Princeton University
Computer Science 217: Introduction to Programming Systems

Building

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Goals of this Lecture

Help you learn about:
- The build process for multi-file programs
- Partial builds of multi-file programs
- **make**, a popular tool for automating (partial) builds

Why?
- A complete build of a large multi-file program typically consumes many hours
- To save build time, a power programmer knows how to do partial builds
- A power programmer knows how to automate (partial) builds using **make**

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Review: Multi-File Programs

intmath.h (interface)

```
#ifndef INTMATH_INCLUDED
#define INTMATH_INCLUDED
int gcd(int i, int j);
int lcm(int i, int j);
#endif
```

intmath.c (implementation)

```
#include "intmath.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;
}
```

testintmath.c (client)

```
#include "intmath.h"
#include <stdio.h>

int main(void)
{  int i;
   int j;
   printf("Enter the first integer:\n");
   scanf("%d", &i);
   printf("Enter the second integer:\n");
   scanf("%d", &j);
   printf("Greatest common divisor: %d.\n",
      gcd(i, j));
   printf("Least common multiple: %d.\n",
      lcm(i, j);
   return 0;
}
```

Note: intmath.h is #included into intmath.c and testintmath.c

See precept handouts for stylistically better version

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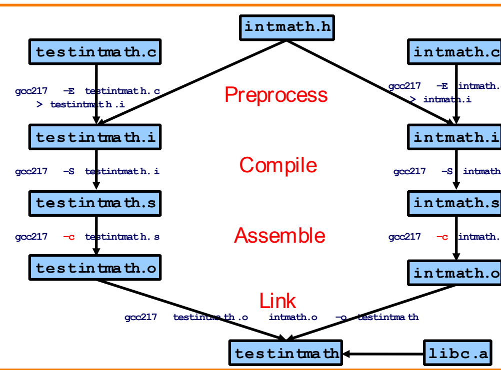
Review: Multi-File Programs



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Agenda

Motivation for Make

Make Fundamentals

Non-File Targets

Macros

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Pattern Rules

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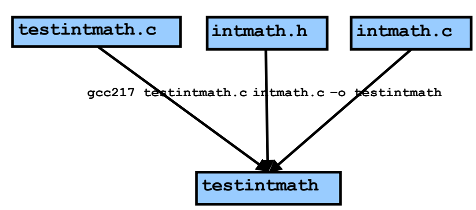
Motivation for Make (Part 1)

Building `testintmath`, approach 1:
- Use one `gcc217` command to preprocess, compile, assemble, and link



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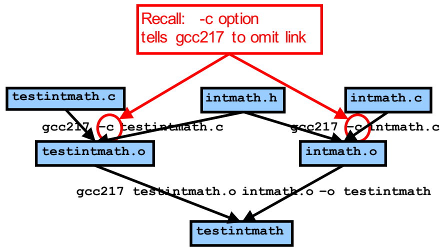
Motivation for Make (Part 2)

Building **testintmath**, approach 2:

- Preprocess, compile, assemble to produce .o files
- Link to produce executable binary file



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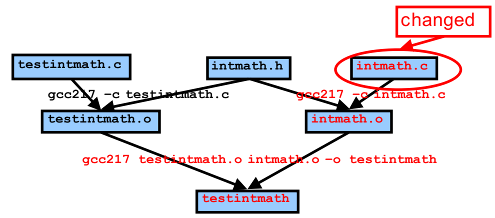
Partial Builds

Approach 2 allows for **partial builds**

- Example: Change **intmath.c**
  - Must rebuild **intmath.o** and **testintmath**
  - Need not rebuild **testintmath.o**!!!



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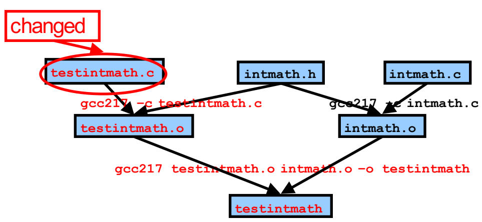
Partial Builds

- Example: Change **testintmath.c**
  - Must rebuild **testintmath.o** and **testintmath**
  - Need not rebuild **intmath.o**!!!

