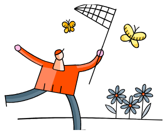
Debugging (Part 2)



"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);
```

What are the errors?

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

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!

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

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

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

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

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

What are the errors?

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

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

(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

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

(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

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

(10) Diagnose seg faults using gdb

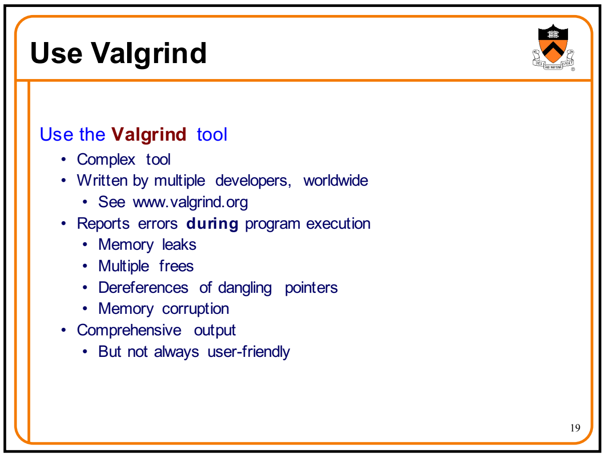
(11) Manually inspect malloc calls

(12) Hard-code malloc calls

(13) Comment-out free calls

(14) Use Meminfo

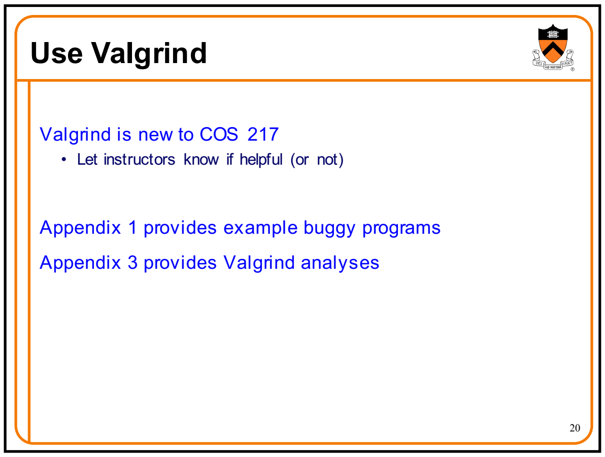
(15) Use Valgrind



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



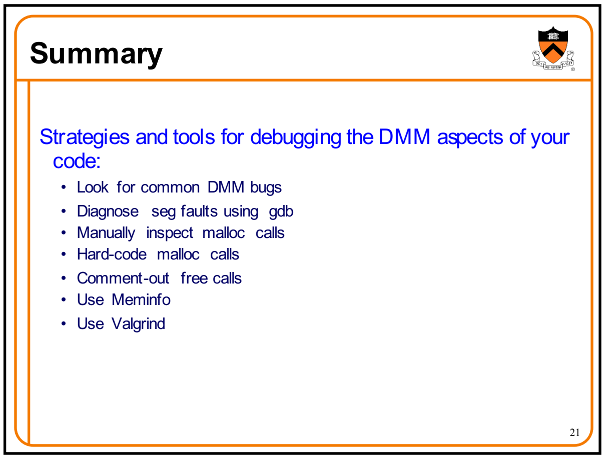
Use Valgrind

Valgrind is new to COS 217

- Let instructors know if helpful (or not)

Appendix 1 provides example buggy programs

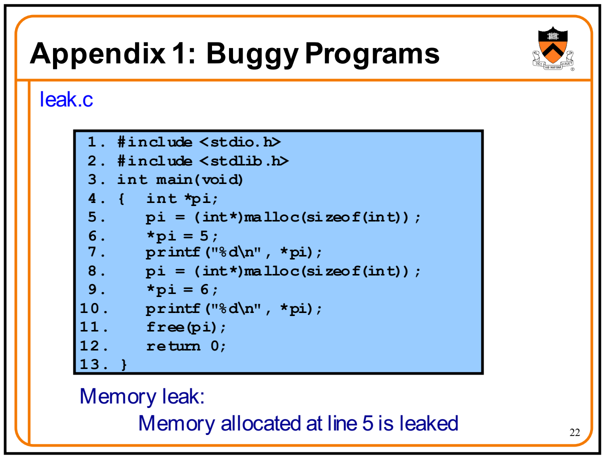
Appendix 3 provides Valgrind analyses



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



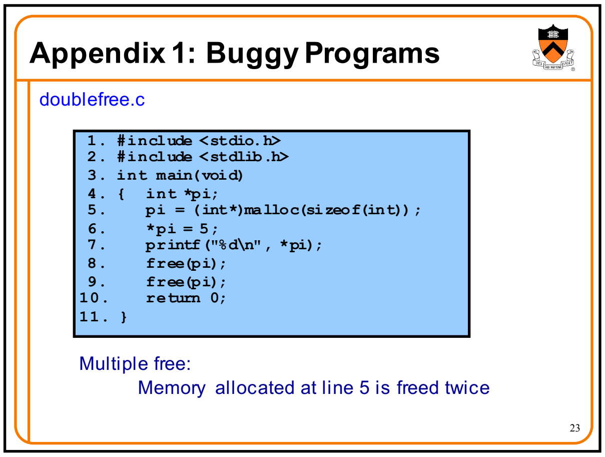
Appendix 1: Buggy Programs

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



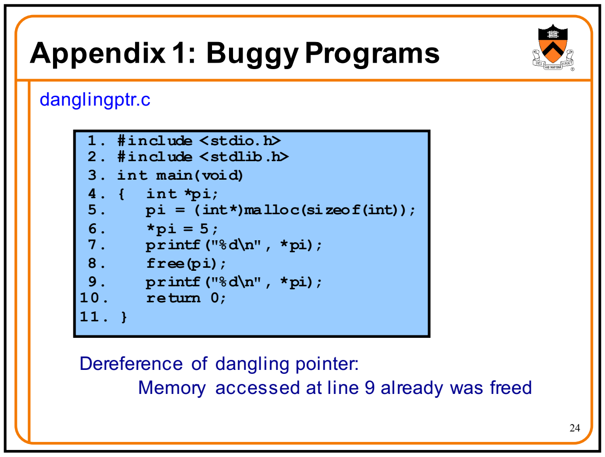
Appendix 1: Buggy Programs

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:

