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

Lab 3 (10 points)
January 31 and February 1, 2017
Due: at 11:59 pm on day of lab session

Laboratory Assignment #3 — Debugging in Eclipse CDT[1]

Objective

To learn to learn to use the *Eclipse* C/C++ debugger.

Introduction

One of the most powerful aspects of an Integrated Development Environment is the integration of a debugger with the graphical user interface. This makes the "edit-compile-debug" loop very easy and quick. You can easily set breakpoints by pointing and clicking. These let you get a good look at what your program is doing at key points during its execution.

Eclipse CDT includes a graphical interface to **`gdb`**, the *GNU Debugger*, which is one of the most powerful and flexible debuggers in the C/C++ development world. Unfortunately, the command-line interface of **`gdb`** has a steep learning curve and requires more keystrokes than the intuitive *Eclipse* interface.

In this Laboratory Assignment, you will learn how to use the basic debugging features of *Eclipse*.

Getting Started

Please sign the attendance sheet.

Login to your virtual machine, and download and unzip the set of files at the following URL:–

http://web.cs.wpi.edu/~cs2303/c17/Resources_C17/Lab3_Sample.zip

The result should be directory named **`Lab3_Sample`** containing a **`makefile`** and a single source code file **`Sample.c`**.

Start *Eclipse* and create a new *C Makefile project* for these two files. Build the project.

Launch Configurations

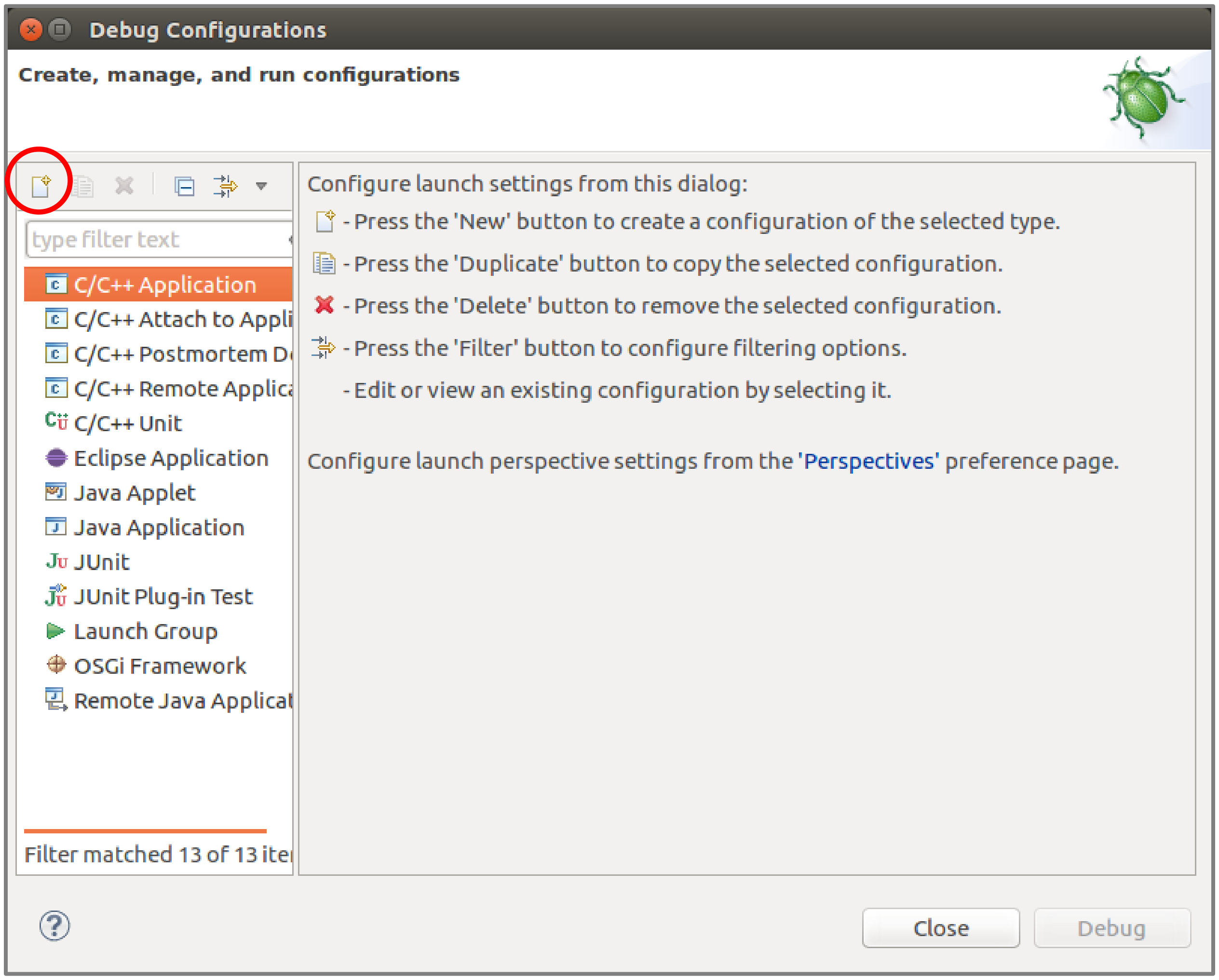
In order to run or debug the program with command line arguments, you need to set up *launch configurations*. A *launch configuration* is information about the arguments, environment, and other information needed to run and/or debug the program. There are two kinds of *launch configurations:–*

- *Debug configurations*
- *Run configurations*

[1] The sample program and the debugging sequence of this lesson were adapted from Chapter 1 of *Debugging with DDD*, version 3.3, by Andreas Zeller. *DDD* is the *Data Display Debugger*, also a graphical interface to *gdb*, but independent of any Integrated Development Environment. It is available on the CCC Linux systems. It was an excellent graphical user interface (GUI) for a debugger. Unfortunately, it has not been maintained for nearly a decade.

