Hardware Support

- Token-based
  - Used to compute response to challenge
    - May encipher or hash challenge
    - May require PIN from user
- Temporally-based
  - Every minute (or so) different number shown
    - Computer knows what number to expect when
  - User enters number and fixed password

C-R and Dictionary Attacks

- Same as for fixed passwords
  - Attacker knows challenge *r* and response *f*(*r*); if *f* encryption function, can try different keys
    - May only need to know *form* of response; attacker can tell if guess correct by looking to see if deciphered object is of right form
    - Example: Kerberos Version 4 used DES, but keys had 20 bits of randomness; Purdue attackers guessed keys quickly because deciphered tickets had a fixed set of bits in some locations

Encrypted Key Exchange

- Defeats off-line dictionary attacks
- Idea: random challenges enciphered, so attacker cannot verify correct decipherment of challenge
- Assume Alice, Bob share secret password s
- In what follows, Alice needs to generate a random public key p and a corresponding private key q
- Also, k is a randomly generated session key, and R_A and R_B are random challenges

EKE Protocol

Alice $\xrightarrow{\text{Alice} \,\|\, E_s(p)}$ *Bob*

Alice $\xleftarrow{E_s(E_p(k))}$ *Bob*

Now Alice, Bob share a randomly generated secret session key k

Alice $\xrightarrow{E_k(R_A)}$ *Bob*

Alice $\xleftarrow{E_k(R_A R_B)}$ *Bob*

Alice $\xrightarrow{E_k(R_B)}$ *Bob*

Biometrics

- Automated measurement of biological, behavioral features that identify a person
  - Fingerprints: optical or electrical techniques
    - Maps fingerprint into a graph, then compares with database
    - Measurements imprecise, so approximate matching algorithms used
  - Voices: speaker verification or recognition
    - Verification: uses statistical techniques to test hypothesis that speaker is who is claimed (speaker dependent)
    - Recognition: checks content of answers (speaker independent)

Other Characteristics

- Can use several other characteristics
  - Eyes: patterns in irises unique
    - Measure patterns, determine if differences are random; or correlate images using statistical tests
  - Faces: image, or specific characteristics like distance from nose to chin
    - Lighting, view of face, other noise can hinder this
  - Keystroke dynamics: believed to be unique
    - Keystroke intervals, pressure, duration of stroke, where key is struck
    - Statistical tests used

Cautions

- These can be fooled!
  - Assumes biometric device accurate *in the environment it is being used in!*
  - Transmission of data to validator is tamperproof, correct

Location

- If you know where user is, validate identity by seeing if person is where the user is
  - Requires special-purpose hardware to locate user
    - GPS (global positioning system) device gives location signature of entity
    - Host uses LSS (location signature sensor) to get signature for entity

Multiple Methods

- Example: “where you are” also requires entity to have LSS and GPS, so also “what you have”
- Can assign different methods to different tasks
  - As users perform more and more sensitive tasks, must authenticate in more and more ways (presumably, more stringently) File describes authentication required
    - Also includes controls on access (time of day, *etc*.), resources, and requests to change passwords
- Pluggable Authentication Modules

PAM

- Idea: when program needs to authenticate, it checks central repository for methods to use
- Library call: *pam_authenticate*
  - Accesses file with name of program in /*etc*/*pam_d*
- Modules do authentication checking
  - *sufficient*: succeed if module succeeds
  - *required*: fail if module fails, but all required modules executed before reporting failure
  - *requisite*: like *required*, but don't check all modules
  - *optional*: invoke only if all previous modules fail

