Final C Details, Build Tools

CSE 333 Spring 2018

Instructor: Justin Hsia

Teaching Assistants:

Danny Allen	Dennis Shao	Eddie Huang
Kevin Bi	Jack Xu	Matthew Neldam
Michael Poulain	Renshu Gu	Robby Marver
Waylon Huang	Wei Lin	

Administrivia

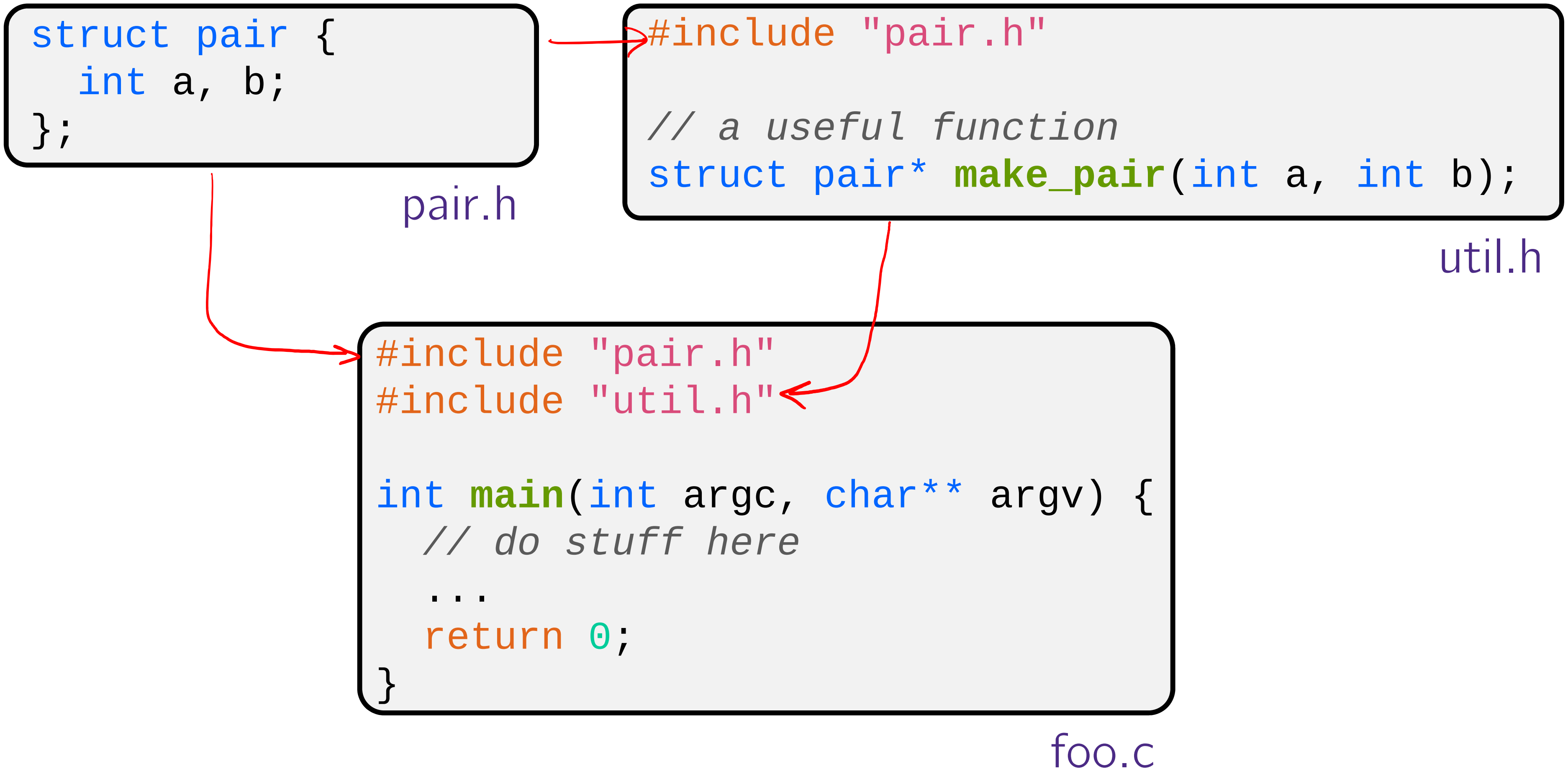
- Exercise 5 posted yesterday, due Monday
- Homework 1 due on Thursday (4/12)
    - Watch that `hashtable.c` doesn't violate the modularity of `ll.h`
    - Watch for pointer to local (stack) variables
    - Use a debugger (*e.g.* `gdb`) if you're getting segfaults
    - Advice: clean up "to do" comments, but leave "step #" markers for graders
    - Late days: don't tag `hw1-final` until you are really ready
    - Extra Credit: if you add unit tests, put them in a new file and adjust the Makefile

