



Building



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**

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)

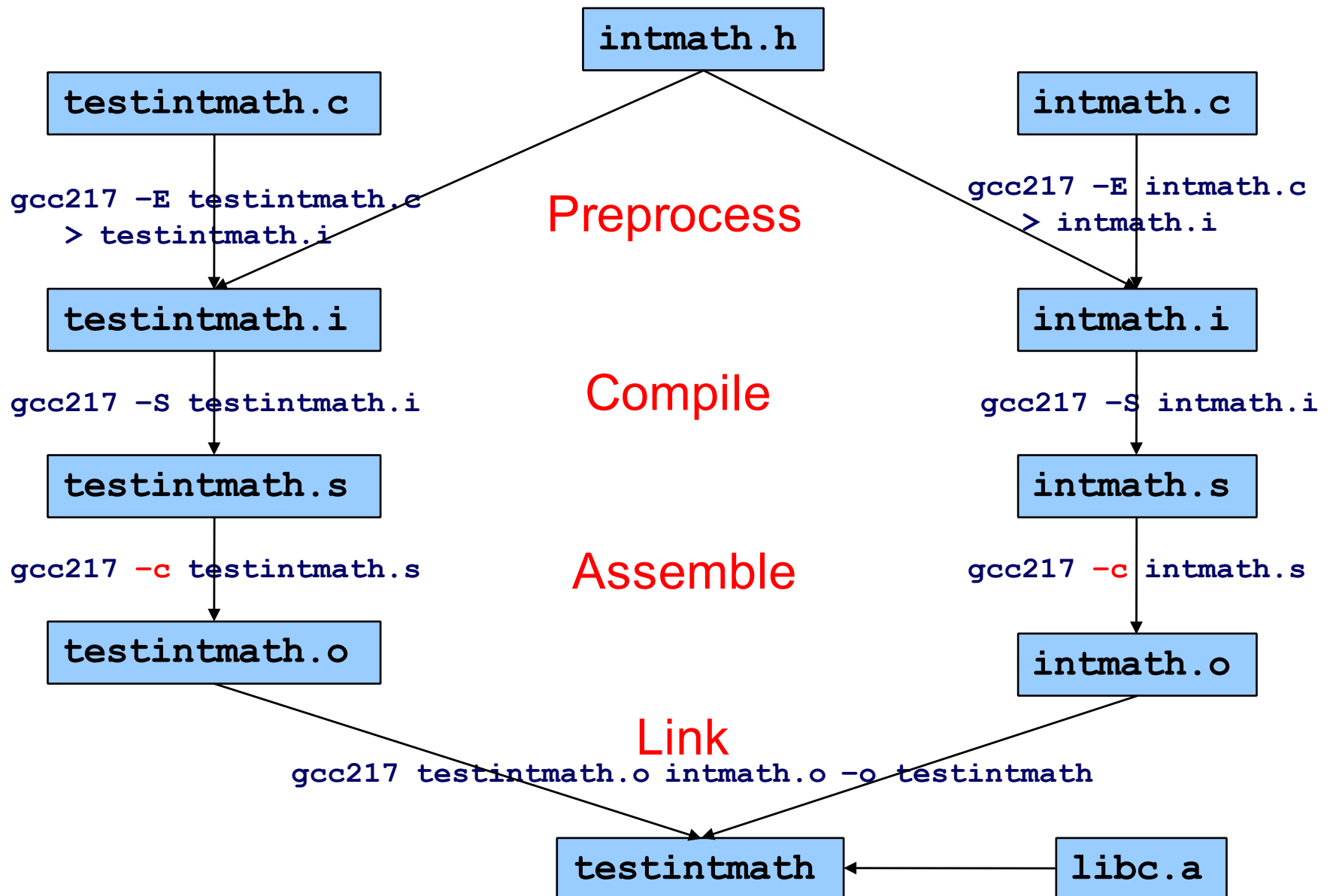
```
#include "intmath.h"
#include <stdio.h>

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

Review: Multi-File Programs



Agenda



