Build Tools (make)
CSE 333

Instructor: Hannah C. Tang

Teaching Assistants:

Deeksha Vatwani Hannah Jiang Jen Xu

Leanna Nguyen Nam Nguyen Sayuj Shahi

Tanay Vakharia Wei Wu Yiqing Wang

Zohar Le

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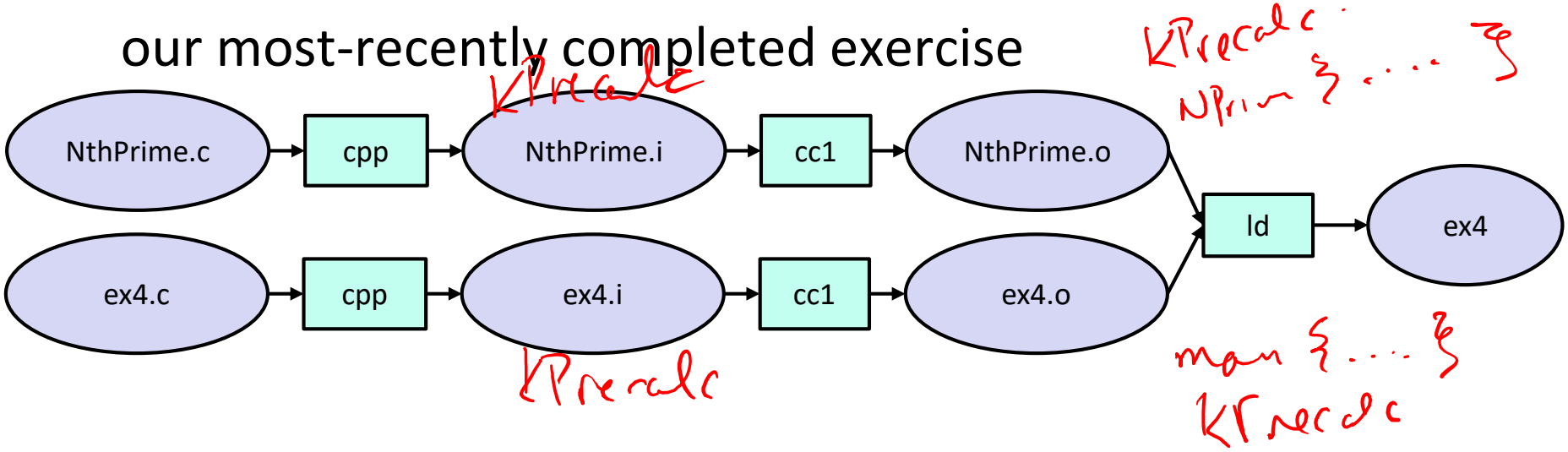
- Assume `NthPrime.h`, `NthPrime.c`, and `ex4.c`, as in our most-recently completed exercise



- … except we are now precalculating the first 20 primes. What are the contents of each .o?

NthPrime.h

```
#define NUM_PRECALC 20
int16_t kPrecalculated[NUM_PRECALC] =
    {2, 3, 5, 7, /* etc */ };

int16_t NthPrime(int16_t n);
```

Administrivia

- New exercise posted today, due Monday morning
- How far we get in lecture will dictate which exercise we post:
  - Ex4 = write a multi-file program
  - Ex5 = use today's best-practices and resubmit your program

Lecture Outline

- **A Few Words about Code Quality**
- Make and Build Tools

Code Quality

- Code quality **really** matters – and not just for homework

- The quality rules we follow are distilled from almost 50 years of bug(fixe)s
  - Bad casts = data loss or data corruption
  - Memory leaks = unexpected crashes or data corruption
  - Non-standard input/output parameters = incorrect usage by callers
    - We saw that on Ed this weekend!
  - And so so so so so much more …


HashTable_Insert create new pointer before pushing #244

Anonymous Mouse
19 hours ago in Homeworks – HW1 (Data Structures)

PIN STAR WATCH 187 VIEWS

4

Thought this might be helpful for other people who might have struggled with the same issue, when pushing the newkeyvalue to the chain in hashtable_insert, **DO NOT** directly push into the linkedlist with &newkeyvalue, instead create a new pointer and dereference the pointer to copy newkeyvalue then pushing the newly created pointer instead into the linkedlist.

Hope this will help someone.

