CSE 303
Concepts and Tools for Software Development

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Lecture 15 – Tools: linker, build scripts, make

Where We Are

- We are done with Linux, shell scripts, and C
- We are in the middle of learning about tools
  - Already completed: preprocessor, debugger
  - Today: libraries, linker, and make
  - Still to come: cvs, gprof

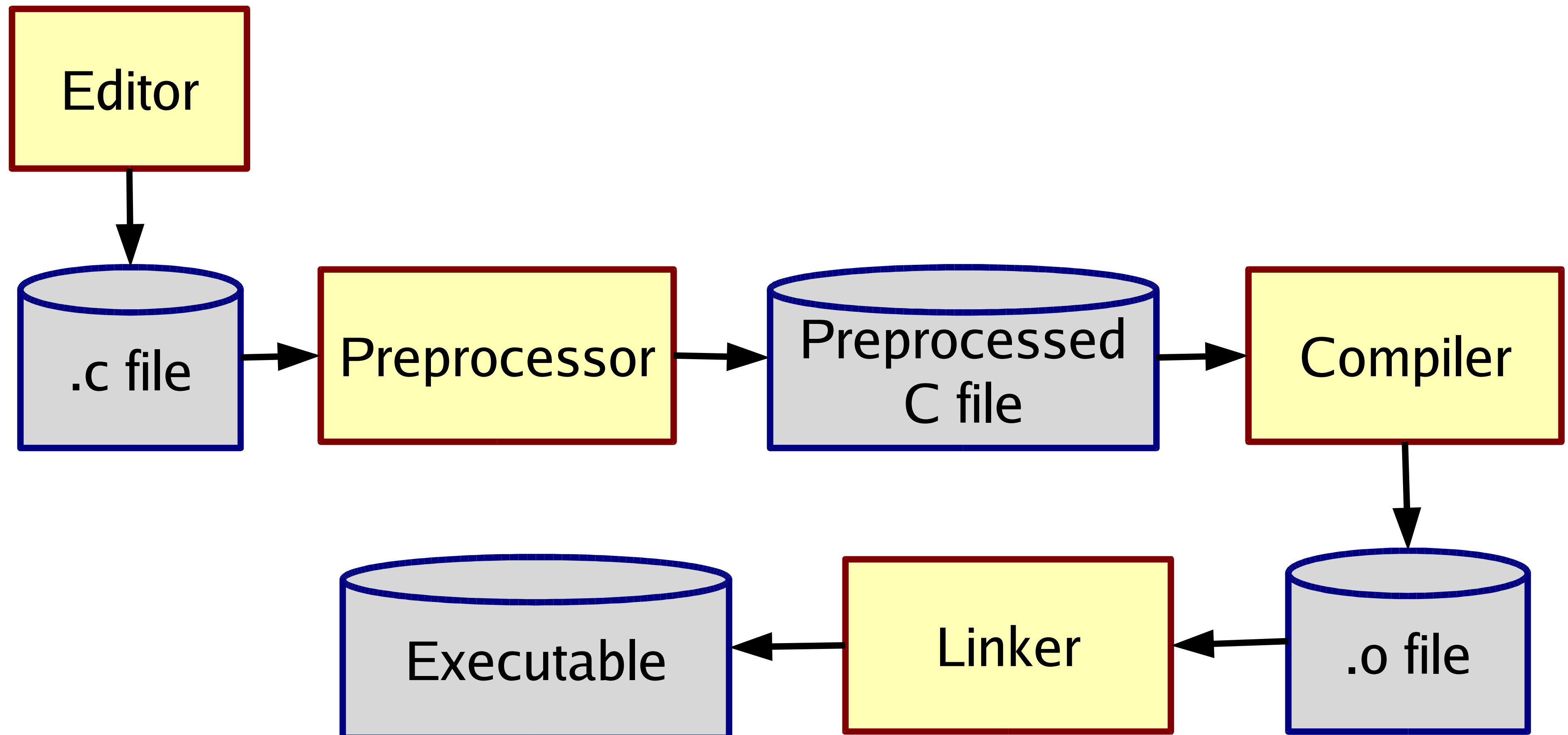
Goal for Today

- At the end of today, you should understand
  - The sequence of operations involved in building an executable and what happens at each step
  - The goal of makefiles
  - Be comfortable writing simple makefiles

