OS Security Basics

CS642: Computer Security

Professor Ristenpart

http://www.cs.wisc.edu/~rist/

rist at cs dot wisc dot edu

We start with some basics about operating system security:

Multics

Multi-level security

Security policies

Access controls

UNIX permissions

Take yourself back to the 1960’s

http://fyeahhippies.tumblr.com/post/135907376

Take yourself back to the 1960's

Time-share multiuser computers coming into use

Courtesy of
http://aficionadous.blogspot.com/

GE-645
36 bit address space
Up to 4 processors
Magnetic tape drives
Supported virtual memory in hardware

Multiplexed Information and Computing Service (Multics)

Project to develop operating system for time-shared systems

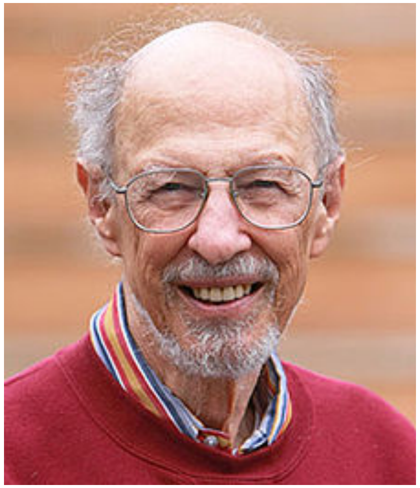
- Designed from 1964-1967.
- MIT project MAC, Bell Labs, and GE
- ~100 installations at greatest extent
- Last one shut down in 2000 (Canadian department of defense)

"A small but useful hardware complement would be 2 CPU units, 128K of core, 4 million words of high speed drum, 16 million words of disc, 8 tapes, 2 card readers, 2 line printers, 1 card punch and 30 consoles."
[Vyssotsky, Corbato, Graham 1965]

Multics: ancestor to many OS's

Lots of innovations in design

- Use of segmentation and virtual memory with hardware support
- SMP (shared memory multiprocessor)
- Written in PL/1 (high level language)

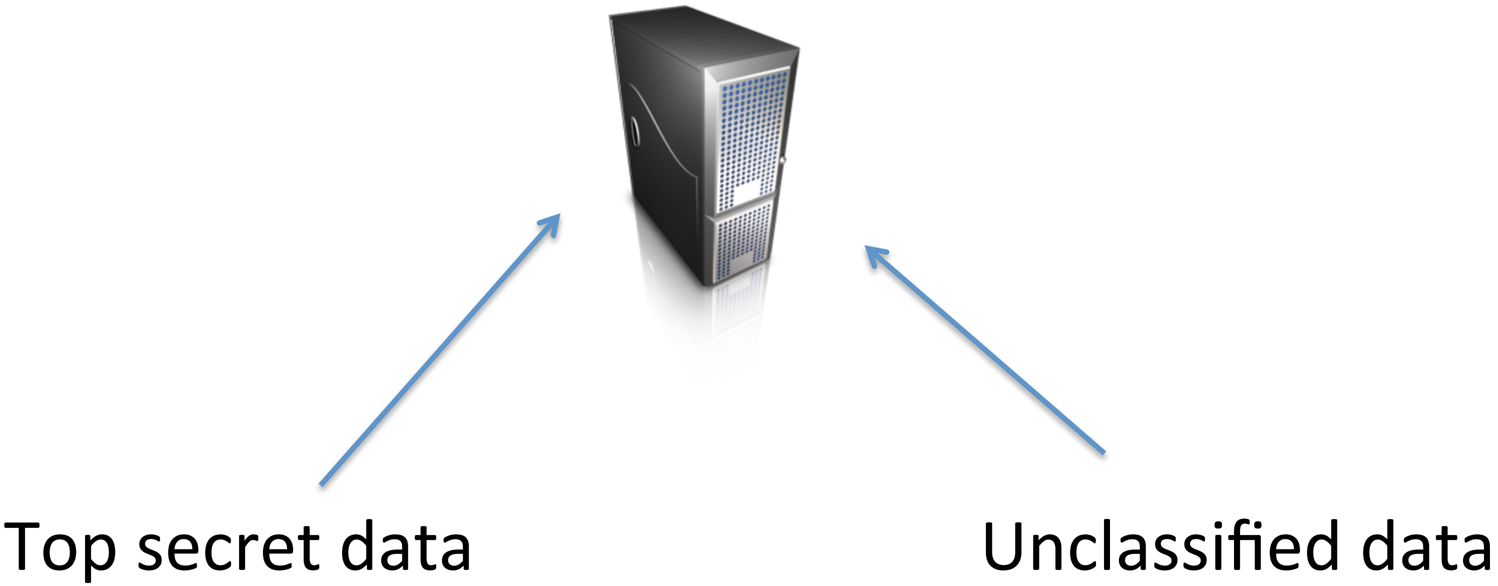


F. Corbato, MIT

Significant attention paid to security

Multi-level security

- Military and other government entities want to use time-sharing too



Top secret data

Unclassified data

Classification levels

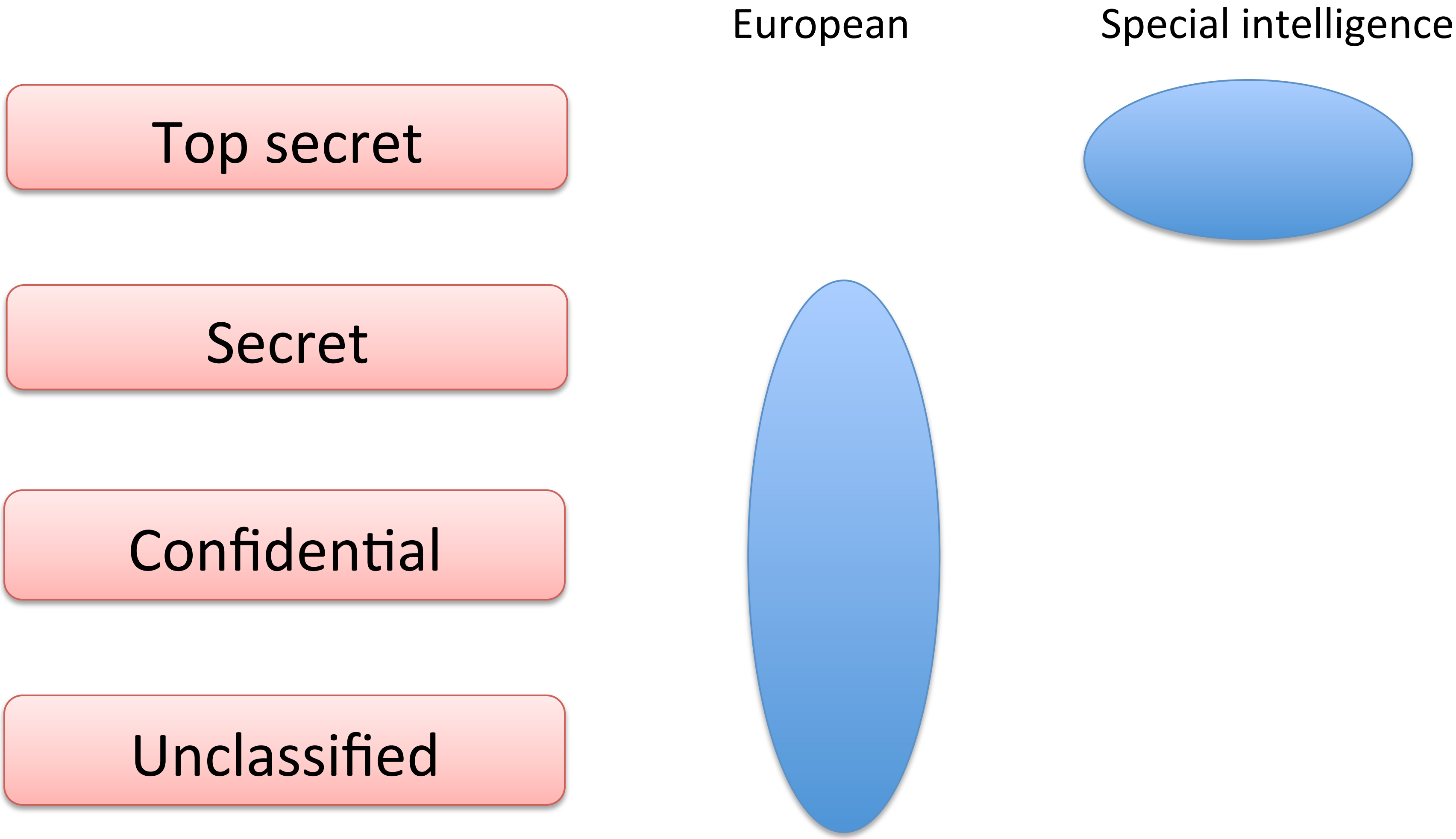
Top secret

Secret

Confidential

Unclassified

Classification levels and compartmentalization



European

Special intelligence

Top secret

Secret

Confidential

Unclassified

Classification levels and compartmentalization

- Security level (L,C)
  - L is classification level (Top secret, secret, …)
  - C is compartment (Europe, Special intelligence…)

Dominance relationship:

(L1,C1) ≤ (L2,C2)

L1 < L2

C1 subset of C2

Bell-Lapadula Confidentiality Model

“no reads up”, “no writes down”

