A Theory for Comparing the Expressive Power of Access Control Models

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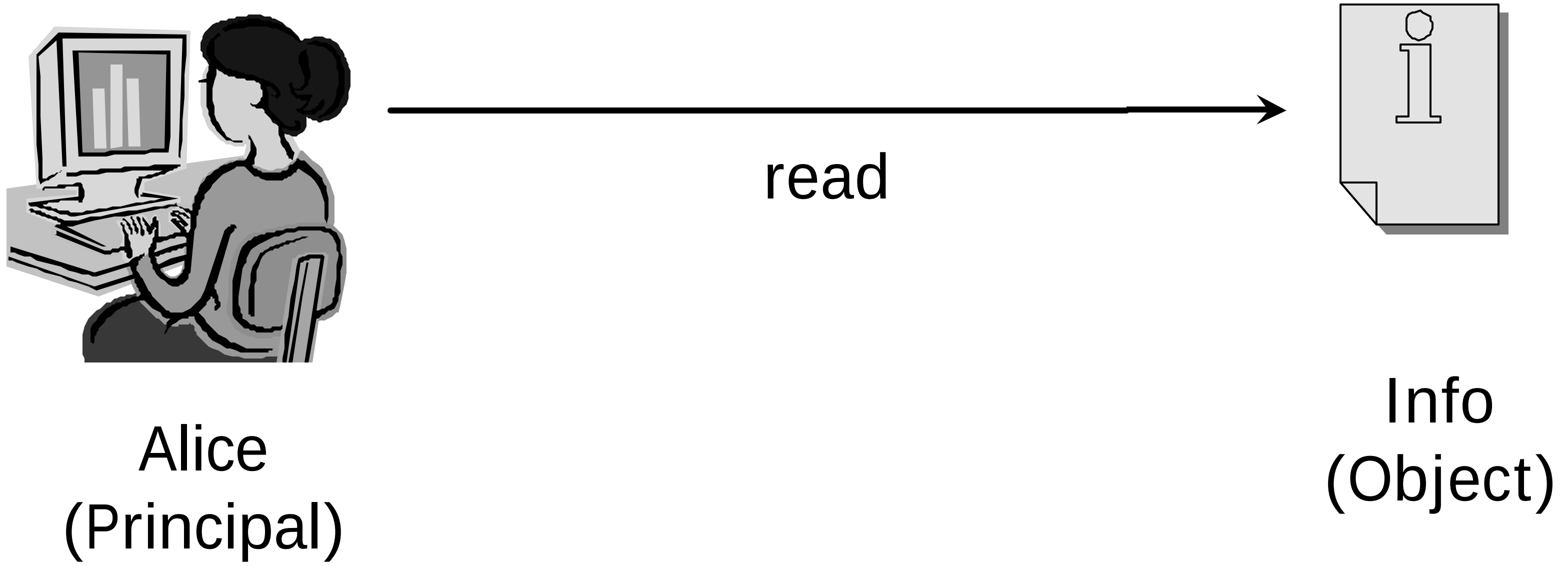
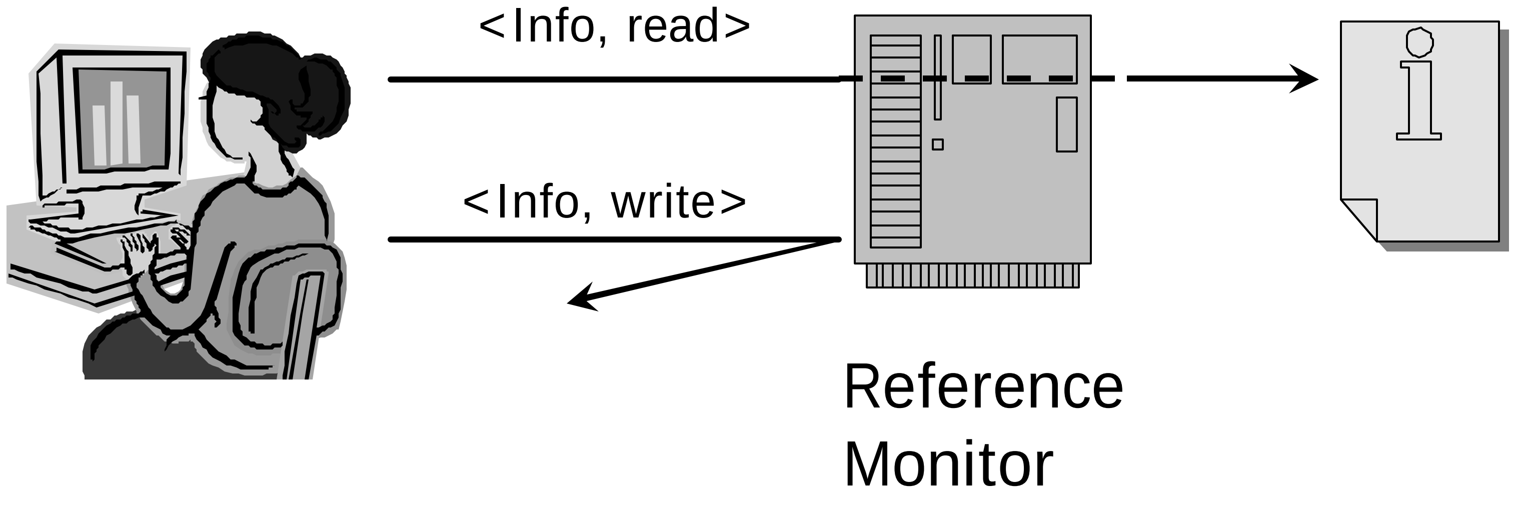
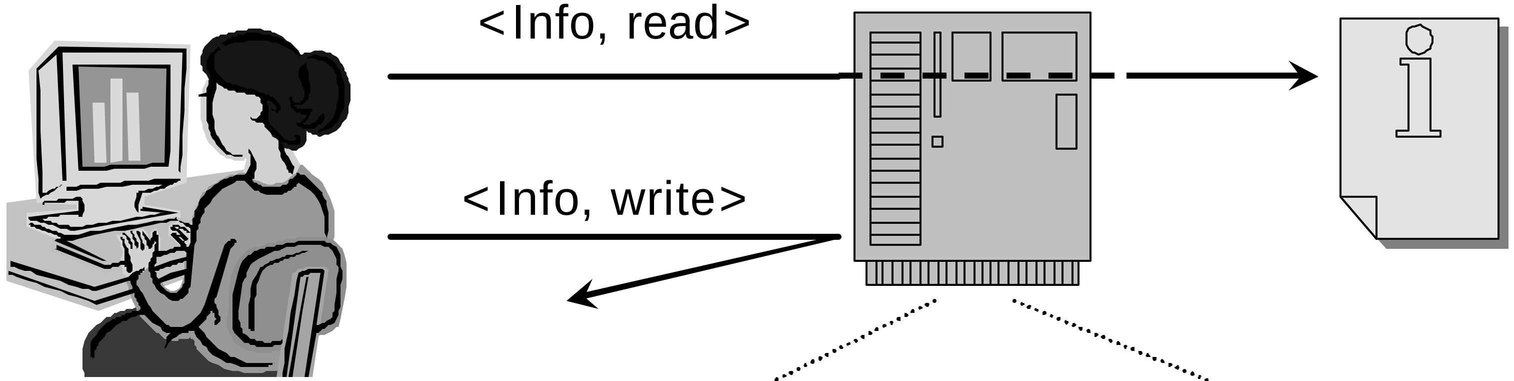
Access Control



