# UNIX System Programming

**Files and Directories**



## File Pointer

- Both read() and write() will change the file pointer.
- The pointer will be incremented by exactly the number of bytes read or written.



## lseek

```
#include <sys/types.h>
#include <unistd.h>
off_t lseek( int fd, off_t offset, int whence );
```

- Repositions the offset of the file descriptor *fd* to the argument offset.
- *whence*
  - SEEK_SET
    - The offset is set to offset bytes.
  - SEEK_CUR
    - The offset is set to its current location plus offset bytes.
  - SEEK_END
    - The offset is set to the size of the file plus offset bytes.

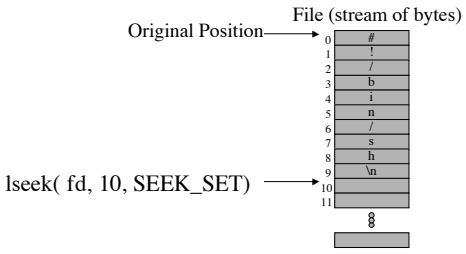


## lseek: Examples

- Random access
  - Jump to any byte in a file
- Move to byte #16
  - `newpos = lseek( file_descriptor, 16, SEEK_SET );`
- Move forward 4 bytes
  - `newpos = lseek( file_descriptor, 4, SEEK_CUR );`
- Move to 8 bytes from the end
  - `newpos = lseek( file_descriptor, -8, SEEK_END );`

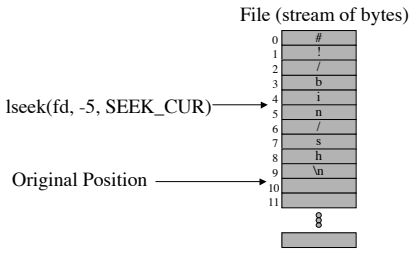


## lseek - SEEK_SET (10)

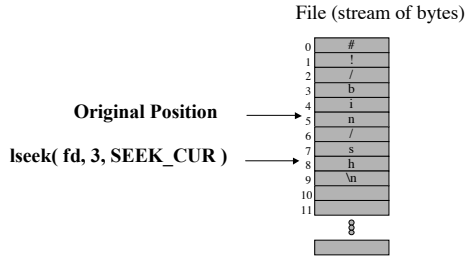





## lseek - SEEK_CUR (-5)



# lseek - SEEK_CUR(3)

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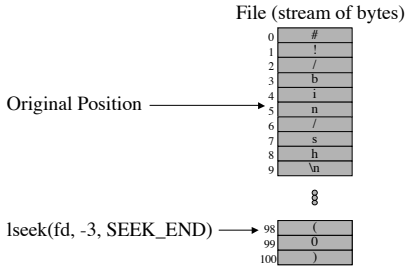
# lseek - SEEK_END (-3)

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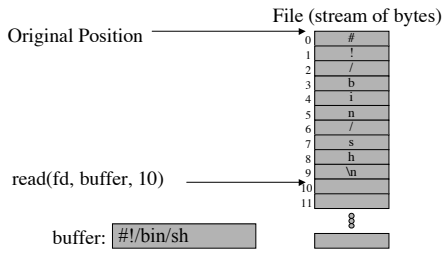
# Read – File Pointer

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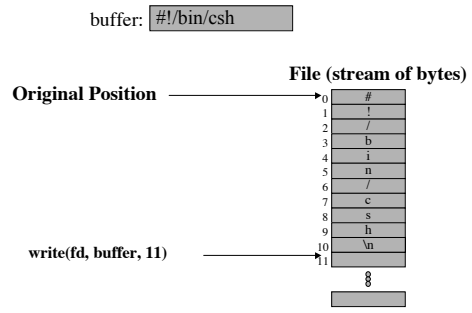
# Write – File Pointer

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# Example #1: lseek

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>

char buf1[] = "abcdefghij";
char buf2[] = "ABCDEFGHIJ";

int main(void)
  {
   int fd;

   if( (fd = creat("file.hole", 0640)) < 0 )
      {
      perror("creat error");
      exit(1);
      }
```

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# Example #1: lseek (2)

