Outline

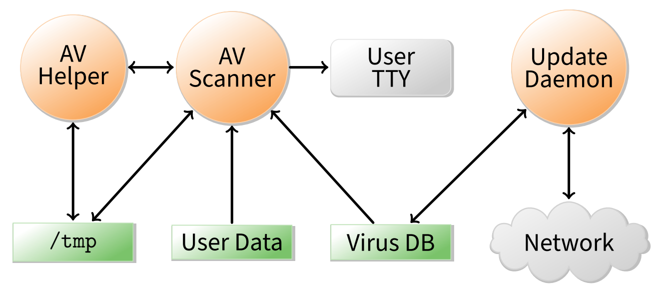
DAC vs. MAC

- **Most people are familiar with *discretionary* access control (DAC)**
  - Unix permission bits are an example
  - E.g., might set file `private` so that only group `friends` can read it:
    `-rw-r--- 1 dm friends 1254 Feb 11 20:22 private`
  - Anyone with access to information can further propagate that information at his/her discretion:
    `$ Mail sigint@enemy.gov < private`
- ***Mandatory* access control (MAC) can restrict propagation**
  - Security administrator may allow you to read but not disclose file
  - Not to be confused with Message Authentication Codes and Medium Access Control, also both "MAC"

MAC motivation

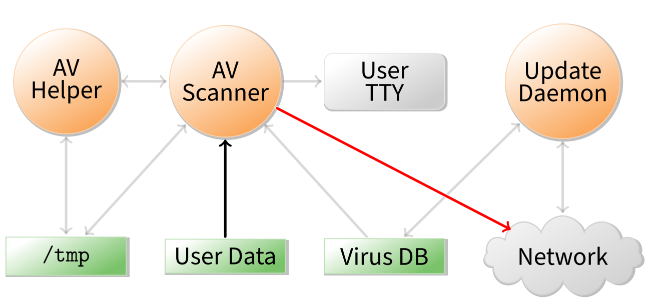
- **Prevent users from disclosing sensitive information (whether accidentally or maliciously)**
  - E.g., classified information requires such protection
- **Prevent software from surreptitiously leaking data**
  - Seemingly innocuous software may steal secrets in the background
  - Such a program is known as a *trojan horse*
- **Case study: Symantec AntiVirus 10**
  - Contained a remote exploit (attacker could run arbitrary code)
  - Inherently required access to all of a user's files to scan them
  - Can an OS protect private file contents under such circumstances?

Example: Anti-virus software



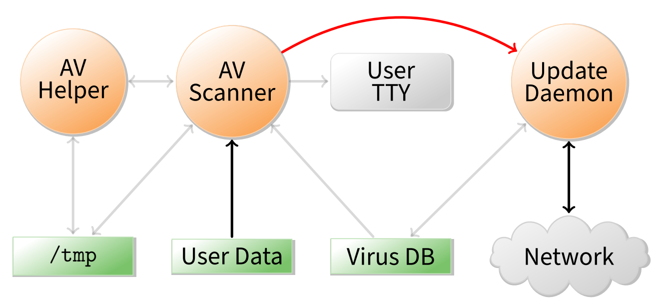
- **Scanner – checks for virus signatures**
- **Update daemon – downloads new virus signatures**
- **How can OS enforce security without trusting AV software?**
  - Must not leak contents of your files to network
  - Must not tamper with contents of your files

Example: Anti-virus software



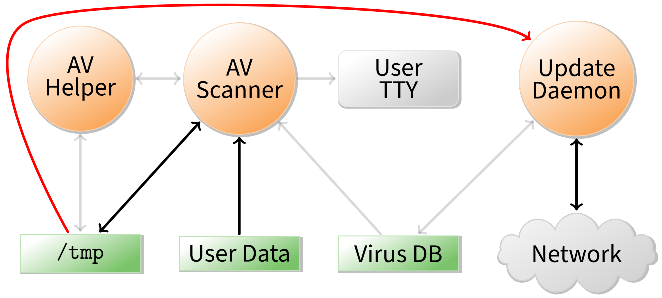
- **Scanner can write your private data to network**
- **Prevent scanner from invoking any system call that might send a network messages?**

