

COMP 206 – Introduction to Software Systems (guest lecture by Prof. Greg Dudek)

Lecture 11 – 2D Arrays

October 5th, 2018

Quick Review

- The code on the right should be starting to feel comfortable.
 - Available on Github under `ExampleCode/Lecture11-2DArrays/pointer_review.c`
- Read through and think it over, then we'll review to get started.

```
#include <stdio.h>
#include <string.h>

int main( int argc, char *argv[] ){

    char letter = 'b';
    char sentence[100] = "2 words.";
    char *c_ptr1 = &letter;
    char *c_ptr2 = sentence;
    sentence[3] = 'i';
    c_ptr2[2] = *c_ptr1;

    printf( "letter holds: %c\n", letter );
    printf( "sentence holds: %s\n", sentence );
    printf( "c_ptr1 holds: %c\n", *c_ptr1 );
    printf( "c_ptr2 holds: %s\n", c_ptr2 );

    int number = 42;
    int lotto_picks[7] = { 8, 18, 28, 38, 48, 58, 68 };
    int *i_ptr1 = &number;
    int *i_ptr2 = lotto_picks;
    lotto_picks[3] = number;
    i_ptr1 = i_ptr2;
    i_ptr2[1] = *i_ptr1;

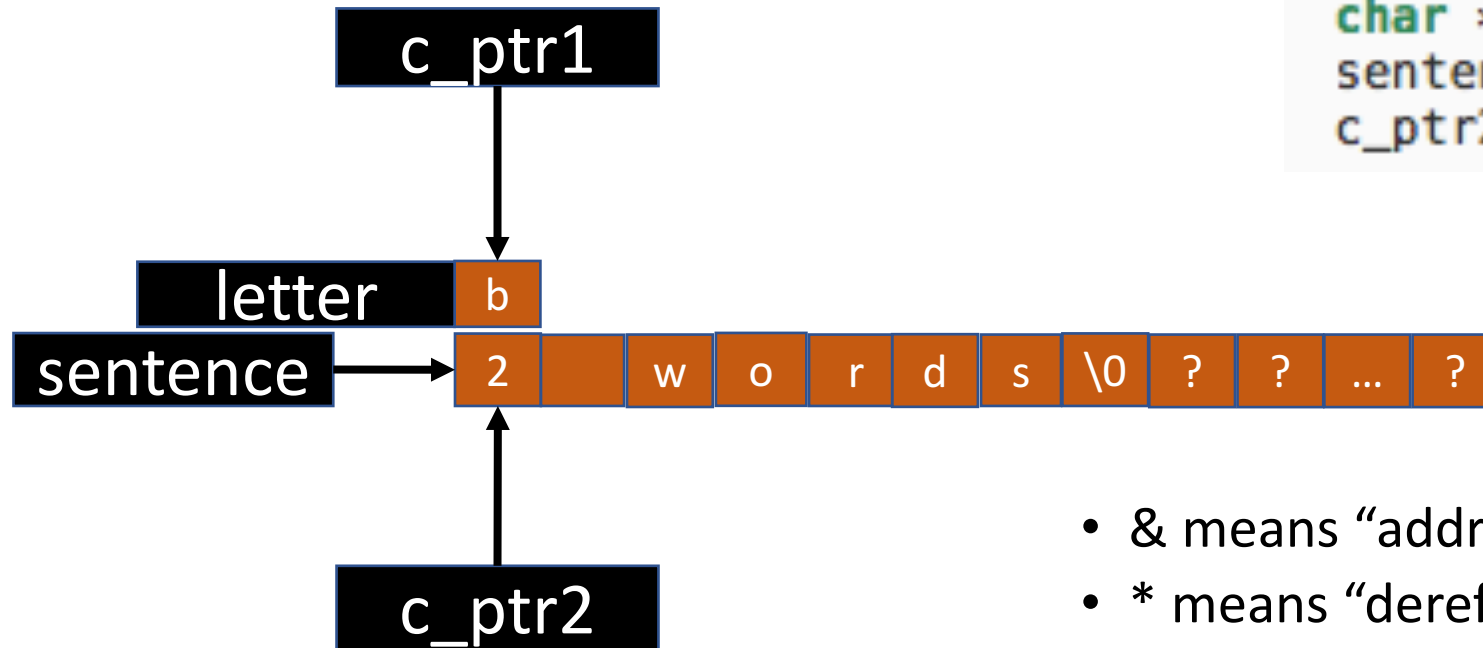
    printf( "number holds: %d\n", number );
    printf( "lotto_picks holds:" );
