PURDUE UNIVERSITY

CS52600: Information Security
Access Control Matrices

Prof. Chris Clifton
August 25, 2010

See Harrison, Ruzzo, Ullman CACM'76

Models: Access Control

- What is access control?
  - Limiting who is allowed to do what
- What is an access control model?
  - Specifying who is allowed to do what
- What makes this hard?
  - Interactions between types of access

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Basics

- State: Status of the system
  - Protection state: subset that deals with protection
- Access Control Matrix
  - Describes protection state
- Formally:
  - Objects O
  - Subjects S
  - Matrix $A \subseteq S \times O$
- Tuple (S, O, A) defines protection states of system

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Access Restriction Facility

- Subject: attributes (name, role, groups)
- Verbs: possible actions
  - Default rule for each verb
- Objects associated with set of verbs
  - Rule for each (object, verb) pair
  - Rule may be function of subject attributes
- Can be converted to Access Control Matrix

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Access Control Matrix: Boolean Evaluation Example

	Internal	Local	State University	Long Distance	International
Public	CR T		R		
Student	CR T	CR T	R	R	R
Staff	CR Transfer	CR T	CR T	R	R
Account	CR T	CR T	CR T	CR T	CR T

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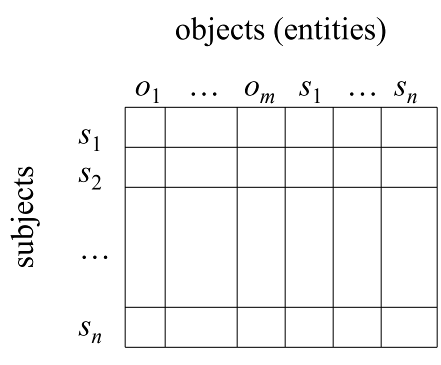
Description



- Subjects $S = \{ s_1,\ldots,s_n \}$
- Objects $O = \{ o_1,\ldots,o_m \}$
- Rights $R = \{ r_1,\ldots,r_k \}$
- Entries $A[s_i, o_j] \subseteq R$
- $A[s_i, o_j] = \{ r_x, \ldots, r_y \}$ means subject s_i has rights $r_x, \ldots, r_y$ over object o_j

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Example 2

- Procedures *inc_ctr*, *dec_ctr*, *manage*
- Variable *counter*
- Rights +, –, *call*

	counter	*inc_ctr*	*dec_ctr*	*manage*
inc_ctr	+			
dec_ctr	–			
manage		*call*	*call*	*call*

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Boolean Expression Evaluation

- ACM controls access to database fields
  - Subjects have attributes
  - Verbs define type of access
  - Rules associated with objects, verb pair
- Subject attempts to access object
  - Rule for object, verb evaluated, grants or denies access

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Example

- Subject annie
  - Attributes role (artist), groups (creative)
- Verb paint
  - Default 0 (deny unless explicitly granted)
- Object picture
  - Rule:
    paint: 'artist' in subject.role and
    'creative' in subject.groups and
    time.hour >= 0 and time.hour < 5

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Protection State Transitions

- State $X_i = (S_i, O_i, A_i)$
- Transitions τ_i
  - Single transition $X_i \vdash_{\tau_{i+1}} X_{i+1}$
  - Series of transitions $X \vdash^* Y$
- Access control matrix may change
  - Change command c associated with transition
  - $X_i \vdash_{c_{i+1}(p_{i+1},\ldots,p_{i+1})} X_{i+1}$
- Commands often called *transformation procedures*

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Special Privileges: Copy, Ownership

- Copy (or grant)
  - Possessor can extend privileges to another
- Own right
  - Possessor can change their own privileges
- Principle of Attenuation of Privilege
  - A subject may not give rights it does not possess

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Primitive Commands
(Harrison, Ruzzo, Ullman CACM'76)

- Create Object *o*
  - Adds *o* to objects with no access
  - $S' = S$, $O' = O \cup \{o\}$, $(\forall x \in S')[a'[x,o] = \emptyset]$, $(\forall x \in S')(\forall y \in O)[a'[x,y] = a[x,y]]$
- Create Subject *s*
  - Adds *s* to objects, subjects, sets relevant access control to $\emptyset$
- Enter *r* into *a*[*s*,*o*]
- Delete *r* from *a*[*s*,*o*]
- Destroy subject *s*, destroy object *o*

