

# 1 Lab 2

**Date:** Sep 9, 2021

This document first describes the aims of this lab. It then provides necessary background. It then describes the exercises which need to be performed.

In the listings which follow, comments are any text extending from a # character to end-of-line.

## 1.1 Aims

The aim of this lab is to introduce you to the use of the `gdb` debugger under Unix. After completing this lab, you should be familiar with the following topics:

- The general capabilities of debuggers.
- The basic usage of `gdb`.
- Some ideas about typical errors in C programming.

## 1.2 Background

Programs break. When that happens, based on the symptoms of the problem and your understanding of the program you may proceed as follows:

1. Inspect the code with the symptoms in mind. You may see the problem right away.
2. Test the program with related inputs trying to detect a pattern in the inputs which result in a problem. If you can find such a pattern, that may often point you to the problem.
3. Fire up a debugger and examine the state of your program with the inputs which cause the problem. This may allow you to track down the bug.

The above assumes that the problem is reproducible. It also assumes that the bug is not a [heisenbug](#) which disappears when you attempt to track it down.

Besides tracking down bugs, debuggers also have other uses:

- Validate new code by looking at it in operation using a debugger.
- Attempt to understand a large code-base by tracing its operation using a debugger.
- Help reverse-engineer a program for which you may not have the source code.

Finally, keep in mind this statement by Kernighan and Pike on pg. 119 of their classic book *The Practice of Programming*:

*As personal choice, we tend not to use debuggers beyond getting a stack trace or the value of a variable or two. One reason is that it is easy to get lost in details of complicated data structures and control flow; we find stepping through a program less productive than thinking harder and adding output statements and self-checking code at critical places. Clicking over statements takes longer than scanning the output of judiciously-placed displays. It takes less time to decide where to put print statements than to single-step to the critical section of code, even assuming we know where that is. More important, debugging statements stay with the program; debugging sessions are transient.*

### 1.2.1 Debugger Capabilities

Most debuggers provide the following capabilities:

- The ability to set *breakpoints* in the program, in a particular function or on a particular line. The program will stop when execution reaches that breakpoint. The breakpoint may be *unconditional* with the program always stopping when the breakpoint is hit, or it may be *conditional* with the program only stopping if some dynamic condition is met.
- The ability to *singlestep* the program, line by line or even by individual machine instructions.
- The ability to examine data when the program is stopped. The facilities would allow the programmer to navigate complex data-structures.
- The ability to set *watchpoints* on the state of the program. A *watchpoint* is a condition on the state of the program and the program will stop when the condition becomes true. Watchpoints can be a performance killer since the condition must typically be re-evaluated whenever any state change could change the condition.

All debuggers will provide at least basic breakpoints, single-stepping and ability to examine data. Using the debugger may require use of the command-line like the `gdb` debugger, or it may involve the use of a GUI like `ddd` or `eclipse`. Or it may be a hybrid between the command-line and full GUI like `gdb` running under `emacs`.

## 1.3 Exercises

When the exercises mention a new Unix command you are unfamiliar with, it is a good idea to do a `man` or google lookup on that command to get an idea of its capabilities.

This lab has two exercises. The first one guides you through a `gdb` session using extremely basic commands to debug a program. The second exercise gives you a slightly modified version of the program from the first exercise and requires you to debug it without any guidance beyond some hints.

Since the programs given are quite simple, you may easily see the bugs by inspection of the code. However, it is still a good idea to play with the debugger to confirm your diagnosis so that you achieve the aims of this lab.

Note that this lab provides you an **extremely limited** glimpse into `gdb`'s capabilities. Please make sure to check-out the references or other sources on the web to get a better idea of what it can do for you.

### 1.3.1 Starting up

Follow the *provided directions* for starting up this lab in a new git `lab2` branch and a new `submit/lab2` directory. You should have copied over the contents of `~/cs220/labs/lab2/exercises` over to your directory.

### 1.3.2 Exercise 1: Debugging a Simple Program

Change over to the `1-hello-args` directory.

```
$ cd exercises/1-hello-args
$ ls -l
```

You should see that the directory contains a C program containing several files. Read the README to see what the program is supposed to do.

Simply type `make` in that directory to build the program. It should compile a `hello` executable without any errors or warnings.

