Systems Programming Laboratory, Spring 2023

Introduction to gdb

Abhijit Das
Bivas Mitra

Department of Computer Science and Engineering
Indian Institute of Technology Kharagpur

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Why debuggers?

- Writing error-free codes (particularly large ones) is every programmer's dream.
  - Compilation errors
  - Logical errors
  - Runtime errors
- The compiler is "*never*" faulty.
- If your program does not run, question your understanding and your code first.
- Debuggers help you out there.
  - You can step through your code line by line.
  - You can keep on watching variables.
  - No need to write diagnostic printf's.
  - ...
- The GNU debugger (gdb) is a popular choice of this day.
- Several graphic debuggers (like xxgdb) are built on top of gdb.

First example: Area of a triangle

tarea.c

```
#include <stdio.h>
#include <stdlib.h>

int main ()
{
   int x1, y1, x2, y2, x3, y3;
   double area;

   printf("Program to calculate the area of a triangle with integer coordinates\n");

   printf("Enter the coordinates of the first corner: ");
   scanf("%d%d", &x1, &y1);
   printf("Enter the coordinates of the second corner: ");
   scanf("%d%d", &x2, &y2);
   printf("Enter the coordinates of the third corner: ");
   scanf("%d%d", &x3, &y3);

   area = x1 * (y2 - y3);
   area += x2 * (y1 - y3);
   area += x3 * (y1 - y2);
   if (area < 0) area = -area;
   area /= 2;

   printf("Area of the triangle is %lf\n", area);

   exit(0);
}
```

Running codes with gdb

```
$ gcc -Wall -g tarea.c
$ gdb ./a.out
GNU gdb (Ubuntu 9.2-0ubuntu1 20.04) 9.2
Copyright (C) 2020 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 ./a.out...
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out
Program to calculate the area of a triangle with integer coordinates
Enter the coordinates of the first corner: 3 8
Enter the coordinates of the second corner: 6 -7
Enter the coordinates of the third corner: -1 5
Area of the triangle is 16.500000
[Inferior 1 (process 6730) exited normally]
(gdb) quit
$
```

Listing your code

- list: Keep on listing your code, ten lines at a time.
- list m,n: List from Line m to Line n of your code.
- list k: List ten lines with Line k at the center.

```
(gdb) list
1       #include <stdio.h>
2       #include <stdlib.h>
3
4       int main ()
5       {
6          int x1, y1, x2, y2, x3, y3;
7          double area;
8
9          printf("Program to calculate the area of a triangle with integer coordinates\n");
10
(gdb) list
11         printf("Enter the coordinates of the first corner: ");
12         scanf("%d%d", &x1, &y1);
13         printf("Enter the coordinates of the second corner: ");
14         scanf("%d%d", &x2, &y2);
15         printf("Enter the coordinates of the third corner: ");
16         scanf("%d%d", &x3, &y3);
17
18         area = x1 * (y2 - y3);
19         area += x2 * (y1 - y3);
20         area += x3 * (y1 - y2);
```

Listing your code: Continued

```
(gdb) list
21          if (area < 0) area = -area;
22          area /= 2;
23
24          printf("Area of the triangle is %lf\n", area);
25
26          exit(0);
27      }
(gdb) list
Line number 28 out of range; tarea.c has 27 lines.
(gdb) list 15
10
11          printf("Enter the coordinates of the first corner: ");
12          scanf("%d%d", &x1, &y1);
13          printf("Enter the coordinates of the second corner: ");
14          scanf("%d%d", &x2, &y2);
15          printf("Enter the coordinates of the third corner: ");
16          scanf("%d%d", &x3, &y3);
17
18          area = x1 * (y2 - y3);
19          area += x2 * (y1 - y3);
(gdb) list 18,22
18          area = x1 * (y2 - y3);
19          area += x2 * (y1 - y3);
20          area += x3 * (y1 - y2);
21          if (area < 0) area = -area;
22          area /= 2;
(gdb)
```

Set a breakpoint and step through your code

```
(gdb) break 11
Breakpoint 1 at 0x11d0: file tarea.c, line 11.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out
Program to calculate the area of a triangle with integer coordinates

Breakpoint 1, main () at tarea.c:11
11          printf("Enter the coordinates of the first corner: ");
(gdb) next
12          scanf("%d%d", &x1, &y1);
(gdb) next
Enter the coordinates of the first corner: 3 8
13          printf("Enter the coordinates of the second corner: ");
(gdb) next
14          scanf("%d%d", &x2, &y2);
(gdb) next
Enter the coordinates of the second corner: 6 -7
15          printf("Enter the coordinates of the third corner: ");
(gdb) next
16          scanf("%d%d", &x3, &y3);
(gdb) next
Enter the coordinates of the third corner: -1 5
18          area = x1 * (y2 - y3);
(gdb) next
19          area += x2 * (y1 - y3);
(gdb) continue
Continuing.
Area of the triangle is 16.500000
[Inferior 1 (process 7195) exited normally]
(gdb) q
```

