CSC 4304 - Systems Programming
Fall 2008

Lecture - XV
Debugging

Tevfik Koşar

Louisiana State University
October 28th, 2008

Good Programming Habits

- More important than debugging: do not write bugs!
- Write simple code!

```
/* How is anyone supposed to understand this syntax? */
for(;P("\n"),R--;P("|"))for(e=C;e--;P("_"+(*u++/8)%2))P("| "+(*u/4)%2);
```

- Always use { } around compounds:

```
/* This code probably does not do what you expect */
while (!found && i < N)
    found = myok(i);
    i++;
```

Check Function Return Values

- Most functions from the C library return values
  - Most often: >= 0 if everything went fine, < 0 in case of error
- Always check these return values!
  - I often don't write it in my slides by lack of space
  - But you do not have any excuse for not doing it...

```
int fd = socket(AF_INET,SOCK_STREAM,0);
if (fd<0) {
  ...
}
```

Use perror()

- There is a standard global variable called `errno`
  - It is defined in `<errno.h>`
- When standard functions fail, they store an error code in `errno`
  - You should look at errno for the cause of the problem
- To convert `int errno` into a human-readable string:

```
int fd = socket(AF_INET,SOCK_STREAM,0);
if (fd<0) {
  perror("Error while opening socket");
  exit(1);
}
```

Use Assertions

- Often in a program you know that a given property should normally be true
  - This variable's value should always between 0 and 10
  - This pointer should not be null
  - `min_data_rate` should always be lower than `max_data_rate`
  - etc...
- Use `assert()` to check if these properties are true!
  - If the property is true, assert will do nothing
  - Otherwise, it will display a message, stop the program and dump a core
    - Use GDB to read the core file and see what happenned!

```
#include <assert.h>
void assert(scalar expression);
```

Use Assertions

```
$ cat prog6.c
#include <assert.h>

int main(int argc, char **argv) {
  /* this program should never take any command-line parameter */
  assert(argc==1);

  return 0;
}
$ prog6
$ prog6 wrongparameter
prog6: prog6.c:6: main: Assertion ‘argc==1’ failed.
Aborted (core dumped)
$
```

Avoid These Functions!

- Certain standard C functions do not let you control buffer boundaries
  - You should never use them!
  - There is always a good replacement for them

Do not use:	Use instead:
strcpy	strncpy
sprintf	snprintf
gets	fgets

Use Proper Formatting

- If you want to display a string:

```
char string[32];
printf("%s", string);   /* This is correct */
printf(string);         /* This is WRONG WRONG WRONG */
```

- Try this program (echo):

```
int main(int argc, char **argv) {
  int i;
  for (i=1;i<argc;i++) { printf(argv[i]); }   /* No format string here */
  printf("\n");
}
```

```
$ ./a.out foo
foo
$ ./a.out foo%dbaz
foo4195836baz
$
```

GDB: The GNU Debugger

- A debugger can do two things for you:
  - Run a program step by step, let you follow what it is doing, examine the content of the memory
  - After a program has crashed, load the core file and let you examine what has happened
- GDB can debug programs written in C, C++, Pascal, ADA, etc.
- Current version: 6.6
  - http://www.gnu.org/software/gdb/

Compiling with Debugging Info

- GDB can debug any program
  - But when it executes an instruction, you probably want to see the source code of the instruction being executed
  - This information is normally not present in executable files
- To get them, you must add a flag at compile time
  - This is not necessary at link time (but it cannot hurt)

```
$ gcc -g -c -Wall foo.c
$ gcc -o foo foo.o
$
```

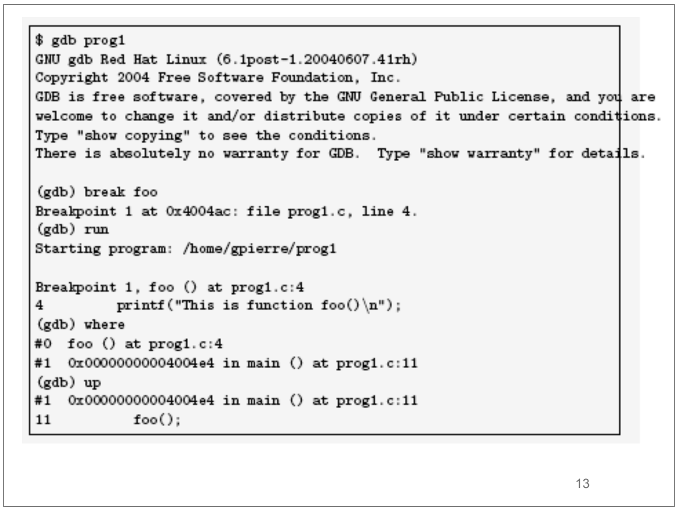
  - This includes line-number informations in your compiled programs

