Rigorous Analysis of UML Access Control Policy Models

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Security Policies

- Security policies
  - Expressed by different languages
    - XACML, OWL/RDF, CIM/SPL, PONDER, UML
- Errors in policy models
  - Can cause security breaches that have serious consequences
  - Correcting the errors once policies are deployed can be expensive
- Need error detection before policies are deployed

Motivation

- We use UML (Unified Modeling Language) for policy specification
  - UML together with OCL can be used to provide a formal and graphical representation of security policies
  - UML is the de facto specification language used in the software industry
  - UML policy models can be transformed to code using existing technologies

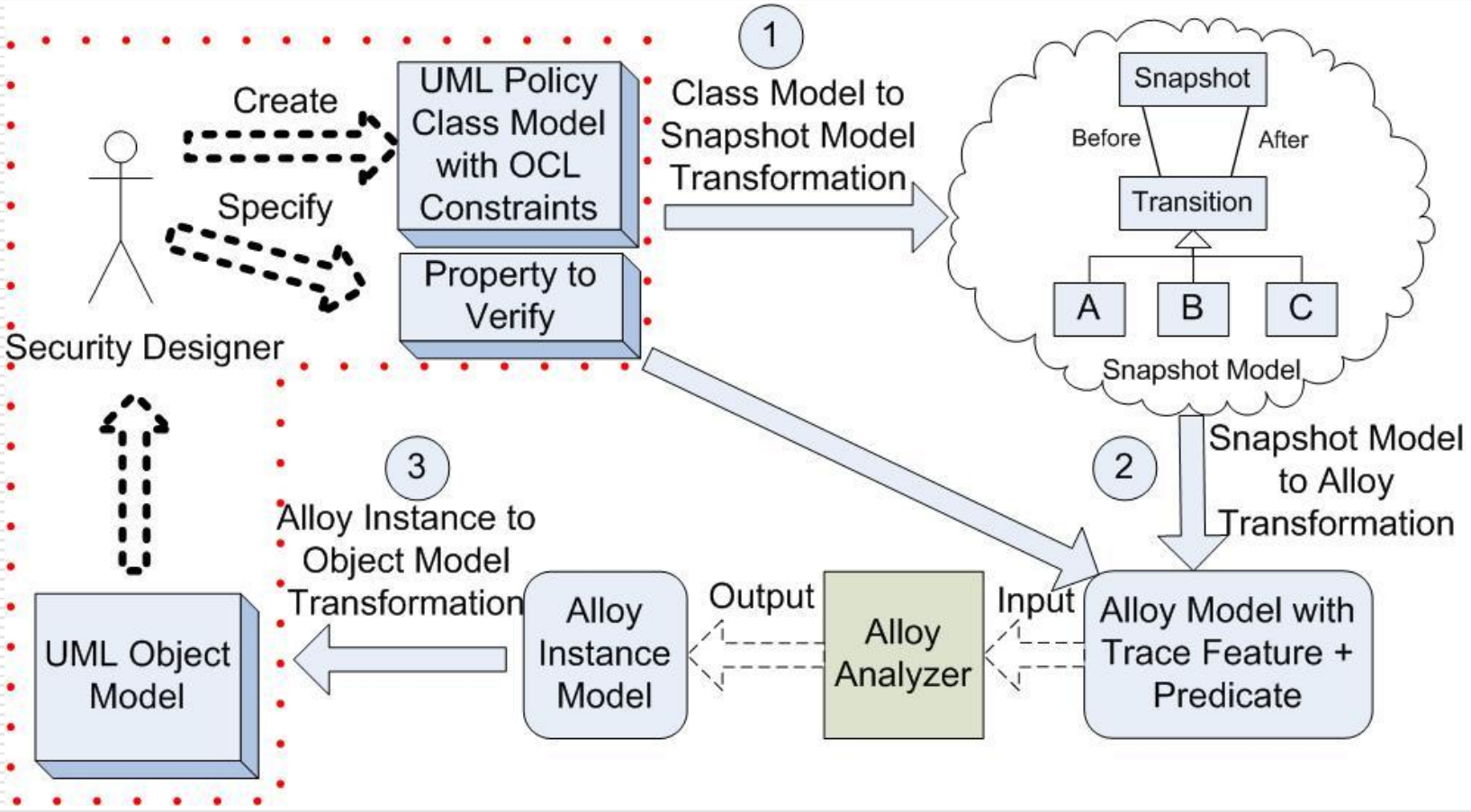
Motivation

- Using UML (Unified Modeling Language) as a policy specification language
  - Challenge: few mature tools supporting rigorous analysis of UML models
  - Solution: Transform UML to Alloy for automated model analysis

Approach

- Rigorous analysis of UML access control policy models
  - Front-end: use UML to describe security policies
  - Back-end: use Alloy Analyzer to analyze the modeled properties
  - Transformation between UML and Alloy: obviate the need for security designers to understand the Alloy language

Approach Overview

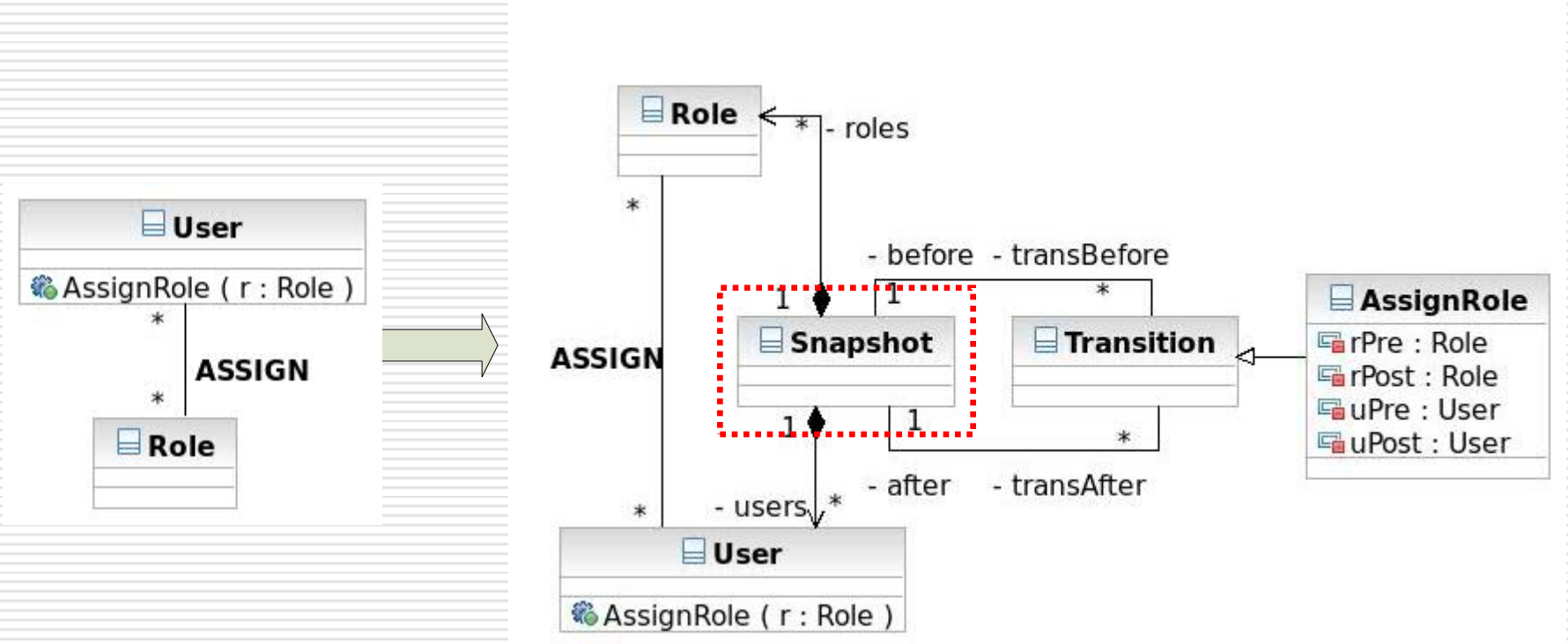


Background: SUDA

- Scenario-based UML Design Analysis (SUDA)
  - A design class model with operation specifications is transformed to a static model of behavior, called a snapshot model.
  - A snapshot is an object configuration that represents a state of the system at a particular time.
  - A snapshot transition describes the behavior of an operation in terms of its before and after effect on the system state.

