

## Lecture 21

### Systems Programming in C

A C program can invoke UNIX system calls directly. A system call can be defined as a request to the operating system to do something on behalf of the program. During the execution of a **system call**, the mode is change from **user mode** to **kernel mode (or system mode)** to allow the execution of the system call. The kernel, the core of the operating system program in fact has control over everything. All OS software is trusted and executed without any further verification. All other software needs to request kernel mode using specific system calls to create new processes and manage I/O. A process is a currently executing instance of a program. All programs by default execute in the user mode. A high level programmer does not have to worry about the mode change from user-mode to kernel-mode as it is handled by a predefined library of system calls.

Unlike processes in user mode, which can be replaced by another process at any time, a process in kernel mode cannot be arbitrarily replaced by another process. A process in kernel mode can only be suspended by an interrupt or exception. A C system call software instruction generates an OS interrupt commonly called the **operating system trap**. The system call interface handles these interruptions in a special way. The C library function passes a unique number corresponding to the system call to the kernel, so kernel can determine the specific system call user is invoking. After executing the kernel command the operating system trap is released and the system returns to user mode. Unix system calls are primarily used to **manage the file system** or **control processes** or to **provide communication** between multiple processes.

A subset of the system calls include

**creat( ), open( ), close( )** -- managing I/O channels  
**read( ), write( )** – handling input and output operations  
**lseek( )** – for random access of files  
**link( ), unlink( )** – aliasing and removing files  
**stat( )** – getting file status  
**access( ), chmod( ), chown( )** – for access control

**exec( ), fork( ), wait( ), exit( )** --- for process control  
**getuid( )** – for process ownership  
**getpid( )** -- for process ID  
**signal( ), kill( ), alarm( )** – for process control  
**chdir( )** – for changing working directory

**mmap( ), shmget( ), mprotect( ), mlock( )** – manipulate low level memory attributes

**time( ), gettimer( ), settimer( ), settimeofday( ), alarm( )** – time management functions

**pipe( )** – for creating inter-process communication

System calls interface often change and therefore it is advisable to place system calls in subroutines so subroutines can be adjusted in the event of a system call interface change. When a system call causes an error, it returns -1 and store the error number in a variable called “**errno**” given in a header file called **/usr/include/errno.h**. When a system call returns an error, the function **perror** can be used to print a diagnostic message. If we call **perror( )**, then it displays the argument string, a colon, and then the error message, as directed by “**errno**”, followed by a newline.

```
if (unlink("text.txt")==-1) {  
    perror("");  
}
```

If the file `text.txt` does not exist, `unlink` will return -1 and that in return will cause the program to print the message “File does not exist”

### Managing the File System with Sys calls

File structure related system calls to manage the file system are quite common. Using file structure related system calls, we can **create, open, close, read, write, remove** and **alias, set permission, get file information** among other things. The arguments to these functions include either the relative or absolute path of the file or a descriptor that defines the IO channel for the file. A channel provides access to the file as an unformatted stream of bytes. We will now look at some of the file related functions provided as system calls.

## UNIX System I/O Calls

The high level library functions given by `<stdio.h>` provide most common input and output operations. These high level functions are built on the top of low-level structures and calls provided by the operating system. In this section, we will look at some low level I/O facilities that will provide insight into how low level I/O facilities are handled and therefore may provide ways to use I/O in ways that are not provided by the `stdio.h`. In UNIX, I/O hardware devices are represented as special files. Input/Output to files or special files (such as terminal or printers) are handled the same way. UNIX also supports “pipes” a mechanism for input/output between processes. Although pipes and files are different I/O objects, both are supported by low level I/O mechanisms.

### Create System Call

A file can be created using the `creat` function as given by the following prototype.

```
#include <sys/file.h> // can be replaced by <fcntl.h>  
int creat(char* filename, mode)
```

The mode is specified as an octal number. For example, 0444 indicates that `r` access for USER, GROUP and ALL for the file. If the file exists, the `creat` is ignored and prior content and rights are maintained. The library

**/usr/include/sys/stat.h**

provides following constants that can be used to set permissions.