GDB Basic Commands

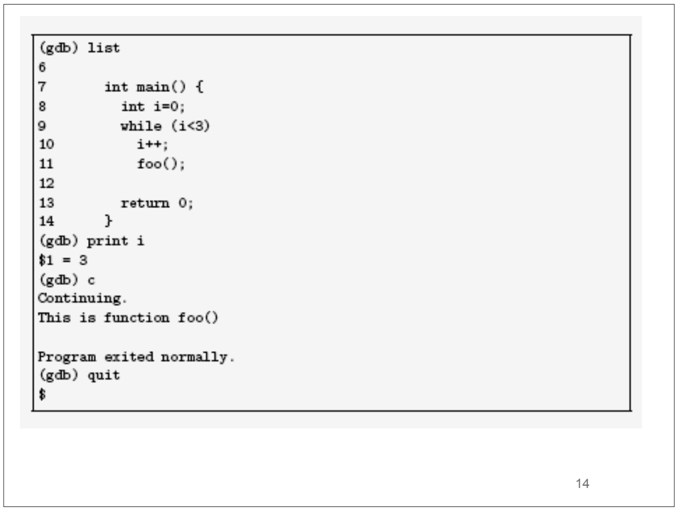
- Basic commands:
  - To run GDB: gdb [program_name]
  - To set a breakpoint: break [function_name]
    or: b [function_name]
    or: b [filename]:[line_nb]
  - To display the source around the current instruction: list (or: l)
  - To start running the program: run [command-line params]
  - To continue the execution after a breakpoint: c
  - To execute one instruction:
    - next or n (treats a function call as a single instruction)
    - step or s (enters inside a function when it is called)
  - To print the value of a variable: print [var] or p [var]
  - To see the function stack: where
  - To re-execute the last command: <enter>
  - To quit: quit

Example

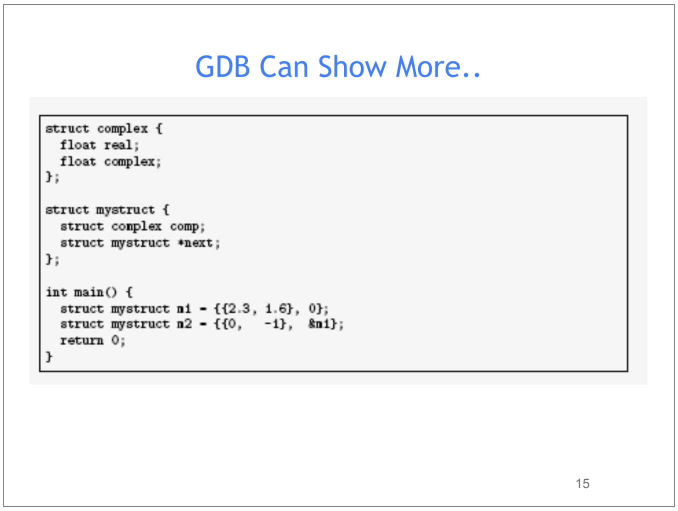
```
#include <stdio.h>

void foo() {
  printf("This is function foo()\n");
}

int main() {
  int i=0;
  while (i<3) /* No { here! */
    i++;
    foo();
          /* No } here! */
  return 0;
}
```



```
$ gdb prog1
GNU gdb Red Hat Linux (6.1post-1.20040607.41rh)
Copyright 2004 Free Software Foundation, Inc.
GDB is free software, covered by the GNU General Public License, and you are
welcome to change it and/or distribute copies of it under certain conditions.
Type "show copying" to see the conditions.
There is absolutely no warranty for GDB.  Type "show warranty" for details.

(gdb) break foo
Breakpoint 1 at 0x4004ac: file prog1.c, line 4.
(gdb) run
Starting program: /home/gpierre/prog1

Breakpoint 1, foo () at prog1.c:4
4          printf("This is function foo()\n");
(gdb) where
#0  foo () at prog1.c:4
#1  0x00000000004004e4 in main () at prog1.c:11
(gdb) up
#1  0x00000000004004e4 in main () at prog1.c:11
11            foo();
```