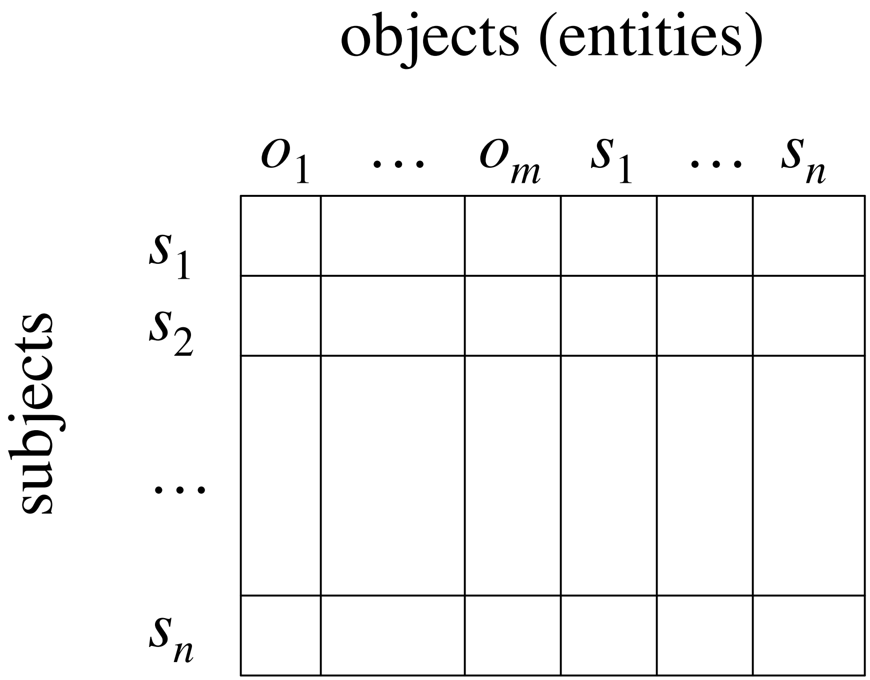
Example PAM File

```
auth sufficient  /usr/lib/pam_ftp.so
auth required    /usr/lib/pam_unix_auth.so use_first_pass
auth required    /usr/lib/pam_listfile.so onerr=succeed \
                        item=user sense=deny file=/etc/ftpusers
```

For ftp:

1. If user “anonymous”, return okay; if not, set PAM_AUTHTOK to password, PAM_RUSER to name, and fail
2. Now check that password in PAM_AUTHTOK belongs to that of user in PAM_RUSER; if not, fail
3. Now see if user in PAM_RUSER named in /etc/ftpusers; if so, fail; if error or not found, succeed

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*

Access Control Lists

- Columns of access control matrix

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

ACLs:

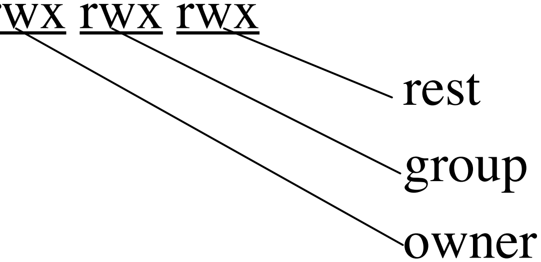
- file1: { (Andy, rx) (Betty, rwxo) (Charlie, rx) }
- file2: { (Andy, r) (Betty, r) (Charlie, rwo) }
- file3: { (Andy, rwo) (Charlie, w) }

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 long … so combine users
  - UNIX: 3 classes of users: owner, group, rest
  - <u>rwx</u> <u>rwx</u> <u>rwx</u>



  - 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

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 Modification

- 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 so honors principle of fail-safe defaults

Handling 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 Question

- 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 NT 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

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) }

Semantics

- Like a 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 (*con't*)

- Cryptography
  - Associate with each capability a cryptographic checksum enciphered 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***

Amplifying

- Allows *temporary* 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 the required capabilities while it is in module