Example: Anti-virus software



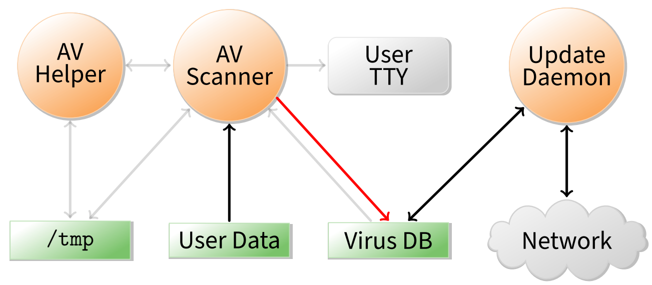
- **Scanner can send private data to update daemon**
- **Update daemon sends data over network**
  - Can cleverly disguise secrets in order/timing of update requests
- **Block IPC & shared memory system calls in scanner?**

Example: Anti-virus software



- **Scanner can write data to world-readable file in `/tmp`**
- **Update daemon later reads and discloses file**
- **Prevent update daemon from using `/tmp`?**

Example: Anti-virus software



- **Scanner can acquire read locks on virus database**
  - Encode secret user data by locking various ranges of file
- **Update daemon decodes data by detecting locks**
  - Discloses private data over the network
- **Have trusted software copy virus DB for scanner?**

The list goes on

- **Scanner can call setproctitle with user data**
  - Update daemon extracts data by running ps
- **Scanner can bind particular TCP or UDP port numbers**
  - Sends no network traffic, but detectable by update daemon
- **Scanner can relay data through another process**
  - Call ptrace to take over process, then write to network
  - Use sendmail, httpd, or portmap to reveal data
- **Disclose data by modulating free disk space**
- **Can we ever convince ourselves we've covered all possible communication channels?**
  - Not without a more systematic approach to the problem

Outline

1. Mandatory access control
2. Labels and lattices
3. LOMAC
4. SELinux

Bell-La Padula model [BL]

- **View the system as subjects accessing objects**
  - Access control: take *requests* as input and output *decisions*
- **Four modes of access are possible:**
  - execute – no observation or alteration
  - read – observation
  - append – alteration
  - write – both observation and modification
- **An *access matrix* M encodes permissible access types**
  - As in last lecture, subjects are rows, objects are columns
- **The *current access set*, b, is (subj, obj, attr) triples**
  - Encodes accesses in progress (e.g., open files)
  - At a minimum, $(S, O, A) \in b$ requires A permitted by cell $M_{S,O}$

Security levels

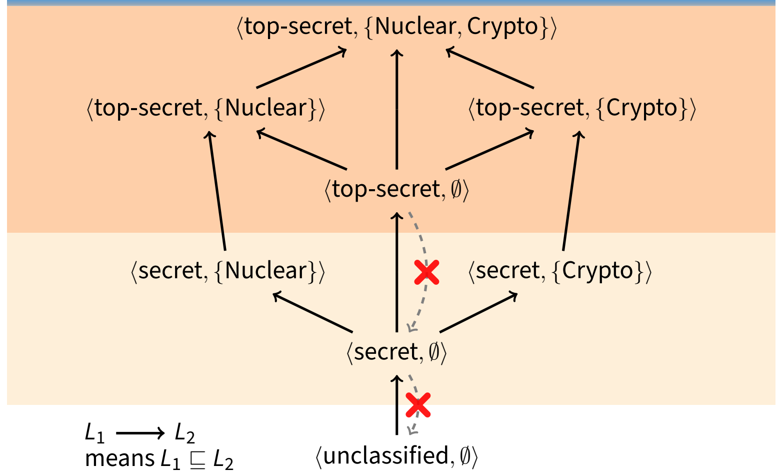
- **A *security level* or *label* is a pair (c, s) where:**
  - c = classification – E.g., 1 = unclassified, 2 = secret, 3 = topsecret
  - s = category-set – E.g., Nuclear, Crypto, Russia, …
- **(c_1, s_1) *dominates* (c_2, s_2) iff $c_1 \geq c_2$ and $s_1 \supseteq s_2$**
  - L_1 *dominates* L_2 is sometimes written $L_1 \succeq L_2$ or $L_1 \sqsupseteq L_2$
  - Labels then form a *lattice* (partial order with lub & glb)
- **Inverse of dominates relation is *can flow to*, written $\sqsubseteq$**
  - $L_1 \sqsubseteq L_2$ ("L_1 can flow to L_2") means L_2 dominates L_1
- **Subjects and objects are assigned security levels**
  - level(S), level(O) – security level of subject/object
  - current-level(S) – subject may operate at lower level
  - level(S) bounds current-level(S) (current-level(S) $\sqsubseteq$ level(S))
  - Since level(S) is max, sometimes called S's *clearance*

