Lab 1 (10 points)
January 17 & 18, 2017

CS-2303, System Programming Concepts, C-term 2017

Laboratory Assignment #1 — Getting Started

Due: at 11:59 pm on the day of your lab session

Abstract

Write two *C* programs and one *C++* program, and then compile and run them in a **`Linux`** shell on CCC systems. Learn about the **`make`** utility and **`makefiles`**.

Outcomes

After successfully completing this assignment, you should be able to:–

- Develop a single-file C or C++ program on a **`Linux`** platform using a command shell and editor
- Read in and print out numbers using formatting strings in C, and do ordinary calculations using floating point arithmetic.
- Understand enough about **`makefiles`** to carry out Programming Assignment #2.

Before Starting

Read Chapters 1 and 2 of *The C Programming Language*, 2nd edition, by Kernighan and Ritchie.[1]

Part 1 of this assignment is to compile and run the "Hello, world!" program of page 7 of K&R and also to compile and run the *C++* version of the same program from §1.1 of *Absolute C++*, by Walter Savitch.[2]

Part 2 of this assignment is a simple arithmetic computation in *C*. *Before coming to the lab, write out your proposed solution to this part!*

Part 3 of this assignment will introduce the **`make`** utility and **`makefiles`**.

> **Note:** If at all possible, you should carry out this lab on your course virtual machine. If your virtual machine is not ready or not usable, you may carry out this lab assignment using the CCC Linux system via a remote connection.

Getting Started

1. Sign the attendance sheet.
2. *If you have the course virtual machine installed on your laptop computer, and if you have it with you today,* start the virtual machine and log in.

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[1] Throughout the course, this book will be referred to as K&R.

[2] Copies of both programs may be found at the end of this document; feel free to copy and paste them.

When the desktop appears, type **CTRL-ALT-T** to bring up a Linux *command shell*. For editing the programs of this assignment, you may use **emacs**, **gedit**, or your favorite editor.

If successful, skip forward to Part 1: Hello, World in C and C++ below.

3. *If you are unable to use your course virtual machine today*, you will use **XWin32** on the lab computer. If **XWin32** is already running, there will be a blue *X-monitor* icon in the system tray at the lower right hand corner of your screen — similar to this:–  . If **XWin32** is not running you must start it on your computer by clicking:–

   Start → All Programs → Utilities → XWin32 9.0 → X-Win32

   XWin32 is a terminal application for Windows computers; it allows Windows users to connect to Linux servers on a local network or via the Internet. **X** applications running on those servers will be displayed onto the Windows desktop. There are two reasons why we run **XWin32** when connecting to Linux:–

   - to enable copy/paste between Linux windows and other windows, and
   - to allow an incoming connection to be accepted. It is this feature that allows you to run **emacs**, **kwrite**, and other programs on the CCC servers so that their windows show up on the desktop of the lab computer.

4. Log onto the Linux system using your WPI username and password:–
   - Double-click the **PuTTY** icon (or start **PuTTY** from the **Start** menu)
   - Type **ccc.wpi.edu** in the connection window and click **OK**
   - Enter your CCC Linux username followed by **return**, followed by your password

5. Create a directory and subdirectory called **cs2303**/**lab1**; make **lab1** your working directory.

> **Note:** If you have never used a command shell or a command prompt before — or if you are unsure of what it means to do step 5 above — please refer to the Appendix of this document.

Part 1: Hello, World in *C* and *C++*

1. Using **emacs**, **gedit**, or your favorite editor,[3] type out the "Hello, world" program exactly as it appears in K&R. Call your resulting program **helloWorld.c**.[4]

2. In the Linux shell, compile the program with the command

   ```
   gcc -Wall helloWorld.c
   ```

   The **-Wall** "switch" means "**W**arnings: **all**"; it instructs the **gcc** compiler to display all warning messages. If you find errors or warnings, make changes and recompile. If you have difficulty, consult a classmate or one of the TAs. When you can compile with no errors or warnings, run the program with the Linux command

   ```
   ./a.out
   ```

3. Experiment with inducing compilation errors. For example, remove the semicolon at the end of line starting with **printf** and recompile. Note that error messages in *C* usually appear one or

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[3] If you don't have a favorite editor, see the section entitled *Creating and editing a program* at the end of this document.

