C Wrap Up

Introduction to Computer Systems, Fall 2024

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- How are you? Any Questions from last lecture?

Upcoming Due Dates

- HW01 (Approx): Due This Past Friday
  - Remember, you can do it ***later in the semester***
  - don't fall behind please
- HW02 (C Strings!): Due This Friday
  - If you didn't get c-strings and how to use the heap you will after this!
- ***The lecture check was due right before lecture***!
  - No extensions except under extenuating circumstances
  - "I forgot" is not extenuating circumstances
  - ***They are always due right before Tuesday's Lecture!***

Recitation

- Wednesday's 4PM – 5PM
  - DRL 3C6
- Had about 10-15 Students…not bad
- Super useful if you need any extra help or want to review topics
- GDB, Valgrind, Makefiles, and etc. covered this week!
- There isn't enough time in lecture to cover these things in more depth; please go if you are still confused!

Lecture Outline

- Building a C-Program
  - Preprocessor
  - Single Program
  - Multi-File Program (Linking

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  - Multi-File Program (Linking)
- Recompilation
- Makefiles
  - Basics, Targets, Rules
  - Variables
  - Phony Targets
- Files (i/o)
  - Reading and writing to the terminal
- Generics
  - Void *

Building a C Program

```c
#define ten 10

int add(int x, int y, int z){
    return x + y + z;
}
int main(int argc, char *argv[]){
    int x = ten;
    int y = 11;
    int z = 12;
    int sum = ten; //comment here
    return 0;
}
```

small.c

- We can now compile C-programs from scratch!
- But what really happens during compilation?

```
clang-15 -Wall -save-temps -g3 -o small small.c
```

- -Wall
  - All warnings! (Produced the ~(!x) warning in HW02)
- -g / -g3
  - Compile and make it debuggable (-g3 means MAX debug info)

Building a C Program

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    return x + y + z;
}
int main(int argc, char *argv[]){
    int x = ten;
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small.c

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- But what really happens during compilation?

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- -save-temps
  - Saves all temporary files created during compilation

Building a C Program

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int main(int argc, char *argv[]){
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    int z = 12;
    int sum = ten; //comment here
    return 0;
}
```

small.c

- -save-temps
  - Saves all temporary files created during compilation

```
-rwxr-xr-x 1 root root 10472 Sep 16 11:43 small
-rw-r--r-- 1 root root  2868 Sep 16 11:43 small.bc
-rw-r--r-- 1 root root   169 Sep 16 11:42 small.c
-rw-r--r-- 1 root root   255 Sep 16 11:43 small.i
-rw-r--r-- 1 root root  3328 Sep 16 11:43 small.o
-rw-r--r-- 1 root root 13499 Sep 16 11:43 small.s
```

C Preprocessor: small.i

- The C preprocessor is run over each source file in your program before it is passed to the compilation stage
  - The preprocessor stage handles various tedious text based operations.
- Some common preprocessor commands
  - #define – substitute the string literal with the following string
  - #include – literally include a file at this location

C Preprocessor: small.i

- Conditional compilation
  - you can include or exclude parts of the program according to various conditions.

```
#ifndef FILE_FOO_SEEN
#define FILE_FOO_SEEN

 the entire file

#endif /* FILE_FOO_SEEN */
```

The C preprocessor is programmed to notice when a header file uses this particular construct and handle it efficiently.

If a header file is contained entirely in a ”#ifndef” conditional, then it ***records that fact***.

If a subsequent ”#include” specifies the same file, and the macro in the ”#ifndef” is already defined, then the file is entirely skipped, without even reading it.

`#include` and the C Preprocessor

- The C preprocessor (`cpp`) transforms your source code before the compiler runs – it's a simple copy-and-replace text processor(!) with a memory
  - Input is a C file (text) and output is still a C file (text)
  - Processes the directives it finds in your code (`#directive`)
    - *e.g.* `#include <ll.h>` is replaced by the post-processed content of `ll.h`
    - *e.g.* `#define str 'hi!'` defines a symbol (a string!) and replaces later occurrences
    - Several others that we'll see soon…
  - Run on your behalf by `clang` during compilation
  - Note: `#include <foo.h>` looks in system (library) directories; `#include "foo.h"` looks first in current directory, then system

#include and the C Preprocessor

- We can manually run the preprocessor:
  - `cpp` is the preprocessor (can also use `clang -E`)
  - "`-P`" option suppresses some extra debugging annotations

```
#define BAR 2 + FOO

typedef long long int verylong;
```

cpp_example.h

```
#define FOO 1

#include "cpp_example.h"

int main(int argc, char** argv) {
  int x = FOO;    // a comment
  int y = BAR;
  verylong z = FOO + BAR;
  return 0;
}
```

cpp_example.c

```
bash$ cpp -P cpp_example.c out.c
bash$ cat out.c
```

C-Preprocessor Changes

small.c

```c
#define ten 10

int add(int x, int y, int z){
    return x + y + z;
}
int main(int argc, char *argv[]){
    int x = ten;
    int y = 11;
    int z = 12;
    int sum = ten; //comment here
    return 0;
}
```

small.i

```c
int add(int x, int y, int z){
    return x + y + z;
}
int main(int argc, char *argv[]){
    int x = 10;
    int y = 11;
    int z = 12;
    int sum = add(x, y, z);
    return 0;
}
```

Define macro is gone

'ten' is replaced with defined value

Comment is gone

Poll Everywhere

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- How many changes will be made after the preprocessor step?

```c
// Define a constant
#define MAX_SIZE 100

/* Define a macro for a greeting message */
#define GREETING "Hello, World!"

int main() {
    // Print a greeting message
    printf("%s\n", GREETING);

    // Print the maximum size
    printf("The maximum size is: %d\n", MAX_SIZE);

    /*
     * why did I become a programmer? Pls help.
     */

    return 0;
}
```

A. 5

B. 9

C. 10

D. 8

E. wtf

Poll Everywhere

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- How many changes will be made after the preprocessor step?

```c
// Define a constant
#define MAX_SIZE 100

/* Define a macro for a greeting message */
#define GREETING "Hello, World!"

int main() {
    // Print a greeting message
    printf("%s\n", GREETING);

    // Print the maximum size
    printf("The maximum size is: %d\n", MAX_SIZE);

    /*
     * why did I become a programmer? Pls help.
     */

    return 0;
}
```

A. 5

B. 9

C. 10

D. 8

E. wtf

Preprocessor: #include <stdlib.h>

- Including standard libraries instructs the preprocessor to *literally include the entire header file.*
- *Let's see this in action.*

Quick Aside: small.s

- The Assembly Language version of the file.
  - X86 (Intel Processors, e.g.)
  - Arm (M1 Chips, Raspberry Pi's, etc)
- We'll talk more about Assembly very soon!
  - (in a couple of weeks)

```
main:
.Lfunc_begin1:
        .loc    1 6 0 is_stmt 1
        .cfi_startproc
// %bb.0:
        sub     sp, sp, #64
        .cfi_def_cfa_offset 64
        stp     x29, x30, [sp, #48]
        add     x29, sp, #48
        .cfi_def_cfa w29, 16
        .cfi_offset w30, -8
        .cfi_offset w29, -16
        mov     w8, wzr
        str     w8, [sp, #12]
        stur    wzr, [x29, #-4]
        stur    w0, [x29, #-8]
        stur    x1, [x29, #-16]
        mov     w8, #10
```

Yup, it's ugly. I know

Multiple File Compilation (Linking)

- More complex programs require multiple files.
- Even printing to the terminal requires the import of the standard library
  - ***#include <stdio.h>*** `for` ***printf***
- Your own string library implementations will be ***#included*** in files which refer to those functions.

Multiple File Compilation (Linking)

utils.h

```
#ifndef UTILS_H
#define UTILS_H
```

utils.c

```
#include ”utils.h"

int fun1(int x, int y){
}
int fun2(int x, int y){
  ...
}
```

- Helper libraries don’t have a main function to “enter from”.
- These .c and .h files can still be partially compiled to have code for the subroutines defined here.
  - -c flag is used for partial compilation
  - ***clang-15 –c utils.c***
- This creates .o or .obj files.

Multiple File Compilation (Linking)

utils.h

```
#ifndef UTILS_H
#define UTILS_H
```

utils.c

```
#include "utils.h"

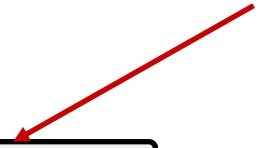
int fun1(int x, int y){
}
int fun2(int x, int y){
  ...
}
```

prog.c

```
#include "utils.h"