Simple security condition

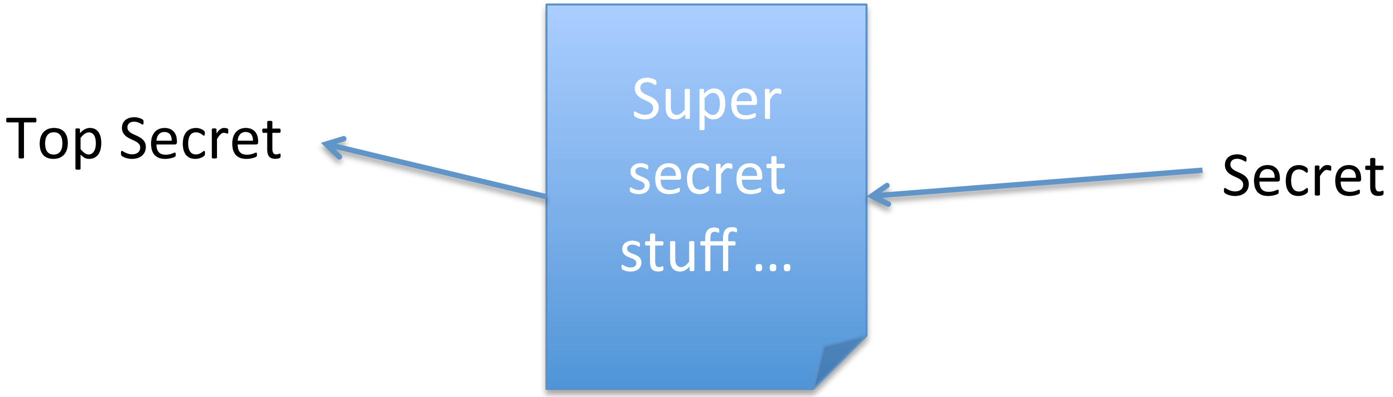
User with (L1,C1) can read file with (L2,C2) if

~~(L1,C1) ≤ (L2,C2)~~ [✓ (L1,C1) ≥ (L2,C2)]

*-property

User with (L1,C1) can write file with (L2,C2) if

[✓ (L1,C1) ≤ (L2,C2)] ~~(L1,C1) ≥ (L2,C2)~~



Say we have just Bell-Lapadula in effect… what could go wrong?

Biba integrity model

“no read down”, “no writes up”

Simple integrity condition

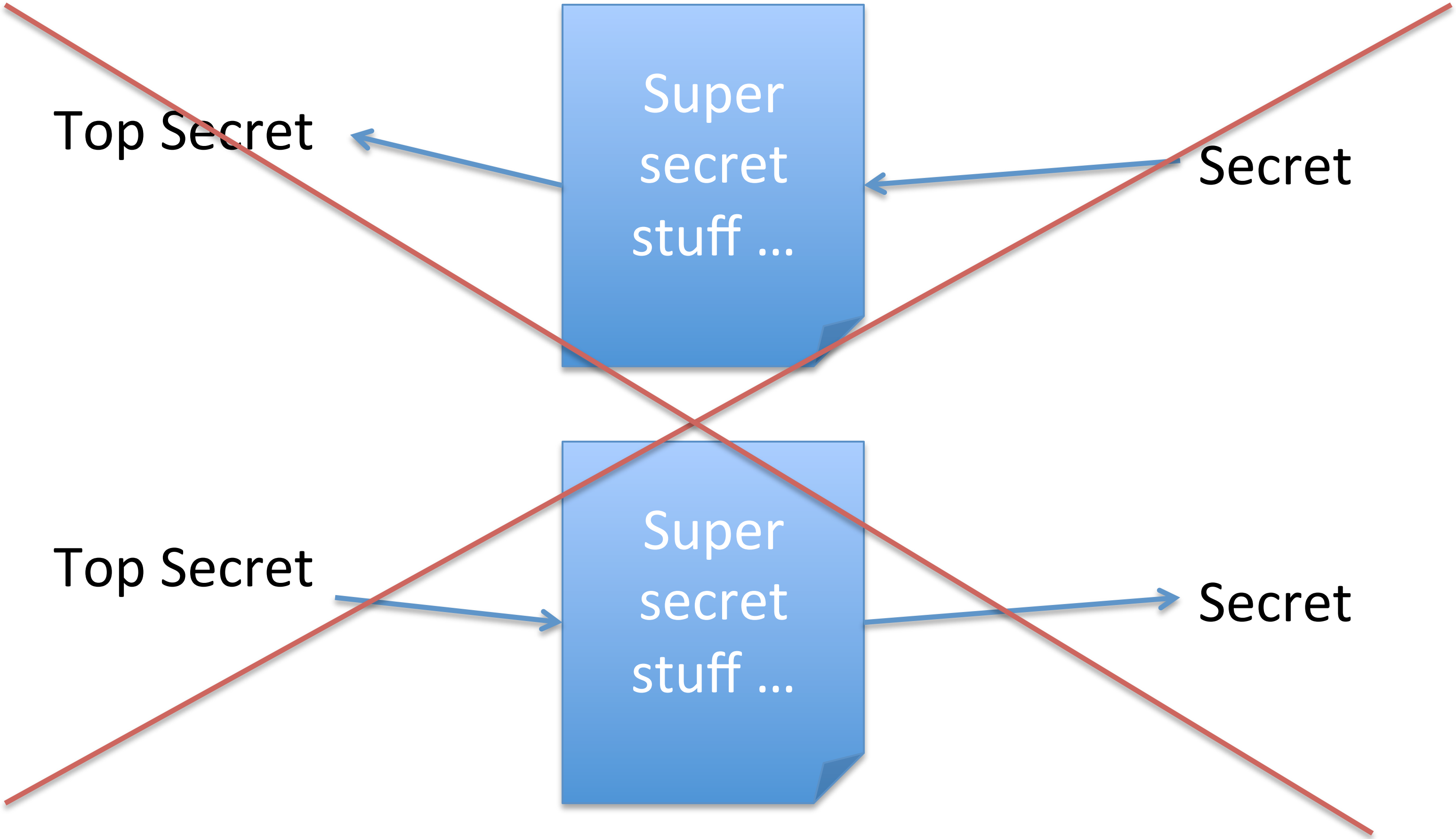
User with (L1,C1) can read file with (L2,C2) if

(L1,C1) ≤ (L2,C2) ~~(L1,C1) ≥ (L2,C2)~~

*-property

User with (L1,C1) can write file with (L2,C2) if

~~(L1,C1) ≤ (L2,C2)~~ (L1,C1) ≥ (L2,C2)



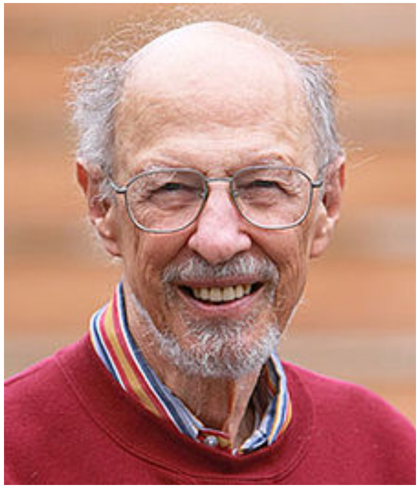
If we combine them… one can only communicate in same classification

Other policy models

- Take-grant protection model
- Chinese wall
- Clarke-Wilson integrity model
- etc.

A good reference is:
Bishop, Computer Security: Art and Science

Multics: ancestor to many OS's



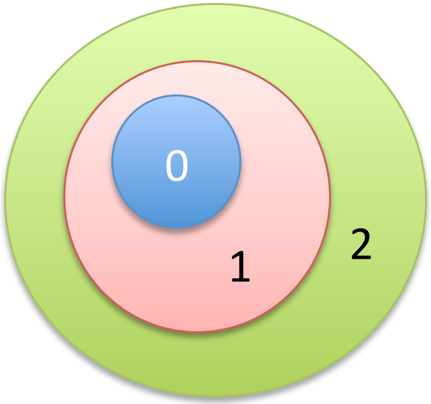
F. Corbato, MIT

Lots of innovations in design

- Use of segmentation and virtual memory with hardware support
- SMP (shared memory multiprocessor)
- Written in PL/1 (high level language)

Significant attention paid to security

Multics: security mechanisms



Protection rings 0-7
in which processes execute

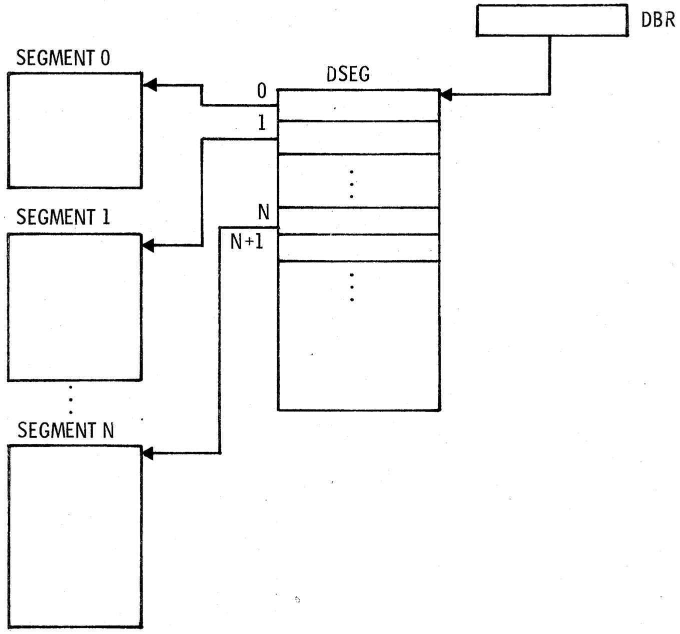
- Lower number = higher privilege
- Ring 0 is “hardcore” supervisor
- Inherit privileges over higher levels

Protection rings included in all typical CPUs today and used by all operating systems

Multics: security mechanisms

Segments

- Virtual memory
- Program and data items stored in a segment
- Descriptor control field (read only, write only, execute only, ...)
- Segments access controlled