[4] A copy of the "Hello World" program appears at the end of this document; you may copy and paste it.

more lines *after* the actual error. Moreover, a single error can cause the appearance of many false errors after it.

Also experiment with warnings. Remove the zero after the return. Compile using the **`-Wall`** switch as in Step 2 and then again *without* the **`-Wall`** the switch. In this course, all programs *must* compile free of warnings (i.e., using the **`-Wall`** the switch) unless an exception is allowed by the Professor.

4. Repeat the same steps for a *C++* program called **`helloWorld.cpp`**. A copy of this program is also found at the end of this document. This time, compile the program with the command

```
g++ -Wall helloWorld.cpp
```

5. Submit both programs to *Canvas*. From a browser, visit the following URL,

https://canvas.wpi.edu

login in, navigate to the course "CS2303-C17-LABS" and to the assignment *Lab1*. Submit the files **`helloWorld.c`** and **`helloworld.cpp`** as part of assignment *Lab1*:–

Be sure to submit your program by 11:59 PM on the date of your lab session in order to get credit for this part of the lab.

Part 2: A simple numerical calculation

Write a *C* program called **`triangle.c`** to prompt the user for the *x*- and *y*-coordinates of the three corners of a triangle, calculate and print the lengths of the three sides, calculate and print the circumference of the triangle, and calculate and print the area of the triangle. The following mathematical formulas may be used in these calculations:–

The formula for determining the length l_{AB} of the line between points (x_A, y_A) and (x_B, y_B) is

$$l_{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$$

If l_{AB}, l_{BC}, and l_{CA} are the lengths of the three sides of a triangle, then the area of the triangle is

$$\sqrt{s \times (s - l_{AB}) \times (s - l_{BC}) \times (s - l_{CA})}$$

where s is one-half the circumference of the triangle – i.e., $s = ½ \times (l_{AB} + l_{BC} + l_{CA})$.

The following illustrates a sample of the program output and input. The program prompts are shown as bold and do *not* end with new-line characters, while the user responses are shown as non-bold and *do* end with new-line characters. All result lines end with new-line characters.

```
Enter the x- and y-coordinates of point A:- 1.05 -2
Enter the x- and y-coordinates of B:- 1.115e+2 21.1
Enter the x- and y-coordinates of point C:- -25 -3.14159
Length of AB is 112.840
Length of BC is 138.636
Length of CA is 26.075
Circumference is 277.551
Area is 237.833
```

The function **`sqrt()`** is declared in the interface **`<math.h>`**. It returns the square root of its argument. The argument of **`sqrt()`** must any non-negative numerical value, and the result of **`sqrt()`** is of type **`double`**. If the argument is negative, **`sqrt()`** fails with an error and the result is undefined. (The program may or may not crash.)

Because you are invoking the **sqrt()** function, you will need to link the **math** library to your code. Therefore, the **gcc** command needs the **-lm** switch, like this:–

```
gcc -Wall triangle.c –lm
```
[5]

The **printf()** function is declared in the interface **<stdio.h>.** It takes the following form:–

```
printf("string in double quotes", arg1, arg2, arg3, …)
```

The string, which is enclosed in double quotes, contains zero or more *conversion specifiers*. Each conversion specifier begins with a **'%'** character and specifies how to convert the corresponding argument to printed characters. The *ith* conversion specifier corresponds to the *ith* argument following the string. For example, a conversion specifier of **'%f'** says to treat the corresponding argument as a floating point number and print it with the default precision – e.g., *3.14159*. See Table 7-1 of K&R for more details.