Background: Snapshot Model

- Example of a snapshot model generated from a class model



UML Class Model

UML Snapshot Model

Background: Snapshot Model

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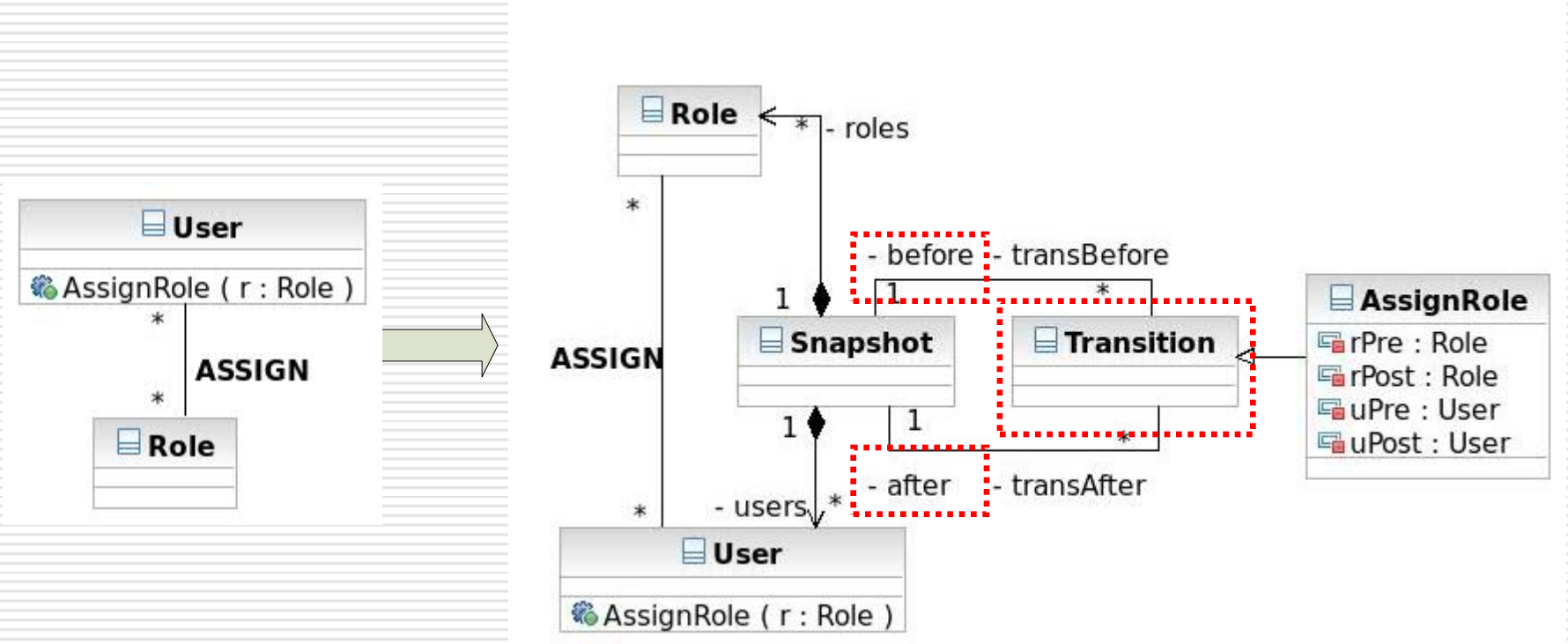

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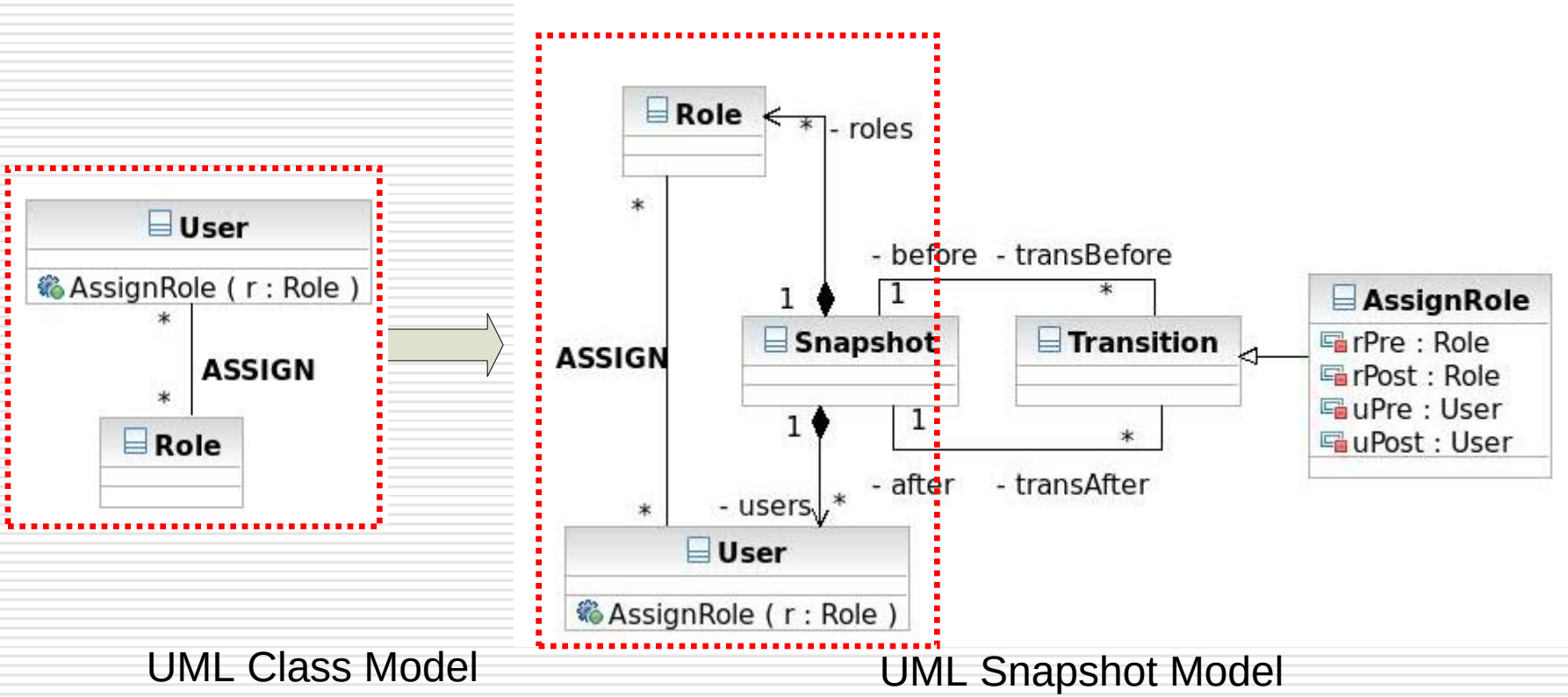

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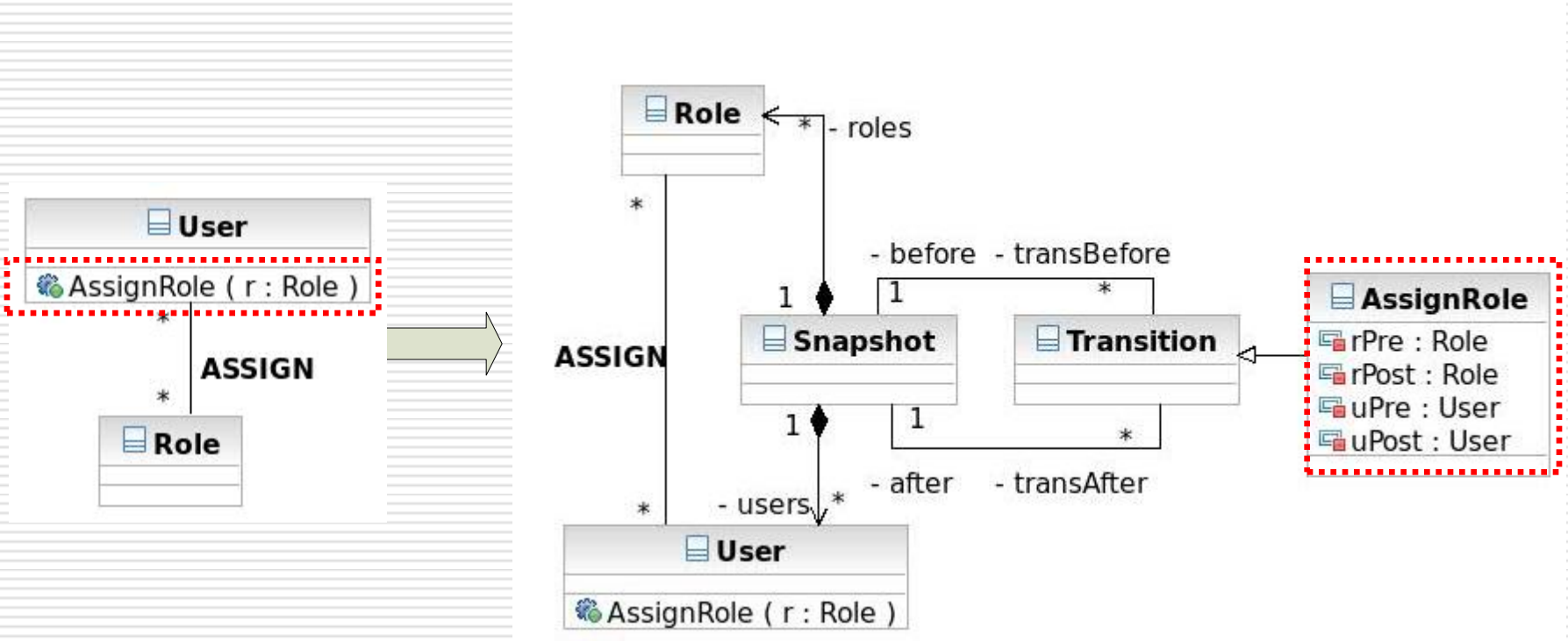

