CSCI 103: Introduction to Programming

Lab 4
GDB and valgrind

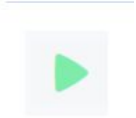
February 2, 2024

Common Causes of Program Terminations

- Segfaults (reading or writing outside memory allocated)
- Aborts
- Infinite recursion (stack overflow)
- Unhandled exceptions / error cases

Recall: The Codio Debugger

The Codio debugger has features to set breakpoints, step through code, and print variable values…

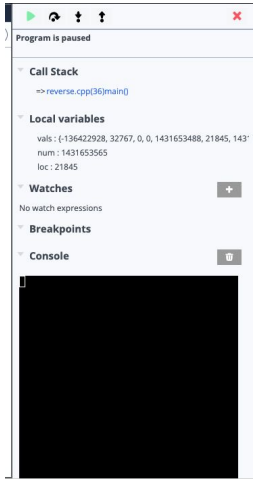


Run

Step out

Step over (next)

Step into



What is GDB?

- gdb = GNU Project Debugger
- Text-based debugger that you can run from the command line and is on most every Mac/Linux operating system
  - So if you aren't on Codio ...OR… **if the Codio debugger isn't working, you should just use gdb.**
  - In fact, the Codio debugger runs it behind the scenes
- After compilation (with the `-g` flag), start GDB at the terminal prompt by typing: `gdb executable`
  - *executable is the program name (e.g. `gdb ./shapes`)*
- You will learn much more about GDB in CS104

Starting GDB

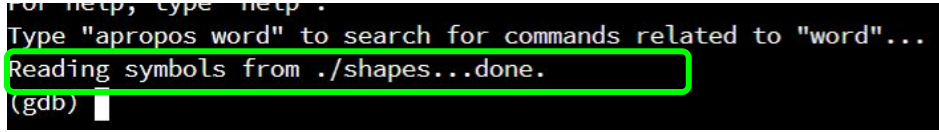
Start at the terminal prompt: gdb *executable*

```
codio@melodywave-westernstudent:~/workspaces$ gdb ./fault
GNU gdb (Ubuntu 8.1-0ubuntu3.2) 8.1.0.20180409-git
Copyright (C) 2018 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
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"...
Reading symbols from ./fault...done.
(gdb)
```

GDB Prompt

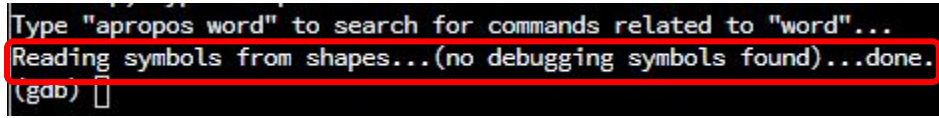
Once started it will show some information and take you to a prompt:
(gdb)

- Remember to compile with the `-g` flag
- If it successfully opens your program you'll see "Reading symbols from <executable>...done."
- If you see "Reading symbols from shapes…(no debugging symbols found)", you forgot to compile with `-g`. Stop and recompile



Good!

Bad!



Basic GDB Commands Reference

- `run` or `r` : Executes the program from start to end
- `backtrace` or `bt`: Lists all the function calls (that leads to the crash) in the stack frame
- `print` or `p`: Used to display a variable/expression value
- `cont`: Continue execution until the next breakpoint or termination of the program
- `break` or `b` : Sets a breakpoint on a particular line
- `next` or `n`: Executes the current line of code fully (even if it contains a function call), stopping at the next line
- `step` or `s`: Executes the current line of code, stopping at the beginning of a function called by the current line
- `finish` or `f`: Completes execution of the current function and stops upon return to the caller
- `up [n]` : Move n frames up the stack; n defaults to 1
- `down [n]` : Move n frames down the stack; n defaults to 1
- `clear`: Clear all breakpoints
- `quit` or `q`: Quit gdb

GDB Commands (1)