    for( int pos=0; pos<7; pos++ )
        printf( "%d ", lotto_picks[pos] );
    printf( "\n" );

    printf( "i_ptr1 holds: %d\n", *i_ptr1 );
    printf( "i_ptr2 holds:" );
    for( int pos=0; pos<7; pos++ )
        printf( "%d ", i_ptr2[pos] );
    printf( "\n" );

    return 0;
}
```

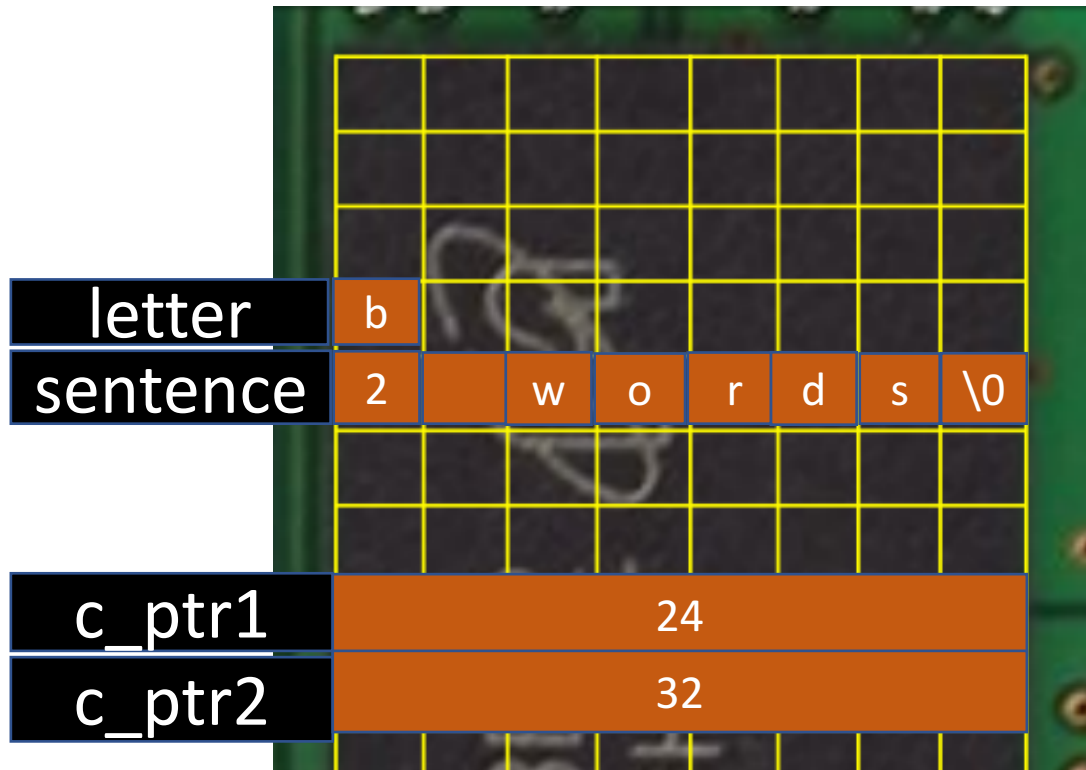
Box and Arrow

```
char letter = 'b';  
char sentence[100] = "2 words.";  
char *c_ptr1 = &letter;  
char *c_ptr2 = sentence;  
sentence[3] = 'i';  
c_ptr2[2] = *c_ptr1;
```



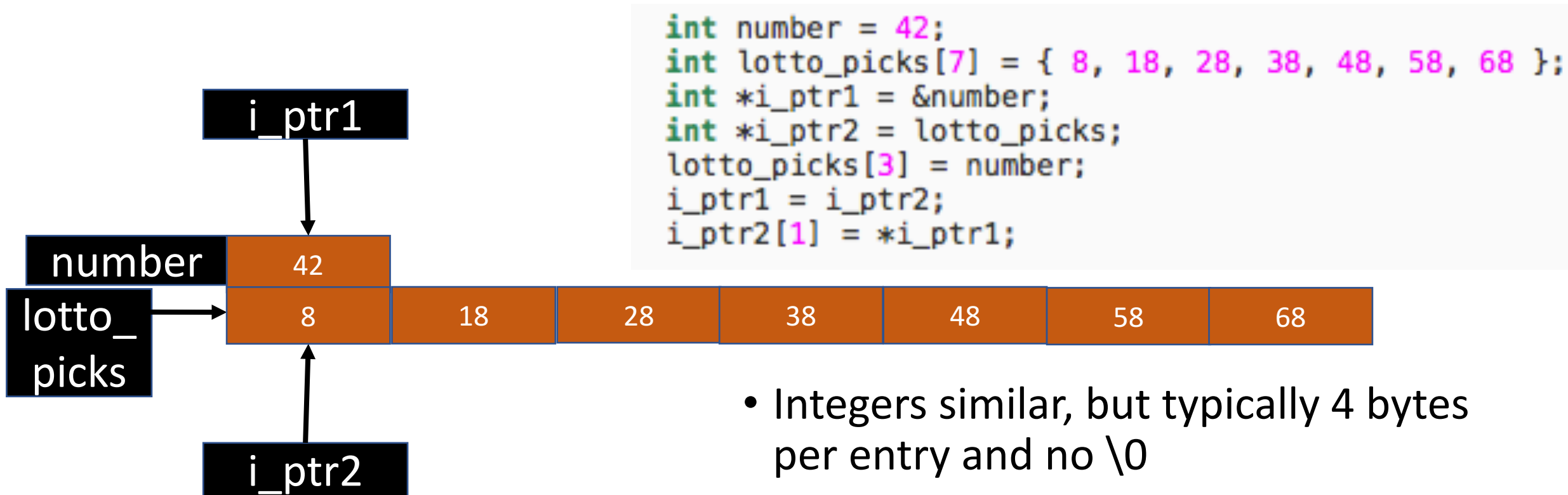
- & means “address of” or “points to” variable