```
if( write(fd, buf1, 10) != 10 )
     {
     perror("buf1 write error");
     exit(1);
     }
 /* offset now = 10 */
if( lseek(fd, 40, SEEK_SET) == -1 )
     {
     perror("lseek error");
     exit(1);
     }
/* offset now = 40 */
if( write(fd, buf2, 10) != 10  )
     {
     perror("buf2 write error");
     exit(1);
     }
/* offset now = 50 */
exit(0);
}
```

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## File control of open files: fcntl()

```
#include <unistd.h>
#include <fcntl.h>

int fcntl( int fd, int cmd );
int fcntl( int fd, int cmd, long arg );
int fcntl( int fd, int cmd, struct lock *ldata )
```

- Performs operations pertaining to *fd,* the file descriptor
- Specific operation depends on cmd

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## fcntl: cmd

- F_GETFL
  - Returns the current file status flags as set by open().
  - Access mode can be extracted from AND'ing the return value
    - return_value & O_ACCMODE
      - e.g. O_WRONLY
- F_SETFL
  - Sets the file status flags associated with fd.
  - Only O_APPEND, O_NONBLOCK and O_ASYNC may be set.
  - Other flags are unaffected

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## Example 1: fcntl()

```
#include <stdio.h>
#include <sys/types.h>
#include <fcntl.h>

int main( int argc, char *argv[] )
   {
   int accmode, val;

   if( argc != 2 )
        {
        fprintf( stderr, "usage: a.out <descriptor#>" );
        exit(1);
        }

   if( (val = fcntl(atoi(argv[1]), F_GETFL, 0)) < 0 )
        {
        perror( "fcntl error for fd" );
        exit( 1 );
        }
   accmode = val & O_ACCMODE;
```

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```
   if( accmode == O_RDONLY )
        printf( "read only" );
   else if(accmode == O_WRONLY )
        printf( "write only" );
   else if( accmode == O_RDWR )
        printf( "read write" );
   else
        {
        fprintf( stderr, "unkown access mode" );
        exit(1);
        }

   if( val & O_APPEND )
        printf( ", append");
   if( val & O_NONBLOCK)
        printf(", nonblocking");
   if( val & O_SYNC )
        printf(", synchronous writes");
   putchar( '\n' );
   exit(0);
   }
```

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## Example #2: fcntl

```
#include <stdio.h>
#include <sys/types.h>
#include <fcntl.h>

/* flags are file status flags to turn on */
void set_fl( int fd, int flags )
   {
   int val;

   if( (val = fcntl( fd, F_GETFL, 0 )) < 0 )
        {
        perror( "fcntl F_GETFL error" );
        exit( 1 );
        }
   val |= flags;     /* turn on flags */
   if( fcntl( fd, F_SETFL, val ) < 0 )
        {
        perror( "fcntl F_SETFL error" );
        exit( 1 );
        }
   }
```

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## errno and perror()

- Unix provides a globally accesible integer variable that contains an error code number
- Error variable: errno – errno.h
- perror( " a string " ): a library routine

more /usr/include/asm/*errno.h

```
#ifndef _I386_ERRNO_H
#define _I386_ERRNO_H

#define EPERM       1   /* Operation not permitted */
#define ENOENT      2   /* No such file or directory */
#define ESRCH       3   /* No such process */
#define EINTR       4   /* Interrupted system call */
#define EIO         5   /* I/O error */
#define ENXIO       6   /* No such device or address */
```

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## errno and perror()

```
// file foo.c
#include <fcntl.h>
#include <unistd.h>
#include <stdio.h>

int main()
  {
  extern int errno;
  int fd;

  /* open file "data" for reading */
  if( fd = open( "nosuchfile", O_RDONLY ) == -1 )
        {
        fprintf( stderr, "Error %d\n", errno );
        perror( "hello" );
        }
  } /* end main */


{dkl:57} gcc foo.c -o foo
{dkl:58} foo
Error 2
hello: No such file or directory
```

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## The Standard IO Library

- fopen,fclose, printf, fprintf, sprintf, scanf, fscanf, getc, putc, gets, fgets, etc.
- #include <stdio.h>

