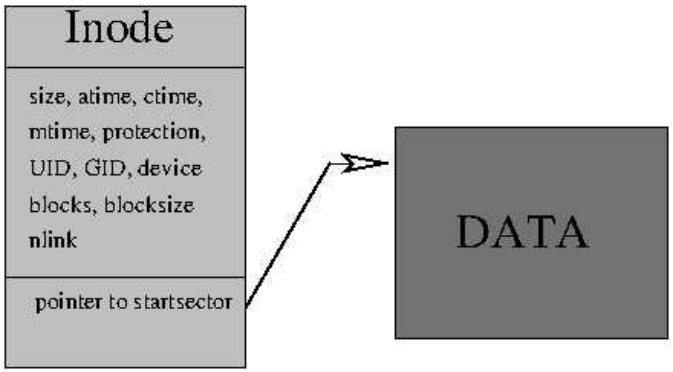
The Inode



Inode Contents

contains administrative data of a file

can be read by the `stat()` system call

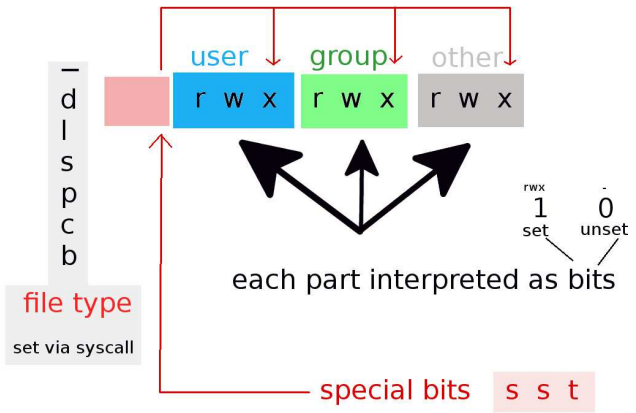

```
struct stat {
    ino_t         st_ino;      /* inode */
    dev_t         st_dev;      /* device of this file */
    mode_t        st_mode;     /* protection + file type */
    nlink_t       st_nlink;    /* number of hard links */
    uid_t         st_uid;      /* user ID of owner */
    gid_t         st_gid;      /* group ID of owner */
    dev_t         st_rdev;     /* device type (if inode device) */
    off_t         st_size;     /* total size, in bytes */
    blksize_t     st_blksize;  /* blocksize for filesystem I/O */
    blkcnt_t      st_blocks;   /* number of blocks allocated */
    time_t        st_atime;    /* time of last access */
    time_t        st_mtime;    /* time of last modification */
    time_t        st_ctime;    /* time of last change */
};
```


The File Type

. . . determines which kind of file it is . . .

type	description	
regular file	,,normal" file with user data or a program	`-`
directory	contains file names pointing to their inodes	`d`
link	points to another file	`l`
socket	UNIX domain socket, process communication	`s`
pipe	process communication	`p`
block device	device handling data in blocks	`b`
character device	device handling data char by char	`c`

The Protection Bits



Default Protection of a New File (umask)

file mask	r	w	–	r	w	–	r	w	– (666)
"unmask"	–	–	–	–	w	–	–	w	– (022)
result	r	w	–	r	–	–	r	–	– (644)
dir mask	r	w	x	r	w	x	r	w	x (777)
"unmask"	–	–	–	–	w	–	–	w	– (022)
result	r	w	x	r	–	x	r	–	x (755)

Setting Protection Bits (chmod)

```
$ ls -l mytestfile
-rw-------    1 dw       users          12 Apr  6 10:53 mytestfile

$ chmod 640 mytestfile

$ ls -l mytestfile
-rw-r-----    1 dw       users          12 Apr  6 10:53 mytestfile
```


Meaning on directories (1)

read a directory: read the file names in it

```
$ ls -ld testdir
dr--------    2 dw       users        1024 Apr  6 11:41 testdir
$ ls -l testdir
/bin/ls: testdir/testfile1: Permission denied
/bin/ls: testdir/testfile2: Permission denied
total 0
$ cd testdir
bash: cd: testdir: Permission denied
$ cat >testdir/testfile3
bash: testdir/testfile3: Permission denied
```

Meaning on directories (2)

execute bit to a directory: search path allowed

```
$ ls -ld testdir
d--x------    2 dw       users        1024 Apr  6 11:41 testdir
$ cd testdir
$ cat testfile1
00000000000000000000
11111111111111111111
22222222222222222222
33333333333333333333
```


