CS 35L Software Construction Lab
Week 4 – Debugging

Debugging Process

- Reproduce the bug
- Simplify program input
- Use a debugger to track down the origin of the problem
- Fix the problem

Debugger

- A program that is used to run and debug other (target) programs
- Advantages:

  Programmer can:
  - step through source code line by line
    - each line is executed on demand
  - interact with and inspect program at run-time
  - If program crashes, the debugger outputs where and why it crashed

GDB – GNU Debugger

- Debugger for several languages
  - C, C++, Java, Objective-C… more
- Allows you to inspect what the program is doing at a certain point during execution
- Logical errors and segmentation faults are easier to find with the help of gdb

Using GDB

1. **Compile Program**
   - Normally: `$ gcc [flags] <source files> -o <output file>`
   - Debugging: `$ gcc [other flags] -g <source files> -o <output file>`
     - enables built-in debugging support
2. **Specify Program to Debug**
   - `$ gdb <executable>`

     or
   - `$ gdb`
   - `(gdb) file <executable>`

Run-Time Errors

- Segmentation fault
  - Program received signal SIGSEGV, Segmentation fault. 0x0000000000400524 in *function* (arr=0x7fffc902a270, r1=2, c1=5, r2=4, c2=6) at *file.c*:12
    - Line number where it crashed and parameters to the function that caused the error
- Logic Error
  - Program will run and exit successfully
- How do we find bugs?

Using GDB

3. **Run Program**
   - `(gdb) run` or
   - `(gdb) run [arguments]`
4. **In GDB Interactive Shell**
   - Tab to Autocomplete, up-down arrows to recall history
   - `help [command]` to get more info about a command
5. **Exit the gdb Debugger**
   - `(gdb) quit`

Setting Breakpoints

- Breakpoints
  - used to stop the running program at a specific point
  - If the program reaches that location when running, it will pause and prompt you for another command
- Example:
  - `(gdb) break file1.c:6`
    - Program will pause when it reaches line 6 of file1.c
  - `(gdb) break my_function`
    - Program will pause at the first line of `my_function` every time it is called
  - `(gdb) break [position] if expression`
    - Program will pause at specified position only when the expression evaluates to true

Breakpoints

- Setting a breakpoint and running the program will stop program where you tell it to
- You can set as many breakpoints as you want
  - `(gdb) info breakpoints|break|br|b` shows a list of all breakpoints

Basic commands

- `(gdb) step` - Step to next line of code. Will step into a function.
- `(gdb) next` - Execute next line of code. Will not enter functions.
- `(gdb) print <var>` - Print value stored in variable.
- `(gdb) continue` - Continue execution to next break point.
- `(gdb) set var <name>=<value>` - Executes rest of program with new value of variable.

Deleting, Disabling and Ignoring BPs

- `(gdb) delete [bp_number | range]`
  - Deletes the specified breakpoint or range of breakpoints
- `(gdb) disable [` *`bp_number`* `|` *`range`*`]`
  - Temporarily deactivates a breakpoint or a range of breakpoints
- `(gdb) enable [` *`bp_number`* `|` *`range`*`]`
  - Restores disabled breakpoints
- If no arguments are provided to the above commands, all breakpoints are affected!!
- `(gdb) ignore` *`bp_number iterations`*
  - Instructs GDB to pass over a breakpoint without stopping a certain number of times.
    - bp_number: the number of a breakpoint
    - Iterations: the number of times you want it to be passed over

Displaying Data

- Why would we want to interrupt execution?
  - to see data of interest at run-time:
  - `(gdb) print [/format]` *`expression`*
    - Prints the value of the specified expression in the specified format
  - Formats:
    - d: Decimal notation (default format for integers)
    - x: Hexadecimal notation
    - o: Octal notation
    - t: Binary notation

Resuming Execution After a Break

- When a program stops at a breakpoint
  - 4 possible kinds of gdb operations:
    - **c or continue**: debugger will continue executing until next breakpoint
    - **s or step**: debugger will continue to next source line
    - **n or next**: debugger will continue to next source line in the current (innermost) stack frame
    - **f or finish**: debugger will resume execution until the current function returns. Execution stops immediately after the program flow returns to the function's caller
      - the function's return value and the line containing the next statement are displayed

