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CSE543 Computer Security
Module: Operating System Security

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MAC in Commercial OSes

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- We have learned that MAC is necessary to enforce security
- How do we add MAC enforcement effectively to a commercial OS?

Security Concerns

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- Various attacks were being launched against Windows systems, essentially compromising all
- Concerns that Linux could also be prone
  - "Inevitability of Failure" paper
    - Any system with network facing daemons (e.g., sshd, ftpd, sendmail, etc) running as root was likely vulnerable
  - Why is that?

Security Concerns

- Various attacks were being launched against Windows systems, essentially compromising all
- Concerns that Linux could also be prone
  - "Inevitability of Failure" paper
    - Any system with network facing daemons running as root was likely vulnerable
  - What can we do?

Approx. Secure OS

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- Maybe Linux cannot be a "secure" OS, but perhaps we can approximate a secure OS closely enough
  - What is required to be a secure OS?
- Security Policy
  - Info Flow or Least Privilege?
- Reference Monitor
  - Complete Mediation, Tamperproof, Validation
- Formal Assurance
  - Validate that OS with reference monitor implementation enforces security policy
- Can we do this?

Approx. Secure OS

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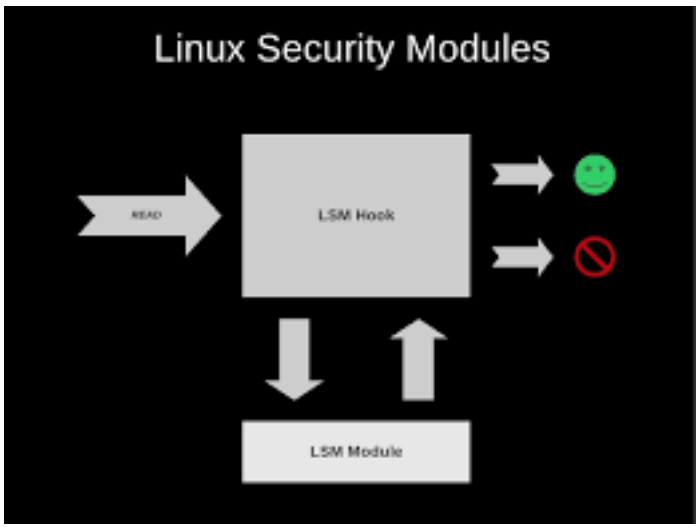
- Secure Linux Project - 2001
- Group of systems security researchers working on refactoring various security features into Linux
  - But, especially a reference monitor
- A variety of different projects were underway
  - Argus Pitbull, Security-Enhanced Linux, Subdomain (AppArmor), grsecurity, RSBAC, …
- Presented ideas to Linus
  - All were different
  - Each group argued that its idea was best
- What would you do if you were Linus?

Linux Security Modules

- *"All problems in computer science problem can be solved by another level of indirection"*
  - Attributed to Butler Lampson
- Linus asked for another level of indirection to host access control enforcement
  - And the Linux Security Modules project was born



Linux Security Modules

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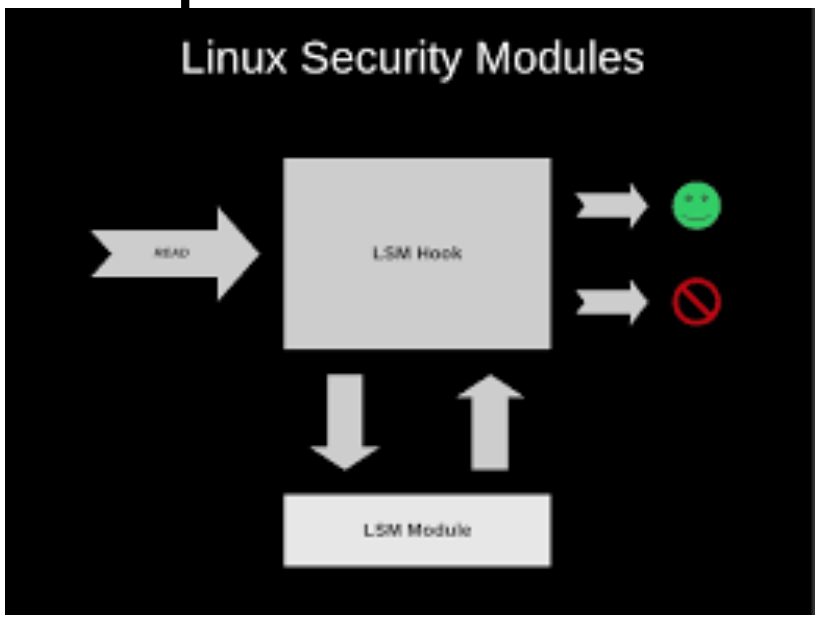
- Defines an authorization interface to enable a chosen security module to make access control decisions
  - Focus on mediation
  - Let LSM module implementations determine the security policy and how they satisfy the reference monitor concept