UML Class Model

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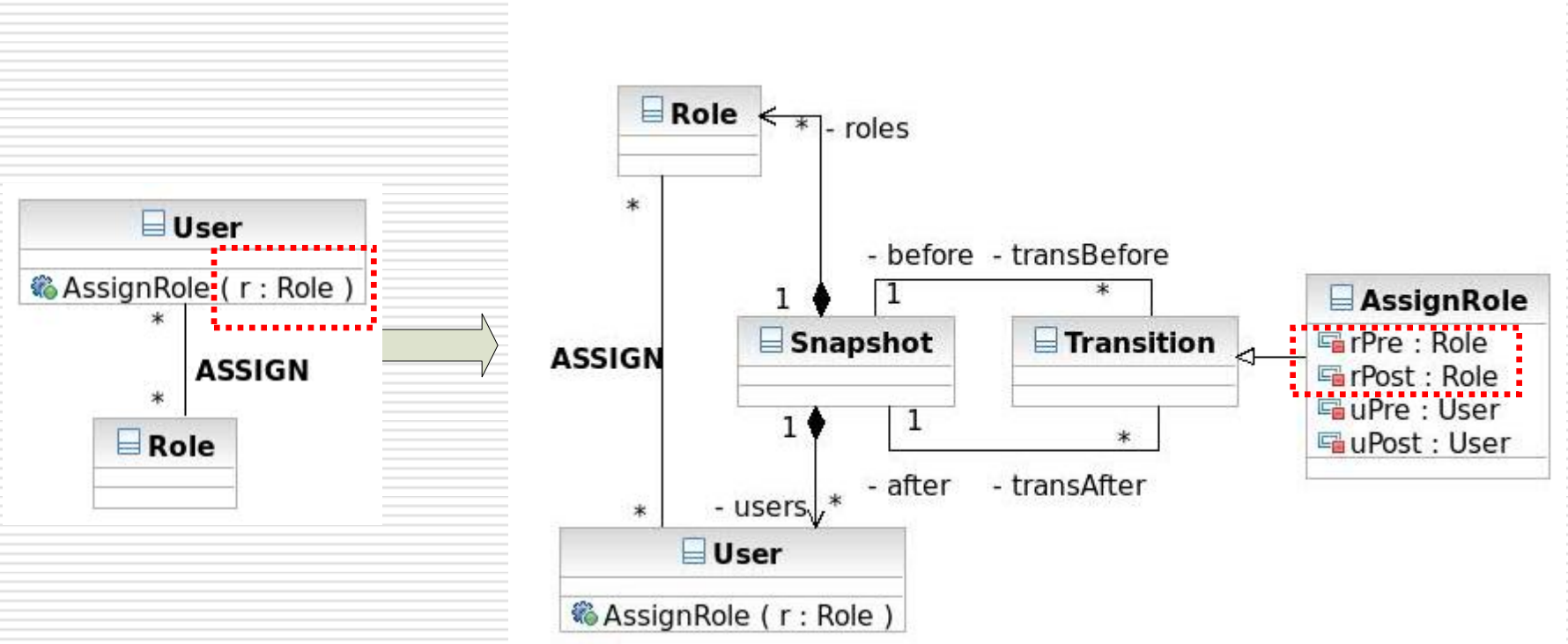


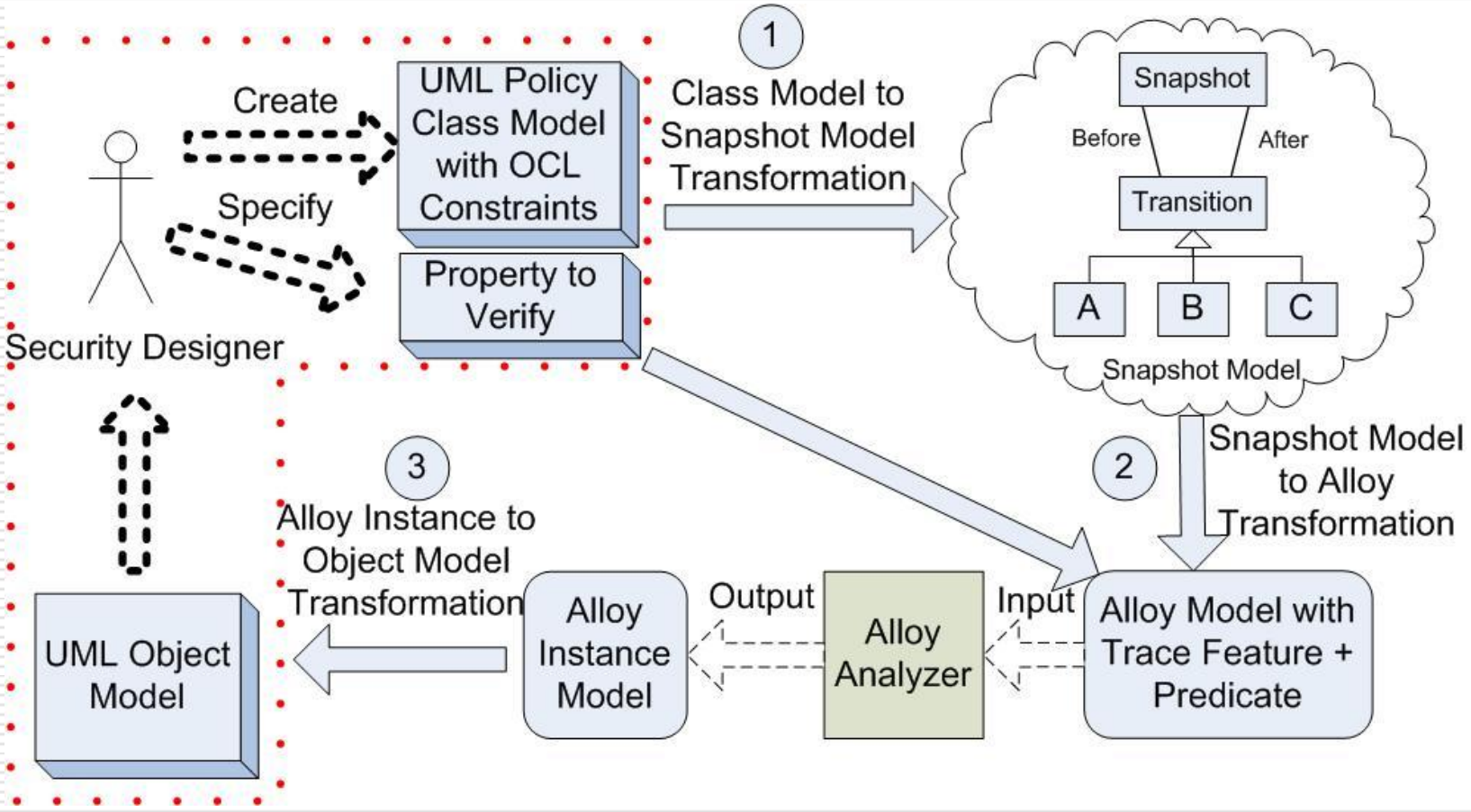
UML Class Model

UML Snapshot Model

Background: SUDA

- SUDA vs. Our approach
  - SUDA: is the given scenario supported by the UML class model?
  - Our approach: is there a scenario supported by the UML class model that starts in a specified valid state and ends in a specified invalid state?

Approach Overview

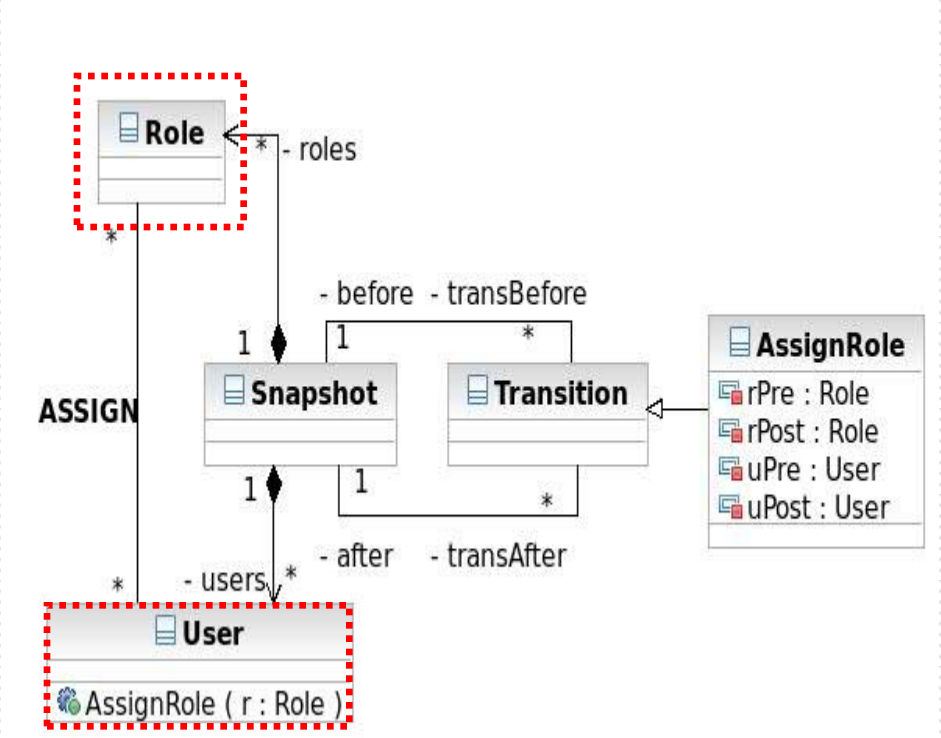


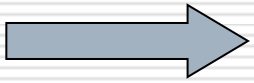
Background: Dynamic Analysis using Alloy

- Alloy
  - Model = signatures + facts + predicates (operation specifications)
  - Facts: define constraints on the elements of the model
  - Predicates: probe model
  - Trace mechanism: specify a fact to associate the transitions triggered by operation invocations with states defined by signatures

Snapshot Model to Alloy Model Transformation

- Step 1: Transform each class that is part of Snapshot class to a signature in Alloy

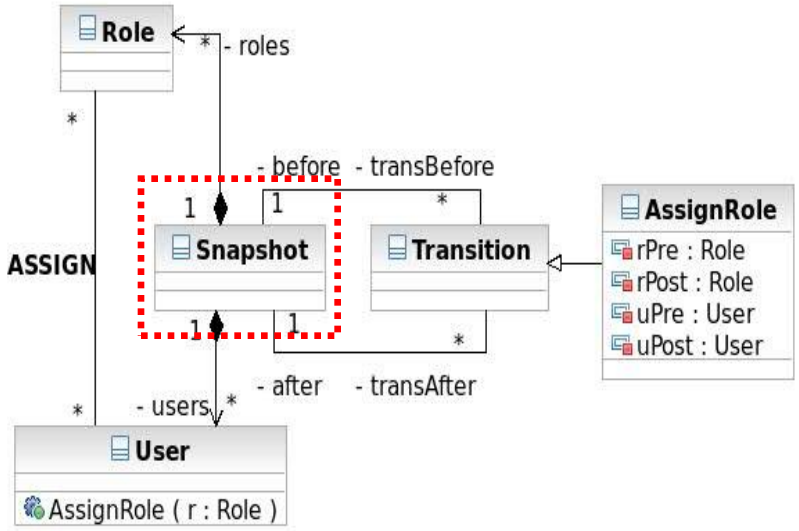




sig Role{}
sig User{}

Snapshot Model to Alloy Model Transformation

- Step 2: Transform the Snapshot class to a Snapshot signature containing fields that specify the object configurations within a snapshot




```
sig Snapshot{
// Object fields
roles: set Role, users: set User,
// Link fields
ASSIGN: User set->set Role,
} {
// Linked objects must exist in the  snapshot
ASSIGN=ASSIGN:>roles&users<: ASSIGN
}
```