If program contains many .c files, could save many hours of build time



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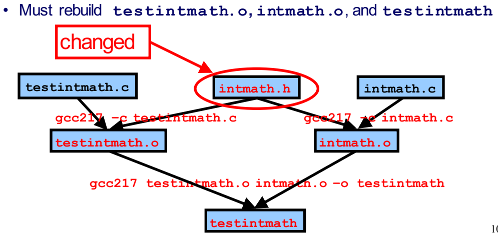
Partial Builds

However, changing a .h file can be more dramatic

- Example: Change **intmath.h**
  - **intmath.h** is #included into **testintmath.c** and **intmath.c**
    - Changing **intmath.h** effectively changes **testintmath.c** and **intmath.c**
  - Must rebuild **testintmath.o**, **intmath.o**, and **testintmath**



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Wouldn't It Be Nice…

Observation

- Doing partial builds manually is tedious and error-prone
- Wouldn't it be nice if there were a tool

How would the tool work?

- Input:
  - Dependency graph (as shown previously)
    - Specifies file dependencies
    - Specifies commands to build each file from its dependents
  - Date/time stamps of files
- Algorithm:
  - If file B depends on A and date/time stamp of A is newer than date/time stamp of B, then rebuild B using the specified command

That's **make**!

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Pattern Rules

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The Make Tool

Who? Stuart Feldman '68

When? 1976

Where? Bell Labs

Why? Automate partial builds

(This is Stu Feldman recently; in 1976 he looked younger)

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Make Command Syntax

Command syntax

```
make [-f makefile] [target]
```

- ***makefile***
  - Textual representation of dependency graph
  - Contains **dependency rules**
  - Default name is **makefile**, then **Makefile**
- ***target***
  - What **make** should build
  - Usually: .o file, or an executable binary file
  - Default is first one defined in ***makefile***

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Dependency Rules

Dependency rule syntax

```
target: dependencies
    <tab>command
```

- ***target***: the file you want to build
- ***dependencies***: the files on which the target depends
- ***command***: what to execute to create the target (after a TAB character)

Dependency rule semantics

- Build ***target*** iff it is older than any of its ***dependencies***
- Use ***command*** to do the build

Work recursively; examples illustrate…

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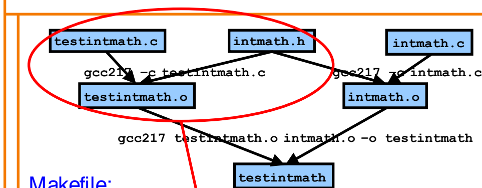
Makefile Version 1



Makefile:

```
testintmath: testintmath.o intmath.o
  gcc217 testintmath.o intmath.o –o testintmath

testintmath.o: testintmath.c intmath.h
  gcc217 -c testintmath.c

intmath.o: intmath.c intmath.h
  gcc217 -c intmath.c
```

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Version 1 in Action

At first, to build testintmath make issues all three gcc commands

Use the touch command to change the date/time stamp of intmath.c

```
$ make testintmath
gcc217 -c testintmath.c
gcc217 -c intmath.c
gcc217 testintmath.o intmath.o -o testintmath

$ touch intmath.c

$ make testintmath
gcc217 -c intmath.c
gcc217 testintmath.o intmath.o -o testintmath

$ make testintmath
make: `testintmath' is up to date.

$ make
make: `testintmath' is up to date.
```

make does a partial build

make notes that the specified target is up to date

The default target is testintmath, the target of the first dependency rule

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Non-File Targets

Adding useful shortcuts for the programmer

- **make all**: create the final executable binary file
- **make clean**: delete all .o files, executable binary file
- **make clobber**: delete all Emacs backup files, all .o files, executable binary file

Commands in the example

- **rm –f**: remove files without querying the user
- Files ending in '~' and starting/ending in '#' are Emacs backup files

```
all: testintmath
clobber: clean
  rm -f *~ \#*\#
clean:
  rm -f testintmath *.o
```

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Makefile Version 2

```
# Dependency rules for non-file targets
all: testintmath
clobber: clean
  rm -f *~ \#*\#
clean:
  rm -f testintmath *.o

# Dependency rules for file targets
testintmath: testintmath.o intmath.o
  gcc217 testintmath.o intmath.o –o testintmath
testintmath.o: testintmath.c intmath.h
  gcc217 -c testintmath.c
intmath.o: intmath.c intmath.h
  gcc217 -c intmath.c
```

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Version 2 in Action

make observes that "clean" target doesn't exist; attempts to build it by issuing "rm" command