- This is not the end of the story
  - Much more to makefiles than what we will show
  - After this class, you should also learn about autoconf and automake

Steps Involved in Creating a C Program

- Review from last lecture

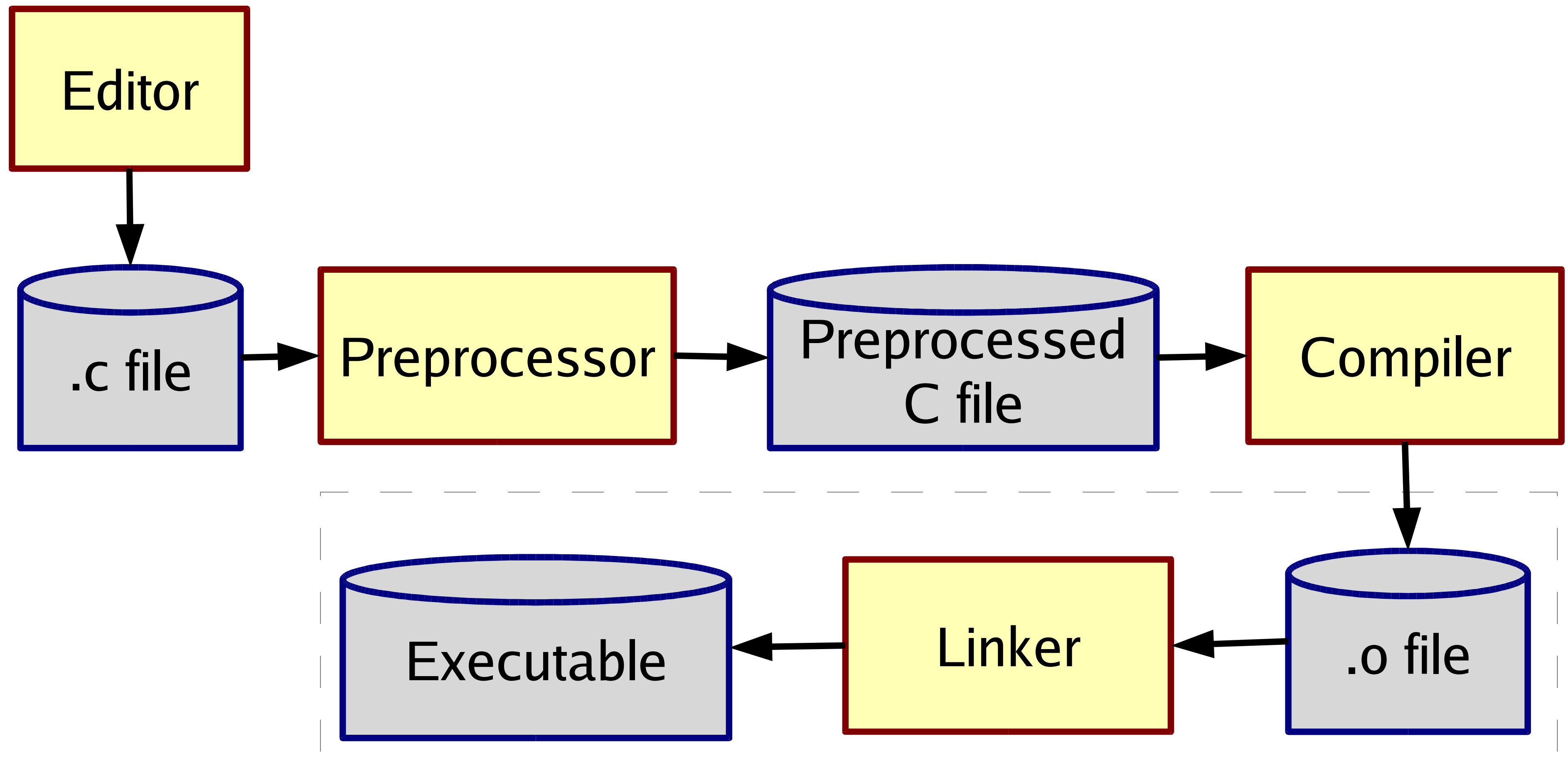


Example

- Program composed of two modules
  - Queue module: `queue.c, queue.h`
  - Main program: `main-queue.c` (uses queue)
- Step 1&2: Preprocess and compile each `.c` file
  - Create `queue.o` and `main-queue.o`
  - `gcc -Wall -g -c queue.c`
  - `gcc -Wall -g -c main-queue.c`
- Step 3: Link files together to create executable
  - `gcc -o main main-queue.o queue.o`

Linking Step

- Linker transforms compiled code (.o files) into executable programs



The Goal of the Linker

- Compiled code (`.o` file) is not "runnable"
- We have to link it with other code to make an executable
  - Where is the code for `printf` and `malloc`?
  - We only included the header files…
  - Need to find that code and put it in executable
  - That is what the linker does
- Normally, gcc/g++ hides this from you

Linking Overview

- If a C/C++ file uses but does not define a function (or global variable), then the `.o` has "undefined references"
  - Note: declarations do not count, only definitions
- Linker takes multiple .o files and "patches them" to include the references
  - Literally moves code and changes instructions like function calls
- Executable has no unresolved references
- Linker is called `ld`, but we will not invoke it directly. We will use `gcc`

Static Linking

- Puts all necessary code into executable
  - The `.o` files are no longer needed after linking
- Note: use option `-static` to also force the use of static linking for standard libraries
- Example: our queue test program
  - `gcc -static -o main main-queue.o queue.o`