When you right-click on an *Eclipse* project and select ***Run As*** or ***Debug As*** you are given the option of running it as a ***Local C/C++ Application***, just as if you had typed the name of the program in a command shell with no arguments. Or you can select from the ***Run Configurations …*** or ***Debug Configurations …*** submenus, respectively. These let you provide arguments and other settings needed to run or debug the application properly.

For this lab assignment, you need to set up a ***Debug Configuration*** for the *Lab3_Sample* project that you just set created. Right click on the project name and select ***Debug As*** and then select ***Debug Configurations …*** from the submenu to bring up a window similar to the following:–



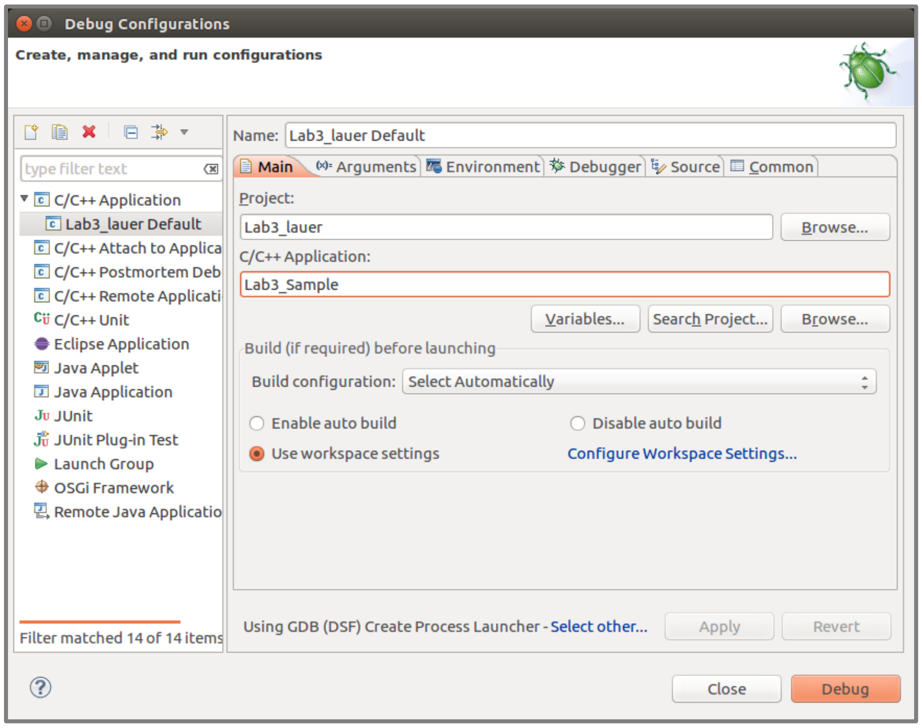
Configure launch settings from this dialog:

- Press the 'New' button to create a configuration of the selected type.
- Press the 'Duplicate' button to copy the selected configuration.
- Press the 'Delete' button to remove the selected configuration.
- Press the 'Filter' button to configure filtering options.
- Edit or view an existing configuration by selecting it.

Configure launch perspective settings from the 'Perspectives' preference page.

Figure 1

The list of things in the left panel may vary depending upon what is already in your *Eclipse* workspace. Click the ***New*** button (circled in red in Figure 1) to create a new configuration for the current *C* or *C++* application in the ***Project Explorer*** panel. This will bring up a template for a new launch setting, shown below in Figure 2.


Debug Configurations

Create, manage, and run configurations

type filter text

- C/C++ Application
  - Lab3_lauer Default
- C/C++ Attach to Applica
- C/C++ Postmortem Deb
- C/C++ Remote Applicati
- C/C++ Unit
- Eclipse Application
- Java Applet
- Java Application
- JUnit
- JUnit Plug-in Test
- Launch Group
- OSGi Framework
- Remote Java Applicatio

Filter matched 14 of 14 items

Name: Lab3_lauer Default

Main | Arguments | Environment | Debugger | Source | Common

Project: Lab3_lauer

C/C++ Application: Lab3_Sample

Build (if required) before launching

Build configuration: Select Automatically

( ) Enable auto build ( ) Disable auto build

(●) Use workspace settings Configure Workspace Settings...

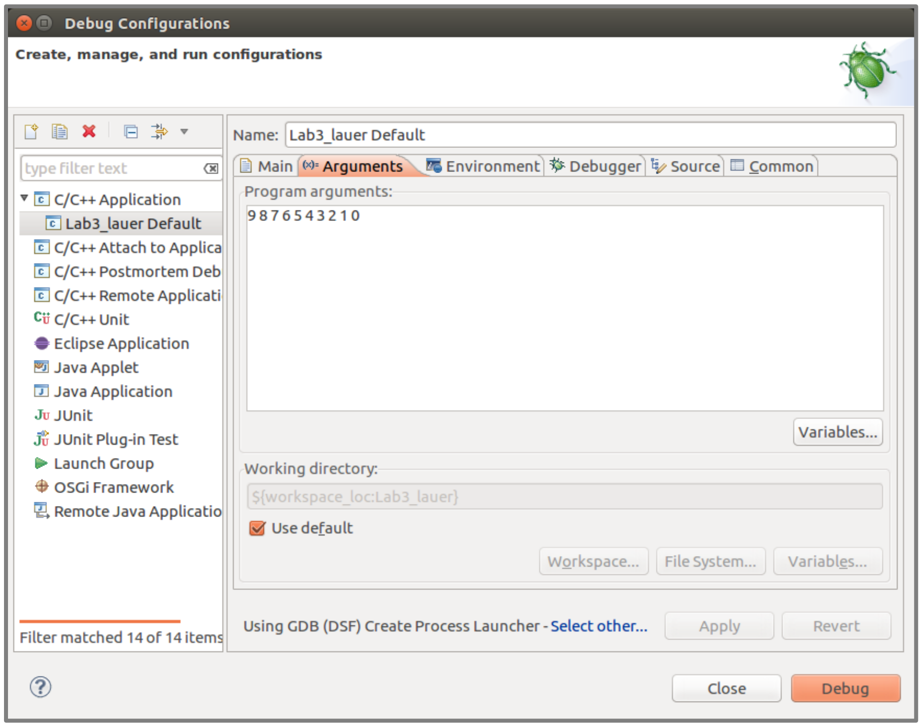
Using GDB (DSF) Create Process Launcher - Select other...