Some notes about gdb

- **Command shortcuts:** You do not have to type the entire command (like list or next). Certain abbreviations are allowed. Here is a short list.

b	break	h	help
bt	backtrace	i	info
c	continue	l	list
d	delete	n	next
dis	disable	p	print
disp	display	q	quit
do	down	ret	return
en	enable	r	run
f	frame	s	step
fin	finish		

- Command name abbreviations are allowed if unambiguous.
- Hit return to repeat the last command.
- **The *unaltered* source file must be present** for gdb to run correctly.

More about breakpoints

- You can set multiple breakpoints.
- Type

  `info break`

  to list all the breakpoints.
- continue stops until the next breakpoint or the end of the program
- Other things that you can do with breakpoints:
  - Disable a breakpoint
  - Enable a disabled breakpoint
  - Delete a breakpoint

```
(gdb) break main
Breakpoint 1 at 0x11a9:  file tarea.c, line 5.
(gdb) break 11
Breakpoint 2 at 0x11d0:  file tarea.c, line 11.
(gdb) break 18
Breakpoint 3 at 0x1257:  file tarea.c, line 18.
(gdb) break 24
Breakpoint 4 at 0x12e5:  file tarea.c, line 24.
```

Breakpoint examples

```
(gdb) info break
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x00000000000011a9 in main at tarea.c:5
2       breakpoint     keep y   0x00000000000011d0 in main at tarea.c:11
3       breakpoint     keep y   0x0000000000001257 in main at tarea.c:18
4       breakpoint     keep y   0x00000000000012e5 in main at tarea.c:24
(gdb) disable 3
(gdb) info break
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x00000000000011a9 in main at tarea.c:5
2       breakpoint     keep y   0x00000000000011d0 in main at tarea.c:11
3       breakpoint     keep n   0x0000000000001257 in main at tarea.c:18
4       breakpoint     keep y   0x00000000000012e5 in main at tarea.c:24
(gdb) enable 3
(gdb) info break
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x00000000000011a9 in main at tarea.c:5
2       breakpoint     keep y   0x00000000000011d0 in main at tarea.c:11
3       breakpoint     keep y   0x0000000000001257 in main at tarea.c:18
4       breakpoint     keep y   0x00000000000012e5 in main at tarea.c:24
(gdb) delete 3
(gdb) info break
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x00000000000011a9 in main at tarea.c:5
2       breakpoint     keep y   0x00000000000011d0 in main at tarea.c:11
4       breakpoint     keep y   0x00000000000012e5 in main at tarea.c:24
(gdb)
```

Printing variables and expressions

```
(gdb) break 18
Breakpoint 1 at 0x1257: file tarea.c, line 18.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out
Program to calculate the area of a triangle with integer coordinates
Enter the coordinates of the first corner: 3 8
Enter the coordinates of the second corner: 6 -7
Enter the coordinates of the third corner: -1 5

Breakpoint 1, main () at tarea.c:18
18          area = x1 * (y2 - y3);
(gdb) print x1
$1 = 3
(gdb) print x2
$2 = 6
(gdb) print x3
$3 = -1
(gdb) print x1 + x2 + x3
$4 = 8
(gdb) print x1 + x2 * x3
$5 = -3
(gdb) print x1 * (y2 - y3) + x2 * (y1 - y3) + x3 * (y1 - y2)
$6 = -33
(gdb) print $6 / 2
$7 = -16
(gdb)
```

Value history: The printed values are stored as $\$1, \$2, \ldots$, and can be accessed later.

