

Week 7

Announcements

- Basic, Advanced 4 due tonight
- Basic, Advanced 5 due October 21

Lecture 7: Build Systems

```
gcc -I inc -o app $(find . -name *.c) -lsomelib
```

Overview

- Building programs
- Build systems
- **make**
- Other build systems

Building programs

- Traditional "compiled" programs have multiple steps to produce an executable
- Source code: human readable code in a (high-level) language
 - CPUs can't directly understand high-level languages
 - Assembly code: human readable "low-level" code that maps to CPU-understandable commands
- Object code: chunk of CPU-understandable "machine code"
 - File formats include additional metadata for tools to deal with
 - Can have dangling references to functions or other data to be resolved when *linking*

Steps

- Compiling: turn high-level code into lower-level code
 - High-level source to lower-level "high-level" language (e.g. Java to C)
 - High-level source to assembly
 - High-level source to object code
- Assembling: turn low-level (assembly) code into machine code
- Linking: putting object code together into something usable
 - Object code is usually just floating chunks of machine code
 - Produces executables: has a starting point (e.g. `main`), has resolved dangling references
 - Produces libraries: code that other programs can call on

Building programs

```
#  
#  
#  
gcc -o app file1.c file2.c file3.c
```



Building programs

```
gcc -c -o file1.o file1.c  
gcc -c -o file2.o file2.c  
gcc -c -o file3.o file3.c  
gcc -o app file1.o file2.o file3.o
```



Building code

```
gcc -o app file1.c file2.c file3.c
```

```
gcc -c -o file1.o file1.c  
gcc -c -o file2.o file2.c  
gcc -c -o file3.o file3.c  
gcc -o app file1.o file2.o file3.o
```

- It can be annoying to type these out every time you compile...

Build systems

Q: Who has used a build system?

What is a build system?

- Tool/system to automate building software
 - Compilation
 - Packaging
 - Testing

A simple build system

```
---  
build.sh  
---  
#!/bin/bash  
gcc -o myapp src/file1.c src/file2.c src/file3.c src/main.c
```

```
---  
build.sh  
---  
#!/bin/bash  
gcc -o myapp $(find src -name "*.c")
```

```
$ ./build.sh
```

Some issues

- Can be a bit of work to custom write a script, especially with larger projects
- Will blindly compile everything, every time
- What if we made a small change to one file and didn't want to recompile all the code?

Aside: incremental building

- It takes my lab computer about 30 minutes to do a clean build of LLVM and Clang while maxing out my CPU's 8 (logical) cores
 - Hours if I restrict how many cores I give it...
 - Took ~4 hours to clean build Android + camera driver at one of my internships
- Imagine if I had to recompile *everything* every time I made a small code change
- Put together independent bits instead of compiling/building everything every time
- Classic model: C/C++ programs
 - Compile individual C/C++ files into *object code* (`.o` files)
 - *Link* the object code files into the final output executable binary
 - Change only one C/C++ file? Just build the object code for that file, then link the object code
- ...now a simple shell script doesn't seem to cut it

Make

(We'll be focusing on [GNU Make](#) as it's probably the most popular)

- Classic tool that helps with build automation
- Provides more abstractions over a plain shell script
- Invoke it by running `make`
- Will look for a `Makefile` (or `makefile`) to run
 - (it's actually possible to run without a `Makefile`, but we won't really get into that)
- The `Makefile` will specify **rules** that have **prerequisites** that have to be met/built before running its **recipe** to build a **target**

```
target: prerequisites
    recipe # <- actual tab character, not spaces!
```

- Make is able tell if the built **target** file is newer than **prerequisite** files to avoid unnecessarily performing the **recipe**
- The **recipe** consists of shell commands
- `make <target>` will build a specific **target**

Simple example

```
myapp: src/file1.c src/file2.c src/file3.c src/main.c  
      gcc -o myapp src/file1.c src/file2.c src/file3.c src/main.c
```

A bit more sophisticated

```
myapp: src/file1.c src/file2.c src/file3.c src/main.c  
      gcc -o $@ $^
```