Figure 2

Note that the project name has been filled in (in this case *Lab3_lauer*) and has the name of the application program (*Lab3_sample*). Select the **Arguments** tab, to reveal a window in which you can type the command-line arguments for this program. Type the following arguments:–

```
9 8 7 6 5 4 3 2 1 0
```

The result should look like this:–


Debug Configurations

Create, manage, and run configurations

type filter text

- C/C++ Application
  - Lab3_lauer Default
- C/C++ Attach to Applica
- C/C++ Postmortem Deb
- C/C++ Remote Applicati
- C/C++ Unit
- Eclipse Application
- Java Applet
- Java Application
- JUnit
- JUnit Plug-in Test
- Launch Group
- OSGi Framework
- Remote Java Applicatio

Filter matched 14 of 14 items

Name: Lab3_lauer Default

Main | Arguments | Environment | Debugger | Source | Common

Program arguments:

```
9 8 7 6 5 4 3 2 1 0
```

Working directory: ${workspace_loc:Lab3_lauer}

[✓] Use default

Using GDB (DSF) Create Process Launcher - Select other...

Figure 3

This is equivalent to the command line

```
./Lab3_Sample 9 8 7 6 5 4 3 2 1 0
```

(where **`Lab3_Sample`** is the name of the program in the box in Figure 2).

This program simply reads its arguments from the command line, sorts them using a well-known sorting algorithm called *Shell Sort*, and prints them in order on the standard output.

Build and run the project. If it works properly, it should print the line

```
0 1 2 3 4 5 6 7 8 9
```

Run it several more times. Vary the number of arguments and their values and convince yourself that it is still running properly. (You can run the program with different arguments simply by selecting *Run Configurations…* from the *Run* menu, and then by selecting the *Arguments* tab.) Enter the arguments you want and click on the *Run* or *Debug* button. The results will be displayed in the *Console* tab at the bottom of the *Eclipse* window.

This program has a bug in it — a rookie error that may be hard to spot and that may or may not show itself.[2] It is possible that you could run many tests and never see the results of the bug, or you may have already seen it. A test case that sometimes brings out the bug is one of the following sets of arguments:–

```
100000000 9 8 7 6 5 4 3 2 1 0
 100000000 8 7 6 5 4 3 2 1 0
```

Another way to bring out the bug is to run the program **`Lab3_Sample`** from a Linux command shell. Run the program from the command prompt with various sets of arguments.

A third, more reliable, way to bring out the bug is to export the project to a CCC Linux system (or to any other Linux system). Build the program with the **`makefile`** and run it with a several argument lists. In some cases, it will run correctly, but in some cases the output is sorted and contains the right number of results, but at least one of the inputs is replaced by a bogus number. In a few cases, the program gets a segmentation fault or other fatal error.

Debugging

To debug your program in *Eclipse*, make sure that it was built with the **`-g`** switch. This tells the compiler to include extra information in the object file so that a debugger can find its way around the compiled code. In this example, the **`-g`** switch is already part of the **`CFLAGS`** variable in the **`makefile`**.

