Fundamentals of Computer Security

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Access Control

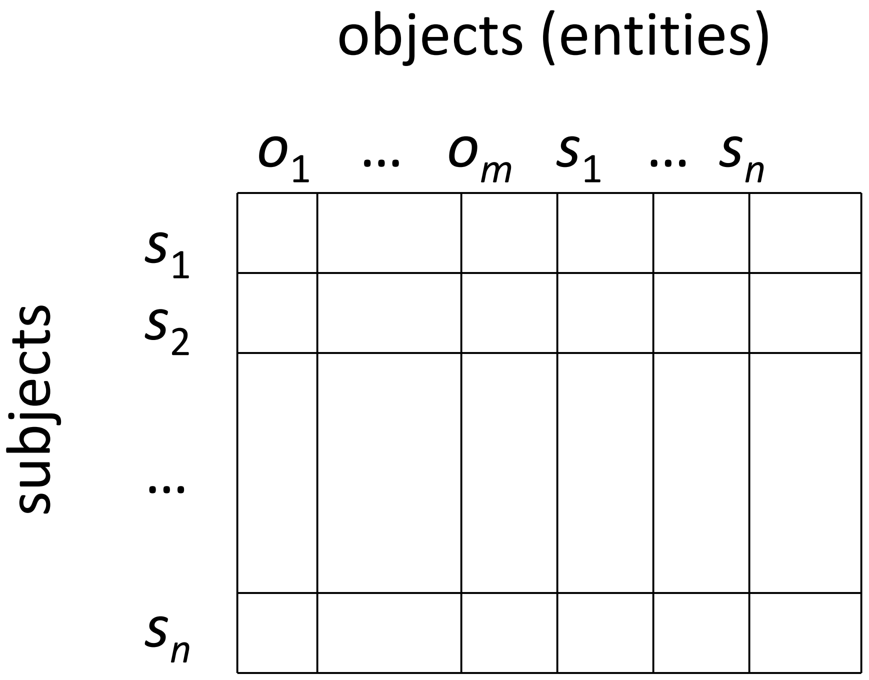
Overview

- Access Control Matrix Model
- Protection State Transitions
  - Commands
  - Conditional Commands
- Mechanisms
  - Access control lists
  - Capability lists
  - Locks and keys
  - Rings-based access control
  - Propagated access control lists

Overview

- Protection state of system
  - Describes current settings, values of system relevant to protection
- Access control matrix
  - Describes protection state precisely
  - Matrix describing rights of subjects
  - State transitions change elements of matrix

AC Matrix 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

Example 1

- Processes *p*, *q*
- Files *f*, *g*
- Rights *r*, *w*, *x*, *a*, *o*

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

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*

State Transitions

- Change the protection state of system
- |– represents transition
  - X_i |– $_\tau$ X_{i+1}: command τ moves system from state X_i to X_{i+1}
  - X_i |– * X_{i+1}: a sequence of commands moves system from state X_i to X_{i+1}
- Commands often called *transformation procedures*

Primitive Ops

- **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*

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
```

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

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

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•read•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
```

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

Own Right

- Usually allows possessor to change entries in corresponding AC Matrix 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

Attenuation of Privilege

- Intuitive principle says *you can't give rights you do not possess*
  - Restricts addition of rights within a system
  - Usually *ignored* for owner
    - Why? Mostly owner can grant herself any rights !

AC Safety

- System AC Safety
  - 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
- Are algorithms *implemented correctly* ?

Example: File System

- Superuser has access to all files
- Users have access to own files
- What is Safety here ?
  - only user A can authenticate as user A
  - no “change mode”, “change owner” commands
  - only superuser can get superuser privileges
- Question: how useful is “safety” ?
  - doesn’t differentate leaks vs. authorized transfers
  - solution: “trust” framework

(Un)decidability of Safety

- Given initial state $X_0 = (S_0, O_0, A_0)$, set of primitive commands *c, c*an 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]? (is a rights leak possible?)

- **Decidability:** Given a system where each command consists of ***a single primitive command*** (*mono-operational*), there exists an algorithm that will determine if a protection system with initial state X_0 is safe with respect to right *r*.

- **Undecidability:** For a given state of an ***arbitrary*** protection system the problem of determining if it is safe with respect to a given right is undecidable (proof: halting problem, "leak" = halting state).