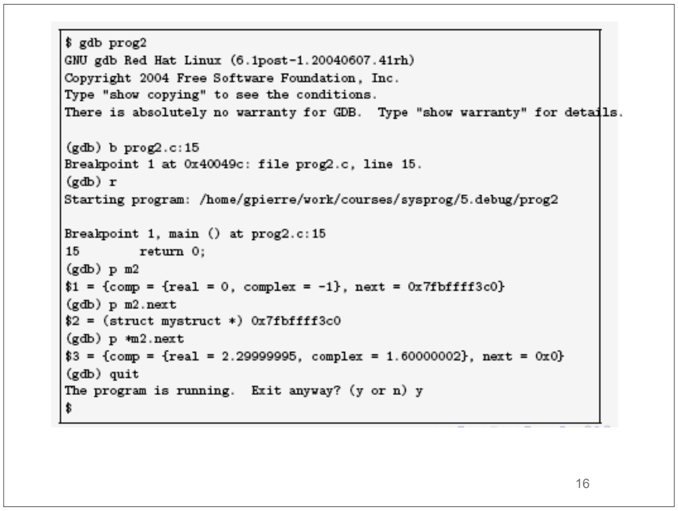


```
(gdb) list
6
7       int main() {
8         int i=0;
9         while (i<3)
10          i++;
11          foo();
12
13        return 0;
14      }
(gdb) print i
$1 = 3
(gdb) c
Continuing.
This is function foo()

Program exited normally.
(gdb) quit
$
```

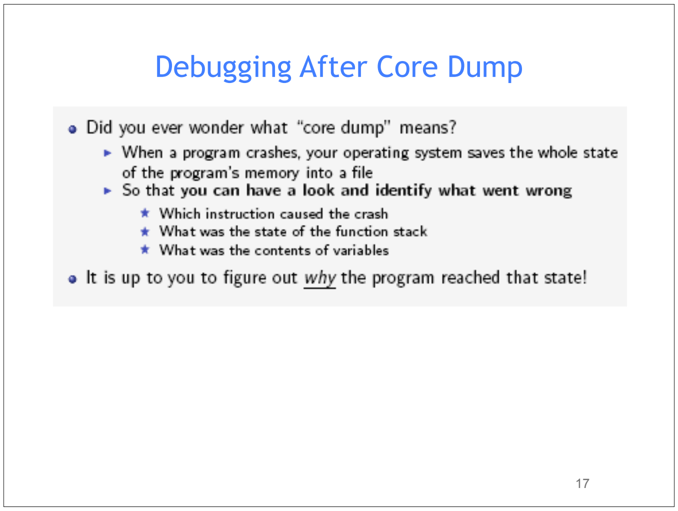


GDB Can Show More..

```
struct complex {
  float real;
  float complex;
};

struct mystruct {
  struct complex comp;
  struct mystruct *next;
};

int main() {
  struct mystruct m1 = {{2.3, 1.6}, 0};
  struct mystruct m2 = {{0,   -1},  &m1};
  return 0;
}
```