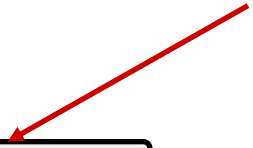
int main(int argc, char *argv[]){
    fun1(10, 11);
    fun2(11, 12);
}
```

clang-15 –c utils.c



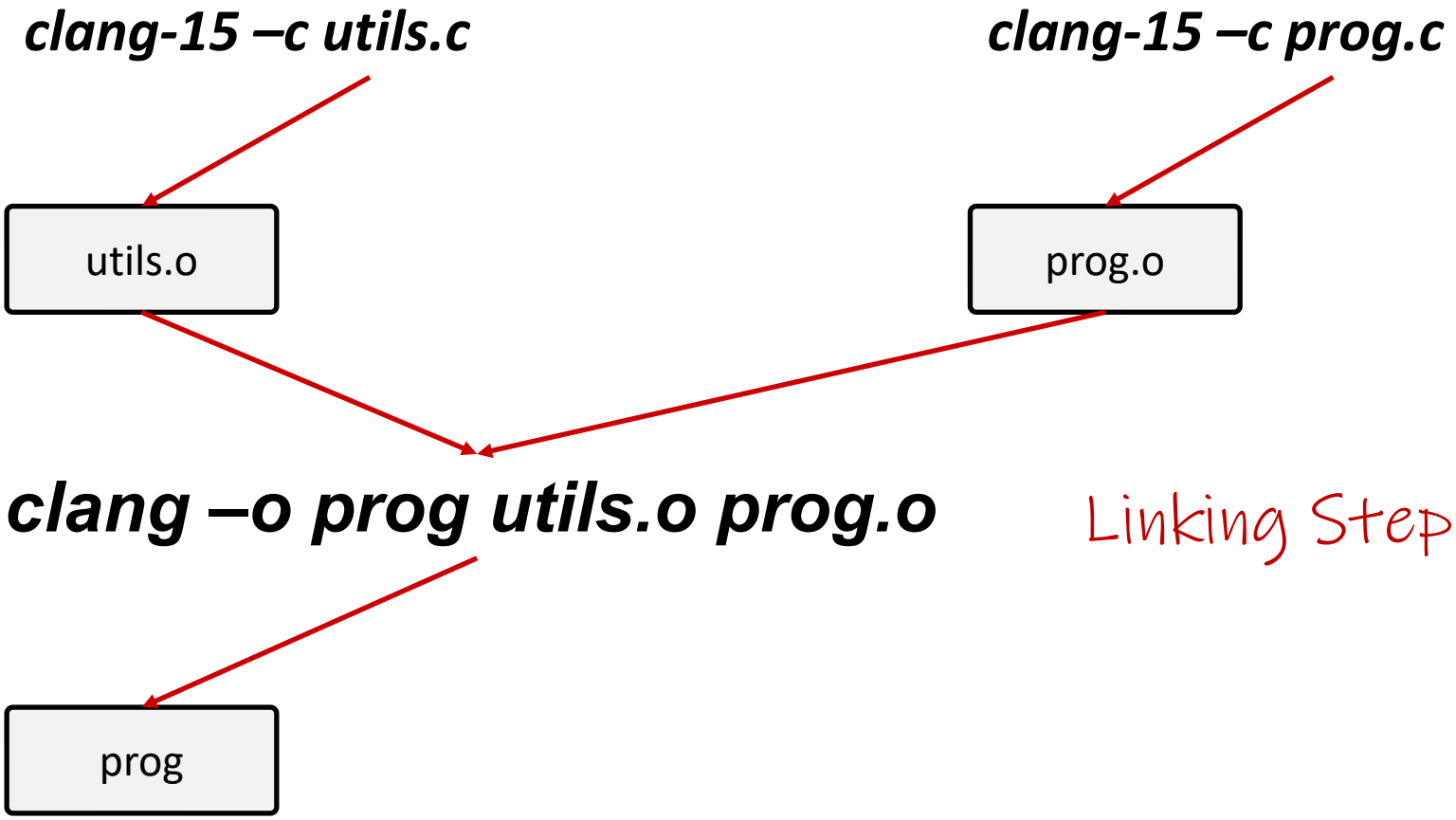
utils.o

clang-15 –c prog.c



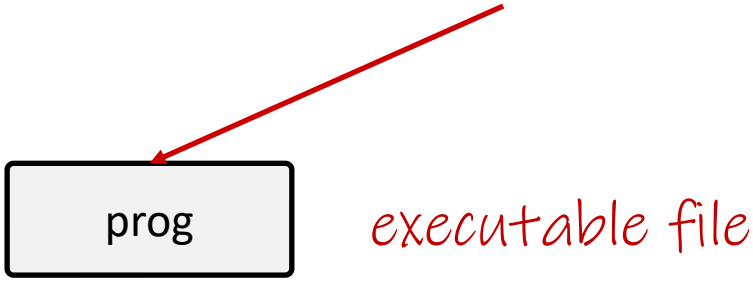
prog.o

Multiple File Compilation (Linking)



Multiple File Compilation (Linking)

clang –o prog utils.o prog.o Linking Step



- a program is combined with all of the libraries it calls to produce the final executable program.
- To do this the linker needs to find the code for every function that is called in the program and ***link*** them together appropriately to produce the final executable binary file.

Lecture Outline

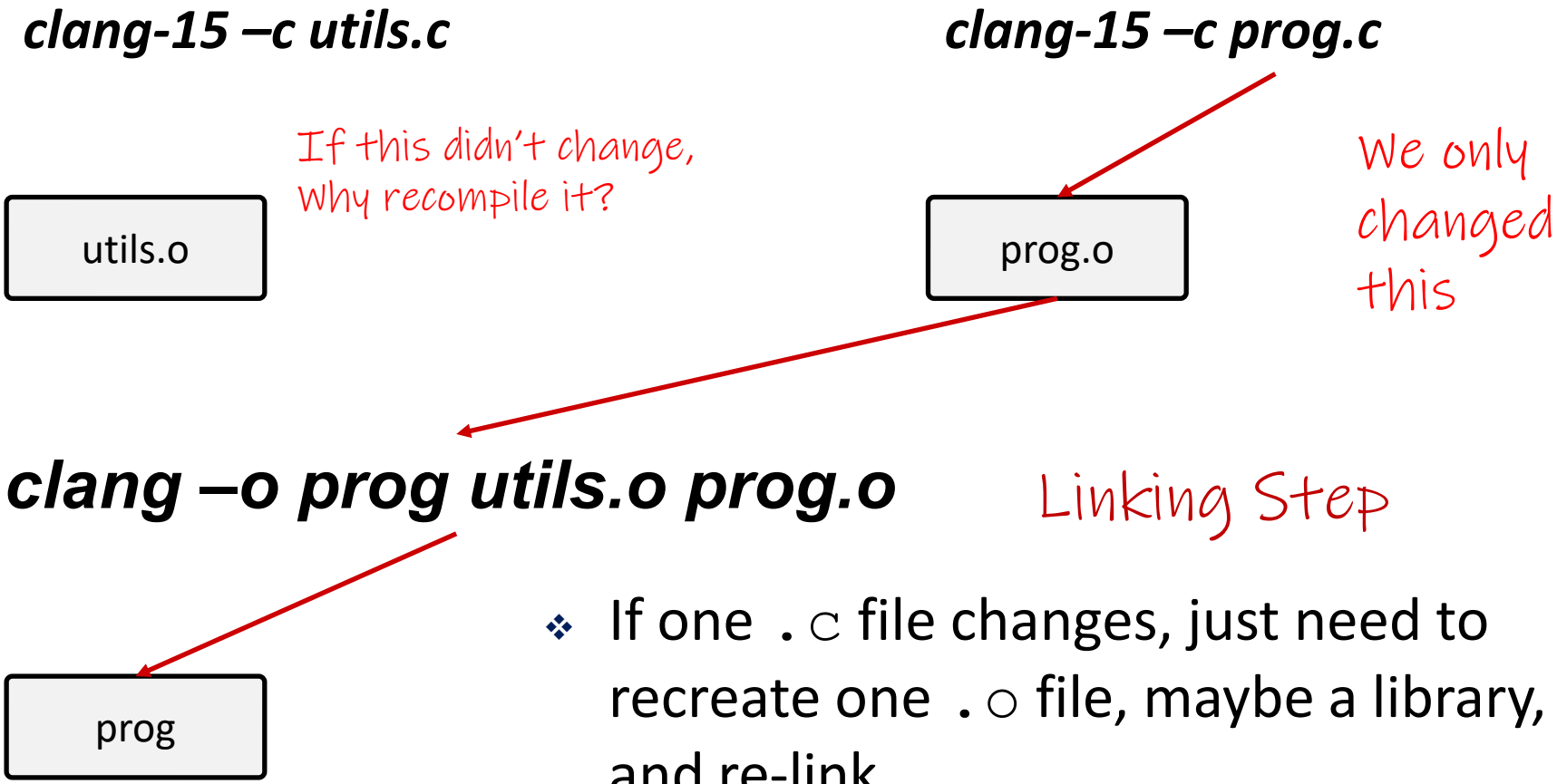
- Building a C-Program
  - Preprocessor
  - Single Program
  - Multi-File Program (Linking)
- Recompilation
- Makefiles
  - Basics, Targets, Rules
  - Variables
  - Phony Targets
- Files (i/o)
  - Reading and writing to the terminal
- Generics
  - Void *

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"!

Recompilation



- 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

Lecture Outline

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Makefiles

- The ***make*** tool was used to simplify the development and building of multiple files.
- Allows you to specify dependencies between source files in your project and indicates how they should be compiled to produce the ***final result***
- Think of the Makefile as a recipe for building your final program from the source file

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 <target>
```

- Defaults:
  - If no `target` specified, will use the first one in the file
  - Will interpret commands in your default shell
- 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)

