

# CL2006 - Operating Systems Spring 2024

## LAB # 4 MANUAL (Common)

**Please note that all labs' topics including pre-lab, in-lab and post-lab exercises are part of the theory and labsyllabus. These topics will be part of your Midterms and Final Exams of lab and theory.**

### Objectives:

Demonstrate System Calls Programmatically:

1. Develop an understanding of system calls by implementing various functions programmatically and explore the functionality and usage of each system call through practical coding exercises, emphasizing their role in process management, information retrieval, and file manipulation.
2. Implement system calls such as fork (), wait(), exit(), exec(), sleep(), getpid(), getppid(), alarm(), open(), read(), write(), and close() to perform essential operating system tasks.

### Lab Tasks:

Use of system calls related to the following:

1. Process creation and control.
2. Information retrieval
3. File creation and manipulation.

### Delivery of Lab contents:

Strictly following the following content delivery strategy. Ask students to take notes during the lab.

#### 1<sup>st</sup> Hour

- Pre-Lab (up to 15 minutes)
- System Call introduction (15 minutes)
- C program structure for making system calls (30 minutes)

#### 2<sup>nd</sup> Hour

- Process management (60 minutes)

#### 3<sup>rd</sup> Hour

- Information retrieval, and File manipulation (60 minutes)

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**\*\* ChatGPT is heavily used to make the contents of this document along with other Internet sources.**

# EXPERIMENT 4

## System Calls

### What are system calls?

A system call is a mechanism that allows a user-level program to request a service or operation from the kernel (the core part of the operating system). These services can range from low-level tasks like accessing hardware devices to higher-level operations like creating or terminating processes.

1. **Communication with the Kernel:** The kernel is the central component of an operating system responsible for managing hardware resources and providing essential services to user programs. User programs, including applications and utilities, operate in a restricted environment known as user mode. Direct access to hardware resources is prohibited in user mode for security and stability reasons.
2. **Transition to Kernel Mode:** When a user program requires a service that only the operating system kernel can provide, it needs to transition from **user mode** to a more **privileged mode** called kernel mode. System calls provide a controlled mechanism for this transition. When a system call is invoked, the program **switches from user mode to kernel mode** to execute the requested operation.
3. **Requesting Operating System Services:** System calls act as an interface between user programs and the operating system kernel. They allow user programs to request various services or operations provided by the kernel. Examples of common system calls include:
  - Opening, reading from, writing to, and closing files.
  - Creating, executing, and terminating processes.
  - Allocating and managing memory.
  - Interacting with hardware devices such as printers and network interfaces.
4. **Implementation by the Kernel:** Each system call has a unique identifier or number associated with it, known as a syscall number. This number is used by the kernel to identify the requested service. The kernel contains implementations for handling different system calls. When a system call is invoked, the kernel executes the corresponding routine to perform the requested operation.
5. **Return Values and Error Handling:** System calls typically return a value to the calling program, indicating the success or failure of the requested operation. If an error occurs during the execution of a system call, the kernel returns a special error code, allowing the user program to handle the error gracefully.

	Windows	Unix
<b>Process control</b>	CreateProcess() ExitProcess() WaitForSingleObject()	fork() exit() wait()
<b>File management</b>	CreateFile() ReadFile() WriteFile() CloseHandle()	open() read() write() close()
<b>Information maintenance</b>	GetCurrentProcessID() SetTimer() Sleep()	getpid() alarm() sleep()

