CSE509 Computer System Security

2023-02-02

Policy, Models, and Trust

Michalis Polychronakis

Stony Brook University

Security Policy

A definition of what it means for a system to be secure

Comprises a set of well-defined rules involving:

- Subjects: entities that interact with the system
- Objects: any resource a security policy protects
- Actions: anything subjects can (or cannot) do on objects
- Permissions: allowed (or not) subject-object-action mappings
- Protections: rules or mechanisms that aid in enforcing a policy

A security policy typically places constraints on what actions subjects can perform on objects to achieve specific security goals

Security Model

An scheme for specifying and enforcing security policies

- Systems are large, complex, and dynamic → hard to manage
- Abstract the system into a simpler *model*

Deal with the *information confinement* problem

- Information should not flow into the wrong parties

Access control: who has access to what

Need ways to *represent access control rights*

- ACLs, Capabilities, …

Need ways to *grant specific rights*

- DAC, MAC, RBAC, …

Access Control Matrix

Abstract representation of a system's security state

- Each cell defines the access rights for the given combination of subject and object
- Empty cells mean that no access rights are granted

Objects: set of protected entities

- Files, directories, devices, resources, …

Subjects: set of active objects

- Users, groups, processes, systems, …

Rights: set of possible actions

- Read, write, execute, own, append, …
- Meaning may vary depending on the object involved

Access Control Matrix

	/etc/passwd	/usr/bin/	/home/bob/	/admin/
root	read, write	read, write, exec	read, write, exec	read, write, exec
bob	read	read, exec	read, write, exec	-
backup	read	read, exec	read, exec	read, exec

Useful conceptual representation, but not practical

- Size: number of subjects/objects will be too large
- Efficiency: too many cells will be empty (no access) or the same (default permissions)
- Management: addition/removal of subjects/objects requires non-trivial operations

Access Control Lists

List of permissions attached to an object

- Object-centered approach: enumeration of all subjects and their access rights for the given object (i.e., the columns of the access control matrix)
- No entry in the ACL ➔ subject has no rights

Facilitates the efficient implementation of default permissions

- Wasteful to have separate entries for *many* different subjects that have the same rights over a given object
- Better idea: define a "wildcard" to match any unnamed subject
- Groups of subjects can also be represented in a similar way

Tied to the object

- Can be stored along with the object in the form of metadata

Access Control Lists

	/etc/passwd	/usr/bin/	/home/bob/	/admin/
root	read, write	read, write, exec	read, write, exec	read, write, exec
bob	read	read, exec	read, write, exec	-
backup	read	read, exec	read, exec	read, exec
		ACL		

Advantages

Dramatically smaller size (empty cells are collapsed)