Motivation for Make

Make Fundamentals

Non-File Targets

Macros

Abbreviations

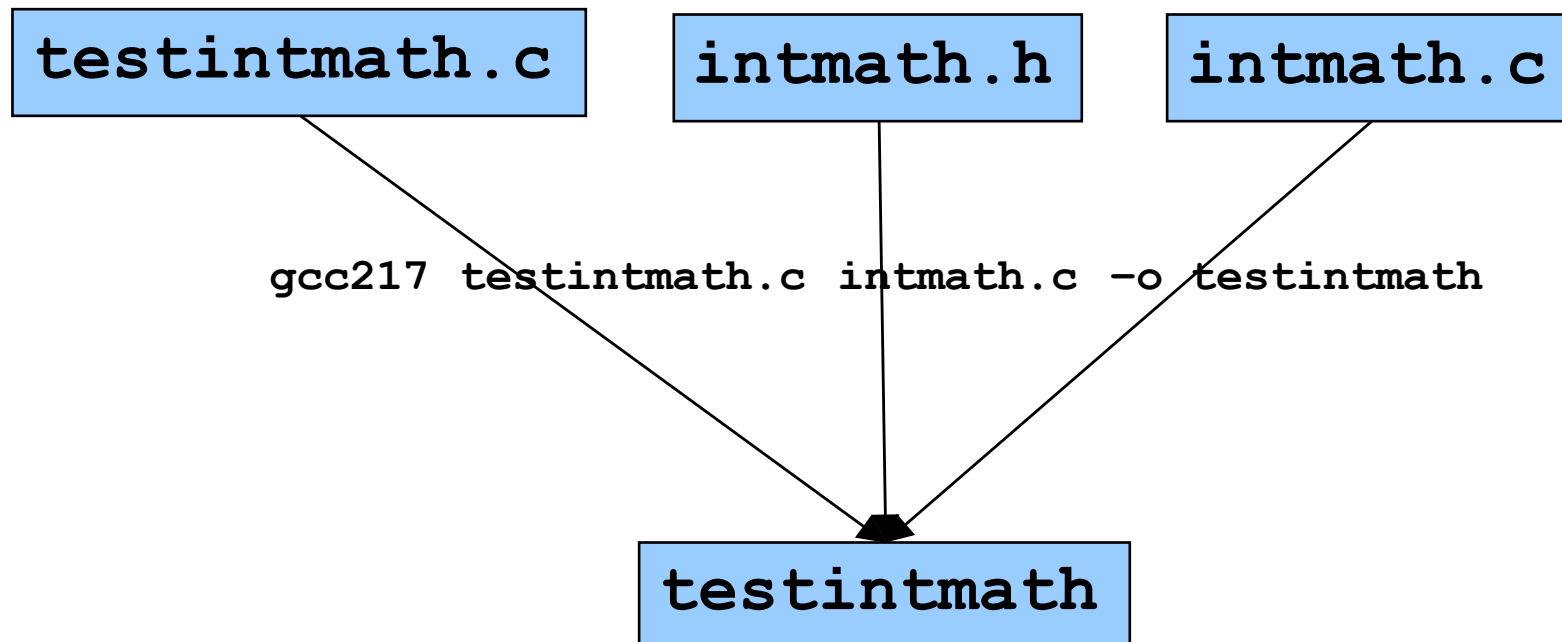
Pattern Rules

Motivation for Make (Part 1)



Building `testintmath`, approach 1:

- Use one `gcc217` command to preprocess, compile, assemble, and link

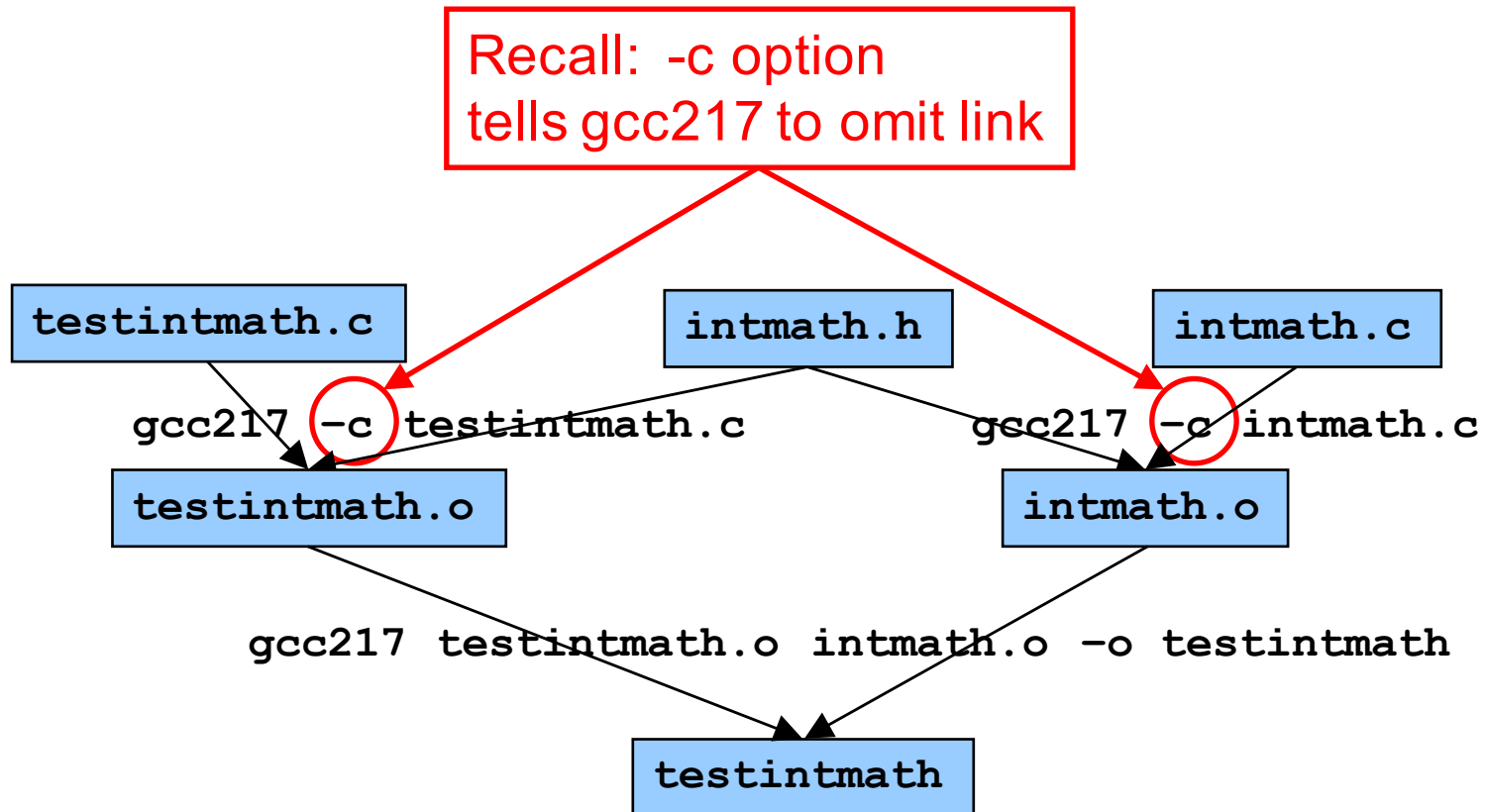