The **scanf()** function is declared in the interface **<stdio.h>,** and takes the following form:–

```
scanf("string in double quotes", &arg1, &arg2, …)
```

The string, enclosed in double quotes, contains one or more *conversion specifiers*. For this assignment, two conversion specifiers are sufficient for each input request. As with **printf(),** each conversion specifier begins with a **'%'** character and specifies how to convert the input characters into a numerical or other value. The *ith* conversion specifier corresponds to the *ith* argument following the string, which *must* be the name of a variable and which *must be preceded* by a **'&'** character. For example, a conversion specifier of **'%f'** says to treat the input string as a floating point number with optional sign and optional exponent and store it in the variable named by the corresponding argument. More details about **scanf()** can be found in §7.4 of K&R.

There are no restrictions on the input data; that is, the user may enter any real or integer values for the *x*- and *y*-coordinates of each of the three points of the triangle. You should not define any functions in the solution for this program other than the **main()** function. You should *not* use any loops or conditional statements.

Submit this assignment using *Canvas* system as above. From a browser, submit the file **triangle.c** as part of assignment *Lab1*.

> *If you have trouble with this lab, ask for help right away. You may ask your classmates, other students, the TAs, the Professor, or anyone else who can help you.*

Part 3: Introducing Makefiles

The remainder of this lab introduces an important tool — the **make** command. *If you do not have time to finish this part, please finish it on your own time prior to next week.*

The **make** command in Linux and Unix allows you to easily maintain and keep your files up to date when you are working on a project that is split across several **.c** files and their associated **.h** files. You will find your multi-file programs easier to manage if you keep all of the files for one project in a separate directory, along with a **makefile** (as described below), to manage the compilation of those files.[6]

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[5] More information about **-lm** and the **math** library can be found in the section *Practice Using Make* on page 6 below.

[6] Very large projects such operating system kernels, compilers, and sophisticated web browsers typically comprise a hierarchy of directories, along with a hierarchy of **makefiles** to support them.

A file named **`makefile`** or **`Makefile`** is the usual input file for a tool called **`make`**, which can be invoked from the command line of a Linux shell. The purpose of **`make`** is to help you build, update, and maintain a collection of related program files. It does this by figuring out which files have changed since you last built or rebuilt your programs. The **`makefile`** specifies dependencies among files, so that **`make`** can figure out which files have to be recompiled as a result of any of your edits or other changes.

A properly designed **`makefile`** *is normal part of every non-trivial programming project in Linux or Unix, both at WPI and in the professional world.* It allows someone else — a grader, a boss, a colleague, or a user — to rebuild your system on another platform by simply typing the command **`make`**. Using the instructions and dependencies encoded in the **`makefile`**, **`make`** takes care of it from there, and the result should be an up-to-date, executable copy of the program, system, or application.

Moreover, the *Eclipse* integrated development environment — which will be introduced next week in the lab assignment — uses **`make`** as its tool for compiling and linking programs. Therefore, this part of this lab is essential for getting started with next week's lab.

Getting started with makefiles

Download the zip file at the following URL and unzip it into your directory:–

http://web.cs.wpi.edu/~cs2303/c17/Resources_C17/Lab1Files.zip

You should now have a folder containing the files **`intarray.c`**, **`intarray.h`**, **`sinewave.c`**, and **`makefile`**.

What's in a Makefile?

The collection of files needed to build a system or application usually includes header files (**`.h`** files), source files (**`.c`** files, **`.cpp`** files, or source code files for the language you are using), compiled files (**`.o`** files), and sometimes other kinds of files. Many of these depend on each other. For example, consider the program downloaded for this week's lab. The final product is an executable file named **`sinewave`**, which is created by linking together two other compiled files, **`sinewave.o`** and **`intarray.o`**. These two compiled files are created by compiling **`sinewave.c`** and **`intarray.c`** , respectively. Moreover, both of these **`.c`** files include the header file named **`intarray.h`**. So, one of the dependencies expressed in the **`makefile`** is:–

> if **`sinewave.c`** or **`intarray.h`** changes, then **`sinewave.o`** must be regenerated by the compiler command:–
>
> ```
> gcc –g –Wall –c sinewave.c
> ```

To see this dependency, open up the file named **`makefile`** in **`kwrite`**, **`emacs`**, or your favorite editor.