**S\_IREAD** --- read permission for the owner  
**S\_IWRITE** --- write permission for the owner  
**S\_IXEXEC** --- execute/search permission for the owner  
**S\_IRWXU** --- read, write, execute permission for the user

**S\_IRGRP** – read for group  
**S\_IWGRP** – write for group  
**S\_IXGRP** – execute for group  
**S\_IRWXG** – read, write, execute for the group

**S\_IROTH** --- read for others  
**S\_IWOTH** – write for others  
**S\_IXOTH** -- execute for others  
**S\_IRWXO** – read , write , execute for others

For example, to create a file with read and write access only to user, we can do the following.

```
creat("myfile", S_IREAD | S_IWRITE);
```

## Open System Call

A file can be open using the open system call as follows.

```
#include <sys/file.h> // can be replaced by <fcntl.h>  
int open(char* filename, int access, int mode);
```

The above code opens the filename for **reading or writing** as specified by the **access** and returns an integer descriptor for that file. **Descriptor is an integer (usually less than 16) that indicates a table entry for the file reference for the current process. The stdin(0), stdout(1) and stderr(3) are given.** Other files will be provided with the next available descriptor when opening. File name can be given as full path name, relative path name, or simple file name. If the file does not exist, then open creates the file with the given name. Let us take a detail look at the arguments to open.

**filename** : A string that represents the absolute, relative or filename of the file

**access** : An integer code describing the access (see below for details)

**mode** : The file protection mode usually given by 9 bits indicating rwx permission

The access codes are given by

**O\_RDONLY** -- opens file for read only  
**O\_WRONLY** – opens file for write only  
**O\_RDWR** – opens file for reading and writing  
**O\_NDELAY** – prevents possible blocking  
**O\_APPEND** --- opens the file for appending

**O\_CREAT** -- creates the file if it does not exist

**O\_TRUNC** -- truncates the size to zero

**O\_EXCL** – produces an error if the O\_CREAT bit is on and file exists

If the open call fails, a -1 is returned; otherwise a descriptor is returned. For example, to open a file for read and truncates the size to zero we could use,

```
open("filename", O_RDONLY | O_TRUNC, 0);
```

We assume that the file exists and note that zero can be used for protection mode. For opening files, the third argument can always be left at 0.

## Reading and Writing to Files

Reading and writing a file is normally sequential. For each open file, a current position points to the next byte to be read or written. The current position can be movable for an actual file, but not for stdin when connected to a keyboard.

### Read System Call

```
#include <sys/types.h> // or #include <unistd.h>
size_t read(int fd, char *buffer, size_t bytes);
```

*fd* is the file descriptor, *buffer* is address of a memory area into which the data is read and *bytes* is the maximum amount of data to read from the stream. The return value is the actual amount of data read from the file. The pointer is incremented by the amount of data read. Bytes should not exceed the size of the buffer.

### Write System Call

The write system call is used to write data to a file or other object identified by a file descriptor. The prototype is

```
#include <sys/types.h>
size_t write(int fd, char *buffer, size_t bytes);
```

*fd* is the file descriptor, *buffer* is the address of the area of memory that data is to be written out, *bytes* is the amount of data to copy. The return value is the actual amount of data written, if this differs from *bytes* then something may be wrong.

**Example:** Consider the C high level function `getline(char [], int)` that reads a line from stdin and store the line in a character array. This function can now be rewritten using low level read as follows

```
int getline(char s[], int size){
    char* tmp = s;
    while (--size>0 && read(0,tmp,1)!=0 && *tmp++ != '\n');
    *tmp = '\0';
    return (tmp-s);
}
```

```
}
```

## Close System Call

The close system call is used to close files. The prototype is

```
#include <unistd.h>
int close(int fd);
```

When a process terminates, all the files associated with the process are closed. But it is always a good idea to close a file as they do consume resources and systems impose limits on the number of files a process can keep open.

## lseek System Call

Whenever a read() or write() operation is performed on a file, the position in the file at which reading or writing starts is determined by the current value of the **read/write pointer**. The value of the read/write pointer is often called the **offset**. It is always measured in bytes from the start of the file. The [lseek\(\)](#) system call allows programs to manipulate this directly by providing the facility for **direct access** to any part of the file. In other words, the lseek allows random access to any byte of the file. It has three parameters and the prototype is

```
#include <sys/types.h>
#include <unistd.h>
long lseek(int fd, int offset, int origin)
```

origin	position
0	beginning of the file
1	Current position
2	End of the file

Call	Meaning
lseek(fd, 0, 0)	places the current position at the first byte
lseek(fd, 0, 2)	places the current position at EOF
lseek(fd, -10, 1)	Backs up the current position by 10 bytes