- * means “dereference” or “get values at” pointer
- Array variables can be thought of as pointer always to the beginning
- Pointers can be indexed with [i] notation just like arrays

Memory and Addresses



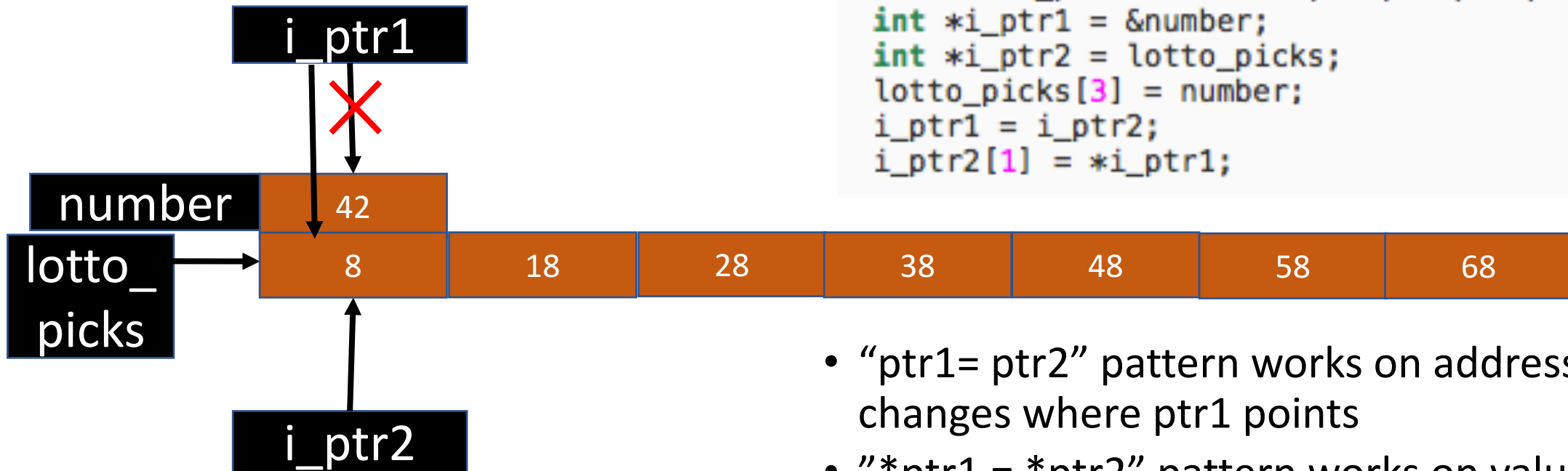
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char *c_ptr1 = &letter;  
char *c_ptr2 = sentence;  
sentence[3] = 'i';  
c_ptr2[2] = *c_ptr1;
```

Box and Arrows: Integers



- Integers similar, but typically 4 bytes per entry and no `\0`
- `*ptr` is equivalent to `ptr[0]`