Near the bottom of the file you'll find these two lines:–

```
sinewave.o: intarray.h sinewave.c
     gcc $(CFLAGS) -Wall -c sinewave.c
```

The first of these is called a *target line*, which begins with a file name followed by a colon. The file is called the *target*. After the colon is a list of zero or more names of files that the target depends on. If the target is missing or older than any of its dependencies, then it is considered "out of date" and must be rebuilt. The **`make`** tool uses target lines and last modification dates to determine which targets must be rebuilt. It does this recursively, so that if one of the files upon which the target depends is itself out of date (or missing), **`make`** causes that file to be rebuilt first, etc.

> **Note:** **`make`** depends upon a consistent and reliable time-of-day and date clock in order to determine whether one file is "newer" than another. If you are using more than one computer and their clocks are not in sync, modification dates on files could be inconsistent with each other, and **`make`** could produce unexpected results.

After the target line, there is a series of commands that tell exactly how to rebuild the target. For the case of **`sinewave.o`**, only one **`gcc`** command is needed to compile the file. Note that this command includes the **`-c`** flag to tell **`gcc`** that it should only compile the specified file(s) and not attempt to link them into an executable program yet.

The **`gcc`** command also includes the notation **`$(CFLAGS)`**. This is not a compiler switch but rather a variable to **`make`**. It lets you control from the command line which compiler switches you wish to apply to all of the files compiled by **`make`**. The **`makefile`** also contains the following line near its beginning:–

```
CFLAGS = -g -Wall
```

This defines the variable **`CFLAGS`** and causes it to default to the text string **`"-g -Wall"`** (without the quotes). This means that the programs should be compiled for debugging (**`-g`**) and that all warnings are displayed. We will see below how to override this default.

The **`-Wall`** flag conforms to a requirement of this course that all warnings must be displayed; this flags is also shown in the **`makefile`** as part of **`CFLAGS`**.

> **Note:** **`makefiles`** have a peculiar requirement — command lines, such as the **`gcc`** command, *must* each begin with exactly one *tab* character, not with a sequence of blanks!

Continuing with the theme of dependencies among files, the executable file **`sinewave`** is created by linking together the object files **`intarray.o`** and **`sinewave.o`**. If either of these two object files should change, then **`sinewave`** also needs to be recreated. Here is the appropriate target line and command from our **`makefile`**:–

```
sinewave: intarray.o sinewave.o
   gcc $(CFLAGS) -Wall sinewave.o intarray.o -o sinewave -lm
```

This target line says that if either **`sinewave.o`** or **`intarray.o`** is newer than the target **`sinewave`** (or if the target **`sinewave`** does not exist), then **`make`** must cause the **`sinewave`** program to be regenerated with the **`gcc`** command shown. The **`-o`** switch specifies that the output program is to be named **`sinewave`**, and that the two input files (**`sinewave.o`** and **`intarray.o`**) are to be linked with the "math" library, which happens to be named **`libm.a`**. The reason is that this program uses a precompiled mathematical function to evaluate the *sine* function **`sin()`**.[7]

Practice Using Make

There are two simple ways to use the **`make`** facility to automatically regenerate your files. The first approach builds a specific file. For example, suppose you want to regenerate **`intarray.o`**. Then you can use the **`make`** command shown here. Type this command in now:–

```
make intarray.o
```

---

[7] In general, the **`gcc`** or **`g++`** switch **`-lxyz`** means "link with the file named **`libxyz.a`**.