Figure 1 System calls for Windows and Unix/Linux Operating Systems

## C program structure for doing System Calls

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <errno.h>

int main () {
    // Declare variables and necessary data structures

    // Make explicit system calls

    // Handle errors if any

    // Perform necessary operations using system calls

    return 0;
}
```

This basic structure provides a framework for writing C programs that utilize explicit Linux/UNIX system calls, enabling developers to interact directly with the underlying operating system for performing various tasks. Explanation of various part of the programs follows:

- **#include <stdio.h>:** The standard input-output library for basic input and output operations.
- **#include <stdlib.h>:** The standard library for general utilities and memory allocation.
- **#include <unistd.h>:** The POSIX (Portable Operating System Interface) standard header file for various system calls, such as process management (fork(), exec(), exit(), etc.).
- **#include <sys/types.h>:** Definitions for various data types used in system calls, such as pid\_t for process IDs.
- **#include <sys/wait.h>:** Definitions for functions related to process management and waiting for child processes to terminate.
- **#include <errno.h>:** Definitions for error numbers that may occur during system calls.
- Inside the main() function:
  - Declare necessary variables and data structures for holding information related to system calls and their results.
  - Make explicit system calls as required for the intended functionality of the program. These system calls could involve process management, file operations, memory allocation, etc.
  - Handle errors that may occur during system calls using error-checking mechanisms like errno and appropriate error-handling techniques.
  - Perform necessary operations using the results obtained from system calls.
  - return 0. Indicates successful termination of the program by returning a status code of 0 to the operating system.

## Process Creation:

The processes in most systems can execute concurrently, and they may be created and deleted dynamically. Thus, these systems must provide a mechanism for process creation and termination.

### 1. fork()

- Has a return value.
- Parent process => invokes fork () system call
- Continue execution from the next line after fork ()
- Has its own copy of any data.
- Return value is > 0 //it's the process id of the child process. This value is different from the Parents own process id.
- Child process => process created by fork() system call
- Duplicate/Copy of the parent process //LINUX
- Separate address space
- Same code segments as parent process
- Execute independently of parent process
- Continue execution from the next line right after fork()
- Has its own copy of any data
- Return value is 0

### 2. wait ()

- Used by the parent process
- Parent's execution is suspended
- Child remains its execution
- On termination of child, returns an exit status to the OS
- Exit status is then returned to the waiting parent process //retrieved by wait ()
- Parent process resumes execution
- #include <sys/wait.h>
- #include <sys/types.h>

### 3. exec()

- The exec() system call replaces the current process image with a new process image, which means it loads a new program into memory and starts its execution. Called by an already existing process.
- It has several variants, such as execl(), execv(), execl(), execve(), etc., each with different ways of passing arguments to the new program.
- Here are the general steps involved in using the exec() system call:
  - Open the Target Program File: The first step is to locate and open the file of the program you want to execute. This could be a binary executable file, a script, or any other executable file.
  - Load the Program into Memory: The exec() system call loads the program into the current process's memory space, replacing the current program image.
  - Set Up Execution Context: The system sets up the execution context for the new program, including initializing the program counter, setting up the stack, and preparing other resources needed for execution.
  - Start Execution: Finally, the new program starts its execution from its entry point, as defined in its binary executable file.
- Has an exist status but cannot return anything (if exec() is successful) to the program that made the call i.e. parent process
- Return value is -1 if not successful.
- Overlay => replacement of a block of stored instructions or data with another.
- `int execlp(char const *file_path, char const *arg0, );`
- Arguments beginning at arg0 are pointers to arguments to be passed to the new process.

- The first argument `arg0` should be the name of the executable file.
- Example: `execlp( /bin/ls , ls ,NULL )` //lists contents of the directoryHeader file used -> `unistd.h`

#### 4. `exit()`:

- The `exit()` system call is used to terminate a process immediately from any point within the program, not just within the `main()` function. `EXIT_SUCCESS` // integer value = 0, `EXIT_FAILURE` // integer value = 1
- It takes an integer argument known as the exit status, which is returned to the parent process or environment to indicate the termination status of the program.
- The `exit()` system call performs cleanup tasks, such as closing open files and releasing allocated memory, before terminating the process.
- Calling `exit()` directly causes the program to exit immediately from the point where it is called, bypassing any further execution of the program.
- Process related:
  - It returns exit status, which is retrieved by the parent process using `wait ()` command.
  - OS reclaims resources allocated by the terminated process (dead process) Typically performs clean-up operations within the process space before returning control.
  - Terminates the current process without any extra program clean-up.
