Debugging

The material for this lecture is drawn, in part, from
The Practice of Programming (Kernighan & Pike) Chapter 5

Goals of this Lecture

- Help you learn about:
  - Strategies and tools for debugging your code

- Why?
  - Debugging large programs can be difficult
  - A power programmer knows a wide variety of debugging **strategies**
  - A power programmer knows about **tools** that facilitate debugging
    - Debuggers
    - Version control systems

Testing vs. Debugging

- Testing
  - What should I do to try to **break** my program?
- Debugging
  - What should I do to try to **fix** my program?

Debugging Heuristics

Debugging Heuristic	**When Applicable**
(1) Understand error messages	Build-time
(2) Think before writing	Run-time
(3) Look for familiar bugs	
(4) Divide and conquer	
(5) Add more internal tests	
(6) Display output	
(7) Use a debugger	
(8) Focus on recent changes	

Understand Error Messages

Debugging at **build-time** is easier than debugging at **run-time**, if and only if you…

(1) Understand the error messages!!!

```
#include <stdioo.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0.
{
   printf("hello, world\n");
   return 0;
}
```

What are the error(s)? (No fair looking at the next slide!)

Understand Error Messages (cont.)

(1) Understand the error messages (cont.)

```
#include <stdioo.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0.
{
   printf("hello, world\n");
   return 0;
}
```

Which tool (preprocessor, compiler, or linker) reports the error(s)?

```
$ gcc209 hello.c -o hello
hello.c:1:20: stdioo.h: No such file or directory
hello.c:3:1: unterminated comment
hello.c:2: error: syntax error at end of input
```

Understand Error Messages (cont.)

(1) Understand the error messages (cont.)

```
#include <stdio.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0. */
{
   printf("hello, world\n")
   retun 0;
}
```

What are the error(s)? (No fair looking at the next slide!)

Understand Error Messages (cont.)

(1) Understand the error messages (cont.)

```
#include <stdio.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0. */
{
   printf("hello, world\n")
   retun 0;
}
```

Which tool (preprocessor, compiler, or linker) reports the error(s)?

```
$ gcc209 hello.c -o hello
hello.c: In function `main':
hello.c:7: error: `retun' undeclared (first use in this
function)
hello.c:7: error: (Each undeclared identifier is reported
only once
hello.c:7: error: for each function it appears in.)
hello.c:7: error: syntax error before numeric constant
```

Understand Error Messages (cont.)

(1) Understand error messages (cont.)

```
#include <stdio.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0. */
{
   prinf("hello, world\n")
   return 0;
}
```

What are the error(s)? (No fair looking at the next slide!)

Understand Error Messages (cont.)

(1) Understand error messages (cont.)

```
#include <stdio.h>
int main(void)
/* Print "hello, world" to stdout and
   return 0. */
{
   prinf("hello, world\n")
   return 0;
}
```

```
$ gcc209 hello.c -o hello
hello.c: In function `main':
hello.c:6: warning: implicit declaration of function
`prinf'
/tmp/cc43ebjk.o(.text+0x25): In function `main':
: undefined reference to `prinf'
collect2: ld returned 1 exit status
```

Which tool (preprocessor, compiler, or linker) reports the error(s)?

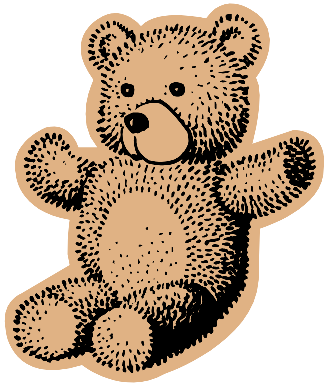
Think Before Writing

Inappropriate changes could make matters worse, so…

(2) Think before writing
- Draw pictures of the data structures

- Take a break
  - Sleep on it!
  - Start early so you can!!!

- Explain the code to:
  - Yourself
  - Someone else
  - A teddy bear!
  - A giant wookie!!!