Makefile Writing Tips

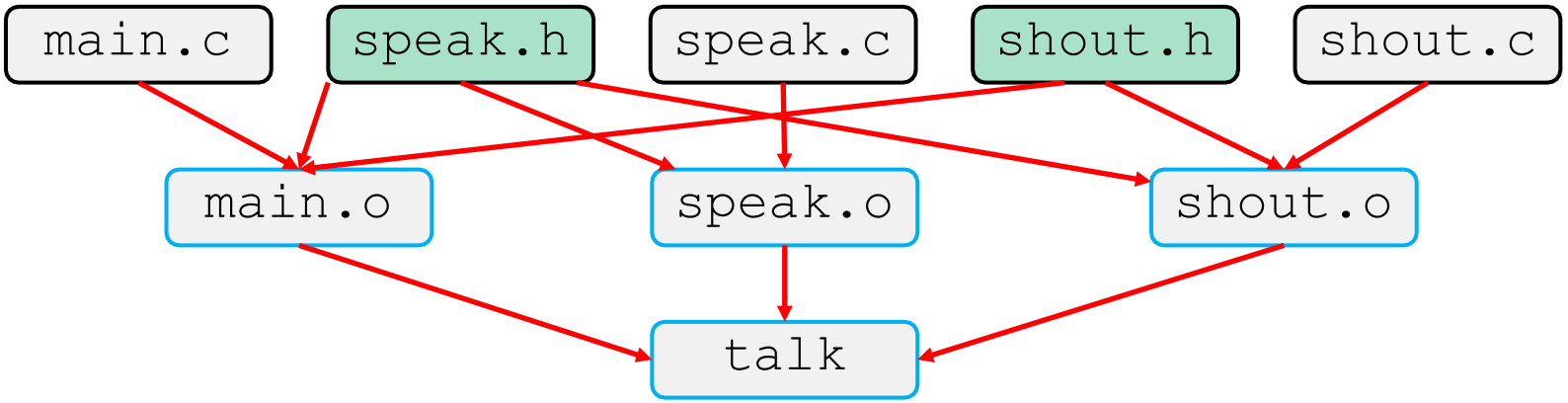
- *When creating a Makefile, first draw the dependencies!!!!*

- C Dependency Rules:
  - `.c` and `.h` files are never targets, only sources.
  - Each `.c` file will be compiled into a corresponding `.o` file
    - Header files will be implicitly used via `#include`
  - Executables will typically be built from one or more `.o` file

- Good Conventions:
  - Include a `clean` rule
  - If you have more than one "final target," include an `all` rule
  - The first/top target should be your singular "final target" or `all`

Writing a Makefile Example

- "talk" program



main.c

```
#include "speak.h"
#include "shout.h"

int main(int argc, char** argv) {…
```

speak.c

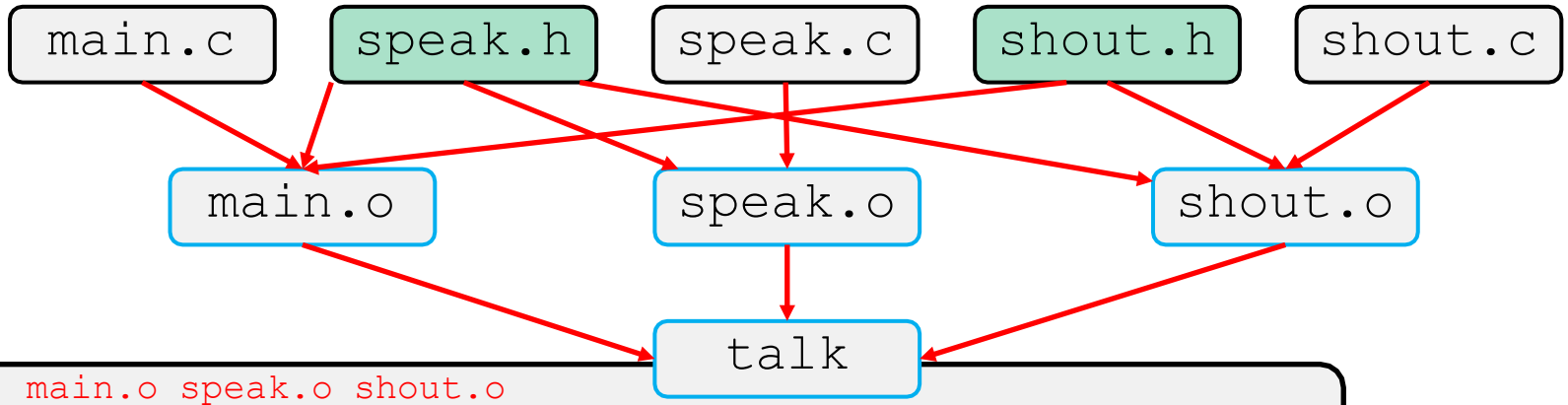
```
#include "speak.h"
...
```

shout.c

```
#include "speak.h"
#include "shout.h"
...
```

Writing a Makefile Example

- "`talk`" program




```
talk: main.o speak.o shout.o
        gcc -g -Wall -o talk main.o speak.o shout.o

main.o: main.c speak.h shout.h
        gcc -g -Wall -c main.c

speak.o: speak.c speak.h
        gcc -g -Wall -c speak.c

shout.o: shout.c speak.h shout.h
        gcc -g -Wall -c shout.c

clean:
        rm talk *.o
```

Makefiles

A "simple" Makefile for our previous example.

utils.h

```
#ifndef UTILS_H
#define UTILS_H
```

utils.c

```
#include "utils.h"

int fun1(int x, int y){
}
int fun2(int x, int y){
  ...
}
```

prog.c

```
#include "utils.h"

Int main(int argc, char *argv[]){
    fun1(10, 11);
    fun2(11, 12);
}
```

Makefiles

A "simple" Makefile for our previous example.

utils.h

```
#ifndef UTILS_H
#define UTILS_H
...
#endif
```

utils.c

```
#include "utils.h"

int fun1(int x, int y){
}
int fun2(int x, int y){
  ...
}
```

prog.c

```
#include "utils.h"

Int main(int argc, char *argv[]){
    fun1(10, 11);
    fun2(11, 12);
}
```

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

Makefiles

A "simple" Makefile for our previous example.

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

- This line specifies that **utils.o** depends on **utils.c** and **utils.h**.
- If either utils.c or utils.h is modified, utils.o will ***need*** to be recompiled.
- This saves time by not recompiling files that don't need to be recompiled.

Makefiles

A "simple" Makefile for our previous example.

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

- This line compiles our first object file, ***utils.o.***

Makefiles

A "simple" Makefile for our previous example.

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

- Same as before, prog.o depends on prog.c and utils.h.
- ***Then we partially compile prog.c into prog.o***

Makefiles

A "simple" Makefile for our previous example.

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

- Finally, our last step where we link all object files together.
- The final executable **prog** depends on prog.o and utils.o.
- **If either of these changed before hand, we relink.**

Makefiles

A "simple" Makefile for our previous example.

makefile

```
utils.o: utils.c utils.h
    clang -c utils.c

prog.o: prog.c utils.h
    clang -c prog.c

prog: prog.o utils.o
    clang -o prog prog.o utils.o

all: prog
```

- When you type "make", it will create the file followed after the ***all***.
- So it will create ***prog***!

`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
OBJFILES = foo.o bar.o baz.o
widget: $(OBJFILES)
	$(CC) $(CFLAGS) -o widget $(OBJFILES)
```

- Advantages:
  - Easy to change things (especially in multiple commands)
    - It's common to use variables to hold lists of filenames
  - Can also specify/overwrite variables on the command line: (*e.g.*, `make CC=clang CFLAGS=-g`)

"Phony" Targets

- A make target whose command does not create a file of the target's name (*i.e.*, a "recipe")
  - As long as target file doesn't exist, the command(s) will be executed because the target must be "remade"

- *e.g.*, target `clean` is a convention to remove generated files to "start over" from just the source

```
clean:
	rm foo.o bar.o baz.o widget *~
```

- *e.g.*, target `all` is a convention to build all "final products" in the makefile
  - Lists all of the "final products" as sources

Makefiles

A "more complex" Makefile for our previous example.

makefile

```
# Define the compiler and flags
CC = clang
CFLAGS = -Wall -g

utils.o: utils.c utils.h
    $(CC) $(CFLAGS) -c utils.c

prog.o: prog.c utils.h
    $(CC) $(CFLAGS) -c prog.c

prog: prog.o utils.o
    $(CC) -o prog prog.o utils.o

all: prog

clean:
    rm -f prog *.o
```

- Here we define some **constants** or **macros** that we can refer to for the rest of the Makefile.
- Allows you to quickly change compiler name in every line or the flags you want to use.
- Every $(macro) is replaced with the corresponding defined constants.

Makefiles

A "more complex" Makefile for our previous example.

makefile

```
# Define the compiler and flags
CC = clang
CFLAGS = -Wall -g

utils.o: utils.c utils.h
    $(CC) $(CFLAGS) -c utils.c

prog.o: prog.c utils.h
    $(CC) $(CFLAGS) -c prog.c

prog: prog.o utils.o
    $(CC) -o prog prog.o utils.o

all: prog

clean:
    rm -f prog *.o
```

- A new phony target: 'clean'
- Typing 'make clean' runs this.
- Removes all generated .o files and the final 'prog' executable created.

rm stands for 'remove' and the flag '-f' means forcefully.

Revenge of the Funny Characters

- Special variables:
  - **$@** for target name
  - **$^** for all sources
  - **$<** for left-most source (first 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 $<
```

Makefiles

A complex Makefile for our previous example.

makefile

```
# Define the compiler and flags
CC = clang
CFLAGS = -Wall -g

# Define the target executable and dependencies
TARGET = prog
DEPS = utils.h

# Pattern rule for compiling .c files into .o files

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

$(TARGET): prog.o utils.o
    $(CC) -o $@ $^

all: $(TARGET)

clean:
    rm -f prog *.o
```

$@ - The Target Filename

prog: prog.o utils.o
$@ would refer to prog.