- More generally `*(ptr+i)` equiv `ptr[i]`

Box and Arrows

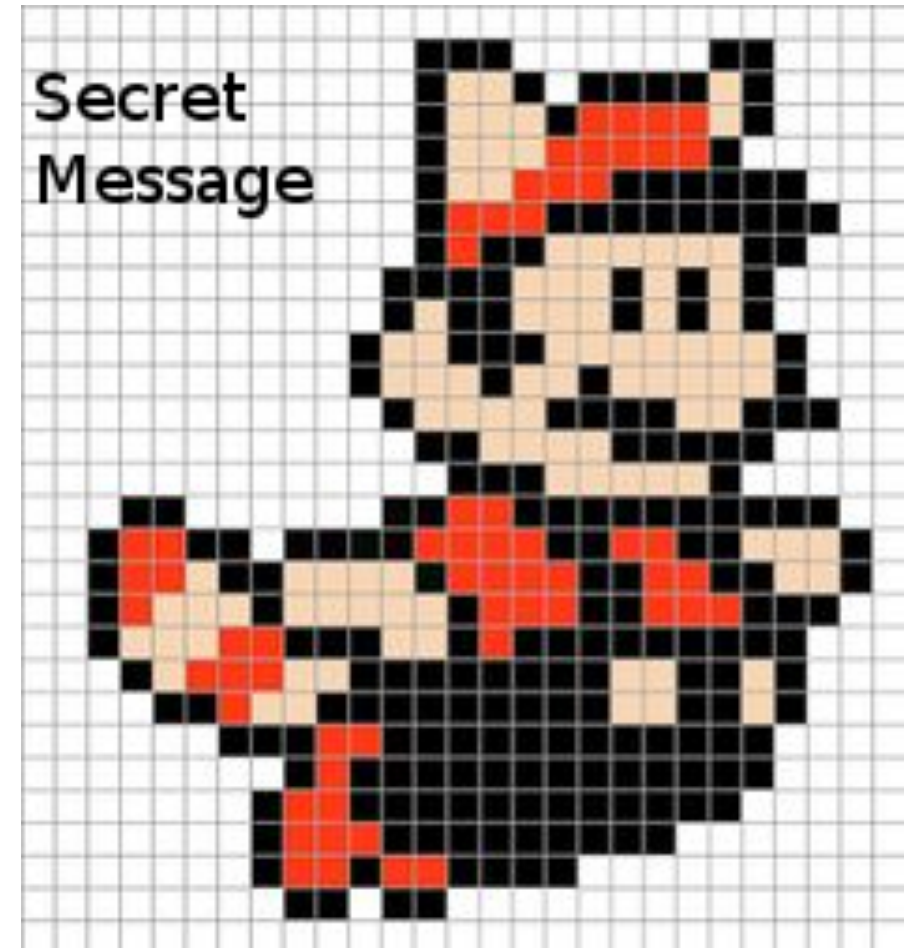


```
int number = 42;
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int *i_ptr1 = &number;
int *i_ptr2 = lotto_picks;
lotto_picks[3] = number;
i_ptr1 = i_ptr2;
i_ptr2[1] = *i_ptr1;
```

- “ptr1= ptr2” pattern works on addresses, changes where ptr1 points
- “*ptr1 = *ptr2” pattern works on values, changes the value of memory at ptr1’s address

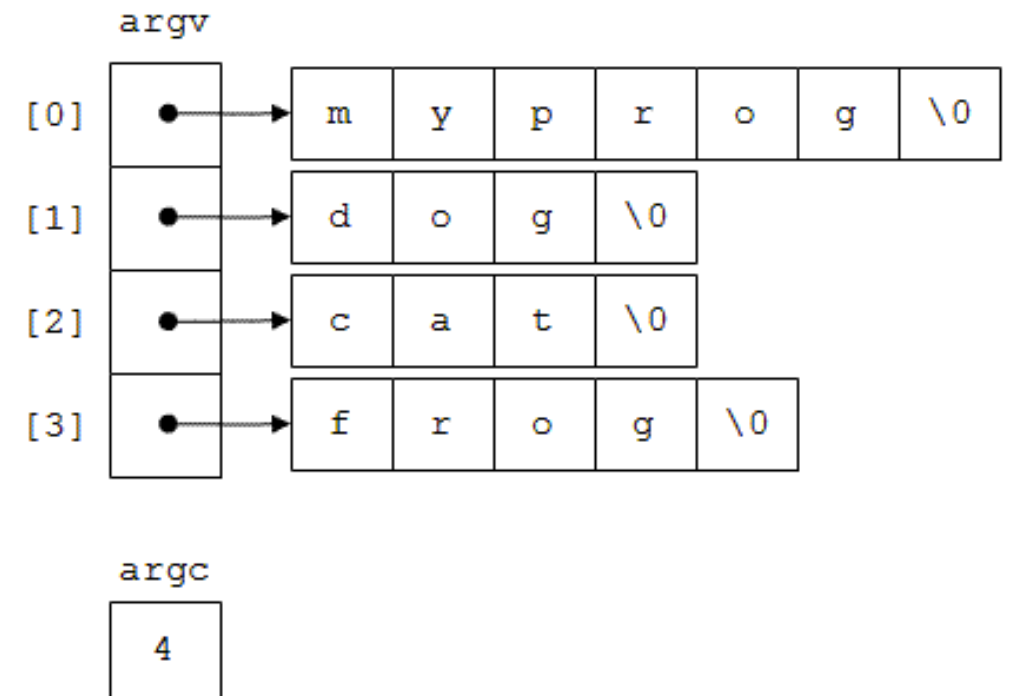
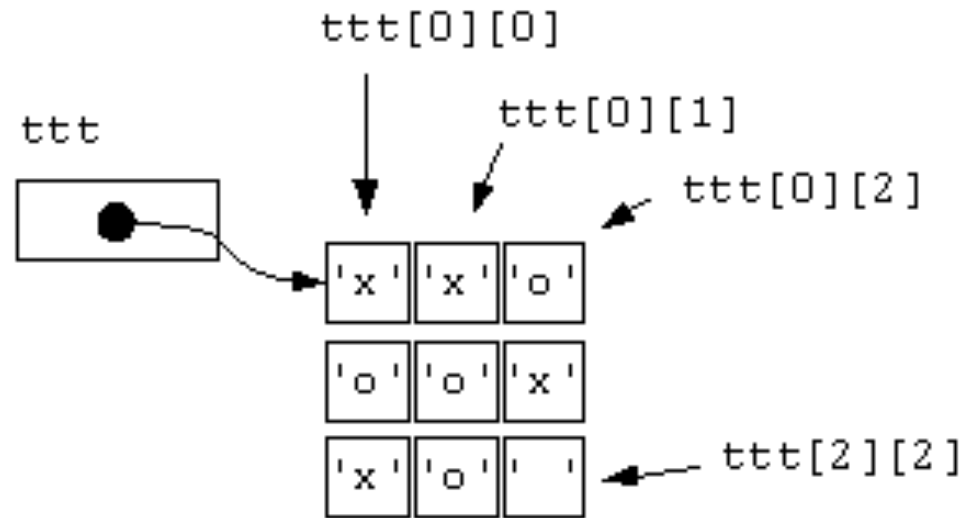
Where are we going today and next week?

