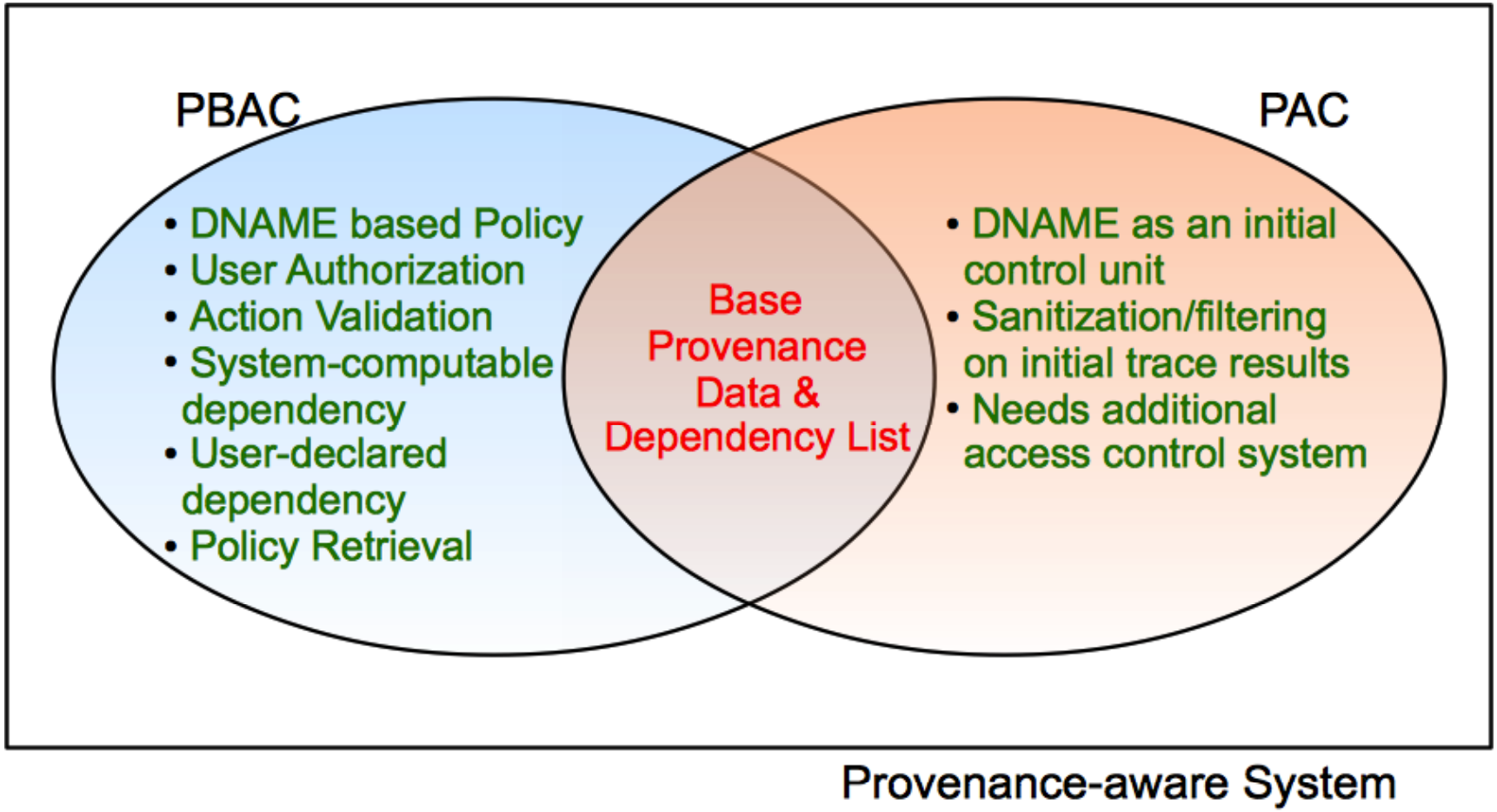
- Direct dependencies
  - Used (u), wasGeneratedBy (g), wasControlledBy (c)
  - Captured from transactions as base provenance data
- Indirect dependencies
  - System-computable dependencies
    - using pre-defined dependency names and matching dependency path patterns
  - User-declared dependencies
    - using pre-defined dependency names

Object Dependency List (DL_O)