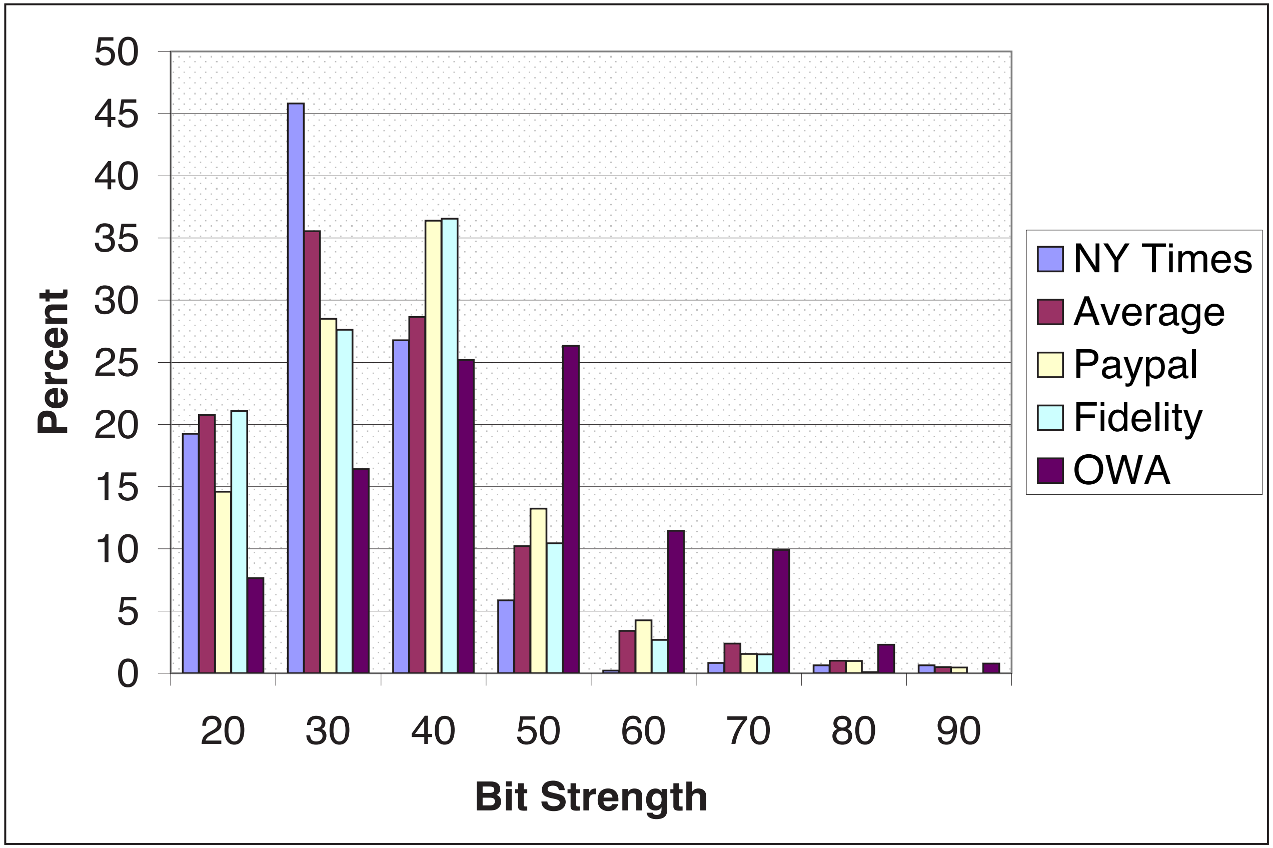
Multics: security mechanisms

Enciphered passwords

pw = 12345

- Couldn't find the algorithm
- Later ones used DES, but Multics predates DES

$$pw \longrightarrow h(pw)$$

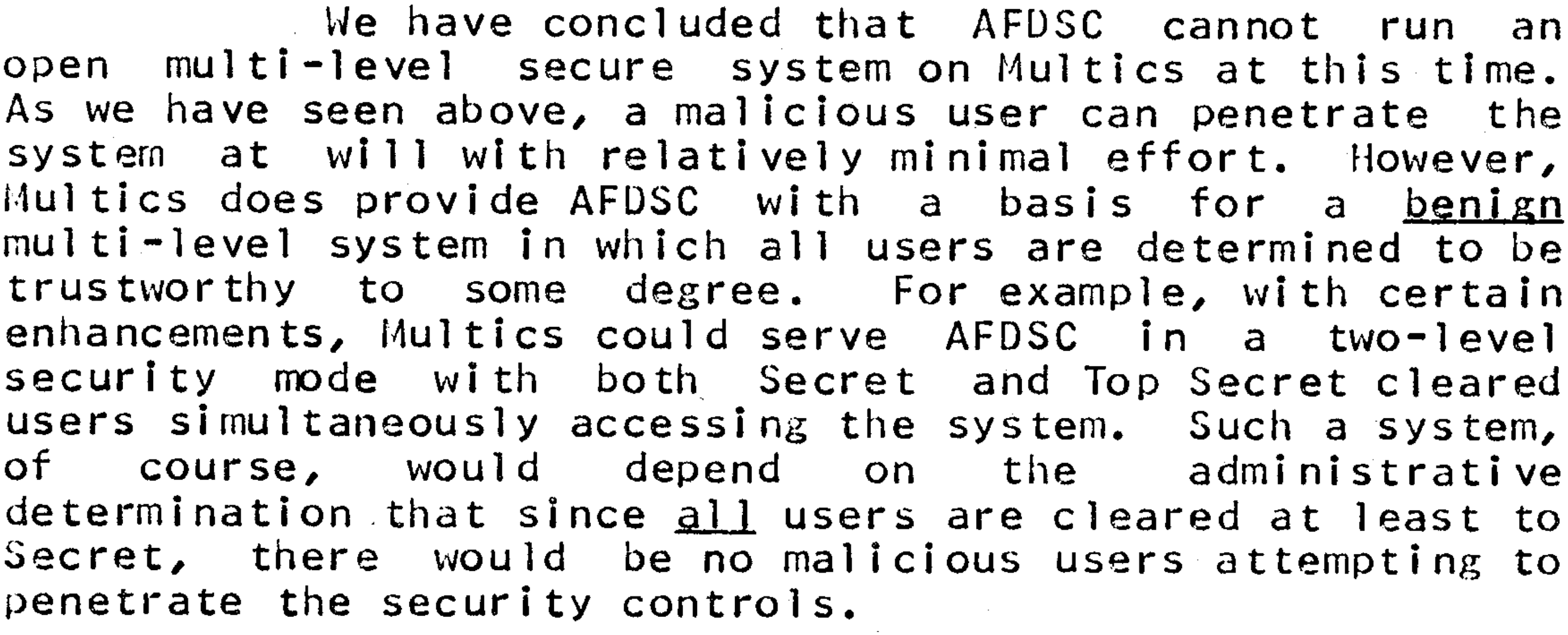


From reading:
A Large-Scale Study of Web Password Habits, by Florencio and Herley

Karger and Schell multicians.org

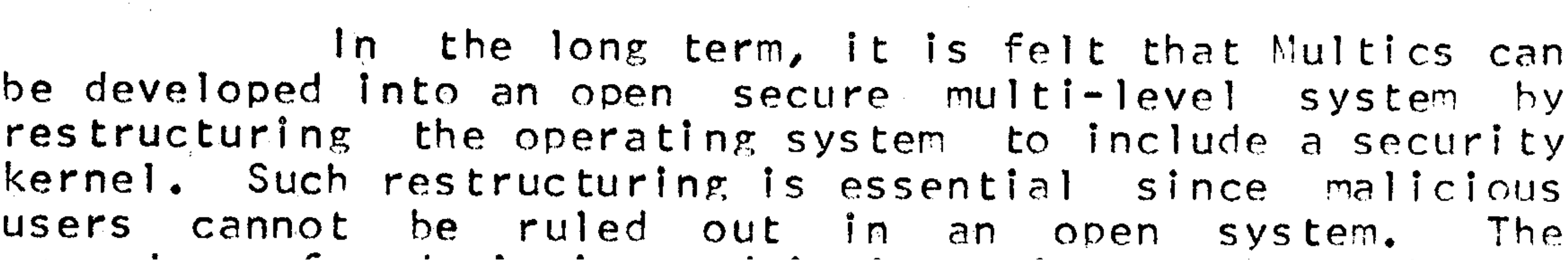
Karger and Schell: security analysis of Multics

- Classic red teaming example



We have concluded that AFDSC cannot run an open multi-level secure system on Multics at this time. As we have seen above, a malicious user can penetrate the system at will with relatively minimal effort. However, Multics does provide AFDSC with a basis for a benign multi-level system in which all users are determined to be trustworthy to some degree. For example, with certain enhancements, Multics could serve AFDSC in a two-level security mode with both Secret and Top Secret cleared users simultaneously accessing the system. Such a system, of course, would depend on the administrative determination that since all users are cleared at least to Secret, there would be no malicious users attempting to penetrate the security controls.

