CSE 333 23sp Section 2

Debugging and Structs

UNIVERSITY of WASHINGTON

Checking In & Logistics

- Exercise 2:
  - Due **Today (10/5) by 10pm**
- Homework 1:
  - Due **Friday (10/13) by 10pm**

Any questions, comments, or concerns?

- Exercises going ok?
- Lectures making sense?

Structs and Typedef Review

Defining Structs

- To define a struct, we use the `struct` statement, which typically has a name (a tag) and must have one or more data members
  - This defines a new data type!

```
struct word_st {
  char* word;
  int   count;
};
struct word_st my_word;
```

Typedef

- The C Programming language provides the keyword `typedef`, which defines an alias (alternate name) for an existing data type
  - This can be used in combination with a `struct` statement

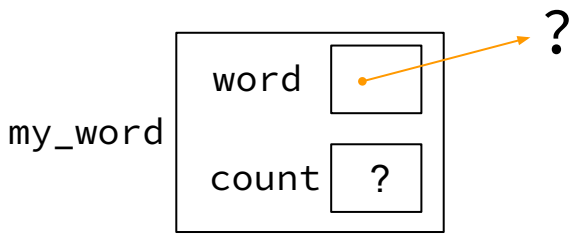
```
struct word_st {
  char* word;
  int   count;
};
typedef struct word_st WordCount;
WordCount my_word;
```

```
typedef struct word_st {
  char* word;
  int   count;
} WordCount;
WordCount my_word;
```

Structs and Memory Diagrams

- `struct` instance is a box, with individual boxes for fields inside of it, labelled with field names
  - Even though we know that field ordering is guaranteed, we can be loose with where we place the fields in our diagram

```
typedef struct word_st {
  char* word;
  int   count;
} WordCount;
WordCount my_word;
```



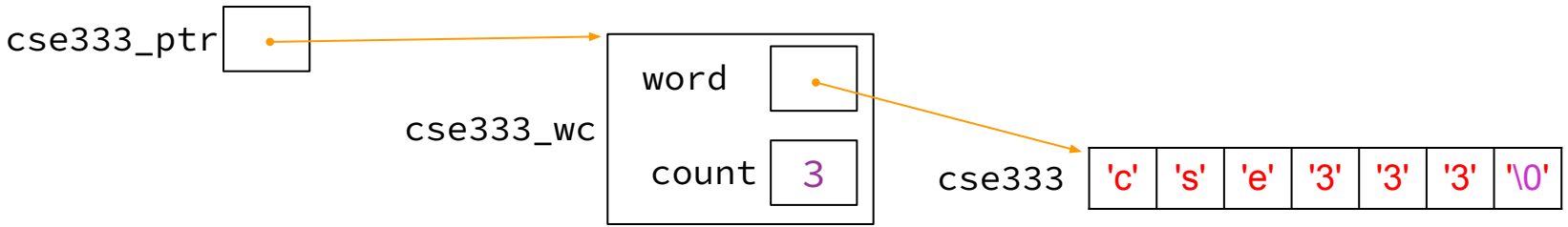
Structs and Pointers

- "`.`" to access field from `struct` instance
- "`->`" to access field from `struct` pointer

```
typedef struct word_st {
  char* word;
  int   count;
} WordCount;
```

```
char cse333[] = "cse333";
WordCount  cse333_wc;
WordCount* cse333_ptr = &cse333_wc;

cse333_wc.word = cse333;
cse333_ptr->count = 3;
```



Passing Structs as Parameters

- Assignment copies over all of the field values
  - Unlike reference copying in Java

- Structs are *pass-by-value* (as arguments and return values)
  - Can imitate pass-by-reference by passing pointer to struct instance instead

Debugging Tools

Debugging

- ✨ **Debugging is a skill that you will need throughout your career!** ✨
- The 333 projects are big with lots of potential for bugs
  - Learning to use the debugging tools will make your life a lot easier
  - Course staff will help you learn the tools in office hours, too
- Debugging tool output can be scary at first, but extremely useful once you know how to parse it
- Why can’t I just use print statements? They got me through 14x?
  - Bigger badder bugs beseech better debuggers!

Debugging Strategies

Many debugging strategies exist but here's a simple 5 step process!

1. **Observation**: Something is wrong with your program!
2. **Hypothesis**: What do you think is going wrong?
3. **Experiment**: Use debuggers and other tools to verify the problem
4. **Analyze**: Identify and implement a fix to the problem.
5. Repeat steps 1-4 until *bug free*!