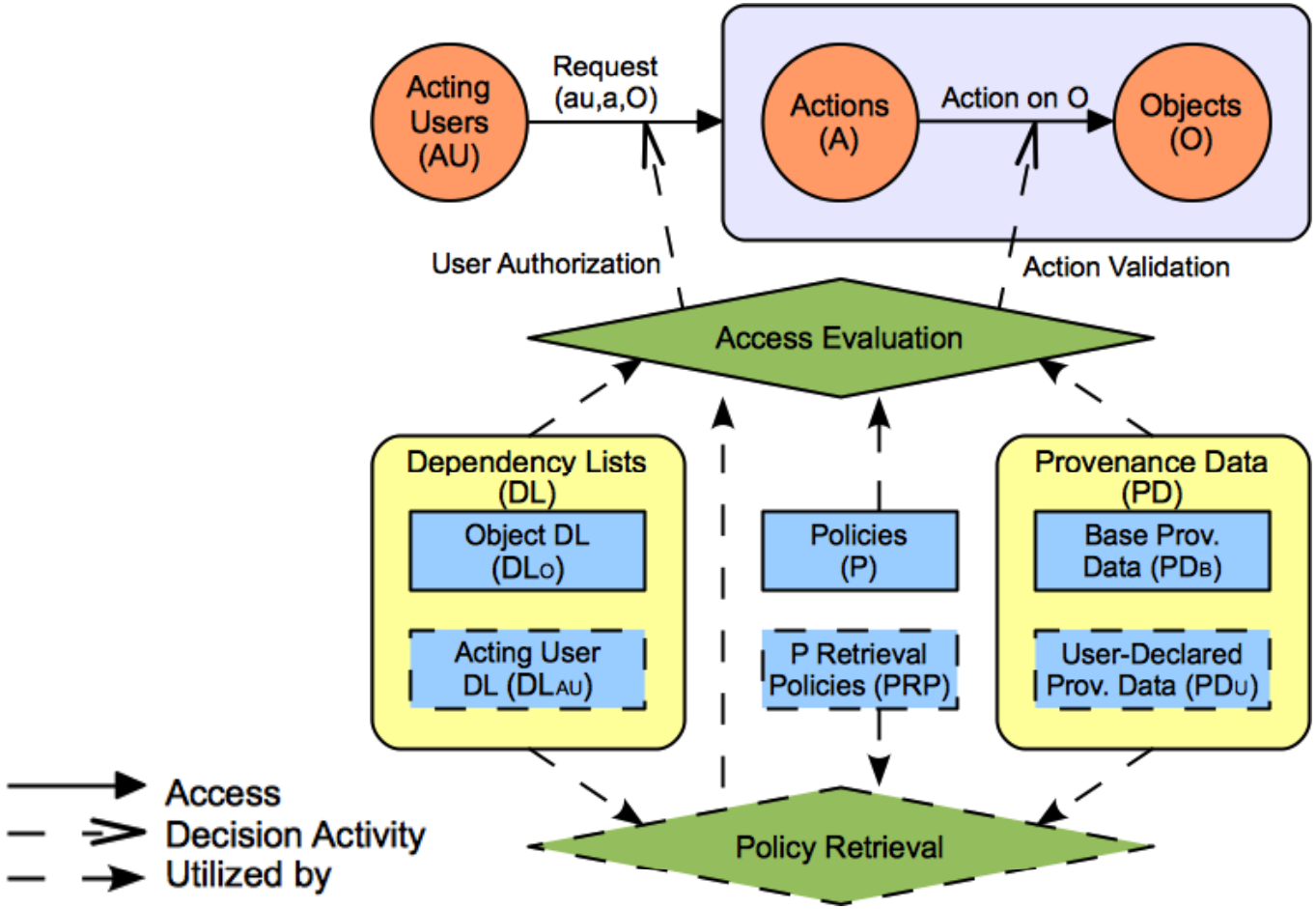
- A set of pairs of
  - abstracted dependency names (DNAME) and
  - regular expression-based object dependency path patterns (DPATH)

- Examples
  - < wasSubmittedVof, $g_{submit}.u_{input}$ >
  - < wasAuthoredBy, wasSubmittedVof?.wasReplacedVof $*.g_{upload}.c$ >

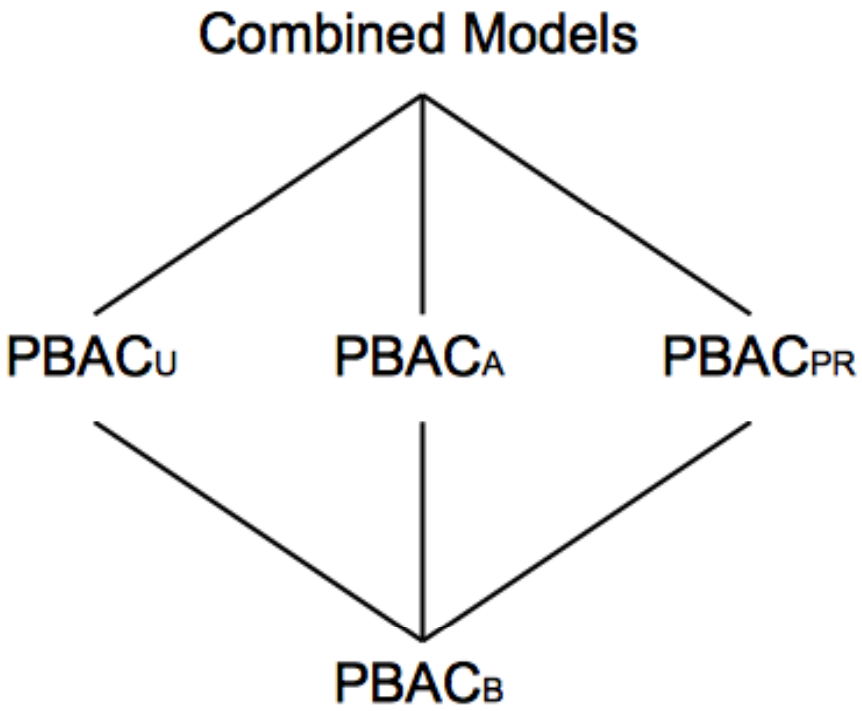
PBAC vs. PAC


PBAC
• DNAME based Policy
• User Authorization
• Action Validation
• System-computable dependency
• User-declared dependency
• Policy Retrieval
Base Provenance Data & Dependency List
PAC
• DNAME as an initial control unit
• Sanitization/filtering on initial trace results
• Needs additional access control system
Provenance-aware System