Now try to run it.

```
$ ./hello
usage: ./hello NAME...
$ ./hello bart lisa
hello bart
hello lisa
hello (null)
$
```

It looks like the program is almost working, but wants to greet someone called `(null)`! Though the problem may appear obvious, let's fire up `gdb` to check it out.

At the shell prompt, start `gdb` by typing `gdb hello`. It should print a greeting message followed by the prompt `(gdb)`.

Start the program with a temporary breakpoint at the start of `main` by typing `start bart lisa`. Note that you provide your command-line arguments to the `start` command. (Instead of using the `start` command, you could similarly `run` the program, but that would not have a temporary breakpoint).

It should break at the start of `main()` printing out the current line. Type `l` to list the lines following the current line. Typing an empty line will simply repeat the previous command and list more lines. Type `l` followed by a line number to print out a listing centered (usually) at the specified line.

Let's put a breakpoint on `say_hello()`. Simply type `b say_hello`. In fact, if you press the <TAB> key after typing the prefix `say` of the function name, `gdb` should provide automatic completion.

You are still at the start of `main()`. You can print out the value of the arguments to `main()`, which are:

**argc** The number of arguments to the program, **including** the name of the program. So if you invoke the program as `./hello lisa bart`, `argc == 3`.

**argv** An array with `argc` elements give the actual command-line arguments as C strings (declared as `char *`, i.e. pointer to `char`). So if you invoke the program as `./hello lisa bart`, `argv[0]` will be `./hello`, `argv[1]` will be `lisa` and `argv[2]` will be `bart`.

Simply type `p argc` to print out the value of `argc`. It should print as a 3; the reason it does so is that in addition to the actual arguments `bart` and `lisa`, `argc` also counts the name of the program. To verify this, type `p argv` to print out `argv`, but you will simply get the base address of the array. To print out the individual elements, type `p argv[0]`, `p argv[1]`, etc. Note that each string is printed out preceded by a hexadecimal address giving the address of the first byte of the string.

Now let execution continue to the next line of the program by typing `n` (for **next**). Type another `n`, to enter the loop. Print out the value of `i`.

Now let execution continue to the next breakpoint by simply typing a `c` (for **continue**). The function `say_hello()` should be invoked and `gdb` will give you back control at the start of its code. Type `l` to print out the code.

Type `p name` to print out the value of the `name` parameter.

Type `backtrace` to see which calls you made to get to `say_hello()`; note that the backtrace contains the function names as well as their arguments.

If you try to print out the value of `argc` while within `say_hello()` you will get an error message since `argc` is not defined within the context of the current `say_hello()` function.

Type `up` to return one level up the call-chain back to `main()`. This does not run the program at all but merely changes the context of the debugger. You

should once again be able to print out the value of `argc`, `argv` and `i`, but will no longer be able to print out the value of `name` which is only defined within the `say_hello()` context.

Print `down` to return back to the `say_hello()` context. You should be able to print out the value of `name`.

Let execution continue to the next breakpoint by typing the `c` command. The function `say_hello()` should be entered again with `name` set to `lisa`.

Continue again till the next breakpoint. `say_hello()` is now being called with a `NULL` pointer. That looks problematic, so do a `up` to look at the `main()` context. Print out `i` and `argc`; they are equal!! But `i` should always be less than `argc`. That should lead you to spot the obvious problem.

Quit `gdb` by typing `q`. Fix the problem, recompile and test. The script you are recording should show that you fixed the problem.