Lecture Outline

- **Header Guards and Preprocessor Tricks**
- Visibility of Symbols
  - `extern`, `static`
- Make and Build Tools

A Problem with #include

- What happens when we compile `foo.c`?



```c
struct pair {
  int a, b;
};
```

pair.h

```c
#include "pair.h"

// a useful function
struct pair* make_pair(int a, int b);
```

util.h

```c
#include "pair.h"
#include "util.h"

int main(int argc, char** argv) {
  // do stuff here
  ...
  return 0;
}
```

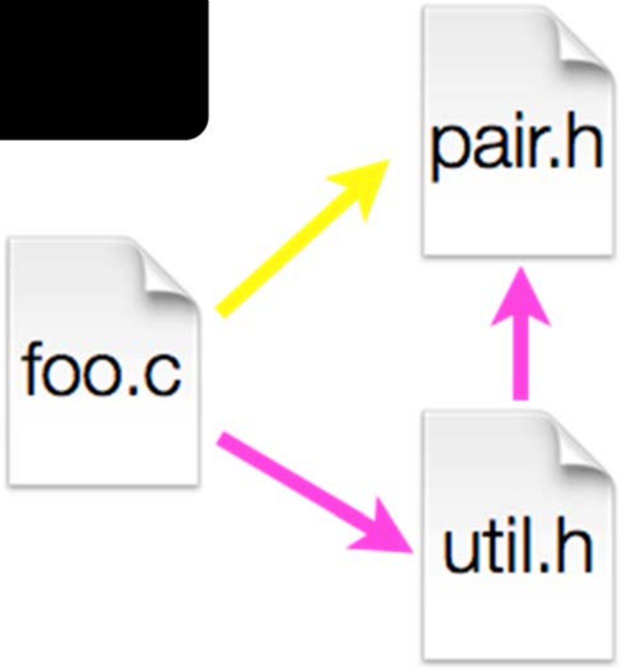
foo.c

A Problem with #include

- What happens when we compile `foo.c`?

```
bash$ gcc -Wall -g -o foo foo.c
In file included from util.h:1:0,
                 from foo.c:2:
pair.h:1:8: error: redefinition of 'struct pair'
 struct pair { int a, b; };
        ^
In file included from foo.c:1:0:
pair.h:1:8: note: originally defined here
 struct pair { int a, b; };
        ^
```

- `foo.c` includes `pair.h` twice!
  - Second time is indirectly via `util.h`
  - Struct definition shows up twice
    - Can see using `cpp`



Header Guards

- A commonly-used C Preprocessor trick to deal with this
  - Uses macro definition (`#define`) in combination with conditional compilation (`#ifndef` and `#endif`)

```c
#ifndef _PAIR_H_
#define _PAIR_H_

struct pair {
  int a, b;
};

#endif   // _PAIR_H_
```

pair.h

```c
#ifndef _UTIL_H_
#define _UTIL_H_

#include "pair.h"

// a useful function
struct pair* make_pair(int a, int b);

#endif   // _UTIL_H_
```

even if #included twice, header guard _PAIR_H_ saves us!

util.h

Other Preprocessor Tricks

- A way to deal with "magic constants"

```c
int globalbuffer[1000];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * 3.1415;
  *area = rad * 3.1415 * 3.1415;
}
```

Bad code
(littered with magic constants)

```c
#define BUFSIZE 1000
#define PI 3.14159265359

int globalbuffer[BUFSIZE];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * PI;
  *area = rad * PI * PI;
}
```