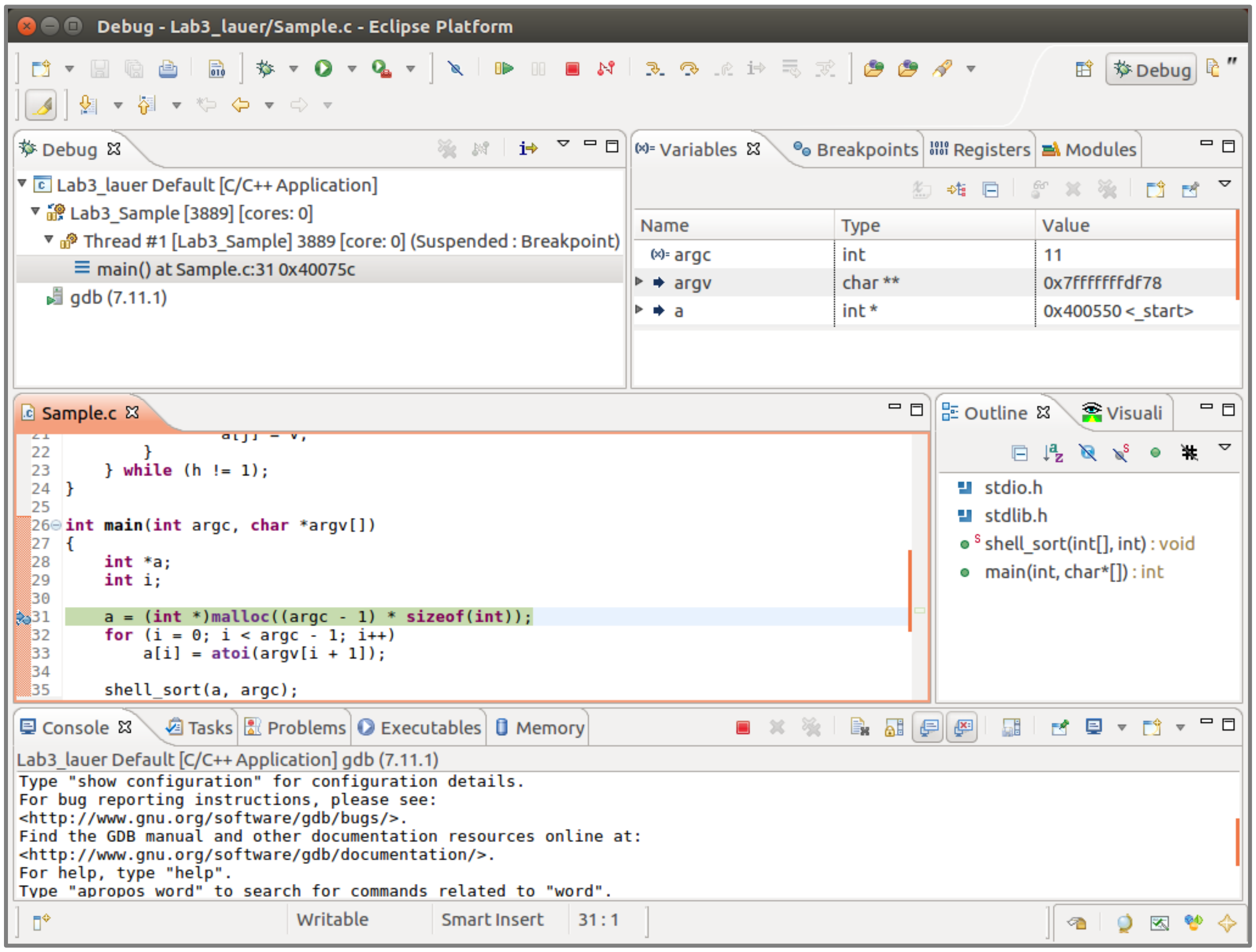
Open the project file **`Sample.c`** in a source code tab. Notice that this program has two functions — **`shell_sort()`** and **`main()`**. Right click at the extreme left margin of the source code to bring up a menu. Select *Show line numbers* to cause line numbers to display in this tab.

Next, set a *breakpoint* where the variable **`a`** is initialized in **`main()`** — i.e., line 31. To set the breakpoint, right click again in the left margin and select *Toggle Breakpoint*. A tiny blue dot will appear next to the line number. This tells the debugger to suspend execution when it reaches this point in the program — specifically, it should pause *before* executing any code on that line.

You can start the debugger and simultaneously load the program to run in debugging mode by invoking the *Debug Configurations…* command under the *Run* menu. *Eclipse* now switches to the *De-*

[2] If you should happen to spot the problem in the code, please continue to work through this laboratory lesson anyway, just to get a feel for tools and actions of debugging in *Eclipse*.

bug perspective. (*Eclipse* may display a dialog box asking if you want to switch to the *Debug perspective*. Say *Yes* to this dialog.) In this arrangement of windows, a *Debug* tab appears in the upper left corner, along with a group of tabs in the upper right (i.e., *Variables*, *Breakpoints*, *Expressions*, *Registers*, and *Modules*), a group of tabs in the left middle containing your open source code tabs, a tab on the right called *Outline*, and a group of console tabs at the bottom. A picture of the *Debug perspective* is shown in Figure 4.[3]



```
Lab3_lauer Default [C/C++ Application]
  Lab3_Sample [3889] [cores: 0]
    Thread #1 [Lab3_Sample] 3889 [core: 0] (Suspended : Breakpoint)
      main() at Sample.c:31 0x40075c
  gdb (7.11.1)
```

Name	Type	Value
argc	int	11
argv	char **	0x7fffffffdf78
a	int *	0x400550 <_start>

```
        }
    } while (h != 1);
}

int main(int argc, char *argv[])
{
    int *a;
    int i;

    a = (int *)malloc((argc - 1) * sizeof(int));
    for (i = 0; i < argc - 1; i++)
        a[i] = atoi(argv[i + 1]);

    shell_sort(a, argc);
```

```
stdio.h
stdlib.h
shell_sort(int[], int) : void
main(int, char*[]) : int
```

```
Lab3_lauer Default [C/C++ Application] gdb (7.11.1)
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.
For help, type "help".
Type "apropos word" to search for commands related to "word".
```

Figure 4

At this point, the debugger is waiting to allow your program to execute its first instruction — i.e., before the first executable line in **`main()`**, which happens to be where you set the breakpoint.

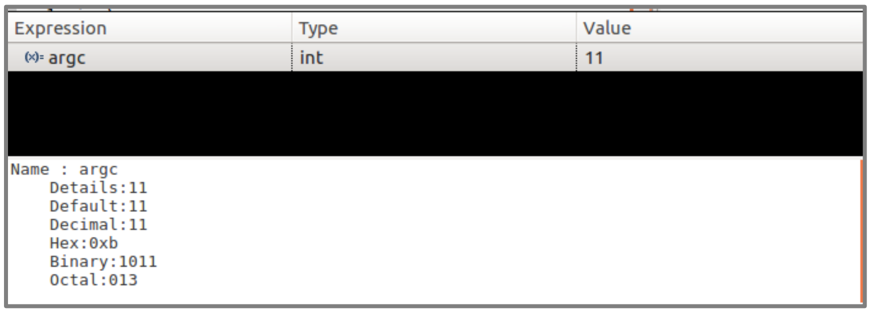
In the left margin of the code of the **`Sample.c`** tab will be a small green arrow indicating the point of execution. In the upper right window, the *Variables* tab shows the names and values of the variables in the current scope at the point of execution. As you can see, **`argc`** contains the number of arguments that you supplied to the program (including the program name itself) and **`argv`** is a pointer. Both **`a`** and **`i`** have garbage values because they have not yet been initialized.

