Lab 1: Introduction to C Programming Environment

Learning outcomes

- Understand and discuss programming environment
- Understand steps involved in writing a C program
- Understand program submission environment

Prerequisites

None if you're using lab computers. If you're using your personal Windows 10 machine, you must install the WSL environment and programming tools. Details are provided on the course's home page.

Introduction

A computer's operating system is a resource manager consisting of a set of programs that coordinate *safe*, *efficient*, and *abstract* access by users and application programs to system resources such as CPU, memory, input/output (I/O) devices including disks, printers, keyboards, monitors, network interfaces, and so on. *Safe* coordination means that the operating system allows only one application program to access a particular system resource at a time. For example, the operating system will allow only one application program to send data to the printer at a time. Data from other programs is spooled until the printer has completed its previous job. After the conclusion of the current print job, the operating system transmits the spooled data to the printer using a first-in-first-out priority. *Efficient* coordination means that programs waiting for their input or output operations to be completed [such as reading from or writing to files] have their execution suspended to make way for the execution of other programs. The operating system provides *abstractions* [such as files rather than disk locations, or network sockets rather than network interface addresses] that isolate application programs and users from low-level hardware details. Finally, operating systems provide *system utilities* or *commands* that allow users to accomplish universal functions such as file maintenance, printing, redirecting file input and file output.

Computers in DigiPen labs have the Windows Subsystem for Linux (WSL) that provides a Linux environment directly on Windows 10. For tutorials and assignments in this course, you'll be editing, compiling, linking, and executing your code in Linux.

You might be wondering why this introductory course in programming doesn't just use Windows and what is to be gained using a Linux environment. There are three main reasons why you should learn Linux.

- First, Linux is everywhere. Whether you are aware of it or not, you're already using Linux every moment of every day. If you've an Android cell phone, you're using a variant of Linux. If you've an Apple cell phone, you're using iOS which is a variant of Unix from which Linux itself is derived. The web and internet are powered by servers running Linux. In-vehicle infotainment systems, airplane in-flight entertainment systems, consumer electronics including smart TVs, DVRs, voice controlled devices such as Amazon Echo and Google Home, home security systems, and numerous industrial applications such as robots, assembly lines, and mass-transit systems are entirely powered by Linux.

- Second, Linux is free. Linux is an open-source operating system, with source code distributed by the Free Software/Open Source community. Anyone who receives it can make changes and redistribute it. No one company or individual owns Linux, which was developed, and is still being debugged and improved, by thousands of corporate-supported and volunteer programmers.
- Third, it is good for your career. Because Linux is free, versatile, and present everywhere, experience in Linux is a necessary requirement for most software developers and engineers. The basic exposure to Linux gained in this course will begin your journey in gaining and developing job skills that are in demand and well paid.

Since Linux on Windows PCs is implemented directly on top of Windows, part of using Linux effectively is learning to use Windows effectively. This tutorial begins with an introduction to the command line features of the Windows operating system. The aim is to get you comfortable using textual commands to get your work done in Windows. The tutorial continues with a short introduction to Linux and the bash shell for doing useful work in Linux. Next, the tutorial introduces the tools that you'll repeatedly use as a software developer. You'll be introduced to the process of creating a program written in C programming language: using Visual Studio Code to edit a C source file, using GCC C compiler toolchain `gcc` to compile the source file into an object file, link this object file with the C standard library to create an executable program, and then executing this C program. The final aim of this tutorial is to expose you to the nitty-gritty details of submitting programming assignments to a server that will automatically grade your program.

Shells and Command-line interfaces

Most operating systems support two forms of interaction with users: command-line interfaces (CLIs) for textual input using a keyboard and graphical user interfaces (GUIs) for interactions involving a mouse device and a keyboard. A *shell* is a text-based CLI program that acts as a *command interpreter* - it takes commands from the keyboard and passes them to the operating system for execution, and then displays the results of these commands on the screen. Using terse textual commands, users can launch programs such as word processors, browsers, games, run a string of commands as a single command by piping the output of one command to another command, and, in general, efficiently interact with the system. Further, tasks can be automated by encapsulating the commands required to execute the tasks into scripts and then running the scripts through the shell. On the other hand, GUI-based applications provide direct user interaction but rely on menus, buttons, a keyboard and a mouse device to get anything done. This means that powerful tools require complicated interfaces so that users can access all the features of the application with a mouse. The more features an application has, the more complicated the interface gets.

Ordinary users of computers prefer to interact with computers and the operating system controlling these computers using a GUI. In conjunction with a keyboard and mouse, a GUI provides such users a visually intuitive interface to view, control, manipulate, and toggle through multiple folders and programs. Almost all of us, irrespective of the operating system loaded on our computer, prefer using the GUI associated with that operating system. However, GUIs are neither convenient nor efficient in many scenarios that arise in software development. Instead, programmers prefer using a shell to interact with the operating system because it increases productivity and is an important part of the tool chain that every programmer must know.

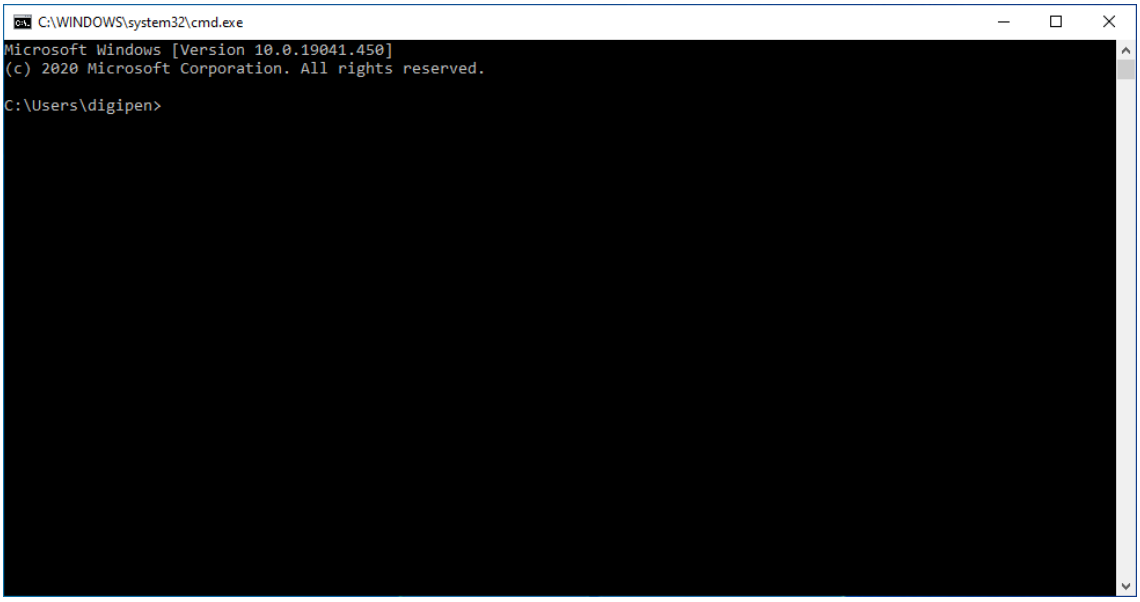
Consider a directory with a single file that has an image encoded in the JPEG format. Suppose you wish to convert the JPEG image to PNG format. You would launch GUI-based image editor, open the file, change certain settings in the editor, and then convert it to the destination PNG format. These actions could potentially take about 2 minutes of your time. Now, suppose the directory contains ten JPEG image files. Although you would find the manual conversion of each file cumbersome, the entire process would require less than 30 minutes. What if the directory contains hundreds or even thousands of JPEG image files? The amount of time required to manually convert a large number of files using the GUI will considerably slow down your productivity for days on end. In this particular situation, you could type a single command in the shell to perform the conversions in a fraction of the time required by the GUI-based manual method. As a software developer, you will be frequently called upon to automate manual tasks, and in such scenarios, knowing how to use a shell will considerably improve your productivity.

Another advantage of using the shell is the ability to collect together a set of textual commands into a simple program called a *script*. You can author scripts whenever you wish to automate certain tasks and run the script using just one command whenever required. This is very useful if you have some specific need or require a specific behavior with some tool, which is not implemented by any graphical application. A perfect example of automating software development tasks is provided by the *make* utility. Suppose your software contains hundreds or even thousands of source files [not inconceivable as your software grows both in scope and ambition]. Individually compiling such a large number of source files is a giant undertaking. Instead, you could specify the set of tasks to be executed by the C compiler as shell commands in a text file called *makefile*. When you type `make` in the shell, the commands in the *makefile* are executed. Although, depending on your computer's configuration, you may have to wait a while for these thousands of source files to be compiled and linked into an executable program.