Disadvantages

No efficient way to enumerate all the rights of a given subject

Example: Unix File Permissions

A form of abbreviated ACL: a list of permissions attached to each file

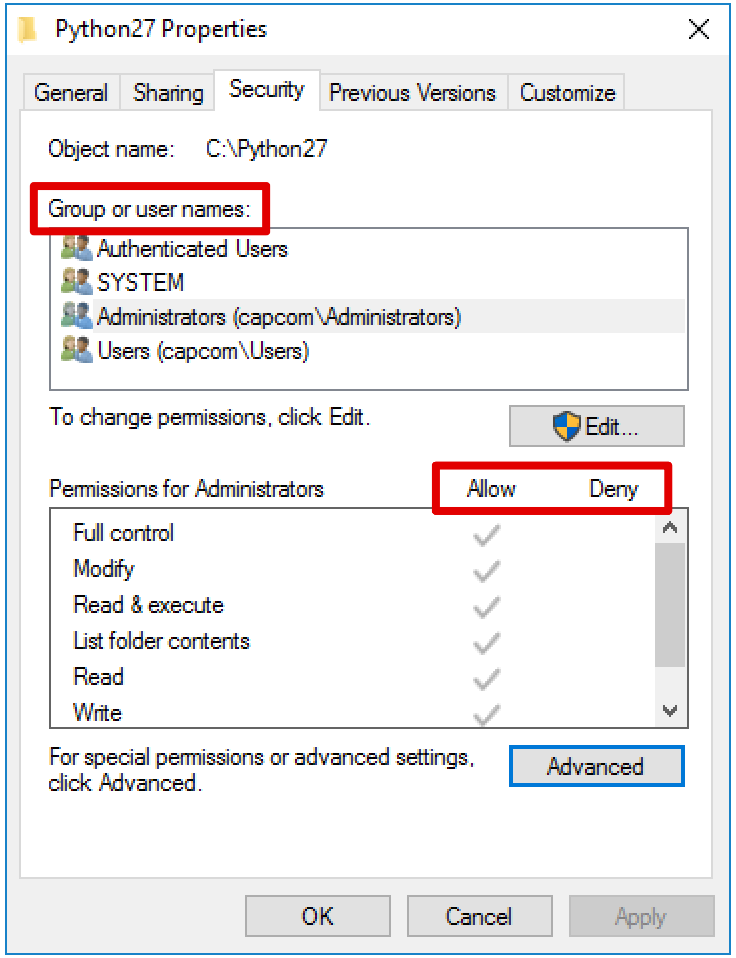
Users are divided in three classes: *owner*, *group*, *all*

- Separate read (`r`), write (`w`), and execute (`x`) permissions per class
- One octal digit (3 bits) per class, with R=4, W=2, X=1
- `rw-r-----` == 640 == Owner: RW, Group: R, All: none