Watching variables after every step

```
(gdb) break 16
Breakpoint 1 at 0x123b: file tarea.c, line 16.
(gdb) run
...
Breakpoint 1, main () at tarea.c:16
16          scanf("%d%d", &x3, &y3);
(gdb) n
Enter the coordinates of the third corner: -1 5
18          area = x1 * (y2 - y3);
(gdb) display area
1: area = 6.953355807476115e-310
(gdb) n
19          area += x2 * (y1 - y3);
1: area = -36
(gdb) n
20          area += x3 * (y1 - y2);
1: area = -18
(gdb) n
21          if (area < 0) area = -area;
1: area = -33
(gdb) n
22          area /= 2;
1: area = 33
(gdb) n
24          printf("Area of the triangle is %lf\n", area);
1: area = 16.5
(gdb) continue
Continuing.
Area of the triangle is 16.500000
[Inferior 1 (process 8608) exited normally]
(gdb)
```

Setting variables: The program

setvar.c

```
#include <stdio.h>
#include <stdlib.h>

int main ()
{
   int a, b;

   a = 5;
   b = 8;
   printf("max(%d,%d) = %d\n", a, b, (a >= b) ? a : b);
   printf("max(%d,%d) = %d\n", a, b, (a >= b) ? a : b);
   exit(0);
}
```

Setting variables: Run gdb

```
(gdb) break main
Breakpoint 1 at 0x1169: file setvar.c, line 5.
(gdb) n
The program is not being run.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at setvar.c:5
5       {
(gdb) n
8           a = 5;
(gdb) n
9           b = 8;
(gdb) n
10          printf("max(%d,%d) = %d\n", a, b, (a >= b) ? a : b);
(gdb) n
max(5,8) = 8
11          printf("max(%d,%d) = %d\n", a, b, (a >= b) ? a : b);
(gdb) set var b = 2
(gdb) print b
$1 = 2
(gdb) n
max(5,2) = 5
12          exit(0);
(gdb) n
[Inferior 1 (process 12878) exited normally]
(gdb)
```

Conditions and loops

- Nothing special needs to be done.
- Stepping at the end of the loop goes back to the start of the loop.
- When the loop breaks, the line following the loop is executed.

average.c

```
#include <stdio.h>
#include <stdlib.h>

int main ()
{
   int n, x, sum;

   n = sum = 0;
   printf("Keep on entering non-negative integers. Enter a negative integer to end.\n");
   while (1) {
      printf("Next number: "); scanf("%d", &x);
      if (x < 0) break;
      ++n; sum += x;
   }
   printf("Average of the numbers entered is %lf\n", (double)sum / (double)n);
   exit(0);
}
```

Conditions and loops: Example run

```
(gdb) break main
Breakpoint 1 at 0x11a9: file average.c, line 5.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at average.c:5
5       {
(gdb) n
8           n = sum = 0;
(gdb) n
9           printf("Keep on entering non-negative integers. Enter a negative integer to end.\n");
(gdb) n
Keep on entering non-negative integers. Enter a negative integer to end.
11              printf("Next number: "); scanf("%d", &x);
(gdb) n
Next number: 5
12              if (x < 0) break;
(gdb) n
13              ++n; sum += x;
(gdb) n
11              printf("Next number: "); scanf("%d", &x);
(gdb) n
Next number: 8
12              if (x < 0) break;
(gdb) n
13              ++n; sum += x;
(gdb) n
```

Conditions and loops: Example run (Continued)

```
11            printf("Next number: "); scanf("%d", &x);
(gdb) n
Next number: 4
12            if (x < 0) break;
(gdb) n
13            ++n; sum += x;
(gdb) n
11            printf("Next number: "); scanf("%d", &x);
(gdb) n
Next number: -1
12            if (x < 0) break;
(gdb) n
15        printf("Average of the numbers entered is %lf\n", (double)sum / (double)n);
(gdb) n
Average of the numbers entered is 5.666667
16        exit(0);
(gdb) n
[Inferior 1 (process 10883) exited normally]
(gdb)
```

Function calls: next and step

- **next** does not go into function calls.
- **step** goes into function calls.
- If you want to go into recursive calls, use steps before any such call.
- **finish** or **return** leaves the function without further stepping.
- **finish** continues normally to the end of the function, prints the returned value, and adds this value to the value history.
- **return** leaves the function immediately after you ask gdb to do so.
- You may set an explicit breakpoint at a function name.
- Except for function calls, step and next work the same way.