  - (try linking with and without the `-static` option and see the difference in size of your executable)

Creating a Static Library

- Create with `ar` (stands for "archiver")
  - `ar rc libdata.a queue.o stack.o`
  - Creates a static library named `libdata.a` and puts copies of object files `queue.o` and `stack.o` in it
  - If `libdata.a` exists, adds or replaces files in it
- Index the archive: `ranlib libdata.a`
  - Same as running `ar` with option `-s`
  - Improves performance during linking
  - Order inside the archive will no longer matter

Static Linking with Library

- Linking with library `libdata.a`

```
gcc -o main main-queue.o -L. -ldata
gcc -static -o main main-queue.o -L. -ldata
```

- Gcc will automatically link your executable with
  - `libgcc.a`
  - `libc.a` for C
  - `libstdc++.a` for C++
- Compile/link with option `-v` to see details

Static Linking Step-by-Step

- Begin: "Set of needed undefined functions" empty
- Action for .o file:
  - Include code in result
  - Remove all defined functions from set
  - Add to set all functions used but not yet defined
- Action for .a file: For each .o in order
  - If defines a needed function, proceed as above
  - Else skip
- End: If set of needed undefined functions empty, create executable, else error

Library Gotchas

- Position of `-ldata` on command-line matters
  - Discover and resolve references in order
  - So typically list libraries after all object files
- Cycles
  - If two `.a` files need each other, you might need

    `-lfoo -lbar -lfoo ...`
- If you include `math.h`, you'll need `-lm`
- Cannot have repeated function names

Summary of Building an Executable

Step1: Compile

Step2: Create Libraries

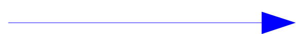
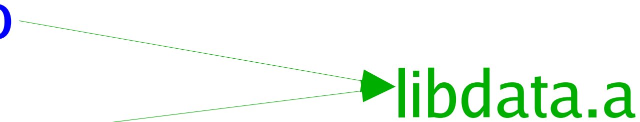
Step3: Link