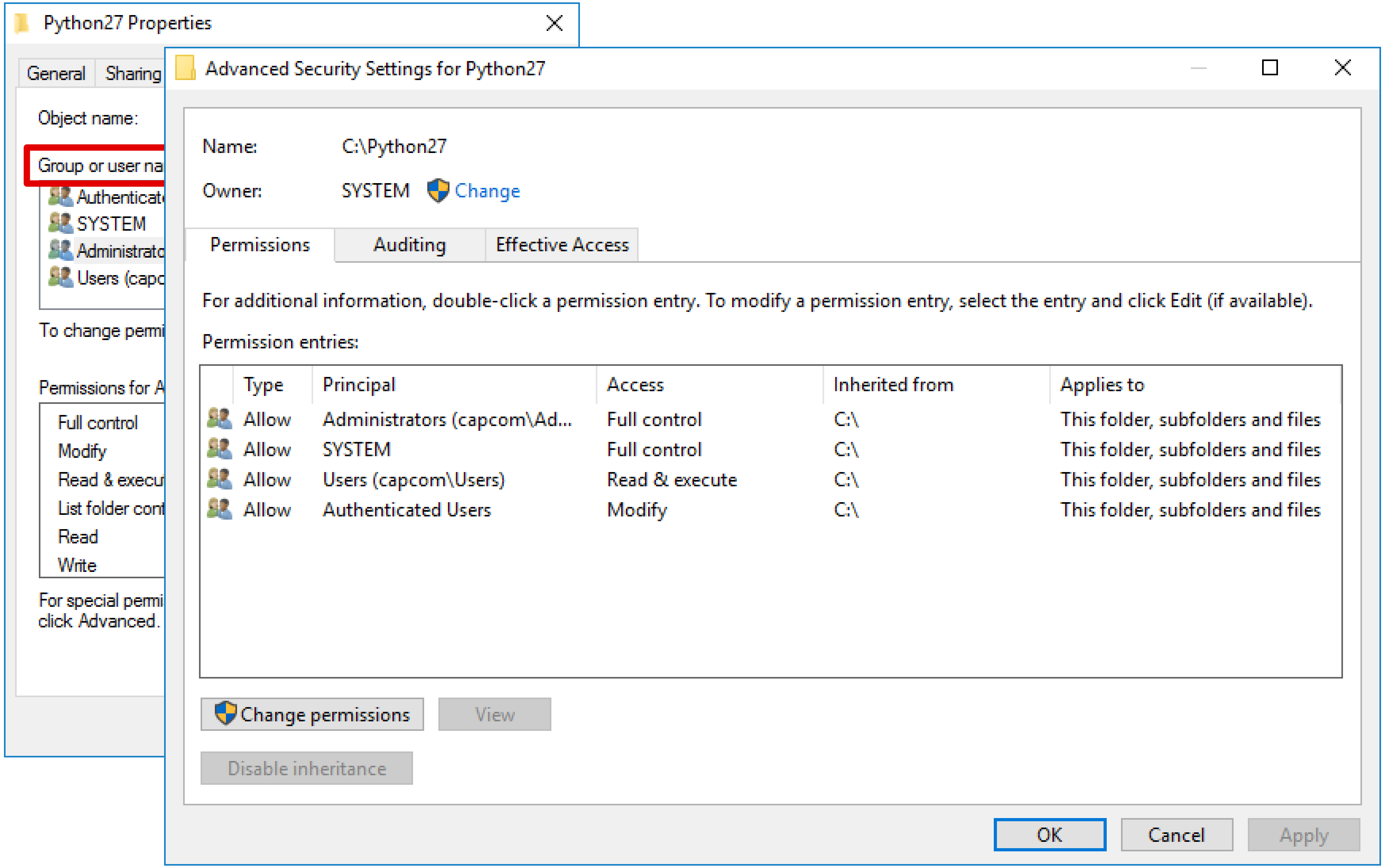
Coarse-grained control

- How can we express "everyone except Bob"?
- Non-standard arrangements require separate groups
- Must create a group of all users except Bob (cumbersome: only root can create groups)

Example: Windows



Example: Windows File Permissions



NAME

acl - Access Control Lists

DESCRIPTION

This manual page describes POSIX Access Control Lists, which are used to define more fine-grained discretionary access rights for files and directories.

ACL TYPES

Every object can be thought of as having associated with it an ACL that governs the discretionary access to that object; this ACL is referred to as an access ACL. In addition, a directory may have an associated ACL that governs the initial access ACL for objects created within that directory; this ACL is referred to as a default ACL.

ACL ENTRIES

An ACL consists of a set of ACL entries. An ACL entry specifies the access permissions on the associated object for an individual user or a group of users as a combination of read, write and search/execute permissions.

An ACL entry contains an entry tag type, an optional entry tag qualifier, and a set of permissions. We use the term qualifier to denote the entry tag qualifier of an ACL entry.

The qualifier denotes the identifier of a user or a group, for entries with tag types of ACL_USER or ACL_GROUP, respectively. Entries with tag types other than ACL_USER or ACL_GROUP have no defined qualifiers.

[let’s open the console]

Capabilities

List of access rights granted to a subject

- Subject-centered approach: enumeration of all objects and the access rights a given subject has on them (i.e., the rows of the access control matrix)

A capability can be a single token of authority

- Unforgeable: must be validated by the OS
- Communicable: can be passed on to other subjects or converted to less-privileged versions (in accordance to the enforced policy)

Tied to the subject

- Typically stored in a privileged data structure
- The subject should not be able to forge access rights or change the object a capability is related to

Capabilities

	/etc/passwd	/usr/bin/	/home/bob/	/admin/
root	read, write	read, write, exec	read, write, exec	read, write, exec
Capability bob	read	read, exec	read, write, exec	-
backup	read	read, exec	read, exec	read, exec

Advantages

Dramatically smaller size (empty cells are collapsed)

Disadvantages

No efficient way to enumerate all the rights on a given object

Example: Unix File Descriptors

To open a file, a process provides the file name and the desired access rights to the kernel

```
int fd = open("/etc/passwd", O_RDWR);
```