A program with a non-recursive function

TAREA.c

```
#include <stdio.h>
#include <stdlib.h>

double tarea ( int x1, int y1, int x2, int y2, int x3, int y3 )
{
   double area;

   area = x1 * (y2 - y3);
   area += x2 * (y1 - y3);
   area += x3 * (y1 - y2);
   if (area < 0) area = -area;
   area /= 2;
   return area;
}

int main ()
{
   int x1, y1, x2, y2, x3, y3;
   double area;

   printf("Program to calculate the area of a triangle with integer coordinates\n");
   printf("Enter the coordinates of the first corner: "); scanf("%d%d", &x1, &y1);
   printf("Enter the coordinates of the second corner: "); scanf("%d%d", &x2, &y2);
   printf("Enter the coordinates of the third corner: "); scanf("%d%d", &x3, &y3);
   area = tarea(x1,y1,x2,y2,x3,y3);
   printf("Area of the triangle is %lf\n", area);
   exit(0);
}
```

Skip going inside the function by next

```
(gdb) break main
Breakpoint 1 at 0x124e: file TAREA.c, line 17.
(gdb) r
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at TAREA.c:17
17      {
(gdb) next
21          printf("Program to calculate the area of a triangle with integer coordinates\n");
(gdb) next
Program to calculate the area of a triangle with integer coordinates
22          printf("Enter the coordinates of the first corner: "); scanf("%d%d", &x1, &y1);
(gdb) next
Enter the coordinates of the first corner: 3 8
23          printf("Enter the coordinates of the second corner: "); scanf("%d%d", &x2, &y2);
(gdb) next
Enter the coordinates of the second corner: 6 -7
24          printf("Enter the coordinates of the third corner: "); scanf("%d%d", &x3, &y3);
(gdb) next
Enter the coordinates of the third corner: -1 5
25          area = tarea(x1,y1,x2,y2,x3,y3);
(gdb) next
26          printf("Area of the triangle is %lf\n", area);
(gdb) next
Area of the triangle is 16.500000
27          exit(0);
(gdb)
```

Step into the function

```
...
(gdb) next
Enter the coordinates of the third corner: -1 5
25          area = tarea(x1,y1,x2,y2,x3,y3);
(gdb) step
tarea (x1=32767, y1=-7504, x2=21845, y2=1431655248, x3=32767, y3=-136046822) at TAREA.c:5
5       {
(gdb) next
8           area = x1 * (y2 - y3);
(gdb) print area
$1 = 6.953355807476115e-310
(gdb) next
9           area += x2 * (y1 - y3);
(gdb) print area
$2 = -36
(gdb) next
10          area += x3 * (y1 - y2);
(gdb) print area
$3 = -18
(gdb) finish
Run till exit from #0 tarea (x1=3, y1=8, x2=6, y2=-7, x3=-1, y3=5) at TAREA.c:10
0x000055555555531c in main () at TAREA.c:25
25          area = tarea(x1,y1,x2,y2,x3,y3);
Value returned is $4 = 16.5
(gdb) n
26          printf("Area of the triangle is %lf\n", area);
(gdb) n
Area of the triangle is 16.500000
27          exit(0);
(gdb)
```

Forced return from a function

```
...
(gdb) next
Enter the coordinates of the third corner: -1 5
25          area = tarea(x1,y1,x2,y2,x3,y3);
(gdb) step
tarea (x1=32767, y1=-7504, x2=21845, y2=1431655248, x3=32767, y3=-136046822) at TAREA.c:5
5       {
(gdb) next
8           area = x1 * (y2 - y3);
(gdb) print area
$1 = 6.953355807476115e-310
(gdb) next
9           area += x2 * (y1 - y3);
(gdb) print area
$2 = -36
(gdb) next
10          area += x3 * (y1 - y2);
(gdb) print area
$3 = -18
(gdb) return
Make tarea return now? (y or n) y
#0 0x00005555555531c in main () at TAREA.c:25
25          area = tarea(x1,y1,x2,y2,x3,y3);
(gdb) n
26          printf("Area of the triangle is %lf\n", area);
(gdb) n
Area of the triangle is -18.000000
27          exit(0);
(gdb)
```

Program with a recursive function

fib.c

```
#include <stdio.h>
#include <stdlib.h>

int Fib ( int n )
{
   if (n < 0) return -1;
   if (n <= 1) return n;
   return Fib(n-1) + Fib(n-2);
}

int main ()
{
   int n, f;

   n = 8;
   f = Fib(n);
   printf("F(%d) = %d\n", n, f);
   exit(0);
}
```

Program with a recursive function: Line numbers

```
(gdb) l
1       #include <stdio.h>
2       #include <stdlib.h>
3
4       int Fib ( int n )
5       {
6          if (n < 0) return -1;
7          if (n <= 1) return n;
8          return Fib(n-1) + Fib(n-2);
9       }
10
(gdb) l
11      int main ()
12      {
13         int n, f;
14
15         n = 8;
16         f = Fib(n);
17         printf("F(%d) = %d\n", n, f);
18         exit(0);
19      }
(gdb)
```

