Access Control Matrix Model

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Models

- Abstract irrelevant details of entity or process being modeled
  - Allows you to focus on aspects that are of interest
  - *If done correctly*, results from analyzing the model apply to entity or process
- Assumption: nothing you omit affects the application of the results

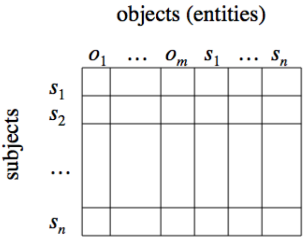
Protection State

Protection state of system describes current settings, values relevant to protection

- Access control matrix representation of protection state
  - Describes protection state precisely
  - Matrix describing rights of subjects (rows) over objects (columns)
  - State transitions change elements of matrix
- *Subject* is active entities (processes, users, *etc.*)
- *Object* has 2 meanings:
  - Passive entity (*not* a subject)
  - Any entity acting passively (so can be a subject)

  Context tells you which sense is used

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

Access Control Matrix for System

- Processes p, q
- Files f, g
- Rights r, w, x, a, o
  - Rights are merely symbols; interpretation depends on system
  - Example: on UNIX, r means "read" for file and "list" for directory

	f	g	p	q
p	rwo	r	$rwxo$	w
q	a	ro	r	$rwxo$

Access Control Matrix for Program

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

	counter	*inc_ctr*	*dec_ctr*	*manage*
inc_ctr	$+$			
dec_ctr	$-$			
manage		*call*	*call*	*call*

Access Control Matrix for Database

- Access control matrix shows allowed 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
  - Result controls granting, denying access

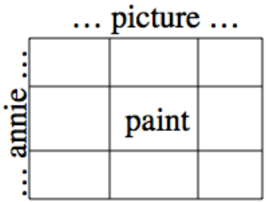
Boolean Expressions and Access

- Subject *annie*: attributes role (artist), groups (creative)
- Verb *paint*: default 0 (deny unless explicitly granted)
- Object *picture*: Rule is

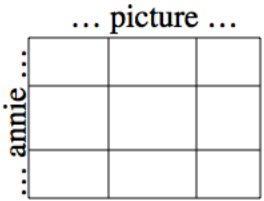
paint: ‘artist’ **in** *subject.role* **and**
‘creative’ **in** *subject.groups* **and**
$time.hour \geq 0$ **and** $time.hour < 5$

Example: ACM at 3 a.m. and 10 a.m.

At 3 a.m., time condition met; ACM is:



At 10 a.m., time condition not met; ACM is



Executing Downloaded Programs

- Downloaded programs may access system in unauthorized ways
  - Example: Download Trojan horse that modifies configuration, control files
- Condition access rights upon the rights of previously executed code (*i.e.*, history)
  - Each piece of code has *set of static rights*
  - Executing process has *set of current rights*
  - When piece of code runs, its rights are *set of current rights* $\cap$ *set of static rights*

Example Programs

main runs, loads *helper_proc* and runs it

```
// This routine has no filesystem access rights
// beyond those in a limited, temporary area
procedure helper_proc()
    return sys_kernel_file;
// But this has the right to delete files
program main()
    sys_load_file(helper_proc);
    file = helper_proc();
    sys_delete_file(file);
```

sys_kernel_file is system kernel

tmp_file file in limited, temporary area *helper_proc* can access

Accesses

- Initial static rights:

	sys_kernel_file	*tmp_file*
main	delete	delete
helper_proc		delete

- Program starts; its rights are those of *main*:

	sys_kernel_file	*tmp_file*
main	delete	delete
helper_proc		delete
process	delete	delete

- After *helper_proc* called, process loses right to delete kernel:

	sys_kernel_file	*tmp_file*
main	delete	delete
helper_proc		delete
process		delete