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Create Subject

- Precondition: $s \notin S$
- Primitive command: **create subject** *s*
- Postconditions:
  - $S' = S \cup \{ s \}$, $O' = O \cup \{ s \}$
  - $(\forall y \in O')[a'[s, y] = \varnothing]$, $(\forall x \in S')[a'[x, s] = \varnothing]$
  - $(\forall x \in S)(\forall y \in O)[a'[x, y] = a[x, y]]$

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Create Object

- Precondition: $o \notin O$
- Primitive command: **create object** *o*
- Postconditions:
  - $S' = S$, $O' = O \cup \{ o \}$
  - $(\forall x \in S')[a'[x, o] = \varnothing]$
  - $(\forall x \in S)(\forall y \in O)[a'[x, y] = a[x, y]]$

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Add Right

- Precondition: $s \in S$, $o \in O$
- Primitive command: enter *r* into *a*[*s*, *o*]
- Postconditions:
  - $S' = S$, $O' = O$
  - $a'[s, o] = a[s, o] \cup \{ r \}$
  - $(\forall x,y \in S \text{x} O - \{ s,o \})$ $[a'[x, y] = a[x, y]]$

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Delete Right

- Precondition: $s \in S$, $o \in O$
- Primitive command: **delete** *r* **from** *a*[*s*, *o*]
- Postconditions:
  - $S' = S$, $O' = O$
  - $a'[s, o] = a[s, o] - \{ r \}$
  - $(\forall x,y \in S \text{x} O - \{ s,o \})$ $[a'[x, y] = a[x, y]]$

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Destroy Subject

- Precondition: $s \in S$
- Primitive command: **destroy subject** *s*
- Postconditions:
  - $S' = S - \{ s \}$, $O' = O - \{ s \}$
  - $(\forall y \in O')[a'[s, y] = \varnothing]$, $(\forall x \in S')[a'[x, s] = \varnothing]$
  - $(\forall x \in S')(\forall y \in O')\ [a'[x, y] = a[x, y]]$

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Destroy Object

- Precondition: $o \in o$
- Primitive command: **destroy object** *o*
- Postconditions:
  - $S' = S$, $O' = O - \{ o \}$
  - $(\forall x \in S')[a'[x, o] = \varnothing]$
  - $(\forall x \in S')(\forall y \in O')\ [a'[x, y] = a[x, y]]$

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Creating File

- Process *p* creates file *f* with *r* and *w* permission
  command *create•file*(*p*, *f*)
  create object *f*;
  enter *own* **into** *A*[*p*, *f*];
  enter *r* **into** *A*[*p*, *f*];
  enter *w* **into** *A*[*p*, *f*];
  end

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Mono-Operational Commands

- Make process *p* the owner of file *g*
  command *make•owner*(*p*, *g*)
  enter *own* **into** *A*[*p*, *g*];
  end
- Mono-operational command
  - Single primitive operation in this command

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Conditional Commands

- Let *p* give *q* *r* rights over *f*, if *p* owns *f*
  command *grant•read•file•1*(*p*, *f*, *q*)
      if *own* **in** *A*[*p*, *f*]
      then
          enter *r* **into** *A*[*q*, *f*];
  end
- Mono-conditional command
  - Single condition in this command

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Multiple Conditions

- Let *p* give *q* *r* and *w* rights over *f*, if *p* owns *f* and *p* has *c* rights over *q*
  command *grant•readwrite•file•2*(*p*, *f*, *q*)
      if *own* **in** *A*[*p*, *f*] **and** *c* **in** *A*[*p*, *q*]
      then
          enter *r* **into** *A*[*q*, *f*];
          enter *w* **into** *A*[*q*, *f*];
  end

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Decidability

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See [Harrison, Ruzzo, Ullman CACM'76]

Copy Right

- Allows possessor to give rights to another
- Often attached to a right, so only applies to that right
  - *r* is read right that cannot be copied
  - *rc* is read right that can be copied
- Is copy flag copied when giving *r* rights?
  - Depends on model, instantiation of model

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Own Right

- Usually allows possessor to change entries in ACM column
  - So owner of object can add, delete rights for others
  - May depend on what system allows
    - Can't give rights to specific (set of) users
    - Can't pass copy flag to specific (set of) users

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Attenuation of Privilege

- Principle says you can't give rights you do not possess
  - Restricts addition of rights within a system
  - Usually *ignored* for owner
    - Why? Owner gives herself rights, gives them to others, deletes her rights.

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Key Points

- Access control matrix simplest abstraction mechanism for representing protection state
- Transitions alter protection state
- 6 primitive operations alter matrix
  - Transitions can be expressed as commands composed of these operations and, possibly, conditions

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What is *Secure*?