Security properties

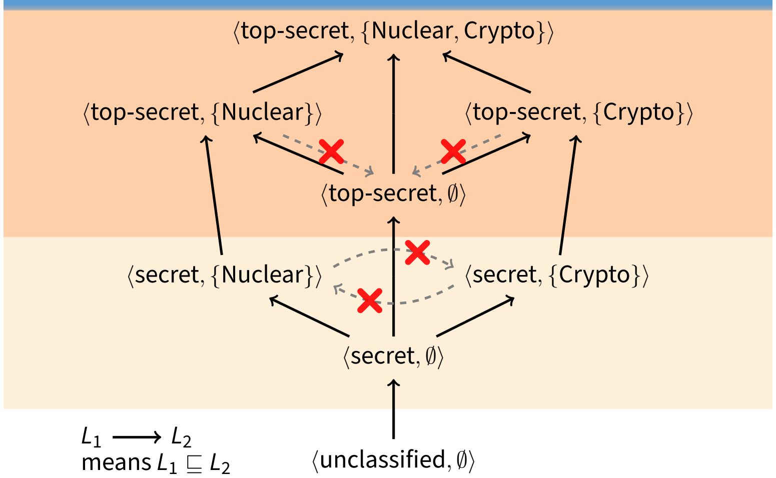
Two access control properties with respect to labels:

- **The simple security or *ss-property* (DAC):**
  - For any $(S, O, A) \in b$, if A includes observation, then level(S) must dominate level(O), i.e., level(O) $\sqsubseteq$ level(S)
  - E.g., an unclassified user cannot read a top-secret document
- **The star security or $\star$-*property* (MAC):**
  - If any subject both observes O_1 and modifies O_2, then level(O_2) dominates level(O_1), i.e., level(O_1) $\sqsubseteq$ level(O_2).
  - E.g., no subject can read a top secret file, then write a secret file
  - More precisely, given $(S, O, A) \in b$:
    if $A = r$ then level(O) $\sqsubseteq$ current-level(S) "no read up"
    if $A = a$ then current-level(S) $\sqsubseteq$ level(O) "no write down"
    if $A = w$ then current-level(S) $=$ level(O)

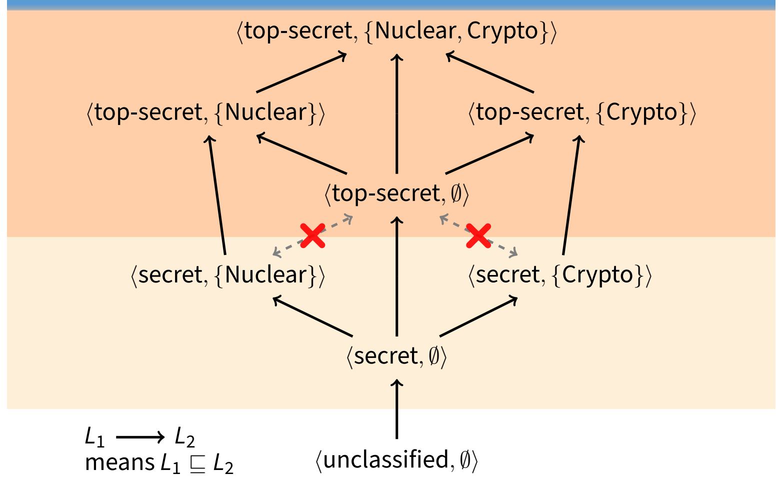
Labels form a lattice [Denning]



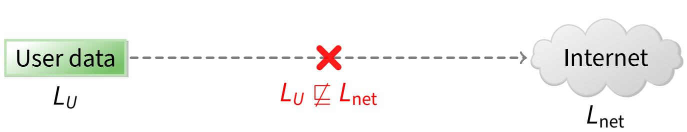
Labels form a lattice [Denning]



Labels form a lattice [Denning]