Meaning on directories (3)

write to a directory: creating/removing files allowed

makes sense only if *execute bit* is set

```
$ ls -ld testdir
drwx------    2 dw       users        1024 Apr  6 11:41 testdir
$ cd testdir
$ ls -l
total 1
-rw-r--r--    1 dw       users          80 Apr  6 11:47 testfile1
-rw-r--r--    1 dw       users           0 Apr  6 11:41 testfile2
$ rm testfile2
$ ls -l
total 1
-rw-r--r--    1 dw       users          80 Apr  6 11:47 testfile1
```


Special Protection Bits Needed

in a world writable directory like `/tmp`

everybody may remove anybody's files

> STICKY DIRECTORIES
>
> When the sticky bit is set on a directory, files in that directory may be unlinked or renamed only by root or their owner. Without the sticky bit, anyone able to write to the directory can delete or rename files. The sticky bit is commonly found on directories, such as /tmp, that are world-writable.

Special Protection Bit: Sticky Bit

The sticky bit is set by a leading 1 in the `chmod` calls.

Example:

```
$ chmod 1777 testdir
$ ls -ld testdir
drwxrwxrwt    2 dw       users        1024 Apr  6 11:50 testdir
```

Special Protection Bit: Setuid Bit (1)

the setuid mechanism is needed for controlled access to

- parts of a file
- a file by a certain set of users

and must be logically controlled by a process

Special Protection Bit: Setuid Bit (2)

example: the file `/etc/master.passwd` on BSD contains encrypted user passwords

```
-rw-------  root  wheel  /etc/master.passwd
```

(`/etc/shadow` on Linux)

```
root:$1$TeLs7PIX$ebgD6bh573GWHN12Aaut5/:
      0:0::0:0:root:/root:/bin/csh
sysi40:$1$dIQvGCrn$f46M9fNfWTmOVsyfQEwdu0:2040:1000:
      :0:0:........:/home/sysi40:/usr/local/bin/bash
```

sysi40 wants to change his password

⇝needs write access to `/etc/master.passwd`

but if he had write access he could change root's password too

Special Protection Bit: Setuid Bit (3)

Solution: processes have two User–IDs

- RUID: real User–ID – who starts the process
- EUID: effective User–ID – decides about file access

normally RUID==EUID

> If the Setuid Bit is set on a program, the EUID is the UID of the program owner.

With the `ps` command, we see the EUID.

Special Protection Bit: Setuid Bit (4)

```
-r-sr-xr-x  root  wheel /usr/bin/passwd

-rw-------  root  wheel /etc/master.passwd
```

- `/etc/master.passwd` owner root, protection `rw-------`
- program `passwd` can change one line in `/etc/master.passwd`
- program `passwd` is owned by root
- program `passwd` has the `setuid bit`
- sysi40 starts program `passwd`
- process `passwd` has RUID=sysi40, EUID=root

⇝ for this process the `rw-` part counts

Special Protection Bit: Setuid Bit (5)

The setuid bit is set by a leading 4 in the chmod calls.

Example:

```
$ chmod 755 my_program
$ ls -l my_program
-rwxr-xr-x    1 dw       users      255996 Jan 17 18:38 my_program
$ chmod 4755 my_program
$ ls -l my_program
-rwsr-xr-x    1 dw       users      255996 Jan 17 18:38 my_program
```


Special Protection Bit: Setgid Bit

The same mechanism holds for the GID field of the protection.

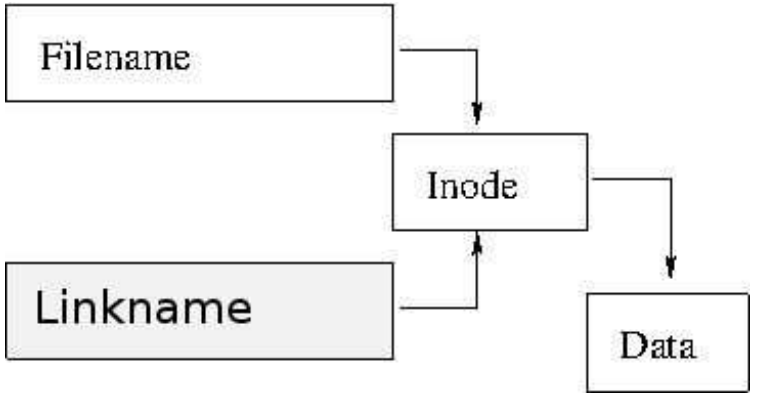
We have

- RGID the real GID
- EGID the effective GID

The setgid bit is set by a leading 2 in the chmod calls.

```
$ chmod 2755 my_other_program
$ ls -l my_other_program
-rwxr-sr-x    1 dw       users     1723139 Feb 15 15:11 my_other_program
```