Philosophy

- Overall idea is to have **rules** that depend on other **rules** that build smaller bits of the system
 - e.g. building the final executable depends on object code, which depends on corresponding source code files
- This composability means that we can incrementally build our project
 - Invaluable with enormous code bases: don't want to recompile *every* file of the Linux kernel if you made a single line change to one file
- Can have additional rules that run/test/debug the application and clean the directory of build output

Make concepts

Make gives us more abstractions to make our lives easier
It's a pretty deep tool; we're going to look at the basics

- Targets and rules
- "Phony" targets
- Powerful variable assignments
- Functions and other expansions
- Automatic variables
- Pattern matching

Targets and rules

```
target: prerequisites
    recipe # <- actual tab character, not spaces!
```

- **Prerequisite** targets will be built before the **target's recipe** will be able to be run
- The **recipe** consists of shell commands
- **make <target>** will build a specific **target**
- The **target** is assumed to be some actual file that gets produced
- Make is able tell if the built **target** file is newer than **prerequisite** files to avoid unnecessarily performing the **recipe**
- If there are no **prerequisites** and the **target** file is present, the **recipe** won't be run again

"Phony" targets

- What if you have a **target** that you want to be a word/concept?
 - e.g. **clean**, **all**, **test**
- If a file called **clean** or **all** is present, the target won't ever be run
- The **.PHONY** target can specify phony targets that don't have actual files

```
.PHONY: all clean test
```

Variable assignments

- You can define variables in Makefiles as well (you can put spaces around the '='!)
- Often times are things like compilation flags, compiler selection, directories, files etc.
- To use Makefile variables and "expand" them, you use `$(varname)` or `${varname}`
 - Parentheses are more common

Two flavors of variables

- Define how they get assigned and how they get expanded
- `varA = $(varB)` recursively expands the right hand side whenever the variable gets expanded
 - If `varB` gets reassigned after this, an expanded `varA` will expand the current value of `varB`
- `varA := $(varB)` performs a simple expansion, taking on the value of the right hand side at assignment time
 - If `varB` gets reassigned after this, an expanded `varA` will expand to the value of `varB` when `varA` got assigned

Another operator

Functions and other expansions

- There are some functions that can be expanded to help with text manipulation
- `$(wildcard <pattern>)` can expand to a file list for files that match the pattern
 - `$(wildcard *.c)`
- `$(<var>:<pattern>=<replacement>)`, known as a substitution reference, can perform replacements
 - `$(SOURCES:%.c=%.o)`
- `$(shell <commands>)` can run a shell command and expand to the command's output
 - `$(shell find . -name "*.c")`
- There's more as well, check out the manual :)

Automatic variables

- In a rule, Make has some automatically assigned variables
- `$@`: **target**'s file name
- `$<`: First **prerequisite**
- `$?`: All **prerequisites** newer than the target
- `$$`: All **prerequisites**
- ...and more

Using what we've learned so far...

```
CC := gcc
BIN := myapp
SRCS := $(shell find src -name *.c)
$(BIN): $(SRCS)
        $(CC) -o $@ $$
```

Pattern matching

Pattern rules

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

- Uses `%` to match file names
- This example compiles `.c` files into `.o` files
- Note that this is a general rule that applies to all `.o` files
 - This is known as an **implicit rule**

Static pattern rules

```
OBJS := $(SRCS:src/%.c=obj/%.o)  
$(OBJS): obj/%.o : src/%.c  
$(CC) -c -o $@ $<
```

- Can narrow down a pattern rule to a particular list of targets

Make

- This is a brief overview of some of the features of Make
- This is by no means a comprehensive look at Make: refer to the manual for more features and details

Other build systems

- Make is a fairly general build system, but other build systems have more abstractions and may be tailored towards a particular language
- General: Ninja, CMake (actually more of a Makefile generator)
- Java: Ant, Maven, Gradle
- Ruby: Rake
- Continuous integration: Jenkins, Travis CI

Demo time

Time to make one from scratch

Questions?