Motivation for Make (Part 2)



Building `testintmath`, approach 2:

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

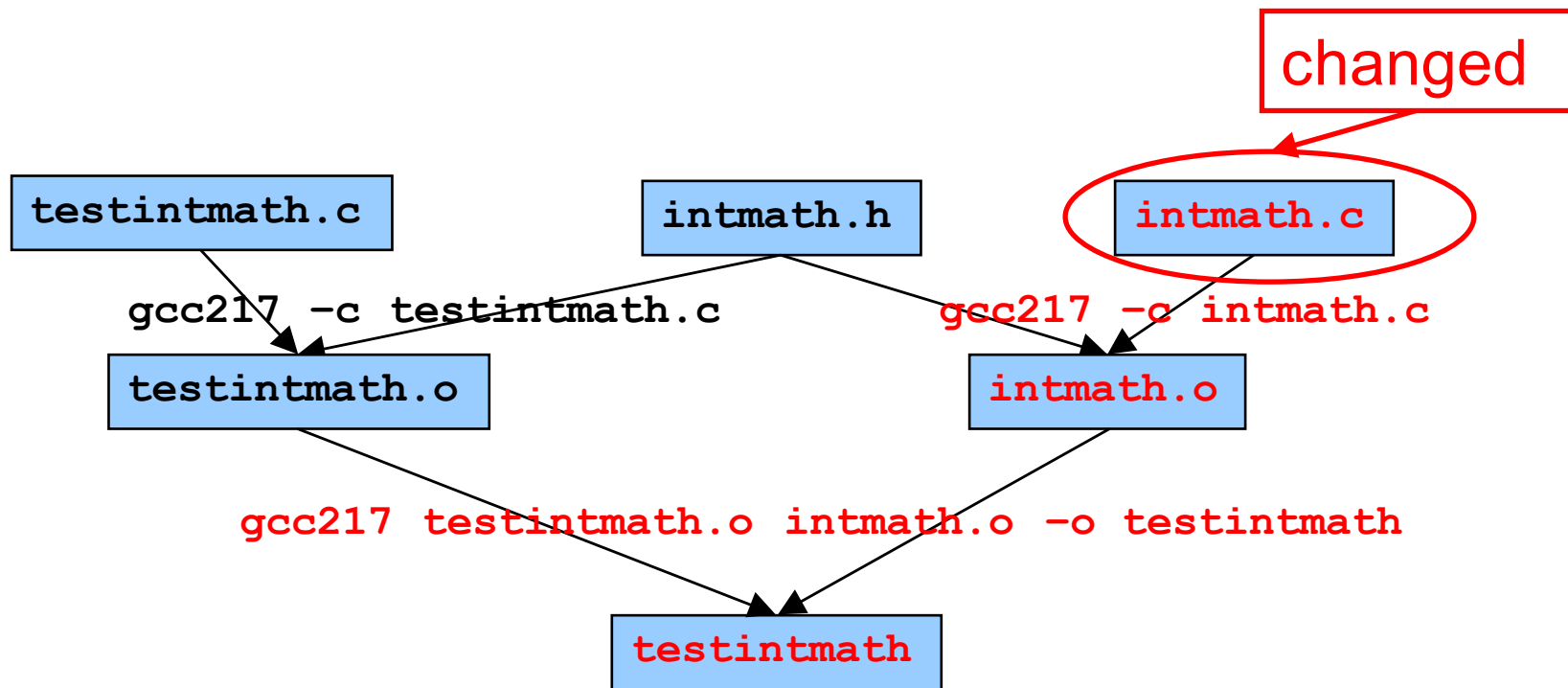


Partial Builds



Approach 2 allows for **partial builds**

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