Task 1: Windows command prompt

Windows provides a command shell [variously called *Command Processor*, *Command Prompt*, `cmd` prompt, or `cmd.exe`] that allows users to directly interact with the Windows operating system. Complete the following tasks to get some practice using the Windows shell.

1. The easiest way to open Windows command shell is to press the keyboard shortcut $\text{WIN}+\text{R}$ to open the Run dialog box. The WIN key contains the Windows logo and is located to the left of the Space Bar. In the Run dialog box, enter `cmd.exe` and hit Enter. Supposing your student login is digipen, the command shell will look like this:



2. To use the Windows command shell, enter a valid command along with any optional parameters followed by the Enter key. The Windows command shell then executes the command as entered and performs the task or function it is designed to perform in Windows. Ok, let's try some typing! Begin by executing command ver. Information about a command can be obtained by reading the built-in help pages for a command. The help pages of a specific command can be printed to the screen by typing command help followed by the command's name followed by the Enter key:

```
C:\Users\digipen>help ver
```

3. Now, type command VER.
4. Was the output for commands ver and VER different? What does this tell you about the case sensitivity of Windows shell? Windows is not case-sensitive. This means that the command help is equivalent to the command HELP or command Help or command HElp. Similarly, a file plot4.R is equivalent to PLOT4.R and to pLOT4.r and to names consisting of all other combinations of uppercase and lowercase characters.
5. Next, type command time. The shell displays the current time and if you've administrative privileges on your computer, the shell also allows you to change the current time.
6. Use command help to obtain additional information about command time. How would you tell Windows to only output the current time, without the prompt for changing current time?
7. Now hit up-arrow key ↑. Watch how your previous command returns. This means that Windows shell has a *command history*. Try using left-arrow ← and right-arrow → keys. These two keys allow you to position the text cursor anywhere in the command line allowing the easy correction of typing mistakes.
8. Another way to view your command history is to type the following command in the shell:

```
C:\Users\digipen>doskey /HISTORY
```

9. You can customize your Windows shell window by typing ALT+SPACEBAR+P to open the shell's *Properties* menu. Clicking the *Font* tab allows you to change character fonts. Clicking the *Colors* tab will allow you to change the shell's background and text colors. Clicking the *Options* tab will allow you to change command history size.

Task 2: Files and directories

A *file* is the primary unit of storage on your computer. Every file has a name, which generally indicates the type of information the file contains. As your collection of files grows from a few hundred to thousands, a hierarchical *file system* is required to locate and access specific files. Think of a file system as a type of index used by the operating system for all the data contained in a storage device.

Every operating system uses *directories* [also known as *folders* in Windows] to organize its files, the files of application programs, and users' files such as images from a digital camera. These directories are organized in a hierarchical tree structure, starting from the *root directory*. In addition to files, directories may contain other directories. A directory within another directory is called a *subdirectory*. Subdirectories may in turn contain sub-subdirectories and files. By creating subdirectories, you can better categorize and organize your files.

Just as a directory is a group of files, a *drive*, which is always represented by a drive letter [C, D, and so on], is a group of directories. Drives are usually associated with physical disk drives. A single physical drive could be logically divided into multiple drives.

Strictly speaking, all directories are subdirectories, except for the *root directory*. The root directory is the starting point from which all other directories branch out. In other words, the root directory is the root of the tree structure used to organize directories. The root directory does not have a name. Instead, it is represented by a backslash \. When the current working directory of the shell is root directory , the shell command prompt appears as C:\>. This prompt indicates that you're in the root directory of drive C.

In practical terms, a hierarchical filesystem means the following. When you first start Windows shell, you will be at a point in your file system known as your *home directory*. Within that directory, you can make subdirectories, and within them you can make sub-subdirectories, and so on. So, your filesystem has a tree-like shape that is a directory in the operating system's filesystem. This hierarchical filesystem helps you to organize your files. For example, suppose you are taking two courses called CS100 and MAT140. You could make directories with these names, and then keep all your files for a given course in that directory. You may have already started looking for a summer internship, so you might create a directory named Internships, and then keep all your resumes, cover letters, and other related documents in that directory.

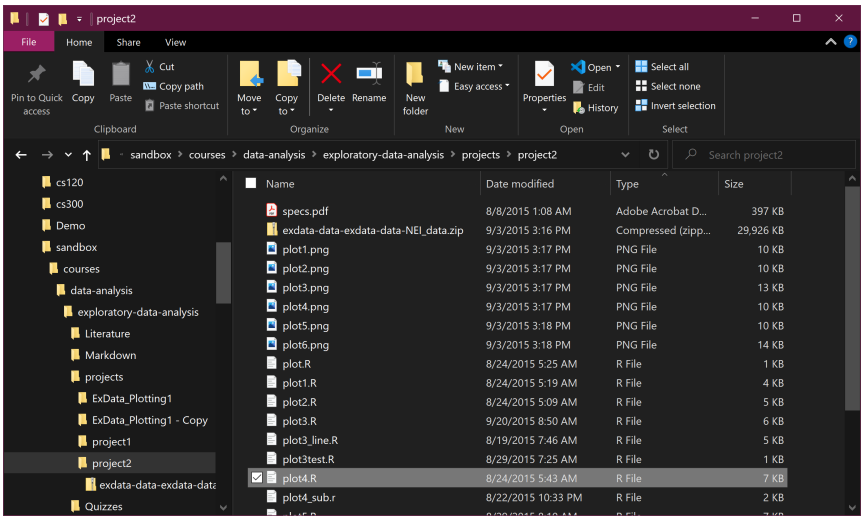
The *current working directory* of the shell is described in the shell's prompt: drive:\current-directory>. Supposing your student login name is digipen, your Windows command shell is launched in directory C:\Users\digipen. Now, complete the following tasks:

1. What happens when you type command dir? Command dir stands for *directory* which in GUI environments such as Windows is also referred to as a *folder*. Are you able to see all the files and directories in the home directory?
2. Use command help to identify the different parameters [or command extensions] available to command dir. In particular, investigate /A, /O, /S, and /W extensions.
3. Close the shell by typing command exit.
4. If you're using your personal machines, use your favorite technique to create a folder called sandbox in C: drive. Such a folder pre-exists on all lab machines.

Task 3: Paths

A *path* is the list of parent directories leading to the file you want to use. The *pathname* is the string of characters starting with the drive letter and including the names of directories, subdirectories and the name of the file to be accessed separated by backslash character \. A pathname can be specified in two ways:

- Absolute pathname: An *absolute pathname* begins from the root directory of a drive. For example, the path to access file plot4.R in the hierarchical tree structure from the following picture will be specified at the command prompt as C:\sandbox\courses\data-analysis\exploratory-data-analysis\projects\project2\plot4.R. This is the absolute pathname to file plot4.R. The first letter and colon [C: here] represent the drive the file is stored on. The first backslash represents root directory sandbox. The second backslash separates the sandbox directory from a subdirectory courses. The third backslash separates the courses subdirectory from a subdirectory data-analysis and so on.



- Relative pathname: A *relative pathname* is the course that leads from the current working directory. For example, if the current working directory is C:\sandbox\courses, then the relative path to access file plot4.R is data-analysis\exploratory-data-analysis\projects\project2\plot4.R.

Now, complete the following tasks:

1. Changing directories: Launch the Windows shell. How will you navigate from your home directory to a new location? To change directories, use command chdir [for *Change Directory*]. The period character . indicates *current working directory* while a string of two period characters .. indicates *parent directory*. Use command chdir .. to move from the current working directory to the parent directory. Use chdir to change your current working directory to C:\sandbox. If you're having trouble, don't forget the built-in help which can be accessed like this:

```
C:\Users\digipen>help chdir
```

2. Creating a directory: Read the built-in help information on command mkdir using command help. In the current working directory C:\sandbox, create a new directory named Fruit. Further, create a subdirectory named Mango in directory Fruit. Change your current working directory to Mango. Does your command prompt now look like this?

```
C:\sandbox\Fruit\Mango>
```

   Change back to parent directory Fruit. The simplest way is to use the two periods .. shortcut in your command.