Reference Monitor

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- Defines a set of requirements on reference validation mechanisms
  - To enforce access control policies correctly
- Complete mediation
  - The *reference validation mechanism* must always be invoked (before executing security-sensitive operations)
- Tamperproof
  - The *reference validation mechanism* must be tamperproof
- Verifiable
  - The *reference validation mechanism* must be small enough to be subject to analysis and tests, the completeness of which can be assured

Access Policy Enforcement

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- A protection system uses a *reference validation mechanism* to produce and evaluate authorization queries
  - Interface: Mediate security-sensitive operations by building authorization queries to evaluate
  - Module: Determine relevant protection state entry (ACLs, capabilities) to evaluate authorization query
  - Manage: Manage the assignment of objects and subjects (processes) to the protection state

- How do we know whether a reference validation mechanism is correct?

Security-Sensitive Operations

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- Broadly, operations that enable interaction among processes that violate secrecy, integrity, availability
- Which of these are security-sensitive? Why?
  - Read a file (*read*)
  - Get the process id of a process (*getpid*)
  - Read file metadata (*stat*)
  - Fork a child process (*fork*)
  - Get the metadata of a file you have already opened? (*fstat*)
  - Modify the data segment size? (*brk*)
- Require protection for all of CIA?

Linux Security Modules

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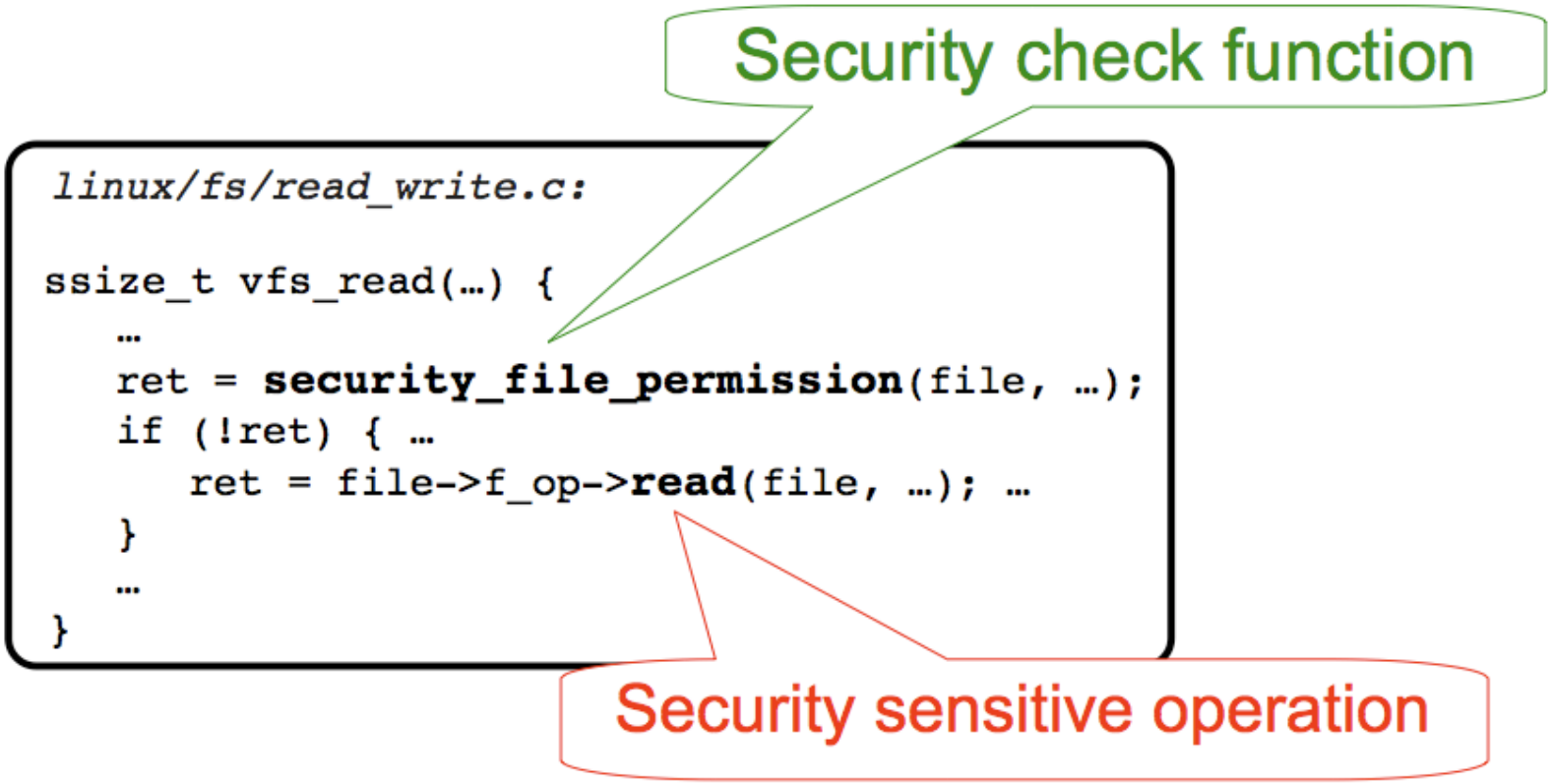
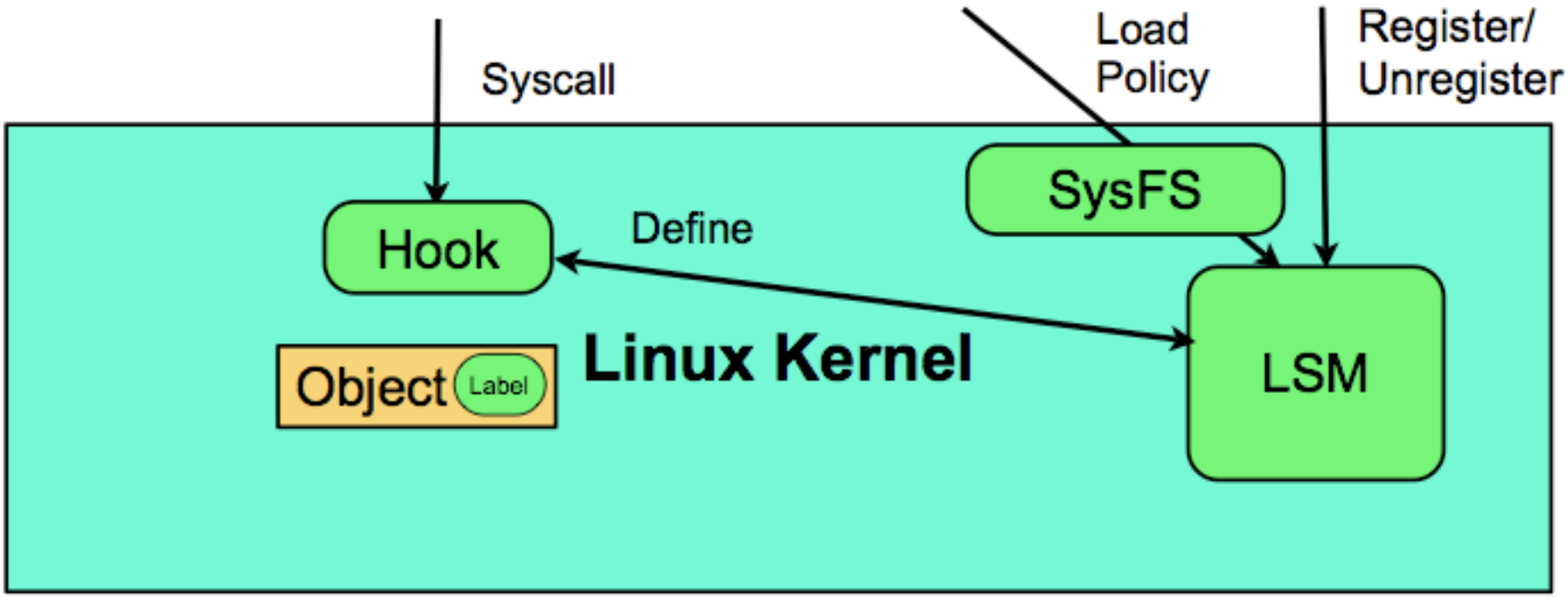
- Reference validation mechanism for Linux
  - Upstreamed in Linux 2.6
  - Support modular enforcement - you choose
    - SELinux, AppArmor, POSIX Capabilities, SMACK, ...
- 150+ authorization hooks
  - Mediate security-sensitive operations on
    - Files, dirs/links, IPC, network, semaphores, shared memory, ...
  - Variety of operations per data type
    - Control access to read of file data and file metadata separately
- Hooks are restrictive - in addition to DAC security

