Multics

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Last Time: Unix

- What is the key innovation of Unix?
  - Unified I/O: Files, pipes, sockets all use same API
- What other important feature offers considerable power?
  - Inheritance of open file descriptors in forked processes combined with notion of standard in and out
- How does protection work in Unix?
  - Through access control lists on file system
    - Owner, group, everyone else
    - Set-user-ID for protection domain transfer

Today: Multics

The Three Questions

- What is the problem?
- What is new or different?
- What are the contributions and limitations?

Diggin' Deeper

- How to design for protection (security)?
  - Design principles
- How to specify access restrictions?
  - Access control lists
- How to authenticate users?
  - Passwords
- How to protect memory?
  - Segments, rings of protection
- Where did we go wrong?
  - Size of *trusted computing base*, complexity of UI

Design Principles

- Five principles
  - Require explicit permission instead of exclusion
  - Check every access (unlike capability systems)
  - Do not rely on security by obscurity
  - Operate with the least necessary privilege
  - Make the UI easy to use
- Two functional objectives
  - Allow decentralized control
  - Make the protection system extensible
    - We cannot anticipate all ways of enforcing protection

Storage System & Access Control

- A hierarchical storage system
  - Comprising catalogs (directories) and segments (files)
    - Later message queues and removable media descriptors
  - Access through memory-mapped I/O
- Each storage system object has an ACL
  - Mapping from principals to access rights
  - Principals partitioned into three parts
    - User name
    - Project
    - Compartment
  - ACL entries may contain wildcards for partitions

More Details on Access Control

- Access control lists are ordered
  - First match determines rights
    - Need to carefully insert entries, favoring more specific ones
- Each directory has a default ACL
  - Copied onto new objects
- Users and projects never go away
  - Otherwise, would have to delete invalid ACL entries (?)
- Object owner has full control over ACL
  - Others cannot restrict it

Even More Details

- Access control is hierarchical
  - Write access to directory implies right to modify ACLs
    - Can be used to provide centralized control
- Detour: Access control in Windows 2000
  - Swift et al., ACM TISSEC 5(4):398–437, Nov. 2002
  - Supports both centralized and local control
    - Using inherited as well as local ACL entries
  - Favors speed of access checks over space used by ACLs
    - Policy propagated down the tree after ACL changes
  - Places local entries before inherited entries
    - First matching entry applies

Some Rejected Design Points

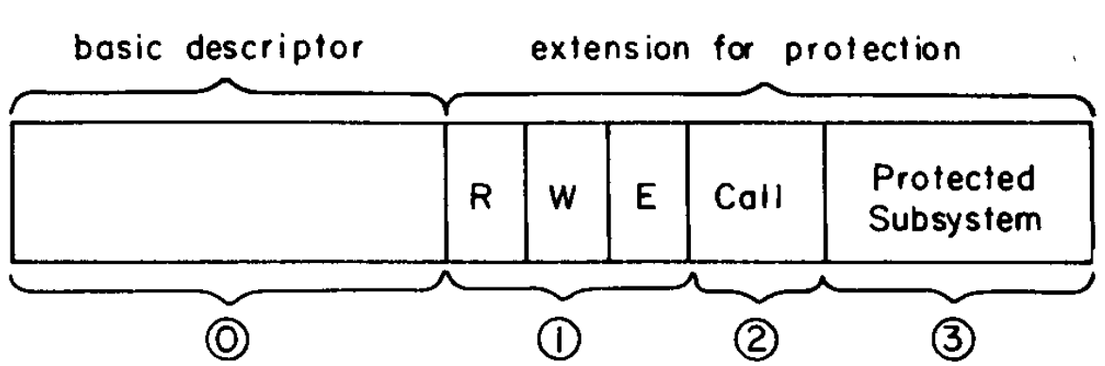
- Placing permissions on objects (instead of in ACLs)
  - Too inflexible as different users need different rights
    - CTSS put permissions on objects,
      used (hard) links as separate entry points (capabilities)
      - Hard to revoke access
      - Access modes to same object depend on name
      - Hard to determine rights
- Using user-specified *reference monitors*
  - Hard to isolate the owner-specified procedure
    - Cannot run as user seeking access—why?
    - Cannot run as supervisor—why?

User Authentication

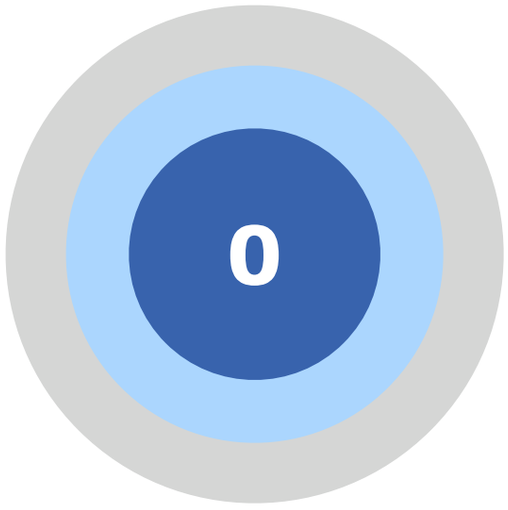
- Based on user names and passwords
  - All operations require (interactive) authentication
- Supports proxy logins (?)
- Generates passwords automatically
  - With English digraph statistics
- Stores passwords in encrypted form
- Does not print passwords
- Automatically logs out idle users
- Tracks (un)successful logins
- Supports anonymous logins as well as stronger checks

Memory Protection

- Memory organized into segments
- Memory accessed through segment descriptors
  - Per-process descriptor segment lists all descriptors
  - Pointer to physical memory
  - List of access rights
  - Number of *gates*
  - ID of protected subsystem (0-7)
    - Which modern processor also uses *rings of protection*?
    - Is this enough?



Detour: Rings of Protection



- 8 rings, with kernel at 0 and users at 4
- CPU tracks current execution level
- Descriptor contains max read/write/execute levels
  - Though lower ring has full power over itself, outer rings
- Call gate
  - Lowers ring level, but only at well-defined entry points
- Stack per ring

Back to Memory Protection

- I/O channel programs (drivers) run as supervisor
- Overall, memory protection relies on economy of mechanism
  - Controls access to data and execution of code
  - Controls everyone, including the supervisor

Two Major Weaknesses

- Size of trusted computing base
  - 15% of all code, 300 modules with ~200 lines (60,000 lines)
  - Three factors
    - Presumed (lack of) execution speed
    - Tight deadlines
    - Lack of understanding
- Complexity of user interface to access control lists
  - Permitted users and projects
  - Corresponding permissions
  - Right to backup, bulk I/O
  - Protected subsystem

More Weaknesses

- Communication lines provide insufficient feedback
- Operator interface provides direct access to hardware
- Users may specify their own passwords
- No semantic checks on supervisor interface
- Secondary storage is cleared on reuse, no deallocation
- Administrators tend to be overprivileged
- Backups expose other users' directory and file names

Even More Weaknesses

- Counter-intelligence is lacking
- Hardware protection may fail
- "Relatively straight-forward modification can easily strengthen any of the areas"
  - Do we believe this?

Discussion