3. Deleting a directory: Read the built-in help information on command rmdir. Delete directory Mango to simplify your directory structure. Further, delete directory Fruit. Were you successful? Can you delete a directory if the Windows shell is in that directory? If you were unsuccessful the first time, you'll have to step up to the parent directory C:\sandbox and then use command rmdir to delete subdirectory Fruit.
4. Close the Windows shell by typing command exit at the command prompt.

Task 4: More file management

This task continues the trip through Windows file management using the Windows shell. In particular, you'll learn how to startup or execute an application program from the shell, work with files, and use *wildcards* to manipulate groups of files.

1. Launch the Windows shell and change your current working directory to `C:\sandbox` and create a subdirectory named `test` in this current working directory.
2. Visual Studio Code [referred to as Code in this document] is a free, modern, multi-platform, and open-source source code editor for a variety of popular programming languages that is installed on all DigiPen lab desktops. Avoid using Notepad [also from Microsoft and also installed on all Windows computers] because it was never designed to be a source code editor. Since Code will be used frequently, you will find it convenient to launch the editor by typing `code` followed by Enter in the shell. Even better, to set Code's current working directory to your current working directory, provide Code the current directory using period character `.`:

```
C:\sandbox>code .
```

3. Use the editor to create and save a text file `foo.001` in directory `C:\sandbox\test`. Type any text you want into the file.
4. Read the built-in help information on command `copy` [using command `help copy` in the shell]. Using command `copy`, make two copies of file `foo.001` named `foo.002` and `foo.003`.
5. Using command `copy`, append files `foo.001`, `foo.002` , and `foo.003` and name the destination file `foo.004`.
6. Read the built-in help information on command `rename`. Using command `rename`, rename file `foo.004` as `boo.004`.
7. Make a copy of `boo.004` called `boo.final`. At this point, you'll have files `foo.001`,`foo.002`, `foo.003`, `boo.004`, and `boo.final` in current working directory `C:\sandbox\test`.
8. If you want to carry out a task for a group of files whose names have something in common, you can use one or more *wildcards* to specify groups of files. Two wildcards are commonly used: question mark ? and asterisk *. Wildcard ? represents *zero or a single* character that a group of files have in common. Wildcard * represents *zero or more* characters that a group of files have in common. Using command `mkdir`, create subdirectory `Math` in current working directory `C:\sandbox\test`. Read the built-in help information on command `move`. Using command `move` and wildcard *, move all files from current working directory to subdirectory `Math`. Use command `dir` to confirm the current working directory is now empty of files.
9. From current working directory `C:\sandbox\test`, use command `move` and wildcard * to move all files in subdirectory `Math` to the current working directory. Use command `dir` to confirm that subdirectory `Math` is now empty of files.
10. Read the built-in help information on command `erase` or command `del` [they are the same command]. Then, use command `erase` to delete file `foo.003`.
11. Use command `erase` and wildcard ? to delete files `foo.001` and `foo.002`. Further, use command `erase` and wildcard * to delete the remaining two files `boo.004` and `boo.final`.
12. Use the two periods shortcut `..` in your pathname to move from the current working directory to `C:\sandbox`. Delete subdirectory `test`.
13. Close the Windows shell by typing command `exit` at the command prompt.

Task 5: I/O streams and redirection operators

Operating systems use a powerful abstraction called *streams* to provide a flexible, portable, and efficient means of input and output (I/O). Regardless of where I/O originates or is destined, it is dealt as streams of characters. A *stream* is a sequence of bytes that may be associated with a file or a physical device such as a printer, keyboard, or monitor. A *text stream* is a sequence of characters divided into lines; each line consists of zero or more characters followed by a newline character. The contents of a text stream can be read or viewed using a text editor. A *binary stream* is a sequence of unprocessed bytes that are unreadable using a text editor. The stream abstraction allows programs to read input data and write output data from a variety of devices without having to handle the details of each individual device.

By default, every program is provided three I/O streams to interact with its environment: *standard input* for the program to read input, *standard output* for the program to write output, and *standard error* for the program to write error or diagnostic messages. Operating systems refer to standard input, standard output, and standard error streams as `stdin`, `stdout`, and `stderr`, respectively. By default, `stdin` stream's input is from the keyboard device, and by default, output from `stdout` and `stderr` is directed to the computer screen. Conceptually, think of `stdin` as a pipe through which input information flows from the keyboard device to the program; `stdout` as a pipe through which output information flows from the program to computer screen; and `stderr` as a pipe through which error and diagnostic information flows from the program to computer screen.

A *redirection operator* can be used to redirect input to `stdin` stream from the default device [which is a keyboard] to a different device such as a file. Likewise, a redirection operator can be used to redirect output from `stdout` stream from the default device [which is the computer screen] to a different device such as a file. More specifically, redirection operator $<$ can redirect input into `stdin` stream from default keyboard device to a file. Likewise, redirection operator $>$ can redirect output of `stdout` and `stderr` streams from default computer screen to a file. Complete the following tasks to learn about redirection of input and output streams:

1. Read this table to understand the various operators that redirect `stdin`, `stdout`, and `stderr` streams.
2. Launch Windows shell and change current working directory to $\mathrm{C:\backslash sandbox}$. Download program $\mathrm{stats\text{-}win.exe}$ from the lab webpage. Your browser may issue a warning about downloading and saving this executable file; ignore the warning because I can vouch that the executable is neither a virus nor a malware. Instead, this program reads zero or more integer values from `stdin` [keyboard device], computes mean and median of these values and writes these two statistics to `stdout` [computer screen]. Next, copy the downloaded file into $\mathrm{C:\backslash sandbox}$.
3. Run the program from command prompt [by typing program name $\mathrm{stats\text{-}win.exe}$ followed by Enter]. The program will wait for the user to enter zero or more integers. The user can signal to the program that no further input is to be expected using keyboard combo $\mathrm{Ctrl{+}D}$. The combo $\mathrm{Ctrl{+}D}$ is a special character in Windows called the *End-of-File* character `EOF` to signal to programs that no further input is to be expected. You enter a sequence of integers $10, 5, 20, 12, 3, 8$ [just the numbers without the commas] followed by $\mathrm{Ctrl{+}D}$ followed by Enter. The program will stop reading from `stdin` as soon as it reads $\mathrm{Ctrl{+}D}$. Next, the program computes mean and median of input integers as floating-point values and prints their values to `stdout`. The entire exercise is illustrated below with line 3 showing the program's output for the input on line 2:

```
C:\sandbox>stats-win.exe
10 5 20 12 3 8 Ctrl+D
9.67 9.00

```

4. Launch Code from command prompt to create file input.txt; type integers [and not the commas] $10, 5, 20, 12, 3, 8$ into the file [the numbers could be on a single line or on multiple lines]; and save the file [in current working directory C:\sandbox]. The simplest way to create file input.txt is like this:

```
C:\sandbox>code input.txt
```

   The Windows shell provides command type to display contents of text file(s). Enter type input.txt at the command prompt to verify that you entered the integers correctly.

5. Instead of using the characters entered through a keyboard device as the default input to `stdin` stream, you can use the *input redirection* symbol $<$ to redirect the contents of a text file as input to `stdin`. That is, you can provide the numbers in text file input.txt as input to program stats-win.exe like this:

```
C:\sandbox>stats-win.exe < input.txt
9.67 9.00

```

   As seen above, the redirection generates the same result as when you manually type integral values in the shell. An implicit *End-of-File* character is generated when the program reads the last character in file input.txt. Input redirection plays an useful role in two scenarios. First, it removes the tedium of typing lots of values. Second, it allows programs to be automated without waiting for user interaction. You'll be relying on input redirection to write programs that read data from files throughout this semester. Therefore, make sure to completely and thoroughly understand the useful technique of input redirection.

6. In a similar fashion, it is possible to redirect the output of the program's `stdout` stream from the default computer screen to a file using *output redirection* symbol $>$:

```
C:\sandbox>stats-win.exe > output.txt
10 5 20 12 3 8 Ctrl+D

```

   In this case, you'll type the input sequence of integer values using the keyboard device while the output is redirected from default computer screen to file output.txt. Confirm the output file's contents using command type:

```
C:\sandbox>type output.txt
9.67 9.00

```

   Note that if file output.txt already exists, it'll be overwritten.