Watchpoints

- Watch/observe changes to variables
  - `(gdb) watch my_var`
    - sets a watchpoint on my_var
    - the debugger will stop the program when the value of *my_var* changes
    - old and new values will be printed
  - `(gdb) rwatch` *`expression`*
    - The debugger stops the program whenever the program reads the value of any object involved in the evaluation of *expression*

Process Memory Layout

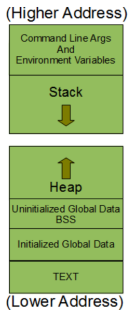


Image source : thegeekstuff.com

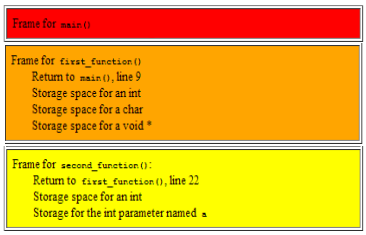
- TEXT segment
  - Contains machine instructions to be executed
- Global Variables
  - Initialized
  - Uninitialized
- Heap segment
  - Dynamic memory allocation
  - malloc, free
- Stack segment
  - Push frame: Function invoked
  - Pop frame: Function returned
  - Stores
    - Local variables
    - Return address, registers, etc
- Command Line arguments and Environment Variables

Stack Info

- A program is made up of one or more functions which interact by calling each other
- Every time a function is called, an area of memory is set aside for it. This area of memory is called a **stack frame** and holds the following crucial info:
  - storage space for all the local variables
  - the memory address to return to when the called function returns
  - the arguments, or parameters, of the called function
- Each function call gets its own stack frame. Collectively, all the stack frames make up the **call stack**

Stack Frames and the Stack

```
1   #include <stdio.h>
2   void first_function(void);
3   void second_function(int);
4
5   int main(void)
6   {
7      printf("hello world\n");
8      first_function();
9      printf("goodbye goodbye\n");
10
11     return 0;
12  }
13
14
15  void first_function(void)
16  {
17     int imidate = 3;
18     char broiled = 'c';
19     void *where_prohibited = NULL;
20
21     second_function(imidate);
22     imidate = 10;
23  }
24
25
26  void second_function(int a)
27  {
28     int b = a;
29  }
```



Analyzing the Stack in GDB

- `(gdb) backtrace|bt`
  - Shows the call trace (the call stack)
  - Without function calls:
    - #0 main () at program.c:10
    - one frame on the stack, numbered 0, and it belongs to main()
  - After call to function display()
    - #0 display (z=5, zptr=0xbffffb34) at program.c:15
      #1 0x08048455 in main () at program.c:10
    - Two stack frames: frame 1 belonging to main() and frame 0 belonging to display().
    - Each frame listing gives
      - the arguments to that function
      - the line number that's currently being executed within that frame

Analyzing the Stack

- (gdb) info frame
  - Displays information about the current stack frame, including its return address and saved register values
- (gdb) info locals
  - Lists the local variables of the function corresponding to the stack frame, with their current values
- (gdb) info args
  - List the argument values of the corresponding function call

Other Useful Commands

- (gdb) info functions
  - Lists all functions in the program
- (gdb) list
  - Lists source code lines around the current line

Lab 4

- Download old version of coreutils with buggy ls program
  - Untar, configure, make
- Bug: ls -t mishandles files whose time stamps are very far in the past. It seems to act as if they are in the future

```
$ tmp=$(mktemp -d)
$ cd $tmp
$ touch -d '1918-11-11 11:00 GMT' wwi-armistice
$ touch now
$ sleep 1
$ touch now1
$ ls -lt wwi-armistice now now1
```

Output:

-rw-r--r-- 1 eggert eggert 0 Nov 11 1918 wwi-armistice
-rw-r--r-- 1 eggert eggert 0 Feb 5 15:57 now1
-rw-r--r-- 1 eggert eggert 0 Feb 5 15:57 now

Goal: Fix the Bug

- **Reproduce the Bug**
  - Follow steps on lab web page
- **Simplify input**
  - Run ls with –l and –t options only
- **Debug**
  - Use gdb to figure out what's wrong
  - $ gdb ./ls
  - (gdb) run –lt wwi-armistice now now1

  (run from the directory where the compiled ls lives)
- **Patch**
  - Construct a patch "lab5.diff" containing your fix
  - It should contain a ChangeLog entry followed by the output of diff -u

Lab Hints

- Use "info functions" to look for relevant starting point
- Compiler optimizations: -O2 -> -O0
  - ./configure CFLAGS="…-O0"