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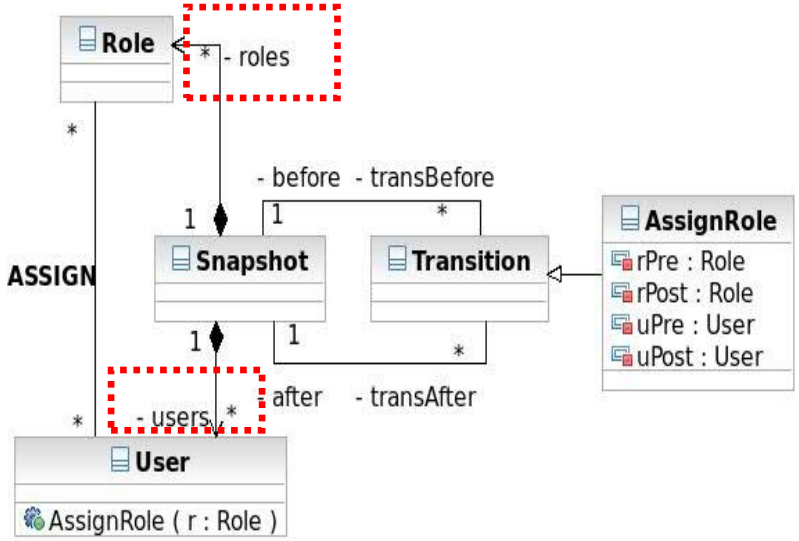


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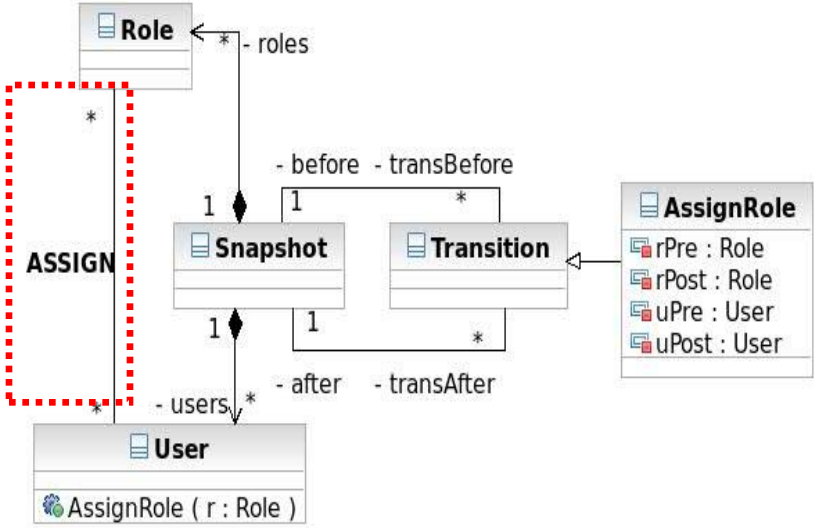


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Snapshot Model to Alloy Model Transformation

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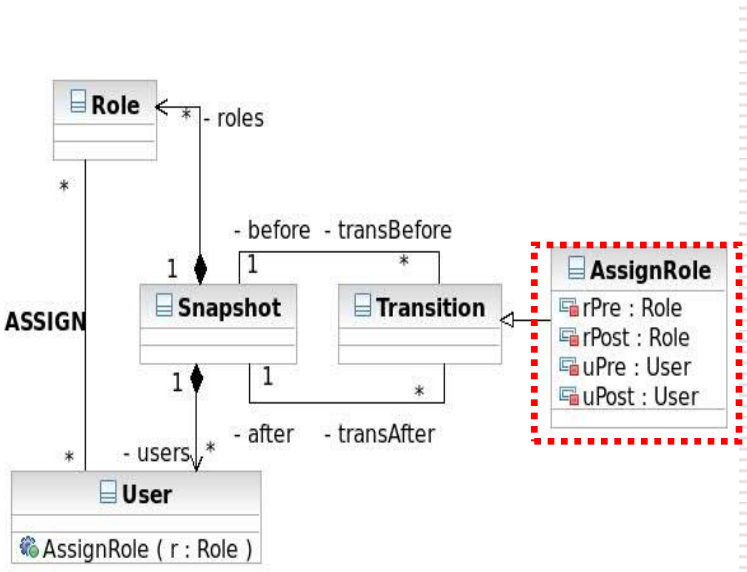



```
pred AssignRole[disj before, after: Snapshot,
rPre, rPost: Role, uPre, uPost: User] {
// Precondition
rPre in before.roles
uPre in before.users
rPre not in uPre.(before.ASSIGN)
// Postcondition
rPost in after.roles
uPost in after.users
uPost.(after.ASSIGN) = uPre.(before.ASSIGN) +
rPost
// Unchanged object configuration
…..
}
```

Snapshot Model to Alloy Model Transformation

- Step 3: Transform each Transition specialization to a predicate in Alloy

Context AssignRole inv:
uPre.ASSIGN->excludes(rPre)
…
…
uPost.ASSIGN =
uPre.ASSIGN->including(rPost)
…
…
after.roles->excluding(rPost)=
before.roles->excluding(rPre)
…

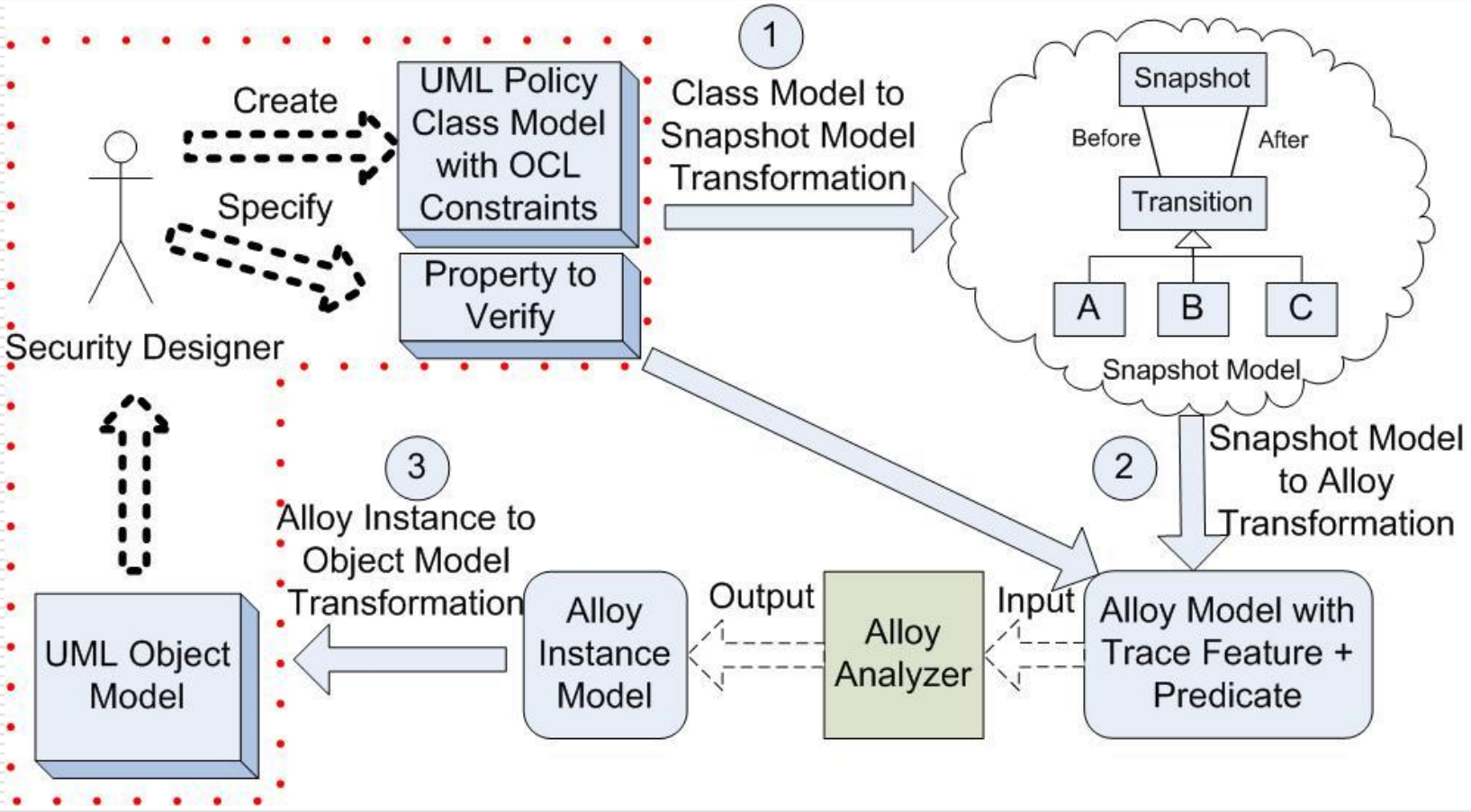
pred AssignRole[disj before, after: Snapshot, rPre, rPost: Role, uPre, uPost: User]{
// Precondition
rPre not in uPre.(before.ASSIGN)
…
// Postcondition
uPost.(after.ASSIGN) = uPre.(before.ASSIGN) + rPost
…
// Unchanged object configuration
after.roles – rPost = before.roles – rPre
…
}