The kernel obtains the file's inode number by resolving the name through the file system hierarchy

It then determines if access should be granted using the access control permissions

If access is granted, the kernel returns a *file descriptor*

The variable `fd` in essence becomes a capability

The value of `fd` corresponds to an index in the process' file descriptor table

It can be *passed around* to other processes (e.g., as a result of `fork()` or by sending it through a socket)

Linux Privileges

Two types of user accounts

Superuser (root): bypasses all permission checks

Standard user: subject to permission checks

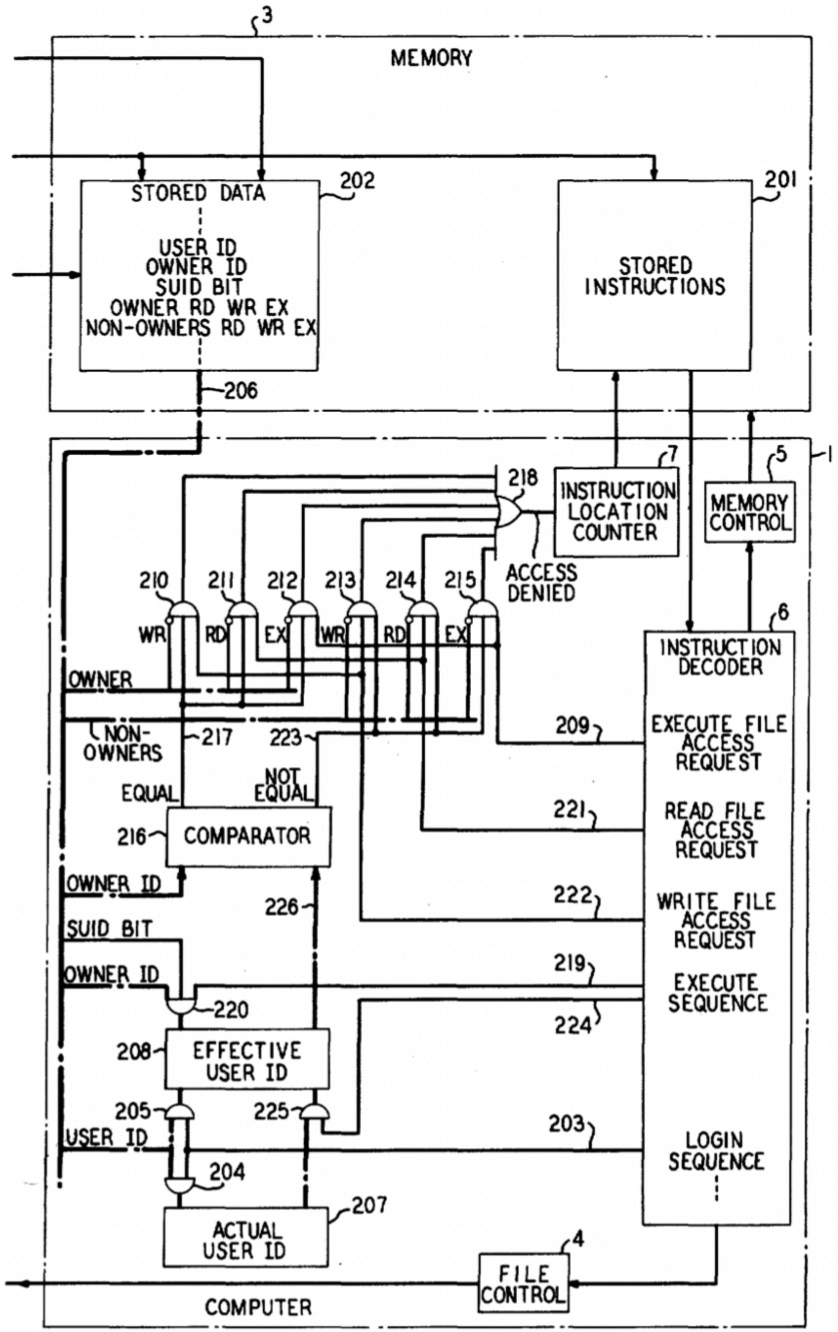
Non-privileged users often need to perform privileged operations