Better code

Macros

- You can pass arguments to macros

```
#define ODD(x) ((x) % 2 != 0)

void foo() {
  if ( ODD(5) )
    printf("5 is odd!\n");
}
```

cpp

```
void foo() {
  if ( ((5) % 2 != 0) )
    printf("5 is odd!\n");
}
```

treated as just text

- Beware of operator precedence issues!
  - Use parentheses

```
#define ODD(x) ((x) % 2 != 0)
#define WEIRD(x) x % 2 != 0

ODD(5 + 1);

WEIRD(5 + 1);
```

cpp

```
((5 + 1) % 2 != 0);

5 + 1 % 2 != 0;
```

Conditional Compilation

❖ You can change what gets compiled:

#ifdef = "if defined"
#ifndef = "if not defined"

```
#ifdef TRACE
#define ENTER(f) printf("Entering %s\n", f);
#define EXIT(f)  printf("Exiting  %s\n", f);
#else
#define ENTER(f)
#define EXIT(f)
#endif

// print n
void pr(int n) {
  ENTER("pr");
  printf("\n = %d\n", n);
  EXIT("pr");
}
```

ifdef.h

Defining Symbols

- Besides `#define`s in the code, preprocessor values can be given as part of the `gcc` command:

```
bash$ gcc -Wall -g -DTRACE -o ifdef ifdef.c
```

-D define

-U undefine

- assert can be controlled the same way – defining NDEBUG causes assert to expand to "empty"
  - It's a macro – see `assert.h`

```
bash$ gcc -Wall -g -DNDEBUG -o faster useassert.c
```

Peer Instruction Question

- What will happen when we try to compile and run?
  - Vote at http://PollEv.com/justinh

```
bash$ gcc -Wall -D~~F~~OO -D~~B~~AR -o condcomp condcomp.c
bash$ ./condcomp
```

FOO and BAR are defined

A. Output "333"

[✓ B. Output "334"]

C. Compiler message about EVEN

D. Compiler message about BAZ

E. We're lost…

```
#include <stdio.h>
#ifdef FOO                    ← yes
✓ #define EVEN(x) !(x%2)
#endif
#ifndef DBAR                  ← no
✓ #define BAZ 333
#endif
                                  evaluates to !0 = 1
int main(int argc, char** argv) {
            !(42%2)          333
  int i = ~~EVEN(42)~~ + ~~BAZ~~;
  printf("%d\n",i);
  return 0;
}
```

Lecture Outline

- Header Guards and Preprocessor Tricks
- **Visibility of Symbols**
  - **`extern`, `static`**
- Make and Build Tools

Namespace Problem

- If I define a global variable named "counter" in one C file, is it visible in another C file in my program?
  - Yes, if you use external linkage
    - The name "counter" refers to the same variable in both files
    - The variable is *defined* in one file and *declared* in the other(s)
    - When the program is linked, the symbol resolves to one location
  - No, if you use internal linkage
    - The name "counter" refers to different variable in each file
    - The variable must be *defined* in each file
    - When the program is linked, the symbols resolve to two locations

External Linkage

- `extern` makes a *declaration* of something externally-visible

```c
#include <stdio.h>

// A global variable, defined and
// initialized here in foo.c.
// It has external linkage by
// default.
int counter = 1;

int main(int argc, char** argv) {
  printf("%d\n", counter);
  bar();
  printf("%d\n", counter);
  return 0;
}
```

foo.c

```c
#include <stdio.h>

// "counter" is defined and
// initialized in foo.c.
// Here, we declare it, and
// specify external linkage
// by using the extern specifier.
extern int counter;

void bar() {
  counter++;
  printf("(b): counter = %d\n",
         counter);
}
```

bar.c

Internal Linkage

this program will print:

```
1
(b): counter = 100
1
```

- `static` (in the global context) restricts a definition to visibility within that file

```c
#include <stdio.h>

// A global variable, defined and
// initialized here in foo.c.
// We force internal linkage by
// using the static specifier.
static int counter = 1;

int main(int argc, char** argv) {
  printf("%d\n", counter);
  bar();
  printf("%d\n", counter);
  return 0;
}
```