Snapshot Model to Alloy Model Transformation

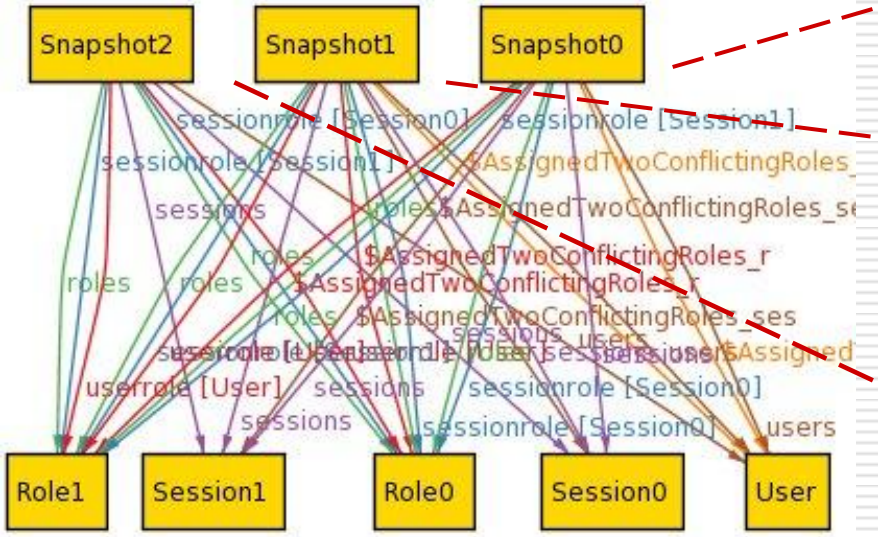
- Step 4: Define a trace fact to associate transitions between two consecutive snapshots with operations

```
fact traces{
        all before: Snapshot - SnapshotSequence/last | let after =
        SnapshotSequence/next[before] | Some r: Role | some u: User |
        AssignRole[before, after, r, r, u, u]
}
```

Approach Overview



Alloy Instance to UML Object Model Transformation



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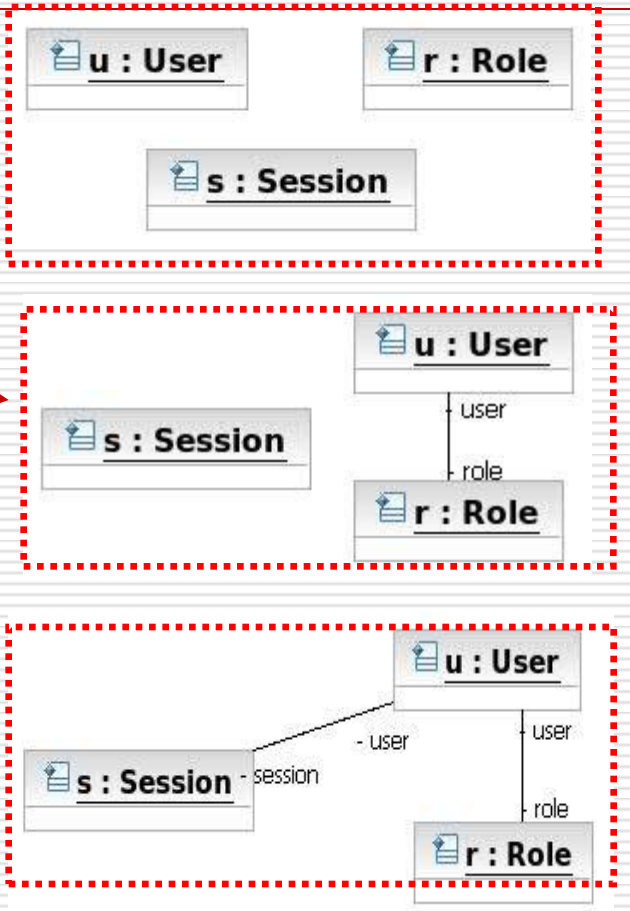


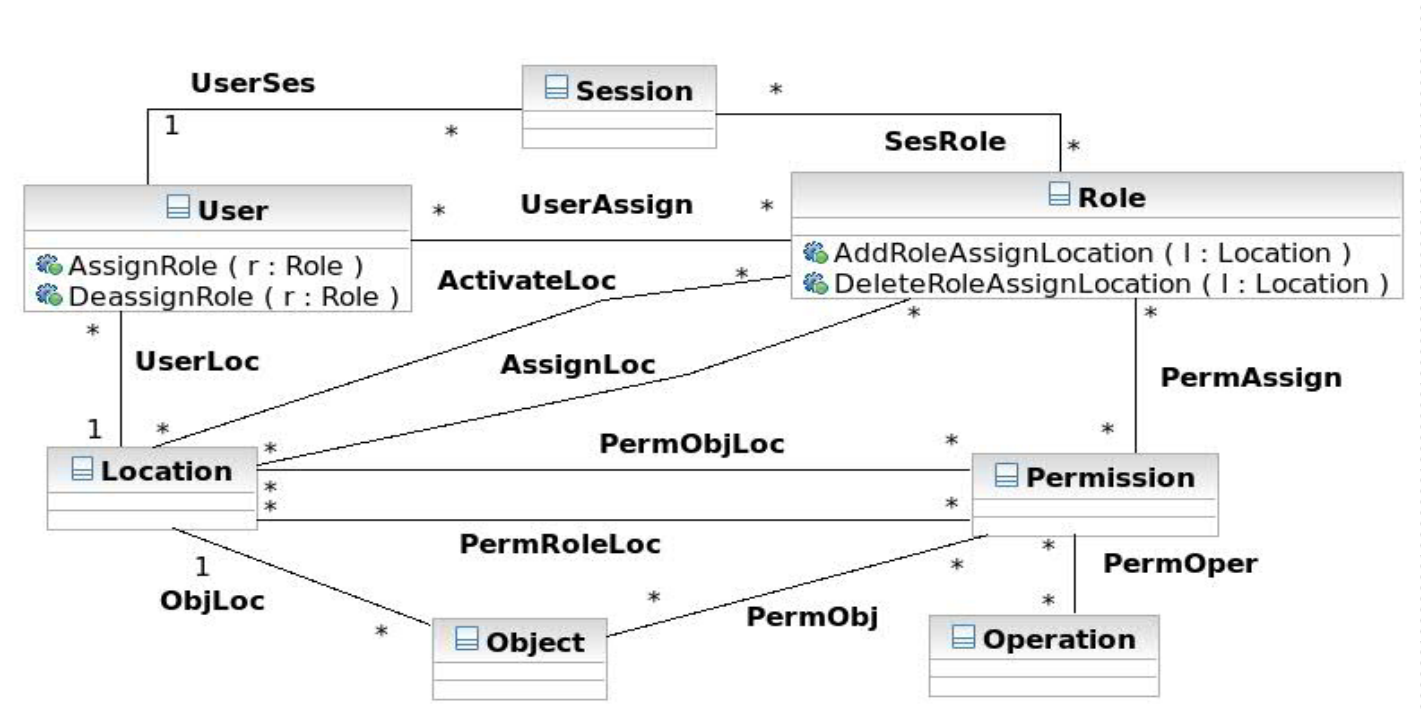
A Sequence of UML Object Models

Research Goal

- Analysis: check whether a system can move from a valid to an invalid state as result of a sequence of access control operation calls
- If analysis uncovers such a sequence, then the designer uses the trace information output by the analysis to help find the source of the errors in the UML policy model

Demonstration Case Study: LRBAC

- Location-aware Role-based Access Control (LRBAC) Model



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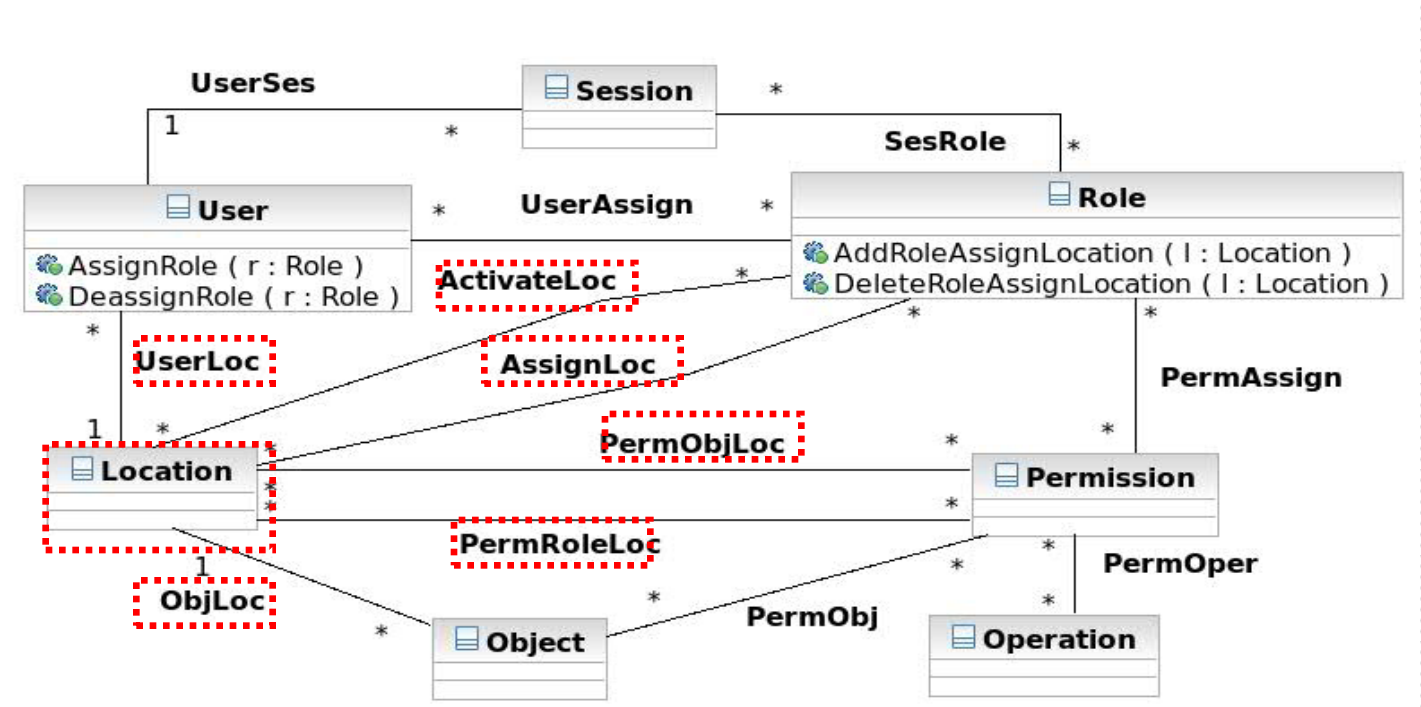