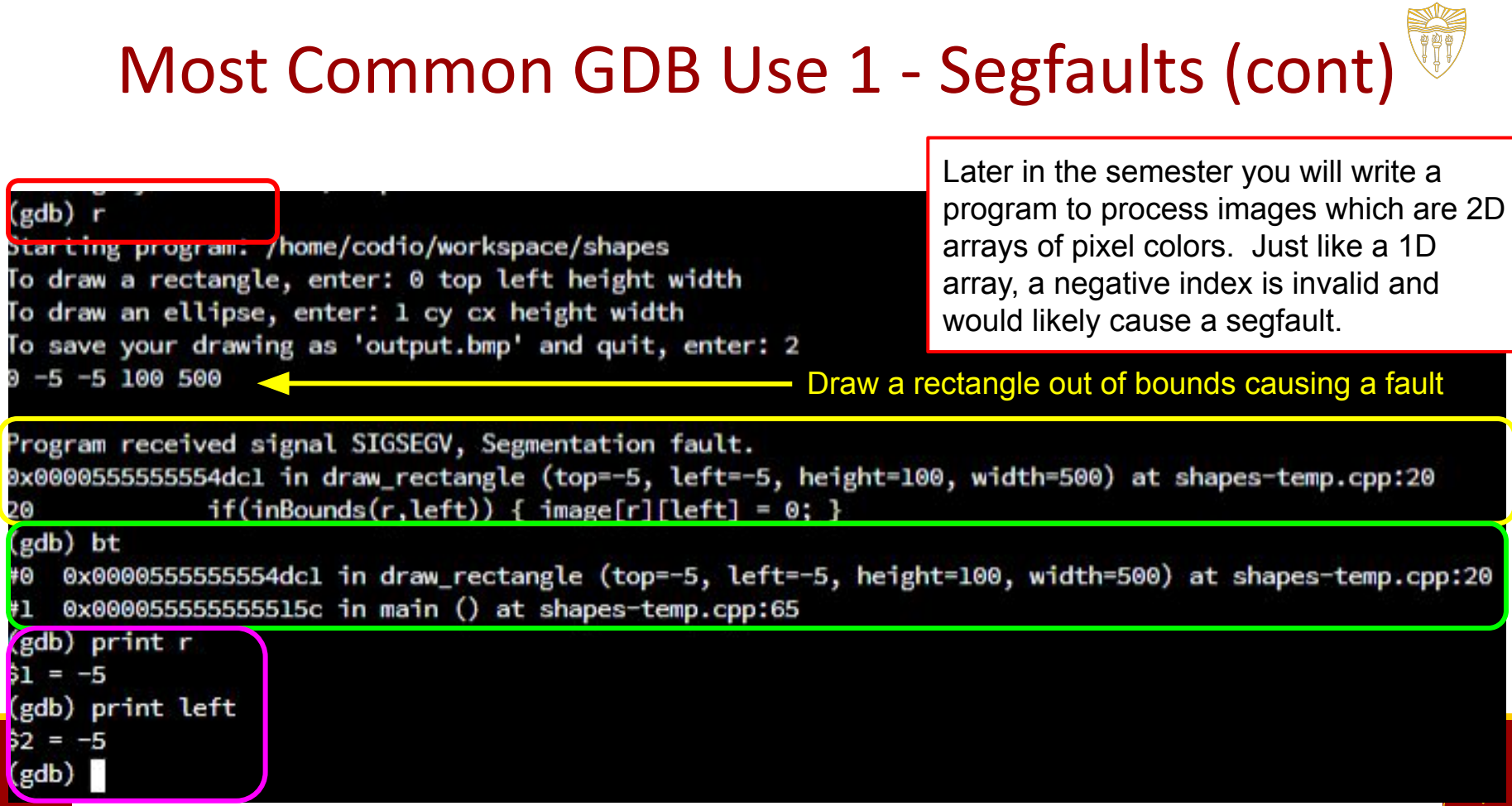
Text based commands for the buttons you use in Codio

- `(gdb) break` or `b` *`<filename:line_number>`*
  - (e.g. `b shapes.cpp:37` - Sets a breakpoint at line 37 of shapes.cpp)
- `(gdb) run` or `r`
  - Runs the program until it hits a breakpoint
- `(gdb) print` or `p` *`<variable>`*
  - Prints the value of a variable at the current point in the code

Most Common GDB Use 1 - Segfaults

- When your program **segfaults**, your **FIRST STEP SHOULD ALWAYS** be to run it in the debugger.
- Step 1: Load gdb (`gdb ./shapes`)
- Step 2: At the prompt, run the program using `run` and let the program crash
- Step 3: When it crashes it will show you the source file and line number.
  - That line is where the error manifested, but the cause may be that line or some earlier line
  - However, it may have crashed deep in some library function. Use `bt` or `backtrace` to show the function call stack and look for the first function (and line number) that you actually wrote and investigate there
- Step 4: Use `print` to print variables relevant to the line where it crashed

Most Common GDB Use 1 - Segfaults (cont)



Draw a rectangle out of bounds causing a fault

Later in the semester you will write a program to process images which are 2D arrays of pixel colors. Just like a 1D array, a negative index is invalid and would likely cause a segfault.