foo.c

```c
#include <stdio.h>

// A global variable, defined and
// initialized here in bar.c.
// We force internal linkage by
// using the static specifier.
static int counter = 100;

void bar() {
  counter++;
  printf("(b): counter = %d\n",
         counter);
}
```

bar.c

Function Visibility

bar.c

```c
// By using the static specifier, we are indicating
// that foo() should have internal linkage.  Other
// .c files cannot see or invoke foo().
static int foo(int x) {
  return x*3 + 1;
}

// Bar is "extern" by default.  Thus, other .c files
// could declare our bar() and invoke it.
int bar(int x) {
  return 2*foo(x);
}
```

bar() can invoke foo() because in same file

main.c

```c
#include <stdio.h>

extern int bar(int x);

int main(int argc, char** argv) {
  printf("%d\n", bar(5));
  return 0;
}
```

not explicitly needed, but indicates that definition is elsewhere

Linkage Issues

- Every global (variables and functions) is `extern` by default
  - Unless you add the `static` specifier, if some other module uses the same name, you'll end up with a collision!
    - Best case: compiler (or linker) error
    - Worst case: stomp all over each other

- It's good practice to:
  - Use `static` to "defend" your globals
    - Hide your private stuff!
  - Place external declarations in a module's header file
    - Header is the public specification

Static Confusion…

- C has a *different* use for the word "`static`": to create a persistent *local* variable
  - The storage for that variable is allocated when the program loads, in either the `.data` or `.bss` segment (Static Data)
  - Retains its value across multiple function invocations

```
void foo() {
  static int count = 1; // persists
  printf("foo has been called %d times\n", count++);
}

void bar() {
  int count = 1;  // re-initialized each time
  printf("bar has been called %d times\n", count++);
}

int main(int argc, char** argv) {
  foo(); foo(); bar(); bar(); return 0;
} 1 times    2 times    1 times    1 times
```

static_extent.c

Additional C Topics

- Teach yourself!
  - **man pages** are your friend!
  - String library functions in the C standard library
    - `#include <string.h>`
      - strlen(), strcpy(), strdup(), strcat(), strcmp(), strchr(), strstr(), …
    - `#include <stdlib.h>` or `#include <stdio.h>`
      - atoi(), atof(), sprint(), sscanf()
  - How to declare, define, and use a function that accepts a variable-number of arguments (`varargs`)
  - `union`s and what they are good for
  - `enum`s and what they are good for
  - Pre- and post-increment/decrement
  - Harder: the meaning of the "`volatile`" storage class

Lecture Outline

- Header Guards and Preprocessor Tricks
- Visibility of Symbols
  - `extern`, `static`
- **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`, "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
  - Both programs that they write and other people write

- Programmers like to automate repetitive tasks
  - Repetitive: `gcc -Wall -g -std=c11 -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

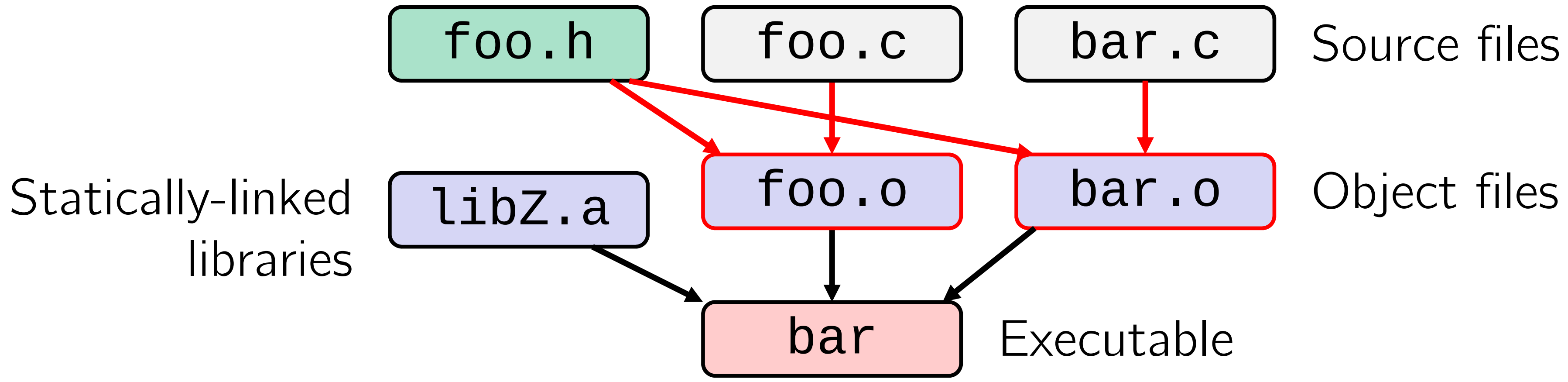
- On larger projects, you can't or don't want to have one big (set of) command(s) that redoes everything every time you change anything:
  1) If `gcc` didn't combine steps for you, you'd need to preprocess, compile, and link on your own (along with anything you used to generate the C files)
  2) If source files have multiple output (*e.g.* javadoc), you'd have to type out the source file name multiple times
  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