M. A. Harrison, W. L. Ruzzo and J. D. Ullman, *Protection in operating systems*, Comm. of the ACM, Vol. 19 (1976)

AC Mechanisms

- Access control lists
- Capabilities
- Locks and keys
- Rings-based access control
- Propagated access control lists

Access Control Lists

- **Columns** of access control matrix

	file1	*file2*	*file3*
Andy	rx	r	rwo
Betty	rwxo	r	
Charlie	rx	rwo	w

ACLs:

- file1: { (Andy, rx) (Betty, rwxo) (Charlie, rx) }
- file2: { (Andy, r) (Betty, r) (Charlie, rwo) }
- file3: { (Andy, rwo) (Charlie, w) }

Default Permissions

- Normal: if not named, *no* rights over file
  - Principle of Fail-Safe Defaults
- If many subjects, may use groups or wildcards in ACL
  - UNICOS: entries are (*user*, *group*, *rights*)
    - If *user* is in *group*, has rights over file
    - ‘*’ is wildcard for *user*, *group*
      - (holly, *, r): holly can read file regardless of her group
      - (*, gleep, w): anyone in group gleep can write file

Abbreviations

- ACLs can be very long !
- Idea: combine users
  - UNIX: 3 classes of users: owner, group, rest
  - rwx rwx rwx

    rest

    group

    owner
  - Ownership assigned based on creating process
    - Some systems: if directory has setgid permission, file group owned by group of directory (SunOS, Solaris)

ACLs + Abbreviations

- Augment abbreviated lists with ACLs
  - Intent is to shorten ACL
- ACLs override abbreviations
  - Exact method varies
- Example: IBM AIX
  - Base permissions are abbreviations, extended permissions are ACLs with user, group
  - ACL entries can add rights, but on deny, access is denied

Example: Permissions in IBM AIX


```
attributes:
base permissions
  owner(bishop): rw-
  group(sys):r--
  others:     ---
extended permissions enabled
  specify     rw- u:holly
  permit      -w- u:heidi, g=sys
  permit      rw- u:matt
  deny        -w- u:holly, g=faculty
```

ACL Modifications

- Who can do this?
  - Creator is given *own* right that allows this
  - System R provides a *grant* modifier (like a copy flag) allowing a right to be transferred, so ownership not needed
    - Transferring right to another modifies ACL

Privileged Users

- Do ACLs apply to privileged users (*root*)?
  - Solaris: abbreviated lists do not, but full-blown ACL entries do
  - Other vendors: varies

Groups and Wildcards

- Classic form: no; in practice, usually
  - AIX: base perms gave group sys read only

    ```
    permit  -w-  u:heidi, g=sys
    ```

    line adds write permission for heidi when in that group
  - UNICOS:
    - holly : gleep : r
      - user holly in group gleep can read file
    - holly : * : r
      - user holly in any group can read file
    - * : gleep : r
      - any user in group gleep can read file

Conflicts

- Deny access if any entry would deny access
  - AIX: if any entry denies access, *regardless or rights given so far*, access is denied
- Apply first entry matching subject
  - Cisco routers: run packet through access control rules (ACL entries) in order; on a match, stop, and forward the packet; if no matches, deny
    - Note default is deny for fail-safe defaults

Default Permissions

- Apply ACL entry, and if none use defaults
  - Cisco router: apply matching access control rule, if any; otherwise, use default rule (deny)
- Augment defaults with those in the appropriate ACL entry
  - AIX: extended permissions augment base permissions

Revocation

- How do you remove subject's rights to a file?
  - Owner deletes subject's entries from ACL, or rights from subject's entry in ACL
- What if ownership not involved?
  - Depends on system
  - System R: restore protection state to what it was before right was given
    - May mean deleting descendent rights too …

Windows ACLs

- Different sets of rights
  - Basic: read, write, execute, delete, change permission, take ownership
  - Generic: no access, read (read/execute), change (read/write/execute/delete), full control (all), special access (assign any of the basics)
  - Directory: no access, read (read/execute files in directory), list, add, add and read, change (create, add, read, execute, write files; delete subdirectories), full control, special access

Enforcement: Accessing Files

- User not in file's ACL nor in any group named in file's ACL: deny access
- ACL entry denies user access: deny access
- Take union of rights of all ACL entries giving user access: user has this set of rights over file