Access Control (contd.)



Access Control (contd.)



	Alice	Info	More Info	
Alice		read	own	
Bob	control	own, write		

Protection State

- In our example, s is characterized by: $<P_s, O_s, R_s, M_s[\ ]>$
  - Specifies *access control model*
- Can query the state:
  - q_1 = “$\sigma \in P$”
  - q_2 = “$\omega \in O$”
  - q_3 = “$r \in M[\sigma,\omega]$”
- Entailment – whether query is true:
  - s ? q_3 iff $\sigma \in P_s$? $\omega \in O_s$? $r \in M_s[\sigma,\omega]$

State can change

	Alice	Info
Alice		read
Bob	control	own, write

	Alice	Info
Alice		own, read
Bob	control	write

State Change Rules

```
createObject(i,o)
    create object o
    enter own into M[i,o]
```

```
destroyObject(i,o)
    if own $\in$ M[i,o]
        destroy object o
```

```
transferOwn(i,p,o)
    if own $\in$ M[i,o]
        enter own into M[p,o]
        remove own from M[i,o]
```

```
grant_r(i,p,o)
    if own $\in$ M[i,o]
        enter r into M[p,o]
```

Systems and Schemes

- Access control system: <s, c, Q, ?>
- Access control scheme: <S, C, Q, ?>
  - $s \in S$
  - $c \in C$

- The above scheme is Strict DAC with Change of Ownership (SDCO)
  - sub-scheme of the Graham-Denning scheme

Another Scheme – ARBAC97

- s = <UA, PA, RH, AR>
- c :

assignUser	revokeUser
assignPermission	revokePermission
addToRoleRange	removeFromRoleRange
assignAsSenior	removeAsSenior

- Q : (1) $<u,r> \in$ UA;

  (2) $\exists$ u s.t. $<u,r> \in$ UA;

  (3) $\exists$ r s.t. $<u,r> \in$ UA;

  (4-6) for permissions;

  (7) $<r_1, r_2> \in$ RH;

  (8) $\exists$ r_1,r_2 s.t. $<r_1,r_2> \in$ RH ? $<u,r_1> \in$ UA ? $<p,r_2> \in$ PA

Other Examples of Schemes

- The HRU scheme (based on the access matrix model).
- Various DAC schemes (based on the access matrix model).
- MAC schemes.
- Other RBAC schemes.
- The RT[?, n] trust management scheme.

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Comparison

- How does SDCO compare to ARBAC97?
- Why is this an important question?
  - can scheme B “represent” every security policy that scheme A can?
- On what basis do we compare?
  - Or, how do we formalize “represent policies”?
- Note: straightforward extension from schemes to models

Examples of Policy Questions

- Can (presumably untrusted) Alice get read access to file, f ?
- Does (administrator) Bob always have access to a configuration file?
- Does someone always have access to the building ?
- Is every object owned by exactly one principal?
- Can anyone other than Dorothy get access to the resource r ?

Our Theory: Introduction

- Does there exist a mapping from scheme A to B with relevant properties?
  - Or, can B “simulate” A?
  - Mapping should be security preserving.
  - Efficiency is not necessarily relevant.
    - But if the mapping is efficient, there is a useful implication.

Security-Preserving Mapping

- For B to be at least as expressive as A:
  - Identify security properties in A and B (e.g., safety, availability, mutual exclusion, liveness).

  - Does there exist a mapping, m from A to B, and p_A to p_B such that: $a \in A$ has p_A iff $m(a) = b \in B$ has p_B.

Questions...

- How do we represent properties of interest?
    - Answer: queries

- How do we determine whether a system satisfies a property?
    - Answer: security analysis

Security Analysis

- Access Control Scheme: <S, C, Q, ?>
- Given a system a = <s_0, c, Q, ?>, we ask:
  - ∃ reachable s_1, such that s_1 ? q?
  - ∀ reachable s_1, does s_1 ? q?
- Can check several interesting properties.

- Other kinds of questions are possible and meaningful for security – future work.
  - Example: Chinese-Wall policies

Back to Security-Preserving Mapping

- m: $(S_A \times C_A)$? Q_A ? $(S_B \times C_B)$? Q_B
- m is security preserving, if it maintains results of security analyses.

- If m is efficient, we can use analysis in B for analysis in A.

- Comparison to NP-hardness reductions.

Strongly Security Preserving Mapping

- m is strongly-security preserving, if it maintains results of compositional security analyses.
  - Compositional security analysis: allows a propositional logic formula of queries.
  - Strongly security preserving implies security preserving.

Return to our Example: SDCO

- Suppose s satisfies: $\forall \omega \in O_s$, $\exists$ exactly one $\sigma \in P_s$ such that own $\in M_s[\sigma, \omega]$

```
createObject(i,o)
   create object o
   enter own into M[i,o]

destroyObject(i,o)
   if own ∈ M[i,o]
      destroy object o

transferOwn(i,p,o)
   if own ∈ M[i,o]
      enter own into M[p,o]
      remove own from M[i,o]

grant_r(i,p,o)
   if own ∈ M[i,o]
      enter r into M[p,o]
```

SDCO (contd.)

- c maintains invariant.
- Let $\omega \in O_s$ with owner σ_1.
  - Can reach a state in which σ_2 is the owner.
  - Cannot reach state, s', in which more than one owner, or no owner (when $\omega \in O_{s'}$)
- Can represent each of the above as formula of queries from Q.

Results for SDCO and ARBAC97

- There exists a security preserving mapping from SDCO to ARBAC97.