7. If output file output.txt already exists and you wish to append new results to the file, use append operator $>>$ instead. Exercise the append operator like this:

```
C:\sandbox>stats-win.exe >> output.txt
10 5 20 12 3 8 Ctrl+D

```

Confirm the output file's contents using command type:

```
C:\sandbox>type output.txt
9.67 9.00
9.67 9.00

```

8. It is sometimes useful to redirect both input and output streams simultaneously, like this:

```
C:\sandbox>stats-win.exe < input.txt > output.txt
```

Confirm input and output redirections are working correctly:

```
C:\sandbox>type output.txt
9.67 9.00

```

9. Delete all files in C:\sandbox and close the Windows shell by typing exit at the command prompt.

Task 6: Piping

Piping is a form of redirection where a program's output is further processed by directing the first program's output as input of another program. Complete the following tasks to put piping into practice.

1. Launch a Windows shell and set current working directory to C:\sandbox. At command prompt, enter command help. The output of command help is too large to fit into the shell's window and most of the output whizzes by too fast and remains unread. Command more takes text as input and formats the text so that it is presented to the user one screen at a time. The concept of piping can now be used to redirect command help's output as input to command more which presents its input in presentable single-window chunks. Exercise command more like this:

```
C:\sandbox>help | more
```

Use the spacebar to update the contents of the shell's window when using command more. Use the Q button if you want to quit from command more.

2. Download program printints-win.exe from the lab webpage [again ignore any warnings from your browser] and copy the file into current working directory C:\sandbox . This program takes as input an integer value from the command line and prints an equivalent number of randomly generated numbers to `stdout`. Run this program at the command prompt to print 1000 randomly generated integer values like this:

```
C:\sandbox>printints-win.exe 1000
```

You're unable to read the 1000 numbers printed to `stdout` because they whiz by too fast. By piping the program's output as input to command more, you can examine the numbers at leisure one terminal screen at a time:

```
C:\sandbox>printints-win.exe 1000 | more
```

3. Piping is a useful feature because it allows different programs to be chained together to create more powerful programs. Let's look at another example of the usefulness of stream redirection and piping. Generate a large set of random numbers in text file random.txt like this:

```
C:\sandbox>printints-win.exe 1000 > random.txt
```

The mean and median of these 1000 random values can be computed like this:

```
C:\sandbox>stats-win.exe < random.txt
```

All of this can be done in a single step using piping:

```
C:\sandbox>printints-win.exe 1000 | stats-win.exe
```

4. Delete all files in C:\sandbox using commands erase or del and close the Windows shell by typing exit at the command prompt.

Linux

Just like Windows and macOS, Linux is a popular operating system originating from another popular operating system called Unix. On a historical note, C was invented in the early 1970's to implement the Unix operating system. Unix has now been popular for more than 50 years. Today, without variants of Unix systems, the Web and Internet would come to a screeching halt. Cellphone calls could not be made, electronic commerce would grind to a halt, and there would have never been console games, or "Jurassic Park" or any other CGI movie.

Unix was first fabricated in 1969 at AT&T Bell Labs (where the transistor was invented in 1947) as the operating system for a *time-sharing* computer that allowed multiple users to run multiple programs that could be (almost) simultaneously executed on the CPU. Later in 1973, Ken Thompson and Dennis Richie succeeded in rewriting Unix in a new high-level programming language called C which itself was invented by them for the sole purpose of authoring Unix. This is an important event because all other previous operating systems were written in assembler in order to extract maximum performance from hardware and were therefore difficult to port to computers made by other vendors. Because Unix was authored in a high level programming language, it became easier to port Unix across different hardware architectures and CPUs. During the 1980s, the multi-user, multi-tasking, hardware-independent nature of Unix made the computer industry adopt Unix as an operating system suitable for all computers.

Starting in 1975, AT&T made Unix widely available and at minimal cost to educational institutions making Unix popular in computer science departments. This led to a ripple effect - computer science students whose lab work had pioneered these new applications of technology were attaining management and decision-making positions inside the burgeoning technology industry and amongst its customers. And they wanted to continue using Unix and making it more versatile by adding additional features. Many variants of Unix were introduced by various hardware vendors. Starting in 1974, the Berkeley campus of the University of California emerged as the

single most important academic hot-spot in Unix development with a variant called Berkeley Unix. In 1983, Berkeley Unix added TCP/IP networking features and other major enhancements at the behest of the Defense Advanced Research Projects Agency to power servers for the ARPANET network. After the addition of TCP/IP, everything changed. The ARPANET network became the precursor to the Internet. And the networking tools and system utilities in Unix became an important reason for the popularity of Unix as servers for the Internet.

The increasing popularity of different flavors of Unix marketed by computer vendors such as IBM, DEC, and HP made it more complex to port applications across hardware, operating systems, and vendors. The POSIX standard was developed in the 1980s to resolve the portability issue. POSIX does not define the operating system, it only defines the application programming interface (API) between an application and an operating system, tools, and programs for software compatibility between variants of Unix and with other operating systems. Programmers have the freedom to write their operating system and application anyway they want as long as the interface between the two is honored. Because POSIX is independent of hardware, operating system or vendor, it's easier to achieve application portability.

Later in 1991, high licensing costs of Unix led to the development of an open source version of Unix called Linux. It has now become the best-known and most used variant of Unix. Aside from Windows powered computers and devices, almost every other device in the computing world is powered by an operating system that is a variant of Unix. The list includes Linux, Android, iOS, Apple desktop operating system macOS, Chrome OS, and Orbis OS [used in PlayStation 4]. Large hardware vendors such as IBM, HP, SGI, Sun, DEC, Compaq had their own versions of Unix. Except for IBM's AIX, the rest are more or less extinct and have been replaced with Linux. This document will use Linux in a general sense rather than referring to a particular variant.

Design features of Linux

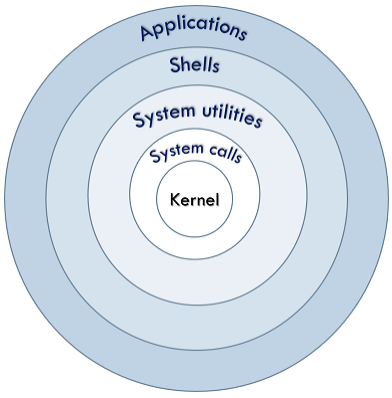
One of the many consequences of the pace of hardware and software development, is that most of what one knows becomes obsolete over every 18 months or so. Linux does not abolish this phenomenon, but does do a good job of containing it. There's a bedrock of unchanging basics: command line languages such as Korn shell, Bourne shell, high-level programming language C, system calls, software development utilities such as *make*, and networking libraries that one can actually keep using for decades. Elsewhere it is impossible to predict what will be stable; even entire operating systems cycle out of use. Thus the loyalty Linux commands. Much of Linux's stability and success are attributed to design decisions made back at the beginning; decisions that have been proven sound over and over. The following is a list of design features that were incorporated in the initial developmental philosophy of Linux that have played a critical role in its popularity.

- Linux is designed as a multi-user, multi-tasking operating system with multiple users having multiple tasks running simultaneously. This was not true with early versions of Windows and Apple's Mac OS.
- Linux is not specific to a particular type of computer hardware; instead, it is a hardware independent operating system. Linux is still the only operating that can present a consistent, documented API across a heterogeneous mix of computers, vendors, and special-purpose hardware. It is the only operating system that can scale from embedded chips and handhelds, up through desktop machines, through servers, and all the way to database back ends, and special-purpose number-crunching supercomputers.

- Linux is flexible for users because it supports multiple styles of user interface: plain text using a terminal and through a Graphical User Interface (GUI) as seen in Linux and macOS. Users can type plain text containing terse commands and messages to interact with Linux. This means that Linux can be implemented as a lightweight operating system without carrying the complexity overhead built into GUI-based operating systems such as Windows 10 and macOS. Note that this is often seen as a weakness because it increases the perceived complexity of the system to end users. The purpose of this tutorial is reduce this perceived complexity of Linux-like systems.
- Linux has become the one indispensable core technology of the entire Internet and its modern face, the World Wide Web. To function effectively as an Internet expert, an understanding of Linux and its components are indispensable.
- Linux was designed to be a software development environment consisting of a toolkit that contains many system utilities that improve the productivity of programmers. Each system utility is specialized to perform only one task very well. The output of every utility is expected to become the input of another, yet unknown, utility. This ability of Linux to glue together utilities mean that components of its basic toolkit can be combined to produce useful effects that designers of individual utilities never anticipated. This allows programmers to rapidly prototype new tools, toolkits, and programs by getting something small working as soon as possible and modifying it incrementally until it is finished.
- The open-source community is most active in the Linux world. High-quality, open-source software and development tools are usually, equal to, or superior to, their proprietary equivalents. See here for a comprehensive list that compares open-source and proprietary software.