You can also hover over an instance of any variable in the code, and a popup box will appear with the value of that variable. This also works for expressions. For example, select the expression

`argc – 1`

[3] If your *Debug perspective* does not resemble this, execute the *Reset Perspective…* command in the *Window* menu. This can be used whenever you get your windows and tabs so mixed up that they become hard to use.

in the argument list of the call to **`malloc()`** on line 31. Now, hover over this expression, to bring up the popup box shown in Figure 5. In this case, the value is 11, because the program had been called with twelve arguments.



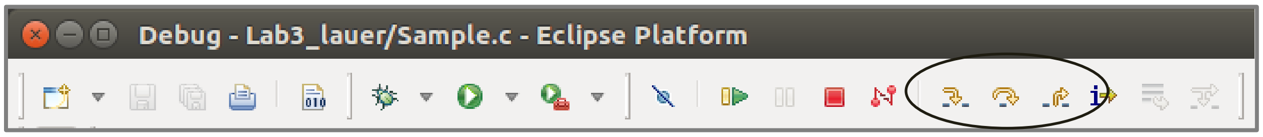
Expression	Type	Value
argc	int	11

```
Name : argc
    Details:11
    Default:11
    Decimal:11
    Hex:0xb
    Binary:1011
    Octal:013
```

Figure 5

Stepping through your program

At the top of Figure 4 is a row of buttons for common debugging actions. This row is shown here in magnified form. Allow the cursor to hover over each icon to see its name.



Debug - Lab3_lauer/Sample.c - Eclipse Platform

Figure 6

Three very useful debugger commands are **`Step into`**, **`Step over`**, and **`Step out`**, represented by the three yellow arrows shown in the oval in Figure 6.[4] Click on **`Step over`**. You will see that the point of execution has advanced to line 32 and that the variable **`a`** now has a valid pointer value.[5]

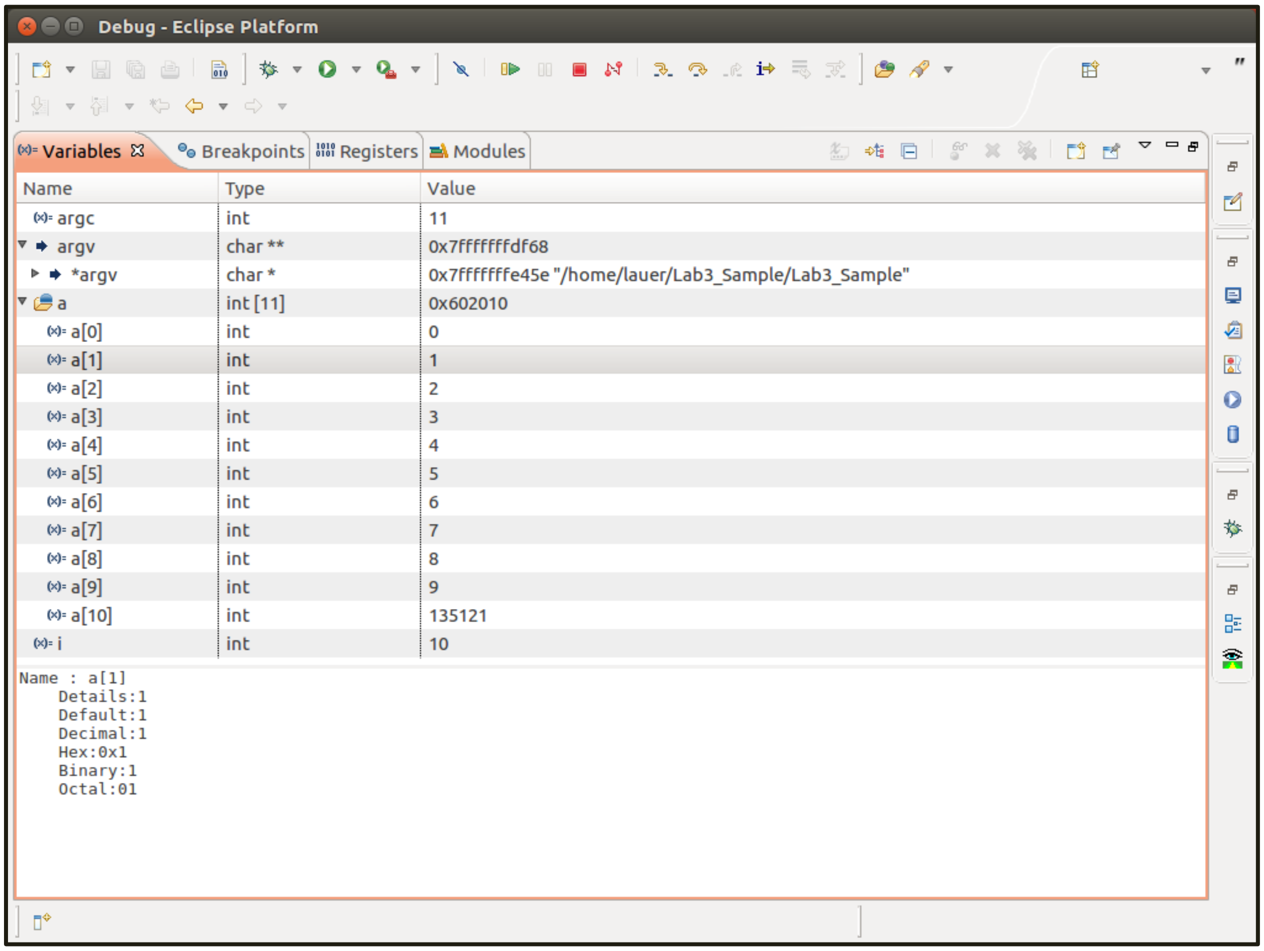
Click on *Step over* twice more to enter the loop that initializes the array **`a`**. Examine the values of the argument of **`atoi`** (i.e., **`argv[i+1]`**) and the resulting assignment to the array element **`a[i]`**. They should be the same value, and that value should be the value of the first argument on your list in the *Run Configurations…* or *Debug Configurations…* menu command.