## Other System Level Operations

Other system level operations include creating a file using

**creat(filename, mode);**

The mode can be selected from the following octal bit patterns

Octal Bit Pattern	Meaning
00400	Read by owner
00200	Write by Owner
00100	Execute or search by owner

00070	Read, Write, Execute(search) by group
00007	Read, Write, Execute(search) by others

Other system calls include link a way to give alternative names to a file (aliases), and unlink a way to remove an alias to a file. The prototypes for the link and unlink are

```
int link (char* file1, char* file2);
int unlink(char* name);
```

The link( ) function creates an alias name file2 for file1, that exists in the current directory. Use of unlink with the original file name will remove the file.

## Creating and removing Directories

Directories can be created and removed using mkdir and rmdir function calls. The function prototypes are

```
int mkdir(char* name, int mode);
int rmdir(char* name);
```

returns 0 or 1 for success or failure. For example, creating a new directory called “newfiles” with only the READ access for the user we can do the following.

```
mkdir(“newfiles”, 00400);
```

Later you can remove this directory by calling

```
rmdir(“newfiles”);
```

**Caution:** Be very careful about removing directories. These are system calls that are executed w/o further confirmation.

You can also reset the file/dir permission with chmod function. The prototype is given by

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

```
int chmod(const char *path, mode_t mode);
```

For example, the directory that was created above called “newfiles” has only read access on the owner. But if you decided to change the read access from owner to all groups, then you can call:

```
chmod(“newfiles”, 00444);
```

## Accessing Directories

A UNIX directory contains a set of files that can be accessed using the sys/dir.h library. We include the library with

```
#include <sys/dir.h>
```

And the function

```
DIR *opendir(char* dir_name)
```

Opens a directory given by dir\_name and provides a pointer to access files within the directory. The open DIR stream can be used to access a struct that contains the file information. The function

```
struct dirent *readdir(DIR* dp)
```

returns a pointer to the next entry in the directory. A NULL pointer is returned when the end of the directory is reached. The struct dirent has the following format.

```
struct dirent {  
    u_long d_ino;                /* i-node number for the dir entry */  
    u_short d_reclen;           /* length of this record */  
    u_short d_namelen ;         /* length of the string in d_name */  
    char d_name[MAXNAMLEN+1] ; /* directory name */  
};
```

Using system libraries, we can write our own “find” function for example. The following function, **search (char\* file, char\* dir)** returns 0 if the file is found in the directory and returns 1 otherwise.

```
#include <string.h>  
#include <sys/types.h>  
#include <sys/dir.h>  
  
int search (char* file, char* dir){  
    DIR *dirptr=opendir(dir);  
    struct dirent *entry = readdir(dirptr);  
    while (entry != NULL) {  
        if ( strlen(entry->d_name) == strlen(file) && (strcmp(entry->d_name, file) == 0)  
            return 0; /* return success */  
        entry = readdir(dirptr);  
    }  
    return 1; /* return failure */  
}
```

## Accessing File Status

Status of a file such as file type, protection mode, time when the file was last modified can be accessed using stat and fstat functions. The prototypes of stat and fstat functions are

```
stat(char* file, struct stat *buf);  
fstat(int fd, struct stat *buf);
```

stat and fstat functions are equivalent except that former takes the name of a file, while the latter takes a file descriptor. For example, we can get the status of a file as follows.

```
struct stat buf; // defines a struct stat to hold file information  
stat("filename", &buf) ; // now the file information is placed in the buf
```

The status of the file that is retrieved and placed in the buf has many information about the file. For example, the stat structure contains useful information such as

```
st_atime --- Last access time  
st_mtime --- last modify time  
st_ctime --- Last status change time  
st_size --- total size of file  
st_uid – user ID of owner  
st_mode – file status (directory or not)
```