Look for Familiar Bugs

(3) Look for familiar bugs

– Some of our favorites:

```
switch (i) {
   case 0:
      …
      break;
   case 1:
      …
   case 2:
      …
}
```

```
if (i = 5)
   …
```

```
if (5 < i < 10)
   …
```

```
int i;
…
scanf("%d", i);
```

```
char c;
…
c = getchar();
```

```
while (c = getchar() != EOF)
   …
```

```
if (i & j)
   …
```

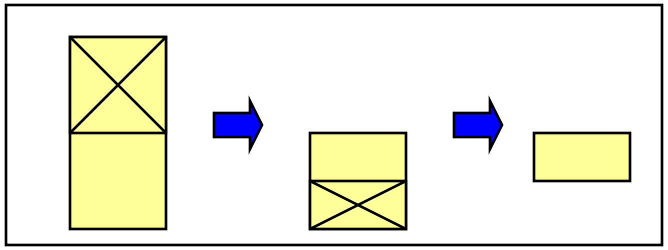
What are the errors?

Divide and Conquer

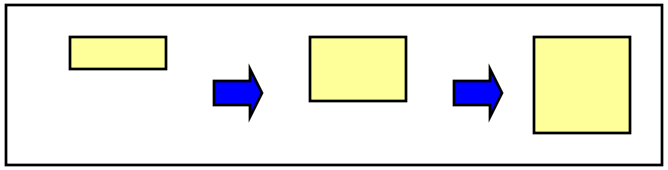
(4) Divide and conquer

- Incrementally find smallest/simplest **input** that illustrates the bug
- Example: Program fails on large input file *filex*

- Approach 1: **Remove** input
  - Start with *filex*
  - Incrementally remove lines of *filex* until bug disappears
    - Maybe in "binary search" fashion



- Approach 2: **Add** input
  - Start with small subset of *filex*
  - Incrementally add lines of *filex* until bug appears



Divide and Conquer (cont.)

(4) Divide and conquer (cont.)

- Incrementally find smallest **code subset** that illustrates the bug
- Example: Test client for your module fails

- Approach 1: **Remove** code
  - Start with test client
  - Incrementally remove lines of test client until bug disappears

- Approach 2: **Add** code
  - Start with minimal client
  - Incrementally add lines of test client until bug appears

Add More Internal Tests

(5) Add more internal tests

- Internal tests help **find** bugs (see "Testing" lecture)
- Internal test also can help **eliminate** bugs
  - Checking invariants and conservation properties can eliminate some functions from the bug hunt

Display Output

(6) Display output

- Print values of important variables at critical spots
- Poor:

```
printf("%d", keyvariable);
```

stdout is buffered; program may crash before output appears

- Maybe better:

```
printf("%d\n", keyvariable);
```

Printing **'\n'** flushes the **stdout** buffer, but not if stdout is redirected to a file

- Better:

```
printf("%d", keyvariable);
fflush(stdout);
```

Call **fflush()** to flush **stdout** buffer explicitly

Display Output (cont.)

(6) Display output (cont.)

– Maybe even better:

```
fprintf(stderr, "%d", keyvariable);
```

– Maybe better still:

```
FILE *fp = fopen("logfile", "w");
…
fprintf(fp, "%d", keyvariable);
fflush(fp);
```

Write debugging output to **stderr**; debugging output can be separated from normal output via redirection

Bonus: **stderr** is unbuffered

Write to a log file

Use a Debugger

(7) Use a debugger

- Alternative to displaying output
- Bonuses:
  - Debugger can load “core dumps”
    - Examine state of program when it terminated
  - Debugger can “attach” to a running program

The GDB Debugger

- **G**NU **D**e**b**ugger
  - Part of the GNU development environment
  - Integrated with Emacs editor
  - Allows user to:
    - Run program
    - Set breakpoints
    - Step through code one line at a time
    - Examine values of variables during run
    - Etc.

- See Appendix 1 for details

Focus on Recent Changes

(8) Focus on recent changes

- Corollary: Debug now, not later

Difficult:

(1) Write entire program
(2) Test entire program
(3) Debug entire program

Easier:

(1) Write a little
(2) Test a little
(3) Debug a little
(4) Write a little
(5) Test a little
(6) Debug a little
…

Focus on Recent Changes (cont.)