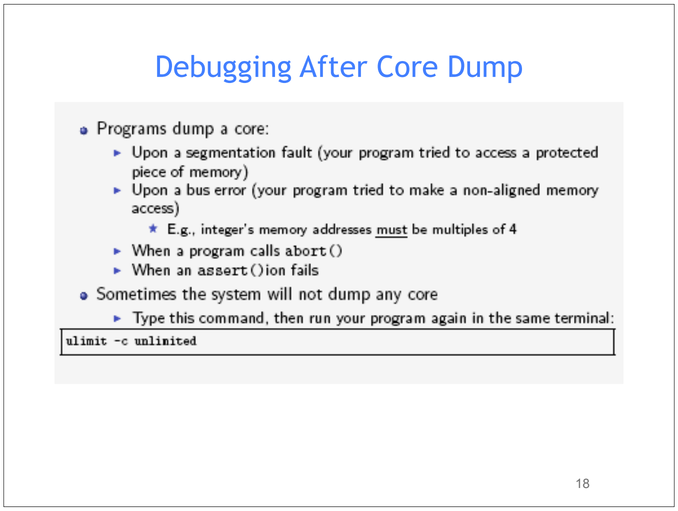


```
$ gdb prog2
GNU gdb Red Hat Linux (6.1post-1.20040607.41rh)
Copyright 2004 Free Software Foundation, Inc.
Type "show copying" to see the conditions.
There is absolutely no warranty for GDB.  Type "show warranty" for details.

(gdb) b prog2.c:15
Breakpoint 1 at 0x40049c: file prog2.c, line 15.
(gdb) r
Starting program: /home/gpierre/work/courses/sysprog/5.debug/prog2

Breakpoint 1, main () at prog2.c:15
15          return 0;
(gdb) p m2
$1 = {comp = {real = 0, complex = -1}, next = 0x7fbffff3c0}
(gdb) p m2.next
$2 = (struct mystruct *) 0x7fbffff3c0
(gdb) p *m2.next
$3 = {comp = {real = 2.29999995, complex = 1.60000002}, next = 0x0}
(gdb) quit
The program is running.  Exit anyway? (y or n) y
$
```



Debugging After Core Dump

- Did you ever wonder what “core dump” means?
  - When a program crashes, your operating system saves the whole state of the program's memory into a file
  - So that you can have a look and identify what went wrong
    - Which instruction caused the crash
    - What was the state of the function stack
    - What was the contents of variables
- It is up to you to figure out *why* the program reached that state!



Debugging After Core Dump

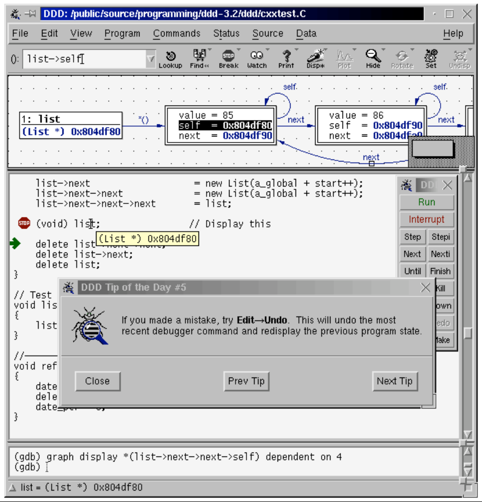
- Programs dump a core:
  - Upon a segmentation fault (your program tried to access a protected piece of memory)
  - Upon a bus error (your program tried to make a non-aligned memory access)
    - E.g., integer's memory addresses must be multiples of 4
  - When a program calls abort()
  - When an assert()ion fails
- Sometimes the system will not dump any core
  - Type this command, then run your program again in the same terminal:

```
ulimit -c unlimited
```

```
$ cat prog3.c
int main() {
  int *i;                          /* Variable i is not initialized! */
  printf("*i=%d\n",*i);
}
$ ./prog3
Segmentation fault (core dumped)
$ gdb prog3 core.8130
(...)

Core was generated by `./prog3'.
Program terminated with signal 11, Segmentation fault.
Reading symbols from /lib64/tls/libc.so.6...done.
Loaded symbols for /lib64/tls/libc.so.6
Reading symbols from /lib64/ld-linux-x86-64.so.2...done.
Loaded symbols for /lib64/ld-linux-x86-64.so.2
#0  0x00000000004004b4 in main () at prog3.c:3
3         printf("*i=%d\n",*i);
(gdb) print i
$1 = (int *) 0x0
(gdb) quit
$
```

DDD: The Data Display Debugger

- When you have complex data structures it can be tedious to explore them with gdb
  - DDD is especially good at displaying them graphically
- DDD is *not* a debugger but just a graphical interface
  - It starts GDB for you
  - Every action you make is translated into a GDB command
  - It displays the result graphically
- It can also interface to the Java debugger, perl, bash, etc.
- Current version: 3.3.11
  - `http://www.gnu.org/software/ddd/`