The **make** command will find the dependency information in the **makefile**. It sees that **intarray.o** depends on two other files, so it will first ensure that those files are present and regenerate them if necessary. In this example, the two files **intarray.h** and **intarray.c** are necessary for generating **intarray.o**. These two files are present, so the **make** command proceeds to generate **intarray.o**, using the **gcc** command that is specified in the **makefile**. When the **gcc** command is executed, it is displayed in your command shell or on your display screen. It this case, it would be:–

```
gcc –g –Wall –c intarray.c
```

After this **make** command finishes, you should list the files in your directory, where you will find the object file **intarray.o** is now present.

Note: You can specify as many targets as you wish to the make command.

Now trying using the **make** command without specifying a file, like this:–

```
make
```

Without a specified file, the **make** command will regenerate the first target that it finds in **makefile**. Try this now, and you will see that the executable file **sinewave** is regenerated, since **sinewave** is the first target in **makefile**.[8] During the process of regenerating the **sinewave** file, **make** discovers that **sinewave** depends on **intarray.o** and on **sinewave.o**. But the file **sinewave.o** is not present. This means that before **make** can build **sinewave**, it must first regenerate **sinewave.o**. Only then it can proceed to regenerate the executable file **sinewave**. On the screen you will see the two steps displayed:–

```
gcc –g –Wall –c sinewave.c
gcc –g –Wall sinewave.o intarray.o –o sinewave -lm
```

Next, edit the file **intarray.h** in some trivial way — for example, by adding or changing a comment. Now type the command

```
make
```

again and you will see that it rebuilds everything. Can you explain why?

Finally, if you wish to turn off the **-g** switch, you may use the following command:–

```
make CFLAGS=
```

This simply sets the variable **CFLAGS** to the null string, thereby disabling compilation for the debugger. You may also change the compiler flags, for example, by

```
make CFLAGS=–O  or   make CFLAGS=–O2
```

This tells the compiler to optimize the compiled code for speed. You can consult the **man** page for the **gcc** command for other compiler switches, which may also be specified in the **CFLAGS** variable.

To get a better feeling about how dependencies work, edit your **makefile** to remove the dependency that **sinewave.o** depends upon **intarray.h**. Again make a trivial edit to **intarray.h**, and then type **make**. You will notice that it did *not* rebuild **sinewave.o**. This, of course, is an error.

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[8] Note that at the end of the **makefile**, there is a target **all** with a dependency on **sinewave**. This is needed for *Lab 2*. You may ignore it for this lab.

Cleaning up

Notice the last two lines of the **makefile**. These say

```
clean:
     rm -f sinewave.o intarray.o sinewave
```

This is a target line to "make" the target called **clean**. *Clean* is not a file but rather an artificial target, sometimes called a "phony" target. You can see that **clean** does not have any dependencies, but it does have one command line, namely a command to remove the **.o** files and the original target file **sinewave**. This is common practice in system programming — to provide a way of cleaning up intermediate files (in this case the **.o** files) needed to build a system, leaving only the original files.

Type the command

```
make clean
```

and then list your directory. You will see that **sinewave** and the **.o** files have disappeared. Now type

```
make
```

and you will see that they have been rebuilt.

"Hello, World" programs

In case you forgot, here is a copy of the "Hello, World" program in *C*:–

```
/* HelloWorld.c  -- type your name here (and on every program
     you write!) */
#include <stdio.h>
int main(void) {
     printf("Hello, World!\n");
     return 0;
}    // int main(void)
```

Likewise, here is the "Hello, World" program in *C++* —

```
// helloworld.cpp  -- type your name here (and on every
//   program you write!)
#include <iostream>
int main(void) {
     std::cout << "Hello World from C++!"<< std::endl;
     return 0;
}    // int main(void)
```

Getting credit for this Lab

To earn credit for this lab, you must submit the following to *Canvas* under the assignment *Lab1*:–

- **HelloWorld.c**
- **HelloWorld.cpp**
- **Triangle.c**
- The output from running **make clean** followed by **make CFLAGS=-O2**.