Key debugging skills to master

1. Stop at “interesting” places
   - Debug after a crash or segfault
   - Use breakpoints to stop during execution
2. Look around when stopped
   - Print values of variables
   - Look at source code
   - Look up/down call chain
3. Resume execution
   - Incrementally, step at a time
   - Until next breakpoint
   - Until finished

333 Debugging Options

- `gdb` (GNU Debugger) is a general-purpose debugging tool
  - Stops at breakpoints and program crashes
  - Lots of helpful features for tracing code, checking current expression values, and examining memory
- `valgrind` specifically check for memory errors
  - Great for catching non-crashing odd behavior (*e.g.*, using uninitialized values, memory leaks on the heap)
  - If your code uses `malloc`, should use `--leak-check=full` option

Basic Functions in GDB

- Setting breakpoints:
  - `break <filename>:<line#>`
- Advancing
  - `step` – into functions
  - `next` – over functions
  - `continue` – to next break
- Reading Values
  - `print` – evaluate expression once
  - `display` – keep evaluating expression
- Examining memory
  - `x` – dereference provided address
  - `bt` – backtracing
- Reference Card: https://courses.cs.washington.edu/courses/cse333/23au/debug/gdb_refcard.pdf

Common Errors

```
Hello World!
Segmentation fault (core dumped)
```

- **Misusing Functions**: Read documentation (online, through man pages, or the `.h` files for your homework) for function parameters and function purpose
  - Oftentimes, this leads to unexpected results!

- **Segmentation Fault**: Dereferencing an uninitialized pointer, `NULL`, a previously-freed pointer, or many other things.
  - GDB automatically halts execution when `SIGSEGV` is received, useful for debugging

- **Memory “Errors”**: Many possible errors, commonly use of uninitialized memory or “memory leaks” (data allocated on heap that does not get free’d).
  - Use `valgrind` to help catch memory errors!

Trying to Run `wordcount.c`

We have a program *`wordcount.c`* that accepts a string from the user and reverses it!

- `wget https://courses.cs.washington.edu/courses/cse333/23au/sections/02/code/wordcount.c`
- `wget https://courses.cs.washington.edu/courses/cse333/23au/sections/02/code/Makefile`
- run `make` to compile the code
- run `make val` to run valgrind

But it has a few problems… let's take a look!

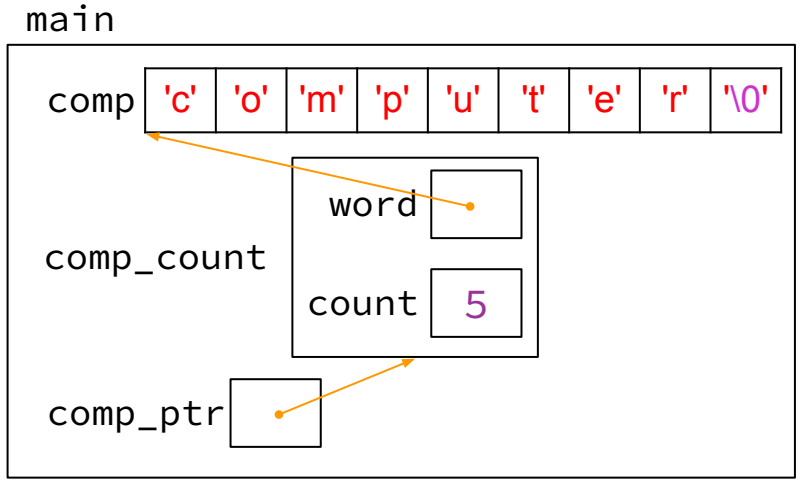
Exercise 1

Complete the Memory Diagram

Note: boxes with a function name above are local variables on the stack

```
int main(int argc, char* argv[]) {
  char comp[] = "computer";
  WordCount comp_count = {comp, 5};
  WordCount* comp_ptr = &comp_count;

  printf("1. %s, %d\n", comp_ptr->word,
         comp_ptr->count);
  ...
}
```