GDB Commands (2)

Corresponding Codio Buttons

Text based commands for the buttons you use in Codio

- `(gdb) step`
  - If current line is function, it steps into the function pausing at the first line
- `(gdb) next`
  - Executes the next line, even if it is a function
- `(gdb) finish`
  - Finishes the current function and pauses back in the caller
- `(gdb) cont`
  - Continue to execute the program at full speed

What is Valgrind?

- Helps track down memory allocation and usage errors
  - Misuse, forgot to deallocate, using garbage values, accessing arrays out of bounds
- `$ valgrind --tool=memcheck --leak-check=yes <executable> <command line args>`
- `$ valgrind --tool=memcheck --leak-check=yes ./scramble wordbank.txt 57`
- You should use valgrind in every lab, hw, and project from now on (and in CS104!)

Valgrind Outputs

No error

```
==8146==
==8146== HEAP SUMMARY:
==8146== in use at exit: 0 bytes in 0 blocks
==8146== total heap usage: 10 allocs, 10 frees, 8,856 bytes allocated
==8146==
==8146== All heap blocks were freed -- no leaks are possible
==8146==
==8146== For counts of detected and suppressed errors, rerun with: -v
==8146== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 2 from 2)
```

Error

```
==8178==
==8178== HEAP SUMMARY:
==8178== in use at exit: 40 bytes in 6 blocks
==8178== total heap usage: 10 allocs, 4 frees, 8,853 bytes allocated
==8178==
==8178== 40 bytes in 6 blocks are definitely lost in loss record 1 of 1
==8178== at 0x4C2AC27: operator new[](unsigned long) (in
/usr/lib/valgrind/vgpreload_memcheck-amd64-linux.so)
==8178== by 0x40109A: main (scramble.cpp:48)
==8178==
==8178== LEAK SUMMARY:
==8178== definitely lost: 40 bytes in 6 blocks
==8178== indirectly lost: 0 bytes in 0 blocks
==8178== possibly lost: 0 bytes in 0 blocks
==8178== still reachable: 0 bytes in 0 blocks
==8178== suppressed: 0 bytes in 0 blocks
==8178==
==8178== For counts of detected and suppressed errors, rerun with: -v
==8178== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 2 from 2)
```

Common Valgrind Errors

Invalid read/write: Array or pointer access/assignment to out-of-bounds location.

Conditional jump depends on uninitialized variables: Use of uninitialized variable

Lost (leaked) memory: Did not free/delete a memory allocation

Double free: Freed/deleted an allocation two or more times

Mismatched delete: new [] / delete ..OR.. new / delete []

Questions to Ask Yourself While Debugging

- What line is the problem on?
  - If your program crashes, first run GDB to find the line number.
  - If gdb, doesn't help find the problem then run valgrind as well (as it may show some additional info that is helpful)
- Might the program behavior be caused by memory issues…always try valgrind
- When does this bug occur?
  - Are there specific circumstances? Edge case? Only breaks if it goes into a specific if statement? Step through the code to see where it executes

Programming Tasks

To practice dynamic allocation and deeper understanding of C-strings (character arrays with null terminators), we provide 2 practice exercises:

1. Kcopy - given a C-string and integer k, return a new C-string which has the original string copied k times (eg. `"abc", 3 => "abcabcabc"`).
2. removeSpaces - Given a C-string, return a copy of that string with all space characters removed: (`"cs 103 ! " => "cs103!"`)

Your Task

Start the Lab 4 assignment on Codio.

- Work through the guided demo to find and fix errors. Finish 3 review questions A,B,C and show answers to the TA/CPs, you will get **50 points**.
- Finish two secondary tasks: kcopy and removeSpaces. You can do them yourself or in a team of 2. If you pass the automated tests, you will get **25 points for each task.**
- To get credit, you need to get 50 points or above.