Code Quality Rules

- Rule 0: The reader's time is ***much*** more important than the writer's
  - Clarity/understandability is critical
    - *(yes, we're talking about code comments)*
    - What does the reader need to know to understand / modify / use the code, that can't be discovered by reading the code itself?
  - Good comments ultimately save the writer's time, too!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Code Quality Rules

- Rule 1: Match existing code
  - Do output parameters go at the end of the param list? The beginning?
  - Yes, whitespace does matter!
    - `char** argv` vs `char **argv` "reads differently" to novice programmers!
    - There's a reason Google's style guide is so pedantic about whitespace
- Rule 2: Make use of the tools provided to you
  - Compiler: fix the warnings!
  - Valgrind: fix all of them unless you know why it's *not* an error
  - style checkers: fix most things; be sure you understand anything you don't fix and can justify it (use of long, types in sizeof( ), readdir, not much else)

Lecture Outline

- A Few Words about Code Quality
- **Make and Build Tools**

make

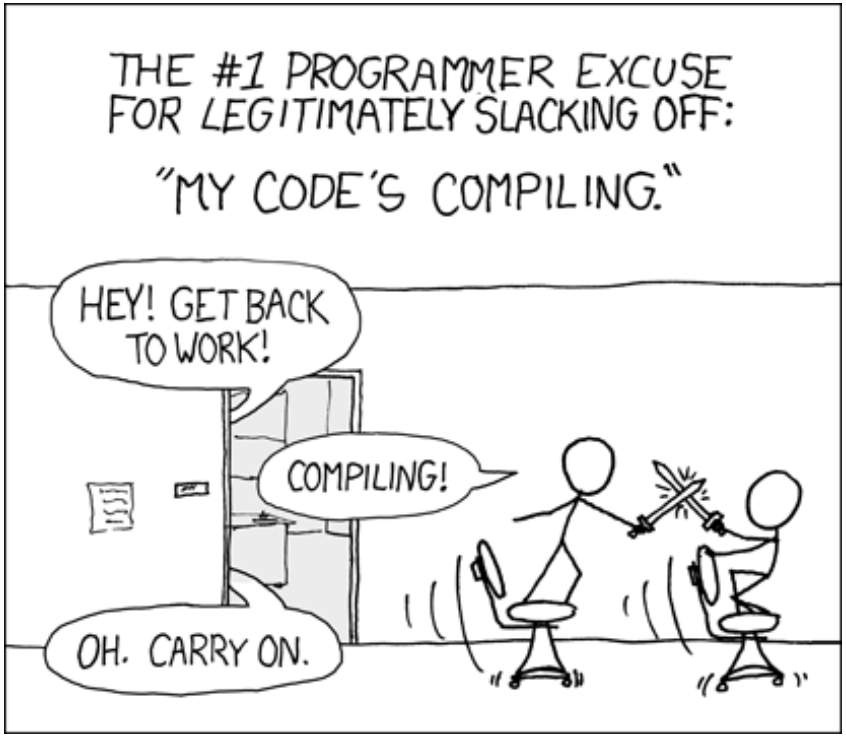
- `make` is a classic program for controlling what gets (re)compiled and how
  - Many other such programs exist (*e.g.* `ant`, `maven`, IDE "projects")

- `make` has tons of fancy features, but only two basic ideas:
  1) Scripts for executing commands
  2) Dependencies for avoiding unnecessary work

- To avoid "just teaching `make` features" (boring and narrow), let's focus more on the concepts…

Building Software

- Programmers spend a lot of time "building"
  - Creating programs from source code
  - Both programs that they write and other people write



https://xkcd.com/303/

Building Software

- Programmers spend a lot of time "building"
  - Creating programs from source code
  - Both programs that they write and other people write

- Programmers like to automate repetitive tasks
  - Repetitive: `gcc -Wall -g -std=c17 -o widget foo.c bar.c baz.c`
    - Retype this every time: 
    - Use up-arrow or history:  (still retype after logout)
    - Have an alias or bash script: 
    - Have a Makefile:  (you're ahead of us)

"Real" Build Process

- On larger projects, you can't or don't want to have one big (set of) command(s) that redoes everything every time you change anything:
  1) If `gcc` didn't combine steps for you, you'd need to preprocess, compile, and link on your own (along with anything you used to generate the C files)
  2) If source files have multiple outputs (*e.g.* javadoc), you'd have to type out the source file name(s) multiple times for each output command
  3) You don't want to have to document the build logic when you distribute source code
  4) You don't want to recompile everything every time you change something (especially if you have 10^5-10^7 files of source code)
- A script can handle 1-3 (use a variable for filenames for 2), but 4 is trickier

An Example

- We have a small program that is split into multiple tiny modules (code on the web linked to this lecture):

`main.c` `speak.h` `speak.c` `shout.h` `shout.c`

- Modules:
  - speak.h/speak.c: write a string to stdout
  - shout.h/shout.c: write a string to stdout LOUDLY
  - main.c: client program
- Demo: build this program incrementally, and recompile only necessary parts when something changes
- How do we automate this "minimal rebuild"?