Karger and Schell: security analysis of Multics



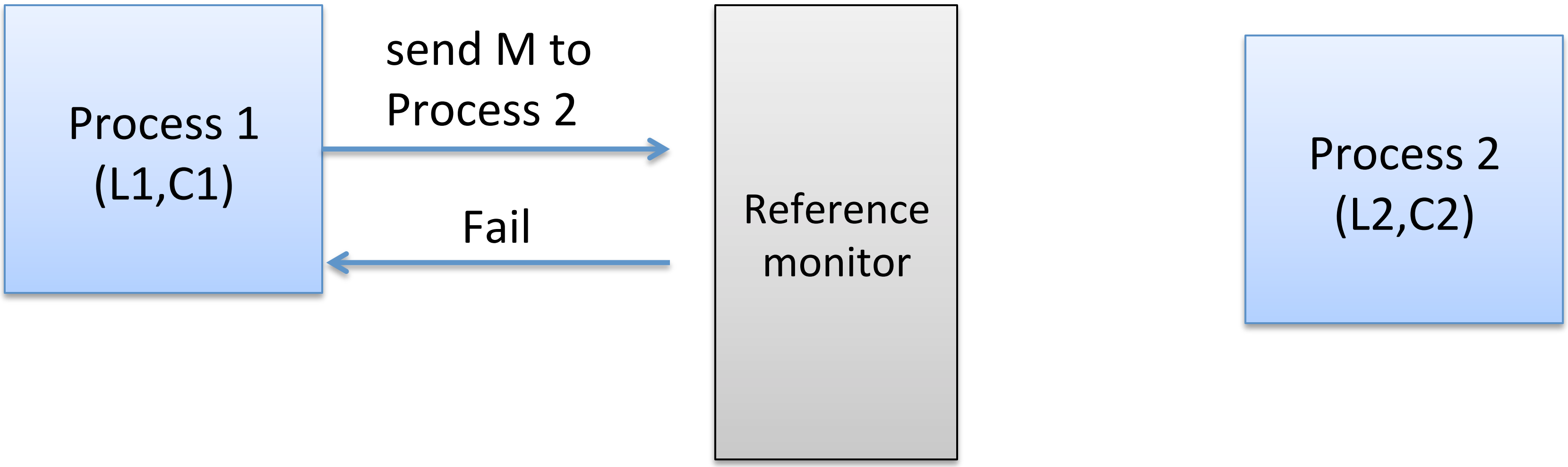
In the long term, it is felt that Multics can be developed into an open secure multi-level system by restructuring the operating system to include a security kernel. Such restructuring is essential since malicious users cannot be ruled out in an open system. The

Reference monitors / security kernels

- System component that monitors (hopefully all) accesses to data for security violations
- Reference monitors may be:
  - kernel
  - hypervisor
  - within applications (Apache)

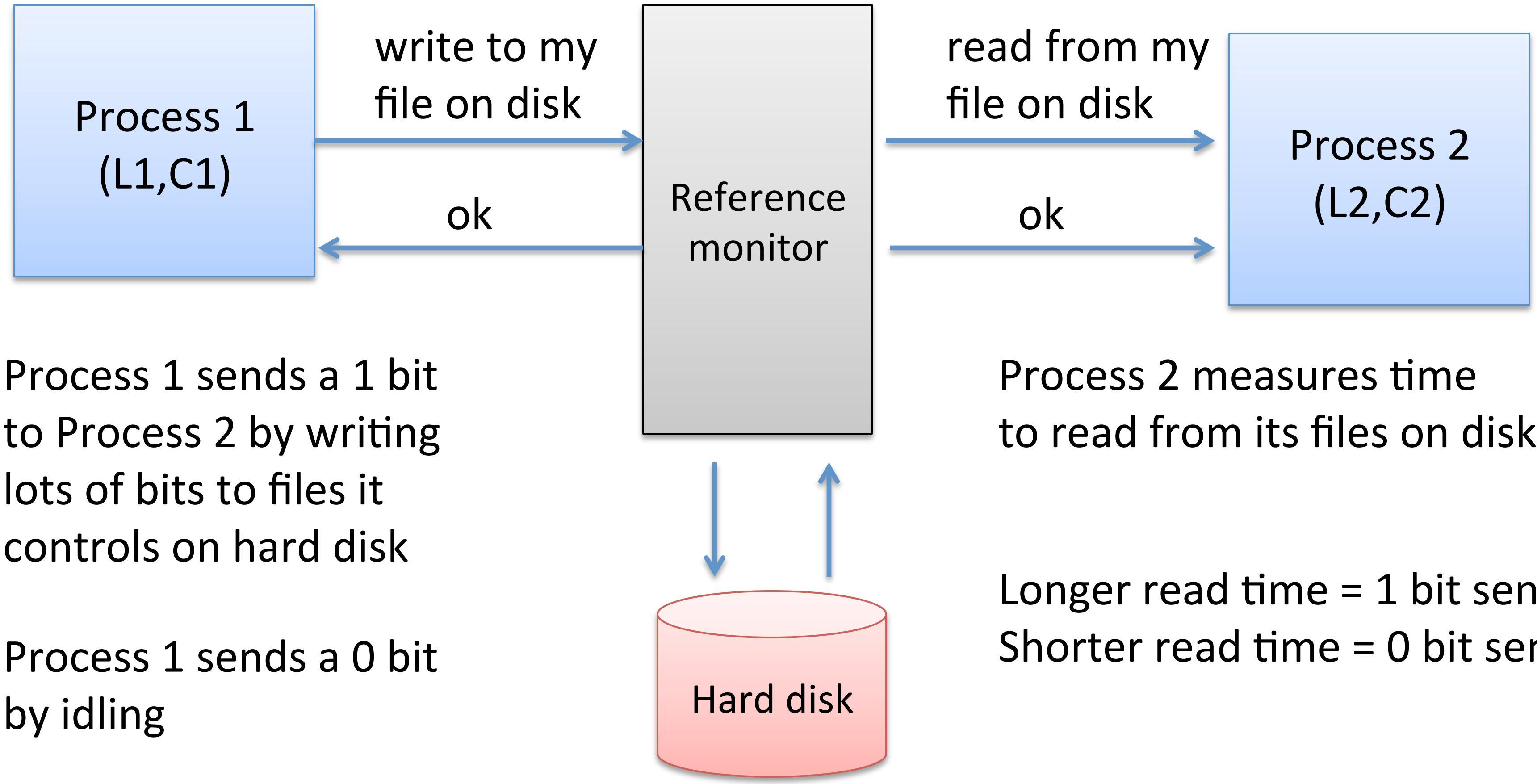
Circumventing access controls: covert channels

(L1,C1) ≥ (L2,C2)



Circumventing access controls: covert channels

(L1,C1) ≥ (L2,C2)



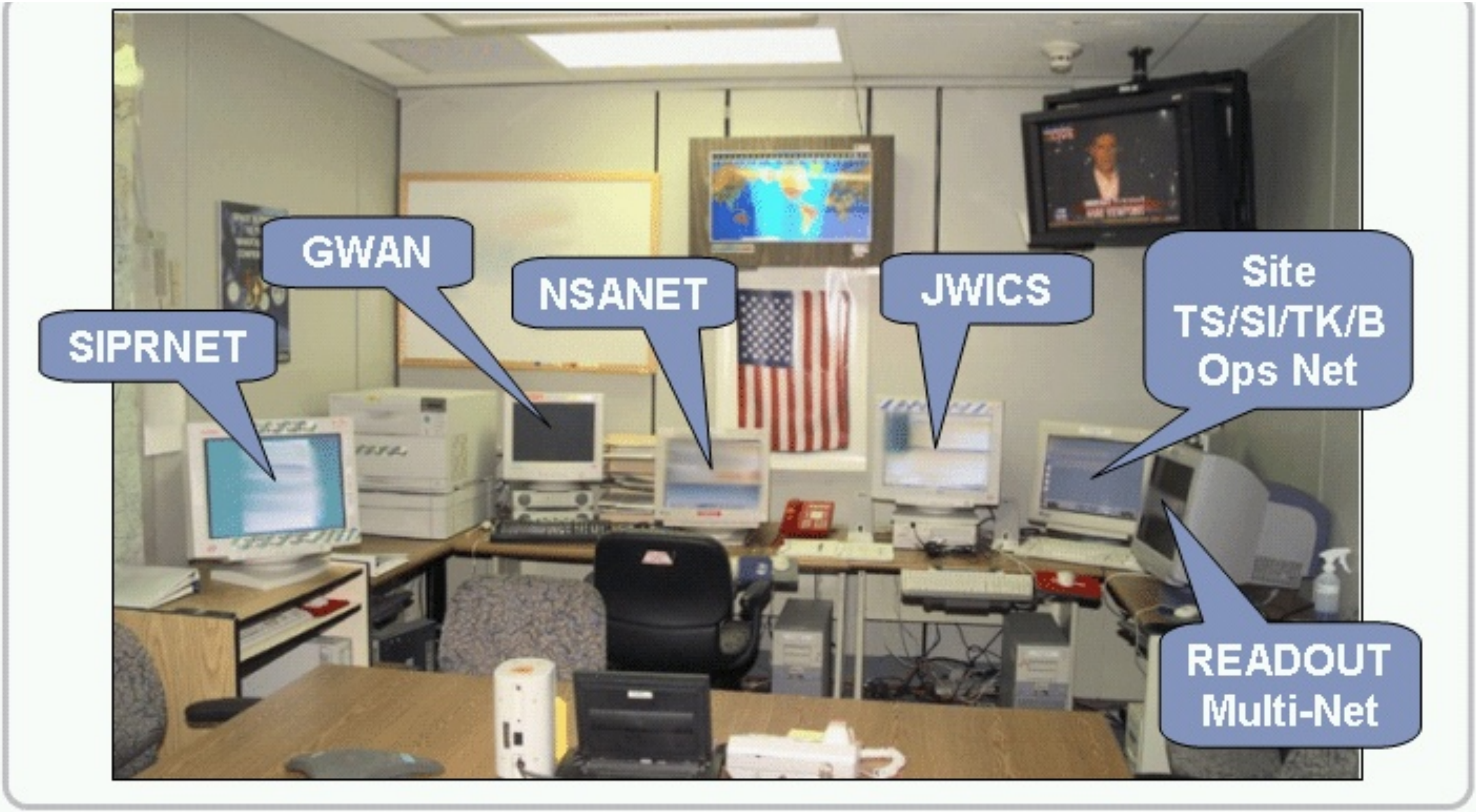
Process 1 sends a 1 bit to Process 2 by writing lots of bits to files it controls on hard disk

Process 1 sends a 0 bit by idling

Process 2 measures time to read from its files on disk

Longer read time = 1 bit sent
Shorter read time = 0 bit sent

Covert channels one of unsolved MLS problems



Access controls

Access control matrix

Objects

Subjects

	file 1	file 2	…	file n
user 1	read, write	read, write, own		read
user 2				
…				
user m	append	read, execute		read,write, own

User i has permissions for file j as indicated in cell [i,j]

Due originally to Lampson in 1971

Two common implementation paradigms

	file 1	file 2	…	file n
user 1	read, write	read, write, own		read
user 2				
…				
user m	append	read, execute		read,write,own

