

Statement of Purpose:

This lab will introduce the basic concepts related to process management through and Writing C++ programs in Linux.

Activity Outcomes:

This lab teaches you the following topics:

1. How to manage processes in Linux.
 2. Compiling and Executing C++ programs in Linux.
-

1) Stage J (Journey)

1. Process management in Linux

A process is the instance of a computer program that is being executed. While a computer program is a passive collection of instructions, a process is the actual execution of those instructions. Several processes may be associated with the same program; for example, opening up several instances of the same program often results in more than one process being executed. When a system starts up, the kernel initiates a few of its own activities as processes and launches a program called `init`. `init`, in turn, runs a series of shell scripts (located in `/etc`) called `init` scripts, which start all the system services. Many of these services are implemented as daemon programs, programs that just sit in the background and do their thing without having any user interface. So even if we are not logged in, the system is at least a little busy performing routine stuff.

The kernel maintains information about each process to help keep things organized. For example, each process is assigned a number called a process ID or PID. PIDs are assigned in ascending order, with `init` always getting PID 1. The kernel also keeps track of the memory assigned to each process, as well as the processes' readiness to resume execution. Like files, processes also have owners and user IDs, effective user IDs, etc. In the following, we will discuss the most common commands; available in Linux to manage processes.

b. Displaying Processes in the System

1.1.1 Static view

The most commonly used command to view processes is `ps`. This command displays the processes for the current shell. We can use the `ps` command as given below

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ ps
  PID TTY          TIME CMD
 4887 pts/0        00:00:00 bash
 4901 pts/0        00:00:00 ps
```

We can display all of the processes owned by the current user by using the x option.

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ ps x
  PID TTY          STAT TIME   COMMAND
 1602 ?            Ss      0:00   /lib/systemd/systemd --user
 1603 ?            S        0:00   (sd-pam)
 1609 ?            Ss      0:00   /usr/bin/dbus-daemon --session --ad
 1646 ?           Ssl      0:00   /usr/lib/at-spi2-core/at-spi-bus-la
 1651 ?            S        0:00   /usr/bin/dbus-daemon --config-file=
 1657 ?           Sl       0:00   /usr/lib/at-spi2-core/at-spi2-regis
 1661 ?           Ssl      0:00   /usr/lib/gvfs/gvfsd
 1666 ?           Sl       0:00   /usr/lib/gvfs/gvfsd-fuse /run/user/
 1710 ?           S<l      0:00   /usr/bin/pulseaudio --start --log-t
 4103 ?           Sl       0:00   /usr/lib/dconf/dconf-service
```

Here, a new column is also added in the output that is STAT. This column shows the current state of the process. The most common states are given below.

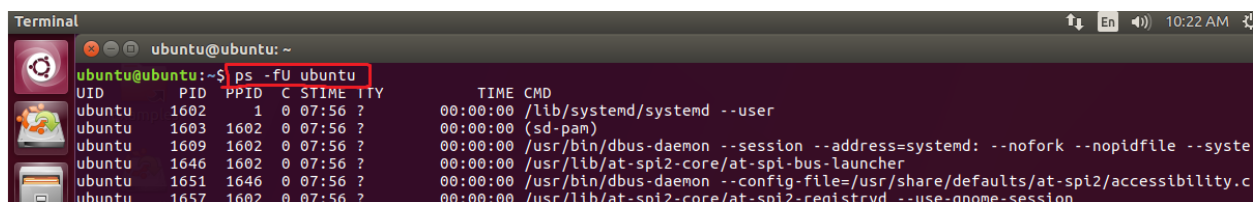
State	Meaning
R	Running
S	Sleeping or waiting for an event such as keystroke
D	Uninterruptible Sleep. Process is waiting for I/O such as a disk drive
T	Stopped
Z	A difunctional or zombie process
l	multithreaded
s	Session leader
+	Foreground process
<	A high priority process

N	A low priority process
---	------------------------

Following are the most common option that can be used with ps command.

Option	Description
-A or -e	Display every active process on a Linux system
-x	Display all of the processes owned by the user
-F	Perform a full-format listing
-U	Select by real user ID or name
-u	Select by effective user ID or name
-p	Select process by pid
-r	Display only running processes
-L	Show number of threads in a process
-G	Show processes by Group

In the following example, we display processes that are related to the user ubuntu.

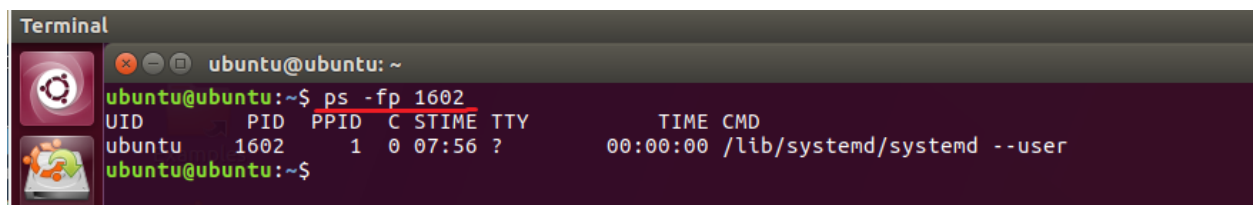


```

Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ ps -fU ubuntu
UID        PID     PPID  C  STIME TTY          TIME CMD
ubuntu    1602         1  0  07:56 ?        00:00:00 /lib/systemd/systemd --user
ubuntu    1603    1602  0  07:56 ?        00:00:00 (sd-pam)
ubuntu    1609    1602  0  07:56 ?        00:00:00 /usr/bin/dbus-daemon --session --address=systemd: --nofork --nopidfile --systemd=
ubuntu    1646    1602  0  07:56 ?        00:00:00 /usr/lib/at-spi2-core/at-spi-bus-launcher
ubuntu    1651    1646  0  07:56 ?        00:00:00 /usr/bin/dbus-daemon --config-file=/usr/share/defaults/at-spi2/accessibility.c
ubuntu    1657    1602  0  07:56 ?        00:00:00 /usr/lib/at-spi2-core/at-spi2-registryd --use-gnome-session