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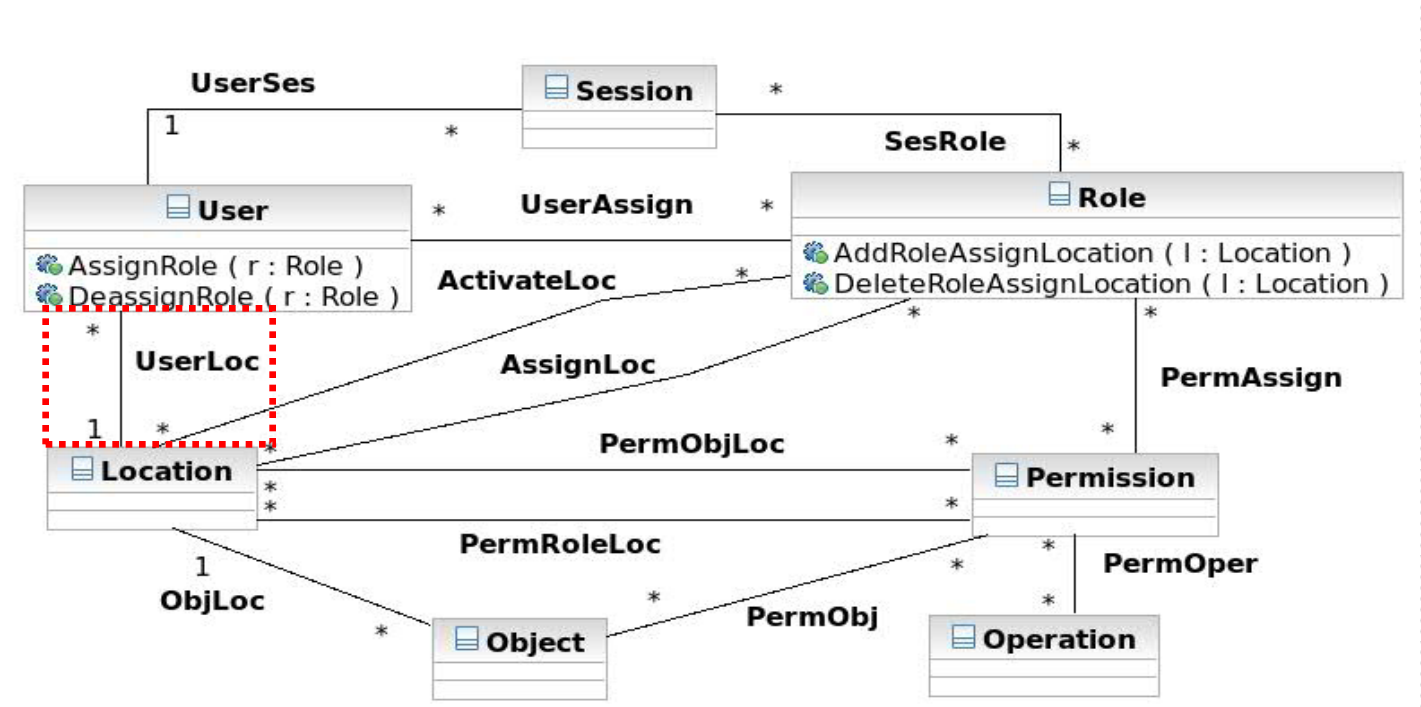

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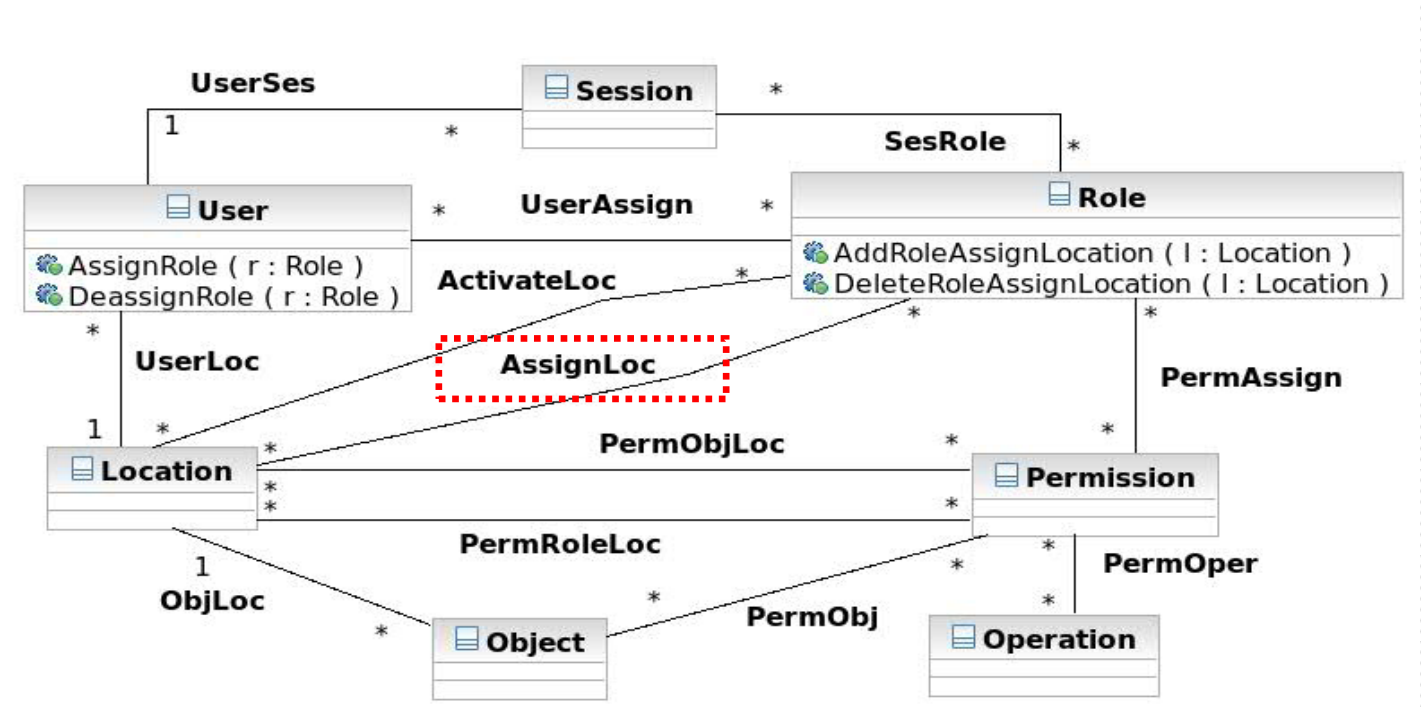


Demonstration Case Study: LRBAC

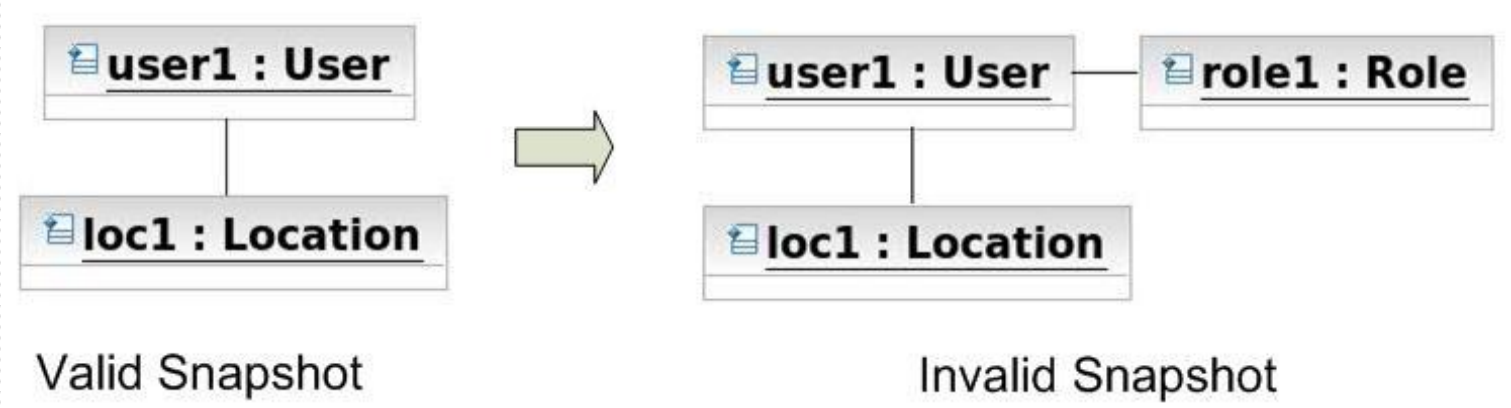
- Operation specifications in form of pre/post-conditions for DeleteRoleAssignLocation

// English specification: remove a location from a set of locations
// in which a role can be assigned
Context Role::DeleteRoleAssignLocation(l:Location)
Precondition: location l has been associated with the role
Postcondition: location l has been removed from a set of locations