Linux components

The following figure presents a highly simplified architecture of a Linux operating system and shows how Linux succeeds in presenting users and application programs with a uniform interface without regard to the details of the underlying hardware.



Kernel: At the center of the figure is the *kernel*, the core of the operating system, that is loaded into memory during system start up [the boot process]. The kernel is in direct control of the underlying resources or hardware of the computer. The kernel provides low-level device, memory and CPU management functions such as dealing with interrupts from hardware devices, sharing the CPU among multiple programs, allocating memory for programs, and so on. Hardware-independent kernel services are provided to *application programs* [such as web browsers and word processors] and *system utility programs* [simple but useful programs that are a part of the operating system and only perform a specific task and no more, for example, a program that finds files that contain certain text] through the *system call* interface. Each system call implements a basic service such as allocating memory to a program, enforcing file permissions, creating a new

file, deleting an old file, start a program's execution, or open a logical network connection to another computer, and so on.

Shell: Linux supports two forms of interaction with users: command line shells for textual input and GUIs for interactions involving a mouse and a keyboard. As explained earlier, a *shell* is a text-based command-line interface program that acts as a command interpreter for users - it takes commands from the keyboard and passes them to the kernel for execution, and then displays the results of these commands on the computer screen. A Linux system contains different shells such as Bourne shell, Korn shell, and Bourne Again shell (*bash*) with each shell having its own strengths and weaknesses. On the other hand, GUI-based applications provide direct user interaction but rely on menus, buttons, a keyboard and a mouse device to get anything done. This means that powerful tools require complicated interfaces so that the user can access almost all the features of the application with a mouse. The more features an application has, the more complicated the interface gets.

System utilities: In Linux, system utilities are designed to be powerful tools that do a single task extremely well. Every variant of Linux provides a standard set of several hundred utilities for accomplishing universal functions such as printing, text editing, file maintenance, maintaining file permissions, and so on. For example, the program called grep [short for *Global Regular Expression Print*] finds text inside files. The utility wc [short for *Word Count*] prints statistics related to the text in a file including the counts of number of words, lines and bytes. Users can often solve problems by interconnecting these tools instead of writing a large monolithic application program.

Application programs: Most versions of Linux provide several open-source applications as standard. Examples include text editors, a powerful typesetting language called latex, image viewers, C and C++ compilers.

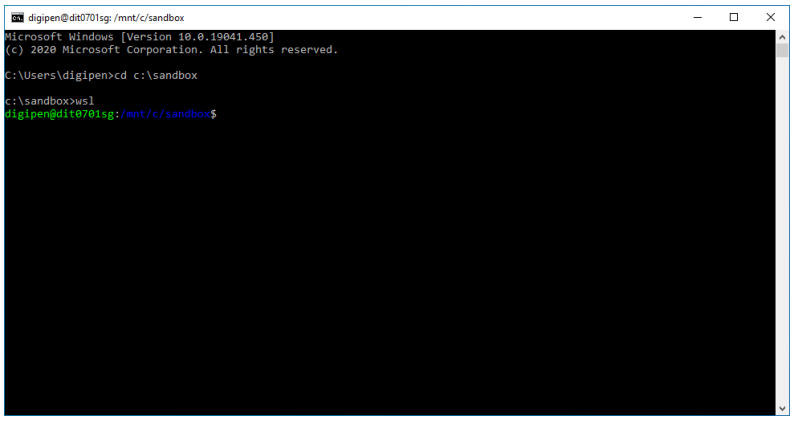
Task 7: Starting Linux bash shell

The Windows Subsystem for Linux (WSL) lets developers run a Linux environment directly and with minimal overhead on Windows so that most Linux facilities such as command-line tools, utilities, and applications can be executed unmodified. WSL provides a comprehensive collection of Linux utilities and programs such as sed, awk, grep, make for programmers to use Linux toolchains in Windows. Most importantly, the GNU Compiler Collection (GCC) - a collection of free, high-quality, open-source compilers and interpreters for C, C++, Python, Fortran, and other languages - can be easily installed in WSL. Think of WSL as an environment that will allow you to execute Windows applications in Linux and write Linux code in Windows. You might use WSL in a practical setting to provide a convenient environment in Windows to build applications for a variety of platforms including embedded chips and handhelds, desktop machines, database back ends for e-commerce, and special-purpose number-crunching supercomputers. Note that a program built in Linux using WSL is a native Linux program meaning that it can be ported to other Linux environments. However, the Linux program will not execute in plain Windows. Complete the following tasks for an introduction to Linux.

1. Begin by launching a Windows shell and change your directory so that the current working directory is C:\sandbox - you've practiced this in earlier tasks. To launch the Linux command shell, run command wsl:

   ```
   c:\sandbox>wsl
   ```

   Windows will launch the Linux shell. Again, it is easy to see because your command prompt has changed:



Remember command wsl as it is the command you use to switch into Linux from Windows. Very conveniently, you will still be in the same directory C:\sandbox as you were in Windows. To get out of Linux and return back to Windows, simply type exit in the Linux shell. If you happen to type exit in the Windows shell, it will close the command prompt and you'll have to reopen it.

Notice the directory you're in after switching to Linux: in Windows you were in directory C:\sandbox while in Linux the directory is /mnt/c/sandbox. When you're in Linux, the entire C drive for Windows is located in /mnt/c. Also notice that directories are separated by a forward slash / in Linux, while Windows uses a backslash \.

You should see a *shell prompt* consisting of your user name, say digipen, followed by @ followed by the name of the lab desktop, say dit0701sg followed by a colon : followed by the Linux path followed by a dollar sign $ followed by a space:

```
digipen@dit0701sg:/mnt/c/sandbox$
```

2. Now type some nonsense characters and hit the Enter key:

```
digipen@dit0701sg:/mnt/c/sandbox$ @#$%
```

You should get an error message from Linux operating system because it cannot find an utility named @#$%:

```
digipen@dit0701sg:/mnt/c/sandbox$ @#$%
@#$%: command not found
```

3. Linux has many shells. You can determine the system's default shell using command echo $SHELL and the current shell being used using command echo $0:

```
digipen@dit0701sg:/mnt/c/sandbox$ echo $SHELL
/bin/bash
digipen@dit0701sg:/mnt/c/sandbox$ echo $0
-bash
```

The results of the two commands indicates that both default and current shells are *bash* shells.

4. Just like the Windows shell, *bash* shell has *command history*. Pressing up-arrow key ↑ makes the previous command appear. Pressing down-arrow key ↓ will bring back the blank line. Say you wish to type command cd with a lengthy pathname:

```
digipen@dit0701sg:/mnt/c/sandbox$ cd ../game/graphics/assets/shadowmaps
```

Just as with the Windows shell, command cd changes directories in a Linux bash shell. Suppose, though, that you mistype the command as

```
digipen@dit0701sg:/mnt/c/sandbox$ cd ../game/graphifx/assets/shadowmaps
```

Also, suppose you have not yet hit the Enter key. Then, you can change the graphifx to graphics as follows: use left-arrow key ← to go to f; hit Delete key to remove f and x; hit keys c and s; and then hit the Enter key to process the command.

5. If you've already hit Enter key and then noticed that you had a typing error, you can use combo CTRL+p to go back to your previous command, and then use the method described earlier to remove the typing error. While CTRL+p behaves similar to up-arrow key ↑, you can replicate the behavior of down-arrow key ↓ with CTRL+n. You can use CTRL+p to go back through the command history and CTRL+n to go forward. You can use CTRL+p or ↑ to repeat without change a previous command.

6. One more bash shell convenience is *auto filename completion*. Suppose, for example you've a file named jack.and.jill.went.up.the.hill, which you'd like to copy to a file named jj. In *bash* shell, the command is

```
digipen@dit0701sg:/mnt/c/sandbox$ cp jack.and.jill.went.up.the.hill jj
```

But rather than explicitly typing the long filename, suppose that this is the only file in the current working directory which begins with the sequence of characters jac. You can type

```
digipen@dit0701sg:/mnt/c/sandbox$ cp jac
```

and then hit the Tab key. The shell will then auto complete that file name for you, so that the command line will look like this

```
digipen@dit0701sg:/mnt/c/sandbox$ cp jack.and.jill.went.up.the.hill
```

You'd continue typing destination filename jj from the end of auto filename completion and then hit Enter.