(1) Access control lists

Column stored with file

(2) Capabilities

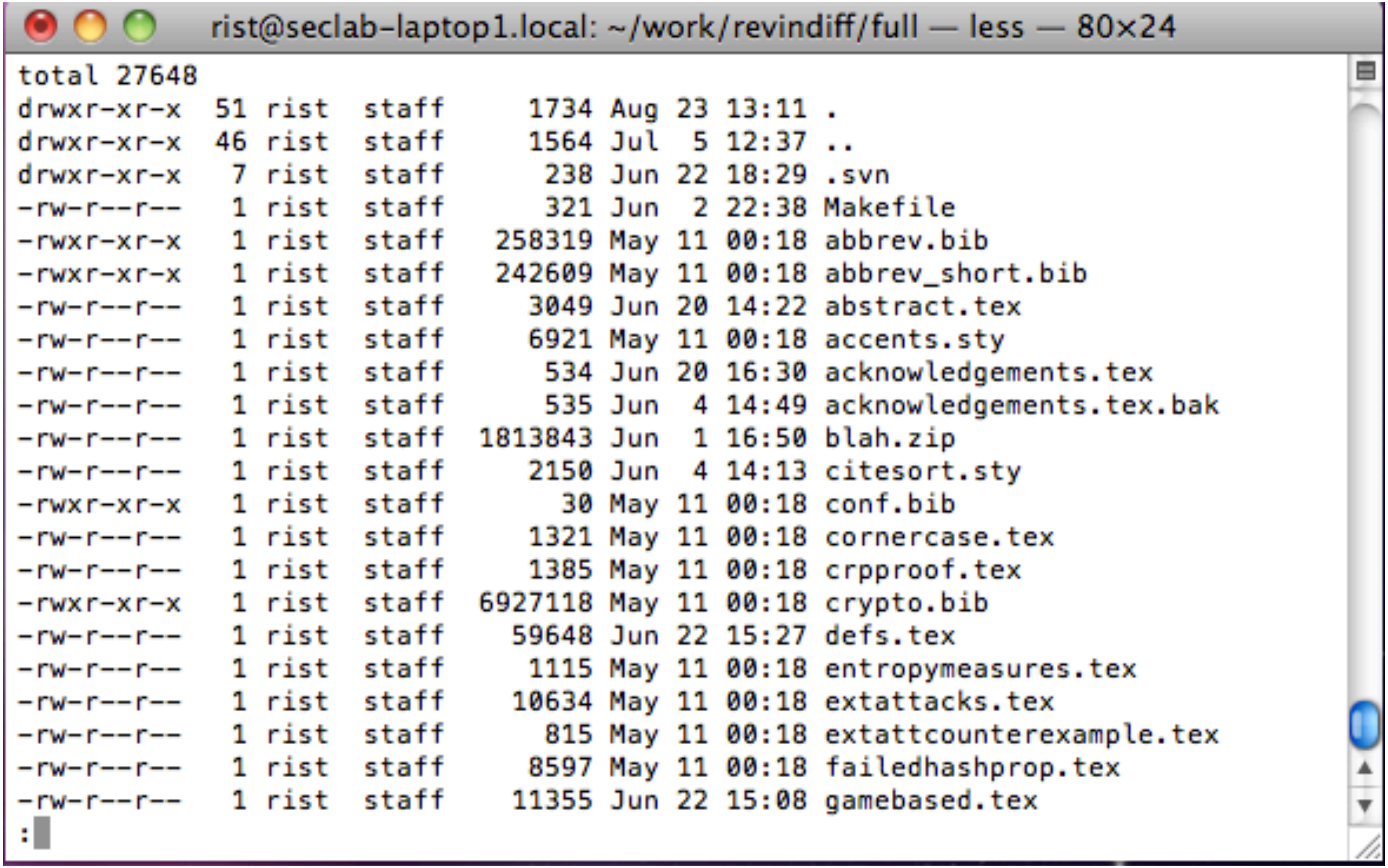
Row stored for each user

Unforgeable tickets given to user

ACLs compared to Capabilities

ACLs requires authenticating user	Token-based approach avoids need for auth
Processes must be given permissions	Tokens can be passed around
Reference monitor must protect permission setting	Reference monitor must manage tokens

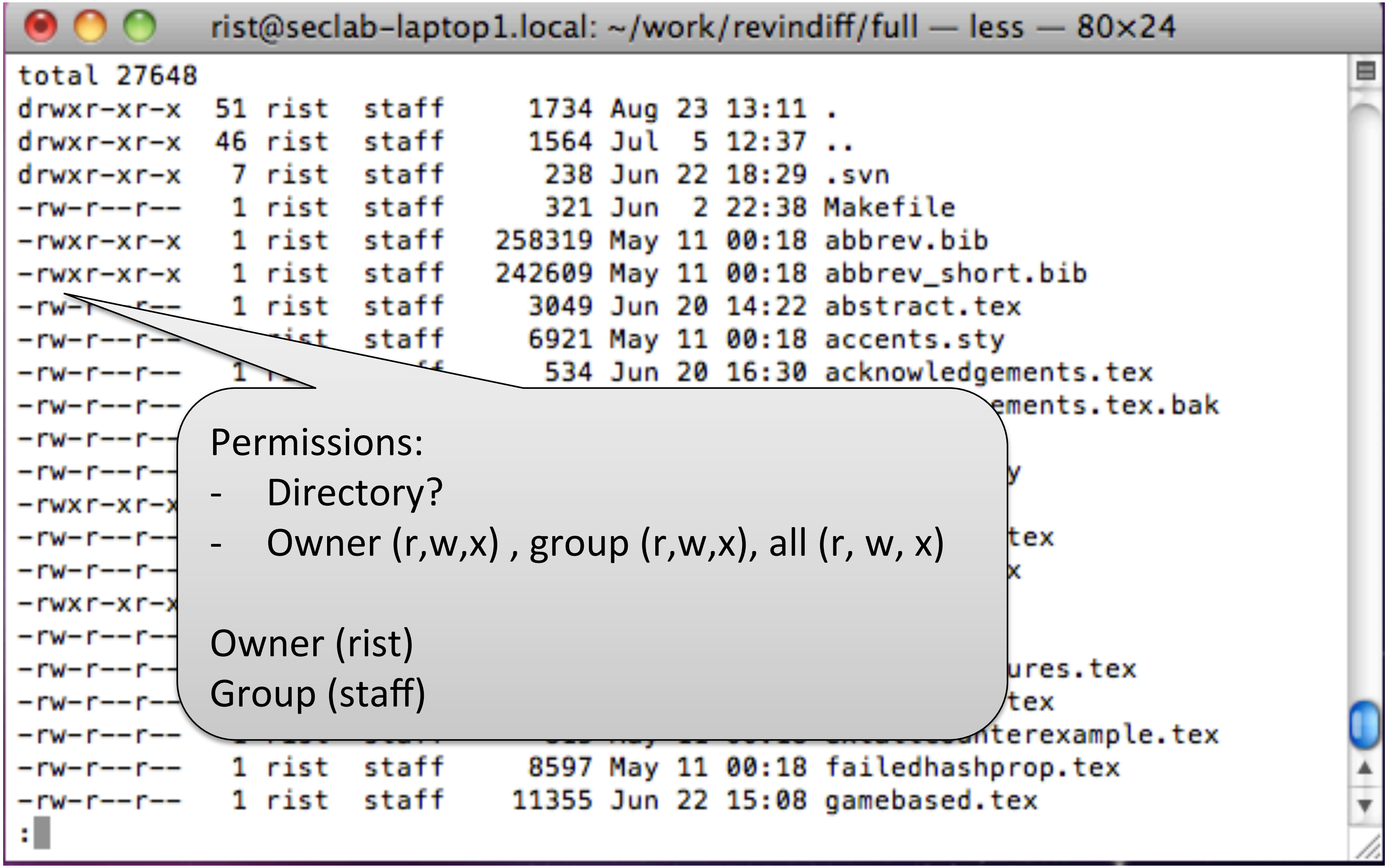
UNIX-style file system



rist@seclab-laptop1.local: ~/work/revindiff/full — less — 80×24

```
total 27648
drwxr-xr-x  51 rist  staff     1734 Aug 23 13:11 .
drwxr-xr-x  46 rist  staff     1564 Jul  5 12:37 ..
drwxr-xr-x   7 rist  staff      238 Jun 22 18:29 .svn
-rw-r--r--   1 rist  staff      321 Jun  2 22:38 Makefile
-rwxr-xr-x   1 rist  staff   258319 May 11 00:18 abbrev.bib
-rwxr-xr-x   1 rist  staff   242609 May 11 00:18 abbrev_short.bib
-rw-r--r--   1 rist  staff     3049 Jun 20 14:22 abstract.tex
-rw-r--r--   1 rist  staff     6921 May 11 00:18 accents.sty
-rw-r--r--   1 rist  staff      534 Jun 20 16:30 acknowledgements.tex
-rw-r--r--   1 rist  staff      535 Jun  4 14:49 acknowledgements.tex.bak
-rw-r--r--   1 rist  staff  1813843 Jun  1 16:50 blah.zip
-rw-r--r--   1 rist  staff     2150 Jun  4 14:13 citesort.sty
-rwxr-xr-x   1 rist  staff       30 May 11 00:18 conf.bib
-rw-r--r--   1 rist  staff     1321 May 11 00:18 cornercase.tex
-rw-r--r--   1 rist  staff     1385 May 11 00:18 crpproof.tex
-rwxr-xr-x   1 rist  staff  6927118 May 11 00:18 crypto.bib
-rw-r--r--   1 rist  staff    59648 Jun 22 15:27 defs.tex
-rw-r--r--   1 rist  staff     1115 May 11 00:18 entropymeasures.tex
-rw-r--r--   1 rist  staff    10634 May 11 00:18 extattacks.tex
-rw-r--r--   1 rist  staff      815 May 11 00:18 extattcounterexample.tex
-rw-r--r--   1 rist  staff     8597 May 11 00:18 failedhashprop.tex
-rw-r--r--   1 rist  staff    11355 Jun 22 15:08 gamebased.tex
:
```