Appendix — Command Shell

A *command shell*[9] (or *command prompt* in Windows terminology) is a simple text-oriented interface for interacting with many kinds of computers. When the shell is ready to receive a command, it types a *command prompt* in the command window, and then it waits for typed input from the user. The language of the command shell is a simple imperative language, and commands typically respond by printing one or more lines of textual information before allowing the shell to issue its next prompt.

The following illustrates the general form of a command:–

```
% commandName operand1 operand2 operand3 ...
```

In this line, the **'%'** character is the command prompt, which is printed by the shell.[10] The string of text typed by the user begins with the name of the command and is followed by zero or more operands. The user terminates the command by typing a **newline** character (i.e., the **RETURN** or **ENTER** key). Most command shells are intelligent enough to recognize **backspace** as meaning "undo the previous keystrokes."

Some useful commands are

```
% ls
```

List the contents of the current (i.e., working) directory. (*Directory* is equivalent to *folder* in graphical environments.)

```
% mkdir cs2303
```

Make a new directory and name it **cs2303**.

```
% cd cs2303
```

Change the working directory (i.e., current directory) to be **cs2303**.

```
% cd
```

Change the working directory to be the user's home directory.

```
% ls cs2303
```

List the contents of the directory **cs2303**.

```
% ls -l cs2303
```

List the contents of the directory **cs2303** in "long form" — i.e., showing not only the names of files and directories within **cs2303** but also their sizes, modification dates, and permissions. Note the **-l** (the letter ell), which is a *switch* of the command. Switches are generally indicated by a minus sign '– ' and they usually precede the principal operands of the command; they control the detailed behavior of the command.

In systems like Linux, Windows, or Macintosh, there are literally thousands of commands for all sorts of purposes. A particularly useful command is

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9 The etymology of the word *shell* in this context is obscure. The best that the Professor can come up with is that the *shell* is a program that surrounds the commands that you run with a "hard" protective environment. The protection is such that even if the command or program goes haywire, the shell continues to work and provides the user a way of running other commands to eventually recover.

10 Some command shells will prefix the user's name and/or the name of the working directory as part of the command prompt. For example, **[lauer@CCCWORK4 ~/CodingExamples]$** in the CCC Linux systems.

```
% man commandName
```

Display the page or pages of the manual describing the command named **commandName**. This display may be many pages, and the **man** command allows you to scroll up and down through them.

System commands and user commands

A very important concept is that each command is actually a program stored in a file whose name is the name of the command. The program is a fully-formed program written in *C*, *C++*, *Java*, or some other language. It has a **main()** function and (probably) many other functions. The command shell picks apart the operands of the command line and stores them in the arguments of the **main()** function before invoking that function.[11]

The command shell has a list of places in which it looks to find the files for the commands. That list of places is called the **PATH**, and it can be displayed in Linux or Macintosh by the command

```
% echo $PATH
```