State Transitions

- Represent changes to the protection state of the system
- $\vdash$ represents transition
  - $X_i \vdash_\tau X_{i+1}$: command τ moves system from state X_i to state X_{i+1}
  - $X_i \vdash^* X_{i+1}$: a sequence of commands moves system from state X_i to state X_{i+1}
- Commands sometimes called *transformation procedures*

Primitive Operations

- **create subject** s; **create object** o
  - Creates new row, column in ACM; creates new column in ACM
- **destroy subject** s; **destroy object** o
  - Deletes row, column from ACM; deletes column from ACM
- **enter** r **into** $A[s, o]$
  - Adds r rights for subject s over object o
- **delete** r **from** $A[s, o]$
  - Removes r rights from subject s over object o

create subject

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

create object

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

enter

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

delete

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

destroy subject

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

destroy object

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

Example: Creating File

Process p creates file f with r and w permissions

command $make \cdot file(p, f)$
    create object f;
    enter *own* **into** $a[p, f]$;
    enter r **into** $a[p, f]$;
    enter w **into** $a[p, f]$;
end

Mono-Operational Commands

- Make process p the owner of file f

command *make·owner*(p, f)
    enter *own* **into** $a[p, f]$;
end

- Single primitive operation in this command
    - So it's *mono-operational*

Conditional Commands

- If p owns f, let p give q r rights over f

```
command grant·rights(p, f)
    if own in A[p, f]
    then
        enter r into A[q, f];
end
```

- Single condition in this command
  - So it's *mono-conditional*

Multiple Conditions

- If p has both r and c rights over f, let p give q r and w rights over f

```
command grant·read·file·ifrandc(p, f)
    if r in A[p, f] and c in [p, q]
    then
        enter r into A[q, f];
        enter w into A[q, f];
end
```

- Two conditions in this command
    - So it's *bi-conditional*

"Or" Conditions

- If p has either r or c rights over f, let p give q r and w rights over f
  - No "or" operator, so we write command for each possibility
  - Then execute them sequentially
  - Note: if multiple conditions hold, actions may be taken more than once (usually to no effect)

r, c Commands

```
command grant·read·file·ifr(p, f)
    if r in A[p, f]
    then
        enter r into A[q, f];
        enter w into A[q, f];
end
command grant·read·file·ifc(p, f)
    if c in A[p, f]
    then
        enter r into A[q, f];
        enter w into A[q, f];
end
```

r or c Command

command $grant\cdot read\cdot file\cdot ifrorc(p, f)$
$grant\cdot read\cdot file\cdot ifr(p, f)$
$grant\cdot read\cdot file\cdot ifc(p, f)$
end

Copy

- 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 or $r{:}c$ is read right that can be copied
  - In this case, called a *copy flag*
- Is copy flag copied with copying the associated right?
  - Depends on rules of model, or instantiation of model

Own

- Usually allows possessor to change entries in ACM column
  - Owner of object can add, delete rights over that object for others
- What can be done is system (instantiation) dependent
  - Some disallow giving rights to specific (set of) users
  - Some disallow passing of copy flag to specific (set of) users

Principle of Attenuation of Privilege

- You increase your rights
- You cannot give rights that 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

Now What?

- Very simple model, but very powerful
- Will use this to examine decidability of security
- Will use very simple definition of "secure":
    - Adding a generic right r where there was not one is *leaking*
    - If a system S begins in initial state s_0 and it cannot leak right r, we consider it secure with respect to the right r

We will formalize this and study it

What is "Secure"?

Leaking

Adding a generic right r where there was not one is *leaking*

Safe

If a system S, beginning in initial state s_0, cannot leak right r, it is *safe* with respect to the right r.

Here, "safe" = "secure" for an abstract model

What is Does “Decidable” Mean?

Safety Question

Does there exist an algorithm for determining whether a protection system S with initial state s_0 is safe with respect to a generic right r?

Mono-Operational Commands

Answer:

Yes!