- Real Software Systems that work with binary (non-text) data
- Specific example: how are images represented in:
 - Gaming
 - Computer Generated Imagery in movies
 - Satellite maps
 - Bunny-ear augmented selfies
- Today: data that has a 2D layout



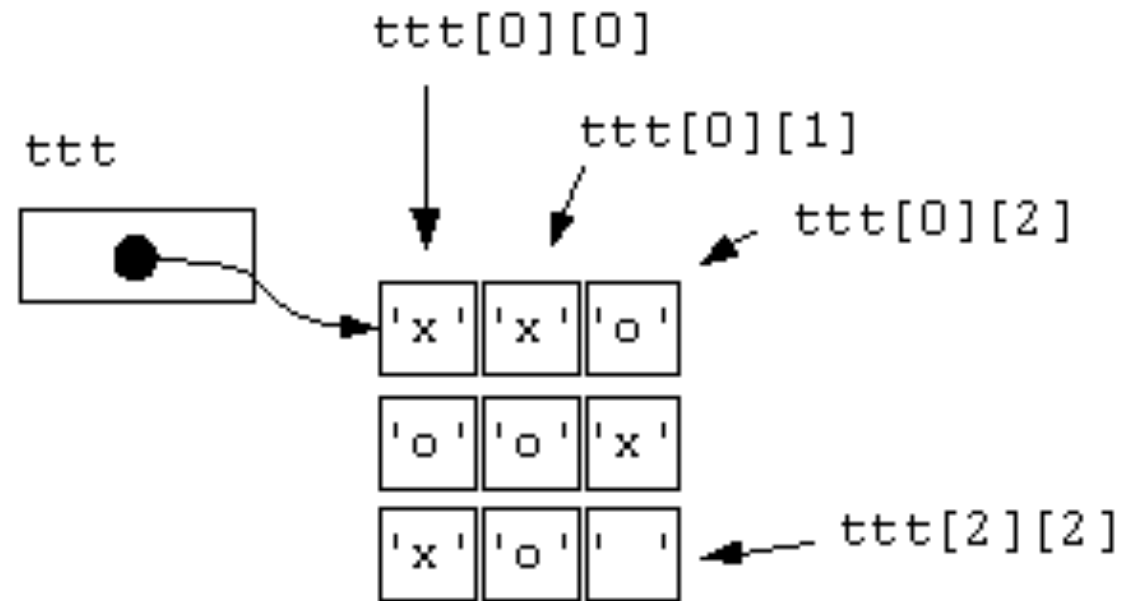
2D Arrays and Arrays of Pointers

```
z123456@turing:~$ myprog dog cat frog
```



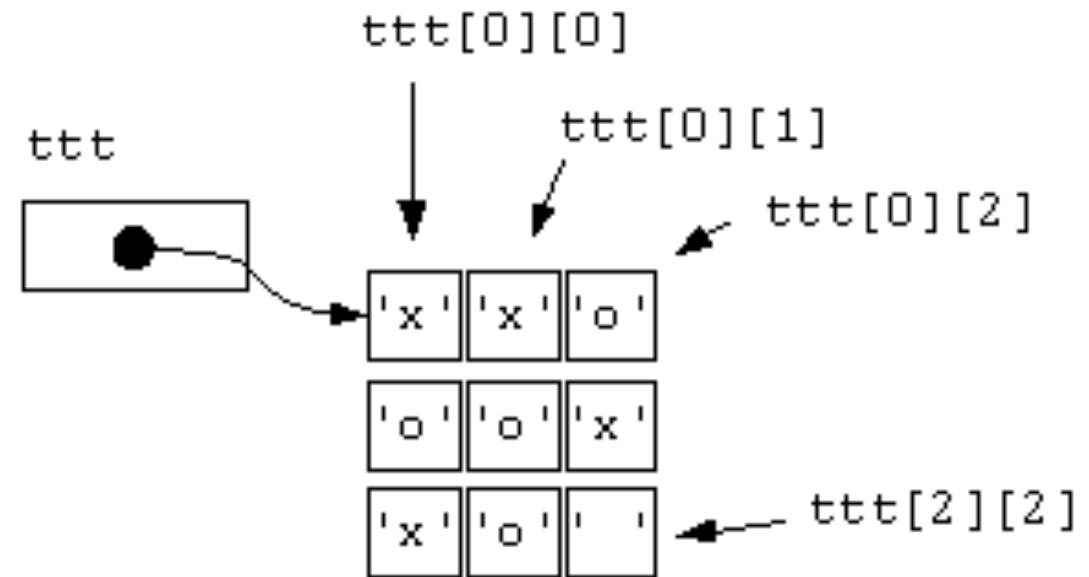
2D Arrays

- Declared by repeating the square bracket syntax:
 - `char ttt[3][3];`
- Creates an array where each entry is itself an array.