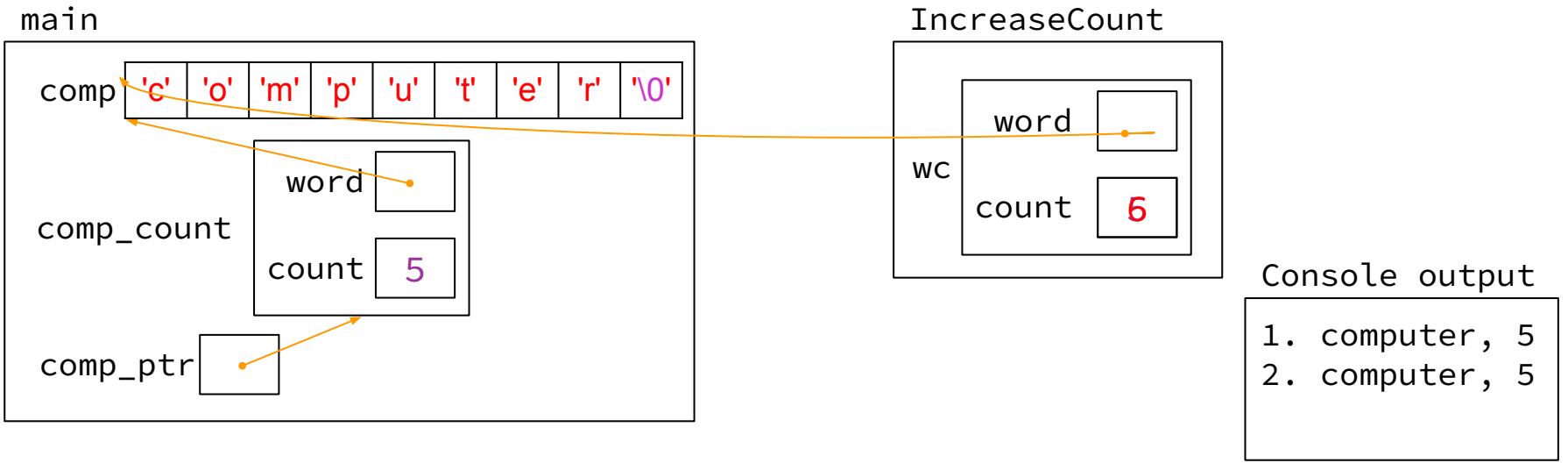


Console output

```
1. computer, 5
```

```
    // continued main code
    IncreaseCount(*comp_ptr);
    printf("2. %s, %d\n", comp_ptr->word,
           comp_ptr->count);
    ...
}
```

```
void IncreaseCount(WordCount wc) {
    wc.count += 1;
}
```



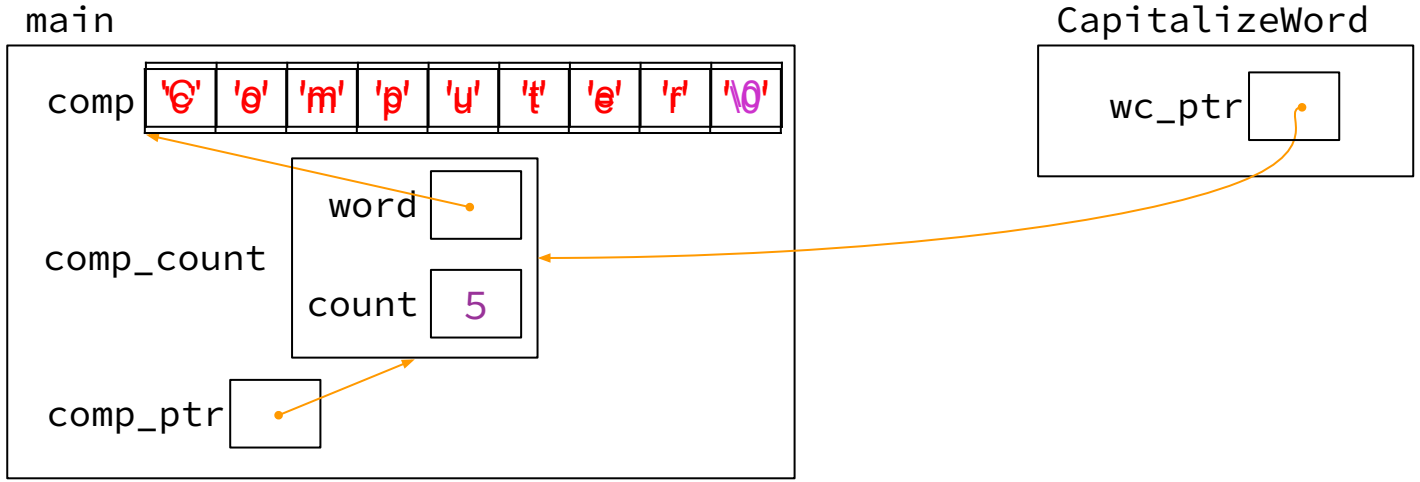
```
    // continued main code
    CapitalizeWord(comp_ptr);
    printf("3. %s, %d\n",
           comp_ptr->word,
           comp_ptr->count);
    ...
}
```

```
void CapitalizeWord(WordCount* wc_ptr) {
  wc_ptr->word[0] &= ~0x20;
}
```