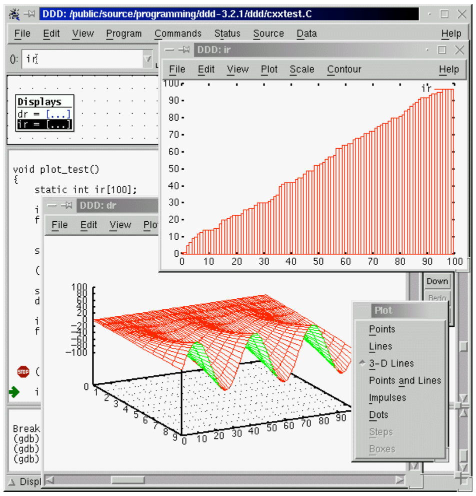
```
    list->next                  = new List(a_global + start++);
    list->next->next            = new List(a_global + start++);
    list->next->next->next      = list;

    (void) list;                // Display this

    delete list
    delete list->next;
    delete list;
}

// Test
void lis
{
    list
}

//
void ref
{
    date
    dele
    date
}
```

(List *) 0x804df80

If you made a mistake, try **Edit→Undo**. This will undo the most recent debugger command and redisplay the previous program state.

```
(gdb) graph display *(list->next->next->self) dependent on 4
(gdb)
```

list = (List *) 0x804df80



```
void plot_test()
{
    static int ir[100];
```

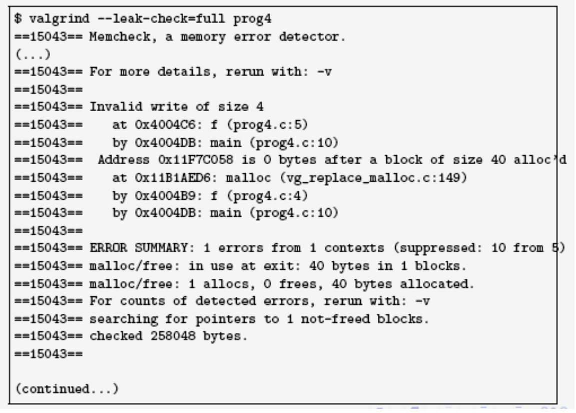
```
Break
(gdb)
(gdb)
(gdb)
```

Valgrind

- GDB does little to detect memory leaks
  - It merely shows you what is going on
  - It does not "know" what is good or bad programming
  - Memory leaks do not directly produce an error
    ⇒ They are hard to locate with GDB
- Valgrind is specialized in memory-related bugs
  - Current version: 3.0.0
  - `http://valgrind.org/`
- Valgrind is a set of tools
  - Two memory error detectors, a thread error detector, a cache profiler and a heap profiler.
  - The most important one: Memcheck (memory debugger)

Example

```
void f() {
  int* x = malloc(10 * sizeof(int));
  x[10] = 0;           /* problem 1: heap block overrun */
                       /* problem 2: memory leak -- x is not freed */
}

int main() {
  f();
  return 0;
}
```



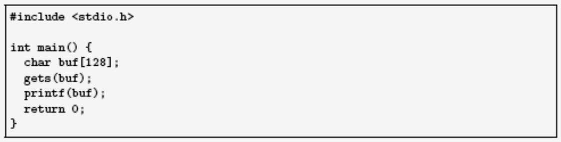
```
$ valgrind --leak-check=full prog4
==15043== Memcheck, a memory error detector.
(...)
==15043== For more details, rerun with: -v
==15043==
==15043== Invalid write of size 4
==15043==    at 0x4004C6: f (prog4.c:5)
==15043==    by 0x4004DB: main (prog4.c:10)
==15043==  Address 0x11F7C058 is 0 bytes after a block of size 40 alloc'd
==15043==    at 0x11B1AED6: malloc (vg_replace_malloc.c:149)
==15043==    by 0x4004B9: f (prog4.c:4)
==15043==    by 0x4004DB: main (prog4.c:10)
==15043==
==15043== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 10 from 5)
==15043== malloc/free: in use at exit: 40 bytes in 1 blocks.
==15043== malloc/free: 1 allocs, 0 frees, 40 bytes allocated.
==15043== For counts of detected errors, rerun with: -v
==15043== searching for pointers to 1 not-freed blocks.
==15043== checked 258048 bytes.
==15043==

(continued...)
```