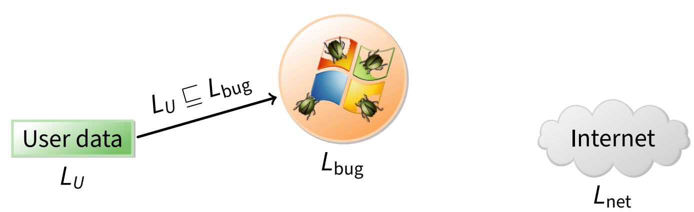


$\sqsubseteq$ is transitive



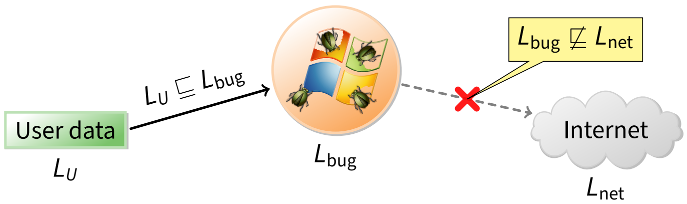
- **Transitivity makes it easier to reason about security**
- **Example: Label user data so it cannot flow to Internet**
  - Policy holds regardless of what other software does

$\sqsubseteq$ is transitive



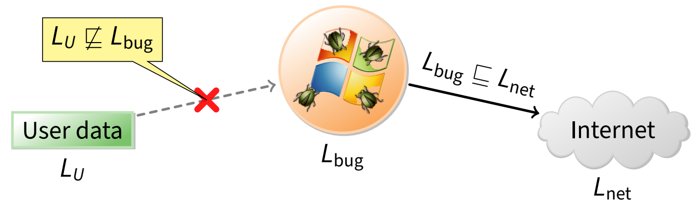
- **Transitivity makes it easier to reason about security**
- **Example: Label user data so it cannot flow to Internet**
  - Policy holds regardless of what other software does
- **Suppose untrustworthy software reads file**
  - Process labeled L_{bug} reads file, so must have $L_U \sqsubseteq L_{bug}$

$\sqsubseteq$ is transitive



- **Transitivity makes it easier to reason about security**
- **Example: Label user data so it cannot flow to Internet**
  - Policy holds regardless of what other software does
- **Suppose untrustworthy software reads file**
  - Process labeled L_{bug} reads file, so must have $L_U \sqsubseteq L_{\text{bug}}$
  - If $L_U \sqsubseteq L_{\text{bug}}$ and $L_U \not\sqsubseteq L_{\text{net}}$, it follows that $L_{\text{bug}} \not\sqsubseteq L_{\text{net}}$.

$\sqsubseteq$ is transitive



- **Transitivity makes it easier to reason about security**
- **Example: Label user data so it cannot flow to Internet**
  - Policy holds regardless of what other software does
- **Conversely, a process that can write to the network cannot read the file**

11 / 43

Straw man MAC implementation

- **Take an ordinary Unix system**
- **Put labels on all files and directories to track levels**
- **Each user *U* assigned a security clearance, level(*U*), on login**
- **Determine current security level dynamically**
  - When U logs in, start with lowest curent-level
  - Increase current-level as higher-level files are observed (sometimes called a *floating label* system)
  - If U's level does not dominate current-level, kill program
  - Kill program that writes to file if current label can't flow to file label
- **Is this secure?**

No: Covert channels

- **System rife with *covert storage channels***
  - Low current-level process executes another program
  - New program reads sensitive file, gets high current-level
  - High program exploits covert channels to pass data to low
- **E.g., high program inherits read-only file descriptor**
  - Can pass 4-bytes of information to low program in file offset
- **Other storage channels:**
  - Exit value, signals, file locks, terminal escape codes, …
- **If we eliminate storage channels, is system secure?**

No: Timing channels

- **Example: CPU utilization**
  - To send a 0 bit, use 100% of CPU in busy-loop
  - To send a 1 bit, sleep and relinquish CPU
  - Repeat to transfer more bits
- **Example: Resource exhaustion**
  - High program allocates all physical memory if bit is 1
  - If low program slow from paging, knows less memory available
- **More examples: Disk head position, processor cache/TLB polution, …**

Reducing covert channels

- **Observation: Covert channels come from sharing**
  - If you have no shared resources, no covert channels
  - Extreme example: Just use two computers (common in DoD)
- **Problem: Sharing needed**
  - E.g., read unclassified data when preparing classified
- **In general, can only hope to bound bandwidth of covert channels**
- **One approach: Strict partitioning of resources**
  - Strictly partition and schedule resources between levels
  - Occasionally reapportion resources based on usage [Browne]
  - Do so infrequently to bound leaked information
  - Approach still not so good if many security levels possible

