# CSE 374
# Programming Concepts & Tools

Hal Perkins

Spring 2022

Lecture 14 – Makefiles and Compilation Management

# Where we are

- Onto tools...
- Basics of make, particular the concepts
- Some fancier make features (revenge of funky characters)

Besides the slides and online Unix docs, the Stanford CSLib notes on Unix Programming Tools has a nice overview of make and other tools:

http://cslibrary.stanford.edu/107/

# Onto tools

- The language implementation (preprocessor, compiler, linker, standard-library) is hardly the only useful thing for developing software
- The rest of the course:
  - Tools (recompilation managers, version control, maybe profilers; we've already seen a debugger)
  - Software-engineering issues
  - Concurrency

# make

- make is a classic program for controlling what gets (re)compiled and how. Many other such programs exist (e.g., ant, maven, “projects” in IDEs, ...)
- 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)

- Programs they write
- Programs other people write

Programmers automate repetitive tasks. Trivial example:

```
gcc -Wall –g -std=c11 -o widget foo.c bar.c baz.c
```

If you:

- Retype this every time: "shame, shame"
- Use up-arrow or history: "shame" (retype after logout)
- Have an alias or bash script: "good-thinkin"
- 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 behind your back, you’d need to preprocess and compile each file, then run the linker
  2. If another program (e.g., sed) created some C files, you would need an “earlier” step
  3. If you have other outputs for the same source files (e.g., javadoc), it’s unpleasant to type the source file names multiple times
  4. If you want to distribute source code to be built by other users, you don’t want to explain the build logic to them
  5. If you have $10^5$ to $10^7$ lines of source code, you don’t want to recompile them all every time you change something
- A simple script handles 1–4 (use a variable for filenames for 3), but 5 is trickier

# An Example

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

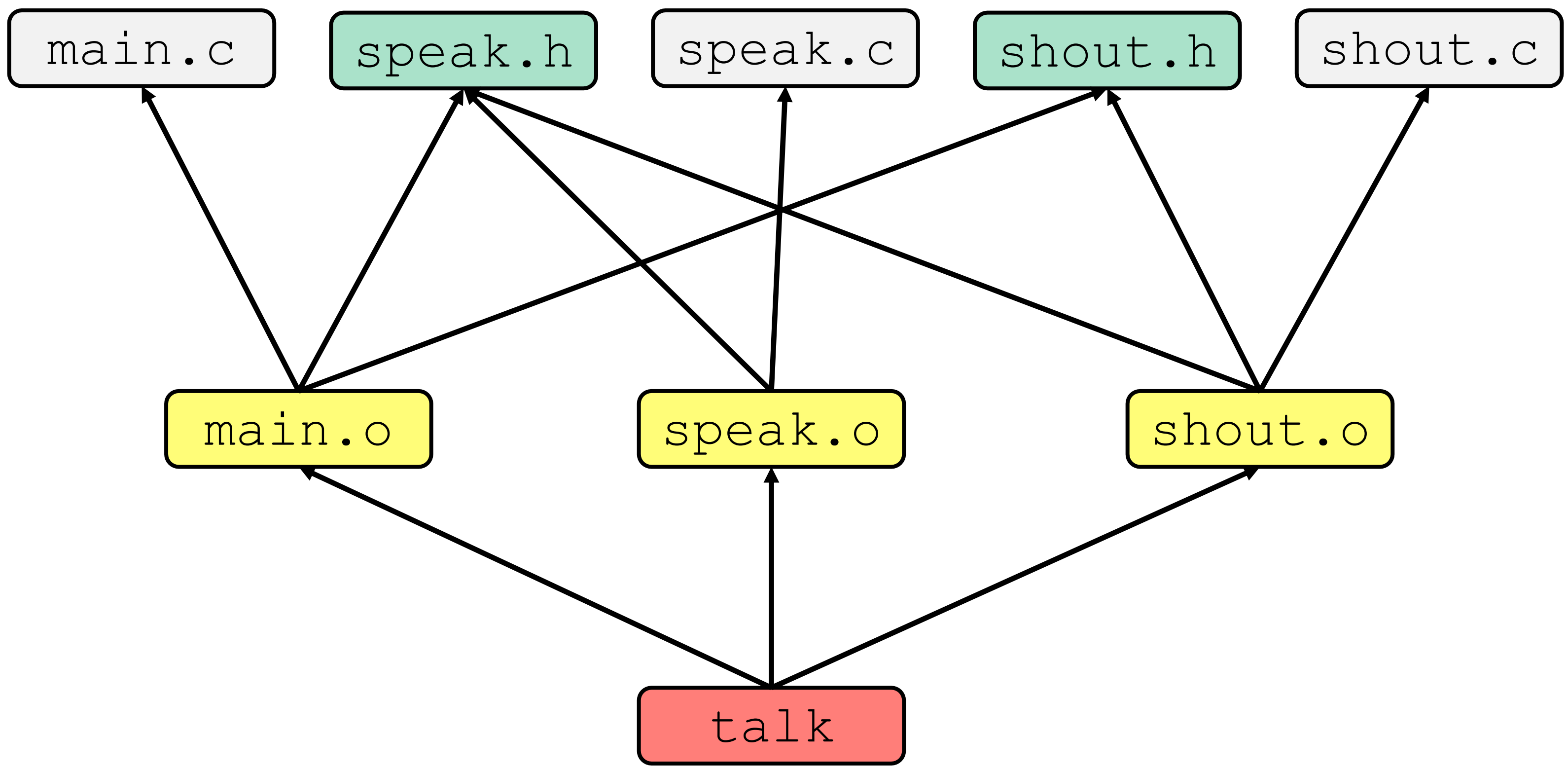
- The "theory" behind avoiding unnecessary compilation is a "dependency dag" (*d*irected, *a*cyclic *g*raph):
- To create a target $t$, you need sources $s_1, s_2, \ldots, s_n$ and a command $c$ (that directly or indirectly uses the sources)
- If $t$ is newer than every source (file-modification times), 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 C