```

Now, we select a process with id 1602



```

Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ ps -fp 1602
UID        PID     PPID  C  STIME TTY          TIME CMD
ubuntu    1602         1  0  07:56 ?        00:00:00 /lib/systemd/systemd --user
ubuntu@ubuntu:~$

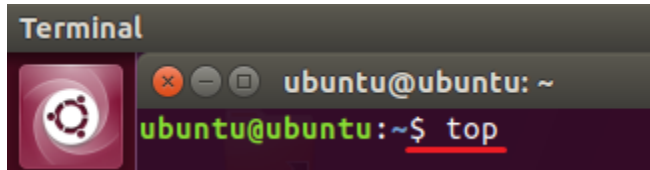
```

1.1.2 Dynamic view

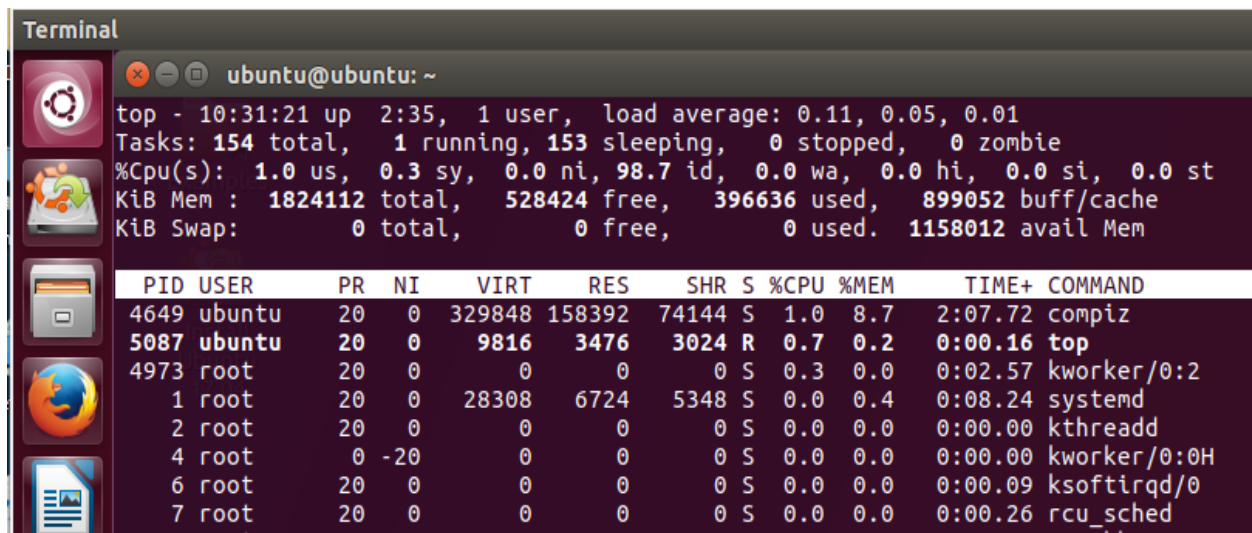
The top command is the traditional way to view your system's resource usage and see the processes that are taking up the most system resources. Top displays a list of processes, with the ones using the most

CPU at the top. An improved version of top command is htop but it is usually not pre-installed in most distributions. When a top program is running, we can highlight the running programs by pressing **z**. we can quit the top program by press **q** or **Ctrl + c**.

In the following example we display the dynamic view of the system process and resource usage.

A terminal window titled 'Terminal' with a dark background. The prompt is 'ubuntu@ubuntu: ~'. The command 'top' has been entered and is highlighted with a red underline.