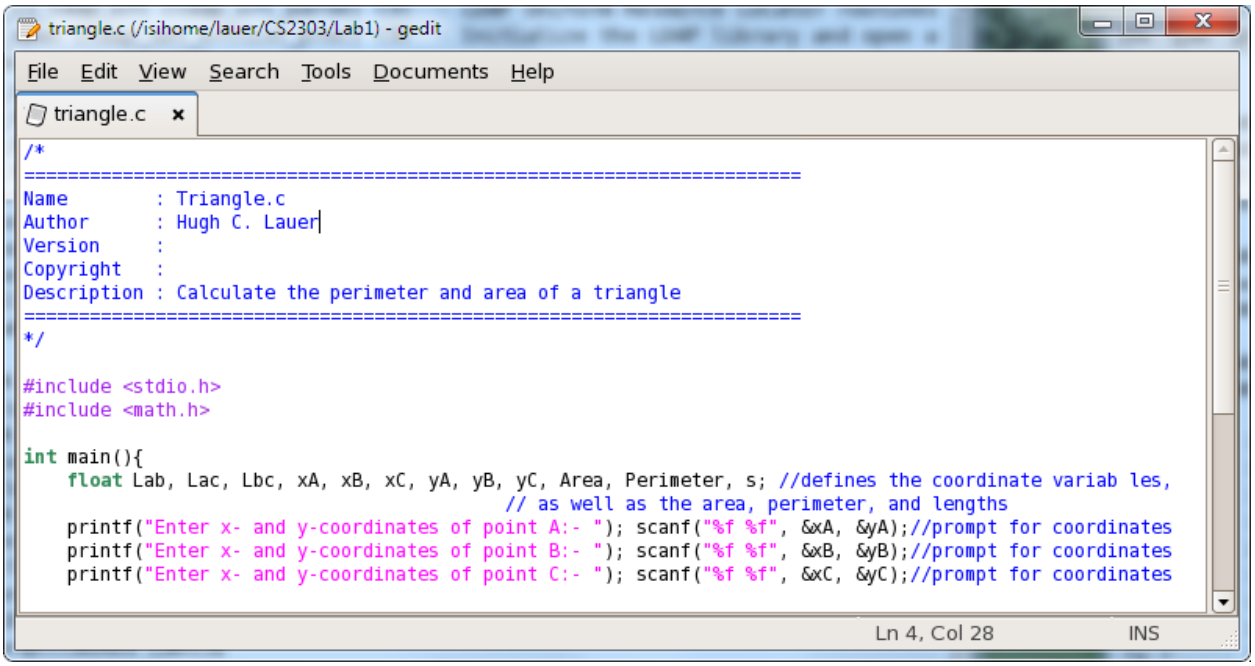
As a result of many years of experience, the user's current directory is *not* in the **PATH**. This helps to avoid the accidental, unintended execution of programs in the current directory. Therefore, to execute a specific command in the current directory — for example, **a.out** or **helloWorld** from part 1 — you need to explicitly prefix the name of the current directory in front of the command. An alias for the current directory is simply **'.'**, and an alias for the parent or containing directory of the current directory is **'..'**. Therefore, to run the **helloWorld** or **a.out** program, you need to type one of the following to the command shell:–

```
% ./helloWorld
% ./a.out
```

Creating and editing a program

The choice of text editor for programming is a highly personal matter, not unlike the choice of one's clothing style. There are dozens of text editors available to command shell users, and all have their advantages and disadvantages. If you have never used one or do not have a preference, the Professor recommends **gedit**. This has a familiar looking point, click, and type interface, and it can be configured to be useful for *C* and *C++* editing. Here is a sample screen:–

[11] We will learn more about command line arguments in Programming Assignment #2.



You can start this editor with the command

```
% gedit filename.c &
```

where **`filename.c`** is replaced with the name of the file you wish to edit. This will bring up a new window, independent of the command shell. The **`'&'`** symbol at the end of the line means "run this command separately from the shell, and let the shell continue to accept and run other commands."[12]

Learning the command shell language

There are many, many resources for learning the commands of *Linux*, *Macintosh*, or *Windows*. Here are a few:–

http://community.linuxmint.com/tutorial/view/100
http://www.ee.surrey.ac.uk/Teaching/Unix/
http://www.linfo.org/command_line_lesson_1.html
http://www.youtube.com/watch?v=imDrXVVHowU (a video)

Although we will be using the command line interface only a little in this course, you will use it intensely in the Operating System course and probably in a number of other contexts.

[12] To configure **`gedit`** for editing *C* programs, select the **`Preferences`** subcommand from the **`Edit`** menu, and select the **`Syntax Highlighting`** option. In this window, select **`C`** in the **`Highlight mode`** box. Later in the course, you should change this selection to **`C++`**.