Next, set a breakpoint on line 35, the call to the **`shell_sort()`** function. Click the *Resume* button (i.e., , just right of the center of Figure 6). The program will finish the **`for`**-loop and suspend execution just prior to the call to **`shell_sort()`**. To see what the arguments to **`shell_sort`** are, go to the *Variables* tab in the upper-right window. So far, the debugger thinks that **`a`** is a pointer. However, *you* know that it is an array. To see the values of the array, right-click on the name **`a`** (in the *Variables* tab) and select **`Display as Array…`**. A new dialog box pops up asking you to enter the starting index and the length of the array. Enter zero for the starting index, and enter the value of **`argc`** for the length, because this is what the program supplied to **`shell_sort()`** on line 35.

[4] All of the icons in this row are explained in more detail in the table at the end of this document.

[5] You really do not want to click **`Step into`** at this point, because that could take you into the **`malloc()`** function, which is very large and contains a lot of executable code but no source code. It would not be useful to spend any time looking around in it. If you do accidentally end up in a system call such as **`malloc()`**, simply click **`Step out`** to return to your program.

Click on the small arrow to the left of **a** in the *Variables* tab. This will expand **a** and show the values of the individual elements of **a**. In addition, you can click on the line representing **a** itself, and in the lower panel of the *Variables* tab, it will show the entire array. Figure 7 shows an example.



Name	Type	Value
argc	int	11
argv	char **	0x7fffffffdf68
*argv	char *	0x7fffffffe45e "/home/lauer/Lab3_Sample/Lab3_Sample"
a	int [11]	0x602010
a[0]	int	0
a[1]	int	1
a[2]	int	2
a[3]	int	3
a[4]	int	4
a[5]	int	5
a[6]	int	6
a[7]	int	7
a[8]	int	8
a[9]	int	9
a[10]	int	135121
i	int	10

```
Name : a[1]
    Details:1
    Default:1
    Decimal:1
    Hex:0x1
    Binary:1
    Octal:01
```

Figure 7

Now the problem becomes apparent:– there are one too many values in the array **a**, and the last value is a garbage value. The **shell_sort()** function correctly sorts this (erroneous) list and puts the garbage value in numerical order along with the rest of the array, and then the **for**-loop of lines 37-39 prints out the sorted array, but of the correct length. There are three possibilities:–

- The garbage value is larger than any of your input values. In this case, it sorts to its original position at the end of the extended array, the print loop prints out the sorted array (not including the garbage value), and the program appears to work correctly.
- The garbage value is smaller than at least one of your input values. In this case, it sorts into the appropriate place in the array, and the largest of your input values is left off the end of the output. Also, the largest value does no damage to anything else, so the program appears to work almost correctly.
- The nastiest case is that garbage value is smaller than at least one element of the array, and the largest of your inputs overwrites some crucial data that just happens to be stored at the end of the array. This crucial data could be control information for **malloc()**, which in many implementations is stored between the allocated storage. If this control information is overwritten in a damaging way, **malloc()** could go haywire, perhaps causing a segmentation fault.

Because of these three possibilities, the error may or may not have made itself known when you were testing your program from a command prompt or a Linux shell.

If you now click the ***Resume*** button and let the program run to completion, the debugger *may* discover that The Heap has been corrupted and exit with the following warning:–

```
warning: HEAP[Lab3_Sample.exe]:
warning: Heap block at 005118B0 modified at 005118E8 past requested size of 30
```

To finish this part of the lab, fix the "error" in the program, rebuild the project, and convince yourself that it works correctly and completes without any warnings about Heap corruption. In particular, show that the value beyond the end of the array is not corrupted.

Managing breakpoints

There are many other things that you can do with breakpoints. Click in the ***Breakpoints*** tab in the upper right group of the ***Debug Perspective***. You should see something resembling the following:–

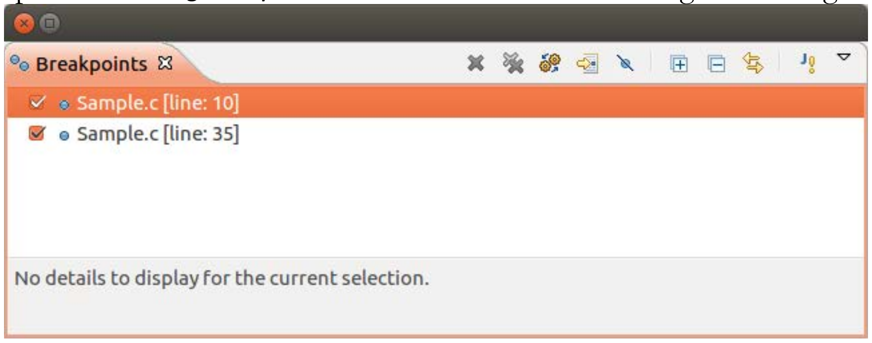


Figure 8

A breakpoint can be enabled or disabled, simply by checking or unchecking the box next to it. If the breakpoint is disabled, the debugger will not stop at that particular line. You can also enable or disable a breakpoint by right-clicking in the margin of the source window next to the line of the breakpoint. Try this now, and notice that the check box in the ***Breakpoint*** tab changes accordingly. In addition, you can enable or disable a breakpoint by holding down *shift* and double-clicking in the margin.