Example: change password

- `passwd` needs to modify `/etc/passwd` and `/etc/shadow` (both owned by root)
- Their file permissions prevent unprivileged processes from modifying them

Example: ping a host

- `ping` needs to use a raw socket to send/receive ICMP packets, a feature limited to root



Dennis Ritchie
Protection of Data File Contents
U.S. patent 4135240
1979

`Setuid`

Unix access rights flags `setuid` ("set user ID") and `setgid`

- Allow users to run an executable with the file system permissions of the executable's *owner* or *group*, respectively

Pragmatic solution for allowing unprivileged users to execute programs with superuser privileges

Violation of the principle of least privilege (!)

- `Setuid` programs have *full privileges* to perform *any critical operation*

Can lead to disastrous outcomes

- Vulnerabilities in `setuid` programs are prevalent
- Allow attackers to achieve arbitrary code execution with root privileges

Linux Capabilities

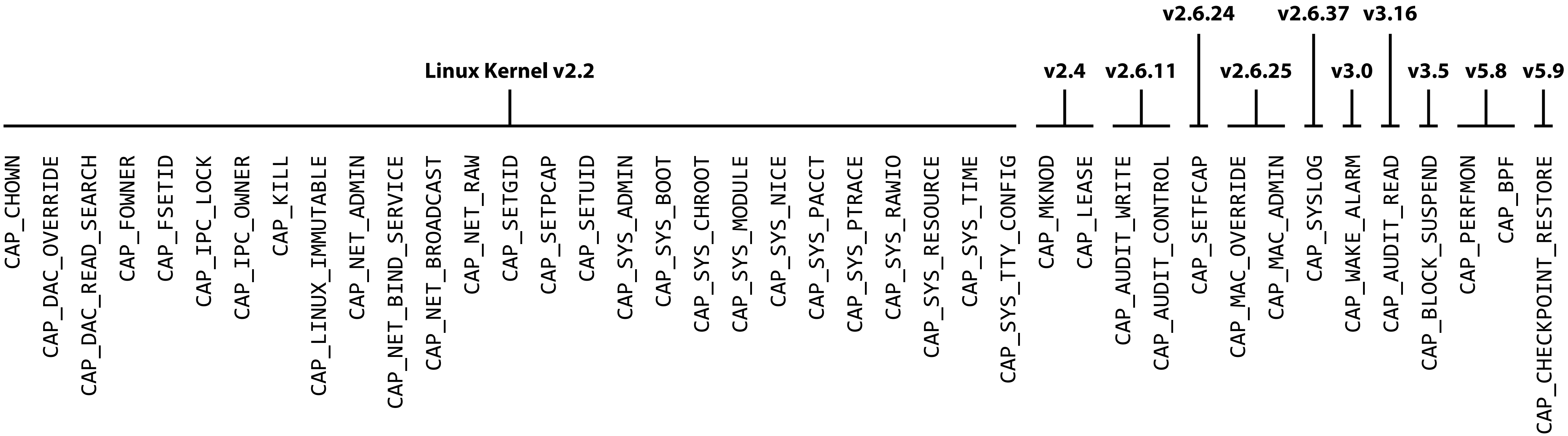
Linux divides superuser privileges into distinct *capabilities*

- Each capability is (typically) associated with a specific privileged operation
- CAP_SETUID, CAP_SYS_ADMIN, CAP_NET_RAW, …
- Introduced with kernel v2.2 (January 1999)