Makefiles

A complex Makefile for our previous example.

makefile

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# Define the compiler and flags
CC = clang
CFLAGS = -Wall -g

# Define the target executable and dependencies
TARGET = prog
DEPS = utils.h

# Pattern rule for compiling .c files into .o files

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

$(TARGET): prog.o utils.o
    $(CC) -o $@ $^

all: $(TARGET)

clean:
    rm -f prog *.o
```

$@ - The Target Filename

prog: prog.o utils.o
$@ would refer to prog.

$^ - All Source Files

prog: prog.o utils.o
$^ would refer to prog.o utils.o
.

clang -o prog prog.o utils.o.

Makefiles

A complex Makefile for our previous example.

makefile

```
# Define the compiler and flags
CC = clang
CFLAGS = -Wall -g

# Define the target executable and dependencies
TARGET = prog
DEPS = utils.h

# Pattern rule for compiling .c files into .o files

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

$(TARGET): prog.o utils.o
    $(CC) -o $@ $^

all: $(TARGET)

clean:
    rm -f prog *.o
```

%.o –
This matches any file ending in .o
It means "any object file."

%.c –
This matches any file ending in .c
It means "any c file."

Note: they will always match
e.g. foo.o : foo.c

$<
This means the first dependent file in the list.

clang -Wall -g -c utils.c -o utils.o

And more…

- There are a lot of "built-in" rules – see documentation
- 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…)

Lecture Outline

- Building a C-Program
  - Preprocessor
  - Single Program
  - Multi-File Program (Linking)
- Recompilation
- Makefiles
  - Basics, Targets, Rules
  - Variables
  - Phony Targets
- Files (i/o)
  - Reading and writing to the terminal
- Generics
  - Void *

Files

- In C files are very ***simple*** objects – they consist of a sequence of bytes.
  - Can be ACII values, UTF-8, machine code to execute, the name of the person who broke your heart last summer in the note's app of your macbook pro, really anything: All up to interpretation.

In general, files start off 'closed'.

Files

- To read from a file (i.e. to see what it contains)
  - You need to open it first.
  - Then you can read from it
- To write to a file (i.e. change its contents or add to it)
  - You need to open() it first.
  - Then you can write() to it.
- When done reading/writing to a file
  - You need to then close() it (in some cases…)

Files: How to refer to them?

- In Unix and Unix like systems, ***File ** are pointers that refer to ***file handlers***
- You can use these to refer to ***files*** that you've opened.
- Some files are already open for you when you run your program.

The terminal itself is treated as a file

- you can "read from" and "write to" it

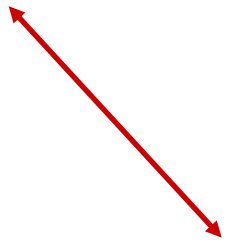
- Three file handlers your programs will always have
  - stdin : standard-input (terminal)
  - stdout : standard-output (terminal, for output)
  - stderr : standard-error (terminal, for error message

Reading and Writing from Terminal

stdin, stdout, and stderr

defined in `#include <stdio.h>`

- `printf("hi\n")` and `fprintf(stdout,“hi\n”);`
  - These are equivalent!
  - The f in fprintf stands for file.



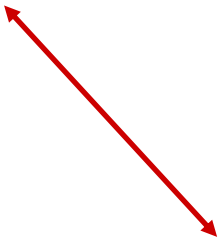
Here, we specify the File Handler to write to.

Reading and Writing from Terminal

stdin, stdout, and stderr

defined in `#include <stdio.h>`

- `fprintf(stderr,“Your progeram failed.\n”);`



Here, we specify to use the stderr **File Handler** to indicate an error.

Reading and Writing from Terminal

Reading from stdin is not so straight forward.

```
int getline(char ** line_buf, int *num_bytes, FILE *handler)
```

- `line_buf`
  - The ***address of char * you declare***.
  - getline will modify this pointer to hold a pointer to a ***heap allocated*** array that holds the line that was read if line_buf is null.
- `num_bytes`
  - The address of an int you declare.
  - num_bytes is the length of the array you pass in via line_buf
  - If it is 0, it will be updated to the size of the array it heap allocates for you.

Reading and Writing from Terminal

Reading from stdin is not so straight forward.

```
int getline(char ** line_buf, int *num_bytes, FILE *handler)
```

- `handler`
  - The file handler / file you want to "read from"
  - For us, *stdin* is the file handler to grab input from terminal.
- Returns the number of bytes put in line_buf.

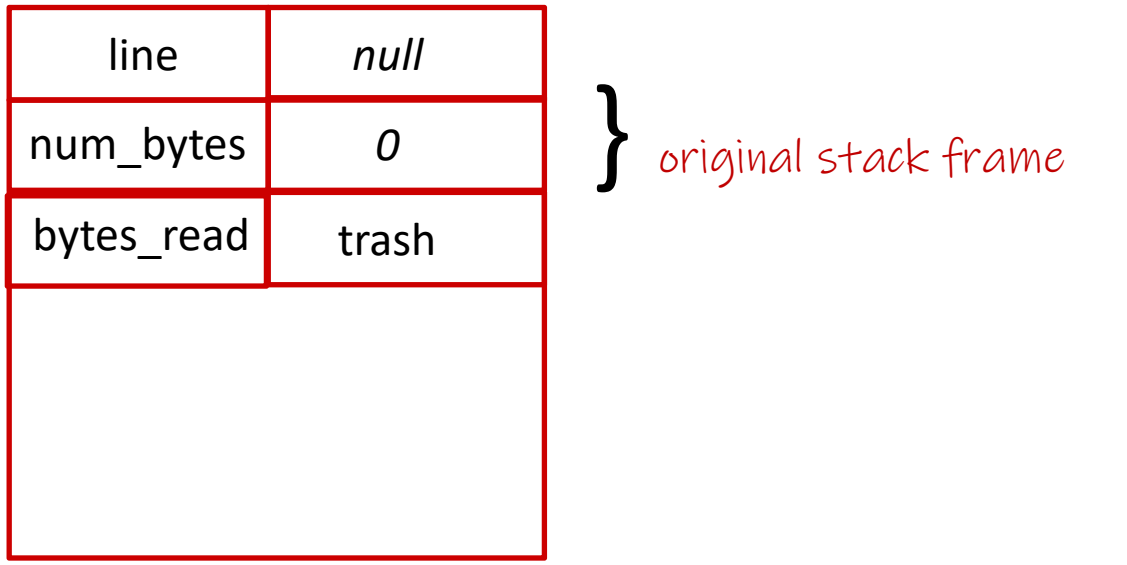
Reading and Writing from Terminal

int getline(char ** line_buf, int *num_bytes, FILE *handler)

```
char *line = NULL;
int num_bytes = 0;
int bytes_read = getline(&line, &num_bytes, stdin));

//should check to see if line is non null first…

free(line); //free the line when done with it.
```



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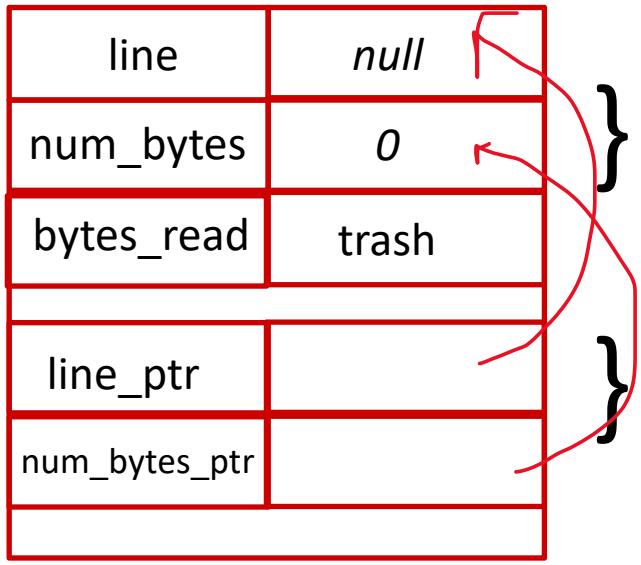
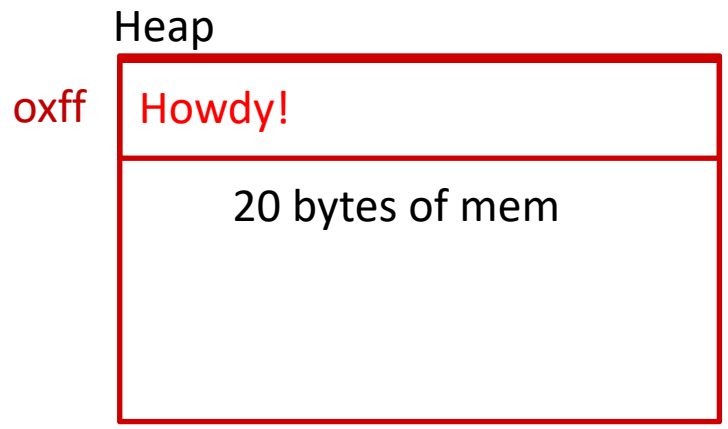
free(line); //free the line when done with it.
```