The ability to enable and disable breakpoints is very handy, because you can set any combination of them in a serious debugging situation without having to delete them and re-create them. You can also see at a glance which breakpoints are present and which are enabled. This is enormously helpful in keeping track of a complex debugging session.

To remove a breakpoint completely, right-click on it in the ***Breakpoints*** tab and select ***Remove***. Alternatively, you can select the line of source code, right-click in the margin next to it, and select ***Toggle Breakpoint***. You can also remove *all* breakpoints in your program by selecting ***Remove All*** from the same menu.

Note that *Eclipse* (and most other debuggers) preserve breakpoints across debugging sessions. This means that you can suspend a debugging session, exit *Eclipse*, and return later to resume debugging the same program with the same breakpoints.

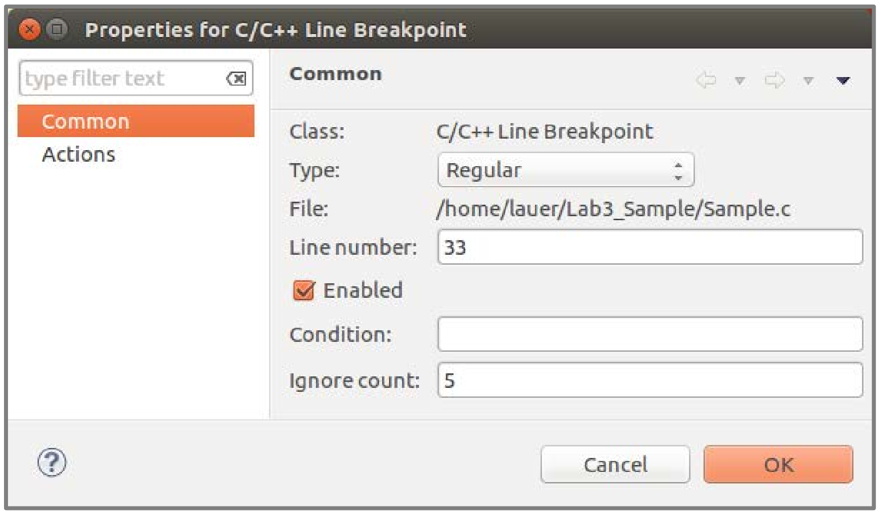
Conditional breakpoints

You can dynamically control whether a breakpoint is taken or not by making it a *conditional* breakpoint. To see how to do this, ***Terminate*** your previous debugging session by clicking on the red square which is two icons to the left of the oval in Figure 6. (Alternatively, you may right-click on the name of your program in the *Debug* tab in the upper left of the *Debug Perspective*.) Set a new breakpoint on line 33 of **`Sample.c`** — i.e.,

```
        a[i] = atoi(argv[i + 1]);
```

In the *Breakpoint* tab, right-click on this breakpoint and select *Breakpoint Properties …* . This brings up the dialog box of Figure 9, which lets you control under what circumstances a breakpoint is actually taken. Select *Common* in the left of this dialog box.

Set the value of the *Ignore count* field to 5 and click *Run > Debug* to start the program in the debugger. Click *Resume*, and it will run to the breakpoint, but it will only stop on the fifth time it encounters it. You can verify this by looking at the *Variables* tab. The value of **`i`** should be 5 (you may have to scroll the tab to see the variable).


Properties for C/C++ Line Breakpoint

Common

Class: C/C++ Line Breakpoint
Type: Regular
File: /home/lauer/Lab3_Sample/Sample.c
Line number: 33
Enabled ✓
Condition:
Ignore count: 5

Figure 9

You can also stop on the value of a variable or expression. To see this, set the *Ignore* count in Figure 9 to zero, and set the condition to

```
        i >= 5 && i <= 8
```

Invoke *Run > Debug*, and click *Resume* to start the program in the debugger. It should stop in the for-loop of main with a value of 5 for **`i`**. Verify this in the *Variables* tab. Click *Resume* again, and it will stop when **`i`** has a value of 6, and then again for values of 7 and 8. However, when you click *Resume* after the value of 8, the program will continue to the end, because the breakpoint condition is no longer satisfied.

You can put an arbitrary *C* expression in the condition field. If it evaluates to zero, the breakpoint is not taken. If it evaluates to a non-zero value, the breakpoint is taken. Experiment with this. For example, you might want to stop on the condition

```
        atoi(argv[i+1]) == 9
```

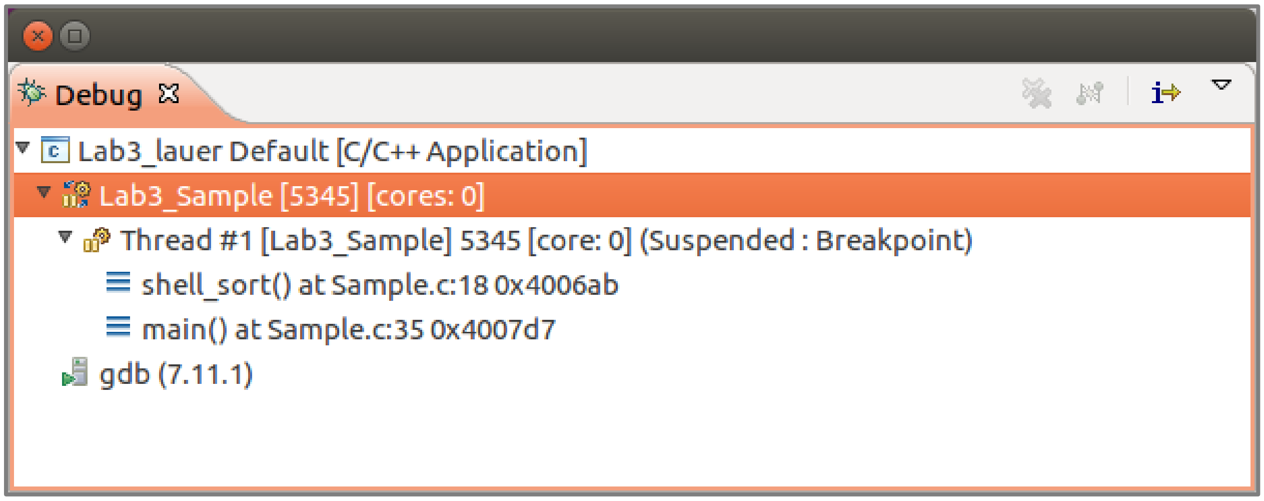
This is a perfectly legal expression in the context of the breakpoint.