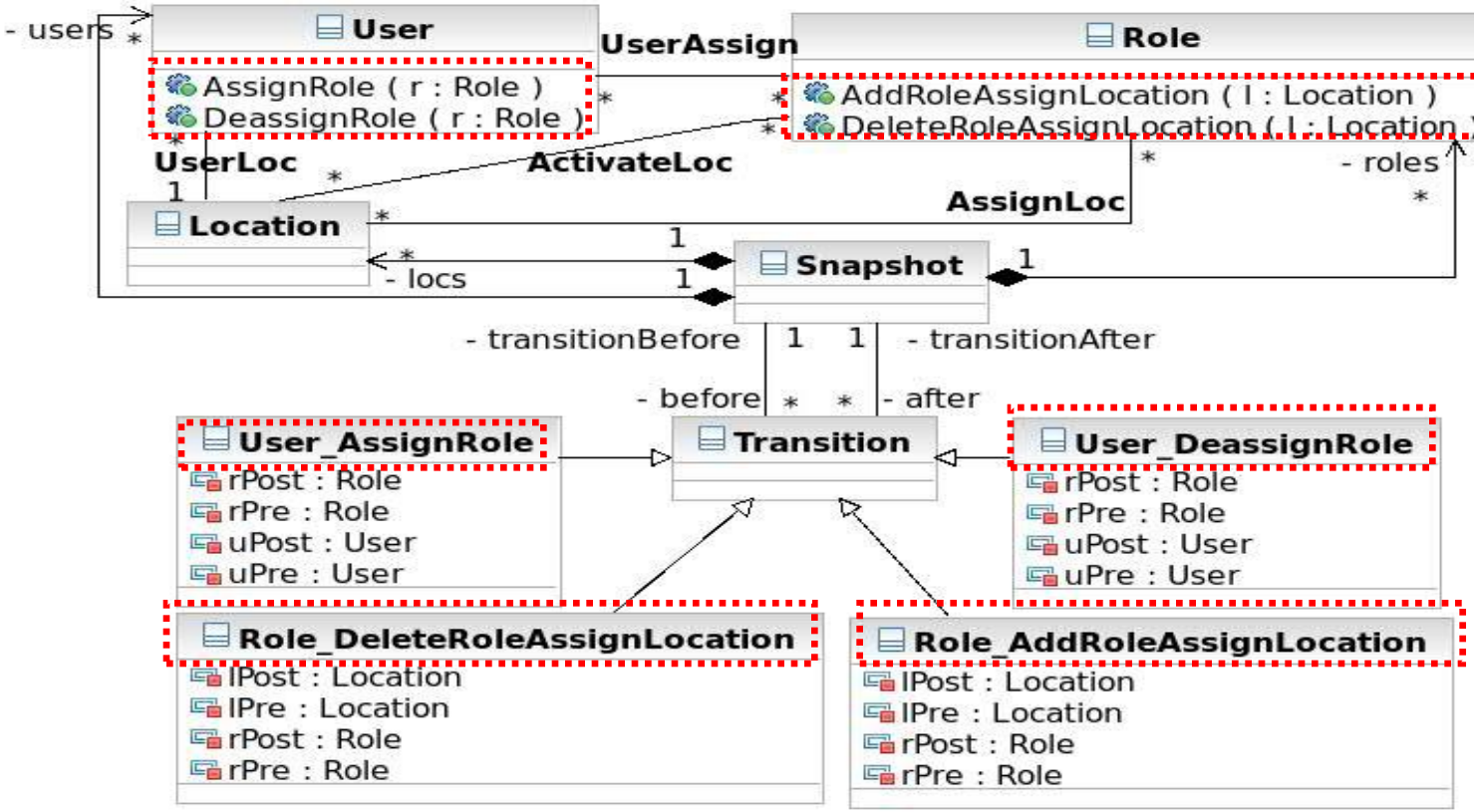
// OCL specification: remove a location from a set of locations
// in which a role can be assigned
Context Role::DeleteRoleAssignLocation(l:Location)
Pre: self.AssignLoc->includes(l)
Post: self.AssignLoc=self.AssignLoc@pre->excluding(l)

Demonstration Case Study: Specifying the Property-to-Verify

- Valid and Invalid LRBAC Snapshot Patterns
  - Is there a sequence of operation invocations that takes the system from a valid state consisting of at least one user in a location to an invalid state in which the user is linked to a role that does not include the user's location?



Demonstration Case Study: Generating the LRBAC Snapshot Model



Demonstration Case Study: Generating an LRBAC Alloy Model

- Role_DeleteRoleAssignLocation predicate generated from the class invariant

```
pred Role_DeleteRoleAssignLocation[disj before,after  :Snapshot,
rPre, rPost:Role, lPre, lPost:Location] {

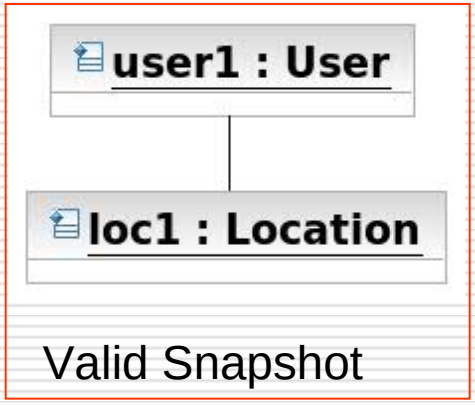
// Precondition
Pre in rPre.(before.AssignLoc) …
// Postcondition
rPost.(after.AssignLoc) = rPre.(before.AssignLoc) – lPost…
// Unchanged parts of object configuration
after.roles - rPost = before.roles – rPre  …

}
```

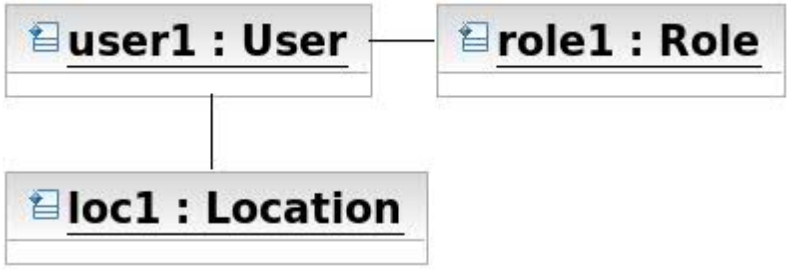
Demonstration Case Study: Analyzing the Alloy Model

- The verification predicate generated from the property-to-verify

```
pred valid2invalid{
// Specify that the first snapshot is valid
let first = SnapshotSequence/first | …
all u:first.users | u.(first.UserAssign) = none and
u.(first.UserLoc) != none …
// Query whether there exists a path from a valid
// state to an invalid state
some s: Snapshot - first | …
l not in r.(s.AssignLoc) and
r in u.(s.UserAssign) and l in u.(s.UserLoc)
}
```