Declassification

- **Sometimes need to prepare unclassified report from classified data**
- **Declassification happens outside of traditional access control model**
  - Present file to security officer for downgrade
- **Job of declassification often not trivial**
  - E.g., Microsoft word saves a lot of undo information
  - This might be all the secret stuff you cut from document
  - Another bad mistake: Redact PDF using black censor bars over or under text, leaving text selectable (e.g., [Cluley])

Biba integrity model [Biba]

- **Problem: How to protect integrity**
  - Suppose text editor gets trojaned, subtly modifies files
  - Might mess up attack plans even without leaking anything
- **Observation: Integrity is the converse of secrecy**
  - In secrecy, want to avoid writing to lower-secrecy files
  - In integrity, want to avoid writing higher-integrity files
- **Use integrity hierarchy parallel to secrecy one**
  - Now *security level* is a $\langle c, i, s\rangle$ triple, where i = integrity
  - $\langle c_1, i_1, s_1\rangle \sqsubseteq \langle c_2, i_2, s_2\rangle$ iff $c_1 \leq c_2$ and $i_1 \geq i_2$ and $s_1 \subseteq s_2$
  - Only trusted users can operate at higher integrity (which is visually lower in the lattice—opposite of secrecy)
  - If you read less authentic data, your current integrity level gets lowered (putting you up higher in the lattice), and you can no longer write higher-integrity files

Outline

LOMAC [Fraser]

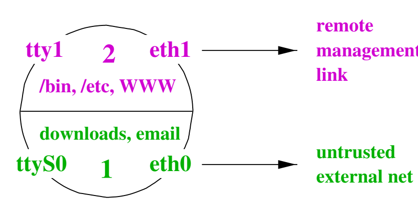
- **MAC not widely accepted outside military**
- **LOMAC's goal: make MAC more palatable**
  - Stands for Low water Mark Access Control
- **Concentrates on Integrity**
  - More important goal for many settings
  - E.g., don't want viruses tampering with all your files
  - Also don't have to worry as much about covert channels
- **Provides reasonable defaults (minimally obtrusive)**
- **Has actually had impact**
  - Originally available for Linux (2.2)
  - Now ships with FreeBSD
  - Windows introduced similar Mandatory Integrity Control (MIC)

LOMAC overview

- **Subjects are *jobs* (essentially processes)**
  - Each subject labeled with an integrity number (e.g., 1, 2)
  - Higher numbers mean more integrity (so unfortunately $2 \sqsubseteq 1$ by earlier notation)
  - Subjects can be reclassified on observation of low-integrity data
- **Objects (files, pipes, etc.) also labeled w. integrity level**
  - Object integrity level is fixed and cannot change
- **Security: Low-integrity subjects cannot write to high integrity objects**
- **New objects have level of their creator**

LOMAC defaults

[note: can-flow-to is downward; opposite of earlier diagram]



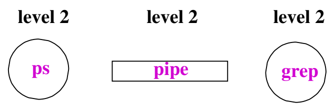
- **Two levels: 1 and 2**
- **Level 2 (high-integrity) contains:**
  - FreeBSD/Linux files intact from distro, static web server config
  - The console, trusted terminals, trusted network
- **Level 1 (low-integrity) contains**
  - NICs connected to Internet, untrusted terminals, etc.
- **Idea: Suppose worm compromises your web server**
  - Worm comes from network → level 1
  - Won't be able to muck with system files or web server config

The self-revocation problem

- **Want to integrate with Unix unobtrusively**
- **Problem: Application expectations**
  - Kernel access checks usually done at file open time
  - Legacy applications don't pre-declare they will observe low-integrity data
  - An application can "taint" itself unexpectedly, revoking its own permission to access an object it created

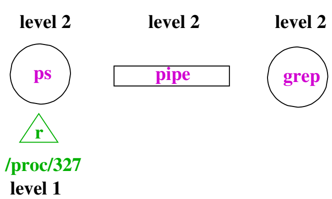
Self-revocation example

- **User has high-integrity (level 2) shell**
- **Runs:** `ps | grep user`
  - Pipe created before `ps` reads low-integrity data
  - `ps` becomes tainted, can no longer write to `grep`