The output of the above command is given below

A terminal window titled 'Terminal' showing the output of the 'top' command. The output includes system statistics and a list of running processes. The 'top' process is highlighted in red.

```
top - 10:31:21 up 2:35, 1 user, load average: 0.11, 0.05, 0.01
Tasks: 154 total, 1 running, 153 sleeping, 0 stopped, 0 zombie
%Cpu(s): 1.0 us, 0.3 sy, 0.0 ni, 98.7 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st
KiB Mem : 1824112 total, 528424 free, 396636 used, 899052 buff/cache
KiB Swap: 0 total, 0 free, 0 used. 1158012 avail Mem

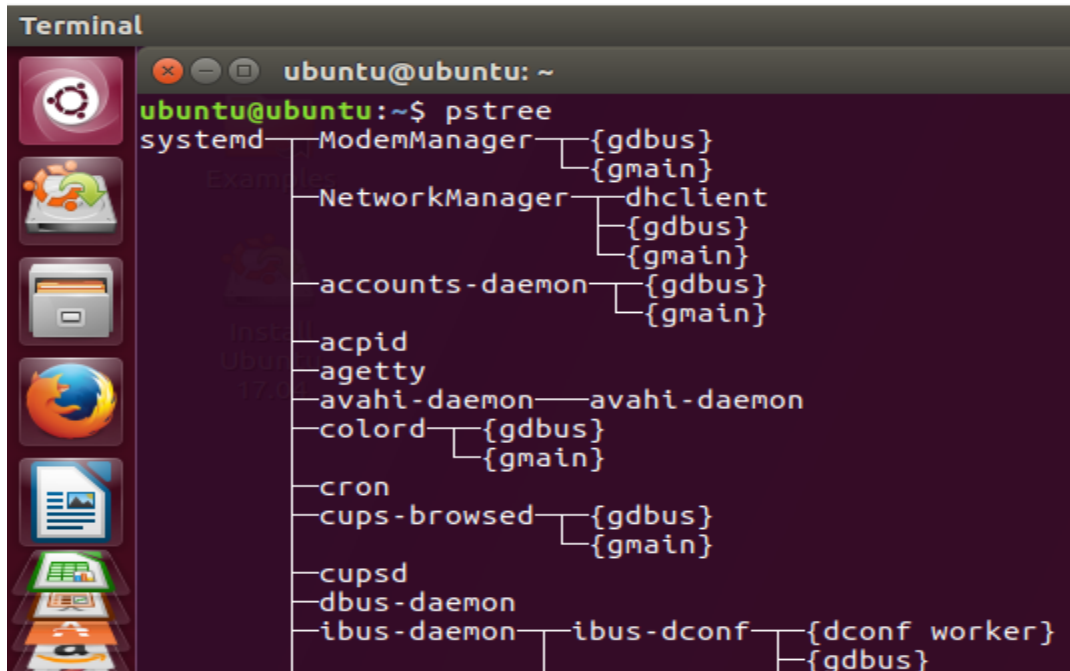
  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM    TIME+  COMMAND
 4649 ubuntu    20   0 329848 158392 74144 S   1.0   8.7   2:07.72 compiz
 5087 ubuntu    20   0   9816   3476   3024 R   0.7   0.2   0:00.16 top
 4973 root      20   0      0      0      0 S   0.3   0.0   0:02.57 kworker/0:2
      1 root      20   0  28308   6724   5348 S   0.0   0.4   0:08.24 systemd
      2 root      20   0      0      0      0 S   0.0   0.0   0:00.00 kthreadd
      4 root       0 -20      0      0      0 S   0.0   0.0   0:00.00 kworker/0:0H
      6 root      20   0      0      0      0 S   0.0   0.0   0:00.09 ksoftirqd/0
      7 root      20   0      0      0      0 S   0.0   0.0   0:00.26 rcu_sched
```

Some of the basic options available with top commands are given below

Options	Description
-u	display specific User process details
-d	To set the screen refresh frequency

1.1.3 Displaying processes in Treelike structure

The pstree command is used to display processes in tree-like structure showing the parent/child relationships between processes.



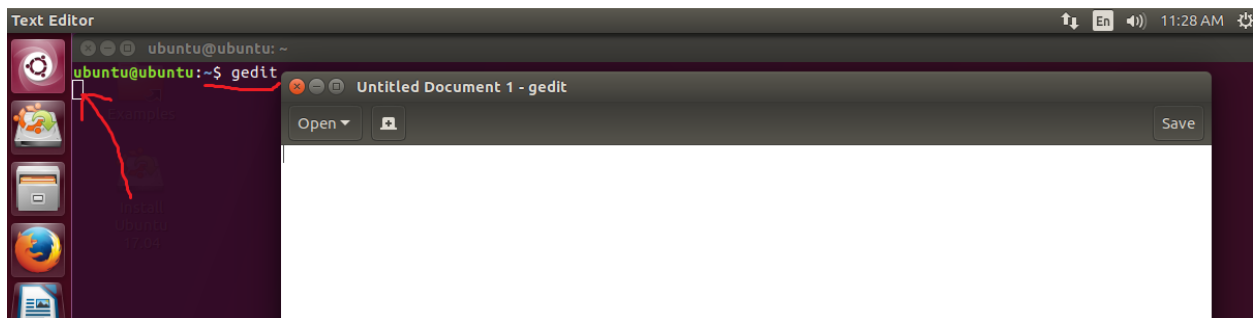
1.2 Interrupting A Process

A program can be interrupted by pressing Ctrl + C. This will interrupt the given processes and stop the process. Ctrl+C essentially sends a SIGINT signal from the controlling terminal to the process, causing it to be killed.

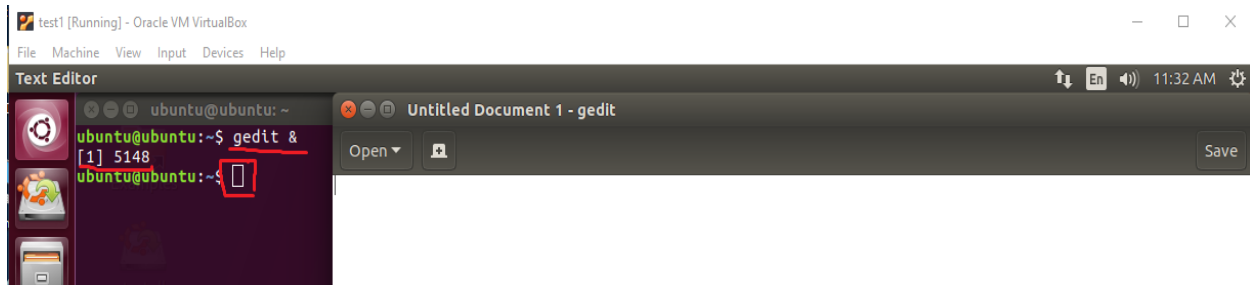
1.3 Putting a Process in the Background

A foreground process is any command or task you run directly and wait for it to complete. Unlike with a foreground process, the shell does not have to wait for a background process to end before it can run more processes. Normally, we start a program by entering its name in the CLI. However, if we want to start a program in background, we will put an & after its name.