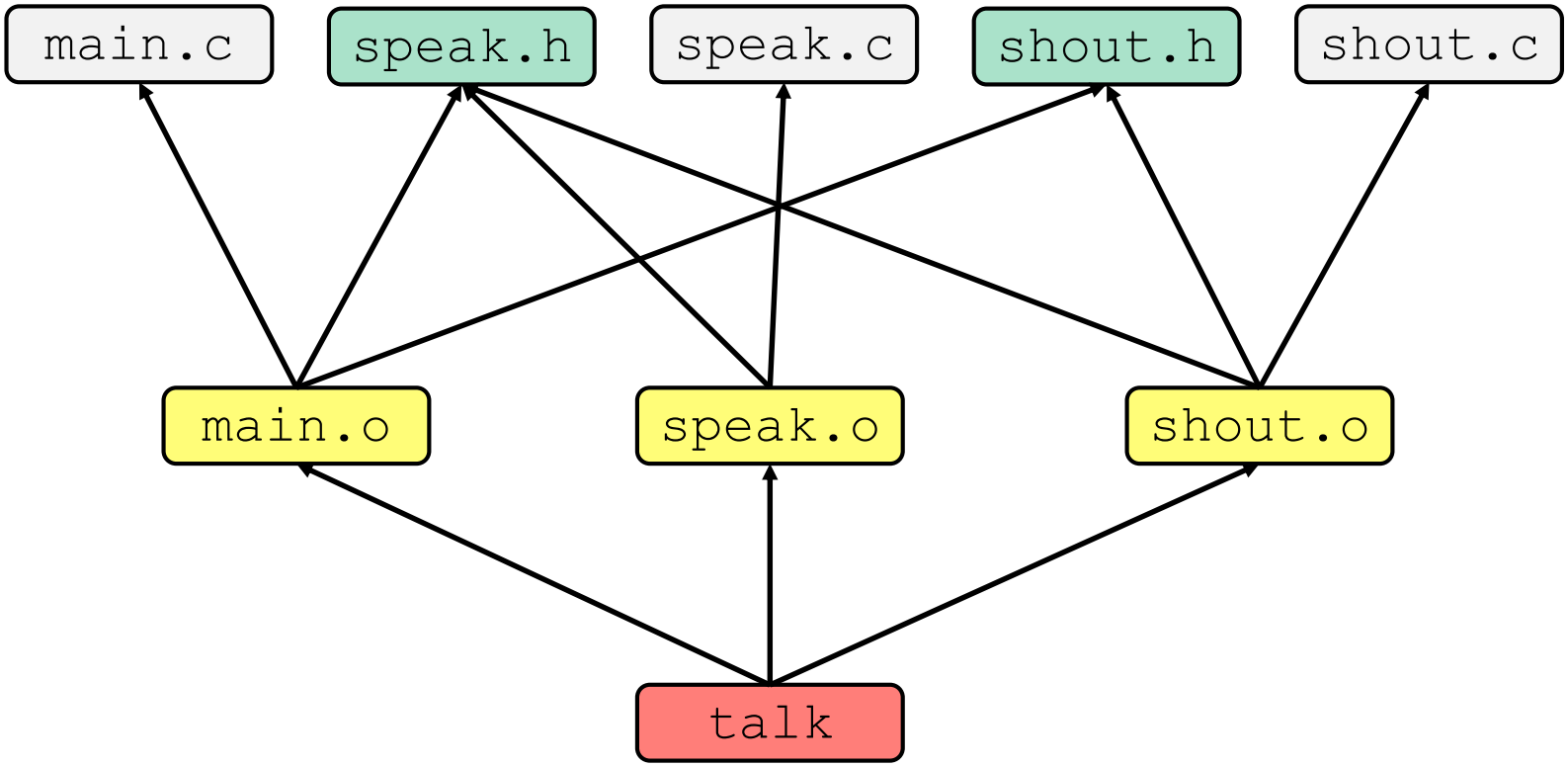
Recompilation Management

- The "theory" behind avoiding unnecessary compilation is a *dependency DAG* (**d**irected, **a**cyclic **g**raph)

- To create a target t, you need sources $s_1, s_2, \ldots, s_n$ and a command c that directly or indirectly uses the sources
  - It t is newer than every source (file-modification times), assume there is no reason to rebuild it
  - Recursive building: if some source s_i is itself a target for some other sources, see if it needs to be rebuilt…
  - Cycles "make no sense"!