PBAC Model Components



A Family of PBAC Models



$PBAC_B$: A Base Model

- System-captured Base Provenance Data only
  - Using only 3 direct dependencies (u, g, c)
  - No user-declared provenance data
- Object dependency only
- Policy is readily available
  - No policy retrieval required

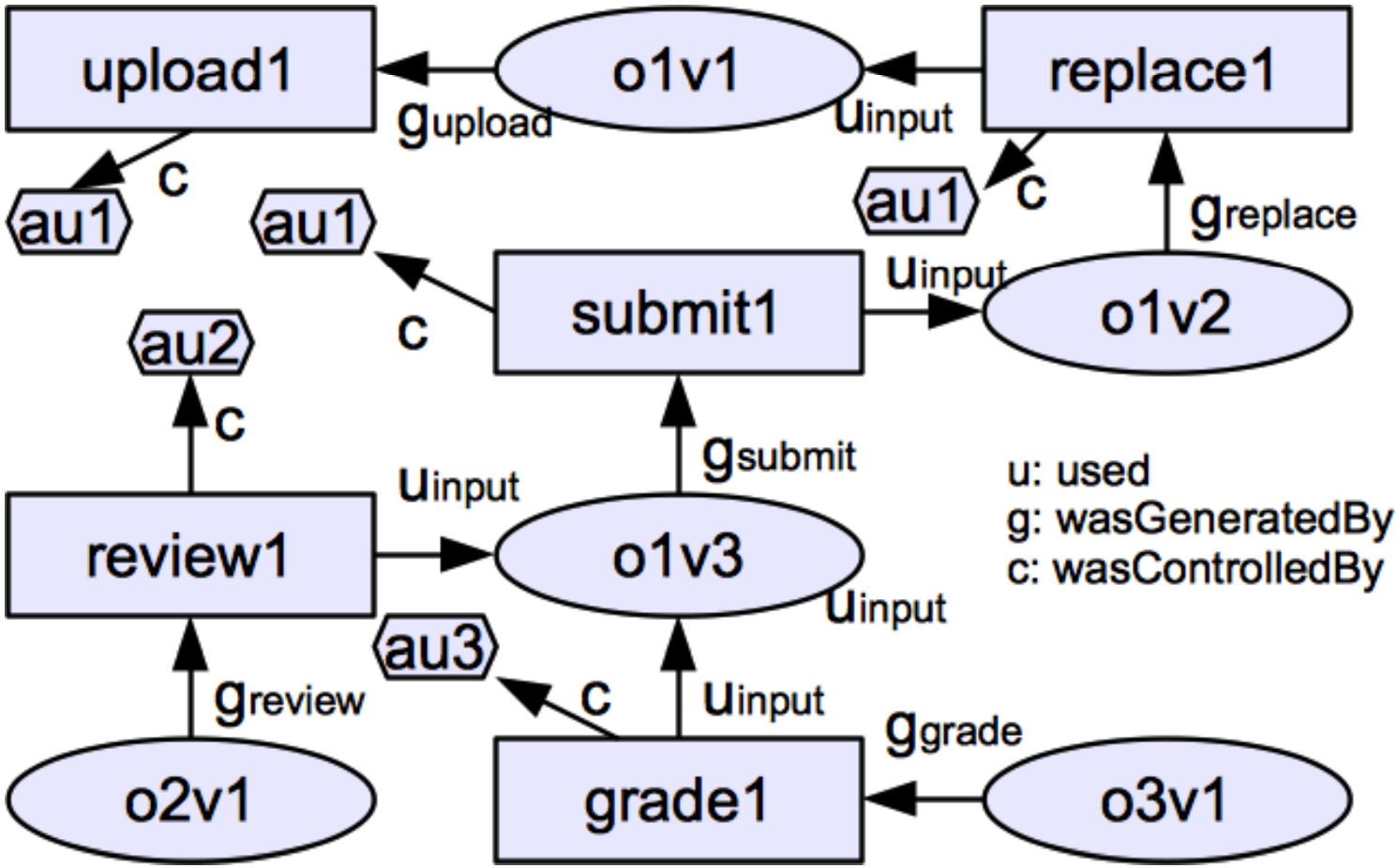
Example: A Homework Grading System

1. Anyone can upload a homework.
2. A user can replace a homework if she uploaded it (origin-based control) and the homework is not submitted yet.
3. A user can submit a homework if she uploaded it and the homework is not submitted already. (workflow control)
4. A user can review a homework if she is not the author of the homework (DSOD), the user did not review the homework earlier, and the homework is submitted already but not graded yet.
5. A user can grade a homework if the homework is reviewed but not graded yet.