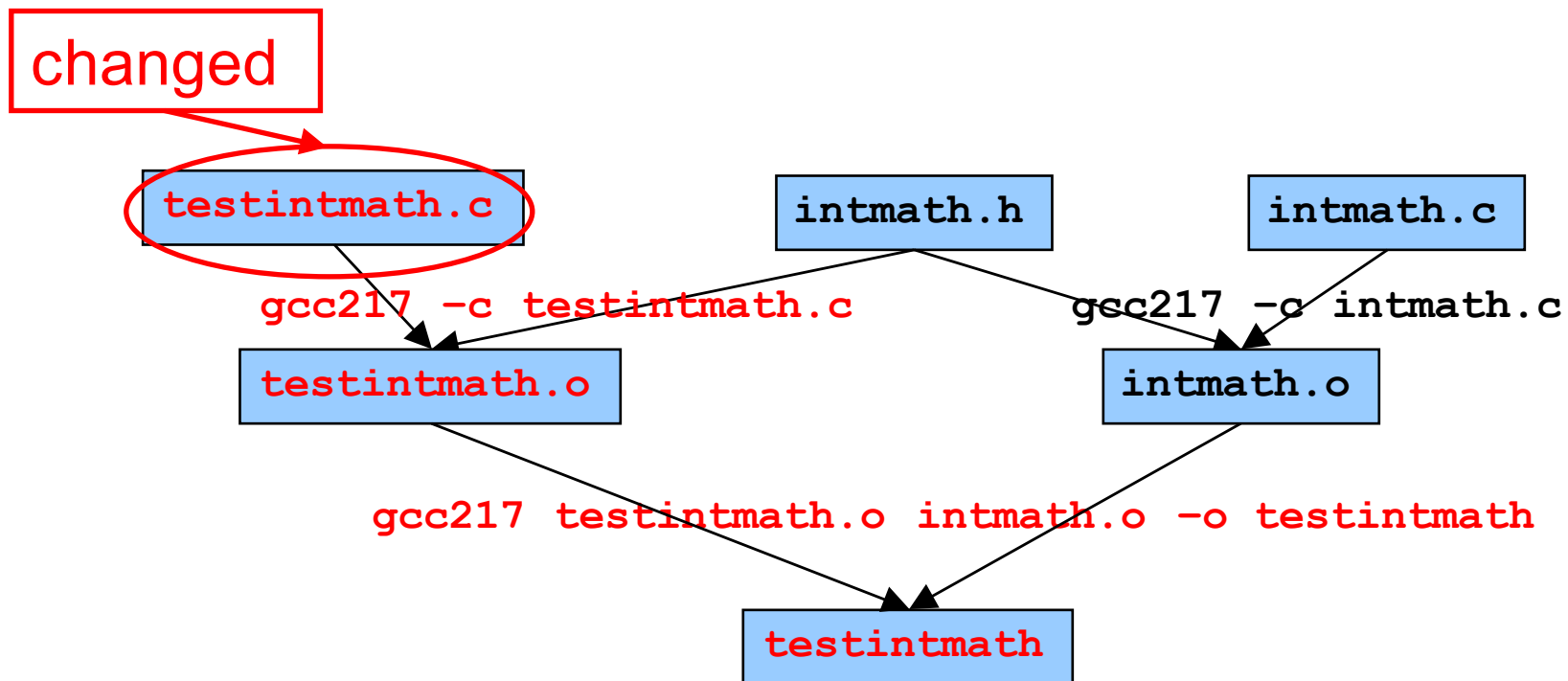


Partial Builds



- 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

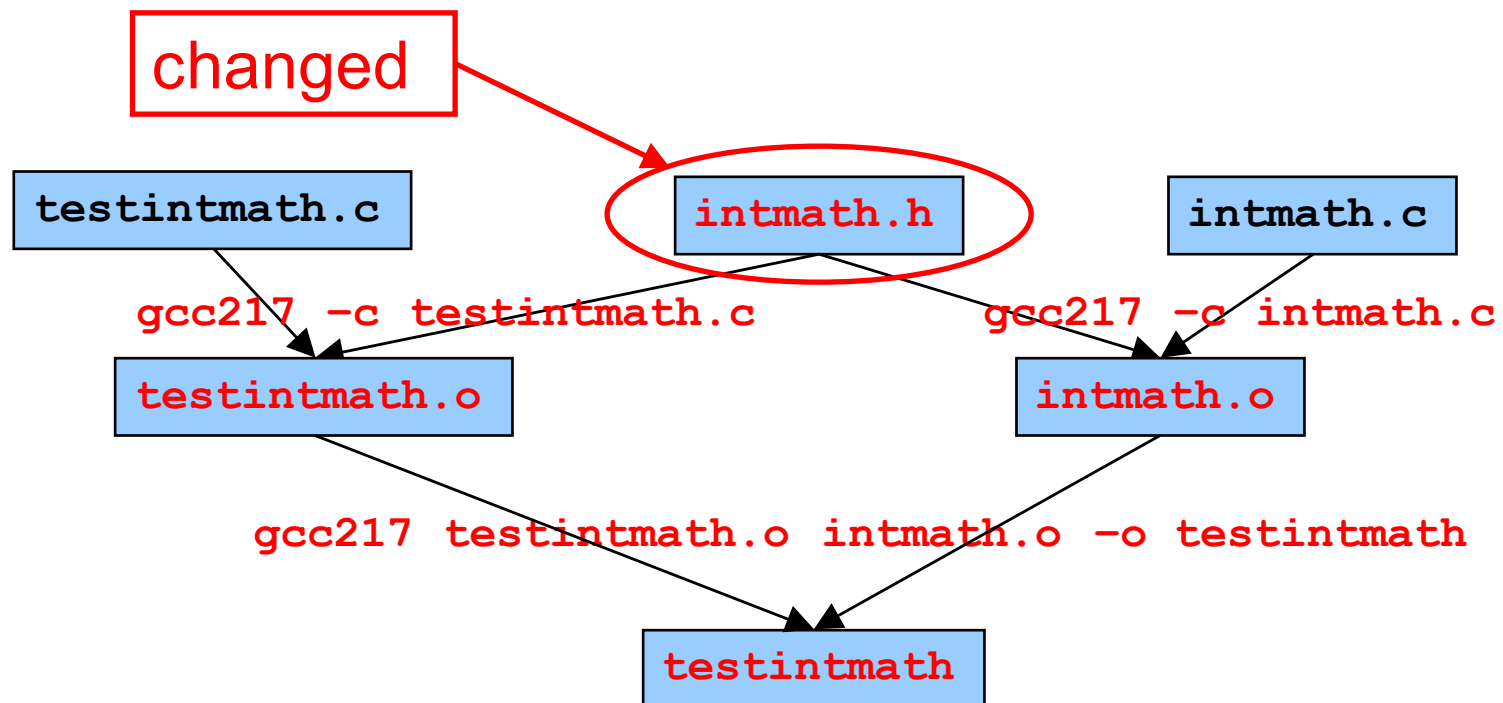


Partial Builds



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`



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!**

Agenda



