Debugging (Part 2)

“Programming in the Large” Steps

Design & Implement

- Program & programming style (done)
- Common data structures and algorithms
- Modularity
- Building techniques & tools (done)

Test

- Testing techniques (done)

Debug

- Debugging techniques & tools <-- we are still here

Maintain

- Performance improvement techniques & tools

Goals of this Lecture

Help you learn about:

- Debugging strategies & tools related to **dynamic memory management (DMM)** *

Why?

- Many bugs occur in code that does DMM
- DMM errors can be difficult to find
  - DMM error in one area can manifest itself in a distant area
- A power programmer knows a wide variety of DMM debugging **strategies**
- A power programmer knows about **tools** that facilitate DMM debugging

* Management of heap memory via **`malloc()`**, **`calloc()`**, **`realloc()`**, and **`free()`**

Agenda

(9) Look for common DMM bugs

(10) Diagnose seg faults using gdb

(11) Manually inspect malloc calls

(12) Hard-code malloc calls

(13) Comment-out free calls

(14) Use Meminfo

(15) Use Valgrind

Look for Common DMM Bugs

Some of our favorites:

```
int *p; /* value of p undefined */
…
*p = somevalue;
```

```
char *p; /* value of p undefined */
…
fgets(p, 1024, stdin);
```

```
int *p;
…
p = (int*)malloc(sizeof(int));
…
*p = 5;
…
free(p);
…
*p = 6;
```

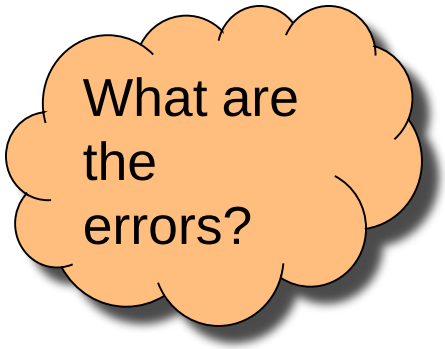
What are the errors?

Look for Common DMM Bugs

Some of our favorites:

```
int *p;
…
p = (int*)malloc(sizeof(int));
…
*p = 5;
…
p = (int*)malloc(sizeof(int));
```

```
int *p;
…
p = (int*)malloc(sizeof(int));
…
*p = 5;
…
free(p);
…
free(p);
```



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Diagnose Seg Faults Using GDB

Segmentation fault => make it happen in gdb

- Then issue the gdb **`where`** command
- Output will lead you to the line that caused the fault
  - But that line may not be where the error resides!

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Manually Inspect Malloc Calls

Manually inspect each call of **`malloc()`**

- Make sure it allocates enough memory

Do the same for **`calloc()`** and **`realloc()`**

Manually Inspect Malloc Calls

Some of our favorites:

```
char *s1 = "Hello";
char *s2;
s2 = (char*)malloc(strlen(s1));
strcpy(s2, s1);
```

```
char *s1 = "Hello";
char *s2;
s2 = (char*)malloc(sizeof(s1));
strcpy(s2, s1);
```

```
double *p;
p = (double*)malloc(sizeof(double*));
```

```
double *p;
p = (double*)malloc(sizeof(p));
```

What are the errors?

Agenda

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Hard-Code Malloc Calls

Temporarily change each call of **`malloc()`** to request a large number of bytes

- Say, 10000 bytes
- If the error disappears, then at least one of your calls is requesting too few bytes

Then incrementally restore each call of **`malloc()`** to its previous form

- When the error reappears, you might have found the culprit

Do the same for **`calloc()`** and **`realloc()`**

Agenda

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Comment-Out Free Calls

Temporarily comment-out every call of **`free()`**

- If the error disappears, then program is
  - Freeing memory too soon, or
  - Freeing memory that already has been freed, or
  - Freeing memory that should not be freed,
  - Etc.

Then incrementally "comment-in" each call of **`free()`**

- When the error reappears, you might have found the culprit

Agenda

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Use Meminfo

Use the **Meminfo** tool

- Simple tool
- Initial version written by Dondero
- Current version written by COS 217 alumnus RJ Liljestrom
- Reports errors **after** program execution
  - Memory leaks
  - Some memory corruption
- User-friendly output

Appendix 1 provides example buggy programs

Appendix 2 provides Meminfo analyses

Agenda

(9) Look for common DMM bugs

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(15) Use Valgrind

Use Valgrind

Use the **Valgrind** tool

- Complex tool
- Written by multiple developers, worldwide
  - See www.valgrind.org
- Reports errors **during** program execution
  - Memory leaks
  - Multiple frees
  - Dereferences of dangling pointers
  - Memory corruption
- Comprehensive output
  - But not always user-friendly

Use Valgrind

Valgrind is new to COS 217

- Let instructors know if helpful (or not)

Appendix 1 provides example buggy programs

Appendix 3 provides Valgrind analyses

Summary

Strategies and tools for debugging the DMM aspects of your code:

- Look for common DMM bugs
- Diagnose seg faults using gdb
- Manually inspect malloc calls
- Hard-code malloc calls
- Comment-out free calls
- Use Meminfo
- Use Valgrind

Appendix 1: Buggy Programs

leak.c

```
 1. #include <stdio.h>
 2. #include <stdlib.h>
 3. int main(void)
 4. {  int *pi;
 5.    pi = (int*)malloc(sizeof(int));
 6.    *pi = 5;
 7.    printf("%d\n", *pi);
 8.    pi = (int*)malloc(sizeof(int));
 9.    *pi = 6;
10.    printf("%d\n", *pi);
11.    free(pi);
12.    return 0;
13. }
```

Memory leak:

Memory allocated at line 5 is leaked

Appendix 1: Buggy Programs

doublefree.c

```
 1. #include <stdio.h>
 2. #include <stdlib.h>
 3. int main(void)
 4. {  int *pi;
 5.    pi = (int*)malloc(sizeof(int));
 6.    *pi = 5;
 7.    printf("%d\n", *pi);
 8.    free(pi);
 9.    free(pi);
10.    return 0;
11. }
```

Multiple free:

Memory allocated at line 5 is freed twice

Appendix 1: Buggy Programs

danglingptr.c

```
 1. #include <stdio.h>
 2. #include <stdlib.h>
 3. int main(void)
 4. {  int *pi;
 5.    pi = (int*)malloc(sizeof(int));
 6.    *pi = 5;
 7.    printf("%d\n", *pi);
 8.    free(pi);
 9.    printf("%d\n", *pi);
10.    return 0;
11. }
```

Dereference of dangling pointer:

Memory accessed at line 9 already was freed

Appendix 1: Buggy Programs

toosmall.c

```
 1. #include <stdio.h>
 2. #include <stdlib.h>
 3. int main(void)
 4. {  int *pi;
 5.    pi = (int*)malloc(1);
 6.    *pi = 5;
 7.    printf("%d\n", *pi);
 8.    free(pi);
 9.    return 0;
10. }
```

Memory corruption:

Too little memory is allocated at line 5

Line 6 corrupts memory

Appendix 2: Meminfo

Meminfo can detect memory leaks:

```
$ gcc217m leak.c -o leak
$ leak
5
6
$ ls
.  ..  leak.c  leak  meminfo30462.out
$ meminforeport meminfo30462.out
Errors:
   ** 4 un-freed bytes (1 block) allocated at leak.c:5
Summary Statistics:
   Maximum bytes allocated at once: 8
   Total number of allocated bytes: 8
Statistics by Line:
          Bytes   Location
             -4   leak.c:11
              4   leak.c:5
              4   leak.c:8
              4   TOTAL
Statistics by Compilation Unit:
              4   leak.c
              4   TOTAL
```

Appendix 2: Meminfo

Meminfo can detect memory corruption:

```
$ gcc217m toosmall.c -o toosmall
$ toosmall
5
$ ls
.  ..  toosmall.c  toosmall  meminfo31891.out
$ meminforeport meminfo31891.out
Errors:
   ** Underflow detected at toosmall.c:8 for memory allocated at toosmall.c:5
Summary Statistics:
   Maximum bytes allocated at once: 1
   Total number of allocated bytes: 1
Statistics by Line:
          Bytes   Location
              1   toosmall.c:5
             -1   toosmall.c:8
              0   TOTAL
Statistics by Compilation Unit:
              0   toosmall.c
              0   TOTAL
```

Appendix 2: Meminfo

Meminfo caveats:

- Don't mix .o files built with **`gcc217`** and **`gcc217m`**
- **`meminfo*.out`** files can be large
  - Should delete frequently
- Programs built with **`gcc217m`** run slower than those built with **`gcc217`**
  - Don't build with **`gcc217m`** when doing timing tests

Appendix 3: Valgrind

Valgrind can detect memory leaks:

```
$ gcc217v leak.c -o leak
$ valgrind leak
==31921== Memcheck, a memory error detector
==31921== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==31921== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==31921== Command: leak
==31921==
5
6
==31921==
==31921== HEAP SUMMARY:
==31921==     in use at exit: 4 bytes in 1 blocks
==31921==   total heap usage: 2 allocs, 1 frees, 8 bytes allocated
==31921==
==31921== LEAK SUMMARY:
==31921==    definitely lost: 4 bytes in 1 blocks
==31921==    indirectly lost: 0 bytes in 0 blocks
==31921==      possibly lost: 0 bytes in 0 blocks
==31921==    still reachable: 0 bytes in 0 blocks
==31921==         suppressed: 0 bytes in 0 blocks
==31921== Rerun with --leak-check=full to see details of leaked memory
==31921==
==31921== For counts of detected and suppressed errors, rerun with: -v
==31921== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 6 from 6)
```