7. Command history prints the command history as a list. Each item in the list consists of an numerical id [starting from 1] followed by the command name. Suppose for example, the tenth item in the list is 10 cp jack.and.jill.went.up.the.hill jj. Rather than typing the entire command, you could have the bash shell automatically execute the command by typing:

```
digipen@dit0701sg:/mnt/c/sandbox$ !10
```

followed by the Enter key. If you want the previous command to be re-executed, just type !! followed by the Enter key.

8. These bash shell conveniences save a lot of typing and don't distract from the programming process that you're concentrating on. Whenever you use text editors, email utility programs, image viewers, and so on, check for these conveniences.

9. Linux is case sensitive. This means that a file named `cs120.txt` is different from both `Cs120.txt` and `cs120.TXT`. Similarly, commands are also case sensitive. The correct command is `history` while typing `HIstory` followed by `Enter` will make the shell print `HIstory: command not found`.
10. Delete files in `/mnt/c/sandbox` and quit the Linux bash shell by typing command `exit` at the command prompt. Type `exit` again at the command prompt to close the Windows shell.

Task 8: Linux filesystem

Just like Windows, the Linux operating system is also built around the concept of a hierarchical *file system* which is used to store the information constituting the system's long-term state. This state includes the operating system kernel itself, executable files for commands and utilities supported by the operating system, configuration information, user data, and various special files for providing controlled access to system hardware and operating system functions. This task is concerned with using the *bash* shell to navigate across a Linux file system and to create, rename, and delete files and directories.

1. Launch Windows command shell by typing `cmd.exe` in the `Run` dialog box obtained by pressing the keyboard shortcut combo `WIN+R`. Supposing your user name is `digipen`, the Windows command shell is created in directory `C:\Users\digipen`. Now use command `wsl` to switch from Windows to Linux bash shell.
2. When you're in Linux, the entire `C` drive for Windows is located in `/mnt/c`. Therefore, your current Windows directory `C:\Users\digipen` will be identified in Linux as `/mnt/c/Users/digipen`. Type command `pwd` [for *Print Working Directory*] in the *bash* shell to find your current working directory:

   ```
   digipen@dit0701sg:/mnt/c/Users/digipen$ pwd
   /mnt/c/Users/digipen
   ```

   The *bash* shell will print your current working directory as `/mnt/c/Users/digipen`. Notice that Linux uses forward-slash separator `/` in path names while Windows uses backslash separator `\`.
3. In Linux, `man` [for *manual* pages] is the command used to interface with the online reference and manual pages. Use command `man` to find out what commands `ls` and `cd` do and what options [or flags or extensions] are available.
4. Using command `cd`, change your current working directory to `c:/sandbox`, like this:

   ```
   digipen@dit0701sg:/mnt/c/Users/digipen$ cd /mnt/c/sandbox
   ```

5. Just as with Windows, bash shells use period character `.` to indicate the current working directory while a string of two period characters `..` indicate the parent directory. Use two period characters to change your current working directory to `/mnt/c`.
6. Also just as with Windows, Linux recognizes wildcards such as `?` and `*` to specify groups of files. Recall that wildcard `?` represents *zero or a single* character that a group of files have in common, while wildcard `*` represents *zero or more* characters that a group of files have in common.
7. Change your current working directory to `/mnt/c/sandbox`.

8. In your current working directory, create a directory labeled CS120 using command mkdir. Confirm that the directory was created using command ls.
9. Using commands mkdir and cd, create subdirectories 01, 02, and 03 in directory CS120. You should now have the following hierarchies: CS120/01, CS120/02, and CS120/03.
10. Change your current working directory to CS120/01. Launch Code just as you would in a Windows shell. If this is being done the very first time, the operating system will install certain software components related to Code. Once Code launches, create a text file named foo.txt. Insert any legible text you wish into this file and shutdown Code.
11. On many occasions, you'd prefer to read contents of text files without resorting to an editor such as Code. Linux provides two convenient commands called cat and more to do exactly that. You can display contents of a text file using command cat:

```
digipen@dit0701sg:/mnt/c/sandbox/CS120/01$ cat foo.txt
```

If the file consists of more lines of text than can fit your shell window, you can display its contents one screen at a time by piping the output of command cat to command more:

```
digipen@dit0701sg:/mnt/c/sandbox/CS120/01$ cat foo.txt | more
```

12. Change current working directory from CS120/01 to CS120/02. Next, use command cp to copy file foo.txt from subdirectory 01 to the current directory as a file named bar.txt. If you're confused about command cp, use the piped command man cp | more to get more information about cp.
13. From the current working directory, use command mv to *move* the file bar.txt to file foobar.txt in directory CS120/03. If you're unable to complete this task, use the piped command man mv | more to get more information about mv.
14. Change your current working directory to CS120/03 and use command ls to check if file foobar.txt exists. The file should exist if the previous steps were completed correctly. The contents of the file can be checked using command cat.
15. To delete hierarchies CS120/01, CS120/02, and CS120/03, change your current working directory to /mnt/c/sandbox and use command rm like this:

```
digipen@dit0701sg:/mnt/c/sandbox$ rm CS120
rm: cannot remove 'CS120': Is a directory
```

As seen from the error message, command rm must be provided additional options to delete directories. Use command man [for manual] to research command rm:

```
digipen@dit0701sg:/mnt/c/sandbox$ man rm | more
```

16. After removing the CS120 directory hierarchy, quit the Linux shell by typing exit at the command prompt. Type exit again at the command prompt to close the Windows shell.

Task 9: Getting started with gcc

The purpose of this portion of the tutorial is to expose you to compiler tools that will be used in this and other programming courses. Lab computers provide GNU Compiler Collection (GCC) - a free collection of compilers and interpreters for C, C++, Python, Fortran, Go, and other languages. GCC is portable - it runs on most platforms available today, and can produce output for many types of processors. GCC is not only a native compiler - it can also cross-compile any program, producing executable files for a different system from the one used by GCC itself. This allows software to be compiled for embedded systems such as entertainment devices and game consoles which are not capable of running a compiler. All of this is good news because you will be learning and using a C compiler that is widely used in a variety of academic, industrial, and professional settings.

1. Begin by launching a Windows shell, changing your directory so that current working directory is C:\sandbox, and then launching the Linux bash shell. Using command mkdir, create directory lab01 and change the current working directory in bash shell to directory lab01. Launch Code from the bash shell and edit *source file* prog1.c with the following C code. I urge you to not copy-and-paste!!! It is important that you read-and-type and potentially make mistakes that can be explained and corrected. This is the only way to gain experience when you're starting out as a beginner with little or no exposure to programming!!!

```c
/*
This is the smallest legal C code.
The program doesn't take any input from the user.
Nor, does the program print any output to the user.
In other words, the program does nothing useful.
These lines between the tokens on lines 1 and 9 constitute
a comment. Comments are meant for human readers of the file
and are not consumed by the compiler.
*/

/*
Every C program requires a function called main that is the entry
point of the program. That is, your computer's CPU will begin
executing the program from the first statement of function main.
In this main function, the statement simply returns the
integer value 0 back to the operating system indicating
successful program execution.
*/
int main(void) {
  return 0;
}

```

   Notice empty line 22. Every legal C source file must have such an empty line at the end.