Function call with next

```
(gdb) break main
Breakpoint 1 at 0x11b6: file fib.c, line 12.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at fib.c:12
12      {
(gdb) n
15          n = 8;
(gdb) n
16          f = Fib(n);
(gdb) n
17          printf("F(%d) = %d\n", n, f);
(gdb) n
F(8) = 21
18          exit(0);
(gdb) n
[Inferior 1 (process 12316) exited normally]
(gdb) q
```

Function call with only one step

```
(gdb) break main
Breakpoint 1 at 0x11b6: file fib.c, line 12.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at fib.c:12
12      {
(gdb) n
15          n = 8;
(gdb) n
16          f = Fib(n);
(gdb) step
Fib (n=21845) at fib.c:5
5       {
(gdb) n
6           if (n < 0) return -1;
(gdb) n
7           if (n <= 1) return n;
(gdb) n
8           return Fib(n-1) + Fib(n-2);
(gdb) n
9       }
(gdb) n
main () at fib.c:17
17          printf("F(%d) = %d\n", n, f);
(gdb) n
F(8) = 21
18          exit(0);
(gdb)
```

Enter recursive calls with step

```
Breakpoint 1, main () at fib.c:12
12      {
(gdb) n
15          n = 8;
(gdb) n
16          f = Fib(n);
(gdb) s
Fib (n=21845) at fib.c:5
5       {
(gdb) n
6           if (n < 0) return -1;
(gdb) n
7           if (n <= 1) return n;
(gdb) n
8           return Fib(n-1) + Fib(n-2);
(gdb) s
Fib (n=0) at fib.c:5
5       {
(gdb) n
6           if (n < 0) return -1;
(gdb) n
7           if (n <= 1) return n;
(gdb) n
8           return Fib(n-1) + Fib(n-2);
(gdb) s
Fib (n=0) at fib.c:5
5       {
(gdb)
```

Set breakpoint with function name

```
(gdb) break main
Breakpoint 1 at 0x11b6: file fib.c, line 12.
(gdb) break Fib
Breakpoint 2 at 0x1169: file fib.c, line 5.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at fib.c:12
12      {
(gdb) n
15          n = 8;
(gdb) n
16          f = Fib(n);
(gdb) n

Breakpoint 2, Fib (n=21845) at fib.c:5
5       {
(gdb) n
6           if (n < 0) return -1;
(gdb) n
7           if (n <= 1) return n;
(gdb) n
8           return Fib(n-1) + Fib(n-2);
(gdb) n

Breakpoint 2, Fib (n=0) at fib.c:5
5       {
(gdb)
```

Stepping into an external function

Stepping in average.c

```
(gdb) break main
Breakpoint 1 at 0x11a9: file average.c, line 5.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, main () at average.c:5
5       {
(gdb) s
8           n = sum = 0;
(gdb) s
9           printf("Keep on entering non-negative integers. Enter a negative integer to end.\n");
(gdb) s
__GI__IO_puts (
    str=0x555555556008 "Keep on entering non-negative integers. Enter a negative integer to end.")
    at ioputs.c:33
33      ioputs.c: No such file or directory.
(gdb) s
35      in ioputs.c
(gdb) s
36      in ioputs.c
(gdb) s
__lll_cas_lock (futex=0x7ffff7fa74c0 <_IO_stdfile_1_lock>)
    at ../sysdeps/unix/sysv/linux/x86/lowlevellock.h:47
47      ../sysdeps/unix/sysv/linux/x86/lowlevellock.h: No such file or directory.
(gdb)
```

The call stack

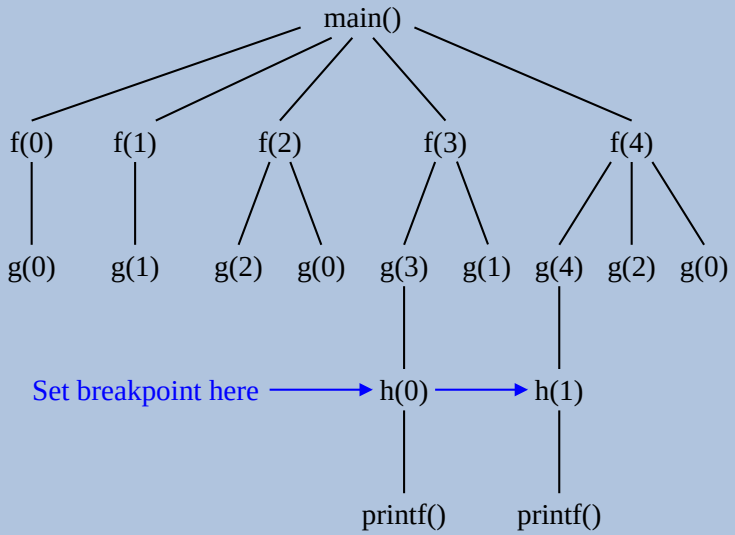
- A function call defines a frame.
- Commands to work with frames:
  - frame: List information about the current frame
  - info frame: List more detailed information about the current frame
  - backtrace: Print the entire stack from top to bottom
  - up: Move one step up in the stack (toward the stack bottom, up in the call tree)
  - down: Move one step down in the stack (toward the stack top, down in the call tree)
- Note: up/down does not change the execution to go up or down. You only move inside the stack, and can see the details of the frames in the stack.