You type "howdy!" in terminal





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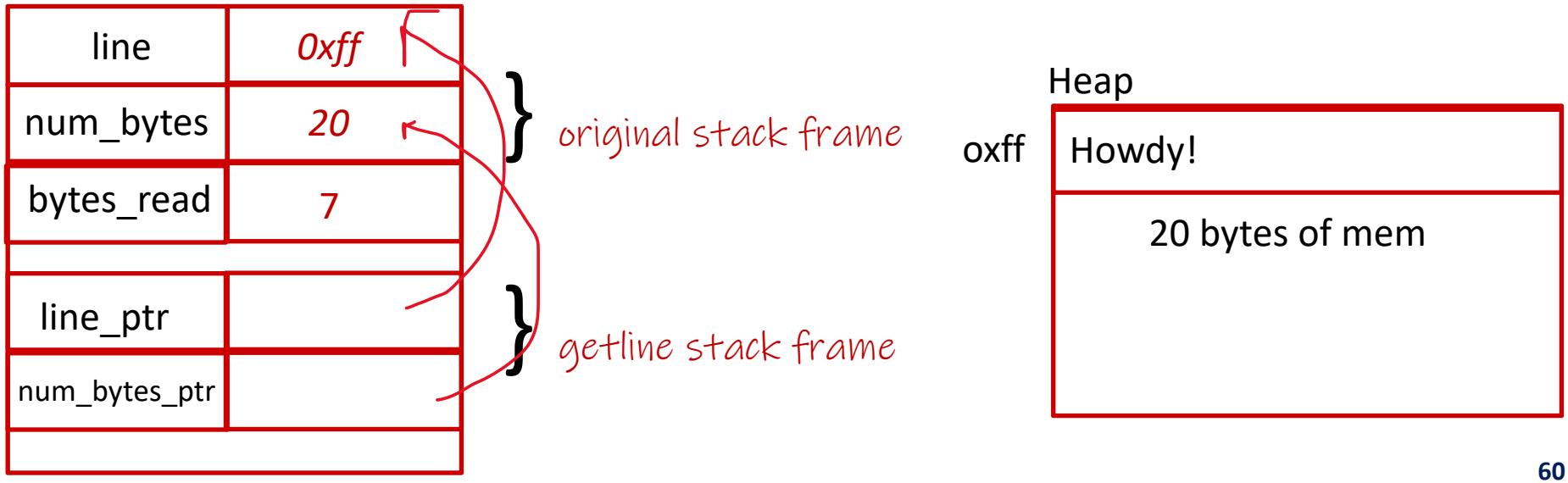

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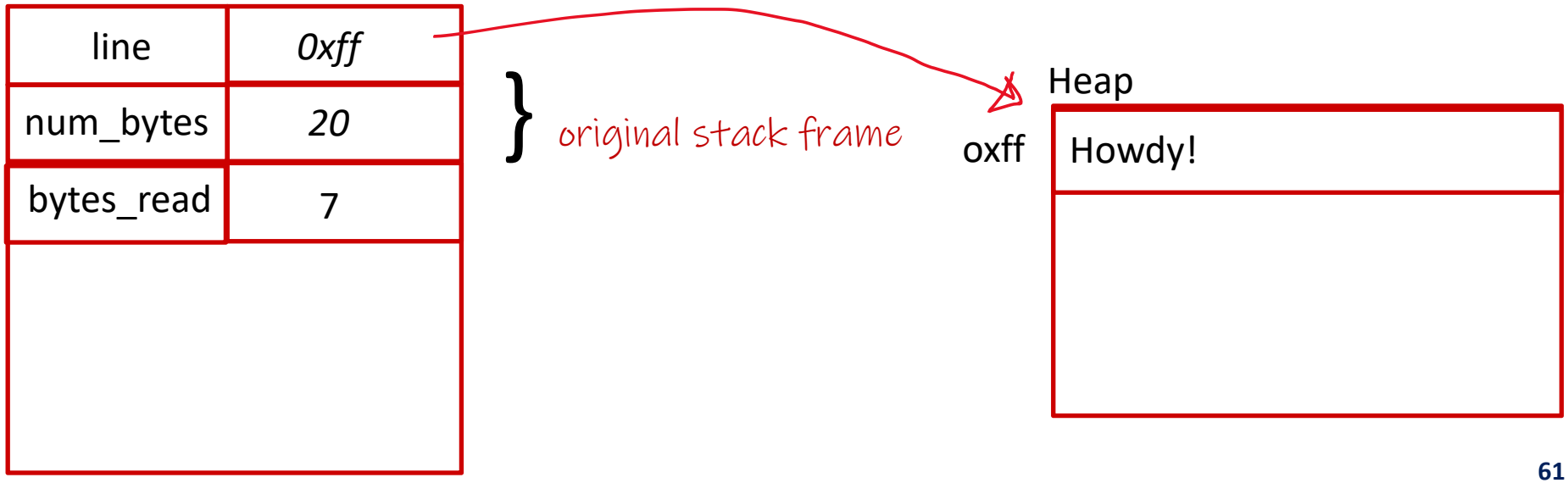

Reading and Writing from Terminal

int getline(char ** line_buf, int *num_bytes, FILE *handler)

```
char *line = NULL;
int num_bytes = 0;
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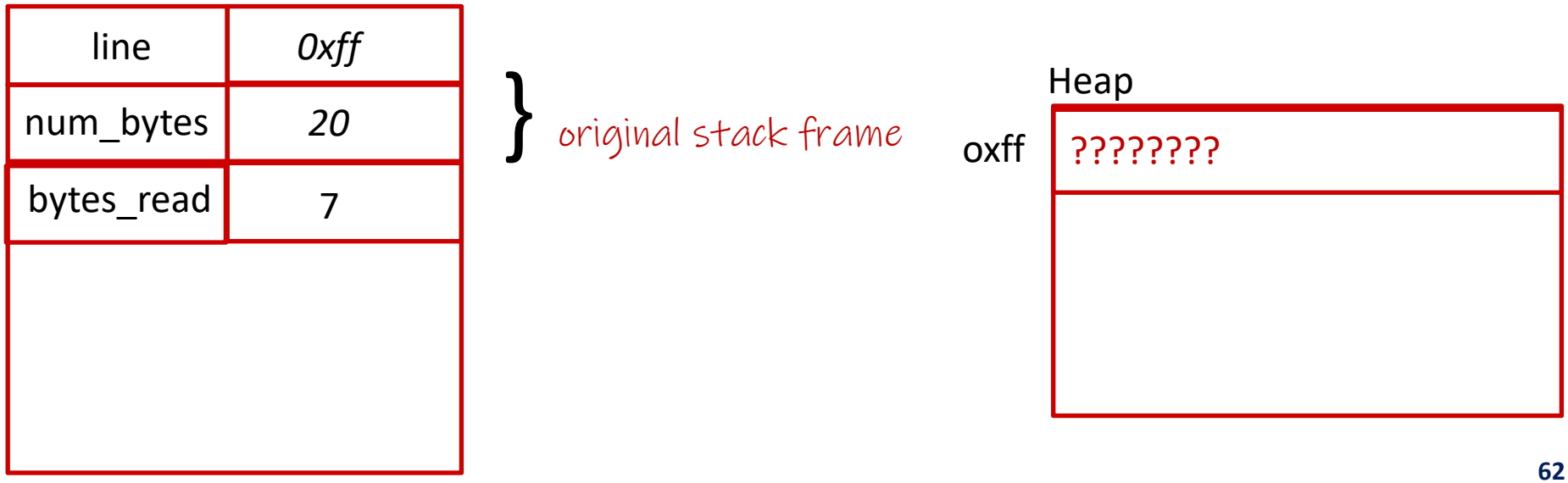
//should check to see if line is non null first…

free(line); //free the line when done with it and set to null
line = null;
```