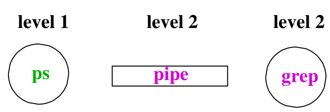
Self-revocation example

- **User has high-integrity (level 2) shell**
- **Runs:** `ps | grep user`
  - Pipe created before `ps` reads low-integrity data
  - `ps` becomes tainted, can no longer write to `grep`



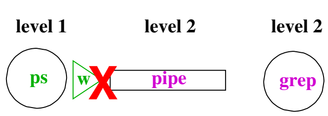
Self-revocation example

- **User has high-integrity (level 2) shell**
- **Runs:** `ps | grep user`
  - Pipe created before `ps` reads low-integrity data
  - `ps` becomes tainted, can no longer write to `grep`



Self-revocation example

- **User has high-integrity (level 2) shell**
- **Runs:** `ps | grep user`
  - Pipe created before `ps` reads low-integrity data
  - `ps` becomes tainted, can no longer write to `grep`



Solution

- **Don't consider pipes to be real objects**
- **Join multiple processes together in a "job"**
  - Pipe ties processes together in job
  - Any processes tied to job when they read or write to pipe
  - So will lower integrity of both ps and grep
- **Similar idea applies to shared memory and IPC**
- **Summary: LOMAC applies MAC to non-military systems**
  - But doesn't allow military-style security policies (i.e., with secrecy, various categories, etc.)

Outline

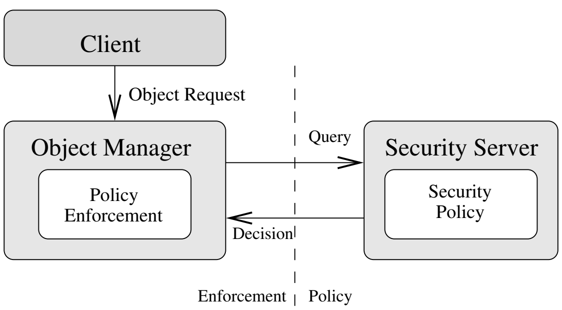
1. Mandatory access control
2. Labels and lattices
3. LOMAC
4. SELinux

The flask security architecture

- **Problem: Military needs adequate secure systems**
  - How to create civilian demand for systems military can use?
- **Idea: Separate policy from enforcement mechanism**
  - Most people will plug in simple DAC policies
  - Military can take system off-the-shelf, plug in new policy
- **Requires putting adequate hooks in the system**
  - Each object has manager that guards access to the object
  - Conceptually, manager consults security server on each access
- **Flask security architecture prototyped in fluke**
  - Now part of SElinux

Following figures from [Spencer]

Architecture



- **Kernel mediates access to objects at “interesting” points**
- **Kicks decision up to external (user-level) security server**

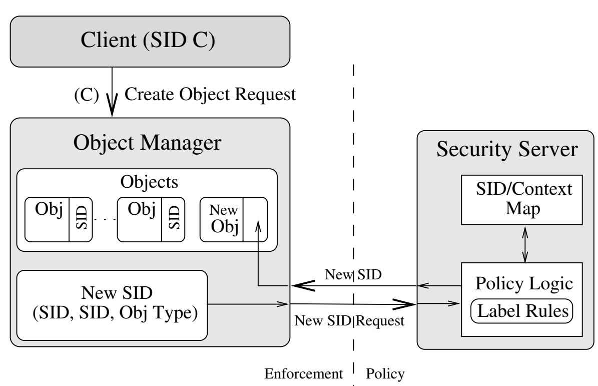
Challenges

- **Performance**
  - Adding hooks on every operation
  - People who don’t need security don’t want slowdown
- **Using generic enough data structures**
  - Object managers independent of policy still need to associate data structures (e.g., labels) with objects
- **Revocation**
  - May interact in a complicated way with any access caching
  - Once revocation completes, new policy must be in effect
  - Bad guy cannot be allowed to delay revocation completion indefinitely

Basic flask concepts

- **All objects are labeled with a *security context***
  - Security context is an arbitrary string—opaque to object manager in the kernel
- **Labels abbreviated with security IDs (SIDs)**
  - 32-bit integer, interpretable only by security server
  - Not valid across reboots (can’t store in file system)
  - Fixed size makes it easier for object manager to handle
- **Queries to server done in terms of SIDs**
  - Create (client SID, old obj SID, obj type)? $\rightarrow$ SID
  - Allow (client SID, obj SID, perms)? $\rightarrow$ $\{$yes, no$\}$