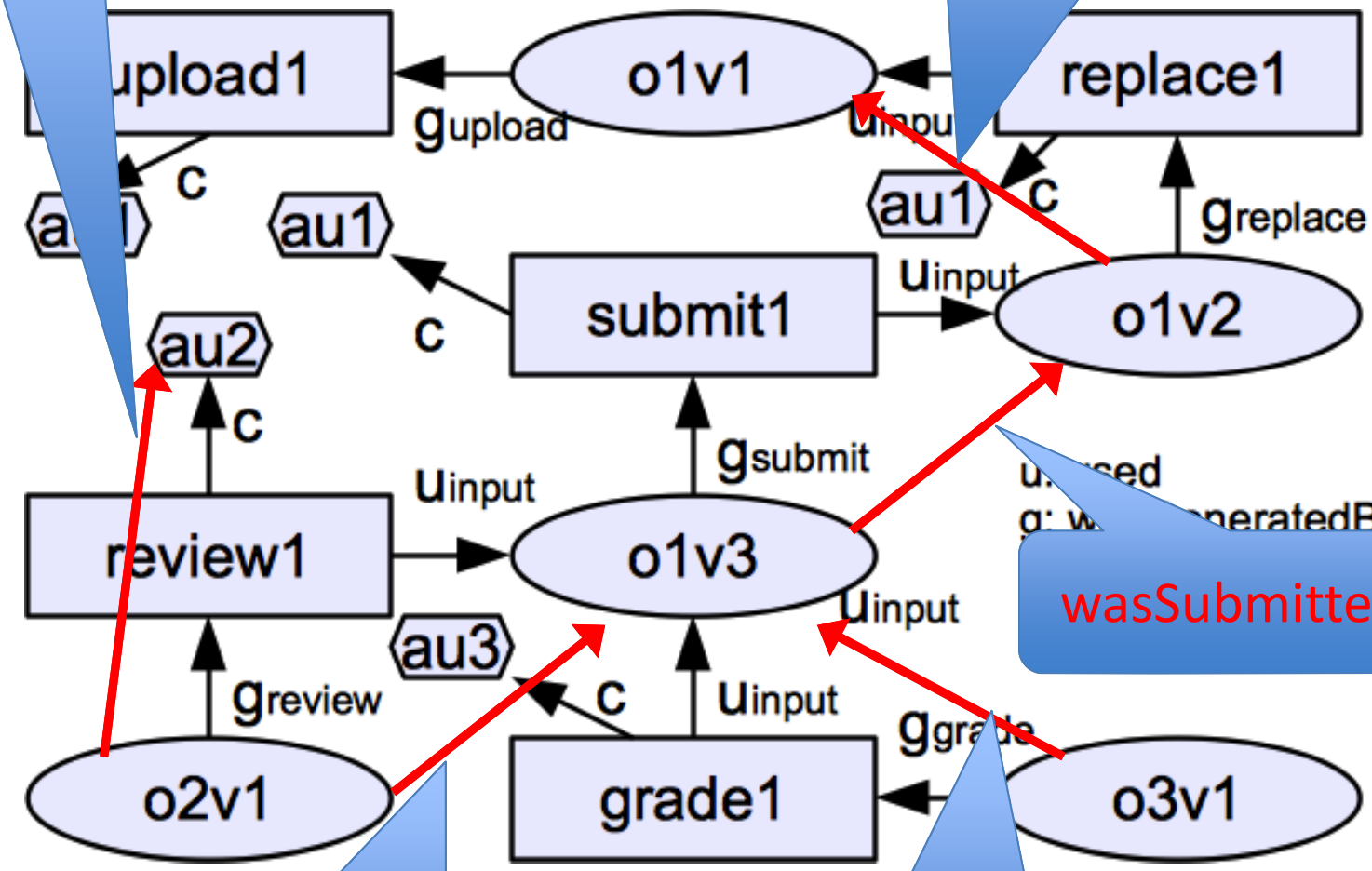
Sample Transactions & Base Provenance Data

- (au1, upload1, o_{1v1}): *< upload1, au1, c >, <o_{1v1},upload1,g_{upload} >*
- (au1, replace1, o_{1v1}, o_{1v2}): *< replace1, au1, c >,< replace1, o_{1v1}, u_{input}>, < o_{1v2}, replace1, $g_{replace}$>*
- (au1, submit1, o_{1v2}, o_{1v3}): *< submit1, au1, c >, <submit1,o_{1v2}, u_{input} >,<o_{1v3},submit1,g_{submit} >*
- (au2, review1, o_{1v3}, o_{2v1}): *< review1, au2, c >, <review1,o_{1v3}, u_{input} >,<o_{2v1},review1,g_{review} >*
- (au3, grade1, o_{1v3}, o_{3v1}): *< grade1, au3, c >, < grade1,o_{1v3}, u_{input} >,< o_{3v1},grade1,g_{grade} >*