By changing the second bit in the upper nibble (6th most significant bit) of the character you can transform a character into uppercase or lowercase. If it's a 1 then it's lowercase, 0 is uppercase.

Going to lowercase: lowch = ch | 0x20;

Going to uppercase: upch = ch & ~0x20;

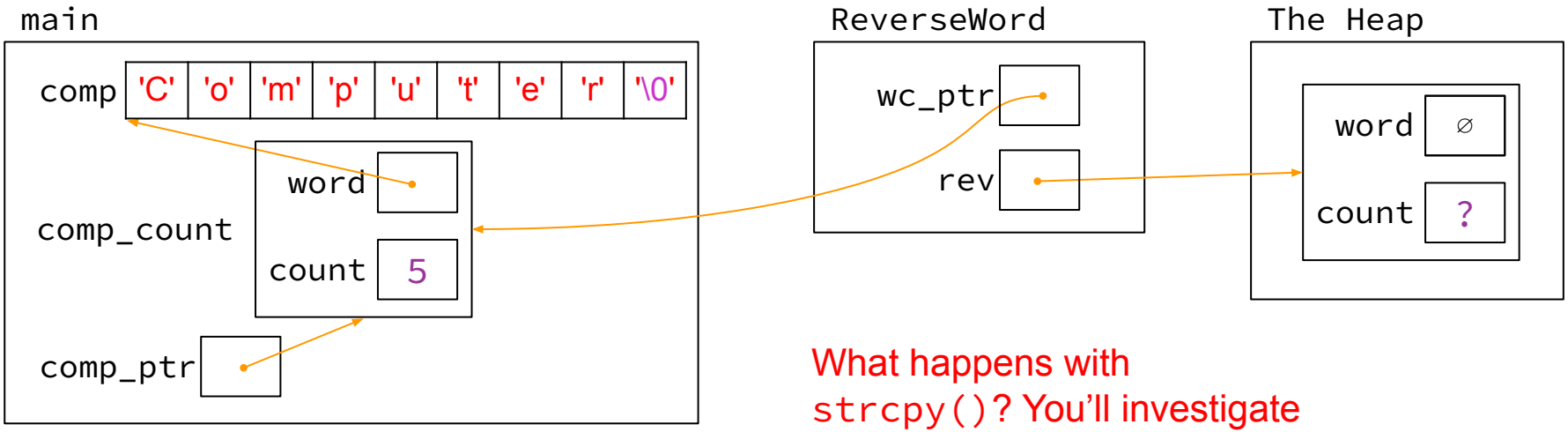


Console output

```
1. computer, 5
2. computer, 5
3. Computer, 5
```

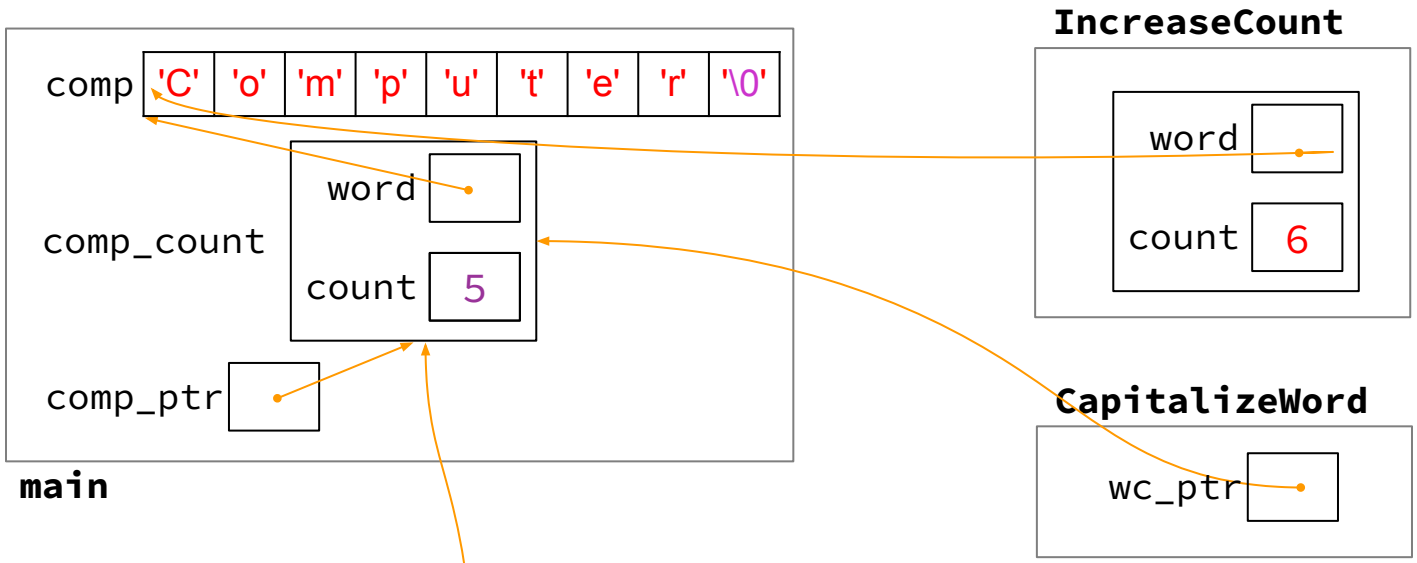
```
    // continued main code
    *comp_ptr = ReverseWord(comp_ptr);
    printf("4. %s, %d\n",
           comp_ptr->word,
           comp_ptr->count);
    return EXIT_SUCCESS;
}
```

```
WordCount ReverseWord(WordCount* wc_ptr) {
    WordCount* rev = (WordCount*)
                     malloc(sizeof(WordCount));
    rev->word = NULL;
    strcpy(rev->word, wc_ptr->word);
    ...
```



What happens with `strcpy()`? You'll investigate in Exercise 2!

The Stack


comp
'C'
'o'
'm'
'p'
'u'
't'
'e'
'r'
'\0'
word
comp_count
count
5
comp_ptr
main
IncreaseCount
word
count
6
CapitalizeWord
wc_ptr
ReverseWord
ch
?
L
?
R
?
wc_ptr
rev
The Heap
word
∅
count
?

Exercise 2

Fix 1: Doesn't increment

- Tool help: stepping through code with gdb
- Old version:

```
void IncreaseCount(WordCount wc) {
  wc.count += 1;
}
```

- New version:

```
void IncreaseCount(WordCount* wc_ptr) {
  wc_ptr->count += 1;
}
```

Fix 2: Segfault