The Call Stack

Another important feature of the debugger is to display the *call stack* — i.e., the nested set of function calls from the current breakpoint back to the call of main. This is displayed in the *Debug* tab in the upper left of the *Debug Perspective*. To see an example, remove all breakpoints, and then set a conditional breakpoint on line 18 with a condition of **`v == 9`** — i.e., at this line:–

```
    for (j = i; j >= h && a[j - h] > v; j -= h)
```

Run the program to the breakpoint. The *Debug* tab should show something like Figure 10. The first line shows the program you are debugging (**`Lab4_Sample.exe`**), and the second line shows the *process number* of the running program (5345, in this figure). This is the operating system's identification of a particular instance of an executing program. Below this is a line labeled *Thread#1*. This represents your program, and the two lines below it show that it is at a breakpoint in **`shell_sort()`** at line 18 and that **`shell_sort()`** was called from **`main()`** at line 35.



```
Lab3_lauer Default [C/C++ Application]
  Lab3_Sample [5345] [cores: 0]
    Thread #1 [Lab3_Sample] 5345 [core: 0] (Suspended : Breakpoint)
      shell_sort() at Sample.c:18 0x4006ab
      main() at Sample.c:35 0x4007d7
    gdb (7.11.1)
```

Figure 10

Click on the **`shell_sort()`** line in Figure 10. The *Variables* tab will show the **`shell_sort()`** variables at the moment of the breakpoint. Now, click on **`main()`** of Figure 10, and the *Variables* tab switches to show the values of the variables in **`main()`**. By this means, you can navigate up and down the call stack to see what conditions were present in each of the calling functions at the time of the breakpoint.

Finally, *Terminate* the debugging session by selecting *Terminate* from the *Run* menu, and the *Debug* tab will contain two lines denoting the carcass of the debugged program. You can remove this by right-clicking on it and selecting *Remove all Terminated*. Alternatively, you can re-launch the program being debugged by selecting that option in the popup menu.

Getting Credit for this Lab

To get full credit for this lab, you need to capture two screenshots of (a portion of) the array representing the Game of Life board in Programming Assignment #3. Capture one screenshot of the array *immediately before* playing a generation, and capture another screenshot *immediately after* playing that generation. Select a non-trivial portion of the game board and convince yourself that the game has played at least that move correctly.

> **Note:** An easy way to capture a screenshot of any tab in *Eclipse* is to do the following:– (a) Drag the tab from its place in the *Eclipse* window to the desktop. It now becomes an independent window on the desktop. (b) Press *ALT* and *PrintScreen*[6] together on the keyboard to make a copy of that window. (c) Paste that copy into a document, which you can later submit. (d) Invoke the *Reset Perspective…* command from the *Window* menu to return the tab to its original place in the *Eclipse* window.

[6] **`ALT-PrintScreen`** is equivalent to calling **`gnome-screenshot`** from a command shell. It automatically selects the active window.

Once you have captured both screenshots, submit them to *Canvas* under the assignment *Lab3*.

If you still have time left, spend it using the debugging tools of this lab to debug your Game of Life.

Quick Reference Guide — Debug view toolbar options

The table below is copied from the *Eclipse CDT* help system. It lists the toolbar icons displayed in the *Debug* view. Note that *breakpoints* supersede the ***Step Over*** and ***Step Out*** commands. This means that if you attempt to step over a function call, and if that function contains a breakpoint, the breakpoint will be taken. Likewise, if you attempt to step out of a function in order to return to its caller, and if that function encounters a breakpoint, that breakpoint will be taken.

Icons	Action	Description
✖	**Remove All Terminated Launches**	Clears all terminated processes in Debug view
	Connect to a Process	Enables the selection of a running process to debug.
🔄	**Restart**	Starts a new debug session for the selected process
▶	**Resume**	Select the Resume command to resume execution of the currently suspended debug target.
⏸	**Suspend**	Select the Suspend command to halt execution of the currently selected thread in a debug target.
🟥	**Terminate**	Ends the selected debug session and/or process. The impact of this action depends on the type of the item selected in the Debug view.
↯	**Disconnect**	Detaches the debugger from the selected process (useful for debugging attached processes).
↴	**Step Into**	Select to execute the current line, including any routines, and proceed to the next statement.
↷	**Step Over**	Select to execute the current line, following execution inside a routine.
↱	**Step Return**	Select to continue execution to the end of the current routine, then follow execution to the routine's caller.
≡	**Drop to Frame**	Select the Drop to Frame command to re-enter the selected stack frame in the Debug view.
i→	**Instruction Stepping Mode**	Activate to enable instruction stepping mode to examine a program as it steps into disassembled code.
↴	**Use Step Filters**	Select the Use Step Filters command to change whether step filters should be used in the Debug view.

	Menu	Use the ***Debug*** view menu to: • change the layout of debug view (tree vs. bread-crumb) • alternate showing of full or no paths on source files • control how views are managed • activate or deactivate the child elements shown in the Debug view