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## Why use read()/write()

- Maximal performance
  - IF you know exactly what you are doing
  - No additional hidden overhead from stdio
- Control exactly what is written/read at what times

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## File Concept – An Abstract Data Type

- File Types
- File Operations
- File Attributes
- File Structure - Logical
- Internal File Structure

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## File Types

- Regular files
- Directory files
- Character special files
- Block special files
- FIFOs
- Sockets
- Symbolic Links

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## File Operations

- Creating a file
- Writing a file
- Reading a file
- Repositioning within a file
- Deleting a file
- Truncating a file

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## Files Attributes

- Name
- Type
- Location
- Size
- Protection
- Time,date and user identification

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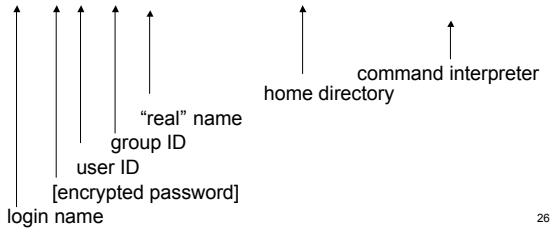
## Users and Ownership: /etc/passwd

- Every File is owned by one of the system's users – identity is represented by the user-id (UID)
- Password file assoicate UID with system users.

```
gates:x:65:20:B. Gates:/home/gates:/bin/ksh
```

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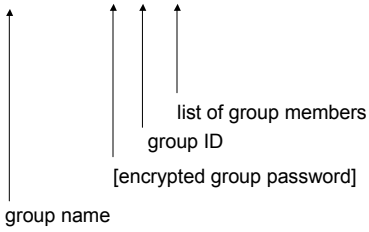
## /etc/group

- Information about system groups

```
faculty:x:23:maria,eileen,dkl
```

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## Real uids

- The uid of the user who *started* the program is used as its *real uid*.
- The real uid affects what the program can do (e.g. create, delete files).
- For example, the uid of `/usr/bin/vi` is `root`:
  - `$ ls -alt /usr/bin/vi`
    `lrwxrwxrwx 1 root root 20 Apr 13...`
- But when I use `vi`, its *real uid* is `dkl` (not `root`), so I can only edit my files.

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## Effective uids

- Programs can change to use the *effective uid*
  - the uid of the program *owner*
  - e.g. the `passwd` program changes to use its effective uid (`root`) so that it can edit the `/etc/passwd` file
- This feature is used by many system tools, such as logging programs.

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## Real and Effective Group-ids

- There are also real and effective group-ids.
- Usually a program uses the *real group-id* (i.e. the *group-id of the user*).
- Sometimes useful to use *effective group-id* (i.e. group-id of program *owner*):
  - e.g. software shared across teams

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## Extra File Permissions

- *Octal Value* *Meaning*
  `04000` Set user-id on execution.
  Symbolic: `--s --- ---`

  `02000` Set group-id on execution.
  Symbolic: `--- --s ---`

- These specify that a program should use the effective user/group id during execution.

- For example:
  - `$ ls -alt /usr/bin/passwd`
    `-rws r-xr-x 1 root root 25692 May 24...`

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## Sticky Bit

- *Octal* *Meaning*
  `01000` Save text image on execution.
  Symbolic: `--- --- --t`

- This specifies that the program code should stay resident in memory after termination.
  - this makes the start-up of the next execution faster
- Obsolete due to virtual memory.

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## The superuser

- Most sys. admin. tasks can only be done by the *superuser* (also called the *root* user)
- Superuser
  - has access to all files/directories on the system
  - can override permissions
  - owner of most system files
- Shell command: `su <username>`
  - Set current user to superuser or another user with proper password access

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## File Mode (Permission)

- S_IRUSR -- user-read
- S_IWUSR -- user-write
- S_IXUSR -- user-execute
- S_IRGRP -- group-read
- S_IWGRP -- group-write
- S_IXGRP -- group-execute
- S_IROTH -- other-read
- S_IWOTH -- other-write
- S_IXOTH -- other-execute

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## *User Mask: umask*

- Unix allows "masks" to be created to set permissions for "newly-created" directories and files.
- The umask command automatically sets the permissions when the user creates directories and files (umask stands for "user mask").
- Prevents permissions from being accidentally turned on (hides permissions that are available).
- Set the bits of the umask to permissions you want to mask out of the file permissions.
- This process is useful, since user may sometimes forget to change the permissions of newly-created files or directories.