- The type (e.g. `char`) is the same for every entry of the inner array.
- Outer array behaves as we expect:
 - Fixed size
 - Always represents the memory of the first entry and cannot be moved (e.g., no `++`)
 - Elements stored directly after one another



Accessing 2D Array Data

- For type `array_name[N][M]`
 - Syntax `array_name[i][j]` is used both to read and write data at entry `i, j`
- First index can be 0 to `N-1`, second index can be 0 to `M-1`
- In the image:
 - `ttt[0][0]` evaluates to 'x'
 - `ttt[2][2] = 'o'`; sets bottom-right value
- **Careful:** not `[i,j]`

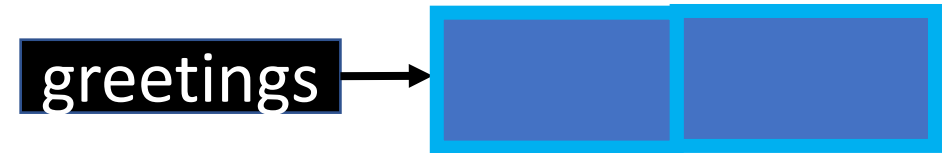


When to use 2D Array?

- When each "row" has the same size always:
 - `int days_in_each_month[2][12] = {
 { 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 },
 { 31, 29, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 } };`
- Often when data looks like a "table":
 - `float grades[number_of_assignments][class_size] = {
 { 100.0, 99.0, 83.0 },
 { 99.9, 99.9, 99.8 } };`

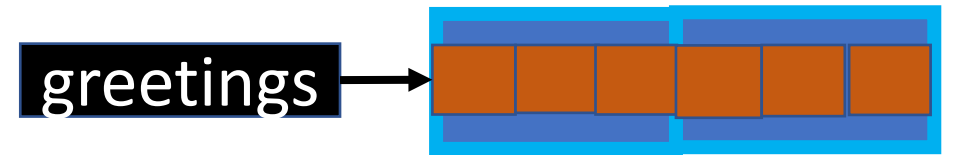
What does it look like in memory?

- `char[2][3] greetings = { "hi", "yo" };`
 - Is first off an array of length 2
 - We know those entries are placed directly in order



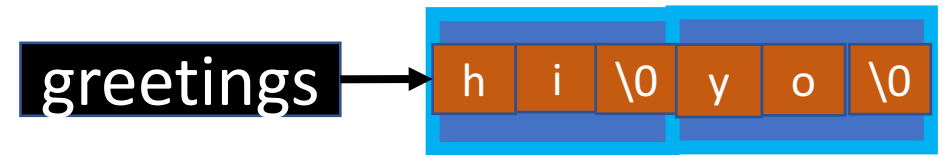
What does it look like in memory?