- A secure system doesn't allow violations of policy
  - Is this a good definition?
  - Can we use it?
- Alternative view: based on rights
  - Start with access control matrix *A*
  - *Leak*: commands can add right *r* to an element of *A* not containing *r*
  - *Safe*: System is *safe with respect to r* if *r* cannot be leaked

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Formally:

- Given
  - initial state $X_0 = (S_0, O_0, A_0)$
  - Set of primitive commands *c*
- Can we reach a state X_n where ∃s,o such that A_n[s,o] includes a right *r* not in A_0[s,o]?
  - If so, the system is not safe
  - But is "safe" secure?

Are commands correctly implemented?

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Example: Unix File System

- Access Control Matrix
  - Root has access to all files
  - Owner has access to their own files
- Safe with respect to file access right?
  - No chmod/chown command
  - Only "root" can get root privileges
  - Only user can authenticate as themselves

Is "Safe" definition useful?

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Solution: Trust

- Safety doesn't distinguish leak from authorized transfer of rights
- Subjects authorized to receive transfer of rights deemed "trusted"
  - Eliminate trusted subjects from matrix

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Decidability Result
(Harrison, Ruzzo, Ullman CACM'76)

- Given a system where each command consists of a single *primitive* command, There exists an algorithm that will determine if a protection system with initial state X_0 is safe with respect to right *r*.
- Proof: determine minimum commands *k* to leak
  - Delete/destroy: Can't leak (or be detected)
  - Create/enter: new subjects/objects "equal", so treat all new subjects as one
  - If *n* rights, leak possible, must be able to leak in $n(|S_0|+1)(|O_0|+1)+1$ commands
- Enumerate all possible to decide

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Decidability: Non-Primitive Commands

- It is undecidable if a given state of a given protection system is safe for a given generic right
- Proof: Reduction from halting problem
  - Symbols, states ⇒ rights
  - Tape cell ⇒ subject (can create new subjects)
  - Right *own*: s_i *owns* s_i*+1* for $1 \le i < k$
  - Cell s_i *A* ⇒ s_i has *A* rights on itself
  - Cell s_k ⇒ s_k has end rights on itself
  - State *p*, head at s_i ⇒ s_i has *p* rights on itself

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Decidability

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CERIAS Student Orientation and Welcome

- Wednesday, 1 September, 5:45-7:15 p.m., LWSN 1142
- Faculty and projects will be introduced
- Learn about the
  - Official CERIAS Student Association
  - New funding opportunities
- CERIAS students are expected to attend.
  - Visitors, faculty and staff are welcome
- Photos will be taken
  - If you have a photo url available, e.g., Departmental photo, please send to walls@cerias.purdue.edu
- Pizza will be served
  - RSVP walls@cerias.purdue.edu with number of pizza slices you would like by 9 a.m. Wednesday, Sept 1

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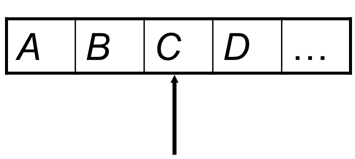
Example:

Turing Machine



Matrix

	s_1	s_2	s_3	s_4
s_1	*A*	*own*		
s_2		*B*	*own*	
s_3			*C*, *p*	*own*
s_4				*D*, *end*

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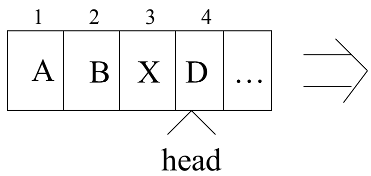
Mapping



	s_1	s_2	s_3	s_4	
s_1	A	*own*			
s_2		B	*own*		
s_3			X	*own*	
s_4				D k_1 end	

After $\delta(k, C) = (k_1, X, R)$ where k is the current state and k_1 the next state

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Command Mapping

$\delta(k, C) = (k_1, X, R)$ at intermediate becomes

```
command c_{k,C}(s_3, s_4)
if own in A[s_3, s_4] and k in A[s_3, s_3]
      and C in A[s_3, s_3]
then
  delete k from A[s_3, s_3];
  delete C from A[s_3, s_3];
  enter X into A[s_3, s_3];
  enter k_1 into A[s_4, s_4];
end
```

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Commands:

- Halting problem Turing Machine: Symbols *A*, *B*; states *p, q*
- $C_{p,A}(s_i, s_{i-1})$ (move left)
  - if *own* $\in a[s_{i-1}, s_i]$ and $p \in a[s_i, s_i]$ and $A \in a[s_i, s_i]$
    - Delete *p* from $a[s_i, s_i]$, *A* from $a[s_i, s_i]$
    - Enter *B* into $a[s_i, s_i]$, *q* into $a[s_{i-1}, s_{i-1}]$
- Similar commands for move right, move right at end of tape
- Simulates Turing machine
  - Leaks halting state $\Rightarrow$ halting state in the matrix $\Rightarrow$ Halting state reached

This is undecidable!