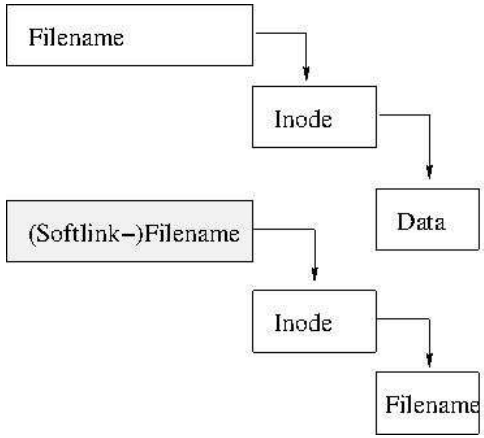

Hardlink Count: Hardlinks



Hardlink count is a reference counter.

The inode gets removed if the hardlink count becomes zero.

Symbolic Links: Softlinks



The file has no idea about whether a softlink points to it.

Hardlinks and Softlinks

	Hardlinks	Softlinks
command	ln	ln –s
performance	faster	slower
have a file type	no	yes
reach across filesystems	no	yes
to directories	no	yes
distinguish original/link	no	yes
traceable	no	yes
may be broken	no	yes

In general, commands and system calls follow softlinks, but there are exceptions: lstat(), tar,. . .

Hardlinks on Directories

.	points to current directory
..	points to parent directory

created via mkdir / removed via rmdir

there is no other way to create hard links (even for root)

reasons:

- would break acyclic structure (disk usage utilities etc)
- would create two or more parent directories

Inode Timestamps

Inode Timestamps:

- atime (access time): time of last access, e.g.
  `functions: read(), execve(), mknod(), pipe(), utime()`
- ctime (change time): time of last change of inode info
  `functions: chown(), chgrp(), chmod(), ...`
- mtime (modification time): time of last change of files's data
  `write(), mknod(), truncate(), utime()`

command that affects timestamps: `touch`

UNIX Time

UNIX time data: seconds elapsed since
01.01.1970, 00:00:00 UTC.
Stored in a signed 32–bit integer.

UTC = universal time coordinated
GMT = Greenwich Mean Time
CET = Central Europe Time
CEST = Central Europe Summer Time

UNIX Time Overflow

One year has 31536000 seconds.

One leap year has 31622400 seconds.

Four years have 126230400 seconds.

2^{31} seconds are 2147483648 seconds (signed 32-bit).

$2147483648 = 17 \cdot 126230400 + 1566848$

$1566848 = 18 \cdot 24 \cdot 3600 + 11648$

$11648 = 3 \cdot 3600 + 14 \cdot 60 + 8$

So the overflow occurs after

$17 \cdot 4 = 68$ years, 18 days, 3 hours, 14 min and 8 sec

which is the

19.01.2038, 03:14:08 GMT.

UNIX Time Overflow (2)

Solutions to the overflow problem:

- use *unsigned* 32-bit integer,
  overflow occurs after $2 \cdot 68 = 136$ years in the February of 2106

  problem: programmers rely on signed integer,
  including positive and negative differences of `time_t` values
- use signed *64-bit* integer, overflow in the year 292.277.026.596
  (default on 64-bit operating systems)

open question: will there be still 32-bit systems in the year 2038?

- embedded CPUs?
- file systems?

Hardware Clock and Time Zones

When a computer boots, it sets its system clock from the Real–Time–Clock (RTC) chip containing a 32768 Hz crystal oscillator.

Problems when RTC has local time:

- at the same time, different times are displayed in different time zones
- booting within an hour after DST ends raises questions whether the clock must be adjusted
- virtualization
  - causes one operating system to adjust RTC
  - causes the next operating system to adjust RTC

$\rightsquigarrow$ RTC *should not* have local time

In Microsoft systems, even in Windows 7/8, RTC *has* local time.

you can create a registry key (up to Windows 8)

`SYSTEM\CurrentControlSet\Control\TimeZoneInformation\RealTimeIsUniversal`