Same idea here, but "clobber" depends upon "clean"

```
$ make clean
rm -f testintmath *.o

$ make clobber
rm -f testintmath *.o
rm -f *~ \#*\#

$ make all
gcc217 -c testintmath.c
gcc217 -c intmath.c
gcc217 testintmath.o intmath.o -o testintmath

$ make
make: Nothing to be done for `all'.
```

"all" depends upon "testintmath"

"all" is the default target

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Macros

make has a macro facility

- Performs textual substitution
- Similar to C preprocessor's **#define**

Macro definition syntax

macroname = *macrodefinition*

- **make** replaces *$(macroname)* with *macrodefinition* in remainder of Makefile

Example: Make it easy to change build commands

```
CC = gcc217
```

Example: Make it easy to change build flags

```
CFLAGS = -D NDEBUG –O
```

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Makefile Version 3

```
# Macros
CC = gcc217
# CC = gcc217m
CFLAGS =
# CFLAGS = -g
# CFLAGS = -D NDEBUG
# CFLAGS = -D NDEBUG -O

# Dependency rules for non-file targets
all: testintmath
clobber: clean
  rm -f *~ \#*\#
clean:
  rm -f testintmath *.o

# Dependency rules for file targets
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) testintmath.o intmath.o -o testintmath
testintmath.o: testintmath.c intmath.h
  $(CC) $(CFLAGS) -c testintmath.c
intmath.o: intmath.c intmath.h
  $(CC) $(CFLAGS) -c intmath.c
```

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Version 3 in Action

Same as Version 2

Agenda

Motivation for Make

Make Fundamentals

Non-File Targets

Macros

Abbreviations

Pattern Rules

Abbreviations

Abbreviations

- Target file: $@
- First item in the dependency list: $<

Example

```
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) testintmath.o intmath.o -o testintmath
```

```
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
```


Makefile Version 4

```
# Macros
CC = gcc217
# CC = gcc217m
CFLAGS =
# CFLAGS = -g
# CFLAGS = -D NDEBUG
# CFLAGS = -D NDEBUG -O

# Dependency rules for non-file targets
all: testintmath
clobber: clean
  rm -f *~ \#*\#
clean:
  rm -f testintmath *.o

# Dependency rules for file targets
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: testintmath.c intmath.h
  $(CC) $(CFLAGS) -c $<
intmath.o: intmath.c intmath.h
  $(CC) $(CFLAGS) -c $<
```


Version 4 in Action

Same as Version 2

Agenda

Motivation for Make

Make Fundamentals

Non-File Targets

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Pattern Rules

Pattern Rules

Pattern rule

- Wildcard version of dependency rule
- Example:

```
%.o: %.c
  $(CC) $(CFLAGS) -c $<
```

  - Translation: To build a .o file from a .c file of the same name, use the command `$(CC) $(CFLAGS) -c $<`
- With pattern rule, dependency rules become simpler:

```
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: testintmath.c intmath.h
intmath.o: intmath.c intmath.h
```

Can omit build command

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Pattern Rules Bonus

Bonus with pattern rules

- First dependency is assumed

```
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: testintmath.c intmath.h
intmath.o: intmath.c intmath.h
```

```
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: intmath.h
intmath.o: intmath.h
```

Can omit first dependency

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Makefile Version 5

```
# Macros
CC = gcc217
# CC = gcc217m
CFLAGS =
# CFLAGS = -g
# CFLAGS = -D NDEBUG
# CFLAGS = -D NDEBUG -O

# Pattern rule
%.o: %.c
  $(CC) $(CFLAGS) -c $<

# Dependency rules for non-file targets
all: testintmath
clobber: clean
  rm -f *~ \#*\#
clean:
  rm -f testintmath *.o

# Dependency rules for file targets
testintmath: testintmath.o intmath.o
  $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: intmath.h
intmath.o: intmath.h
```

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Version 5 in Action

Same as Version 2

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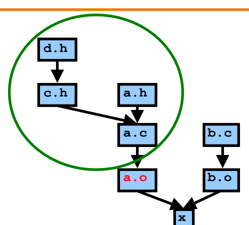
Makefile Guidelines




```
a.o: a.c a.h c.h d.h
  gcc217 -c a.c
```

In a proper Makefile, each object file:

- Depends upon its .c file
  - Does not depend upon any other .c file
  - Does not depend upon any .o file
- Depends upon any .h file that its .c file #includes **directly or indirectly**