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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)

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*

Dependency Rules



Dependency rule syntax

target: *dependencies*
 <tab>*command*

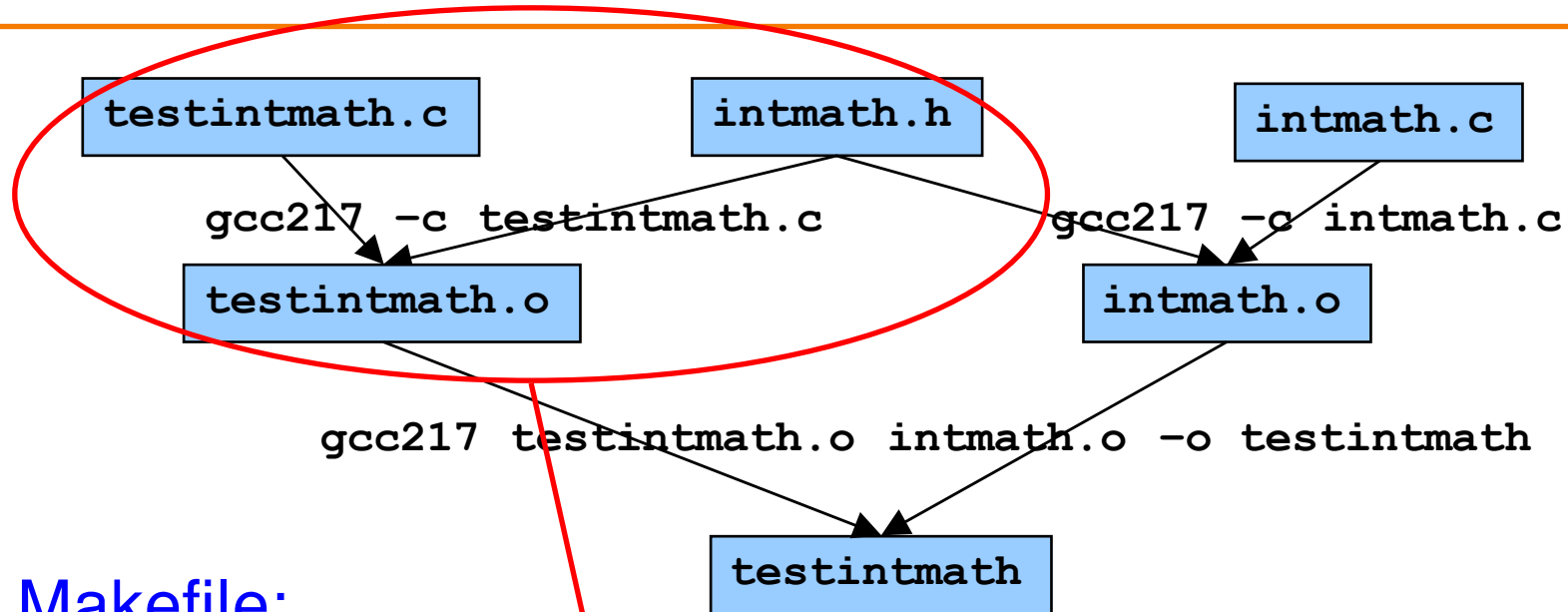
- *target*: the file you want to build
- *dependencies*: the files on which the target depends
- *command*: what to execute to create the target (after a TAB character)

Dependency rule semantics

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

Work recursively; examples illustrate...

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
```