- Here is what we need to know today for C (still need to talk more about linking in a future lecture)
  - Compiling a .c creates a .o – the .o depends on the .c and all included files (.h files, recursively/transitively)
  - Creating an executable (“linking”) depends on .o files
  - So if one .c file changes, just need to recreate one .o file and relink
  - If a header file changes, may need to rebuild more
  - Of course, this is only the simplest situation

# Theory Applied to Our Example

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



# An algorithm

- What would a program (e.g., a shell script) that did this for you look like? It would take:
  - a bunch of triples: target, sources, command(s)
  - a “current target to build”
- It would compute what commands needed to be executed, in what order, and do it (it would detect cycles and give an error)
- This is exactly what programs like make, ant, and build tools integrated into IDEs do!

# make basics

The “triples” are typed into a “makefile” like this:

```
target:  sources
         command
```

Example:

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

Syntax gotchas:

- The colon after the target is required
- Command lines must start with a ***TAB NOT SPACES***
- You can actually have multiple commands (executed in order); if one command spans lines you must end the previous line with \
- Which shell-language interprets the commands? (Typically bash; to be sure, set the SHELL variable in your makefile.)

Demo: look at Makefile for our example program

# Using make

At the prompt:

prompt% make -f nameOfMakefile aTarget

Defaults:

- If no -f specified, use a file named Makefile
- If not target specified, use the first one in the file

- Open source usage: You can download a tarball, extract it, type make (four characters) and everything should work
- Actually, there's typically a "configure" step too, for finding things like "where is the compiler" that generates the Makefile (but we won't get into that)
  - The mantra: ./configure; make; make install

# Basics summary

So far, (almost) enough for next homework and basic use.

- A tool that combines scripting with dependency analysis to avoid unnecessary recompilation
- Not language or tool-specific: just uses file-modification times and shell-commands

But there's much more you want so that your Makefiles are:

- Short and modular
- Easy to reuse (with different flags, platforms, etc.)
- Useful for many tasks
- Automatically maintained with respect to dependencies

Also, reading others' makefiles can be tough because of all the features: see info make or entire books

# Precise review

A Makefile has a bunch of these:

```
target: source_1 ...source_n
        shell_command
```

Running make target does this:

- For each source, if it is a target in the Makefile, process it recursively
- Then:
  - If some source does not exist, error
  - If some source is newer than the target (or target does not exist), run shell_command (presumably updates target, but that is up to you; shell_command can do anything)

# make variables

You can define variables in a Makefile. Example:

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

Why do this?

- Easy to change things once and affect many commands
- Can change variables on the command-line (overrides definitions in file) (For example make CFLAGS=-g)
- Easy to reuse most of a Makefile on new projects
- Can use conditionals to set variables (using inherited environment variables)…

# More variables & ”phony” targets

- It’s also 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 any generated files, to “start over” and have just the source (needed in hw5)
- It’s “funny” because the target doesn’t exist and there are no sources, but that’s okay:
  – If target doesn’t exist, it must be “remade” so run the commands
  – These “phony” targets have several uses, another is an “all” target....

# “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) ...

# Revenge of the funny characters

And you thought we were done with this after bash, sed…

In commands:

- $@ for target
- $^ for all sources
- $< for left-most source
- …

Examples:

```
widget$(EXE): foo.o bar.o
        $(CC) $(CFLAGS) -o $@ $^
foo.o: foo.c foo.h bar.h
        $(CC) $(CFLAGS) -c $<
```

# make conditionals

```
EXE=
ifdef WINDIR      # defined on Windows (from folklore)
  EXE=.exe
endif
widget$(EXE): foo.o bar.o
        $(CC) $(CFLAGS) -o widget$(EXE) foo.o bar.o
```

- Other forms of conditionals exist (e.g., are two strings equal)

# And more…

- There are a lot of "built-in" rules. E.g., make just "knows" to create foo.o by calling $(CC) $(CFLAGS) on foo.c. (Opinion: may be more confusing than helpful. YMMV)
- There are "suffix" rules and "pattern" rules. Example:

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

- Remember you can put any shell command on the command-line, even whole scripts
- You can repeat target names to add more dependencies (useful with automatic dependency generation)

- Often this stuff is more useful for reading makefiles than writing your own (until some day…)

# Build-script summary

- Always script complicated tasks
- Always automate “what needs rebuilding” via dependency analysis
- make is a text-based program with lots of bells and whistles for doing this. It is not language-specific. Use it.
  - It also is independent of particular IDEs/editors so everyone on the project can have a repeatable build
- With language-specific tools, you can automate dependency generation
- make files have a way of starting simple and ending up unreadable. It is worth keeping them clean.
- There are conventions like make all and make clean common when distributing source code