Capabilities are independently assigned to non-privileged programs

- Example: CAP_NET_BIND_SERVICE allows a non-root process to bind a network socket to privileged ports

```
snum = ntohs(cma_port(cma_src_addr(id_priv)));
if (snum < PROT_SOCK && !capable(CAP_NET_BIND_SERVICE))
      return -EACCES;
```



Linux kernel v5.17 (May 2022) provides 41 capabilities

Setuid ➔ Linux Capabilities

Is this really necessary? What if `ping` is vulnerable?

```
$ ls -l /bin/ping
-rwsr-xr-x 1 root root 44K May  7  2014 /bin/ping*
```

Remember the principle of least privilege?

```
$ ls -l /bin/ping
-rwxr-xr-x 1 root root 84K Feb  4  2022 /bin/ping
$ getcap /bin/ping
/bin/ping = cap_net_raw=ep
```

Program	**Ubuntu 18.04** (April 2018)	**Ubuntu 20.04** (April 2020)	**Ubuntu 21.10** (October 2021)
`ping`	×	✓	✓
`ping6`	×	✓	✓
`noping`	×	×	✓
`traceroute6.iputils`	×	✓	✓
`arping`	×	✓	✓
`oping`	×	×	✓
`pinger`	×	✓	✓

Out of **201** `setuid` programs in Ubuntu 18.04, only **seven** have become capability-aware in Ubuntu 21.10

Decap: Deprivileging Programs by Reducing Their Capabilities. Md Mehedi Hasan, Seyedhamed Ghavamnia, and Michalis Polychronakis. In *Proceedings of the 25th International Symposium on Research in Attacks, Intrusions and Defenses (RAID)*, pp. 395–408. October 2022, Limassol, Cyprus.

NAME

capabilities - overview of Linux capabilities

DESCRIPTION

For the purpose of performing permission checks, traditional UNIX implementations distinguish two categories of processes: privileged processes (whose effective user ID is 0, referred to as superuser or root), and unprivileged processes (whose effective UID is nonzero). Privileged processes bypass all kernel permission checks, while unprivileged processes are subject to full permission checking based on the process's credentials (usually: effective UID, effective GID, and supplementary group list).

Starting with kernel 2.2, Linux divides the privileges traditionally associated with superuser into distinct units, known as capabilities, which can be independently enabled and disabled. Capabilities are a per-thread attribute.

Capabilities list

The following list shows the capabilities implemented on Linux, and the operations or behaviors that each capability permits:

CAP_AUDIT_CONTROL (since Linux 2.6.11)

Enable and disable kernel auditing; change auditing filter rules; retrieve auditing status and filtering rules.

CAP_AUDIT_READ (since Linux 3.16)

[let’s open the console]

Access Control Policies

Different approaches to granting access rights

- Who is responsible? admin, user, owner, …
- Based on what? identity, role, group, rule, …