Program to demonstrate the call stack

callstack.c

```
#include <stdio.h>
#include <stdlib.h>

void h ( int n )
{
   printf("+++ Called h(%d)\n", n);
}

void g (int n )
{
   if (n >= 3) h(n-3);
}

void f ( int n )
{
   while (n >= 0) { g(n); n -= 2; }
}

int main ()
{
   int i;
   for (i=0; i<5; ++i) f(i);
   exit(0);
}
```

The call tree



View the call stack

```
(gdb) break h
Breakpoint 1 at 0x1169: file callstack.c, line 5.
(gdb) run
Starting program: /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, h (n=0) at callstack.c:5
5       {
(gdb) backtrace
#0  h (n=0) at callstack.c:5
#1  0x00005555555551b3 in g (n=3) at callstack.c:11
#2  0x00005555555551d1 in f (n=3) at callstack.c:16
#3  0x00005555555551fe in main () at callstack.c:23
(gdb) next
6           printf("+++ Called h(%d)\n", n);
(gdb) step
__printf (format=0x555555556004 "+++ Called h(%d)\n") at printf.c:28
28      printf.c: No such file or directory.
(gdb) backtrace
#0  __printf (format=0x555555556004 "+++ Called h(%d)\n") at printf.c:28
#1  0x000055555555518e in h (n=0) at callstack.c:6
#2  0x00005555555551b3 in g (n=3) at callstack.c:11
#3  0x00005555555551d1 in f (n=3) at callstack.c:16
#4  0x00005555555551fe in main () at callstack.c:23
(gdb) continue
Continuing.
+++ Called h(0)

Breakpoint 1, h (n=1) at callstack.c:5
5       {
(gdb) backtrace
```

View the call stack (continued)

```
#0  h (n=1) at callstack.c:5
#1  0x00005555555551b3 in g (n=4) at callstack.c:11
#2  0x00005555555551d1 in f (n=4) at callstack.c:16
#3  0x00005555555551fe in main () at callstack.c:23
(gdb) up
#1  0x00005555555551b3 in g (n=4) at callstack.c:11
11          if (n >= 3) h(n-3);
(gdb) up
#2  0x00005555555551d1 in f (n=4) at callstack.c:16
16          while (n >= 0) { g(n); n -= 2; }
(gdb) info frame
Stack level 2, frame at 0x7fffffffe2a0:
 rip = 0x5555555551d1 in f (callstack.c:16); saved rip = 0x5555555551fe
 called by frame at 0x7fffffffe2c0, caller of frame at 0x7fffffffe280
 source language c.
 Arglist at 0x7fffffffe278, args: n=4
 Locals at 0x7fffffffe278, Previous frame's sp is 0x7fffffffe2a0
 Saved registers:
  rbp at 0x7fffffffe290, rip at 0x7fffffffe298
(gdb) up
#3  0x00005555555551fe in main () at callstack.c:23
23          for (i=0; i<5; ++i) f(i);
(gdb) up
Initial frame selected; you cannot go up.
(gdb) down 2
#1  0x00005555555551b3 in g (n=4) at callstack.c:11
11          if (n >= 3) h(n-3);
(gdb) continue
Continuing.
+++ Called h(1)
```

Call stack in recursive Fibonacci program

```
(gdb) break Fib
Breakpoint 1 at 0x1169:  file fib.c, line 5.
(gdb) run
Starting program:  /home/abhij/IITKGP/course/lab/SPL/Spring22/prog/gdb/a.out

Breakpoint 1, Fib (n=21845) at fib.c:5
5       {
(gdb) continue 7
Will ignore next 6 crossings of breakpoint 1.  Continuing.

Breakpoint 1, Fib (n=0) at fib.c:5
5       {
(gdb) bt
#0  Fib (n=0) at fib.c:5
#1  0x000055555555519e in Fib (n=2) at fib.c:8
#2  0x000055555555519e in Fib (n=3) at fib.c:8
#3  0x000055555555519e in Fib (n=4) at fib.c:8
#4  0x000055555555519e in Fib (n=5) at fib.c:8
#5  0x000055555555519e in Fib (n=6) at fib.c:8
#6  0x000055555555519e in Fib (n=7) at fib.c:8
#7  0x000055555555519e in Fib (n=8) at fib.c:8
#8  0x00005555555551d3 in main () at fib.c:16
(gdb) c
Continuing.

Breakpoint 1, Fib (n=1) at fib.c:5
5       {
```