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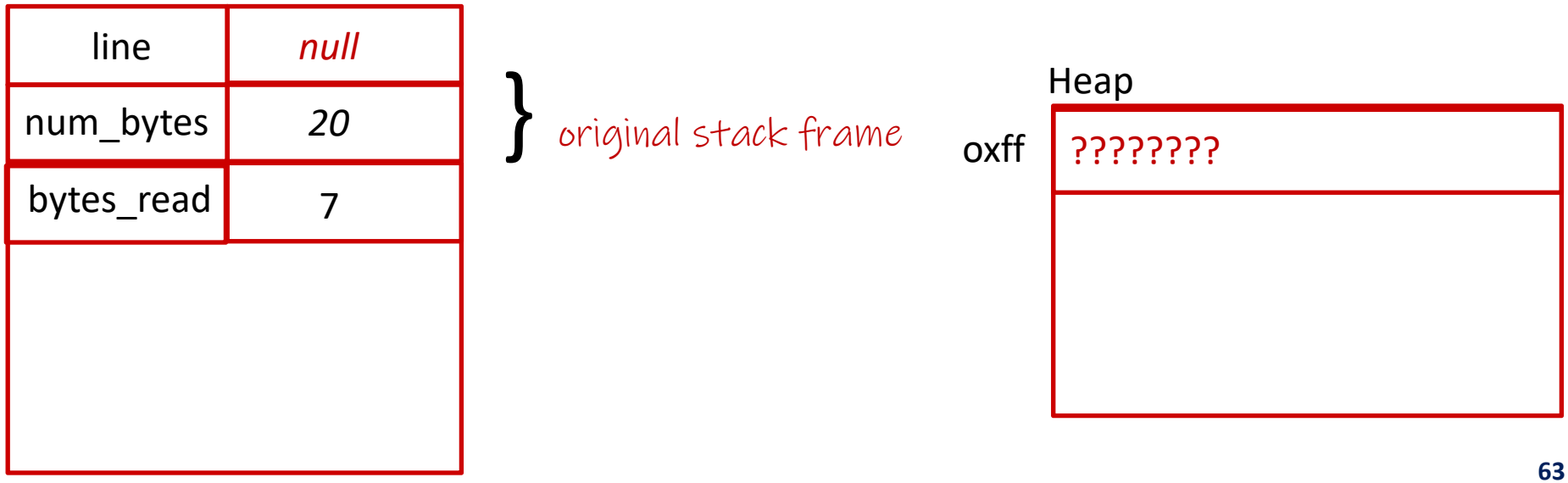

Reading Variables from Format String

- **int sscanf(char *_str_, char * _format_, ...);**
  - Allows us to insert values from a string into corresponding variables.
  - Best shown by example.

Reading Variables from Format String

- **int sscanf(char *_str_, char * _format_, ...);**

```
int main() {
    char str[] = "123 45.6 hello";
    int num1;
    float num2;
    char word[20];

    // Read formatted input from the string
    int count = sscanf(str, "%d %f %s", &num1, &num2, word);
    ...
}
```

- After this
  - num1 will be 123
  - num2 will be 45.6
  - word will be “hello”
- count will be the number of variable correctly assigned
  - here it will be 3

stdio.h

- There are many more functions in the standard library
- Check them out at your own discretion…

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- Generics
  - Void *

Generics

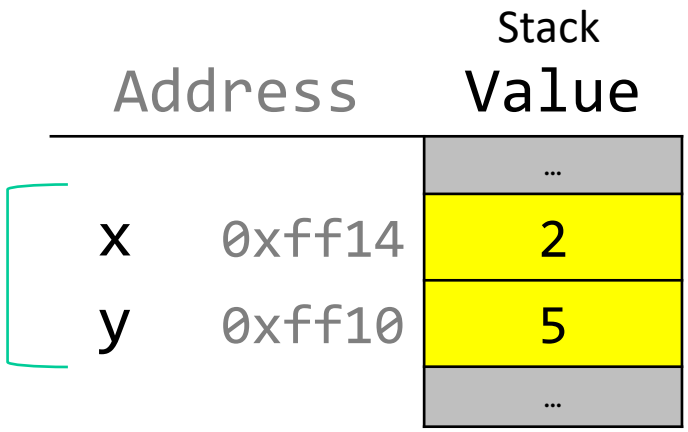
- We always want to write code that is as general-purpose as possible.
- Generic code reduces code duplication and means you can make improvements and fix bugs in one place rather than many.
- Generics is used throughout C for functions to sort any array, search any array, free arbitrary memory, and more.
- How can we write generic code in C? (Pointers are key!)

Void *: Generic Swap

- You're asked to write a function that swaps two ints.

```
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```



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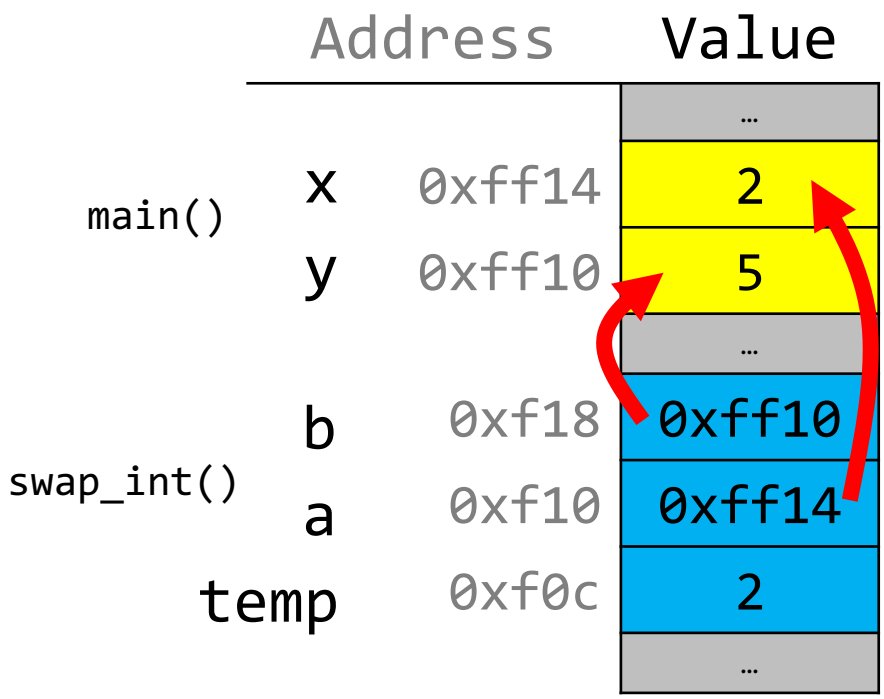
    return 0;
}
```



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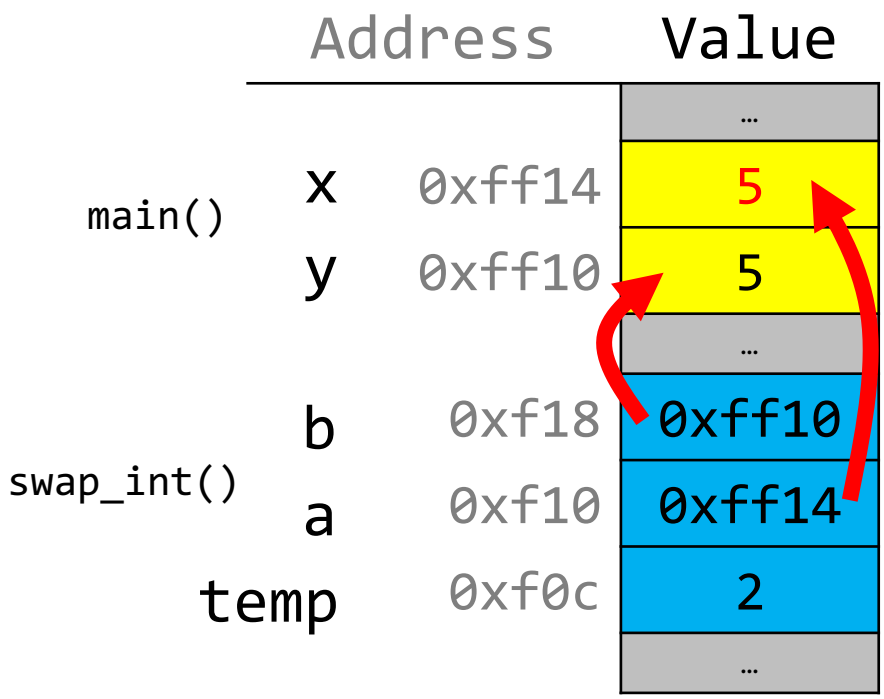

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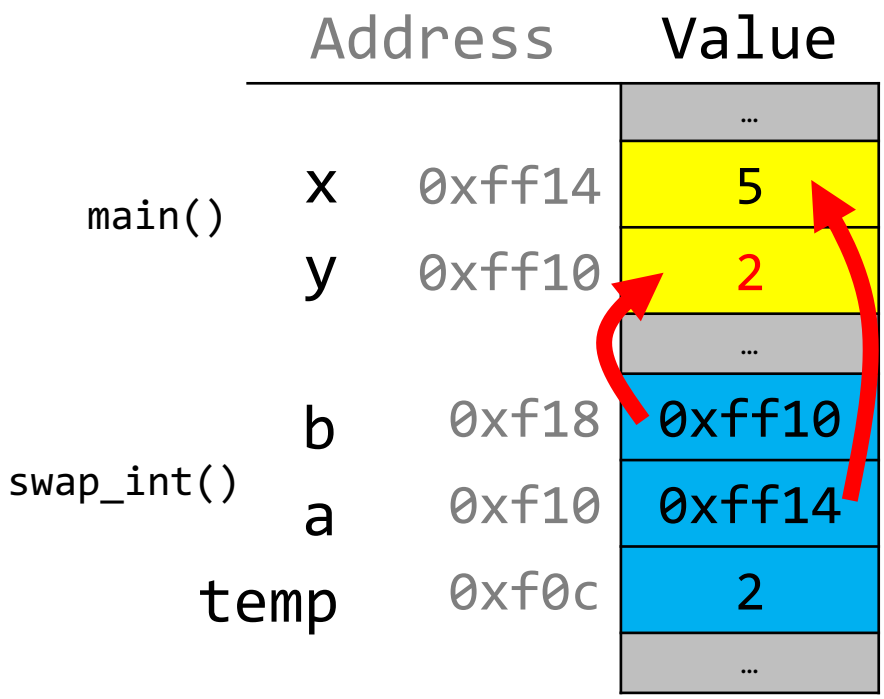