(8) Focus on recent change (cont.)

- Corollary: Maintain old versions

Difficult:

(1) Change code
(2) Note bug
(3) Try to remember what changed since last working version!!!

Easier:

(1) Backup working version
(2) Change code
(3) Note bug
(4) Compare code with working version to determine what changed

Maintaining Previous Versions

- To maintain old versions
  - Approach 1: Manually copy project directory

```
…
$ mkdir myproject
$ cd myproject

   Create project files here.

$ cd ..
$ cp -r myproject myprojectDateTime
$ cd myproject

   Continue creating project files here.
…
```

    - Repeat occasionally
  - Approach 2: Use RCS

RCS

- **R**evision **C**ontrol **S**ystem
  - A simple personal version control system
  - Provided with many Linux distributions
    - Available on hats
  - Allows developer to:
    - Create a **source code repository**
    - **Check** source code files **into** repository
      - RCS saves old versions
    - **Check** source code files **out of** repository
  - Appropriate for **one-developer** projects
  - **Not** appropriate for **multi-developer** projects
    - Use **CVS** or **Subversion** instead
- See Appendix 2 for details

Summary

Debugging Heuristic	When Applicable
(1) Understand error messages	Build-time
(2) Think before writing	Run-time
(3) Look for familiar bugs	
(4) Divide and conquer	
(5) Add more internal tests	
(6) Display output	
(7) Use a debugger *	
(8) Focus on recent changes **	

* Use GDB

** Use RCS

Appendix 1: Using GDB

- An example program

File testintmath.c:

```
#include <stdio.h>

int gcd(int i, int j) {
   int temp;
   while (j != 0) {
      temp = i % j;
      i = j;
      j = temp;
   }
   return i;
}

int lcm(int i, int j) {
   return (i / gcd(i, j)) * j;
}
…
```

```
…
int main(void) {
   int iGcd;
   int iLcm;
   iGcd = gcd(8, 12);
   iLcm = lcm(8, 12);
   printf("%d %d\n", iGcd, iLcm);
   return 0;
}
```

Euclid's algorithm; Don't be concerned with details

The program is correct

But let's pretend it has a runtime error in **gcd()**…

Appendix 1: Using GDB (cont.)

- General GDB strategy:
  - Execute the program to the point of interest
    - Use breakpoints and stepping to do that
  - Examine the values of variables at that point

Appendix 1: Using GDB (cont.)

- Typical steps for using GDB:

(a) Build with –g

```
gcc209 -g testintmath.c –o testintmath
```

– Adds extra information to executable file that GDB uses

(b) Run Emacs, with no arguments

```
emacs
```

(c) Run GDB on executable file from within Emacs

```
<Esc key> x gdb <Enter key> testintmath <Enter key>
```

(d) Set breakpoints, as desired

```
break main
```

– GDB sets a breakpoint at the first executable line of main()

```
break gcd
```

– GDB sets a breakpoint at the first executable line of gcd()

Appendix 1: Using GDB (cont.)

- Typical steps for using GDB (cont.):

  (e) Run the program

  `run`
  - GDB stops at the breakpoint in main()
  - Emacs opens window showing source code
  - Emacs highlights line that is to be executed next

  `continue`
  - GDB stops at the breakpoint in gcd()
  - Emacs highlights line that is to be executed next

  (f) Step through the program, as desired

  `step` (repeatedly)
  - GDB executes the next line (repeatedly)

  - Note: When next line is a call of one of your functions:
    - **`step`** command *steps into* the function
    - **`next`** command *steps over* the function, that is, executes the next line without stepping into the function

Appendix 1: Using GDB (cont.)