In the following example, first we open the gedit program normally as given below.



It can be noted that gedit is opened as foreground process and control does not return to terminal unless it is closed. Now, we start the gedit again as a background process.

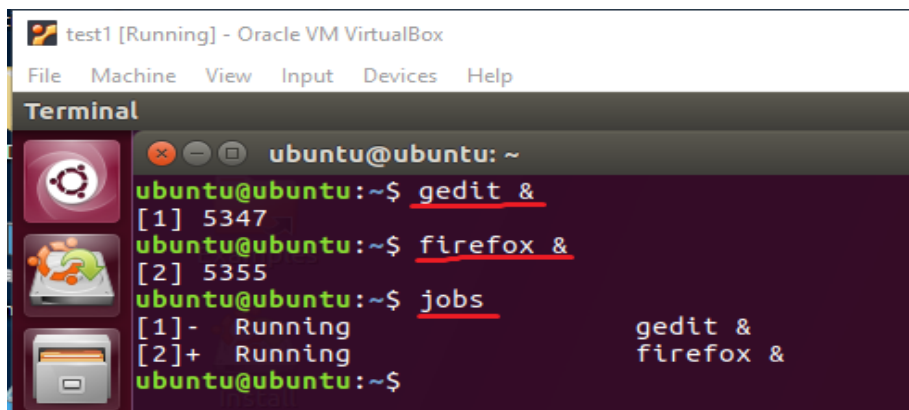


It can be seen that after starting the gedit program control returns to the terminal and user can interact with both terminal and gedit.

1.4 jobs command

The shell's job control facility also gives us a way to list the jobs that have been launched from our terminal. Using the **jobs** command, we can see this list.

In the following example, we first launch two jobs in background and then use the jobs command to view the running jobs.



1.5 Bringing a process to the foreground

A process in the background is immune from keyboard input, including any attempt to interrupt it with a Ctrl-c. fg command is used to bring a process to the foreground. In the following example, we start the gedit editor in background. Then use the jobs command to see the list of jobs launched and then, bring this process to the foreground.

```
Terminal Terminal File Edit View Search Terminal Help
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ gedit &
[1] 4973
ubuntu@ubuntu:~$ jobs
[1]+  Running                  gedit &
ubuntu@ubuntu:~$ fg %1
gedit
```

1.6 Killing a process

We can kill a process using the kill command. To kill a process, we provide the process id as an argument (We could have also specified the process using a jobspec). In the following example, we start the gedit program and then kill it using kill command.

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ gedit &
[1] 5031
ubuntu@ubuntu:~$ ps
  PID TTY          TIME CMD
 4838 pts/0    00:00:00 bash
 5031 pts/0    00:00:00 gedit
 5037 pts/0    00:00:00 ps
ubuntu@ubuntu:~$ kill 5031
ubuntu@ubuntu:~$
```

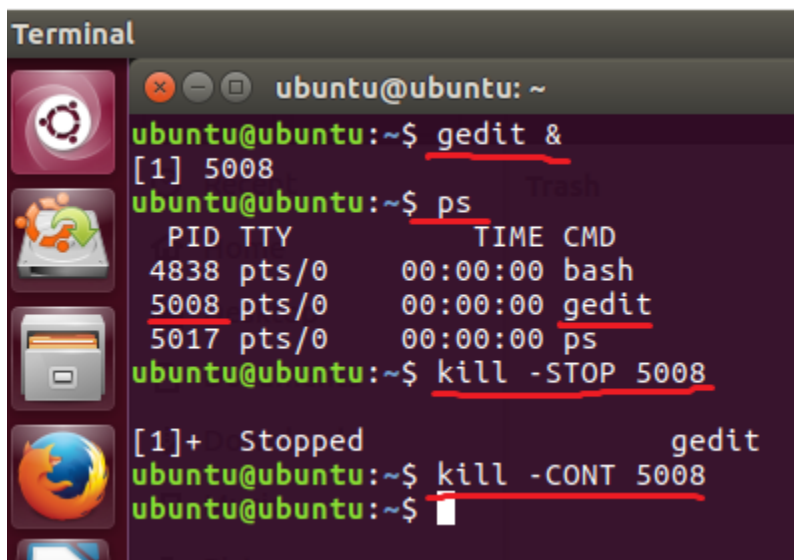
The kill command doesn't exactly "kill" processes, rather it sends them *signals*. Signals are one of several ways that the operating system communicates with programs. Programs, in turn, "listen" for signals and may act upon them as they are received. Following are most common signals that can be send with kill command.

Signal	Meaning
INT	INT Interrupt. Performs the same function as the Ctrl-c key sent from the terminal. It will usually terminate a program.
TERM	Terminate. This is the default signal sent by the kill command. If a program is still "alive" enough to receive signals, it will terminate.
STOP	Stop. This signal causes a process to pause without terminating.
CONT	Continue. This will restore a process after a STOP signal.

1.7 Pausing a process

Linux allows you to pause a running process rather than quitting or killing it. Pausing a process just suspends all of its operation so it stops using any of your processor power even while it still resides in memory. This may be useful when you want to run some sort of a processor intensive task, but don't wish to completely terminate another process you may have running. Pausing it would free up valuable processing time while you need it, and then continue it afterwards.

We can pause a process by using kill command with STOP option. The process id is required as an argument in kill command. In the following example, we start the gedit program in the background. Then we find the pid of gedit using ps command and then; we pause the process using kill command. Later, we can resume the process by using the kill command with CONT option.