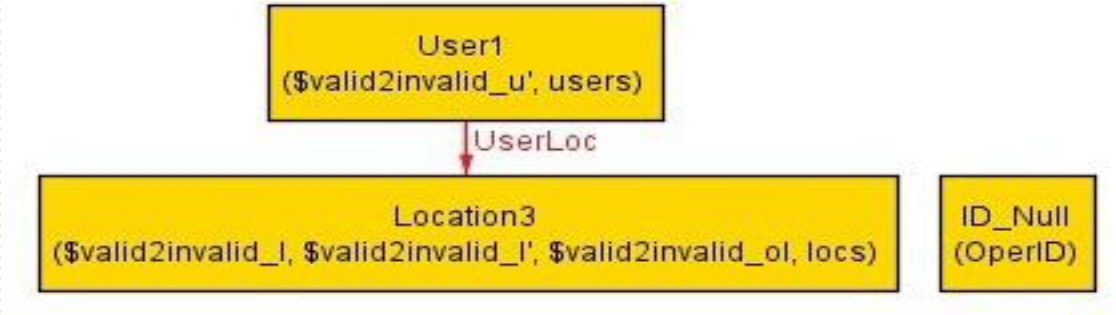


Valid Snapshot

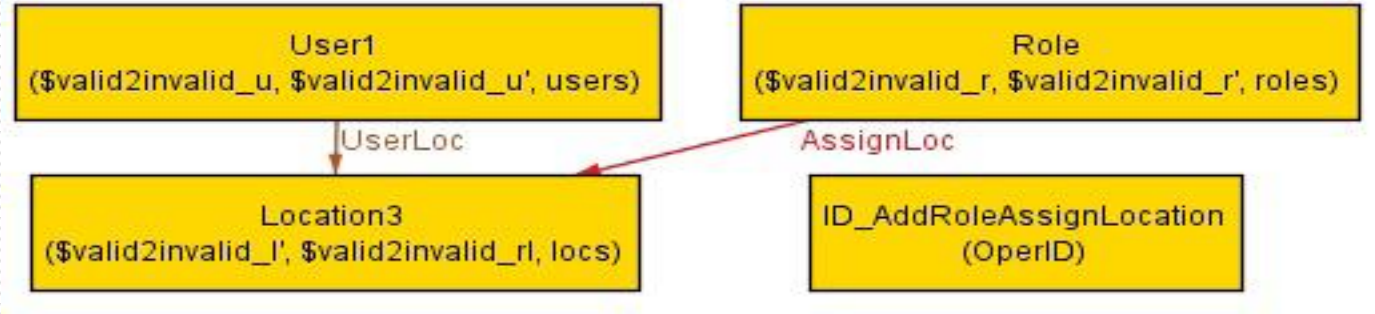


Invalid Snapshot

Demonstration Case Study: Analyzing the Alloy Model

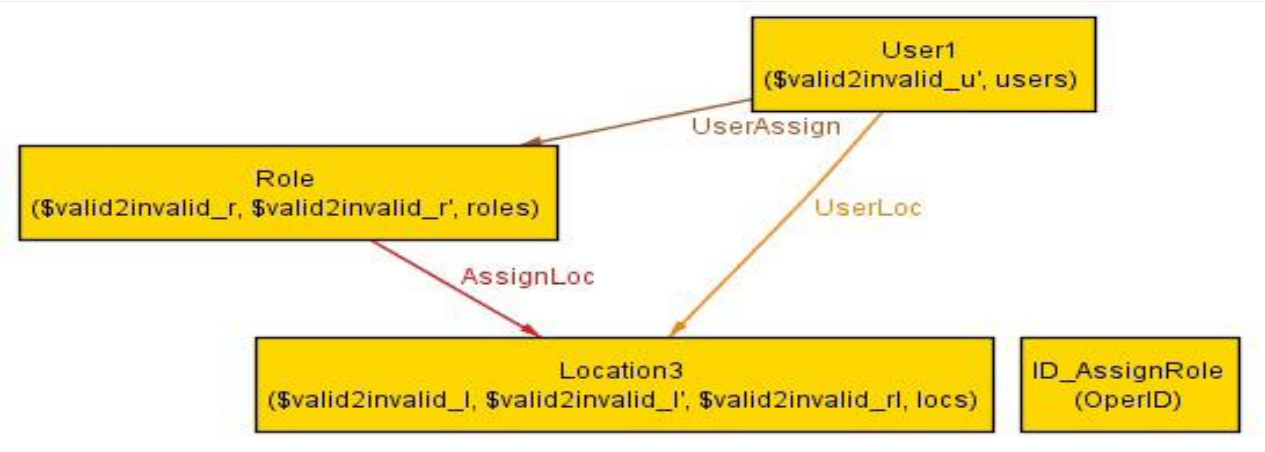


First Snapshot: Valid

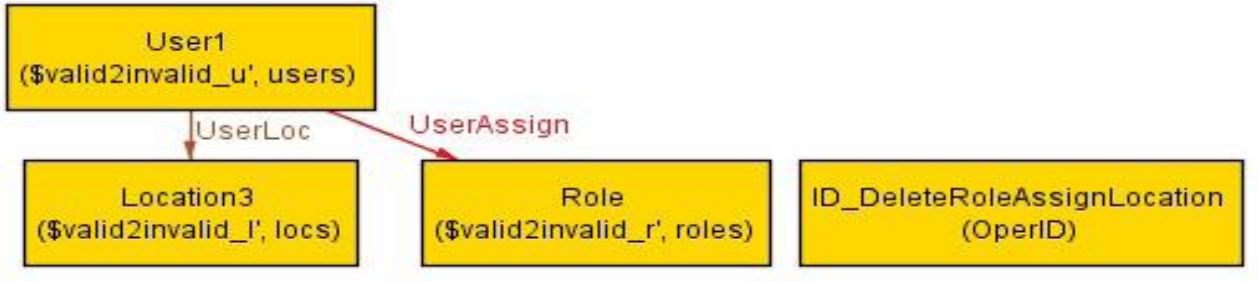


Second Snapshot: Valid

Demonstration Case Study: Analyzing the Alloy Model



Third Snapshot: Valid



Fourth Snapshot: Invalid

Demonstration Case Study: Analyzing the Alloy Model

- Constraint modification: a role can be removed from a set of roles associated with a location only if the role is not assigned to any users

Context Role::DeleteRoleAssignLocation(l:Location)

Pre: self.AssignLoc→includes(l)

and self.UserAssign→isEmpty()

Post: self.AssignLoc = self.AssignLoc@pre →excluding(l)

Conclusion and Future Work

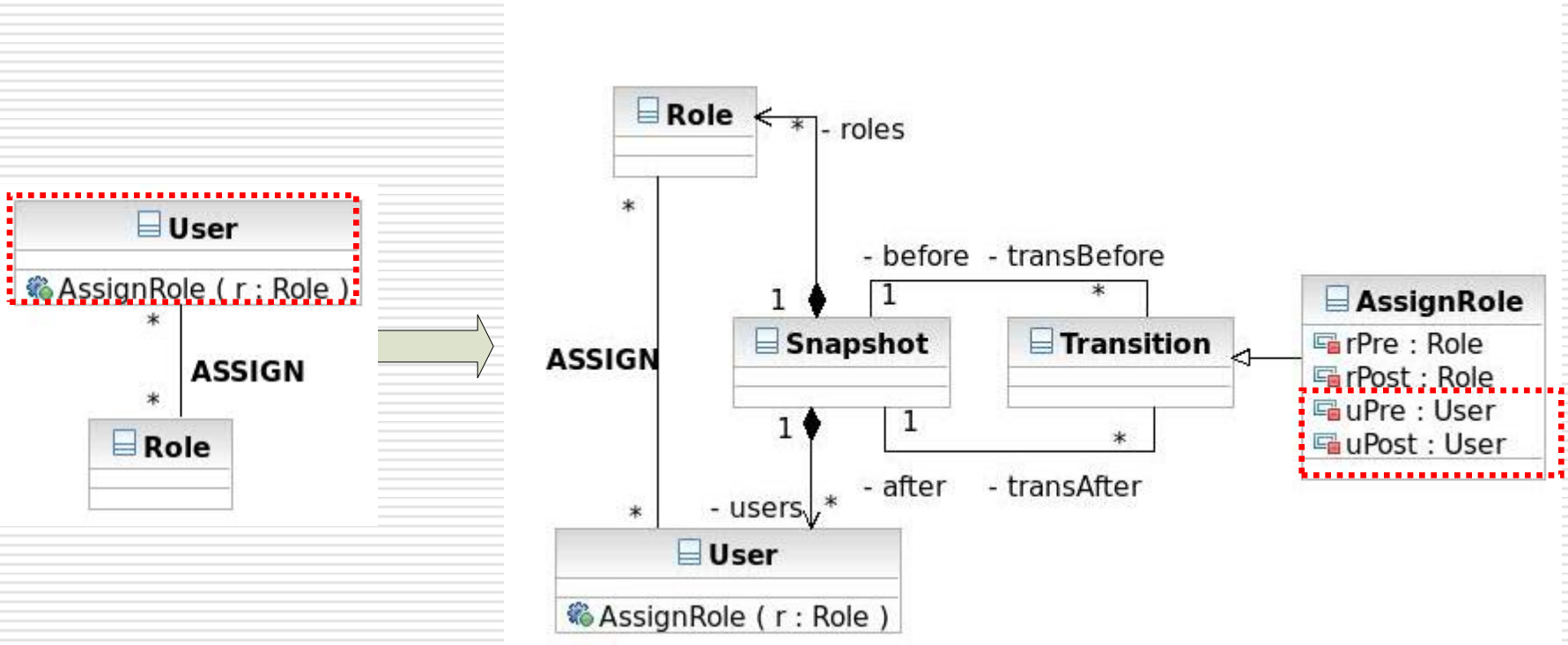
- Contribution
  - Propose a general framework for, but not limited to, security policy analysis
  - Address a usability issue: a usable verification tool needs to be integrated with the UML-based development processes and notations used by software developers
- Future work
  - Investigating how safety and liveness access control properties can be analyzed using model-checking techniques at the back-end in a usable manner

*Acknowledgment: the work was supported by the National Science Foundation grant CCF-1018711.

Colorado State University
Computer Science Department

Background: Snapshot Model

- Example of a snapshot model generated from a class model



UML Class Model

UML Snapshot Model

Background: Snapshot Model

- Operation specification for AssignRole(r:Role) in the original design class model:

```
// English specification: assign a role to a user
Context User::AssignRole(r:Role)
Precondition: role r is not assigned  to the user
Postcondition: role r is assigned to  the user

// OCL specification: assign a role to a user
Context User::AssignRole(r:Role)
Pre: self.ASSIGN->excludes(r)
Post: self.ASSIGN = self.ASSIGN@pre->including(r)
```

Background: Snapshot Model

- Example of the specialized class invariant in a snapshot model generated from the operation specification in a design class model:

Context AssignRole inv:
// Generated from precondition of User::AssignRole(r:Role)
// role r is not assigned to the user
uPre.ASSIGN->excludes(rPre) and …

// Generated from postcondition of User::AssignRole(r:Role)
// role r is assigned to the user
uPost.ASSIGN = uPre.ASSIGN->including(rPost) and …

// Unchanged parts of object configuration
after.roles->excluding(rPost)=before.roles->excluding(rPre)
…

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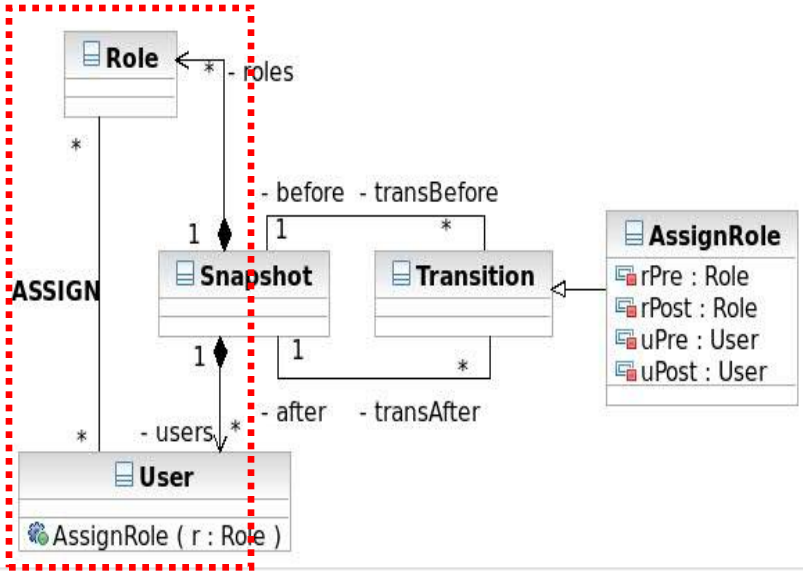
Snapshot Model to Alloy Model Transformation

- Step 2: Transform the Snapshot class to a Snapshot signature containing fields that specify the object configurations within a snapshot

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roles: set Role, users: set User,
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}
```

Demonstration Case Study: Generating the LRBAC Snapshot Model

- Invariant for Role_DeleteRoleAssignLocation class generated from the specification of DeleteRoleAssignLocation operation

```
Context Role_DeleteRoleAssignLocation inv:
// Generated from precondition of DeleteRoleAssignLocation
rPre.AssignLoc->includes(lPre)
…
// Generated from postcondition of DeleteRoleAssignLocation
rPost.AssignLoc=rPre.AssingLoc->excluding(lPost) and
…
// Unchanged parts of object configuration
after.roles->excluding(rPost)
=before.roles->excluding(rPre) and
...
```

Alloy Instance to UML Object Model Transformation