- Typical steps for using GDB (cont.):

  (g) Examine variables, as desired

  ```
  print i
  print j
  print temp
  ```

  – GDB prints the value of each variable

  (h) Examine the function call stack, if desired

  ```
  where
  ```

  – GBB prints the function call stack

  – Useful for diagnosing crash in large program

  (i) Exit gdb

  ```
  quit
  ```

  (j) Exit Emacs

  ```
  <Ctrl-x key> <Ctrl-c key>
  ```

Appendix 1: Using GDB (cont.)

- GDB can do much more:
  - Handle command-line arguments

```
run arg1 arg2
```

  - Handle redirection of stdin, stdout, stderr

```
run < somefile > someotherfile
```

  - Print values of expressions
  - Break conditionally
  - Etc.
- See *Programming with GNU Software* (Loukides and Oram) Chapter 6

Appendix 2: Using RCS

- Typical steps for using RCS:

  (a) Create project directory, as usual

  ```
  mkdir helloproj
  cd helloproj
  ```

  (b) Create RCS directory in project directory

  ```
  mkdir RCS
  ```

  – RCS will store its repository in that directory

  (c) Create source code files in project directory

  ```
  emacs hello.c …
  ```

  (d) Check in

  ```
  ci hello.c
  ```

  – Adds file to RCS repository
  – Deletes local copy (don't panic!)
  – Can provide description of file (1st time)
  – Can provide log message, typically describing changes

Appendix 2: Using RCS (cont.)

- Typical steps for using RCS (cont.):

  (e) Check out most recent version for reading

  ```
  co hello.c
  ```

  - Copies file from repository to project directory
  - File in project directory has read-only permissions

  (f) Check out most recent version for reading/writing

  ```
  co –l hello.c
  ```

  - Copies file from repository to project directory
  - File in project directory has read/write permissions

  (g) List versions in repository

  ```
  rlog hello.c
  ```

  - Shows versions of file, by number (1.1, 1.2, etc.), with descriptions

  (h) Check out a specified version

  `co –l –r`*`versionnumber`*` hello.c`

Appendix 2: Using RCS (cont.)

- RCS can do much more:
  - Merge versions of files
  - Maintain distinct development branches
  - Place descriptions in code as comments
  - Assign symbolic names to versions
  - Etc.
- See *Programming with GNU Software* (Loukides and Oram) Chapter 8

- Recommendation: Use RCS
  - **`ci`** and **`co`** can become automatic!

Appendix 3: Debugging Mem Mgmt

- Some debugging techniques are specific to **dynamic memory management**
  - That is, to memory managed by **`malloc()`**, **`calloc()`**, **`realloc()`**, and **`free()`**

- Soon will be pertinent in the course

- For future reference…

Appendix 3: Debugging Mem Mgmt (cont.)

(9) Look for familiar dynamic memory management bugs

- Some of our favorites:

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

Dangling pointer

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

Dangling pointer

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

Dangling pointer

Appendix 3: Debugging Mem Mgmt (cont.)

(9) Look for familiar dynamic memory management bugs (cont.)

- Some of our favorites (cont.):

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

Memory leak
alias
Garbage creation

Detection: Valgrind, etc.

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

Multiple free

*Detection: man malloc, MALLOC_CHECK_*

Appendix 3: Debugging Mem Mgmt (cont.)

(9) Look for familiar dynamic memory management bugs (cont.)

- Some of our favorites (cont.):

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

Allocating too few bytes

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

Allocating too few bytes

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

Allocating too few bytes

Appendix 3: Debugging Mem Mgmt (cont.)

(10) Segmentation fault? Make it happen within gdb, and then issue the gdb **`where`** command. The output will lead you to the line that caused the fault. (But that line may not be where the error resides.)

(11) Manually inspect each call of malloc(), calloc(), and realloc() in your code, making sure that it allocates enough memory.

(12) Temporarily hardcode each call of malloc(), calloc(), and realloc() such that it requests a large number of bytes. If the error disappears, then you'll know that at least one of your calls is requesting too few bytes.

Appendix 3: Debugging Mem Mgmt (cont.)

(13) Temporarily comment-out each call of free() in your code. If the error disappears, then you'll know that you're freeing memory too soon, or freeing memory that already has been freed, or freeing memory that should not be freed, etc.