- There exists no strongly-security preserving mapping from SDCO to ARBAC97.
    - Any ARBAC97 system must enter “extra” or “bad” state that violates invariant in trying to maintain it.

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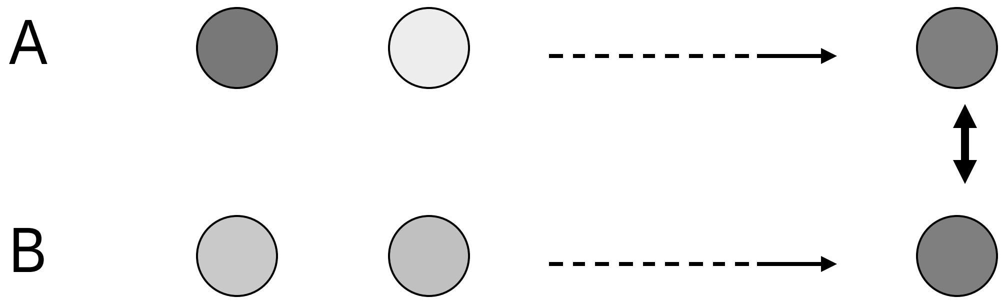
More Usable Definitions



- Are there corresponding reachable states under m?
  - Reduction: for each query.
  - State-matching reduction: for all queries.

More Usable Definitions (contd.)

- Necessary and sufficient conditions for
  - security-preserving mapping: reduction
  - strongly security-preserving mapping: state-matching reduction

- Reduction: $A =_R B$
- State-Matching Reduction: $A =_S B$

Proof Strategy

- If there exists (state-matching) reduction:
  - By construction of m
  - Show properties are satisfied
- If there exists no (state-matching) reduction:
  - By contradiction
  - Find system in A and reachable state, s_a such that for any corresponding system in B, in reaching $m(s_a)$, we have to traverse a “bad” state.

Results

- SDCO $=_R$ ARBAC97 scheme.
- SDCO $?_S$ ARBAC97 scheme.
- URA97 scheme $=_S$ RT[? , n] scheme.
- ATAM $?_S$ TAM.
- Graham-Denning scheme $?_S$ HRU scheme.

- RT[ ] scheme $?_S$ HRU scheme.

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HRU Scheme

- S = access matrix instances
- C = all command-sets, with each command:

```
command c($p_1$, $p_2$, ..., $p_n$)
  if $r_1 \in M[p_i,p_j]$ ? … ? $r_n \in M[p_k, p_l]$
    primitive op 1
    primitive op 2
    ...
```

  - Primitive op: create subject/object, destroy subject/object, enter/remove right.
- Q: (1) $r \in M[\sigma,\omega]$; (2) $r \notin M[\sigma,\omega]$

HRU Scheme (contd.)

- Safety problem: can a right appear where it does not exist in start-state?
  - Result: undecidable in general
- Import of result:
  - “Safety is undecidable in DAC”
  - “Shows limits of formal methods in security”
  - “HRU scheme is too expressive”

RT[ ] Scheme

- S = collection of assertions of two kinds:
  - A.r ? B (simple member)
  - A.r ? B.r_1 (simple inclusion)
- c = (G, H)
  - G: set of growth-restricted roles
  - H: set of shrink-restricted roles
- Q: (1) { B } ? A.r;

  (2) A.r ? { B };

  (3) A.r ? B.r_1

Result and Intuition

- RT[ ] scheme $?_S$ HRU scheme

- RT[ ] system:
  - Start with A.r being empty, and not growth-restricted.
  - Adding a single statement A.r ? B causes an unbounded number of queries of the form { B’ } ? A.r to become false.
- Any HRU system has to traverse “bad” state.
  - Only bounded number of queries can change from true to false (or vice versa) in single state-change.

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Related Work

- Based on preservation of safety:
  - Sandhu (JCS, ’92)
  - Ammann, Lipton, Sandhu (JCS, ’96)
  - Sandhu, Ganta (CSFW, ’93)

- Not based on preservation of safety:
  - Bertino, Catania, Ferrari, Perlasca (TISSEC, ‘03)
  - Chander, Dean, Mitchell (CSFW, ’01)
  - Osborn, Sandhu, Munawer (TISSEC, ’00)

Summary

- A theory for comparing access control models based on expressive power.
- Validated with applications
  - ATAM, TAM relationship was an open problem
  - SDCO, ARBAC97 result contradicts existing assertion from literature
  - Results on HRU are first formal evidence of its limited expressive power