Main Types of Access Control

Discretionary

Mandatory

Role-based

Rule-based

…

Discretionary Access Control

Subjects determine who has access to their objects

Key concept: *the owner*

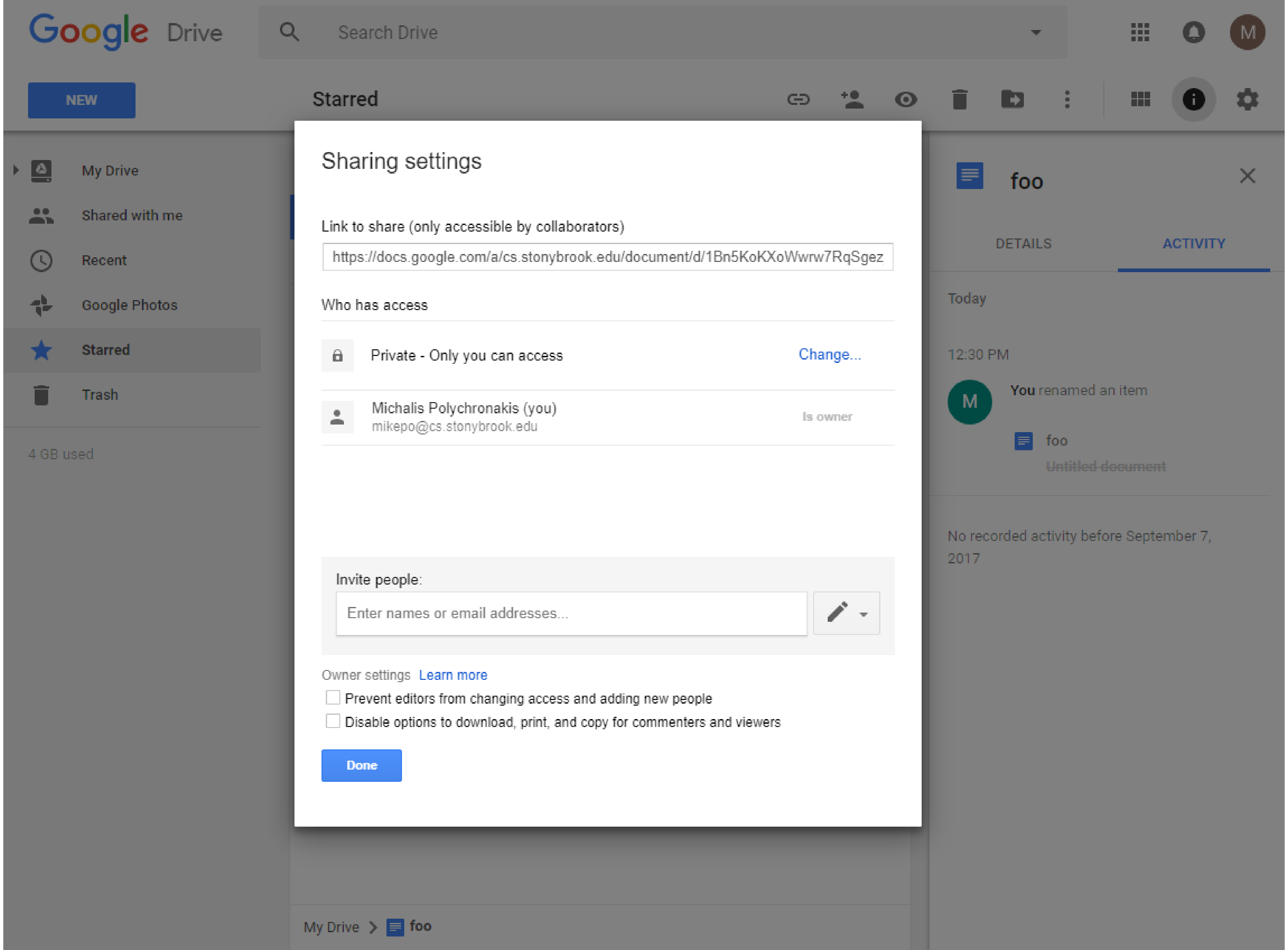
Determines the access rights of other subjects on that object

A subject with a certain access permission can pass it on to any other subject

Commonly used in most operating systems

Example: Linux and Windows allow non-root users to specify file and folder permissions based on ACLs

On existing files they can already access, or any new files they will create


Google Drive
Search Drive
NEW
Starred
My Drive
Shared with me
Recent
Google Photos
Starred
Trash
4 GB used
Sharing settings
Link to share (only accessible by collaborators)
https://docs.google.com/a/cs.stonybrook.edu/document/d/1Bn5KoKXoWwrw7RqSgez
Who has access
Private - Only you can access
Change...
Michalis Polychronakis (you)
mikepo@cs.stonybrook.edu
Is owner
Invite people:
Enter names or email addresses...
Owner settings
Learn more
Prevent editors from changing access and adding new people
Disable options to download, print, and copy for commenters and viewers
Done
foo
DETAILS
ACTIVITY
Today
12:30 PM
You renamed an item
foo
Untitled document
No recorded activity before September 7, 2017
My Drive
foo