Source Files

Object Files

Static Libraries

Executable

queue.c  queue.o  libdata.a

stack.c stack.o

main-queue.c main-queue.o main

libgcc.a

libc.a

...

```
gcc -c queue.c
gcc -c stack.c
gcc -c main-queue.c
```

`-I` specifies location of header files

```
ar rcs libdata.a stack.o queue.o
```

```
gcc -static -o main main-queue.o -L. -ldata
```

Dynamic Linking

- Static linking has disadvantages
  - More disk space, more memory when programs run
- Instead can use
  - Shared libraries (extension `.so`)
    - Link in when program starts executing
    - Saves disk space and memory
  - Dynamically linked/loaded libraries (while running)
- To experiment, link `main` with no option or with `-static`, or `-shared-libgcc`
  - In between commands execute: `ldd main`
  - And also check the size of `main`

Linking and Libraries Summary

- Main steps when building executable
  - Preprocessing (specific to C)
  - Compiling
  - Linking
- Process can get complex for large systems
  - Definitely don't want to do manually each time
  - Would like to automate the process... Makefile
- Know about potential problems. Learn how to solve them as you encounter them

The Java story

- Compiling: `javac` transforms `.java` into `.class`
  - One file at the time: `A.java`, `B.java`, etc.
  - Need to find and compile other referenced classes
    - `CLASSPATH`, `-classpath`, and system defaults
- Running: `java` is just a program that find `A.class` and knows what to do
  - Interpretation or just-in-time compilation
  - But, needs to find other classes too (`.class, .jar`)
  - Load classes lazily when needed during execution
  - Jar files are equivalent of libraries