UNIX-style file system ACLs



rist@seclab-laptop1.local: ~/work/revindiff/full — less — 80×24

```
total 27648
drwxr-xr-x  51 rist  staff     1734 Aug 23 13:11 .
drwxr-xr-x  46 rist  staff     1564 Jul  5 12:37 ..
drwxr-xr-x   7 rist  staff      238 Jun 22 18:29 .svn
-rw-r--r--   1 rist  staff      321 Jun  2 22:38 Makefile
-rwxr-xr-x   1 rist  staff   258319 May 11 00:18 abbrev.bib
-rwxr-xr-x   1 rist  staff   242609 May 11 00:18 abbrev_short.bib
-rw-r--r--   1 rist  staff     3049 Jun 20 14:22 abstract.tex
-rw-r--r--   1 rist  staff     6921 May 11 00:18 accents.sty
-rw-r--r--   1 rist  staff      534 Jun 20 16:30 acknowledgements.tex
-rw-r--r--                                            ements.tex.bak
-rw-r--r--
-rw-r--r--                                            y
-rwxr-xr-x
-rw-r--r--                                            tex
-rw-r--r--                                            x
-rwxr-xr-x
-rw-r--r--
-rw-r--r--                                            ures.tex
-rw-r--r--                                            tex
-rw-r--r--                                         nterexample.tex
-rw-r--r--   1 rist  staff     8597 May 11 00:18 failedhashprop.tex
-rw-r--r--   1 rist  staff    11355 Jun 22 15:08 gamebased.tex
:
```

Permissions:

- Directory?
- Owner (r,w,x) , group (r,w,x), all (r, w, x)

Owner (rist)
Group (staff)

Who uses capabilities?

- Amoeba: distributed operating system (1990's)
- Eros (extremely reliable operating system)

(From Wikipedia)

- IBM System 38
- Intel iAPX 432

Capabilities are used in various ways inside modern systems all over

Delegation

Need to give a process, other user access

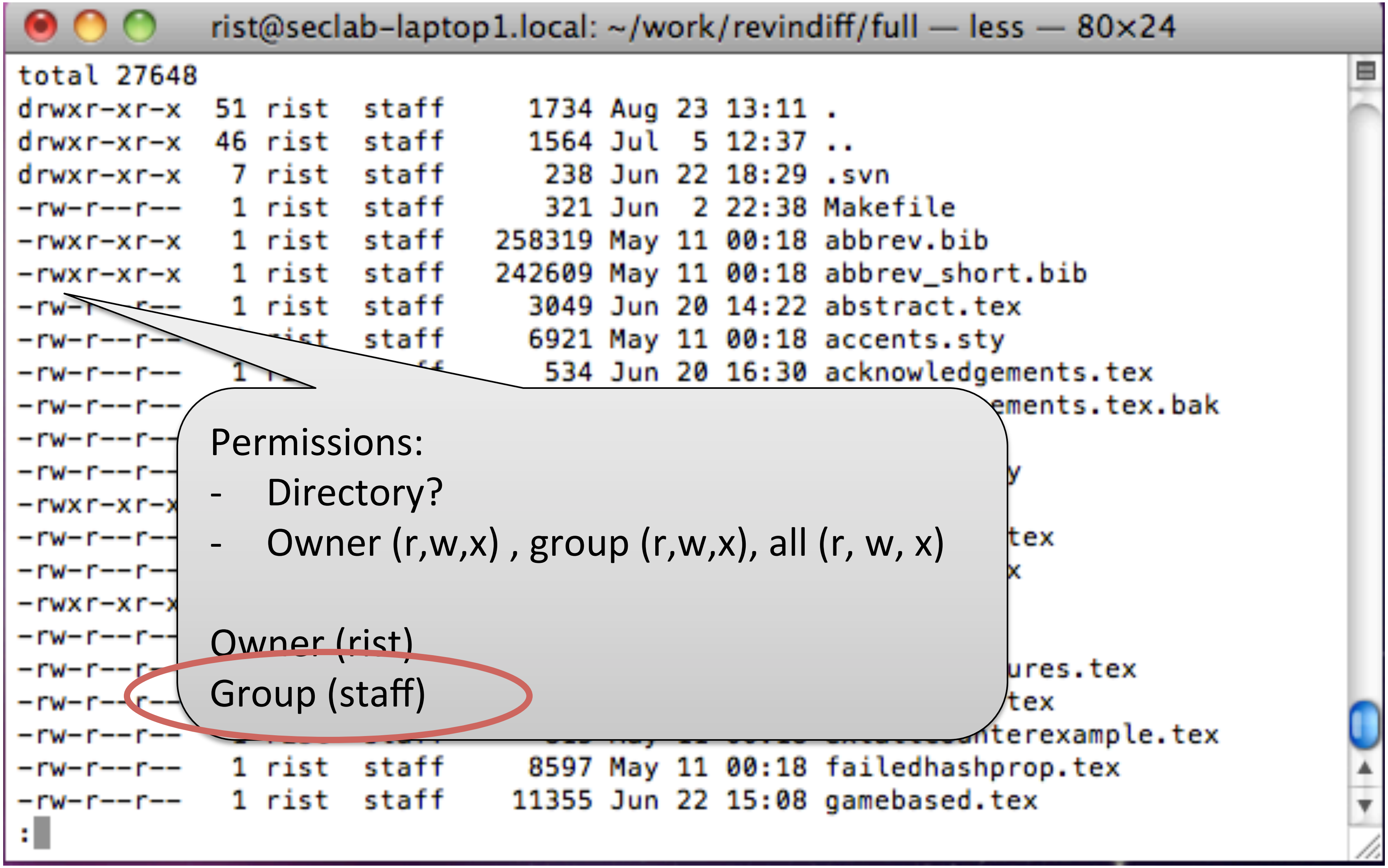
- In ACL, process run by user inherits user’s permissions
- In Cap, process can pass around token

Revocation

Take away access from user or process

- In ACL, remove user from list
- In Cap, more difficult
  - Reference monitor must know where tokens are
  - Using pointer indirection

UNIX-style file system ACLs



rist@seclab-laptop1.local: ~/work/revindiff/full — less — 80×24

```
total 27648
drwxr-xr-x  51 rist  staff     1734 Aug 23 13:11 .
drwxr-xr-x  46 rist  staff     1564 Jul  5 12:37 ..
drwxr-xr-x   7 rist  staff      238 Jun 22 18:29 .svn
-rw-r--r--   1 rist  staff      321 Jun  2 22:38 Makefile
-rwxr-xr-x   1 rist  staff   258319 May 11 00:18 abbrev.bib
-rwxr-xr-x   1 rist  staff   242609 May 11 00:18 abbrev_short.bib
-rw-r--r--   1 rist  staff     3049 Jun 20 14:22 abstract.tex
-rw-r--r--   1 rist  staff     6921 May 11 00:18 accents.sty
-rw-r--r--   1 rist  staff      534 Jun 20 16:30 acknowledgements.tex
-rw-r--r--                                    ements.tex.bak
-rw-r--r--
-rw-r--r--                                    y
-rwxr-xr-x
-rw-r--r--                                    tex
-rw-r--r--                                    x
-rwxr-xr-x
-rw-r--r--
-rw-r--r--                                    ures.tex
-rw-r--r--                                    tex
-rw-r--r--                                    nterexample.tex
-rw-r--r--   1 rist  staff     8597 May 11 00:18 failedhashprop.tex
-rw-r--r--   1 rist  staff    11355 Jun 22 15:08 gamebased.tex
:
```

Permissions:

- Directory?
- Owner (r,w,x) , group (r,w,x), all (r, w, x)

Owner (rist)

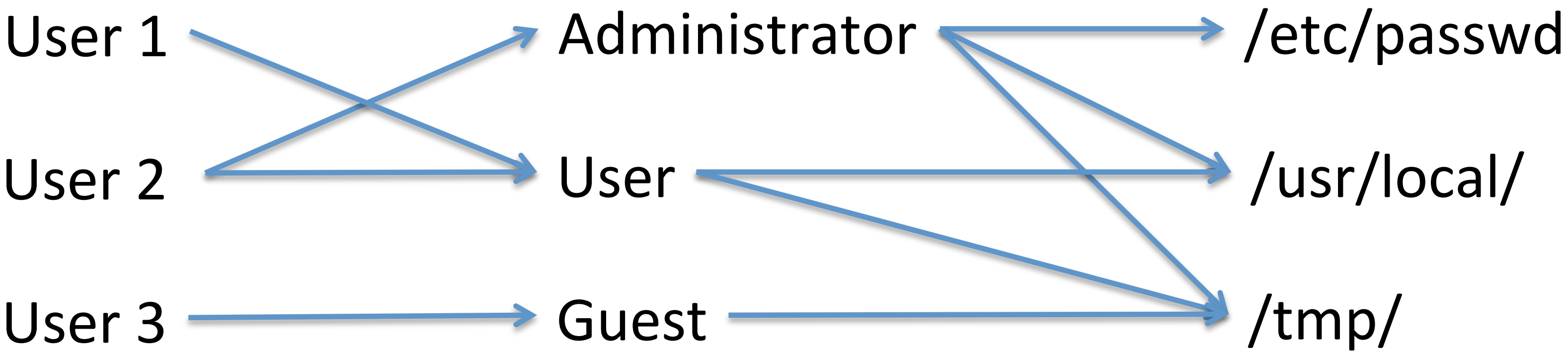
Group (staff)

Roles (groups)