```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ gedit &
[1] 5008
ubuntu@ubuntu:~$ ps
  PID TTY          TIME CMD
 4838 pts/0    00:00:00 bash
 5008 pts/0    00:00:00 gedit
 5017 pts/0    00:00:00 ps
ubuntu@ubuntu:~$ kill -STOP 5008

[1]+  Stopped                  gedit
ubuntu@ubuntu:~$ kill -CONT 5008
ubuntu@ubuntu:~$
```

1.8 Changing process priority

Every running process in Linux has a priority assigned to it. We can change the process priority using nice and renice utility. Nice command will launch a process with a user defined scheduling priority. Renice command will modify the scheduling priority of a running process. In Linux system priorities are 0 to 139 in which 0 to 99 for real time and 100 to 139 for users. nice value range is -20 to +19 where -20 is highest, 0 default and +19 is lowest. Relation between nice value and priority is:

$PR = 20 + NI$

So, the value of $PR = 20 + (-20 \text{ to } +19)$ is 0 to 39 that maps to 100-139.

In the following example, we start the gedit program in background and see its nice value using ps command.

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ gedit &
[1] 5104
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu   4838  4830  0  80   0 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu   5104  4838  3  80   0 - 33618 poll_s 10:40 pts/0    00:00:00 gedit
0 R ubuntu   5113  4838  0  80   0 - 2407 -    10:40 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$
```

Now, we start the gedit program again using nice command.

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ nice -10 gedit &
[1] 5117
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu   4838  4830  0  80   0 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu   5117  4838  4  90  10 - 33652 poll_s 10:42 pts/0    00:00:00 gedit
0 R ubuntu   5127  4838  0  80   0 - 2407 -    10:42 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$
```

We can change the priority of a running process using renice command. In the following example, we first start the gedit program in background. Then we change its priority using renice command.

```
Terminal Terminal File Edit View Search Terminal Help
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ gedit &
[1] 5161
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu   4838  4830  0  80   0 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu   5161  4838  6  80   0 - 33618 poll_s 10:54 pts/0    00:00:00 gedit
0 R ubuntu   5170  4838  0  80   0 - 2407 -    10:54 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$ sudo renice -n -12 -p 5161
5161 (process ID) old priority 0, new priority -12
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu   4838  4830  0  80   0 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu   5161  4838  1  68  -12 - 33618 poll_s 10:54 pts/0    00:00:00 gedit
0 R ubuntu   5174  4838  0  80   0 - 2407 -    10:55 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$
```

We can also use the renice command to change the priority of all of the processes belonging to a user or a group. In the following example, we change the nice value of all of the process belonging to user ubuntu.

```

Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu    4838 4830  0  80   0 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu    5161 4838  0  68  -12 - 33618 poll_s 10:54 pts/0    00:00:00 gedit
0 R ubuntu    5178 4838  0  80   0 - 2407 - 11:01 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$ sudo renice -n -12 -u ubuntu
999 (user ID) old priority -12, new priority -12
ubuntu@ubuntu:~$ ps -lf
F S UID      PID  PPID  C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S ubuntu    4838 4830  0  68  -12 - 2231 wait  09:26 pts/0    00:00:00 bash
0 S ubuntu    5161 4838  0  68  -12 - 33618 poll_s 10:54 pts/0    00:00:00 gedit
0 R ubuntu    5181 4838  0  68  -12 - 2407 - 11:02 pts/0    00:00:00 ps -l
ubuntu@ubuntu:~$

```

1.9 Few more useful commands related to processes

1.9.1 vmstat command

Outputs a snapshot of system resource usage including, memory, swap and disk I/O. To see a continuous display, follow the command with a time delay (in seconds) for updates. For example: `vmstat 5`.