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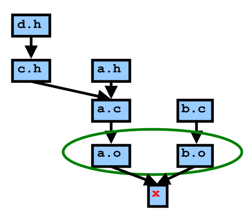
Makefile Guidelines




```
x: a.o b.o
  gcc217 a.o b.o -o x
```

In a proper Makefile, each executable binary file:

- Depends upon the .o files that comprise it
- Does not depend upon any .c files
- Does not depend upon any .h files

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Making Makefiles

In this course

- Create Makefiles manually

Beyond this course

- Can use tools to generate Makefiles
  - See **mkmf**, others

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Makefile Gotchas

Beware:

- Each command (i.e., second line of each dependency rule) must begin with a tab character, not spaces
- Use the **rm -f** command with caution

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Make Resources

C Programming: A Modern Approach (King) Section 15.4

GNU make

- http://www.gnu.org/software/make/manual/make.html

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Summary

Motivation for Make

- Automation of partial builds

Make fundamentals (Makefile version 1)

- Dependency rules, targets, dependencies, commands

Non-file targets (Makefile version 2)

Macros (Makefile version 3)

Abbreviations (Makefile version 4)

Pattern rules (Makefile version 5)

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Princeton University

Computer Science 217: Introduction to Programming Systems

Debugging (Part 1)

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

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For Your Amusement

"When debugging, novices insert corrective code; experts remove defective code."

– Richard Pattis

"If debugging is the act of removing errors from code, what's programming?"

– Tom Gilb

"Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it."

– Brian Kernighan

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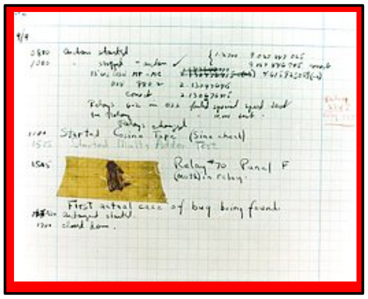
For Your Amusement



The first computer bug
(found in the Harvard Mark II computer)

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"Programming in the Large" Steps

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

Test
- Testing techniques (done)

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

Maintain
- Performance improvement techniques & tools

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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

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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?

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Agenda

(1) Understand error messages

(2) Think before writing

(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

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Understand Error Messages

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

Understand the error messages!

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

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

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Understand Error Messages

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

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

```
$ gcc217 hello.c -o hello
hello.c:1:20: error: stdioo.h: No such file or
directory
hello.c:2:1: error: unterminated comment
hello.c:7: warning: ISO C forbids an empty
translation unit
```

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Understand Error Messages

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

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

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Understand Error Messages

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

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

```
$ gcc217 hello.c -o hello
hello.c: In function 'main':
hello.c:6: error: expected ';' before 'return'
```

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Understand Error Messages

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

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

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Understand Error Messages

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

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

```
$ gcc217 hello.c -o hello
hello.c: In function 'main':
hello.c:5: warning: implicit declaration of function
'prinf'
/tmp/ccLSPMTR.o: In function `main':
hello.c:(.text+0x1a): undefined reference to `prinf'
collect2: ld returned 1 exit status
```

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Understand Error Messages

```
#include <stdio.h>
#include <stdlib.h>
enum StateType
{  STATE_REGULAR,
   STATE_INWORD
}
int main(void)
{  printf("just hanging around\n");
   return EXIT_SUCCESS;
}
```

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

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Understand Error Messages

```
#include <stdio.h>
#include <stdlib.h>
enum StateType
{  STATE_REGULAR,
   STATE_INWORD
}
int main(void)
{  printf("just hanging around\n");
   return EXIT_SUCCESS;
}
```

What does this error message even mean?

```
$ gcc217 hello.c -o hello
hello.c:7: error: two or more data types in declaration specifiers
hello.c:7: warning: return type of 'main' is not 'int'
```

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Understand Error Messages

Caveats concerning error messages

- Line # in error message may be approximate
- Error message may seem nonsensical
- Compiler may not report the real error

Tips for eliminating error messages

- Clarity facilitates debugging
  - Make sure code is indented properly
- Look for missing semicolons
  - At ends of structure type definitions
  - At ends of function declarations
- Work incrementally
  - Start at first error message
  - Fix, rebuild, repeat

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Agenda

(1) Understand error messages

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(5) Add more internal tests

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(8) Focus on recent changes

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Think Before Writing

Inappropriate changes could make matters worse, so…

Think before changing your code

- Explain the code to:
  - Yourself
  - Someone else
  - A Teddy bear?
- Do experiments
  - But make sure they're disciplined

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Agenda

(1) Understand error messages

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Look for Common Bugs

Some of our favorites:

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

```
int i;
…
scanf("%d", i);
```

```
char c;
…
c = getchar();
```

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

```
if (i = 5)
   …
```

```
if (5 < i < 10)
   …
```

```
if (i & j)
   …
```

What are the errors?