Call stack in recursive Fibonacci program (continued)

```
(gdb) bt
#0  Fib (n=1) at fib.c:5
#1  0x00005555555551ad in Fib (n=2) at fib.c:8
#2  0x000055555555519e in Fib (n=3) at fib.c:8
#3  0x000055555555519e in Fib (n=4) at fib.c:8
#4  0x000055555555519e in Fib (n=5) at fib.c:8
#5  0x000055555555519e in Fib (n=6) at fib.c:8
#6  0x000055555555519e in Fib (n=7) at fib.c:8
#7  0x000055555555519e in Fib (n=8) at fib.c:8
#8  0x00005555555551d3 in main () at fib.c:16
(gdb) c
Continuing.

Breakpoint 1, Fib (n=2) at fib.c:5
5       {
(gdb) bt
#0  Fib (n=2) at fib.c:5
#1  0x00005555555551ad in Fib (n=3) at fib.c:8
#2  0x000055555555519e in Fib (n=4) at fib.c:8
#3  0x000055555555519e in Fib (n=5) at fib.c:8
#4  0x000055555555519e in Fib (n=6) at fib.c:8
#5  0x000055555555519e in Fib (n=7) at fib.c:8
#6  0x000055555555519e in Fib (n=8) at fib.c:8
#7  0x00005555555551d3 in main () at fib.c:16
(gdb)
```

If you are lost/inquisitive, ask for help

```
(gdb) help
List of classes of commands:

aliases -- Aliases of other commands.
breakpoints -- Making program stop at certain points.
data -- Examining data.
files -- Specifying and examining files.
internals -- Maintenance commands.
obscure -- Obscure features.
running -- Running the program.
stack -- Examining the stack.
status -- Status inquiries.
support -- Support facilities.
tracepoints -- Tracing of program execution without stopping the program.
user-defined -- User-defined commands.

Type "help" followed by a class name for a list of commands in that class.
Type "help all" for the list of all commands.
Type "help" followed by command name for full documentation.
Type "apropos word" to search for commands related to "word".
Type "apropos -v word" for full documentation of commands related to "word".
Command name abbreviations are allowed if unambiguous.
(gdb) help step
Step program until it reaches a different source line.
Usage: step [N]
Argument N means step N times (or till program stops for another reason).
(gdb) help set var
Evaluate expression EXP and assign result to variable VAR.
Usage: set variable VAR = EXP
...
```

Practice exercises

1. Explain how you can do the following tasks using the list directive of gdb.

   (a) Start the listing of a specified function.

   (b) Change the number of lines printed in each list directive.

   (c) List a file backward. (You have a 1000-line file. Normal listing prints lines 1–10, 11–20, 21–30, ..., 991–1000. You want to list lines 991–1000, 981–990, ..., 11–20, 1–10 in that order. You should avoid specifying the line numbers explicitly.)

2. You have written a program in four `.c` files. The three files **`part1.c`**, **`part2.c`** and **`part3.c`** implement some functions. The file **`allparts.c`** contains the main function (along possibly with some others). You include the individual parts as **`#include "partx.c"`** in **`allparts.c`**. Show how you should compile to generate the final executable file **`a.out`** with debugging enabled. You run this using gdb. If you use the list directive, what do you see? Explain how you can list the individual part files **`partx.c`** (with line numbers). Also explain how you can set breakpoints at specified line numbers in the part files.

3. You have the same situation as in the previous exercise. But now, you do not **`#include "partx.c"`** in **`allparts.c`**. You instead generate individual object files **`part1.o`**, **`part2.o`**, and **`part3.o`**. Finally, you combine these object files and **`allparts.c`** to generate an **`a.out`** with debugging enabled. Mention the compilation commands you use in the process. You run **`a.out`** using gdb. If you use the list directive, what do you see? Explain how you can list the individual part files **`partx.c`** (with line numbers). Also explain how you can set breakpoints at specified line numbers in the part files.