```

Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ vmstat 3
procs -----memory----- --swap--  -----io----- -system--  -----cpu-----
r  b   swpd   free   buff   cache   si   so    bi    bo    in    cs   us  sy  id  wa  st
2  0     0  520200 169728 744484   0   0    70    0   42  340   3  1  96   0   0
0  0     0  519936 169728 744484   0   0     0    0   37  303   4  1  95   0   0
0  0     0  519936 169728 744484   0   0     0    0   35  287   4  1  96   0   0
0  0     0  519936 169728 744484   0   0     0    0   39  284   4  1  95   0   0
0  0     0  519960 169728 744484   0   0     0    0   36  239   2  1  97   0   0

```

1.9.2 xload command

Displays the system load over time.

1.9.3 tload command

This command is similar to `xload` but displays output in the terminal.

2. Compiling and Executing C++ Programs

Compiling is the way toward making an interpretation of source code into the local language of the PC's processor. The PC's processor works at an extremely basic level, executing programs in what is called machine language. This is a numeric code that portrays extremely little activities, for example, "include this byte," "point to this area in memory," or "duplicate this byte". Each of these instructions is expressed in binary which were hard to write. This issue was overwhelmed by the appearance of assembly language, which supplanted the numeric codes with (marginally)

simpler to utilize character mnemonics, for example, CPY (for duplicate) and MOV (for move). Programs written in assembly language are processed into machine language by a program called an assembler.

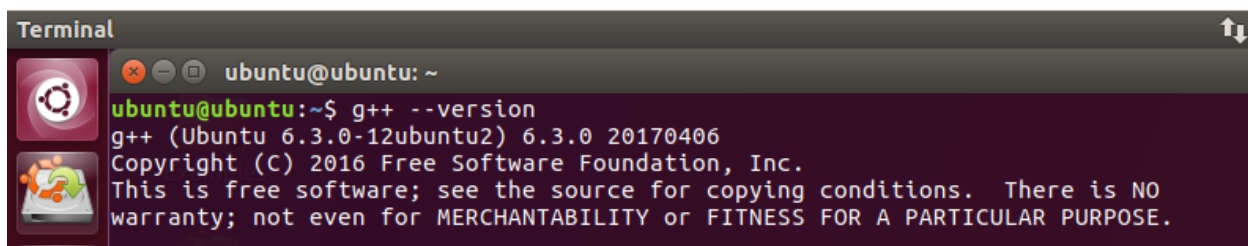
We next come to what are called high-level languages. They are called this since they enable the developer to be less worried about the details of what the processor is doing and more with taking care of the current issue. Programs written in high-level programming languages are converted into machine language by processing them with another program, called a compiler.

a. C++ compiler for Linux

C++ is a general-purpose programming language and widely used nowadays for competitive programming. It has imperative, object-oriented and generic programming features. C++ runs on lots of platform like Windows, Linux, Unix, Mac etc. Before we start programming with C++. We will need an environment to be set-up on our local computer to compile and run our C++ programs successfully. GNU C++ Compiler (g++) is a compiler in Linux which is used to compile C++ programs. It compiles both files with extension .c and .cpp as C++ files.

i. Installing g++ compiler

By default, g++ is provided with most of the Linux distributions. We can find the details of installed g++ compiler by writing the following command:

A terminal window titled "Terminal" with a dark background. The prompt is "ubuntu@ubuntu: ~". The command "g++ --version" has been entered, and the output is displayed in green and white text. The output shows the version as 6.3.0 20170406, the copyright as 2016 Free Software Foundation, Inc., and a disclaimer that it is free software with no warranty.

```
Terminal
ubuntu@ubuntu: ~
ubuntu@ubuntu:~$ g++ --version
g++ (Ubuntu 6.3.0-12ubuntu2) 6.3.0 20170406
Copyright (C) 2016 Free Software Foundation, Inc.
This is free software; see the source for copying conditions. There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
```

If g++ is not installed on your system; then it can be installed by writing the following commands

```
$ sudo apt-get update
$ sudo apt install g++
```

2.2 Compiling C++ program

We can compile a C++ program using the following command

```
$ sudo g++ source-file.cpp
```

The above command will generate an executable file a.out. We can use -o option to specify the output file name for the executable.

```
$ sudo g++ source-file.cpp -o executable-file
```

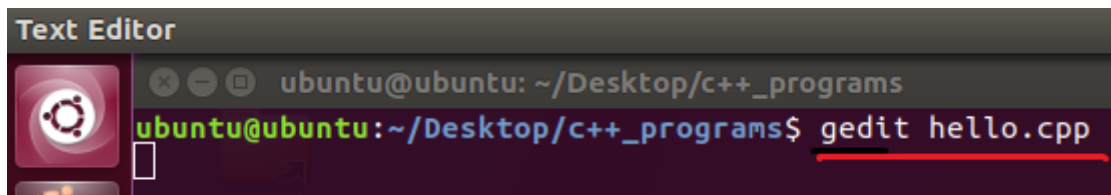
2.3 Running a C++ program

Once a C++ program is successfully compiled, we can execute the created executable file by using the following command:

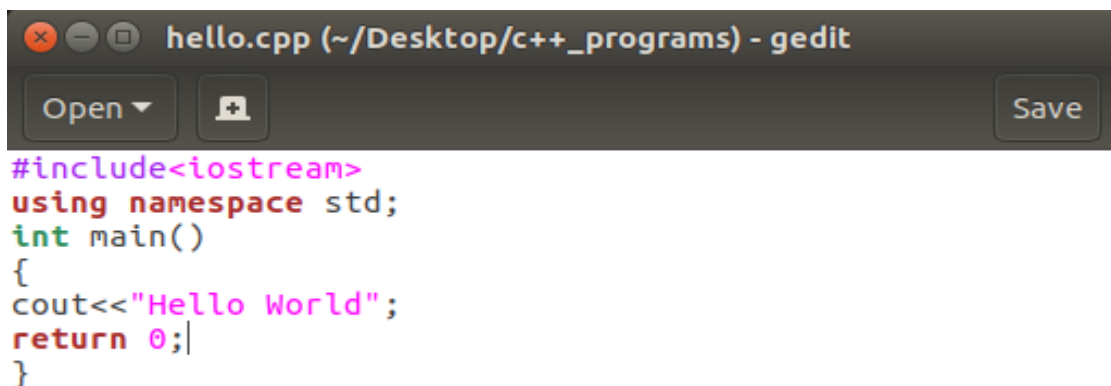
```
$ ./executable-file
```

In the following example, we write a simple C++ program that displays a Hello World message and then compile and execute this program using the above commands. To write the program, we use the gedit text editor. The source code file is saved with .cpp extension.

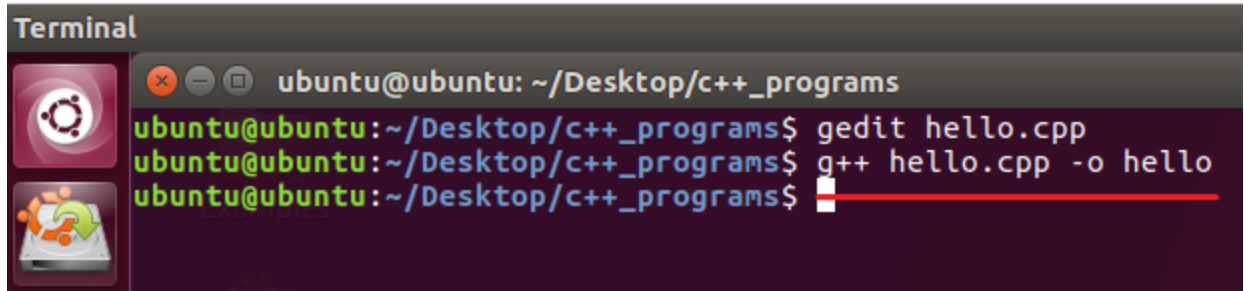
Open the gedit editor and pass the name of the file (hello.cpp) to be created



Write the following code

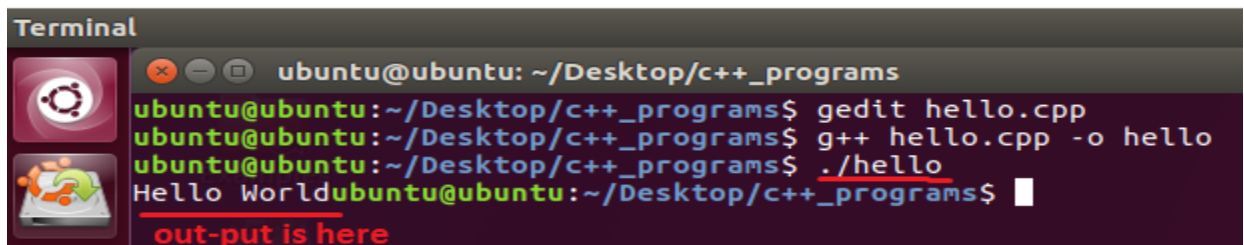


Now, close the source file and write the following command to compile hello.cpp

A terminal window titled "Terminal" with a dark background. The prompt is "ubuntu@ubuntu: ~/Desktop/c++_programs". The user enters "gedit hello.cpp", then "g++ hello.cpp -o hello", and finally a red underline appears under the prompt, indicating the next command to be entered.