Proof sketch:
Consider minimal sequence of commands $c_1, \ldots, c_k$ 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, o objects, and n rights initially, upper bound is $k \leq n(s+1)(o+1)$

Proof (1)

- Consider minimal sequences of commands (of length m) needed to leak r from system with initial state s_0
  - Identify each command by the type of primitive operation it invokes
- Cannot test for *absence* of rights, so **delete**, **destroy** not relevant
  - Ignore them
- Reorder sequences of commands so all **create**s come first
  - Can be done because **enter**s require subject, object to exist
- Commands after these **create**s check only for *existence* of right

Proof (2)

- It can be shown (see homework):
  - Suppose s_1, s_2 are created, and commands test rights in $A[s_1, o_1]$, $A[s_2, o_2]$
  - Doing the same tests on $A[s_1, o_1]$ and $A[s_1, o_2] = A[s_1, o_2] \cup A[s_2, o_2]$ gives same result
  - Thus all **create**s unnecessary
    - Unless s_0 is empty; then you need to create it (1 **create**)
- In s_0:
  - $|S_0|$ number of subjects, $|O_0|$ number of objects, n number of (generic) rights
- In worst case, 1 create
  - So a total of at most $(|S_0| + 1)(|O_0| + 1)$ elements
- So $m \leq n(|S_0| + 1)(|O_0| + 1)$

General Case

Answer:

No

Proof sketch:

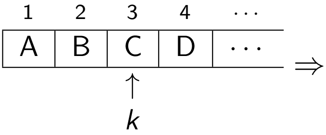
1. Show arbitrary Turing machine can be reduced to safety problem
2. Then deciding safety problem means deciding the halting problem

Turing Machine Review

- Infinite tape in one direction
- States K, symbols M, distinguished blank $\not{b}$
- State transition function $\delta(k, m) = (k', m', \text{L})$
  in state k with symbol m under the TM head
  replace m with m', move head left one square, enter state k'
- Halting state is q_f

Mapping

Turing machine



access control matrix representation

	s_1	s_2	s_3	s_4	$\cdots$
s_1	A	o			$\cdots$
s_2		B	o		$\cdots$
s_3			C k	o	$\cdots$
s_4				D e	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

Turing machine with head over square 3 on tape, in state k and its representation as an access control matrix

o is *own* right

e is *end* right

Mapping

Turing machine

1	2	3	4	⋯
A	B	X	D	⋯
			↑ k_1	

⇒

access control matrix representation

	s_1	s_2	s_3	s_4	⋯
s_1	A	o			⋯
s_2		B	o		⋯
s_3			X	o	⋯
s_4				D k_1 e	⋯
⋮	⋮	⋮	⋮	⋮	⋱

After $\delta(k, \text{C}) = (k_1, \text{X}, \text{R})$, where k is the previous state and k_1 the current state

Command Mapping

$\delta(k, \mathrm{C}) = (k_1, \mathrm{X}, \mathrm{R})$ at intermediate becomes:

command $c_{k,C}(s_i, s_{i+1})$
if o **in** $A[s_i, s_{i+1}]$ **and** k **in** $A[s_i, s_i]$ **and** C **in** $A[s_i, s_i]$
then
  delete k **from** $A[s_i, s_i]$;
  delete C **from** $A[s_i, s_i]$;
  enter X **into** $A[s_i, s_i]$;
  enter k_1 **into** $A[s_{i+1}, s_{i+1}]$;
end

Mapping

Turing machine

1	2	3	4	5
A	B	X	Y	$\not b$

$\uparrow$ (under cell 5)
k_2

$\Rightarrow$

access control matrix representation

	s_1	s_2	s_3	s_4	s_5
s_1	A	o			
s_2		B	o		
s_3			X	o	
s_4				Y	o
s_5					k_2 e

After $\delta(k_1, \text{D}) = (k_2, \text{Y}, \text{R})$, where k_1 is the previous state and k_2 the current state