## Example

```
#include <sys/types.h>  
#include <sys/stat.h>  
#include <dirent.h>  
  
struct stat statbuf;  
char dirpath[256];  
getcwd(dirpath, 256);  
DIR *dir = opendir(dirpath);  
struct dirent *dp;  
for (dp=readdir(dir); dp != NULL ; dp=readdir(dir)){  
    stat(dp->d_name, &statbuf);  
    printf("the file name is %s \n", dp->d_name);  
    printf("dir = %d\n", S_ISDIR(statbuf.st_mode));  
    printf("file size is %ld in bytes \n", statbuf.st_size);  
    printf("last modified time is %ld in seconds \n",  
        statbuf.st_mtime);  
    printf("last access time is %ld in seconds \n",  
        statbuf.st_atime);  
    printf("The device containing the file is %d\n", statbuf.st_dev);  
    printf("File serial number is %d\n\n", statbuf.st_ino);  
}
```

More can be found at

<http://www.opengroup.org/onlinepubs/000095399/functions/stat.html>



## Working Directory

The working directory of the program can be found using `getcwd`. The prototype is given by

```
#include <unistd.h>
char* getcwd(char * dirname, int );
```

This copies the full path name of the current working directory into the `dirname` and returns a pointer to it. The description can be found

## Summary

This section summarizes the “how to” use standard functions when doing system programming. This is only a subset of things that can be done. But a basic list that may be needed for many common tasks

How to	Functions	Example	Libraries
Create a file	<code>int creat(char* filename, mode)</code>	<code>creat("newfile",0666);</code>	<code>#include &lt;sys/file.h&gt;</code>
Open a file	<code>int open(char* filename, int access, int mode);</code>	<code>open("filename", O_RDONLY   O_TRUNC, 0);</code>	<code>#include &lt;sys/file.h&gt;</code>
Read bytes from a file	<code>size_t read(int fd, char *buffer , size_t bytes);</code>	<code>read(0, buf, 100);</code>	<code>#include &lt;sys/types.h&gt;</code>
Write bytes to a file	<code>size_t write(int fd, char *buffer, size_t bytes);</code>	<code>write(1,buf, 100);</code>	<code>#include &lt;sys/types.h&gt;</code>
Closing a file	<code>int close(int fd);</code>	<code>close(fd);</code>	<code>#include&lt;unistd.h&gt;</code>
Seeking file positions	<code>long lseek(int fd,int offset,int origin)</code>	<code>lseek (fd, 0, 0) lseek (fd, 0, 2) lseek (fd, -10, 1)</code>	<code>#include &lt;sys/types.h&gt; #include &lt;unistd.h&gt;</code>
Creating a directory	<code>int mkdir(char* name, int mode);</code>	<code>mkdir("dirname",0666);</code>	
Removing a directory	<code>int rmdir(char* name);</code>	<code>rmdir("dirname");</code>	
Setting file permission	<code>int chmod(const char *path, mode_t mode);</code>	<code>chmod("newfiles", 00444);</code>	<code>#include &lt;sys/stat.h&gt;</code>
Opening a directory	<code>DIR *opendir(char* dir_name)</code>	<code>opendir("dirname");</code>	<code>#include &lt;sys/dir.h&gt;</code>
Reading directory entries	<code>struct dirent *readdir(DIR* dp)</code>		<code>#include &lt;sys/dir.h&gt;</code>
Accessing file status	<code>stat(char* file, struct stat *buf); fstat(int fd, struct stat *buf);</code>	<code>struct stat buf; stat("filename", &amp;buf) ;</code>	<code>#include &lt;sys/stat.h&gt;</code>
Getting the working directory	<code>char* getcwd(char * dirname, int );</code>		<code>#include &lt;unistd.h&gt;</code>

## EXERCISES

1. Write a function `foo(int fd, char* buf, int b_size, int n, int skip)` that reads to `buf` from file with file descriptor `fd`, `n` blocks of size `b_size` each. The last argument specifies how many bytes to skip after reading each block. Return -1 if the operation is unsuccessful. Else return total number of bytes read.
2. Write a program to read all txt files (that is files that ends with .txt) in the current directory and merge them all to one txt file and returns a file descriptor for the new file.
3. Write a program that a string as an argument and return all the files that begins with that name in the current directory. For example `> ./a.out foo` will return all file names that begins with `foo`.
4. Write a program that will categorize all files in the current folder based on their file type. That is all .txt file in one folder called `txt`, all .bmp files in another folder called `bmp` etc.
5. Given a directory, write a program that will find all files with the same name. Show their name, which folder they are in and what date they were created. Expand the program to remove all duplicate copies based on user input. That is, ask users if each one of the file is to be kept or deleted. Based on user input, perform the appropriate action.