Creating new object



Security server interface [Loscocco]

```
int security_compute_av(
    security_id_t ssid, security_id_t tsid,
    security_class_t tclass, access_vector_t requested,
    access_vector_t *allowed, access_vector_t *decided,
    __u32 *seqno);
```

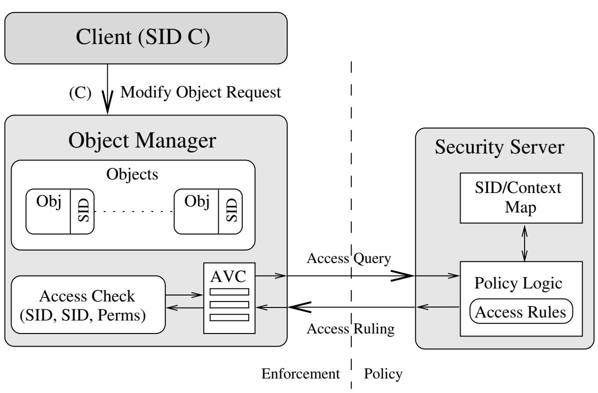
- `ssid`, `tsid` – **source and target SIDs**
- `tclass` – **type of target**
  - E.g., regular file, device, raw IP socket, TCP socket, ...
- **Server can decide more than it is asked for**
  - `access_vector_t` is a bitmask of permissions
  - `decided` can contain more than `requested`
  - Effectively implements decision prefetching
- `seqno` **used for revocation (in a few slides)**

Access vector cache (AVC)

- **Want to minimize calls into security server**
- **AVC caches results of previous decisions**
  - Note: Relies on simple enumerated permissions
- **Decisions therefore cannot depend on parameters:**
  - ✗ Andy can authorize expenses up to $999.99
  - ✗ Bob can run processes at priority 10 or higher
- **Decisions also limited to two SIDs**
  - Complicates file relabeling, which requires 3 checks:

Source	Target	Permission checked
Subject SID	Old file SID	Relabel-From
Subject SID	New file SID	Relabel-To
Old file SID	New file SID	Transition-From

AVC in a query



AVC interface

```
int avc_has_perm_ref(
    security_id_t ssid, security_id_t tsid,
    security_class_t tclass, access_vector_t requested,
    avc_entry_ref_t *aeref);
```

- `avc_entry_ref_t` **points to cached decision**
  - Contains `ssid`, `tsid`, `tclass`, decision vec., & recently used info
- `aeref` **argument is hint**
  - After first call, will be set to relevent AVC entry
  - On subsequent calls speeds up lookup
- **Example: New kernel check when binding a socket:**

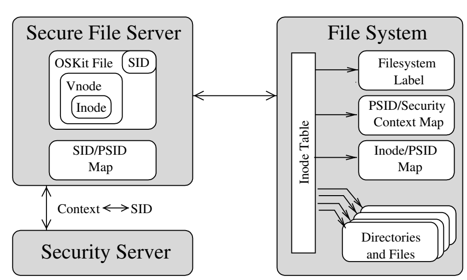
```
ret = avc_has_perm_ref(
    current->sid, sk->sid, sk->sclass,
    SOCKET__BIND, &sk->avcr);
```

  - Now `sk->avcr` is likely to be speed up next socket op

Revocation support

- **Decisions may be cached in AVC entries**
- **Decisions may implicitly be cached in migrated permissions**
  - E.g., Unix checks file write permission on *open*
  - But may want to disallow future writes even on open file
  - Write permission migrated into file descriptor
  - May also migrate into page tables/TLB w. `mmap`
  - Also may migrate into open sockets/pipes, or operations in progress
- **AVC contains hooks for callbacks**
  - After revoking in AVC, AVC makes callbacks to revoke migrated permissions
  - `seqno` can be used to ensure strict ordering of policy changes

Persistence



- **Must label persistent objects in file system**
  - Persistently map each file/directory to a security context
  - Security contexts are variable length, so add level of indirection
  - "Persistent SIDs" (PSIDs) – numbers local to each file system

Transitioning SIDs

- **May need to relabel objects**
  - E.g., files in file system
- **Processes may also want to transition their SIDs**
  - Depends on existing permission, but also on program
  - SElinux allows programs to be defined as *entrypoints*
  - Thus, can restrict with which programs users enter a new SID (similar to the way setuid transitions uid on program entry)