Splint

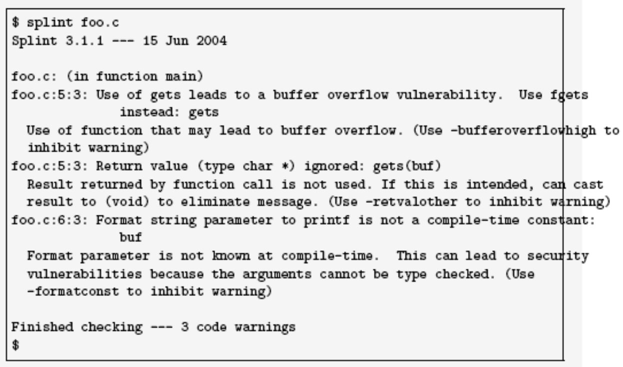
- Very long ago, somebody wrote a program called `lint`
  - It took a C source file as input
  - And checked for common mistakes
- Even better: `splint`
  - `http://www.splint.org/`
  - It checks for common bugs
  - Focuses mostly on security holes (but not only)
- splint will issue warnings
  - Some warnings you may decide to ignore (at your own risk)
  - Remember: even if splint does not display anything, this does not mean that your program is correct!

Example

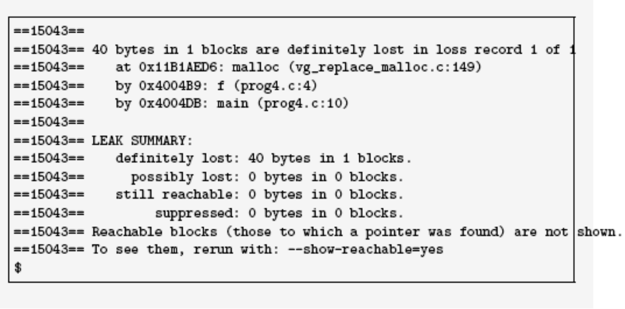
- Let us write a very bad program:



```
#include <stdio.h>

int main() {
  char buf[128];
  gets(buf);
  printf(buf);
  return 0;
}
```



```
$ splint foo.c
Splint 3.1.1 --- 15 Jun 2004

foo.c: (in function main)
foo.c:5:3: Use of gets leads to a buffer overflow vulnerability.  Use fgets
              instead: gets
  Use of function that may lead to buffer overflow. (Use -bufferoverflowhigh to
  inhibit warning)
foo.c:5:3: Return value (type char *) ignored: gets(buf)
  Result returned by function call is not used. If this is intended, can cast
  result to (void) to eliminate message. (Use -retvalother to inhibit warning)
foo.c:6:3: Format string parameter to printf is not a compile-time constant:
              buf
  Format parameter is not known at compile-time.  This can lead to security
  vulnerabilities because the arguments cannot be type checked. (Use
  -formatconst to inhibit warning)

Finished checking --- 3 code warnings
$
```



```
==15043==
==15043== 40 bytes in 1 blocks are definitely lost in loss record 1 of 1
==15043==    at 0x11B1AED6: malloc (vg_replace_malloc.c:149)
==15043==    by 0x4004B9: f (prog4.c:4)
==15043==    by 0x4004DB: main (prog4.c:10)
==15043==
==15043== LEAK SUMMARY:
==15043==    definitely lost: 40 bytes in 1 blocks.
==15043==      possibly lost: 0 bytes in 0 blocks.
==15043==    still reachable: 0 bytes in 0 blocks.
==15043==         suppressed: 0 bytes in 0 blocks.
==15043== Reachable blocks (those to which a pointer was found) are not shown.
==15043== To see them, rerun with: --show-reachable=yes
$
```

Acknowledgments

- Advanced Programming in the Unix Environment by R. Stevens
- The C Programming Language by B. Kernighan and D. Ritchie
- Understanding Unix/Linux Programming by B. Molay
- Lecture notes from B. Molay (Harvard), T. Kuo (UT-Austin), G. Pierre (Vrije), M. Matthews (SC), B. Knicki (WPI), M. Shacklette (UChicago), and J.Kim (KAIST).