```
Terminal
ubuntu@ubuntu: ~/Desktop/c++_programs
ubuntu@ubuntu:~/Desktop/c++_programs$ gedit hello.cpp
ubuntu@ubuntu:~/Desktop/c++_programs$ g++ hello.cpp -o hello
ubuntu@ubuntu:~/Desktop/c++_programs$
```

To execute the hello executable file, write the following command.

A terminal window titled "Terminal" with a dark background. The prompt is "ubuntu@ubuntu: ~/Desktop/c++_programs". The user enters "gedit hello.cpp", then "g++ hello.cpp -o hello", and finally ". /hello". The output "Hello World" is displayed, followed by a red underline under the prompt and the text "out-put is here" in red.

```
Terminal
ubuntu@ubuntu: ~/Desktop/c++_programs
ubuntu@ubuntu:~/Desktop/c++_programs$ gedit hello.cpp
ubuntu@ubuntu:~/Desktop/c++_programs$ g++ hello.cpp -o hello
ubuntu@ubuntu:~/Desktop/c++_programs$ ./hello
Hello World
out-put is here
ubuntu@ubuntu:~/Desktop/c++_programs$
```

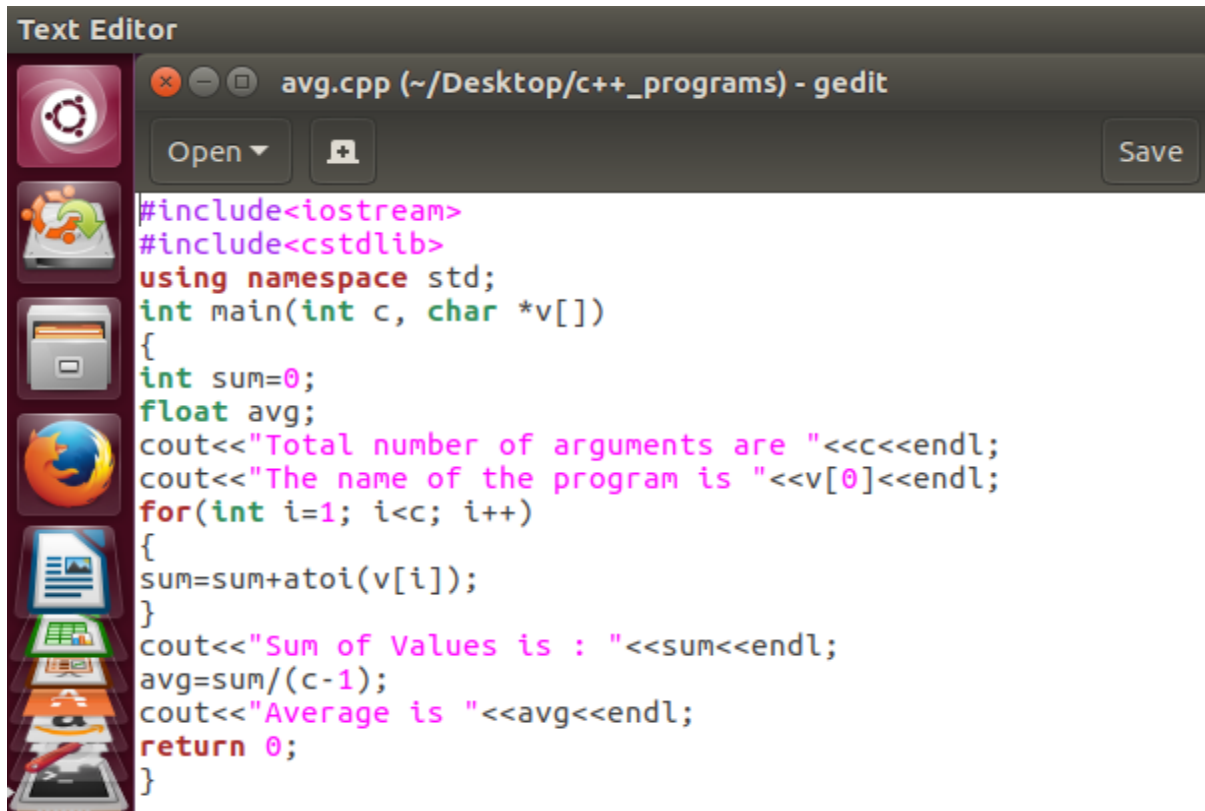
2.4 Passing command-line arguments to a C++ program

Command line argument is a parameter supplied to the program when it is invoked. Command line argument is an important concept in C++ programming. It is mostly used when you need to control your program from outside. Command line arguments are passed to the `main ()` method. To pass command line arguments, we typically define `main ()` with two arguments: first argument counts the number of arguments on the command line and the second is a pointer array which holds pointers of type `char` which points to the arguments passed to the program. The syntax to define the main method is