Recompilation Management

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

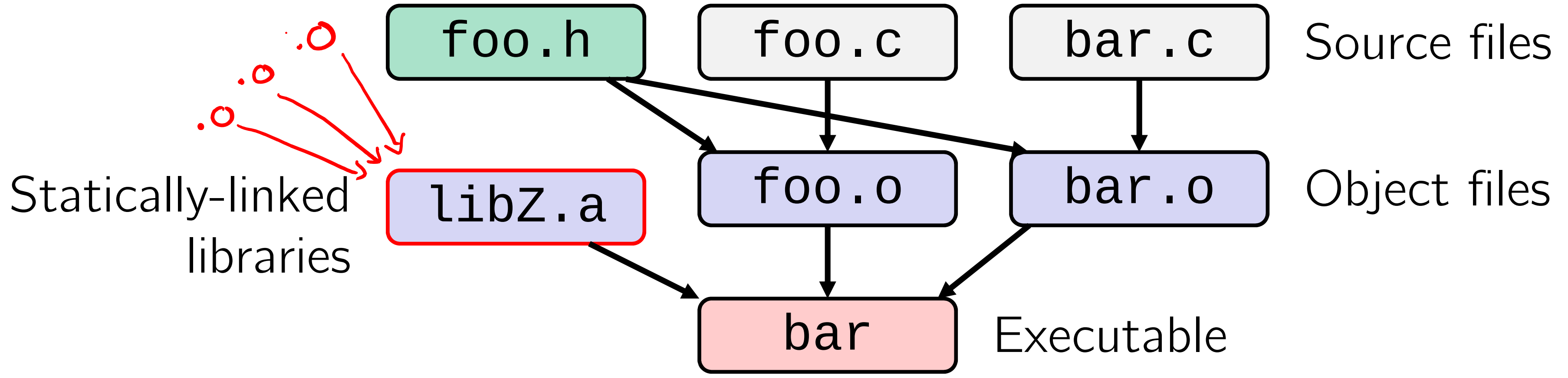
- To create a target $\overset{\textcircled{1}}{t}$, you need sources $\overset{\textcircled{2}}{s_1}, s_2, \ldots, s_n$ and a command $\overset{\textcircled{3}}{c}$ that directly or indirectly uses the sources
  - It t is newer than every source (file-modification times), assume there is no reason to 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 C