Linux Security Modules

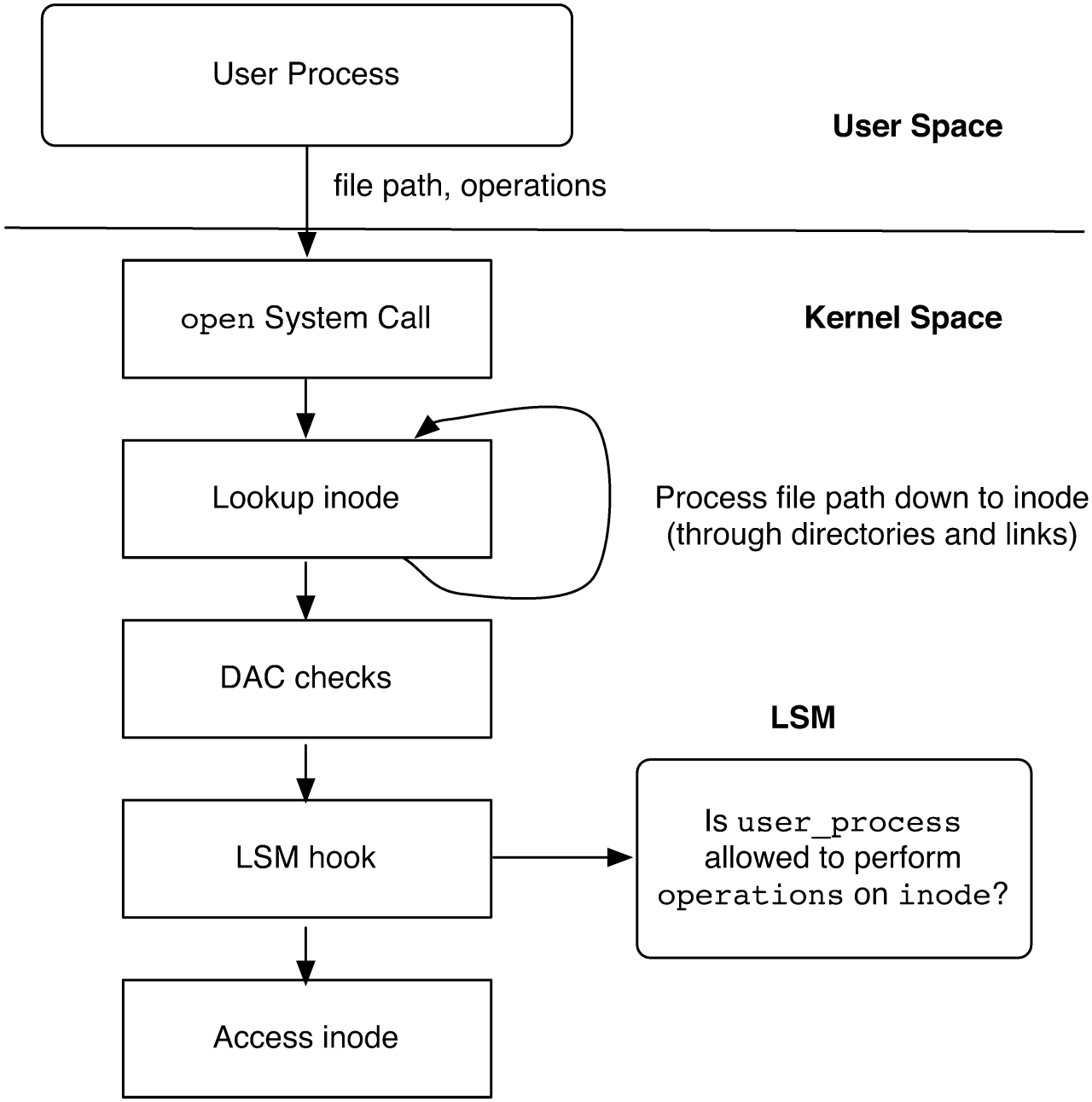


Linux Security Modules

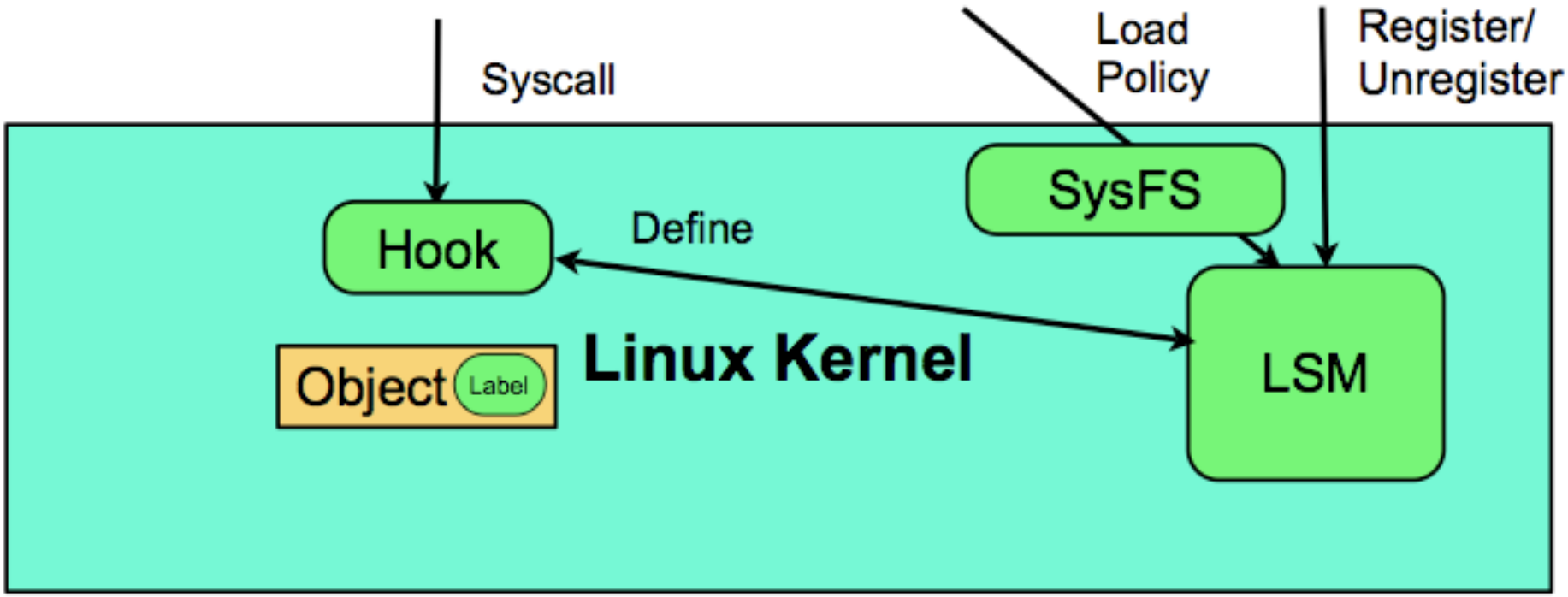


- Register (install) module
- Load policy (open and write to special file)
- Produce authorization queries at hooks