  - Usually used by the child process to prevent from erroneously release of resources belonging to the parent process.

### Information Maintenance:

#### i. `sleep()`

- Process goes into an inactive state for a time period
- Resume execution if
- Time interval has expired
- Signal/Interrupt is received
- Takes a time value as parameter (in seconds on Unix-like OS and in milliseconds on Windows OS)
- `sleep(2)` // sleep for 2 seconds in Unix
- `Sleep(2*1000)` // sleep for 2 seconds in Windows

#### ii. `getpid()` // returns the PID of the current process

- `getppid()` // returns the PID of the parent of the current process
- Header files to use
- `#include <sys/types.h>`
- `#include <unistd.h>`
- `getppid()` returns 0 if the current process has no parent

#### iii. `alarm()`

- Use to set an alarm timer for a process. It takes an argument representing the number of seconds after which the alarm signal will be delivered to the calling process.
- The signal, known as `SIGALRM`, interrupts the normal execution of the process and can be used to perform specific actions or handle timeouts. The program to respond accordingly, such as terminating the operation or executing a signal handler function.
- Common use cases for `alarm()` include implementing timeouts for certain operations, scheduling periodic tasks, or triggering events after a specified delay.
- Additionally, the return value of `alarm()` provides information about any previously set alarm timer, allowing programs to query or cancel existing timers as needed. Overall, `alarm()` is a

versatile system call that facilitates time-based programming and event handling in Unix-based systems.

## File Management:

### 1. open ()

- **Specify File Path and Access Mode:** Provide the file path of the file you want to open as well as the access mode (e.g., read-only, write-only, read-write).
- **Check File Permissions:** The kernel checks whether the process has the necessary permissions to open the file based on the access mode specified.
- **Locate File Descriptor:** If permissions are granted, the kernel locates an available file descriptor (an integer representing the file) for the file within the process's file descriptor table.
- **Open File and Return Descriptor:** The kernel opens the file and associates it with the file descriptor. If successful, it returns the file descriptor to the calling process.

### 2. read ()

- **Specify File Path and Access Mode:** Provide the file path of the file you want to open as well as the access mode (e.g., read-only, write-only, read-write).
- **Check File Permissions:** The kernel checks whether the process has the necessary permissions to open the file based on the access mode specified.
- **Locate File Descriptor:** If permissions are granted, the kernel locates an available file descriptor (an integer representing the file) for the file within the process's file descriptor table.
- **Open File and Return Descriptor:** The kernel opens the file and associates it with the file descriptor. If successful, it returns the file descriptor to the calling process.

### 3. write ()

- **Specify File Descriptor and Data:** Provide the file descriptor of the file to which you want to write data and the data to be written.
- **Check File Descriptor Validity:** The kernel verifies that the file descriptor provided is valid and points to an open file.
- **Write Data:** The kernel writes the specified data to the file associated with the file descriptor.
- **Update File Position:** After writing, the kernel updates the file position indicator associated with the file descriptor to reflect the new position in the file.
- **Return Number of Bytes Written:** The write() system call returns the number of bytes successfully written to the file to the calling process.

### 4. close ()

- **Specify File Descriptor:** Provide the file descriptor of the file you want to close.
- **Check File Descriptor Validity:** The kernel verifies that the file descriptor provided is valid and points to an open file.
- **Release Resources:** The kernel releases any resources associated with the file descriptor, such as closing the file and freeing memory.
- **Invalidate File Descriptor:** After closing the file, the kernel invalidates the file descriptor, making it available for reuse.
- **Return Status:** The close () system call returns a status indicating whether the file was successfully closed or if an error occurred to the calling process.

**In-lab problems:**

1. Write a program that creates two child processes. The first child process should print its process ID (PID). The second child process should print its parent process ID (PPID) along with a random number (between 1 and 100). The parent process should wait for both child processes to terminate and then print: **"All child processes completed."**
2. Write a program that prints the current process ID (PID) and the parent process ID (PPID) of the running process. Additionally, the program should print a custom message **"Process information displayed successfully!"** after printing the IDs. **Hint:** Use getpid() and getppid().
3. Write a program that reads the first 100 characters from a file named **"source.txt"** and writes them in reverse order to another file named **"destination.txt"**. Ensure proper error handling for file opening, reading, and writing operations. **Hint:** Use open(), read(), write(), and close().
4. Write a program that uses the fork() system call to create a child process. The child process should list all files and directories in the current directory. The parent process should wait for the child process to complete and then print **"Child process has finished listing the directory."**
5. Write a program that enters a sleep loop, printing a message every second for a total of 5 seconds. After completing the loop, the program should print **"Execution completed successfully."** before terminating. **Hint:** Use sleep().