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Look for Common Bugs

Some of our favorites:

```
for (i = 0; i < 10; i++)
{  for (j = 0; j < 10; i++)
   {  ...
   }
}
```

```
for (i = 0; i < 10; i++)
{  for (j = 10; j >= 0; j++)
   {  ...
   }
}
```

What are the errors?

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Look for Common Bugs

Some of our favorites:

```
{  int i;
   …
   i = 5;
   if (something)
   {  int i;
      …
      i = 6;
      …
   }
   …
   printf("%d\n", i);
   …
}
```

What value is written if this statement is present? Absent?

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Agenda

(1) Understand error messages

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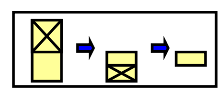
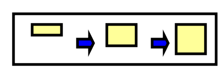
Divide and Conquer

Divide and conquer: To debug a **program**…

- Incrementally find smallest **input file** that illustrates the bug
- Approach 1: **Remove** input
  - Start with file
  - Incrementally remove lines until bug disappears
  - Examine most-recently-removed lines



- Approach 2: **Add** input
  - Start with small subset of file
  - Incrementally add lines until bug appears
  - Examine most-recently-added lines



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Divide and Conquer

Divide and conquer: To debug a **module**…

- Incrementally find smallest **client code subset** that illustrates the bug
- Approach 1: **Remove** code
  - Start with test client
  - Incrementally remove lines of code until bug disappears
  - Examine most-recently-removed lines
- Approach 2: **Add** code
  - Start with minimal client
  - Incrementally add lines of test client until bug appears
  - Examine most-recently-added lines

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Agenda

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Add More Internal Tests

(5) Add more internal tests

- Internal tests help **find** bugs (see "Testing" lecture)
- Internal test also can help **eliminate** bugs
  - Validating parameters & checking invariants can eliminate some functions from the bug hunt

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Agenda

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(8) Focus on recent changes

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Display Output

Write 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

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Display Output

- Maybe even better:

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

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

Bonus: `stderr` is unbuffered

- Maybe better still:

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

Write to a log file

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Agenda

(1) Understand error messages

(2) Think before writing

(3) Look for common bugs

(4) Divide and conquer

(5) Add more internal tests

(6) Display output

(7) Use a debugger

(8) Focus on recent changes

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Use a Debugger

Use a debugger

- Alternative to displaying output

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The GDB Debugger

GNU **Deb**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.

For details see precept tutorial, precept reference sheet, Appendix 1

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Agenda

(1) Understand error messages

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Focus on Recent Changes

Focus on recent changes

- Corollary: Debug now, not later

Difficult:

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

Easier:

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

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Focus on Recent Changes

Focus on recent change (cont.)

- Corollary: Maintain old versions

Difficult:

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

Easier:

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

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Maintaining Old 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.
…
```

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Maintaining Old Versions

Approach 2: Use a **Revision Control System** such as subversion or git
- Allows programmer to:
  - **Check-in** source code files from **working copy** to **repository**
  - **Commit** revisions from **working copy** to **repository**
    - saves all old versions
  - **Update** source code files from **repository** to **working copy**
    - Can retrieve old versions
- Appropriate for one-developer projects
- Extremely useful, almost *necessary* for multideveloper projects!

Not required for COS 217, but good to know!

Google “subversion svn” or “git” for more information.

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Summary

General debugging strategies and tools:

(1) Understand error messages
(2) Think before writing
(3) Look for common bugs
(4) Divide and conquer
(5) Add more internal tests
(6) Display output
(7) Use a debugger
- Use GDB!!!

(8) Focus on recent changes
- Consider using RCS, etc.

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Appendix 1: Using GDB

An example program

File testintmath.c:

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

```
#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;
}
```

The program is correct

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

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Appendix 1: Using GDB

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

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Appendix 1: Using GDB

Typical steps for using GDB:

(a) Build with –g
`gcc217 -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()

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Appendix 1: Using GDB

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

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Appendix 1: Using GDB

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>`

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Appendix 1: Using GDB

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.

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