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

Agenda



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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
```

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
```

Version 2 in Action



make observes that “clean” target doesn’t exist; attempts to build it by issuing “rm” command

```
$ 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'.
```

Same idea here, but “clobber” depends upon “clean”

“all” depends upon “testintmath”

“all” is the default target

Agenda



Motivation for Make

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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
```

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
```


Version 3 in Action



Same as Version 2

Agenda



Motivation for Make

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Abbreviations

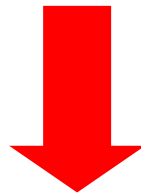


Abbreviations

- 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

Macros

Abbreviations

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

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

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

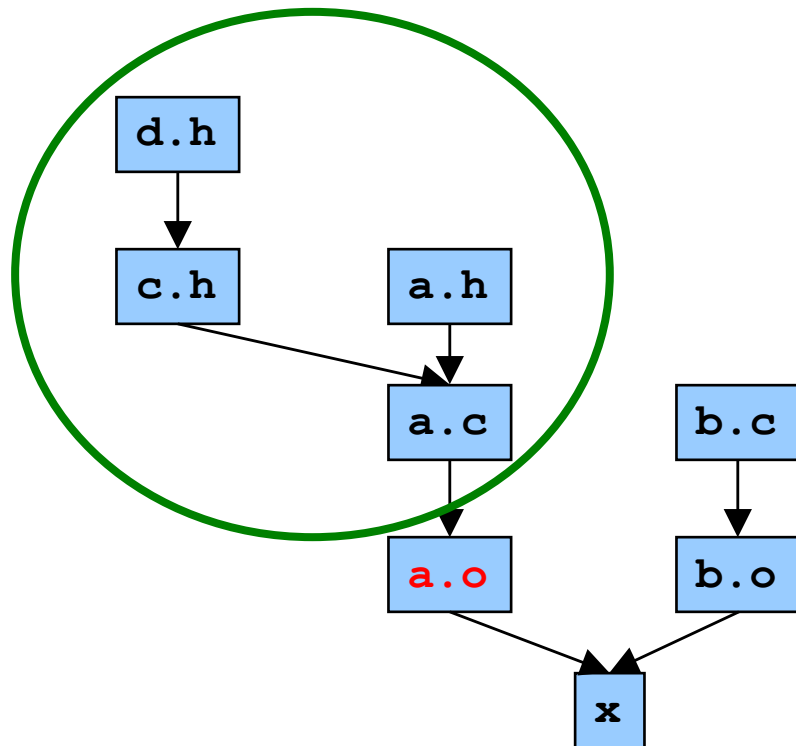
# Dependency rules for file targets
testintmath: testintmath.o intmath.o
    $(CC) $(CFLAGS) $< intmath.o -o $@
testintmath.o: intmath.h
intmath.o: intmath.h
```

Version 5 in Action



Same as Version 2

Makefile Guidelines

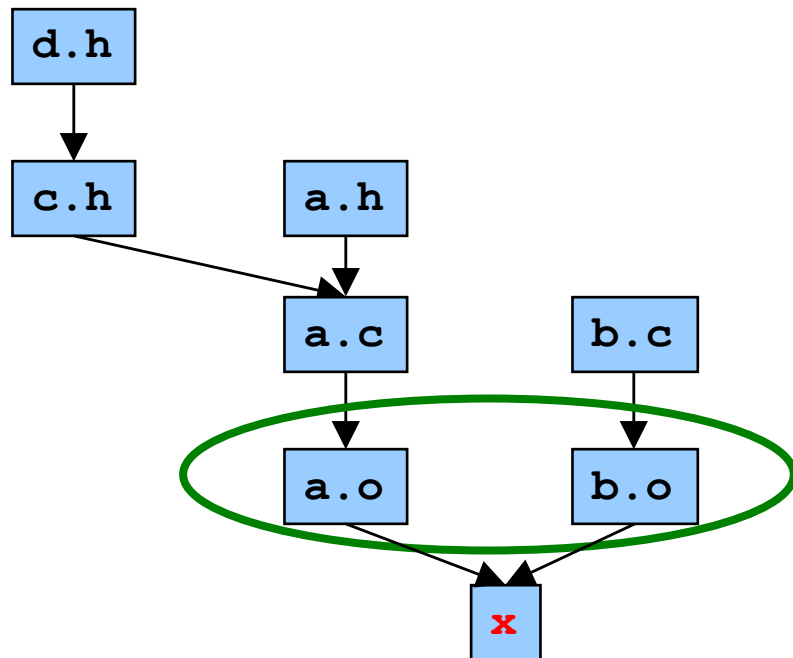