```
int main (int argc, char *argv[])
```

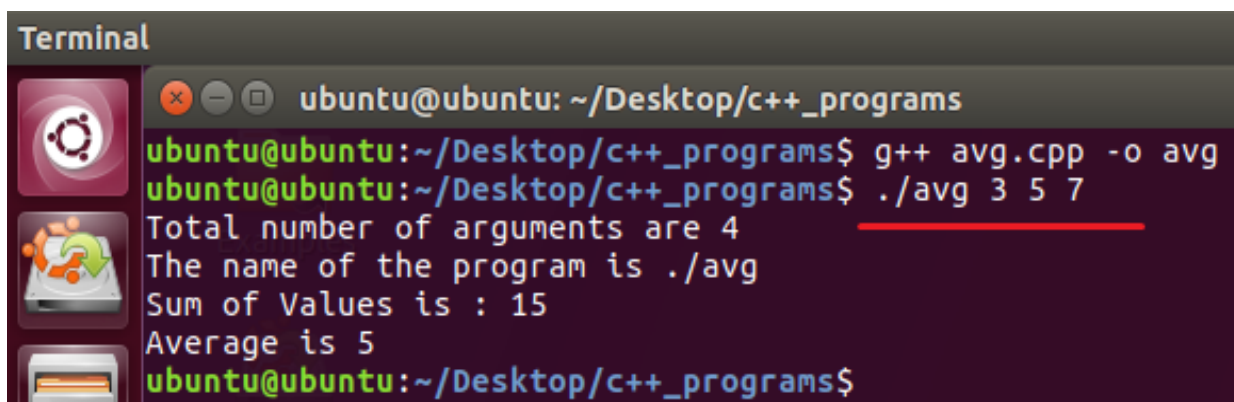
Here, `argc` variable will hold the number of arguments pass to the program while the `argv` will contain pointers to those variables. `argv[0]` holds the name of the program while `argv[1]` to `argv[argc]` hold the arguments. Command-line arguments are given after the name of the program in command-line shell of Operating Systems. Each argument separated by a space. If a space is included in the argument, then it is written in `""`.

In the following example, we calculate the average of numbers; passed in the command-line. Write the following code and save the file named as avg.cpp. Compile the avg.cpp and create an executable file named avg and execute it. While writing the command to execute avg pass the numbers whose average is required. It is shown below.



The screenshot shows a text editor window titled "avg.cpp (~/Desktop/c++_programs) - gedit". The code is as follows:

```
#include<iostream>
#include<cstdlib>
using namespace std;
int main(int c, char *v[])
{
    int sum=0;
    float avg;
    cout<<"Total number of arguments are "<<c<<endl;
    cout<<"The name of the program is "<<v[0]<<endl;
    for(int i=1; i<c; i++)
    {
        sum=sum+atoi(v[i]);
    }
    cout<<"Sum of Values is : "<<sum<<endl;
    avg=sum/(c-1);
    cout<<"Average is "<<avg<<endl;
    return 0;
}
```



The screenshot shows a terminal window with the following commands and output:

```
ubuntu@ubuntu: ~/Desktop/c++_programs
ubuntu@ubuntu:~/Desktop/c++_programs$ g++ avg.cpp -o avg
ubuntu@ubuntu:~/Desktop/c++_programs$ ./avg 3 5 7
Total number of arguments are 4
The name of the program is ./avg
Sum of Values is : 15
Average is 5
ubuntu@ubuntu:~/Desktop/c++_programs$
```

2) Stage a1 (apply)

Lab Activities

Activity 1:

This activity is related to process monitoring in Linux

1. Display all of the process in current shell
2. Display every active process in the system
3. Provide a full-format listing of process owned by you
4. Display a full-format listing of processes owned by user ubuntu
5. Display a process with id 1
6. Display the dynamic view of the current processes in the system and set the refresh interval 0.5 second
7. Display the dynamic view of the processes owned by user with id 999 (or name ubuntu)
8. Start the gedit program in background and then bring it foreground
9. Suspend the gedit program
10. Resume the gedit program

Activity 2:

Perform the following tasks

1. Start the gedit program with priority 90
2. Reset the priority of gedit to 65

Activity 3:

Write a program in C++ that find the maximum and minimum number from an array.

Activity 4:

Change the above program such that it accepts the input at command-line.