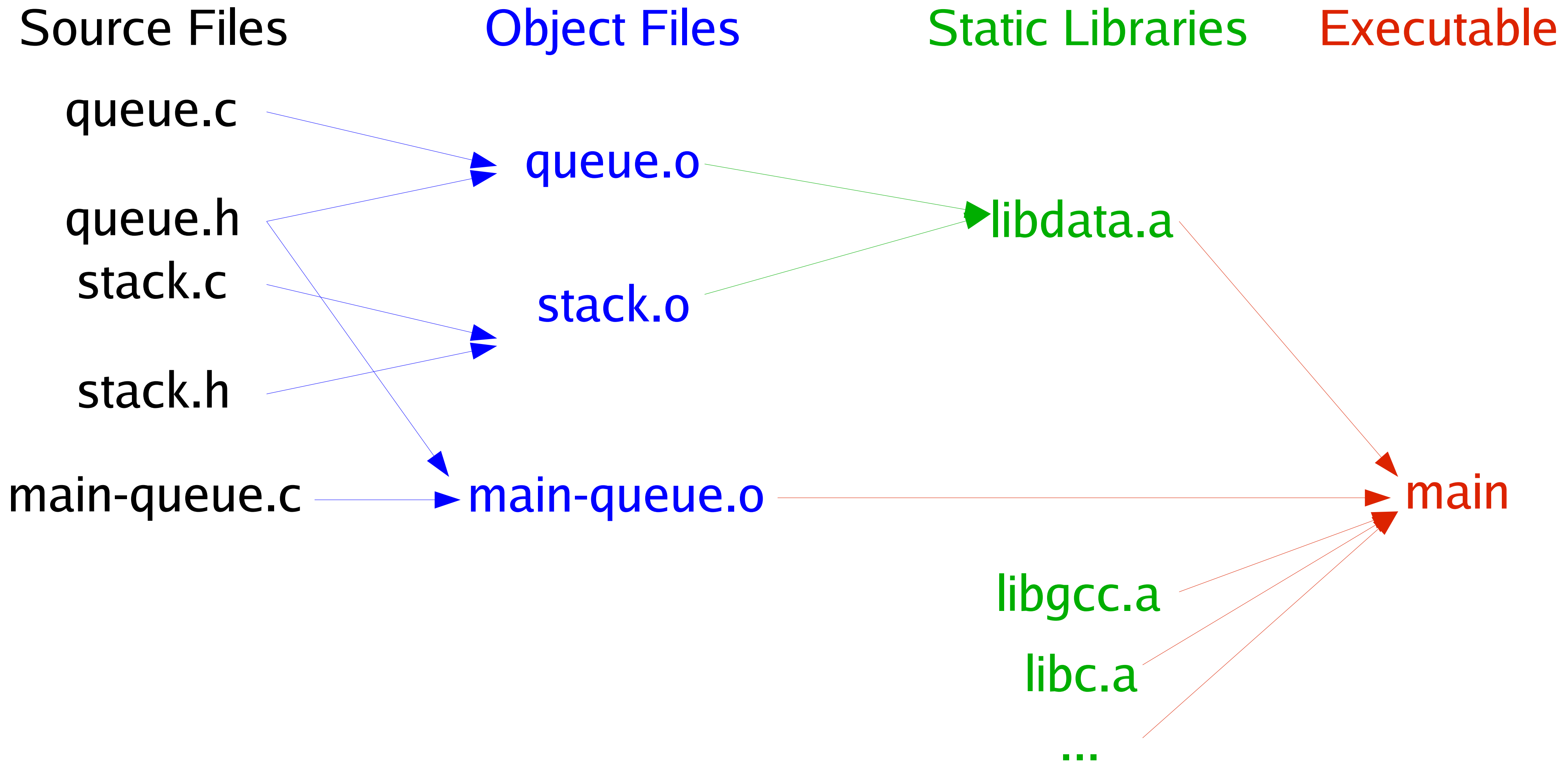
Make

- Two main goals
  - Automate the build process with a script
  - When a source file changes, rebuild only what is needed: keep track of *dependencies*
- Why?
  - Do not want to retype long, complex commands
  - Easier for others to build the system
  - Want to shorten build time
- Especially important for large systems

Recompilation Management

- The "theory" behind avoiding unnecessary compilation is a "dependency graph"
- To create target t, need
  - Sources $s_1, s_2, ..., s_n$ and a command a
- If t newers than all s_i, assume no reason to rebuild it
- Otherwise, recursive rebuild
  - If s_i is itself a target, check if need to rebuild it
  - If need to rebuild, use the given command a

Dependency Graph Example



Basic Idea Behind a Makefile

- Enables us to define targets & dependencies
- In form of triples: target, source, command(s)

```
target: sources (aka dependencies)
        command1
        command2
        ...
queue.o: queue.c queue.h
         gcc -Wall -c queue.c
```

- Warning: command lines must start with TAB
- If a command spans multiple lines, use \

Make

- On the command line

  `make -f nameOfMakefile target`

- Defaults
  - If no `-f`, looks for a file named `Makefile`
  - If no target specified, uses first target in the file
- The make utility
  - Examines the dependency graph
  - Examines the file-modification times
  - Recursively decides what to rebuild
  - Note: make is **language independent** (java, c, latex)

Standard Targets

- all: make everything

```
all: main-queue main-stack
```

- clean: remove any generated files, to “start over” and have just the source

```
clean:
    rm -f *.o main-queue main-stack
```

- Phony targets: “all” and “clean” never exist

Variables

- We have seen the basics, now let's get more sophisticated with our Makefiles
- You can define variables in a Makefile

```
OBJ = main-stack.o stack.o
main-stack: $(OBJ)
	gcc -o main-stack $(OBJ)
```

- Help avoid error-prone duplications
  - List of object files
  - List of executables
- In make, variables are often called macros

Readings

- Programming in C
  - Chapter 15 and Appendix C
- Make/Makefile tutorials
  - http://palantir.swarthmore.edu/maxwell/classes/tutorials/maketutor/
  - http://www.gnu.org/software/make/manual/make.html
  - http://www.eng.hawaii.edu/Tutor/Make/
- Extra references: man pages for gcc, ranlib, ar, ld
- In the future (no need to read for this class)
  - autoconf/automake: http://www.gnu.org/manual/