Group is a set of users

Administrator User Guest

Simplifies assignment of permissions at scale



User 1 Administrator /etc/passwd

User 2 User /usr/local/

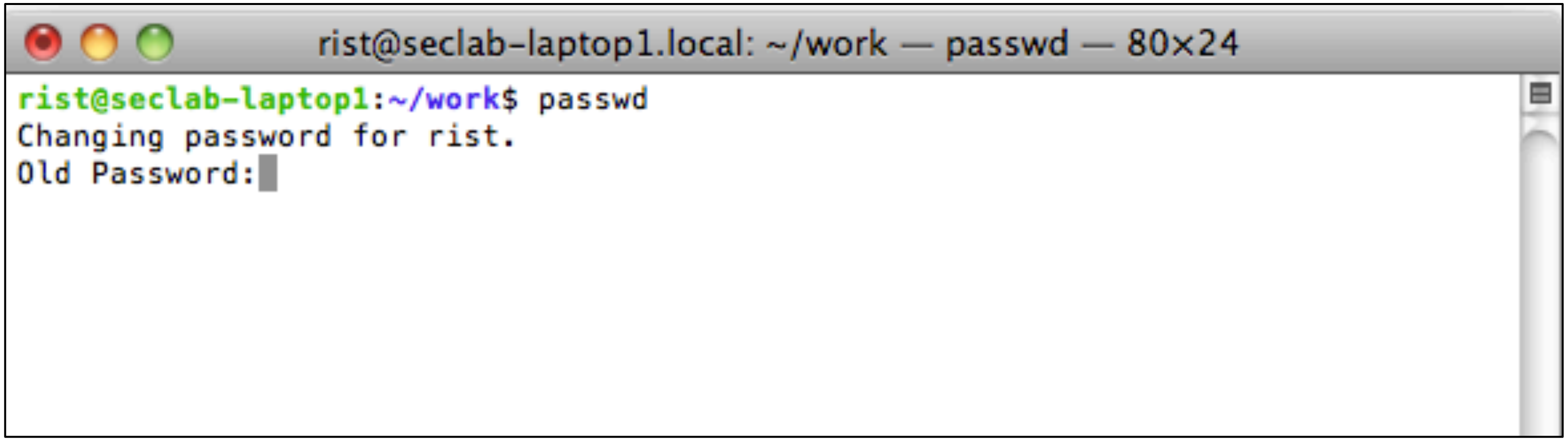
User 3 Guest /tmp/

UNIX file permissions

- Owner, group
- Permissions set by owner / root
- Resolving permissions:
  - If user=owner, then owner privileges
  - If user in group, then group privileges
  - Otherwise, all privileges

UNIX Process permissions

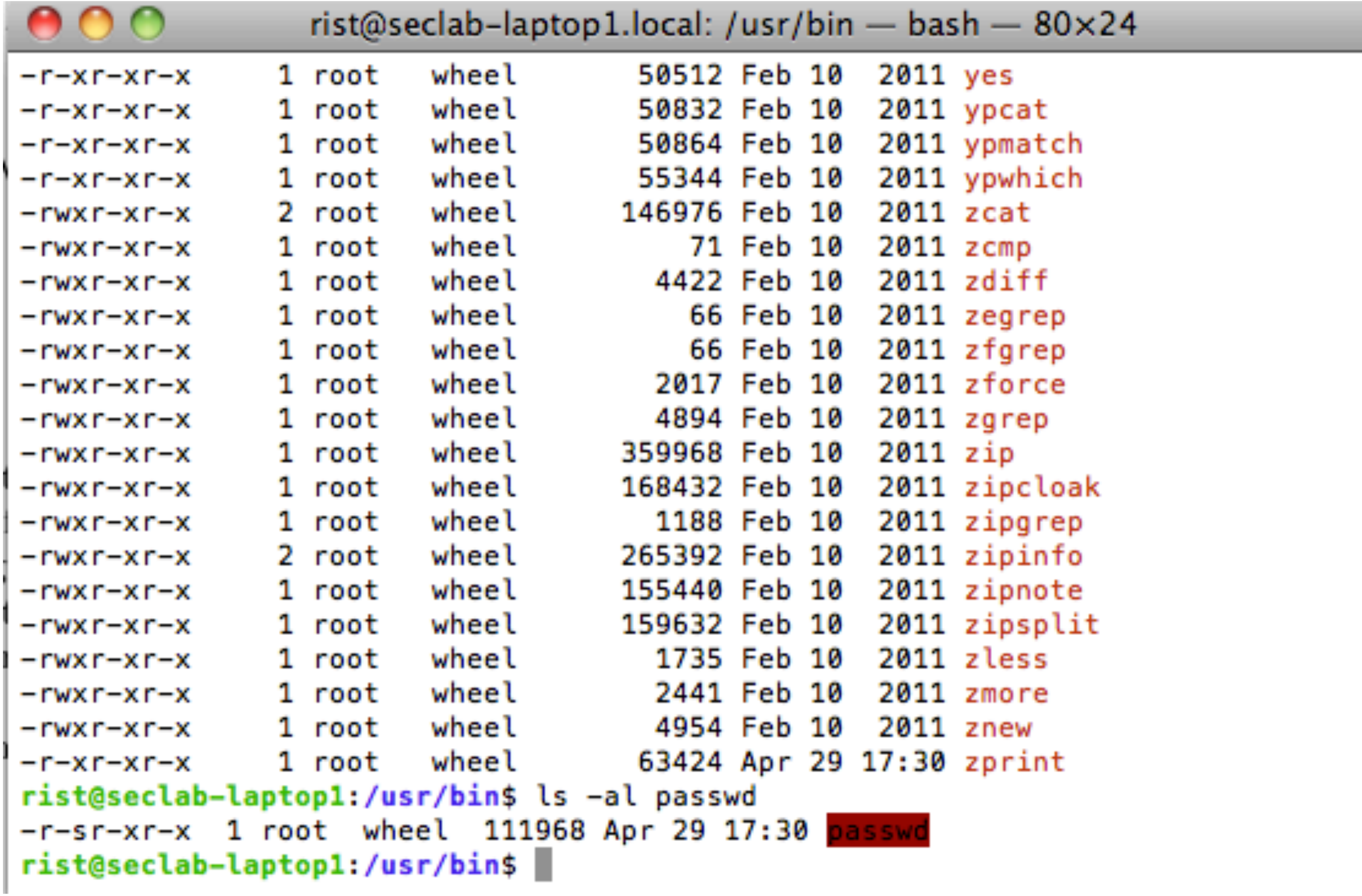
- Process (normally) runs with permissions of user that invoked process



```
rist@seclab-laptop1:~/work$ passwd
Changing password for rist.
Old Password:
```

/etc/passwd is owned by root

Users shouldn’t be able to write to it generally



```
-r-xr-xr-x     1 root   wheel      50512 Feb 10  2011 yes
-r-xr-xr-x     1 root   wheel      50832 Feb 10  2011 ypcat
-r-xr-xr-x     1 root   wheel      50864 Feb 10  2011 ypmatch
-r-xr-xr-x     1 root   wheel      55344 Feb 10  2011 ypwhich
-rwxr-xr-x     2 root   wheel     146976 Feb 10  2011 zcat
-rwxr-xr-x     1 root   wheel         71 Feb 10  2011 zcmp
-rwxr-xr-x     1 root   wheel       4422 Feb 10  2011 zdiff
-rwxr-xr-x     1 root   wheel         66 Feb 10  2011 zegrep
-rwxr-xr-x     1 root   wheel         66 Feb 10  2011 zfgrep
-rwxr-xr-x     1 root   wheel       2017 Feb 10  2011 zforce
-rwxr-xr-x     1 root   wheel       4894 Feb 10  2011 zgrep
-rwxr-xr-x     1 root   wheel     359968 Feb 10  2011 zip
-rwxr-xr-x     1 root   wheel     168432 Feb 10  2011 zipcloak
-rwxr-xr-x     1 root   wheel       1188 Feb 10  2011 zipgrep
-rwxr-xr-x     2 root   wheel     265392 Feb 10  2011 zipinfo
-rwxr-xr-x     1 root   wheel     155440 Feb 10  2011 zipnote
-rwxr-xr-x     1 root   wheel     159632 Feb 10  2011 zipsplit
-rwxr-xr-x     1 root   wheel       1735 Feb 10  2011 zless
-rwxr-xr-x     1 root   wheel       2441 Feb 10  2011 zmore
-rwxr-xr-x     1 root   wheel       4954 Feb 10  2011 znew
-r-xr-xr-x     1 root   wheel      63424 Apr 29 17:30 zprint
rist@seclab-laptop1:/usr/bin$ ls -al passwd
-r-sr-xr-x  1 root  wheel  111968 Apr 29 17:30 passwd
rist@seclab-laptop1:/usr/bin$ 
```

Process permissions continued

UID 0 is root

Real user ID (RUID) --
same as UID of parent (who started process)

Effective user ID (EUID) --
from set user ID bit of file being executed or due to sys call

Saved user ID (SUID) --
place to save the previous UID if one temporarily changes it