Capability lists

- **Rows** of access control matrix

	file1	*file2*	*file3*
Andy	rx	r	rwo
Betty	rwxo	r	
Charlie	rx	rwo	w

C-Lists:

- Andy: { (file1, rx) (file2, r) (file3, rwo) }
- Betty: { (file1, rwxo) (file2, r) }
- Charlie: { (file1, rx) (file2, rwo) (file3, w) }

Meaning of Capabilities

- "bus ticket"
  - Mere possession indicates rights that subject has over object
  - Object identified by capability (as part of the token)
    - Name may be a reference, location, or something else
  - Architectural construct in capability-based addressing; this just focuses on protection aspects
- Must prevent process from altering capabilities
  - Otherwise subject could change rights encoded in capability or object to which they refer

Implementation

- Tagged architecture
  - Bits protect individual words
    - B5700: tag was 3 bits and indicated how word was to be treated (pointer, type, descriptor, *etc*.)
- Paging/segmentation protections
  - Like tags, but put capabilities in a read-only segment or page (CAP system did this)
  - Programs must refer to them by pointers
    - Otherwise, program could use a copy of the capability - which it could modify

Implementation (cont'd)

- Cryptography
  - Associate with each capability a cryptographic checksum encrypted using a key known to OS
  - When process presents capability, OS validates checksum
  - Example: Amoeba, a distributed capability-based system
    - Capability is (*name*, *creating_server*, *rights*, *check_field*) and is given to owner of object
    - *check_field* is 48-bit random number; also stored in table corresponding to *creating_server*
    - To validate, system compares *check_field* of capability with that stored in *creating_server* table
    - ***Vulnerable if capability disclosed to another process***

Question

- Bad guy: why not simply copy capability ?
  - ***What can the OS do to prevent this ?***

Amplification

- *temporary* elevation/increase of privileges
- Needed for modular programming:
  - Module pushes, pops data onto stack

    ```
    module stack … endmodule.
    ```
  - Variable *x* declared of type stack

    ```
    var x: module;
    ```
  - *Only* stack module can alter, read *x*
    - So process doesn't get capability, but needs it when *x* is referenced - a problem!
- Solution: give process required capabilities while it is in module

Examples

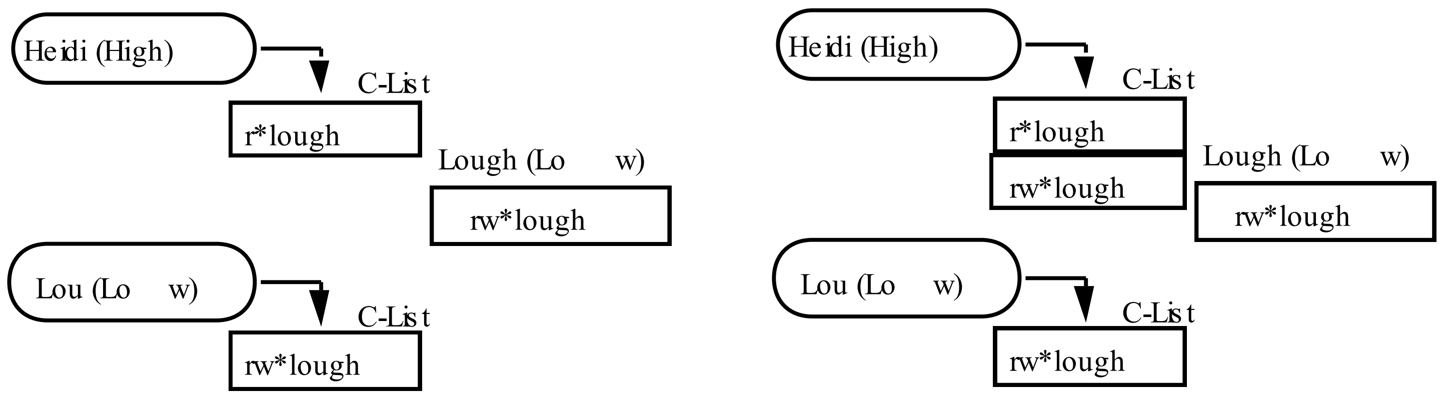
- HYDRA: templates
  - Associated with each procedure, function in module
  - Adds rights to process capability *while the procedure or function is being executed*
  - Rights deleted on exit
- Intel iAPX 432: access descriptors for objects
  - These are really capabilities (!)
  - 1 bit in this controls amplification
  - When ADT constructed, permission bits of type control object set to what procedure needs (ADT = access descriptor)
  - On call, if amplification bit in this permission is set, the above bits or'ed with rights in access descriptor of object being passed