Examples

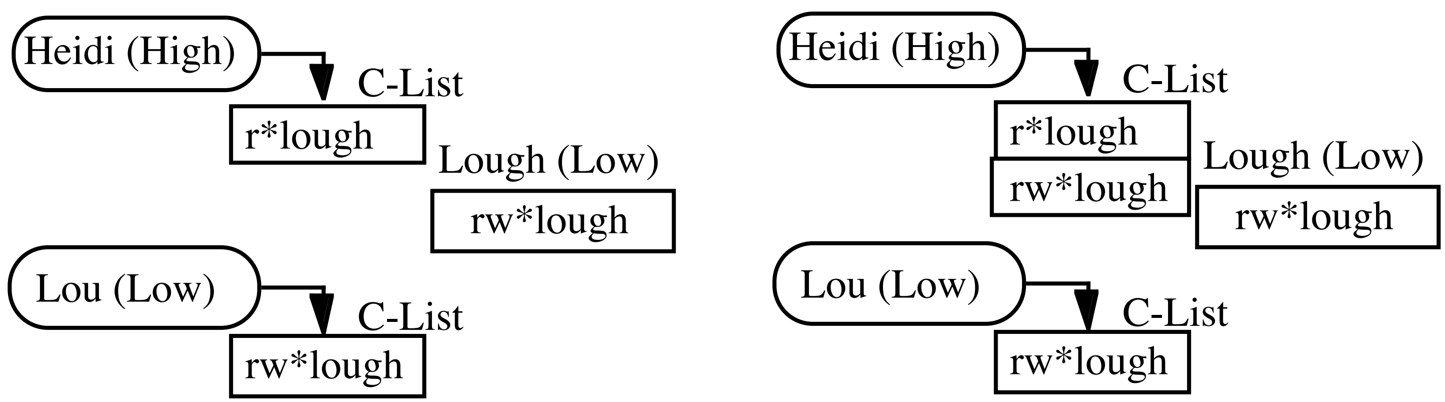
- HYDRA: templates
  - Associated with each procedure, function in module
  - Adds rights to process capability *while the procedure or function is being executed*
  - Rights deleted on exit
- Intel iAPX 432: access descriptors for objects
  - These are really capabilities
  - 1 bit in this controls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

- 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!

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
- Suggested that the second question, which in the past has been of most interest, is the reason 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 key is lock; deciphering key is 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

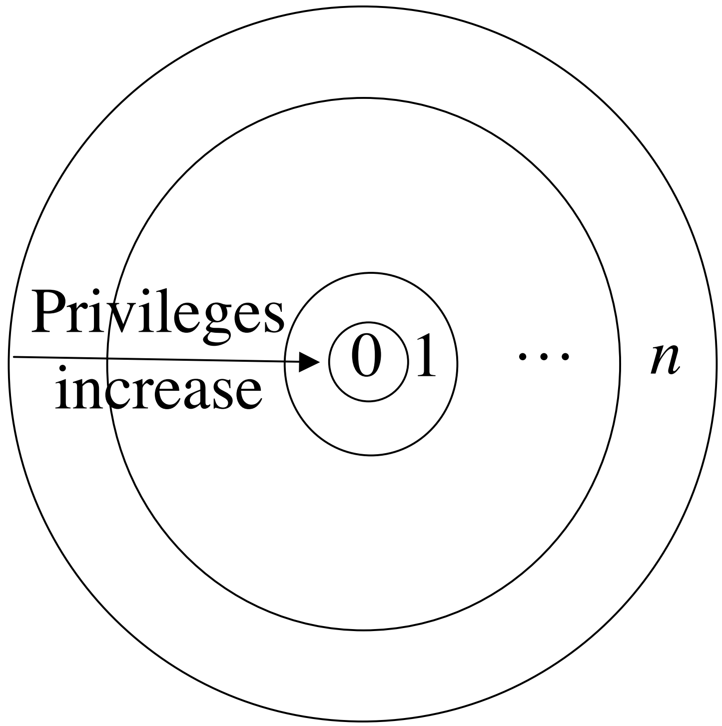
Type Checking

- 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" becore 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
  - $r \le a_1$ allow access
  - $a_1 < r \le a_2$ 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
  - $a_1 \le r \le a_2$ allow access; no ring-crossing fault
  - $a_2 < r \le a_3$ 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

PACLs

- Propagated Access Control List
  - Implements ORGON
- 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*

Multiple Creators

- Betty reads Ann's file *dates*

  $\text{PACL(Betty)} = \text{PACL}_{\text{Betty}} \cap \text{PACL}(\textit{dates})$

  $= \text{PACL}_{\text{Betty}} \cap \text{PACL}_{\text{Ann}}$

- Betty creates file *dc*

  $\text{PACL}(\textit{dc}) = \text{PACL}_{\text{Betty}} \cap \text{PACL}_{\text{Ann}}$

- $\text{PACL}_{\text{Betty}}$ allows Char to access objects, but PACL_{Ann} does not; both allow June to access objects
  - June can read *dc*
  - Char cannot read *dc*