Practice exercises

4. Repeat the last two exercises under the assumption that the part files **`partx.c`** reside in a subdirectory.
5. How can you load or replace an executable file for running, from the command prompt of gdb?
6. How can you re-run a program in gdb from the beginning? What happens to the breakpoints set in the earlier run? The values of the variables set in the earlier run? The value history?
7. How can you print the value history in gdb? How can you print variables or expressions without sending the printed value to the value history?
8. Study how to **`ignore`** breakpoints.
9. Explain how you can use *new* gdb variables not defined in the source file(s).
10. **[Conditional break]** You have the following loop (with the specified line numbers) in your C program.

```
123  for (n=0; n<1000000; ++n) {
124      ...
         ...
234      a = p -> value;
         ...
344      ...
345  }
```

You notice that the program encounters a segmentation fault, because **`p`** unexpectedly becomes NULL at line 234 for some (not all) value(s) of **`n`**. Propose a break instruction for gdb so that you can *easily* detect whenever this happens for the first time. Also explain how you can get the value of **`n`** at this point.

Practice exercises

11. You have the following loop (with the specified line numbers) in your C program.

```
123  for (n=0; n<1000000; ++n) {
124      ...
         ...
234      a = f(n);
         ...
344      ...
345  }
```

Suppose that the loop works without errors for $0 \leqslant n < n_0$, and some problem happens in the return values of the function calls `f(n)` for $n_0 \leqslant n < 1000000$. You want to locate the exact value of n_0 using gdb. Assume that you can understand a faulty return value by simply inspecting it. Propose an efficient strategy of doing this interactively from the gdb prompt.

12. [Watchpoints] A breakpoint is a point where the execution of a program in gdb stops conditionally or unconditionally. A watchpoint is a point where the execution stops whenever the value of a variable or expression changes. This can often be a powerful debugging tool. For example, if a buffer overflow corrupts some variable(s) unintentionally, the source of the problem can be effectively identified by this feature. Investigate how you can set a watchpoint, list all watchpoints set, enable/disable/delete watchpoints.

13. Investigate how you can examine the contents of your program's memory using the `x` command.

Practice exercises

14. You set a breakpoint at the first printf line in the following program.

```
int main ()
{
   int i, A[5] = {15,16,17};
   printf("Hello\n");
   for (i=0; i<5; ++i)
      printf("A[%d] = %d\n", i, A[i]);
}
```

Examine what **`x/5wx A`**, **`x/5wx A+1`**, **`x/5wx A-1`**, and **`x/1wx &i`** print at the breakpoint. Explain. Notice that **`i`** is uninitialized at this point.

15. You write a C program in which Line 100 (this line is in your main() function) makes the following assignment.

```
z = f(x) + g(y);
```

Here, **`f()`** and **`g()`** are two functions in your program, and are called for the first time in this line. Both these functions are called multiple times later, but you suspect that there is some problem in the first call **`g(y)`**. You need to scrutinize how **`g()`** works line by line only in the first call (but not in the later calls). Also, you do not want to scrutinize the line-by-line working of **`f()`** in any of its calls. Explain how you can use gdb interactively to solve this debugging problem. Notice that you do not know beforehand whether **`f(x)`** or **`g(y)`** is computed first before the addition and assignment to **`z`**.

Practice exercises

16. Repeat the last exercise if the line `z = f(x) + g(y);` makes the last call of `g()`.

17. You write a C program in which Line 64 (this line is in your main() function) makes the following assignment.

```
t = g(f(n));
```

Here, `f()` and `g()` are two functions in your program, and both are called multiple times before and after this line. You suspect that there is some problem in the call of `g()` in this line, so you need to scrutinize the line-by-line working of `g()` only for this call. You do not want to scrutinize the line-by-line working of any other call of `g()` or any call of `f()`. Explain how you can use gdb interactively to solve this debugging problem. Assume that `f(n)` returns the correct value.

18. A function `myfunc()` in your C program has a loop from Line 123 to Line 127, which is supposed to set a local int variable `t` to a value greater than or equal to 10 when the loop ends. In Line 128 (also inside `myfunc()`), you make a division by `t`. Therefore if the loop breaks (due to some bug) with `t = 0`, then the program encounters a division-by-zero error, and terminates abnormally. You do not want this to happen. Assume that `myfunc()` is called only once and from the `main()` function. If `t` is non-zero in Line 128, you allow the program to continue normally. If `t` is zero, you go back to `main()` without proceeding further in the function. Explain how you can use gdb interactively to achieve this.

19. Suppose that you want to count how many times a function `f()` is called in your C program. Explain how you can automate this process using gdb.