Revocation / Deletion of Rights

- Scan all C-lists, remove relevant capabilities
  - Far too expensive!
- Use indirection
  - Each object has entry in a global object table
  - Names in capabilities name the entry, not the object
    - To revoke, zap the entry in the table
    - Can have multiple entries for a single object to allow control of different sets of rights and/or groups of users for each object
  - Example: Amoeba: owner requests server change random number in server table
    - All capabilities for that object now invalid

Limits

- Problems if you don't control copying of capabilities



The capability to write file *lough* is Low, and Heidi is High so she reads (copies) the capability; now she can write to a Low file, violating the *-property! (Bell-LaPadula)

Remedies

- Label capability itself
  - Rights in capability depends on relation between its compartment and that of object to which it refers
    - In example, as as capability copied to High, and High dominates object compartment (Low), write right removed
- Check to see if passing capability violates security properties
  - In example, it does, so copying refused
- Distinguish between “read” and “copy capability”
  - Take-Grant Protection Model does this (“read”, “take”)

ACLs vs. Capabilities

- Both theoretically equivalent; consider 2 questions
  1. Given a subject, what objects can it access, and how?
  2. Given an object, what subjects can access it, and how?
  - ACLs answer second easily; C-Lists, first
- second question has been of most interest in the past thus ACL-based systems more common than capability-based systems
  - As first question becomes more important (in incident response, for example), this may change

Locks and Keys

- Associate information (*lock*) with object, information (*key*) with subject
  - Latter controls what the subject can access and how
  - Subject presents key; if it corresponds to any of the locks on the object, access granted
- This can be dynamic
  - ACLs, C-Lists static and must be manually changed
  - Locks and keys can change based on system constraints, other factors (not necessarily manual)

Cryptographic Implementation

- Enciphering with lock; deciphering with key
  - Encipher object o; store $E_k(o)$
  - Use subject's key k' to compute $D_{k'}(E_k(o))$
  - Any of n can access o: store

$$o' = (E_1(o), \ldots, E_n(o))$$

  - Requires consent of all n to access o: store

$$o' = (E_1(E_2(\ldots(E_n(o))\ldots))$$

Example: IBM

- IBM 370: process gets access key; pages get storage key and fetch bit
  - Fetch bit clear: read access only
  - Fetch bit set, access key 0: process can write to (any) page
  - Fetch bit set, access key matches storage key: process can write to page
  - Fetch bit set, access key non-zero and does not match storage key: no access allowed

Example: Cisco Router

- Dynamic access control lists

```
access-list 100 permit tcp any host 10.1.1.1 eq telnet
access-list 100 dynamic test timeout 180 permit ip any host \
   10.1.2.3 time-range my-time
time-range my-time
   periodic weekdays 9:00 to 17:00
line vty 0 2
   login local
   autocommand access-enable host timeout 10
```

- Limits external access to 10.1.2.3 to 9AM–5PM
  - Adds temporary entry for connecting host once user supplies name, password to router
  - Connections good for 180 minutes
    - Drops access control entry after that