Appendix 3: Valgrind

Valgrind can detect memory leaks:

```
$ valgrind --leak-check=full leak
==476== Memcheck, a memory error detector
==476== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==476== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==476== Command: leak
==476==
5
6
==476==
==476== HEAP SUMMARY:
==476==     in use at exit: 4 bytes in 1 blocks
==476==   total heap usage: 2 allocs, 1 frees, 8 bytes allocated
==476==
==476== 4 bytes in 1 blocks are definitely lost in loss record 1 of 1
==476==    at 0x4A069EE: malloc (vg_replace_malloc.c:270)
==476==    by 0x400565: main (leak.c:5)
==476==
==476== LEAK SUMMARY:
==476==    definitely lost: 4 bytes in 1 blocks
==476==    indirectly lost: 0 bytes in 0 blocks
==476==      possibly lost: 0 bytes in 0 blocks
==476==    still reachable: 0 bytes in 0 blocks
==476==         suppressed: 0 bytes in 0 blocks
==476==
==476== For counts of detected and suppressed errors, rerun with: -v
==476== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 6 from 6)
```

Appendix 3: Valgrind

Valgrind can detect multiple frees:

```
$ gcc217v doublefree.c -o doublefree
$ valgrind doublefree
==31951== Memcheck, a memory error detector
==31951== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==31951== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==31951== Command: doublefree
==31951==
5
==31951== Invalid free() / delete / delete[] / realloc()
==31951==    at 0x4A063F0: free (vg_replace_malloc.c:446)
==31951==    by 0x4005A5: main (doublefree.c:9)
==31951==  Address 0x4c2a040 is 0 bytes inside a block of size 4 free'd
==31951==    at 0x4A063F0: free (vg_replace_malloc.c:446)
==31951==    by 0x400599: main (doublefree.c:8)
==31951==
==31951==
==31951== HEAP SUMMARY:
==31951==     in use at exit: 0 bytes in 0 blocks
==31951==   total heap usage: 1 allocs, 2 frees, 4 bytes allocated
==31951==
==31951== All heap blocks were freed -- no leaks are possible
==31951==
==31951== For counts of detected and suppressed errors, rerun with: -v
==31951== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 6 from 6)
```

Appendix 3: Valgrind

Valgrind can detect dereferences of dangling pointers:

```
$ gcc217v danglingptr.c -o danglingptr
$ valgrind danglingptr
==336== Memcheck, a memory error detector
==336== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==336== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==336== Command: danglingptr
==336==
5
==336== Invalid read of size 4
==336==    at 0x40059E: main (danglingptr.c:9)
==336==  Address 0x4c2a040 is 0 bytes inside a block of size 4 free'd
==336==    at 0x4A063F0: free (vg_replace_malloc.c:446)
==336==    by 0x400599: main (danglingptr.c:8)
==336==
5
==336==
==336== HEAP SUMMARY:
==336==     in use at exit: 0 bytes in 0 blocks
==336==   total heap usage: 1 allocs, 1 frees, 4 bytes allocated
==336==
==336== All heap blocks were freed -- no leaks are possible
==336==
==336== For counts of detected and suppressed errors, rerun with: -v
==336== ERROR SUMMARY: 1 errors from 1 contexts (suppressed: 6 from 6)
```

Appendix 3: Valgrind

Valgrind can detect memory corruption:

```
$ gcc217v toosmall.c -o toosmall
$ valgrind toosmall
==436== Memcheck, a memory error detector
==436== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==436== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==436== Command: toosmall
==436==
==436== Invalid write of size 4
==436==    at 0x40056E: main (toosmall.c:6)
==436==  Address 0x4c2a040 is 0 bytes inside a block of size 1 alloc'd
==436==    at 0x4A069EE: malloc (vg_replace_malloc.c:270)
==436==    by 0x400565: main (toosmall.c:5)
==436==
==436== Invalid read of size 4
==436==    at 0x400578: main (toosmall.c:7)
==436==  Address 0x4c2a040 is 0 bytes inside a block of size 1 alloc'd
==436==    at 0x4A069EE: malloc (vg_replace_malloc.c:270)
==436==    by 0x400565: main (toosmall.c:5)
==436==
5
```

Continued on next slide

Appendix 3: Valgrind

Valgrind can detect memory corruption (cont.):

Continued from previous slide

```
==436==
==436== HEAP SUMMARY:
==436==     in use at exit: 0 bytes in 0 blocks
==436==   total heap usage: 1 allocs, 1 frees, 1 bytes allocated
==436==
==436== All heap blocks were freed -- no leaks are possible
==436==
==436== For counts of detected and suppressed errors, rerun with: -v
==436== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 6 from 6)
```

Appendix 3: Valgrind

Valgrind caveats:

- Don't mix .o files built with **`gcc217`** and **`gcc217v`**
- Not intended for programmers who are new to C
  - Messages may be cryptic
- Suggestion:
  - Observe line numbers referenced by messages
  - Study code at those lines
  - Infer meanings of messages