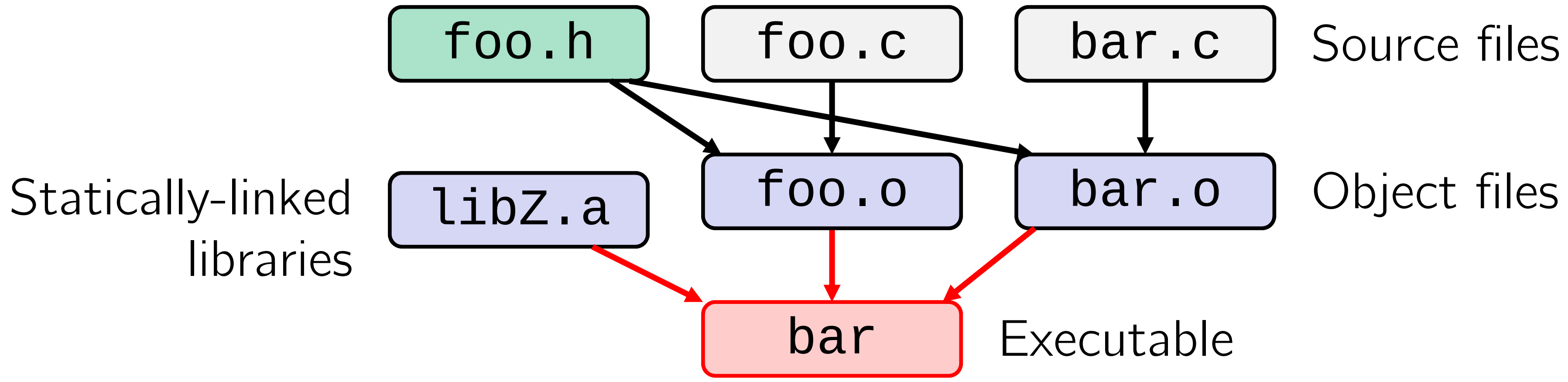
- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)

Theory Applied to C



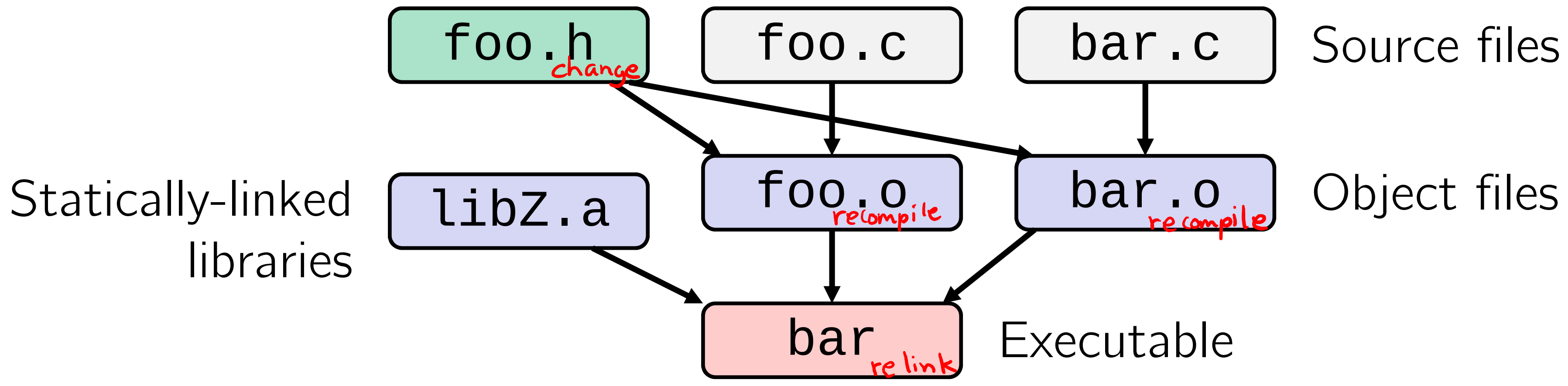
- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)
- An archive (library, `.a`) depends on included `.o` files

Theory Applied to C



- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)
- An archive (library, `.a`) depends on included `.o` files
- Creating an executable ("linking") depends on `.o` files and archives
  - Archives linked by `-L<path> -l<name>` (*e.g.* `-L. -lfoo` to get `libfoo.a` from current directory)

Theory Applied to C



- If one `.c` file changes, just need to recreate one `.o` file, maybe a library, and re-link
- If a `.h` file changes, may need to rebuild more
- Many more possibilities!

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 SPACES
  - 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
```

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=c11
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 (`CFLAGS=-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 *~
```

- `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

bash $ make all
checks every target!

```
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...
```

① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Writing A Makefile Example

- "talk" example (if time)

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

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

- Write a program that:
  - Prompts the user to input a string (use `fgets()`)
    - Assume the string is a sequence of whitespace-separated integers (*e.g.* `"5555 1234 4 5543"`)
  - Converts the string into an array of integers
  - Converts an array of integers into an array of strings
    - Where each element of the string array is the binary representation of the associated integer
  - Prints out the array of strings

Extra Exercise #2

- 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