- Tool help: `run` in gdb to find segfault, `man` for `strcpy`
- Old version:

```
rev->word = NULL;
strcpy(rev->word, wc_ptr->word);
```

- New version:

```
rev->word = (char*) malloc((strlen(wc_ptr->word) + 1)
                           * sizeof(char) );
strcpy(rev->word, wc_ptr->word);
```

Fix 3: Doesn't reverse string

- Tool help: break on `ReverseWord`, step through code, `print /s rev->word` at end of function (prints as string)
- Old version:

```
char ch;
int L = 0, R = strlen(rev->word);
```

- New version:

```
char ch;
int L = 0, R = strlen(rev->word) - 1;
```

Fix 4: Reading uninitialized memory

- Tool help: run under valgrind, identify error line number
- Old version:

  Did not set count!
- New version:

```
rev->count = 0;
```

Fix 5: Memory leaks

- Tool help: run under valgrind, identify unfreed allocation line numbers
- Old version:

```
WordCount ReverseWord(WordCount* wc_ptr) { ...
return *rev; }
```

- New version:

```
WordCount* ReverseWord(WordCount* wc_ptr) { ...
return rev; }
At end of main:    free(comp_ptr->word);
                   free(comp_ptr);
```

Exercise 3

Style Fixes

- Tool help: Lecture slides! Google C++ Style Guide! Course website!
- `malloc` error checking:

```
if (rev == NULL) { return NULL; }
if (rev->word == NULL) { return NULL; }
```

- struct passing:

```
WordCount* ReverseWord(WordCount* wc);
```