Mandatory Access Control

An administrator grants all access rights

- Cannot be altered by subjects ➔ users cannot override decisions either accidentally or intentionally

MAC-enabled systems allow policy administrators to implement strict organization-wide security policies

- Multilevel security (MLS) and specialized military systems

Getting traction in mainstream OSes as a means of minimizing abuse and preventing misconfigurations

- Linux: SELinux, AppArmor
- Windows: Mandatory Integrity Control

Example: The Bell-LaPadula Model

Inspired by the military multilevel security paradigm

Used for document classification and personnel clearance

Security levels

Each object is classified at one of the security levels

Each use obtains clearance at one of the security levels

Example: MLS classification

Unclassified ➔ Confidential ➔ Secret ➔ Top Secret

Goal: protect the confidentiality of information

Prevent read access to objects at a security classification higher than the subject's clearance

Example: The Bell-LaPadula Model

Access to objects is controlled by two rules

Simple security property

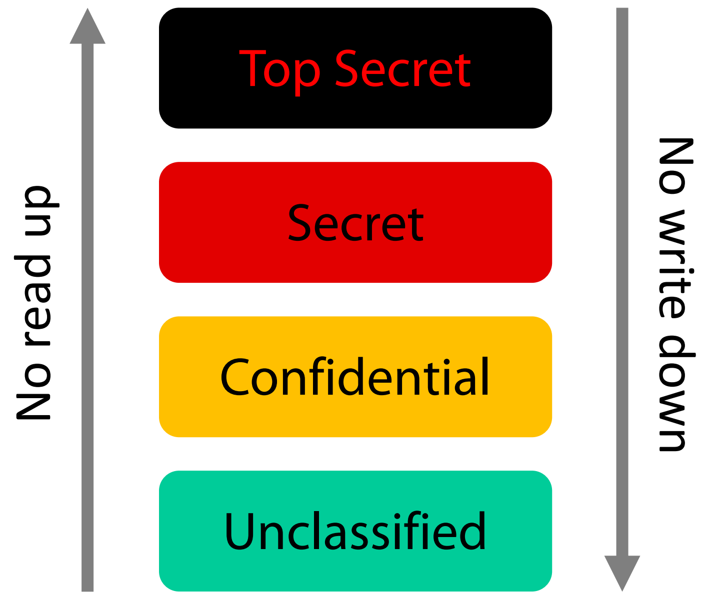
A subject cannot read an object of higher sensitivity

"no read up"

Star (*) property

A subject cannot write to an object of lower sensitivity

"no write down"



Role-based Access Control

Access to an object is governed by the *role* of the subject within an organization

Administrators define roles, specify access rights for each role, and assign subjects to roles

- Much more convenient than managing subjects individually

Example: roles for a computer science department

- Student, faculty, administrative personnel, sysadmin, …

Role hierarchies

- More privileged roles may inherit the access rights of less privileged roles
- Key difference from user groups

Rule-based Access Control

Allow or deny access to resources based on conditions other than the subject's identity

- Time of day, location, type of device, …

Attribute-based Access Control

Policies based on user, resource, environmental, or other attributes

- Can be expressed in the form of complex Boolean logic rules

Context-based Access Control

Take into account relevant state information

- E.g., block externally-initiated but allow internally-initiated TCP connections

…

Trust

A security policy is in essence a set of axioms that the policy makers *believe* can be enforced

Relies on several assumptions

- The policy correctly captures all possible secure and insecure states of the system
- The enforcement mechanisms prevent the system from entering an insecure state
- The associated risks have been adequately assessed

How can we trust the policy?

- Is it correct? Complete? Unambiguous?

How can we trust the mechanisms?

- Do they contain flaws? Are they configured correctly? Do they enforce all aspects of the policy? Is there a backdoor?