2. Preprocessing, compiling, assembling, and linking are the various stages involved in converting the source code in prog1.c to an executable program. Rather confusingly, most programmers refer to these distinct stages using the umbrella term *compiling* [confusing because compiling is also one of the stages] or *compiler driver* or *compiler toolchain*. gcc is the name of the command that implements these distinct steps using the GCC C compiler. Compile file prog1.c with gcc, like this:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ gcc -std=c11 -pedantic-errors -
Wstrict-prototypes -Wall -Wextra -Werror prog1.c -o prog1.out
```

This compiles source code in prog1.c to executable machine code and stores it in executable file prog1.out. The name of the output file containing the machine code is specified using option -o. This option is usually given as the last argument on the command line. If it is omitted, the output is written to a default executable file called a.out. Note that if a file with the same name as the executable file already exists in the current directory, the old file will be overwritten with the contents of the new file.

Option -std=c11 specifies the base ISO C11 standard. Options -Wstrict-prototypes, -Wall , and -Wextra individually turn on different types of compiler diagnostic warnings while options -pedantic-errors and -Werror convert these warnings to full-fledged errors. Options are not required for gcc to produce warnings and errors for obvious syntax related issues. The options listed above produce diagnostic warnings in non-obvious situations that could potentially lead to hard-to-detect bugs. Further, options -std=c11 and -pedantic-errors, and -Wstrict-prototypes aim to make the best possible attempt to ensure C code conforms as a subset of C++. Since compiler warnings are an essential aid in detecting problems when programming in C and C++, you are required to ***always use*** these options! The biggest cause of students getting a C grade rather than an A grade can be attributed to not following this advice. An itemized listing of these options is detailed in this section.

3. Compiling prog1.c should not produce any warnings nor errors if the program was typed exactly as shown. Source code which does not produce any warnings is said to *compile cleanly*. To run the program, type the pathname of the executable like this:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ ./prog1.out
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

This loads executable file prog1.out into memory and causes the CPU to begin executing the instructions contained within it. The period character . indicates *current working directory* and therefore the path ./prog1.out refers to file prog1.out in the current working directory. Since the program doesn't do anything, you'll not see any output generated by it.

Recall that when you executed Windows executable stats-win.exe in the Windows shell, you did not have to provide the path to the current directory. Instead, you were able to execute the program like this:

```
C:\sandbox>stats-win.exe < input.txt
9.67 9.00

```

This is because unlike Linux bash shell, the Windows shell automatically specifies a path to the current directory.

Task 10: Second C program

Let's now write a classic program that prints the text Hello World to the `stdout` stream.

1. Create a source file prog2.c and type the following C source code:

```c
// While the tokens /* and */ can be used to specify multi-line
// comments, token // is used to specify single-line comment.
#include <stdio.h> // contains function prototype of printf

int main(void) {
  printf("Hello World\n");
  return 0;
}

```

2. Use instructions from the previous task to compile source file prog2.c and store the executable in prog2.out.
3. Executing program prog2.out should generate the following output:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ ./prog2.out
Hello World
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

Characters `\n` in string `"Hello World\n"` represents a newline. Note the two lines of output generated by the program: the sequence of characters in string `"Hello World"` followed by a newline. If you get compilation errors, then you must have typed the source code incorrectly. Go back and review the source code to make sure there are no syntax errors.

Task 11: Debugging - finding errors in program

As mentioned earlier, compiler warnings are an essential aid when programming in C. This is demonstrated in the sequence of steps below.

1. Create a source file prog3.c and type the following C source code:

```c
/*
This program will print the text "DigiPen's zip code is 13960".
Rather than printing a constant value, we store the zip code in
variable called zcode so that whenever the zip code changes, the
printf function will print the updated zip code.
*/

#include <stdio.h> // contains function prototype of printf

int main(void) {
  // zip is a variable; 139660 is an integer literal
  // here, we're defining the variable and also initializing
  // the variable to have value 139660
  int zip = 139660;

  printf("DigiPen's zip code is %d.\n", zip);
  return 0;
}

```

2. Compile the program and store the executable in prog3.out.
3. Executing program prog3.out should generate the following output:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ ./prog3.out
DigiPen's zip code is 139660.
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

4. Change the initializer for variable `zip` to various integral values [such as your hometown zip code], recompile, run the executables, and observe the outputs generated by these programs.

5. To demonstrate that compiler warnings are an essential aid to debugging C/C++ programs, a subtle bug is introduced in the code that makes function `printf` misbehave while the code itself is successfully compiled by gcc. On line 16 [of the code above], change the *integer* format `%d` to a *floating-point* [that is, having fractions] format `%f`. This will introduce an error into the program's behavior because the programmer should specify her intent to print an integral zip code by using integer format `%d`. However, the programmer has mistakenly typed the format specifier as `%f` leading function `printf` to print floating-point values rather than integer values.

6. Compile prog3.c. Because of the subtle error you've introduced, gcc generates some diagnostic messages before successfully compiling the source file:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ gcc -std=c11 prog3.c -o prog3.out
prog3.c: In function ‘main’:
prog3.c:16:34: warning: format ‘%f’ expects argument of type ‘double’,
but argument 2 has type ‘int’ [-Wformat=]
   16 |   printf("DigiPen's zip code is %f.\n", zip);
      |                                  ~^      ~~~
      |                                   |      |
      |                                   double int
      |                                  %d
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

7. Suppose you ignore these diagnostic messages and execute the program. The program generates incorrect output:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ ./prog3.out
DigiPen's zip code is 0.000000.
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

   The incorrect format specifier `%f` causes the output to be corrupted because function `printf` is passed an integer instead of a floating-point number. Integers and floating-point numbers are stored in different formats in memory, leading to a spurious result. The actual output of your program depends on the specific platform and environment and may differ from the one shown above.

8. The moral of the story here is to always read and correct diagnostic messages from gcc. In this instance, the warning message indicates a format string has been used incorrectly in file prog3.c at line 16. Messages produced by gcc always have the form file:line-number:message. The compiler distinguishes between *error messages*, which prevent successful compilation, and *warning messages* which indicate possible problems but do not stop the program from compiling. In this case, the correct format specifier should have been `%d` because variable `zip` is of type `int`. Page 37 of the text contains a partial list of allowed format specifiers. The entire list is available here.

Although the compiler has flagged warning messages for the text in line 16, it still compiles the incorrect program prog3.c into an executable. This is a problem because the incorrect executable could be distributed for use by others. For example, you could upload this buggy program as your submission for an assignment causing your grade to be a 🐓. What you would really want is for gcc to convert these warnings to errors. Compared to warnings, errors are catastrophic - the compiler cannot or will not generate an executable. This is possible by using an additional option -Werror:

```
digipen@dit0701sg:/mnt/c/sandbox/lab01$ gcc -std=c11 prog3.c -o
prog3.out
prog1.c: In function ‘main’:
prog1.c:16:34: error: format ‘%f’ expects argument of type ‘double’, but
argument 2 has type ‘int’ [-Werror=format=]
   16 |   printf("DigiPen's zip code is %f.\n", zip);
   |                                  ~^      ~~~
      |                                  |      |
      |                                  |      double int
      |                                 %d
cc1: all warnings being treated as errors
digipen@dit0701sg:/mnt/c/sandbox/lab01$
```

Notice that gcc has converted the diagnostic warning message to an error message and quit the compilation process without creating the executable file.

The moral of the story is to always use the -Werror option when you compile. The best defensive technique you could adopt is to always use all these options -std=c11, -pedantic-errors, -Wstrict-prototypes, -Wall, -Wextra, and -Werror every time you compile, irrespective of whether you're programming for fun or for your project or when submitting assignments. Although this tutorial has not illustrated the use of options other than -Werror, their uses will be necessary in more complex programs.

Task 12: Submission and automatic evaluation

Create a source file q.c and type the code on page 15 of Lecture 2's presentation deck.

Testing

Compile and link your source file q.c using the full suite of required gcc options:

```
digipen@dit0701sg:/mnt/c/sandbox/tut02$ gcc -std=c11 -pedantic-errors -
Wstrict-prototypes -Wall -Wextra -Werror q.c -o q.out
```

If your source file doesn't compile and link successfully, use the diagnostic messages from gcc to determine the errors in your source file, repair those errors, and recompile. Repeat this process until you've successfully generated executable q.out. Now, run executable q.out like this to display the prompt `Enter base and power:`:

```
digipen@dit0701sg:/mnt/c/sandbox/tut02$ ./q.out
Enter base and power:
```

Provide input to the program by typing integer values 3 and 4 followed by the Enter key:

```
digipen@dit0701sg:/mnt/c/sandbox/tut02$ ./q.out
Enter base and power: 3 4
```

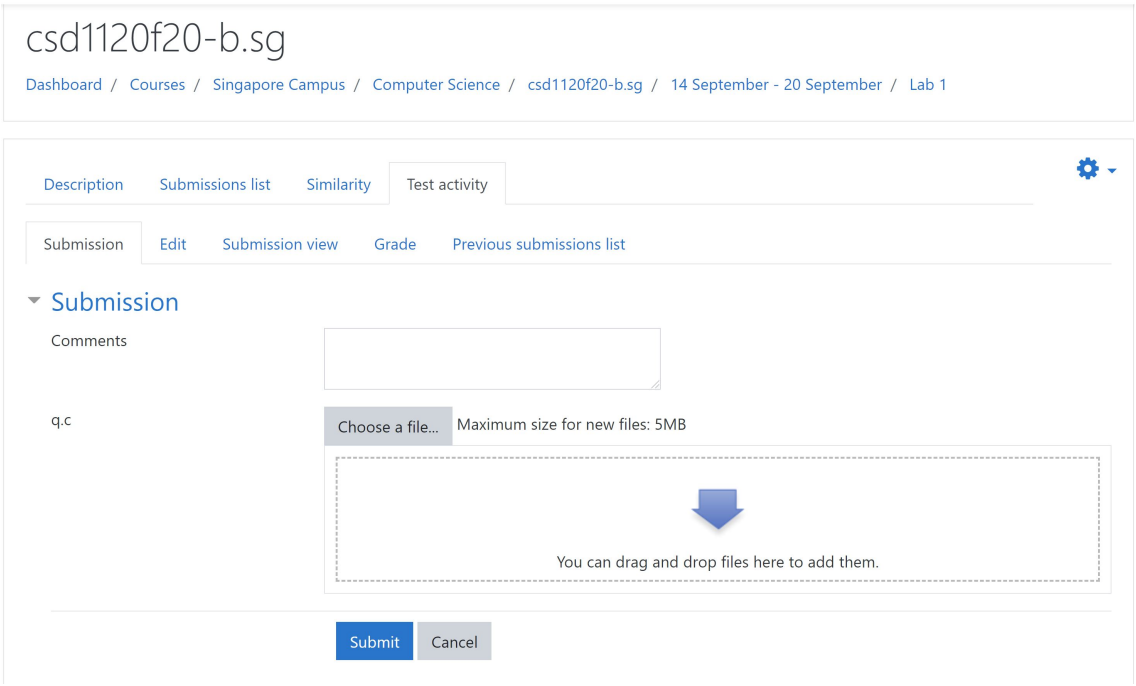
The program will generate the following output:

```
3 ^ 4 is: 81
```

Test the program's behavior by evaluating the exponents of a variety of base numbers.

Submission and automatic evaluation

1. In the course web page, click on ***Lab 1 Submission Page***. Next, click on the ***Submission*** button: you'll see something like this:



2. Drag and drop your submission file `q.c` and click the ***Submit*** button followed by the ***Continue*** button. The automatic grading will begin: your submission `q.c` will first be compiled and linked to create an executable file. Next, the executable is run and its output is compared with the correct output:

3. The automatic grader will assign a grade for this and future programming assignments and labs based on the whether your source code successfully compiles, successfully links, and successfully generates the correct output. If you're not satisfied with your grade, you should go back and repeat the entire process: amend your source code to ensure compilation and linking are successful, and that your program generates the correct output. You can repeat this process as many times as necessary up until the submission deadline.
4. All submissions will also provide a set of rubrics [think of a rubric as a grading rule] specifying how your grade will be computed. The rubrics for this submission are:
    1. F grade if `q.c` doesn't compile with the full suite of `gcc` options.
    2. F grade if `q.c` doesn't link to create an executable.
    3. F grade if the program's output is not correct.
    4. $A+$ grade if program's output is correct output.

Review

After completing this tutorial, you should be comfortable with the basic knowledge and skills required to use the programming environment for this course, that is, navigate through your computer's filesystem using both Windows shell and Linux bash shell; edit, compile, and link source files using the gcc compiler toolchain; and submitting source code for automatic grading. In particular,

1. You should be able to launch the Windows shell and implement basic file management.
2. You should be able to launch and use Code to edit source code from Windows shell.
3. You should be able to launch the Linux bash shell from the Windows shell and implement basic file management.
4. You should be able to launch and use Code to edit source code from Linux bash shell.
5. You understand the abstraction of streams. You know the meaning of `stdin` [standard input] and `stdout` [standard output] streams.
6. You understand the meaning of stream redirection. You know how to redirect program output to a file and redirect program input from a file.
7. You understand the idea of pipes and piping so that individual programs can be strung together to create a toolchain.
8. You understand the edit-compile-execute cycle using gcc compiler toolchain. You know the purpose of gcc issuing warnings and you know the various options available to programmers. You understand option **-o** used with gcc that allows programmers to provide names other than a.out to executables.
9. You understand how to write, compile, and link code that uses function `printf` to write specific text to *stdout*.
10. You understand the steps involved in submitting source code for tutorials and programming assignments.
11. You should have practiced the following Windows shell and Linux bash shell commands:

What does command do?	Windows shell	Linux bash shell
Provide information on commands	help	man
List files	dir	ls
Copy files	copy	cp
Delete files	erase and del	rm
Move files	move	mv
Rename files	ren and move	mv
Print contents of text files	type	cat
Display output one screen at a time	more	more or less
Create directory	mkdir or md	mkdir
Delete directory	rmdir or rd	rm

What does command do?	Windows shell	Linux bash shell
Change directory	chdir or cd	cd
Print current working directory	chdir or cd	pwd

What does command do?	Windows shell	Linux bash shell
Create links between files	mklink [not covered]	ln
Clear shell screen	cls	clear
Time of day	time	time
Date	date	date

GCC C compiler options

This is an itemized listing of gcc options that are required whenever you write code. Your programming submissions will always be compiled using *all* of the listed options.

- -std=c11: Information about the ISO C11 standard is available in the C11 N1570 standard draft.
- -pedantic-errors: Gives an error when base standard C11 requires a diagnostic message to be produced. C89 allows the declaration of a variable, function argument, or structure member to omit the type specifier, implicitly defaulting its type to `int`. Although, legal in C89, this is considered illegal in C99, C11, and C++:

```
#include <stdio.h>
int main(void) {
  static x = 10; // notice the lack of type specifier int
  printf("x: %d\n", x);
  return 0;
}

```

However, compiling this code with a C11 compiler, as in: `gcc -std=c11 tester.c` elicits only a warning message. However, compiling the same code with option -pedantic-errors produces an error.

According to Section 5.1.1.3 of the C11 N1570 standard draft,

> 1 A conforming implementation shall produce at least one diagnostic message (identified in an implementation-defined manner) if a preprocessing translation unit or translation unit contains a violation of any syntax rule or constraint, even if the behavior is also explicitly specified as undefined or implementation-defined. Diagnostic messages need not be produced in other circumstances.[9])
>
> 9. The intent is that an implementation should identify the nature of, and where possible localize, each violation. Of course, an implementation is free to produce any number of diagnostics as long as a valid program is still correctly translated. It may also successfully translate an invalid program.

Based on the above text, option -pedantic-errors cannot be solely used to check programs for strict ISO C conformance. The flag finds some non-ISO practices, but not all - only those for which ISO C *requires* a diagnostic, and some others for which diagnostics have been added.

- -Wall: This enables all the warnings about constructions that some users consider questionable, and that are easy to avoid [or modify to prevent the warning]. Some of them warn about constructions that users generally do not consider questionable, but which occasionally you might wish to check for; others warn about constructions that are necessary or hard to avoid in some cases, and there is no simple way to modify the code to suppress the warning. Some of them are enabled by option -Wextra but many of them must be enabled individually. The entire list of warning flags enabled by option -Wall for GCC can be found here.
- -Wextra: This enables some extra warning flags that are not enabled by -Wall. The entire list can be found here.
- -Werror: Converts diagnostic messages generated by the base compiler and warnings generated by flags -Wall and -Wextra to errors. This is a necessary feature for generating cleanly compiled code that doesn't generate any warning messages.
- -Wstrict-prototypes: It is legal in all ISO C standards to specify a function declaration as:

```
int f();
```

C89, C99, and C11 compilers read the above declaration as `f` is a function that takes unknown number of parameters with unknown types and return a value of type `int`. This means the following code in a source file test.c will compile and link with undefined behavior when executed.

```
#include <stdio.h>

int foo();

int main(void) {
  int x = 2, y = 4, z = 6;
  printf("%d + %d = %d\n", x, y, foo(x, y));
  printf("%d + %d + %d = %d\n", x, y, z, foo(x, y, z));
  return 0;
}

int foo(int i, int j) {
  return i + j;
} // don't forget to add empty line after this
```

The code will compile with GCC and Clang [and also with Microsoft Compiler] without any diagnostic messages:

```
$ gcc -std=c11 -pedantic-errors -Wall -Wextra -Werror test.c
```

However, the same code will not compile with a ISO C++ compiler:

```
$ g++ -std=c++11 test.c
```

since the declaration `int f();` in ISO C++ compilers indicates that `f` is a function that takes no parameters and returns a value of type `int`.

To ensure compatibility with ISO C++ standards, option -Wstrict-prototypes must be used with GCC and Clang to ensure that test.c doesn't successfully compile.