LSM Hook Architecture

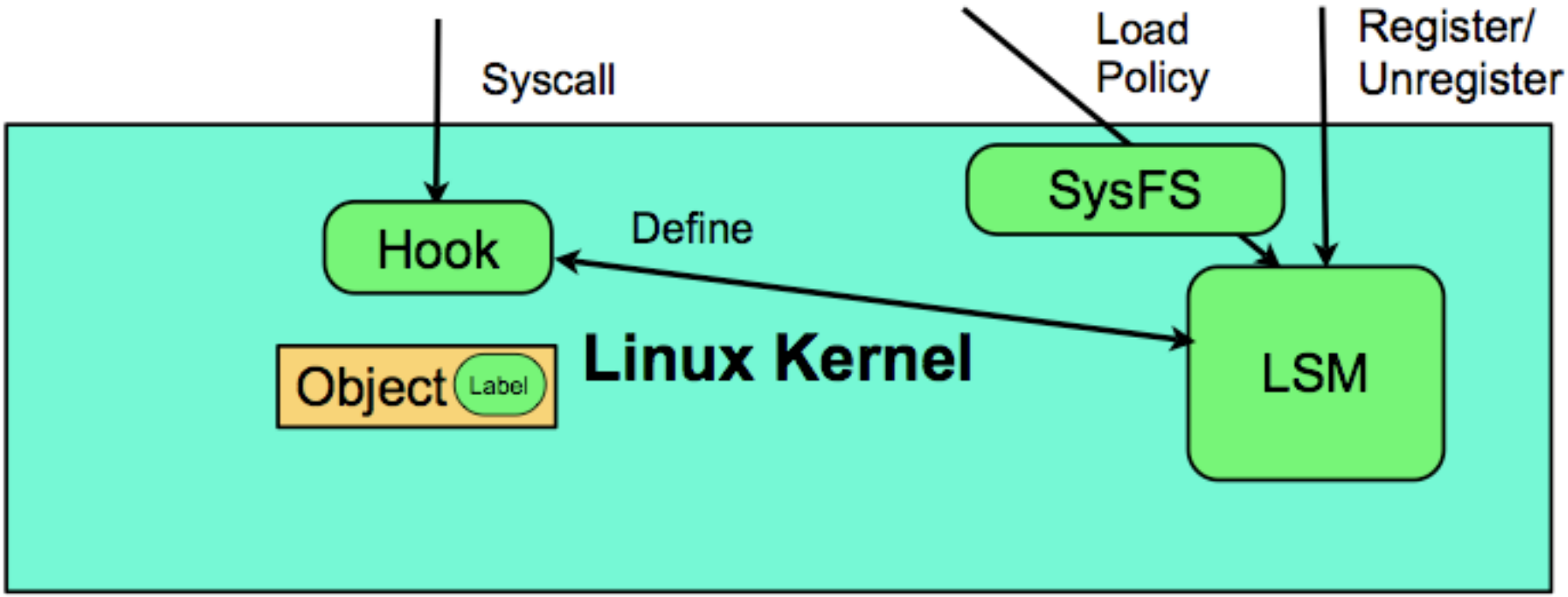


Linux Security Modules



- Attacks on "register"
- Attacks on "install policy"
- Attacks on "system calls"

Linux Security Modules



- To prevent attacks on registration
- And attacks on function pointers of LSM
- LSMs are now statically compiled into the kernel

LSM & Reference Monitor

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- Does LSM satisfy reference monitor concept?

LSM & Reference Monitor

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- Does LSM satisfy reference monitor concept?
  - Tamperproof
    - Can MAC policy be tampered?
    - Can kernel be tampered?

Access Control Administration

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There are two central ways to manage a policy

1. Discretionary - Object "owners" define policy
   - Users have discretion over who has access to what objects and when (trusted users)
   - Canonical example, the UNIX filesystem
     - RWX assigned by file owners
2. Mandatory - Environment defines policy
   - OS distributor and/or administrators define a system policy that cannot be modified by normal users (or their processes)
   - Typically, information flow policies are mandatory
     - More later…

LSM & Reference Monitor

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- Does LSM satisfy reference monitor concept?
  - Tamperproof
    - Can MAC policy be tampered?
    - Can kernel be tampered?
  - Verifiable
    - How large is kernel?
    - Can we perform complete testing?