### 1.3.3 Exercise 2: Debugging a Program from Scratch

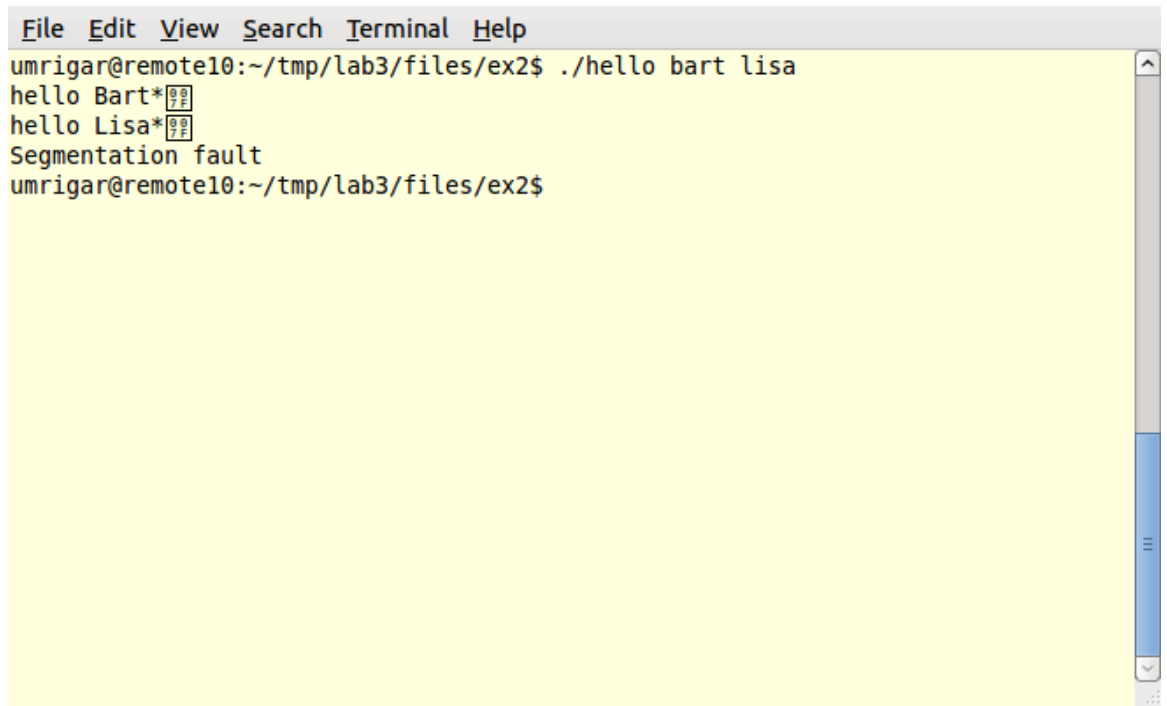
Change over to the [2-hello-upcase-args](#) directory and type `make`. Another `hello` program should be built without any problems.

This `hello` program is very similar to the previous `hello` program except that it is slightly more complex. Before printing out each name, the program tries to make each name more human-friendly by ensuring that the first character of each alphabetical word in the name is printed in upper-case.

If the program is working properly, its output should look as follows:

```
$ ./hello lisa bart
Hello Lisa
Hello Bart
$ ./hello 'lisa simpson' 'bart simpson'
Hello Lisa Simpson
Hello Bart Simpson
$
```

Unfortunately, when you run the given program, it seems to work, but **may** print out garbage characters after each name and/or crash. YMMV depending on how your particular environment is setup; in fact, even though the program contains a bug, it may even work perfectly (which in a way is the worst possible behavior!). If you do not see incorrect behavior, try increasing the size of the names to say 16 characters or more. If you still can't see the buggy behaviour, here is a screenshot showing one buggy behavior:

A terminal window with a menu bar (File, Edit, View, Search, Terminal, Help) and a yellow background. The prompt is 'umrigar@remote10:~/tmp/lab3/files/ex2\$'. The user enters './hello bart lisa'. The program prints 'hello Bart\*' followed by a cursor. Then it prints 'hello Lisa\*' followed by a cursor. Then it prints 'Segmentation fault' and returns to the prompt 'umrigar@remote10:~/tmp/lab3/files/ex2\$'.

Use the debugger to understand the problem and fix it.

Hints:

- A C "string" is represented as an array of **char** terminated by a `'\0'` NUL character.
- `strlen(s)` returns the number of characters in string `s` without accounting for the terminating `'\0'` character.
- The fix for the problem will require making changes in two different places in the code.

The symptoms you see and the above hints should help you get to the problem quite easily.

## 1.4 Winding Up

Wind up your lab by using the *provided directions* to terminate your log in a `lab2.LOG` file and merging your `lab2` branch into the `master` branch. Once you have the lab on your `master` branch, commit and push your changes to github. Be sure to include your `lab2.LOG` file as well as all the exercise directories.

## 1.5 References

Online [gdb documentation](#).

Do a web search on *gdb tutorial* to find many tutorials.

Norman Matloff and Peter Salzman, *The Art of Debugging with GDB and DDD*, No Starch Press, 2008.