```
a.o: a.c a.h c.h d.h  
gcc217 -c a.c
```

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**

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

Making Makefiles



In this course

- Create Makefiles manually

Beyond this course

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

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

Make Resources



C Programming: A Modern Approach (King) Section 15.4

GNU make

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

Summary



Motivation for Make

- Automation of partial builds

Make fundamentals (Makefile version 1)

- Dependency rules, targets, dependencies, commands

Non-file targets (Makefile version 2)

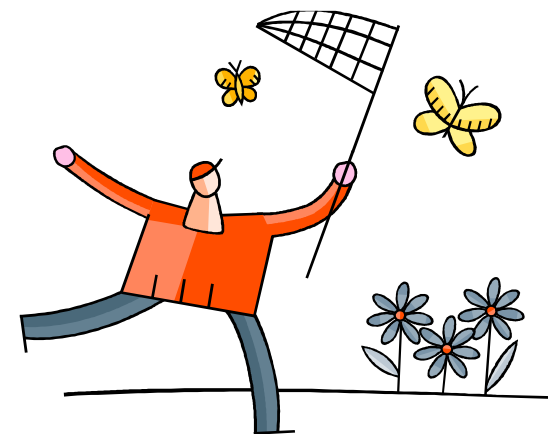
Macros (Makefile version 3)

Abbreviations (Makefile version 4)

Pattern rules (Makefile version 5)



Debugging (Part 1)



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

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

For Your Amusement



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

“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

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?

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

Understand Error Messages



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

Understand the 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!)

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(s)?

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

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!)

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'
```

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!)

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

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!)

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'
```

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

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

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



Agenda



- (1) Understand error messages
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- (3) Look for common bugs**
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Look for Common 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?

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?

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?

Agenda



- (1) Understand error messages
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Divide and Conquer

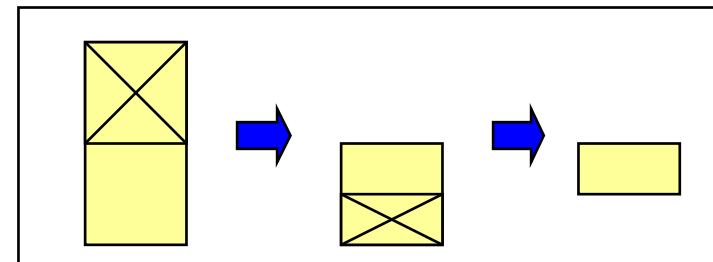


Divide and conquer: To debug a program...

- Incrementally find smallest **input file** that illustrates the bug

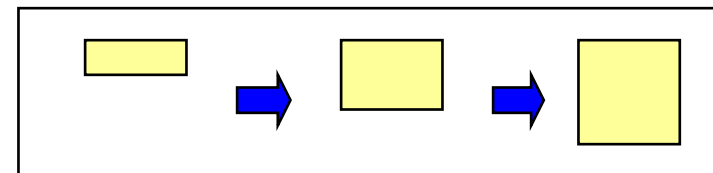
- Approach 1: **Remove** input

- 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



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

Agenda



- (1) Understand error messages
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- (5) Add more internal tests**
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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

Agenda



- (1) Understand error messages
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- (6) Display output**
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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

Display Output



- Maybe even better:

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

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

- Maybe better still:

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

Bonus: **stderr** is unbuffered

Write to a log file

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

Use a Debugger



Use a debugger

- Alternative to displaying output

The GDB Debugger



GNU Debugger

- 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

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**

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

...

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

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.  
...
```

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.

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.

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()**...

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

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()`

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

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
```

- GDB 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



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.