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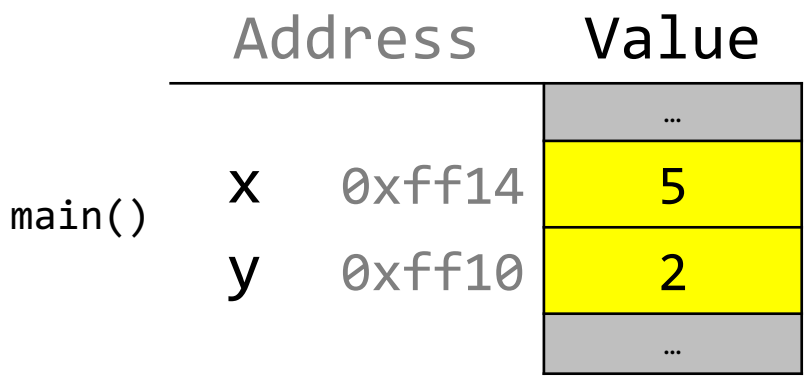


Average PM: Nevermind, I meant shorts not ints…

Ok not that bad of a fix…

Void *: Generic Swap

- You're asked to write a function that swaps two shorts.

```
void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    short x = 2;
    short y = 5;
    swap_short(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```

Everything that was an int, we need to change to be a short!

Average PM: You know what, I goofed. We're going to use strings. Could you write something to swap those?

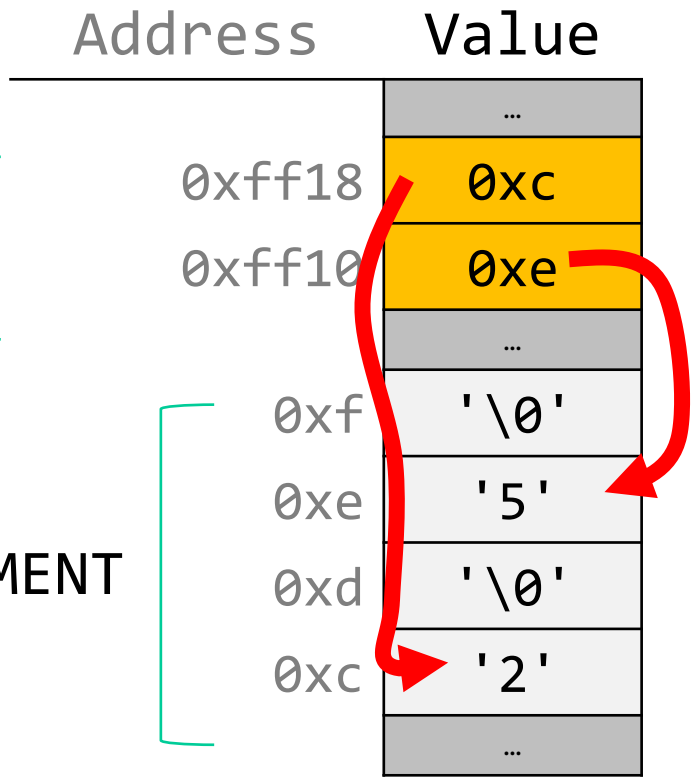
Um sure……

Void *: Generic Swap

- You're asked to write a function that swaps two srtings.

```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
```



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    *a = *b;
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}

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    char *y = "5";
    swap_string(&x, &y);
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    printf("x = %s, y = %s\n", x, y);
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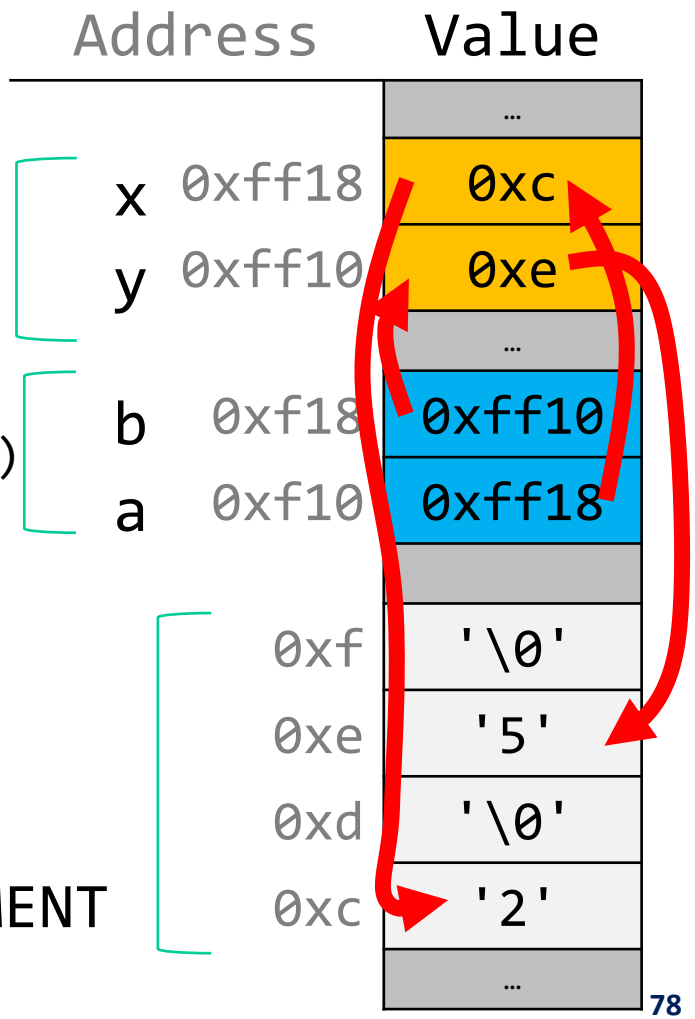
}
```