A Sample Base Provenance Data



Sample Base Pro



wasReviewedOby

wasReplacedVof

DL_O: < wasReplacedVof, $g_{replace}.u_{input}$ >

wasSubmittedVof

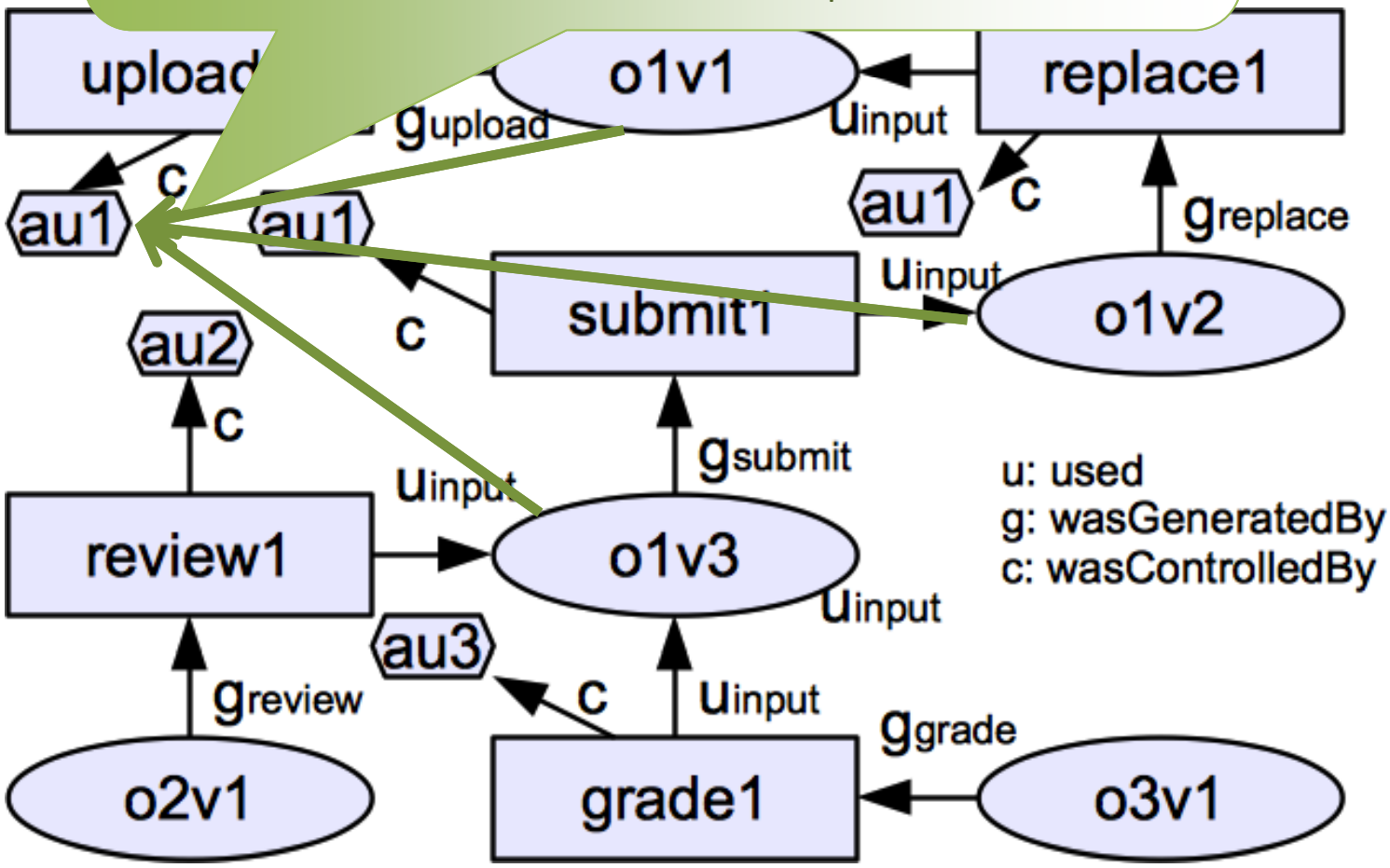
wasReviewedOof

wasGradedOof

A ... Data

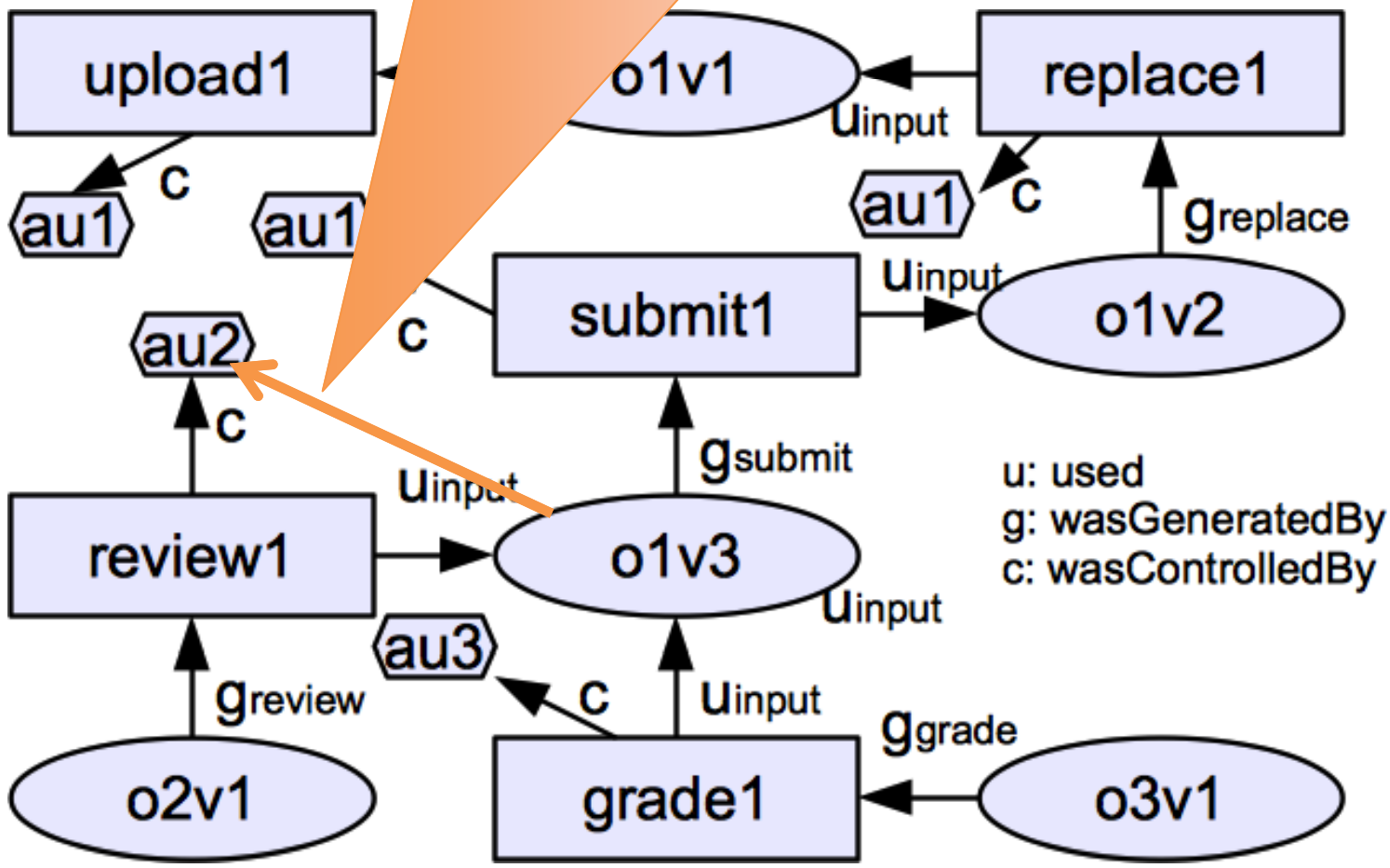
wasAuthtoredBy

DL_O: <wasAuthoredBy, wasSubmittedVof?. wasReplacedVof $*.g_{upload}.c$ >



A San

wasReviewedBy
DL_O: < wasReviewedBy, wasReviewedOof^{-1}.
wasReviewedOby >



Sample Object Dependency List (DL_O)

1. < wasReplacedVof, $g_{replace}.u_{input}$ >
2. < wasSubmittedVof, $g_{submit}.u_{input}$ >
3. < wasReviewedOof, $g_{review}.u_{input}$ >
4. < wasReviewedOby, $g_{review}.c$ >
5. < wasGradedOof, $g_{grade}.u_{input}$ >
6. < wasAuthoredBy, wasSubmittedVof?.wasReplacedVof $*.g_{upload}.c$ >
7. < wasReviewedBy, $wasReviewedOof^{-1}$. wasReviewedOby >

Sample Policies

1. Anyone can upload a homework.
2. A user can replace a homework if she uploaded it (origin-based control) and the homework is not submitted yet.
3. A user can submit a homework if she uploaded it and the homework is not submitted already. (workflow control)

1. allow(au, upload, o) ⇒ true
2. allow(au, replace, o) ⇒ au∈(o, wasAuthoredBy) ∧|(o,wasSubmittedVof)| = 0.
3. allow(au, submit, o) ⇒ au∈(o, wasAuthoredBy) ∧|(o,wasSubmittedVof)|=0.

Sample Policies (cont.)

4. A user can review a homework if she is not the author of the homework (DSOD), the user did not review the homework earlier, and the homework is submitted already but not graded yet.
5. A user can grade a homework if the homework is reviewed but not graded yet.