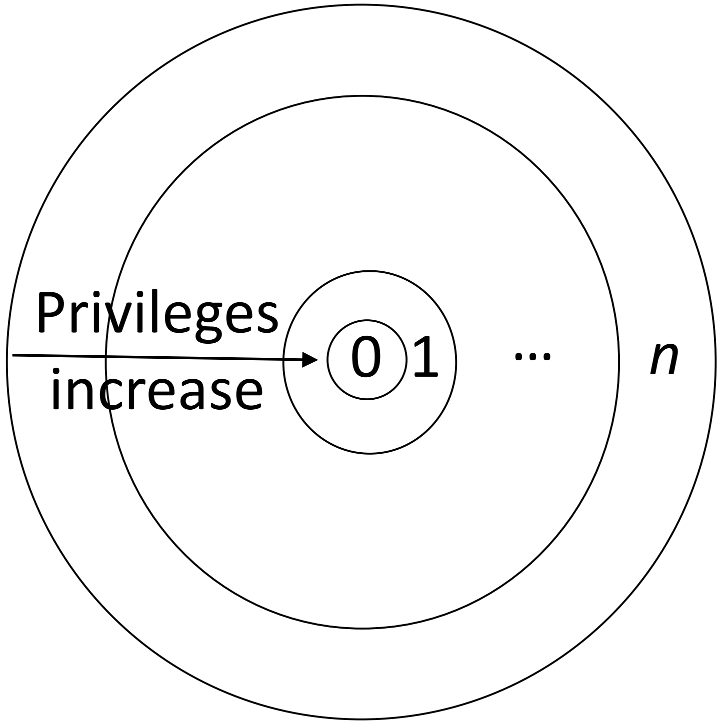
Type Checking

- Lock is type, key is operation
  - Example: UNIX system call *write* can't work on directory object but does work on file
  - Example: split I&D space of PDP-11
  - Example: countering buffer overflow attacks on the stack by putting stack on non-executable pages/segments
    - Then code uploaded to buffer won't execute
    - Does not stop other forms of this attack, though …

More Examples

- LOCK system:
  - Compiler produces “data”
  - Trusted process must change this type to “executable” before program can be executed
- Sidewinder firewall
  - Subjects assigned domain, objects assigned type
    - Example: ingress packets get one type, egress packets another
  - All actions controlled by type, so ingress packets cannot masquerade as egress packets (and vice versa)

Ring-based Access Control



- Process (segment) accesses another segment
  - Read
  - Execute
- *Gate* is an entry point for calling segment
- Rights:
  - *r* read
  - *w* write
  - *a* append
  - *e* execute

Reading/writing/appending

- Procedure executing in ring r
- Data segment with *access bracket* (a_1, a_2)
- Mandatory access rule
  - $r \leq a_1$ allow access
  - $a_1 < r \leq a_2$ allow r access; not w, a access
  - $a_2 < r$ deny all access

Executing

- Procedure executing in ring *r*
- Call procedure in segment with *access bracket* (a_1, a_2) and *call bracket* (a_2, a_3)
  - Often written (a_1, a_2, a_3)
- Mandatory access rule
  - $r < a_1$ allow access; ring-crossing fault
  - $a_1 \leq r \leq a_2$ allow access; no ring-crossing fault
  - $a_2 < r \leq a_3$ allow access if through valid gate
  - $a_3 < r$ deny all access

Versions

- Multics
  - 8 rings (from 0 to 7)
- Digital Equipment’s VAX
  - 4 levels of privilege: user, monitor, executive, kernel
- Older systems
  - 2 levels of privilege: user, supervisor
- Today
  - Linux (2/3+ rings, depending on processor etc)

Propagated ACLs

- Propagated Access Control List
- Creator kept with PACL, copies
  - Only owner can change PACL
  - Subject reads object: object's PACL associated with subject
  - Subject writes object: subject's PACL associated with object
- Notation: $PACL_s$ means *s* created object; PACL(*e*) is PACL associated with entity *e*

Example with Multiple Creators

- Betty reads Ann's file *dates*

  $PACL(Betty) = PACL_{Betty} \cap PACL(\mathit{dates}) = PACL_{Betty} \cap PACL_{Ann}$

- Betty creates file *datescopy*

  $PACL(\mathit{datescopy}) = PACL_{Betty} \cap PACL_{Ann}$

- $PACL_{Betty}$ allows Cher to access objects, but $PACL_{Ann}$ does not; both allow June to access objects
  - June can read *datescopy*
  - Cher cannot read *datescopy*
- Can be augmented by discretionary AC, e.g. ACLs
  - Betty decides Cher should not read *datescopy*

Example with Multiple Creators

ACL vs. PACL

- ACL
  - associated with *object*
  - static, with object

- PACL
  - associated with *data*,
  - follows information flow
  - slower (implementation)
  - ORCON Policies

Key Points

- AC matrix - simple abstraction mechanism for representing protection state
  - 6 primitive operations alter matrix
  - transitions can be expressed as commands composed of these operations and, possibly, conditions
- AC mechanisms control users accessing resources
- Many different forms
  - ACLs, capabilities, locks and keys
    - Type checking too
  - Ring-based mechanisms
  - PACLs