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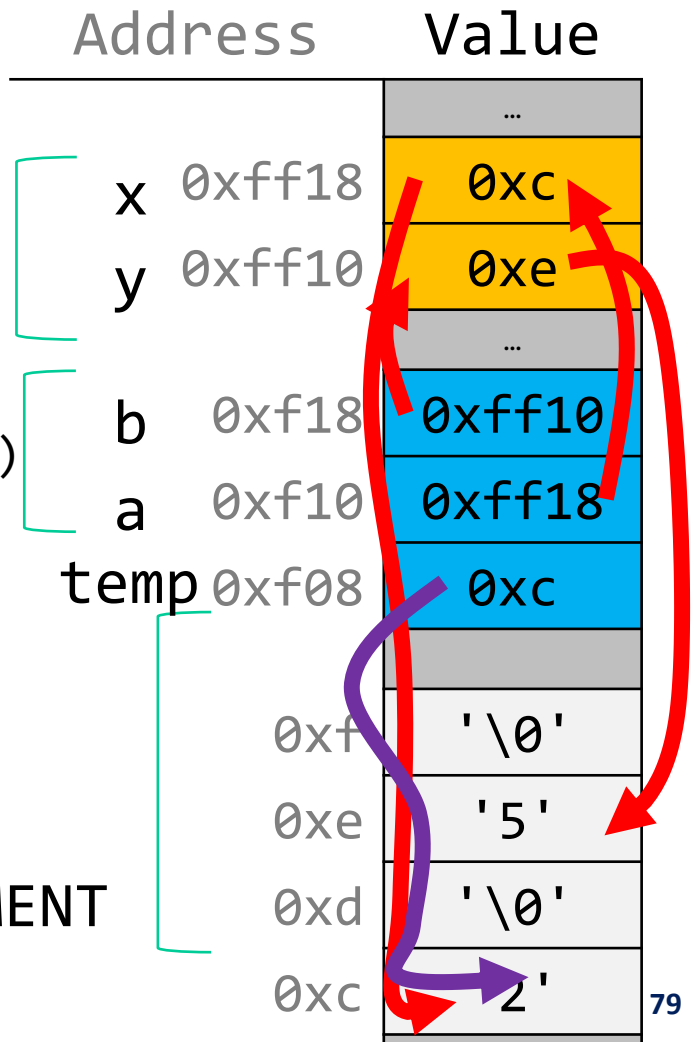
    return 0;
}
```



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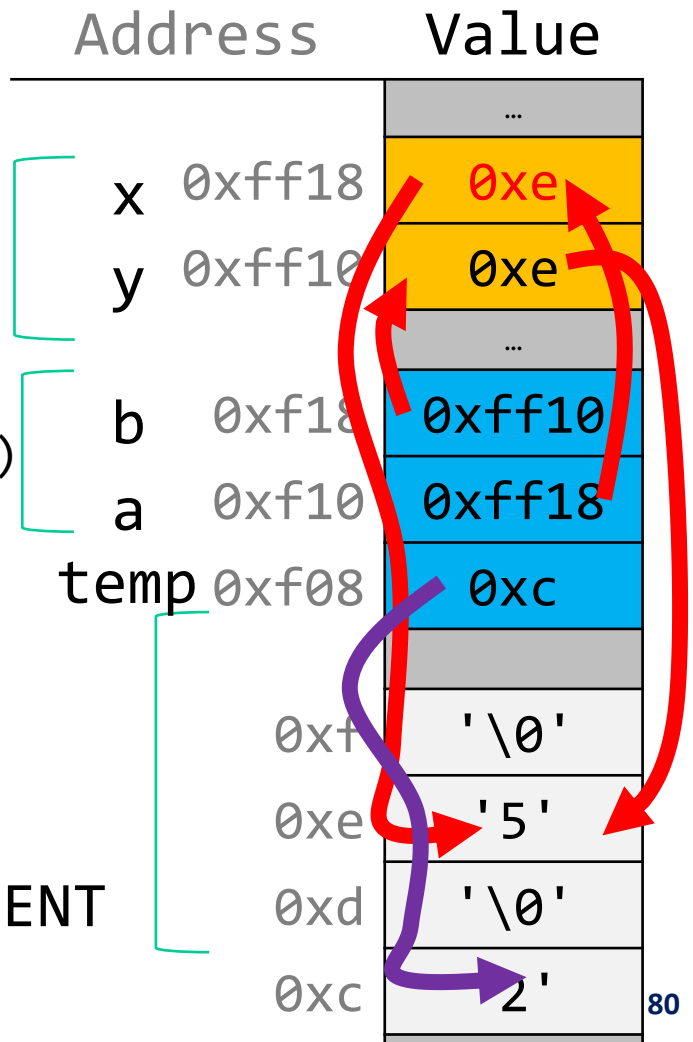

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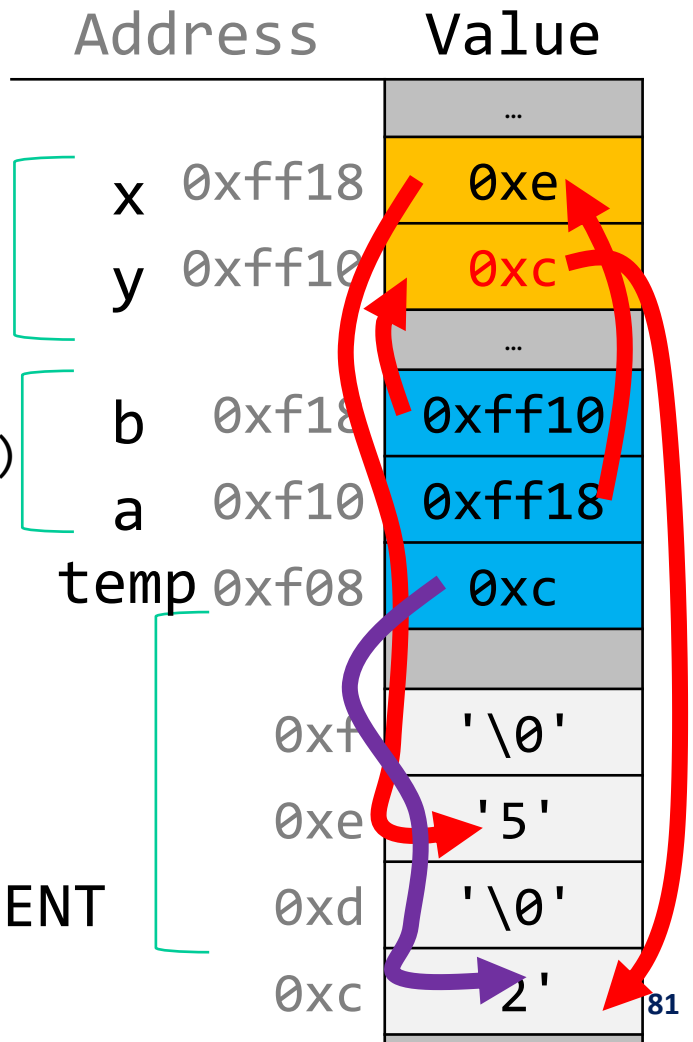

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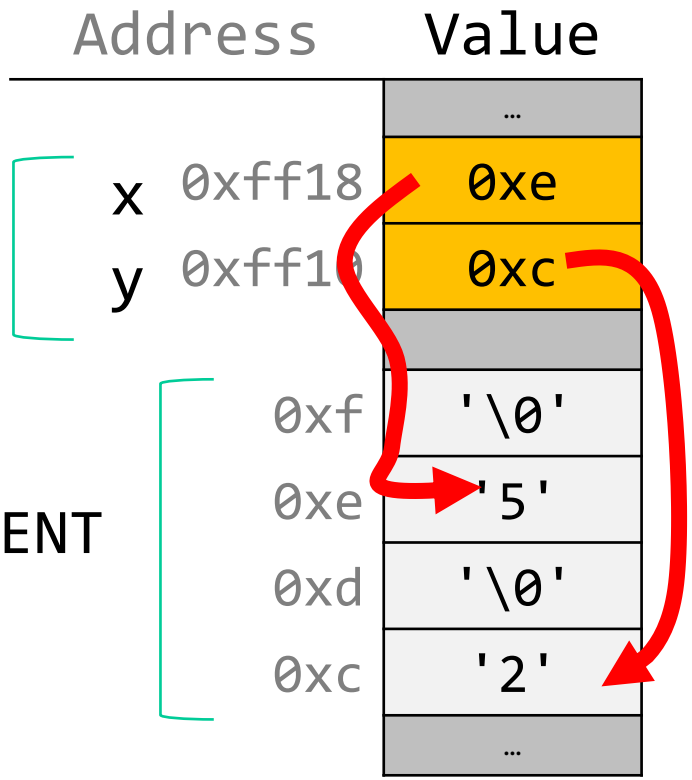

Average PM: You know what, we have 60 different custom structs. Can you write a custom swap for each one?

Umm I quit…

Imagine a World Where…

We could write *one* function to swap two values of any single type?

```
void swap_int(int *a, int *b) { … }
void swap_float(float *a, float *b) { … }
void swap_size_t(size_t *a, size_t *b) { … }
void swap_double(double *a, double *b) { … }
void swap_string(char **a, char **b) { … }
void swap_mystruct(mystruct *a, mystruct *b)
{ … }
…
```

Generic Swap

```
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}
```

All 3:

- Take pointers to values to swap
- Create temporary storage to store one of the values
- Move data at **b** into where **a** points
- Move data in temporary storage into where **b** points

General Swap Outline

```
void swap(pointer to data1, pointer to data2) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

We don't know the sizes of the pointers now! Would be wrong to use **char ***, **int ***, etc.

Introducing Void *

```
void swap(void *data1, void * data2) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

Void *: a generic pointer to some memory address.

Big Note: We have no idea what type we are pointing at.

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

If we don't know the data type, we don't know how many bytes it is. Let's take that as another parameter.

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    void temp; ???
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

Let's start by making space to store the temporary value.
How can we make **nbytes** of temp space?

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

Chars are only 1 byte! So let's make an nbyte char array…

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
```

Now, how can we copy in what **data1** points to into **temp**?

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    temp = *data1ptr; ???

    // copy data2 to location of data1
    // copy data in temporary storage to location of data2

}
```

We can't dereference a **void** * (or set an array equal to something). C doesn't know what it points to! Therefore, it doesn't know how many bytes it should grab.

memcpy

```
void *memcpy(void *dest, const void *src, size_t n);
```

- **memcpy** is a function that copies a specified number of bytes at one address to another address.
- It copies the next **n** bytes that **src** points to to the location pointed to by **dest**. (It also returns **dest**). It does not support regions of memory that overlap.

```
int x = 5;
int y = 4;
memcpy(&x, &y, sizeof(x)); // just like x = y;
```

memmove

```
void *memmove(void *dest, const void *src, size_t n);
```

- **memmove** is the same as memcpy but supports overlapping regions of memory. (Unlike its name implies, it still "copies").
- It copies the next **n** bytes that **src** points to to the location pointed to by **dest**. (It also returns **dest**).

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    memcpy(temp, data1ptr, nbytes);

    // copy data2 to location of data1
    // copy data in temporary storage to location of data2

}
```

We can copy the bytes ourselves into temp! This is equivalent to **temp = *data1ptr** in non-generic versions, but this works for *any* type of *any* size.

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);

    // copy data2 to location of data1
    // copy data in temporary storage to location of data2

}
```

How can we copy data2 to the location of data1?

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);

    // copy data in temporary storage to location of data2

}
```

How can we copy data2 to the location of data1?
memcpy!

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

Our last step, copy data in **temp** into **data2**

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

```
int x = 2;
int y = 5;
swap(&x, &y, sizeof(x));
```

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

```
short x = 2;
short y = 5;
swap(&x, &y, sizeof(x));
```

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

```
char *x = "2";
char *y = "5";
swap(&x, &y, sizeof(x));
```

Introducing Void *

```
void swap(void *data1, void * data2, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

```
mystruct x = {…};
mystruct y = {…};
swap(&x, &y, sizeof(x));
```

C Generics and Void *

- We can use **void *** and **memcpy** to handle memory as generic bytes.
- If we are given where the data of importance is, and how big it is, we can handle it!

```
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    memcpy(temp, data1ptr, nbytes);
    memcpy(data1ptr, data2ptr, nbytes);
    memcpy(data2ptr, temp, nbytes);
}
```

That's all folks!

- Goodluck on HW 02!
- See y'all on Thursday!

Have a great weekend!