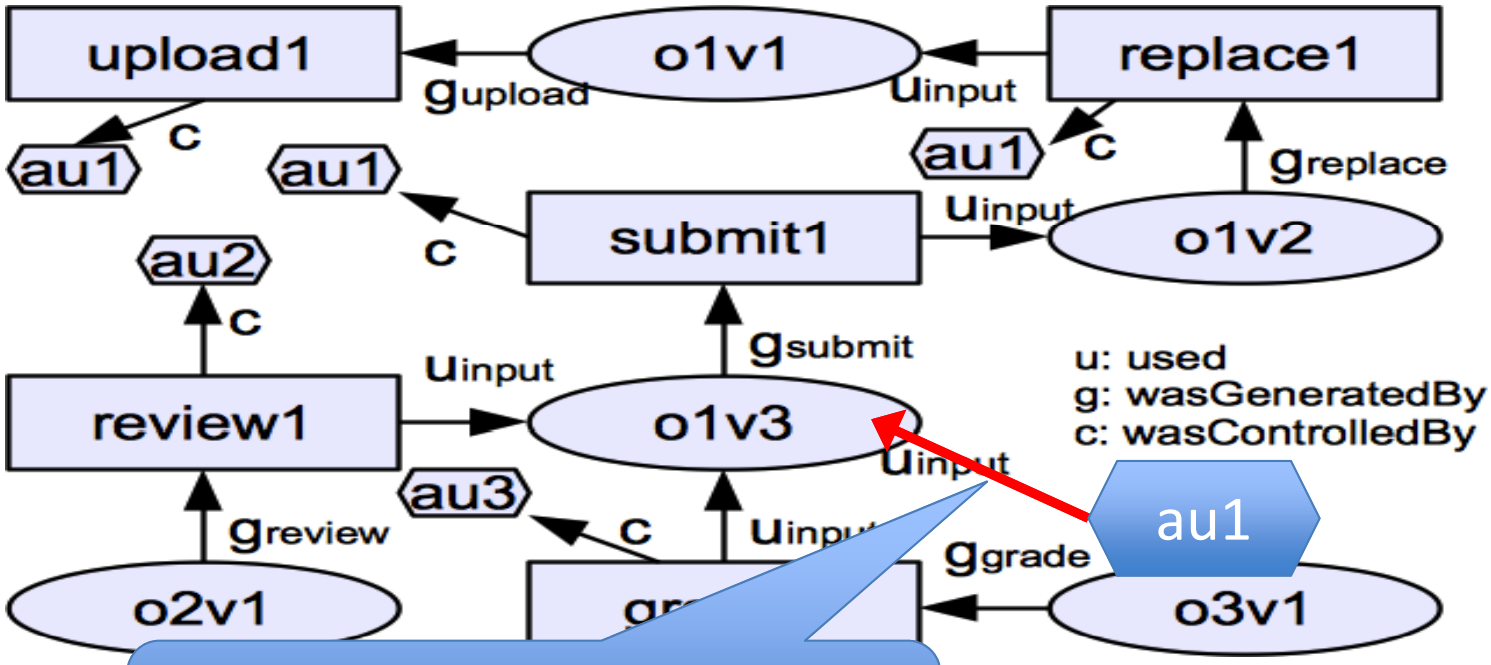
4. $allow(au, review, o) \Rightarrow au \notin (o, wasAuthoredBy) \wedge au \notin (o, wasReviewedBy) \wedge |(o, wasSubmittedV\ of)| \neq 0 \wedge |(o, wasGradedOof^{-1})| = 0.$
5. $allow(au, grade, o) \Rightarrow |(o, wasReviewedOof)| \neq 0 \wedge |(o, wasGradedOof^{-1})| = 0).$

Access Evaluation Procedure

- Rule collecting phase
- User authorization (UAuth) phase
- Action validation (AVal) phase
- conjunctive decision of UAuth and AVal

Access Evaluation Example

- Policy: user can submit a homework if she uploaded it (origin-based control) and the homework is not submitted already. (workflow control)