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## umask: Calculations (1)

- **Defaults**

| **File Type** | **Default Mode** |
|---|---|
| Non-executable files | 666 |
| Executable files | 777 |
| Directories | 777 |

From this initial mode, Unix "ands" the value of the umask.

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## umask: Calculations (2)

- If you want a file permission of 644 (by default, without manually executing chmod) on a regular file, the umask would need to be 022.

| | |
|---|---|
| Default Mode | 666 |
| umask | -022 |
| New File Mode | 644 |

- Bit level: new_mask = mode & ~umask

```
    umask = 000010010 = ---rw-rw = 0022
   ~umask       = 111101101
     mode = 110110110 = rw-rw-rw = 0666
 new_mask       = 111100100 = rw------ = 0600
```

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## umask

```
#include <sys/types.h>
#include <sys/stat.h>
mode_t    umask( mode_t mask );
```

- Set file mode creation *mask* and return the old value.
- When creating a file, permissions are turned off if the corresponding bits in *mask* are set.
- Return value
  - This system call always succeeds and the previous value of the mask is returned.
  - cf. "umask" shell command

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## Example: umask

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>

int main(void)
   {
   umask(0);

   if( creat( "foo",
   S_IRUSR|S_IWUSR|S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH ) < 0 )

        {
        perror("creat error for foo");
        exit(1);
        }

   umask( S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH );
   if( creat( "bar",
   S_IRUSR|S_IWUSR|S_IRGRP|S_IWGRP|S_IROTH|S_IWOTH) < 0 )
        {
         perror("creat error for bar");
         exit(1);
        }
   exit(0);
   }
```

```
{saffron:maria:68} ls -ltra foo bar
-rw-rw-rw-   1 dkl   faculty        0 Apr  1 20:35 foo
-rw-------   1 dkl   faculty        0 Apr  1 20:35 bar
```

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## chmod and fchmod

```
#include <sys/types.h>
#include <sys/stat.h>
int chmod( const char *path, mode_t mode ) ;
int fchmod( int fd, mode_t mode );
```

- Change permissions of a file.
- The mode of the file given by *path* or referenced by *fd* is changed.
- *mode* is specified by OR'ing the following.
  - S_I{R,W,X}{USR,GRP,OTH} (basic permissions)
  - S_ISUID, S_ISGID, S_ISVTX (special bits)
- Effective uid of the process must be zero (superuser) or must match the owner of the file.
- On success, zero is returned. On error, -1 is returned.

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## Example: chmod

```
 /* set absolute mode to "rw-r--r--" */
if( chmod("bar", S_IRUSR|S_IWUSR|S_IRGRP|S_IROTH) < 0)
     {
     perror("chmod error for bar");
     exit(1);
     }
exit(0);
}
```

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## chown, fchown, lchown

```
#include <sys/types.h>
#include <unistd.h>
int chown( const char *path, uid_t owner, gid_t group
);
int fchown( int fd, uid_t owner, gid_t group );
int lchown( const char *path, uid_t owner, gid_t
group );
```

- The owner of the file specified by *path* or by *fd*.
- Only the superuser may change the owner of a file.
- The owner of a file may change the group of the file to any group of which that owner is a member.
- When the owner or group of an executable file are changed by a non-superuser, the S_ISUID and S_ISGID mode bits are *cleared*.

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## Obtaining File Information

- stat(), fstat(), lstat()

For analyzing files.

- Retrieve all sorts of information about a file
  - Which device it is stored on
  - Don't need access right to the file, but need search rights to directories in path leading to file
  - Information:
    - Ownership/Permissions of that file,
    - Number of links
    - Size of the file
    - Date/Time of last modification and access
    - Ideal block size for I/O to this file



## `struct stat`

We will look at st_mode in detail.