Theory Applied to Our Example

- What are the dependencies between built and source files?
- What needs to be rebuilt if something changes?



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- Draw the dependency graph for example_program_ll.c and example_program_ht.c
  - *(ignore the existence of CSE333.h, libhw1.a, and the _priv.h's)*

`make` Basics

- A makefile contains a bunch of triples:

```
target: sources
← Tab → command
```

  - Colon after target is *required*
  - Command lines must start with a **TAB**, not space
  - Multiple commands for same target are executed *in order*
    - Can split commands over multiple lines by ending lines with '\'

- Example:

```
foo.o: foo.c foo.h bar.h
	gcc -Wall -o foo.o -c foo.c
```

- Demo: look at Makefile for our example program

Using `make`

```
bash% make -f <makefileName> target
```

- Defaults:
  - If no `-f` specified, use a file named `Makefile`
  - If no `target` specified, will use the first one in the file
  - Will interpret commands in your default shell
    - Set `SHELL` variable in makefile to ensure
- Target execution:
  - Check each source in the source list:
    - If the source is a target in the Makefile, then process it recursively
    - If some source does not exist, then error
    - If any source is newer than the target (or target does not exist), run `command` (presumably to update the target)

`make` Variables

- You can define variables in a makefile:
  - All values are strings of text, no "types"
  - Variable names are case-sensitive and can't contain '`:`', '`#`', '`=`', or whitespace

- Example:

```
CC = gcc
CFLAGS = -Wall -std=c17
foo.o: foo.c foo.h bar.h
	$(CC) $(CFLAGS) -o foo.o -c foo.c
```

- Advantages:
  - Easy to change things (especially in multiple commands)
  - Can also specify on the command line (`CC=clang FLAGS=-g`)

More Variables

- It's common to use variables to hold list of filenames:

```
OBJFILES = foo.o bar.o baz.o
widget: $(OBJFILES)
	gcc -o widget $(OBJFILES)
clean:
	rm $(OBJFILES) widget *~
```

"Phony" Targets

- It's common to use variables to hold list of filenames:

```
OBJFILES = foo.o bar.o baz.o
widget: $(OBJFILES)
	gcc -o widget $(OBJFILES)
clean:
	rm $(OBJFILES) widget *~
```

- `clean` is a convention
  - Remove generated files to "start over" from just the source
  - It's "funny" because the target doesn't exist and there are no sources, but it works because:
    - The target doesn't exist, so it must be "remade" by running the command
    - These "phony" targets have several uses, such as "`all`"…

"all" Example

```
all: prog B.class someLib.a
      # notice no commands this time

prog: foo.o bar.o main.o
      gcc -o prog foo.o bar.o main.o

B.class: B.java
      javac B.java

someLib.a: foo.o baz.o
      ar r foo.o baz.o

foo.o: foo.c foo.h header1.h header2.h
      gcc -c -Wall foo.c

# similar targets for bar.o, main.o, baz.o, etc...
```

Revenge of the Funny Characters

- Special variables:
  - **$@** for target name
  - **$^** for all sources
  - **$<** for left-most source
  - Lots more! – see the documentation

- Examples:

```
# CC and CFLAGS defined above
widget: foo.o bar.o
        $(CC) $(CFLAGS) -o $@ $^
foo.o: foo.c foo.h bar.h
        $(CC) $(CFLAGS) -c $<
```

And more…

- There are a lot of "built-in" rules – see documentation
- There are "suffix" rules and "pattern" rules
  - Example:

```
%.class: %.java
	javac $<  # we need the $< here
```

- Remember that you can put *any* shell command – even whole scripts!
- You can repeat target names to add more dependencies
- Often this stuff is more useful for reading makefiles than writing your own (until some day…)

Extra Exercise #1

- Modify the linked list code from Lecture 5 Extra Exercise #1
  - Add static declarations to any internal functions you implemented in `linkedlist.h`
  - Add a header guard to the header file
  - Write a `Makefile`
    - Use Google to figure out how to add rules to the `Makefile` to produce a library (`liblinkedlist.a`) that contains the linked list code