```
$ gcc217  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)
```

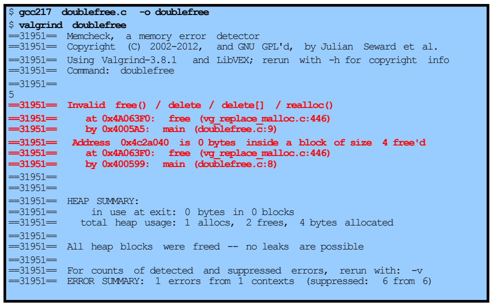
Appendix 3: Valgrind

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

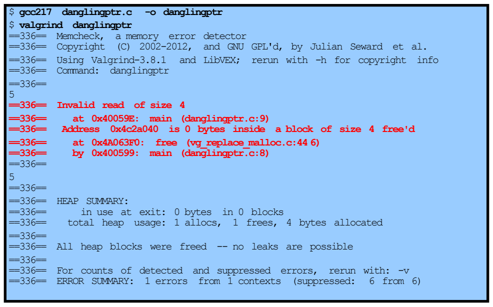
Valgrind can detect multiple frees:



```
$ gcc217  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

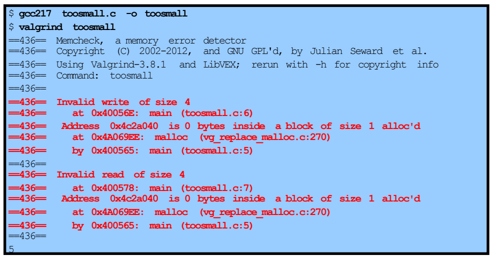
Valgrind can detect dereferences of dangling pointers:



```
$ gcc217  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:44 6)
==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:



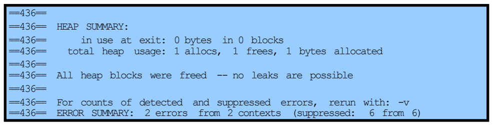
```
$ gcc217  toosmall.c  -o  toosmall
$ valgrind  toosmall
==436==  Memcheck,  a memory  error  detector
==436==  Copyright  (C)  2002-2012,  and GNU  GPL'd,  by  Julian  Seward  et al.
==436==  Using Valgrind-3.8.1  and LibVEX;  rerun  with  -h  for  copyright  info
==436==  Command:  toosmall
==436==
==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:

- 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