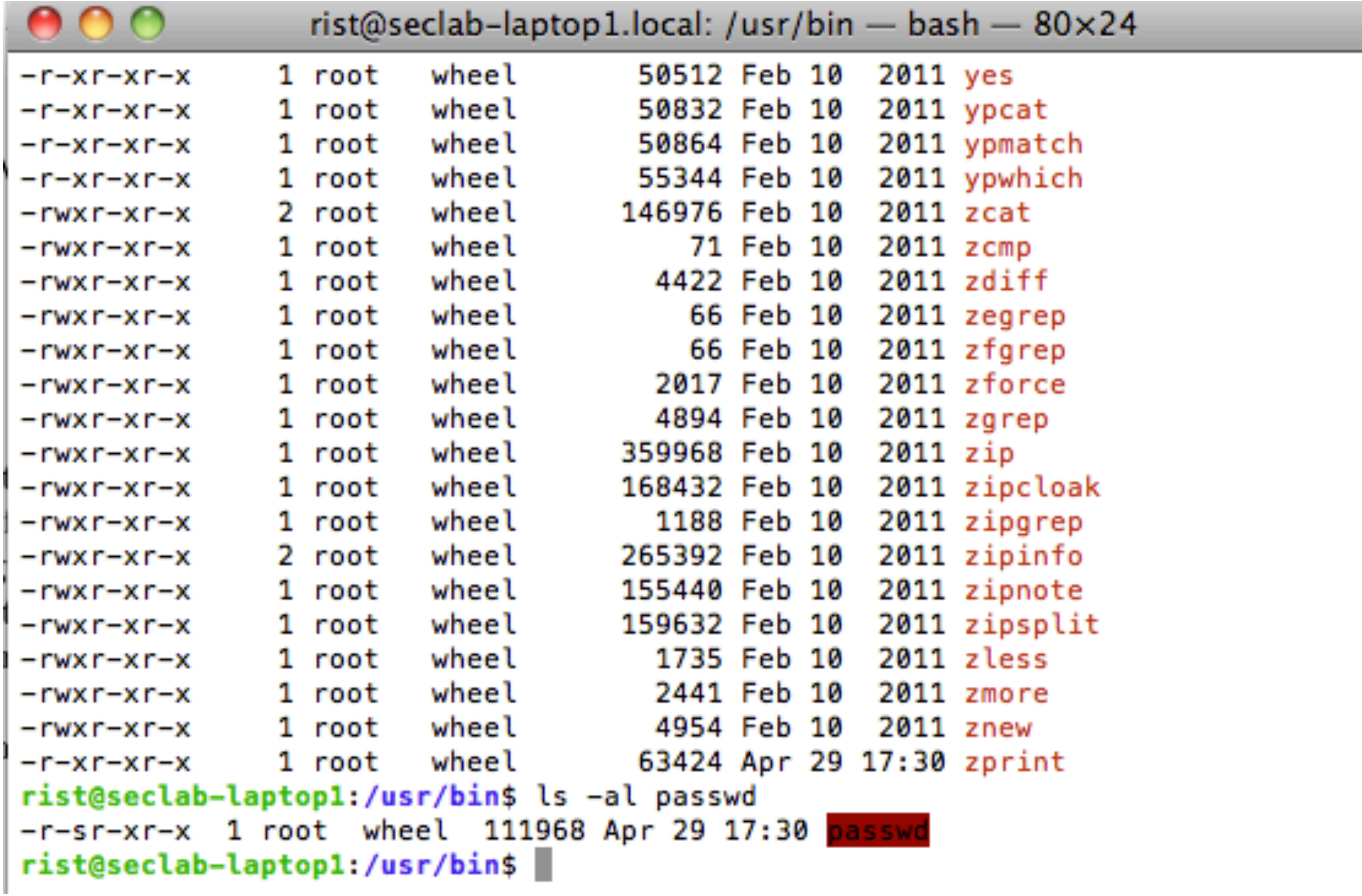
Also SGID, EGID, etc..

Executable files have 3 setuid bits

- Setuid bit – set EUID of process to owner's ID
- Setgid bit – set EGID of process to group's ID
- sticky bit:
  - 0 means user with write on directory can rename/ remove file
  - 1 means only file owner, directory owner, root can do so

So passwd is a setuid programs

program runs at permission level of owner, not user that runs it



```
-r-xr-xr-x     1 root    wheel        50512 Feb 10  2011 yes
-r-xr-xr-x     1 root    wheel        50832 Feb 10  2011 ypcat
-r-xr-xr-x     1 root    wheel        50864 Feb 10  2011 ypmatch
-r-xr-xr-x     1 root    wheel        55344 Feb 10  2011 ypwhich
-rwxr-xr-x     2 root    wheel       146976 Feb 10  2011 zcat
-rwxr-xr-x     1 root    wheel           71 Feb 10  2011 zcmp
-rwxr-xr-x     1 root    wheel         4422 Feb 10  2011 zdiff
-rwxr-xr-x     1 root    wheel           66 Feb 10  2011 zegrep
-rwxr-xr-x     1 root    wheel           66 Feb 10  2011 zfgrep
-rwxr-xr-x     1 root    wheel         2017 Feb 10  2011 zforce
-rwxr-xr-x     1 root    wheel         4894 Feb 10  2011 zgrep
-rwxr-xr-x     1 root    wheel       359968 Feb 10  2011 zip
-rwxr-xr-x     1 root    wheel       168432 Feb 10  2011 zipcloak
-rwxr-xr-x     1 root    wheel         1188 Feb 10  2011 zipgrep
-rwxr-xr-x     2 root    wheel       265392 Feb 10  2011 zipinfo
-rwxr-xr-x     1 root    wheel       155440 Feb 10  2011 zipnote
-rwxr-xr-x     1 root    wheel       159632 Feb 10  2011 zipsplit
-rwxr-xr-x     1 root    wheel         1735 Feb 10  2011 zless
-rwxr-xr-x     1 root    wheel         2441 Feb 10  2011 zmore
-rwxr-xr-x     1 root    wheel         4954 Feb 10  2011 znew
-r-xr-xr-x     1 root    wheel        63424 Apr 29 17:30 zprint
rist@seclab-laptop1:/usr/bin$ ls -al passwd
-r-sr-xr-x  1 root  wheel  111968 Apr 29 17:30 passwd
rist@seclab-laptop1:/usr/bin$ 
```

seteuid system call

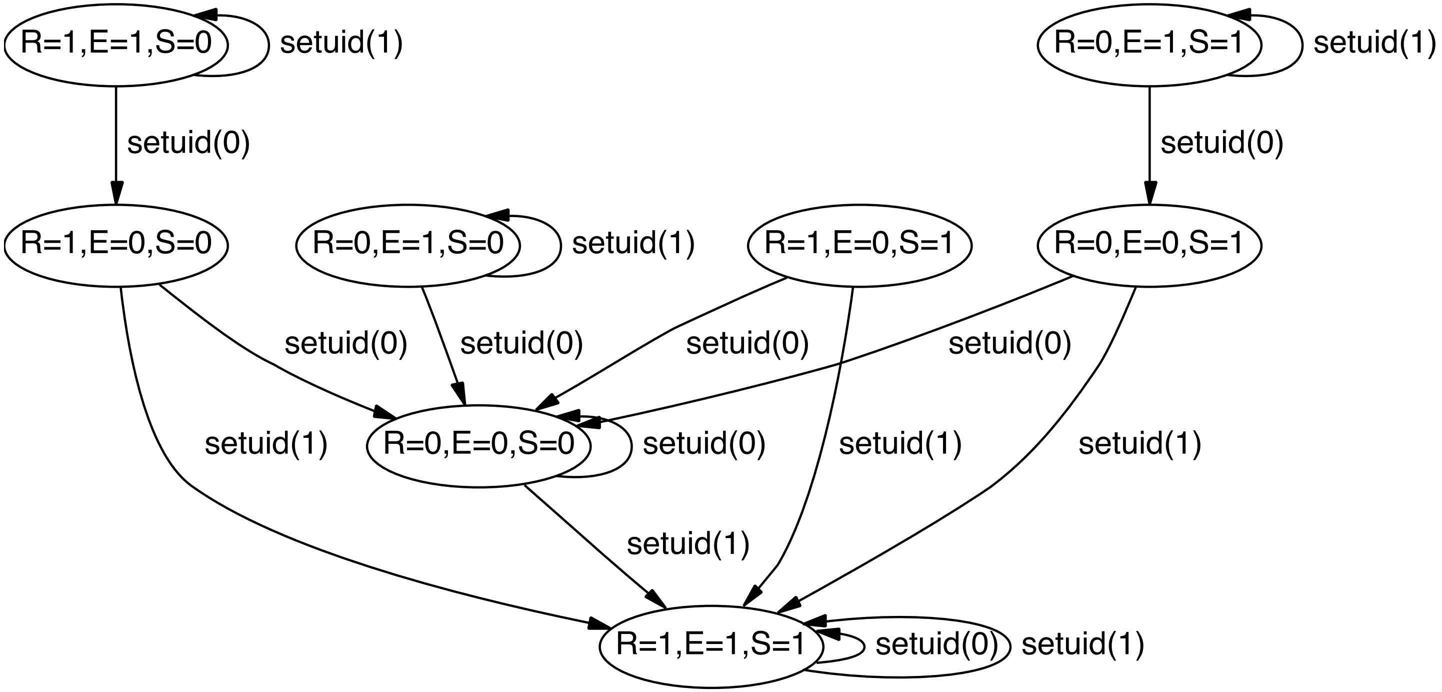
seteuid can:

- go to SUID or RUID always
- any ID if EUID is 0

```
uid = getuid();
eid = geteuid();
seteuid(uid);      // Drop privileges
…
seteuid(eid);      // Raise privileges
file = fopen( “/etc/passwd”, “w” );
…
seteuid(uid);     // drop privileges
```

Details of setuid more complicated

Chen, Wagner, Dean “Setuid Demystified”



(a) An FSA describing *setuid* in Linux 2.4.18

Setuid allows necessarily privilege escalation but…

- Source of many privilege escalation vulnerabilities

Buffer overflow (next lecture) in local setuid program gives privilege escalation

Race conditions

Race conditions
Time-of-check-to-time-of-use (TOCTTOU)

```
if( access(“/tmp/myfile”, R_OK) != 0 ) {
    exit(-1);
}
file = open( “/tmp/myfile”, “r” );
read( file, buf, 100 );
close( file );
print( “%s\n”, buf );
```

Say program is setuid root:
access checks RUID, but open only checks EUID

```
access(“/tmp/myfile”, R_OK)
```

```
ln –s /tmp/myfile  /home/root/.ssh/id_rsa
```

```
open( “/tmp/myfile”, “r” );
```

```
print( “%s\n”, buf );
```

Prints out the root’s secret key…

Better code

```
euid = geteuid();
ruid = getuid();
seteuid(ruid);              // drop privileges
file = open( “/tmp/myfile”, “r” );
read( file, buf, 100 );
close( file );
print( “%s\n”, buf );
```

Summary

- Multics: seminal multi-user operating system
  - many security features
  - significant auditing performed, achieved high security certifications
- MLS security principles
  - covert channels
- Access controls (matrixes, ACLs, capabilities)
- UNIX style file and process permissions