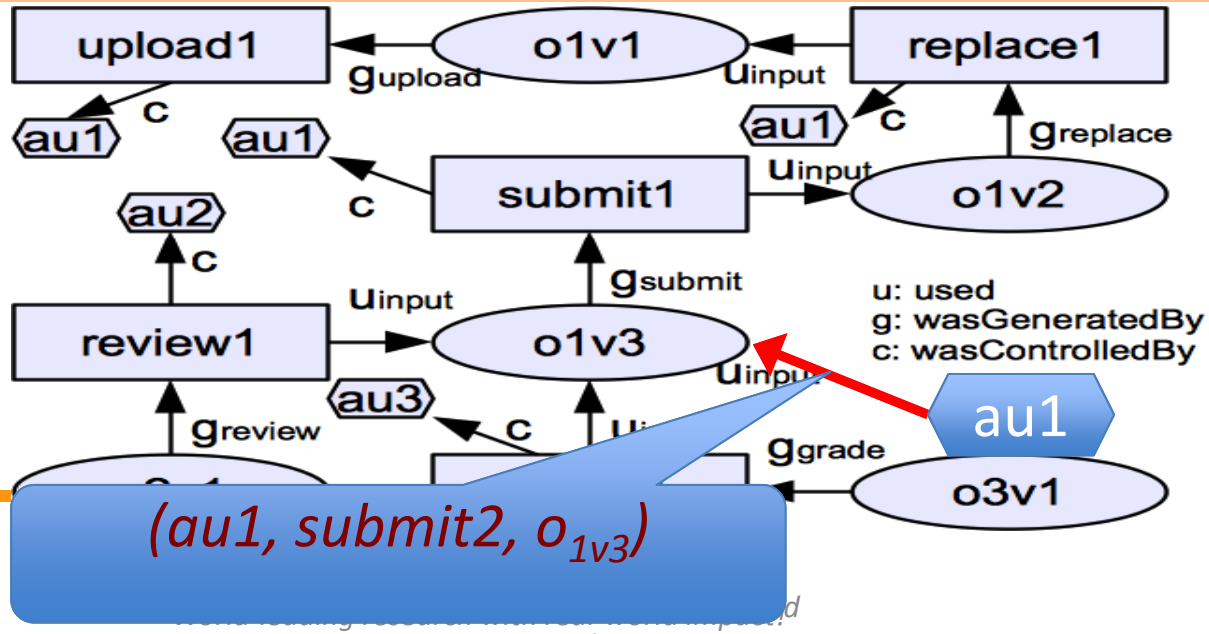


Rule Collecting Phase

- Request: *(au1, submit2, o_{1v3})*
- Action type: *submit*
- Policy for *submit*
  - *allow(au, submit, o) ⇒ au∈(o, wasAuthoredBy) ∧|(o,wasSubmittedVof)| = 0.*
- User authorization rule
  - *au∈(o, wasAuthoredBy)*
- Action Validation rule
  - *|(o,wasSubmittedVof)| = 0*

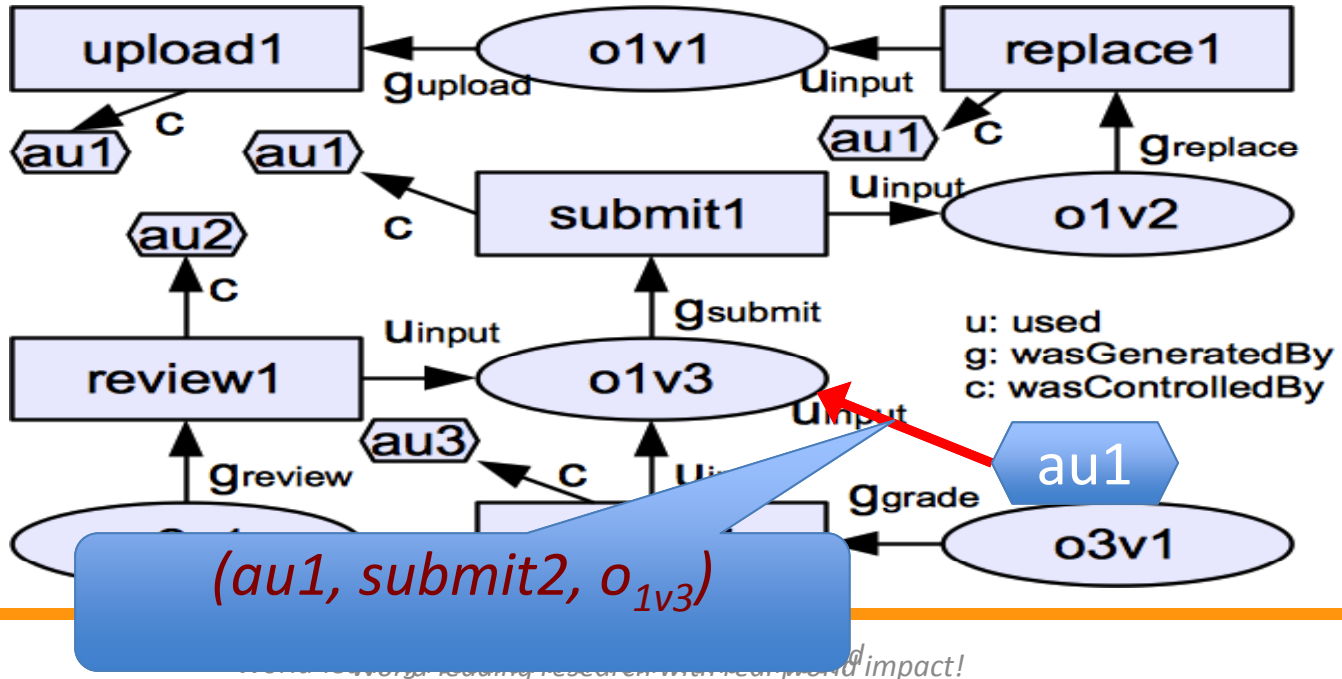
User Authorization Phase

- *User Authorization Rule: au ∈(o, wasAuthoredBy)*
- Dependency List (DL)
  - *< wasReplacedVof, $g_{replace}.u_{input}$ >, < wasSubmittedVof, $g_{submit}.u_{input}$ >*
  - *< wasAuthoredBy, wasSubmittedVof?.wasReplacedVof *.$g_{upload}.c$ >*
- *au1 ∈ (o1v3, $[g_{submit}.u_{input}]?.[g_{replace}.u_{input}]^*.g_{upload}.c$) = {au1}*



Action Validation Phase

- *Action Validation Rule: |(o,wasSubmittedVof)| = 0*
- Dependency List (DL): *< wasSubmittedVof, $g_{submit}.u_{input}$ >*
- *$|(o1v3, g_{submit}.u_{input})| \neq 0$*



Summary

- Proposed a foundation for PBAC and PAC
  - the notion of named abstractions of causality dependency path patterns
  - Regular expression-based dependency path pattern
- Identified a Family of PBAC models
- Developed a Base model for PBAC
  - Supports Simple and effective policy specification and access control management
  - Supports DSOD, workflow control, origin-based control, usage-based control, object versioning, etc.

What's next?

- Enhancing/extending PBAC model
- Provenance Access Control Models
- Provenance data sharing in multiple systems

Thank you!

- Questions and Comments?