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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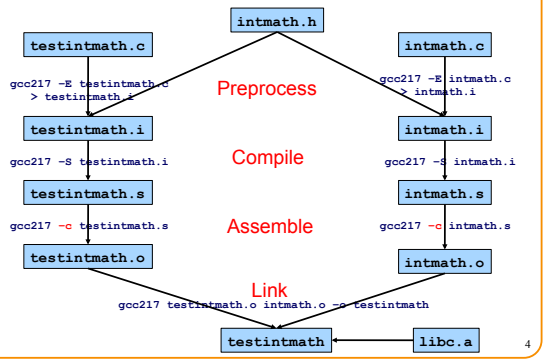
Review: Multi-File Programs



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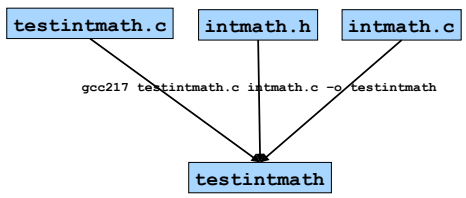
Motivation for Make (Part 1)

Building `testintmath`, approach 1:

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



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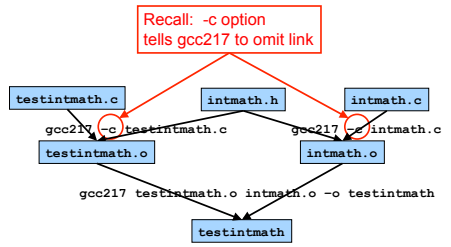
Motivation for Make (Part 2)

Building **testintmath**, approach 2:

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



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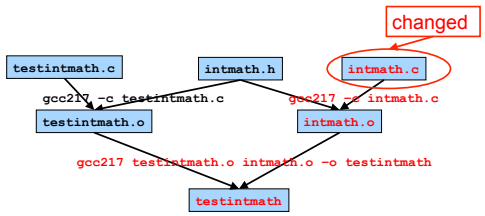
Partial Builds

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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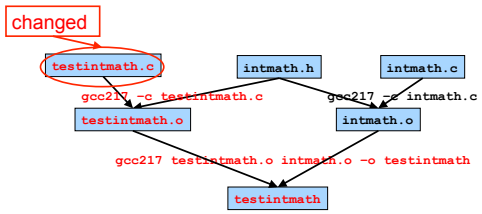
Partial Builds

- 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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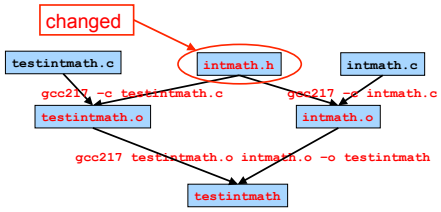
Partial Builds

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

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The Make Tool

Who? Stuart Feldman

When? 1976

Where? Bell Labs

Why? Automate partial builds

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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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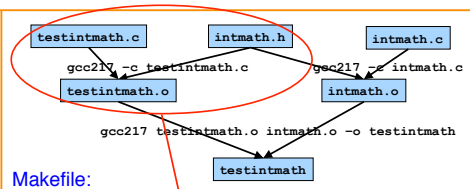
Makefile Version 1



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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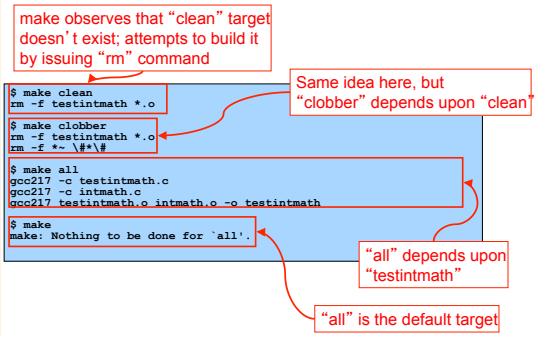
Version 2 in Action



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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

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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 $@
```

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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 $<
```

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Version 4 in Action

Same as Version 2

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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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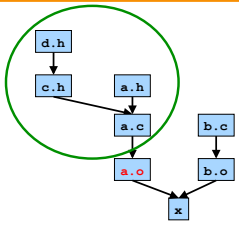
Makefile Guidelines




```
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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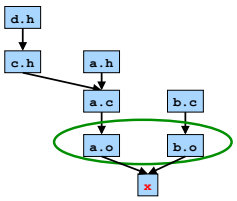
Makefile Guidelines




```
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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