SElinux contexts

- **In practice, SElinux contexts have four parts:**

  user: `system_u` : role: `system_r` : type: `sshd_t` : level: `s0`

- ***user* is not Unix user ID, e.g.:**

```
$ id
uid=1000(dm) gid=1000(dm) groups=1000(dm) 119(admin)
context=unconfined_u:unconfined_r:unconfined_t:s0-s0:c0.c255
$ /bin/su
Password:
# id
uid=0(root) gid=0(root) groups=0(root)
context=unconfined_u:unconfined_r:unconfined_t:s0-s0:c0.c255
# newrole -r system_r -t sysadm_t
Password:
# id -Z
unconfined_u:system_r:sysadm_t:s0-s0:c0.c255
```


Users, roles, types

- **SElinux user is assigned on login, based on rules**

```
# semanage login -l
Login Name      SELinux User     MLS/MCS Range
__default__     unconfined_u     s0-s0:c0.c255
root            root_u           s0-s0:c0.c255
```

- **A user is allowed to assume different roles w.** `newrole`
- **But roles are restricted by SElinux (not Unix) users**

```
# semanage user -l
SELinux User     ... SELinux Roles
root                 staff_r sysadm_r system_r
unconfined_u         system_r unconfined_r
user_u               user_r
```


Types

- **Each role allows only certain *types***
  - Can check with `seinfo -x --role=`*name*
- **Types allow non-hierarchical security policies**
  - Each subject is assigned a *domain*, each object a *type*
  - Policy stated in terms of what each domain can to do each type
- **Example: Suppose you wish to enforce that each invoice undergoes the following processing:**
  - Receipt of the invoice recorded by a clerk
  - Receipt of of the merchandise verified by purchase officer
  - Payment of invoice approved by supervisor
- **Can encode state of invoice by its type**
  - Set transition rules to enforce all steps of process

Example: Loading kernel modules

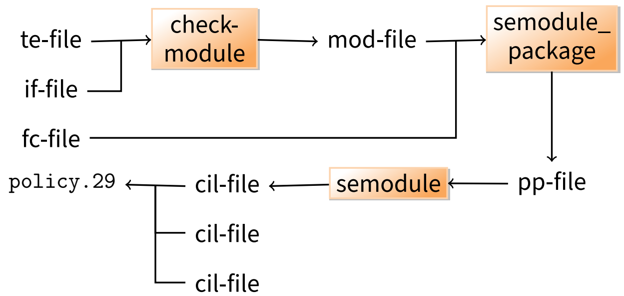
```
(1) allow sysadm_t insmod_exec_t:file x_file_perms;
(2) allow sysadm_t insmod_t:process transition;
(3) allow insmod_t insmod_exec_t:process { entrypoint execute };
(4) allow insmod_t sysadm_t:fd inherit_fd_perms;
(5) allow insmod_t self:capability sys_module;
(6) allow insmod_t sysadm_t:process sigchld;
```

1. Allow sysadm domain to run insmod
2. Allow sysadm domain to transition to insmod
3. Allow insmod program to be entrypoint for insmod domain
4. Let insmod inherit file descriptors from sysadm
5. Let insmod use CAP_SYS_MODULE (load a kernel module)
6. Let insmod signal sysadm with SIGCHLD when done

Policy specification

- **Very complicated sets of rules**
  - E.g., on Fedora, `sesearch --all | wc -l` shows 73K rules
  - Rules based mostly on types
- **Allowed/restricted transitions very important**
  - E.g., init can run initscripts, can run httpd
  - Nowadays `systemd` needs to be able to transition to arbitrary types
  - `httpd` program has special `httpd_exec_t` type, allows process to have `httpd_t` type.
  - Might label `public_html` directories so `httpd` can access them, but not access rest of home directory
- **Can also use levels to enforce MLS**
  - E.g., "`:s0-s0:c0.c255`" means process is at sensitivity `s0` with no categories, but has all categories in clearance.

Policy construction



- **Very low quality tooling around policy construction**
  - Broken build systems, incompatible kernel policy formats, ...
- **Hard to check `/sys/fs/selinux/policy` matches expectations**
  - No single-pass decompilation, tools seem to hang on real policies
  - Even rebuilding from source is hard (e.g., actual compilation happens during RPM install, using tons of spec macros)