```
struct stat
  {
  dev_t st_dev;     /* device num.          */
  dev_t st_rdev;    /* device # spcl files  */
  ino_t st_ino;     /* i-node num.          */
  mode_t st_mode;   /* file type,mode,perms */
  nlink_t st_nlink; /* num. of links        */
  uid_t st_uid;     /* uid of owner         */
  gid_t st_gid;     /* group-id of owner    */
  off_t st_size;    /* size in bytes        */
  time_t st_atime;  /* last access time     */
  time_t st_mtime;  /* last mod. time       */
  time_t st_ctime;  /* last stat chg time   */
  long st_blksize;  /* best I/O block size  */
  long st_blocks;   /* # of 512 blocks used */
  }
```



## Recall: File Types

1. Regular File (text/binary)
2. Directory File
3. Character Special File
   e.g. I/O peripherals, such as `/dev/ttyp0`
4. Block Special File
   e.g. cdrom, such as `/dev/mcd`
5. FIFO (named pipes)
6. Sockets
7. Symbolic Links



## File Mix on a Typical System

| *File Type* | *Count* | *Percentage* |
|---|---|---|
| regular file | 30,369 | 91.7% |
| directory | 1,901 | 5.7 |
| symbolic link | 416 | 1.3 |
| char special | 373 | 1.1 |
| block special | 61 | 0.2 |
| socket | 5 | 0.0 |
| FIFO | 1 | 0.0 |



## `st_mode` Field

- This field contains type and permissions (12 lower bits) of file in bit format.
- It is extracted by `AND`-ing the value stored there with various constants
  - see `man stat`
  - also `<sys/stat.h>` and `<linux/stat.h>`
  - some data structures are in `<bits/stat.h>`



## Getting the Type Information

- `AND` the `st_mode` field with `S_IFMT` to get the type bits.
- Test the result against:
  - `S_IFREG` Regular file
  - `S_IFDIR` Directory
  - `S_IFSOCK` Socket
  - etc.

## Example

```
struct stat sbuf;
   :
if( stat( file, &sbuf ) == 0 )
  if( (sbuf.st_mode & S_IFMT) ==
S_IFDIR )
       printf("A directory\n");
```

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## Type Info. Macros

- Modern UNIX systems include test macros in <sys/stat.h> and <linux/stat.h>:
  - S_ISREG() regular file
  - S_ISDIR() directory file
  - S_ISCHR() char. special file
  - S_ISBLK() block special file
  - S_ISFIFO() pipe or FIFO
  - S_ISLNK() symbolic link
  - S_ISSOCK() socket

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## Example

```
struct stat sbuf;
  :
if( stat(file, &sbuf ) == 0 )
  {
  if( S_ISREG( sbuf.st_mode ) )
       printf( "A regular file\n" );
  else if( S_ISDIR(sbuf.st_mode) )
       printf( "A directory\n" );
  else ...
  }
```

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## Getting Mode Information

- AND the st_mode field with one of the following masks and test for non-zero:
  - S_ISUID set-user-id bit is set
  - S_ISGID set-group-id bit is set
  - S_ISVTX sticky bit is set
- Example:

```
if( (sbuf.st_mode & S_ISUID) != 0 )
  printf("set-user-id bit is set\n");
```

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## Getting Permission Info.

- AND the st_mode field with one of the following masks and test for non-zero:
  - S_IRUSR 0400 user read
    S_IWUSR 0200 user write
    S_IXUSR 0100 user execute
  - S_IRGRP 0040 group read
    S_IWGRP 0020 group write
    S_IXGRP 0010 group execute
  - S_IROTH 0004 other read
    S_IWOTH 0002 other write
    S_IXOTH 0001 other execute

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## Example

- 
```
struct stat sbuf;
   :
printf( "Permissions: " );
if( (sbuf.st_mode & S_IRUSR) != 0 )
   printf( "user read, " );
if( (sbuf.st_mode & S_IWUSR) != 0 )
   printf( "user write, " );
   :
```

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