LSM & Reference Monitor

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- Does LSM satisfy reference monitor concept?
  - Tamperproof
    - Can MAC policy be tampered?
    - Can kernel be tampered?
  - Verifiable
    - How large is kernel?
    - Can we perform complete testing?
  - Complete Mediation
    - What is a security-sensitive operation?
    - Do we mediate all paths to such operations?

LSM & Complete Mediation

- What is a security-sensitive operation?
  - Instructions? Which?
  - Structure member accesses? To what data?
  - Data types whose instances may be controlled?
    - Inodes, files, IPCs, tasks, ...
- Approaches
  - Mediation: Check that authorization hook dominates all control-flow paths to structure member access on security-sensitive data type
  - Consistency: Check that every structure member access that is mediated once is always mediated
    - Several bugs found - some years later

LSM & Complete Mediation

- Static analysis of Zhang, Edwards, and Jaeger [USENIX Security 2002]
  - Based on a tool called CQUAL
- Found a TOCTTOU bug
  - Authorize filp in *sys_fcntl*
  - But pass fd again to *fcntl_getlk*
- Many supplementary analyses were necessary to support CQUAL

```
/* from fs/fcntl.c */
long sys_fcntl(unsigned int fd,
               unsigned int cmd,
               unsigned long arg)
{
  struct file * filp;
  ...
  filp = fget(fd);
  ...

  err = security_ops->file_ops
        ->fcntl(filp, cmd, arg);
  ...
  err = do_fcntl(fd, cmd, arg, filp);

  ...
}

static long
do_fcntl(unsigned int fd,
         unsigned int cmd,
         unsigned long arg,
         struct file * filp) {
  ...
  switch(cmd){
    ...
    case F_SETLK:

      err = fcntl_setlk(fd, ...);

    ...
  }
  ...
}

/* from fs/locks.c */
fcntl_getlk(fd, ...) {
  struct file * filp;
  ...

  filp = fget(fd);

  /* operate on filp */
  ...
}
```

Figure 8: Code path from Linux 2.4.9 containing an exploitable type error.

LSM Enforcement

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- Several LSMs have been deployed
  - Most prominent: AppArmor, SELinux, Smack, TOMOYO
- The most comprehensive is SELinux
  - Used by RedHat Fedora and some others

LSM Enforcement

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- Several LSMs have been deployed
  - Most prominent: AppArmor, SELinux, Smack, TOMOYO
- The most comprehensive is SELinux
  - Created by the NSA - Result of many years work
  - Used by RedHat Fedora and some others

SELinux Challenges

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- (1) Protection state definition
  - Per program access control policy
  - Thousands of rules - produced by runtime auditing
- (2) Assigning objects and subjects (processes) to labels
  - Policy module per program on install
  - Control how a new program obtains its label
    - Different approach to *setuid* problem

Setuid Problem

- In Setuid, program runs with UID of file owner
  - Usually root, so too many permissions
    - SELinux - run with permissions of program
  - Anyone can start any setuid program
    - Limit to authorized processes by label

SELinux Transition State

- For user to run passwd program
  - Only passwd should have permission to modify */etc/shadow*
- Need permission to execute the passwd program
  - *allow user_t passwd_exec_t:file execute (user can exec /usr/bin/passwd)*
  - *allow user_t passwd_t:process transition (user gets passwd perms)*
- Must transition to passwd_t from user_t
  - *allow passwd_t passwd_exec_t:file entrypoint (run w/ passwd perms)*
  - *type_transition user_t passwd_exec_t:process passwd_t*
- Passwd can the perform the operation
  - *allow passwd_t shadow_t:file {read write}* (can edit passwd file)

Take Away

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- Goal: Build authorization into operating systems
  - Multics and Linux
- Requirements: Reference monitor
  - Satisfy reference monitor concept
- Multics
  - Hierarchical Rings for Protection
  - Call/Access Bracket Policies (in addition to MLS)
- Linux
  - Did not enforce security (*DAC, Setuid, root daemons*)
  - So, the Linux Security Modules framework was added
  - Approximates reference monitor assuming network threats only -- some challenges in ensuring complete mediation