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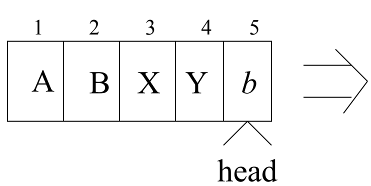
Mapping



After $\delta(k_1, D) = (k_2, Y, R)$ where k_1 is the current state and k_2 the next state

	s_1	s_2	s_3	s_4	s_5
s_1	A	*own*			
s_2		B	*own*		
s_3			X	*own*	
s_4				Y	*own*
s_5					$b\ k_2$ end

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Command Mapping

$\delta(k_1, D) = (k_2, Y, R)$ at end becomes

```
command crightmost_{k,C}(s_4, s_5)
if end in A[s_4, s_4] and k_1 in A[s_4, s_4]
      and D in A[s_4, s_4]
then
  delete end from A[s_4, s_4];
  create subject s_5;
  enter own into A[s_4, s_5];
  enter end into A[s_5, s_5];
  delete k_1 from A[s_4, s_4];
  delete D from A[s_4, s_4];
  enter Y into A[s_4, s_4];
  enter k_2 into A[s_5, s_5];
end
```

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Rest of Proof

- Protection system exactly simulates a TM
  - Exactly 1 *end* right in ACM
  - 1 right in entries corresponds to state
  - Thus, at most 1 applicable command
- If TM enters state q_f, then right has leaked
- If safety question decidable, then represent TM as above and determine if q_f leaks
  - Implies halting problem decidable
- Conclusion: safety question undecidable

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Other Results
(most from the same authors)

- Set of unsafe systems recursively enumerable
- Without create primitive, safety in P-SPACE
  - Like halting problem reduction, but no unlimited tape
- Without delete/destroy, still undecidable
  - Decidable if at most one condition allowed per command
  - Still holds if delete allowed

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Mono-Operational Commands

- Answer: *yes*
- Sketch of proof:

  Consider minimal sequence of commands c_1, …, c_k to leak the right.

  –Can omit **delete**, **destroy**

  –Can merge all **create**s into one

  Worst case: insert every right into every entry; with s subjects and o objects initially, and n rights, upper bound is $k \le n(s+1)(o+1)$

What Else Might We Add?

- Default Rule
  - General default: Receive
  - Object default: Call Internal
  - Requires ability to override with negative and positive access
- Time-based access
  - Allow students to call on State University system after hours?
- History-based access

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Access Control by History

- Example: Statistical Database
  - Allows queries for general statistics
  - But not individual values
- Valid queries: Statistics on 20+ individuals
  - Total salary of all Deans
  - Salary of Computer Science Professors
- See a problem coming?
  - Salary of CS Professors who aren't Deans

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Solution: Query Set Overlap Control (Dobkin, Jones & Lipton '79)

- Query valid if intersection of query coverage and each previous query < *r*
- Given *K* minimum query size, r overlap:
  - Need *1 + (K-1)/r* queries to compromise
- Can represent as access control matrix
  - Subjects: entities issuing queries
  - Objects: *Powerset* of records
  - $O_s(i)$: objects referenced by *s* in queries *1..i*
  - *A*[*s,o*] = read iff $\forall_{q \in \cup_s -} \cap < $

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Next

- Optional reading: Dobkin, Jones, and Lipton (TODS 4(1), see course web site)
- Basic theorems on protection states
  - Decidability of safety of a state with respect to a right
- More Protection Models

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Protection Study: Your Homework

- What does it take to make sure your homework is secure?
  - Let's assume a Unix system (mentor.ics)
  - Issues?
- *Participation Expected!*

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Where does this leave us?

- Safety decidable for some models
  - Are they practical?
- Safety only works if maximum rights known in advance
  - Policy must specify all rights someone could get, not just what they have
  - Where might this make sense?
- Next: Example of a decidable model
  - Take-Grant Protection Model

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