- `char[2][3] greetings = { "hi", "yo" };`
 - Is first off an array of length 2
 - Each of the outer entries contains an array of length 3, following the same rules



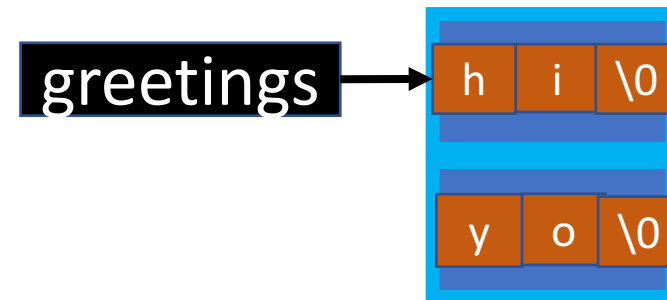
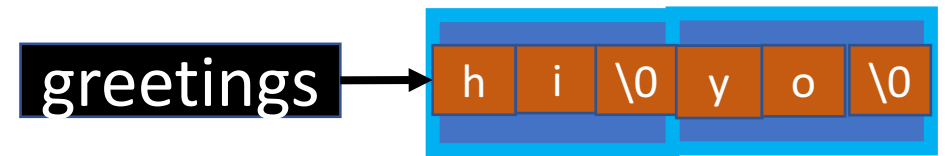
What does it look like in memory?

- `char[2][3] greetings = { "hi", "yo" };`
- The system memory is addressed in ascending linear order (1D). This view shows the layout in address space.



What does it look like in memory?

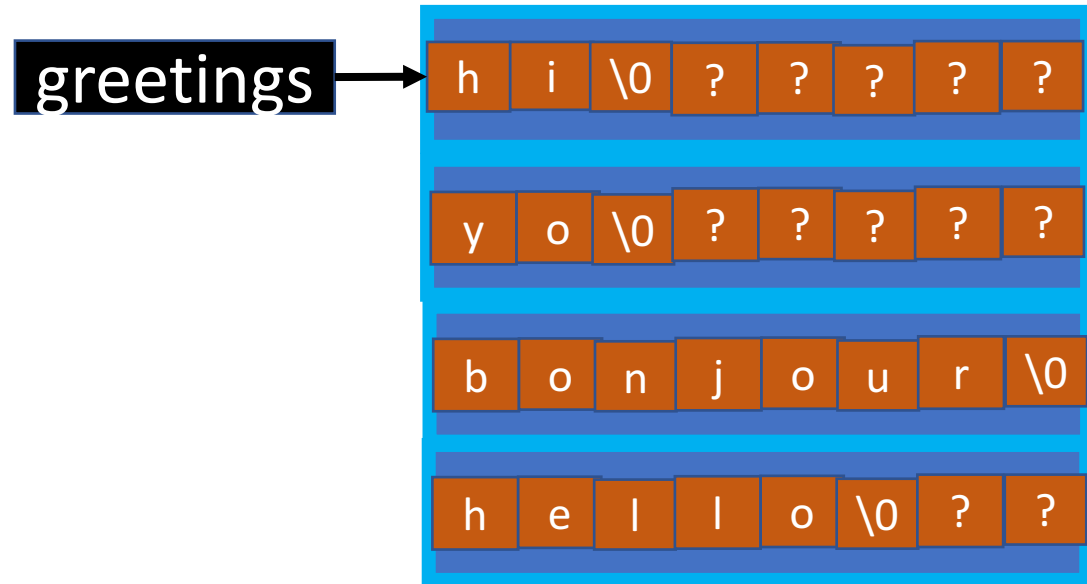
- `char[2][3] greetings = { "hi", "yo" };`
- The system memory is addressed in ascending linear order (1D). This view shows the layout in address space.
- NOTE: it's often nice to draw it this way to understand working with images etc, but it is only for convenience.
 - Does not indicate bigger jumps in memory between `'\0'` and `'y'`, compared to `'y'` and `'o'`



When not to use 2D Arrays?

- If the data in each entry “row” can vary in length
- If the length of each entry “row” isn’t known when coding, for example it will change based on user input
- Handling these cases with 2D arrays forces us to use enough space for the longest possible row... for every row!

```
char greetings[4][8] = { “hi”,  
“yo”, “bonjour”, “hello” };
```

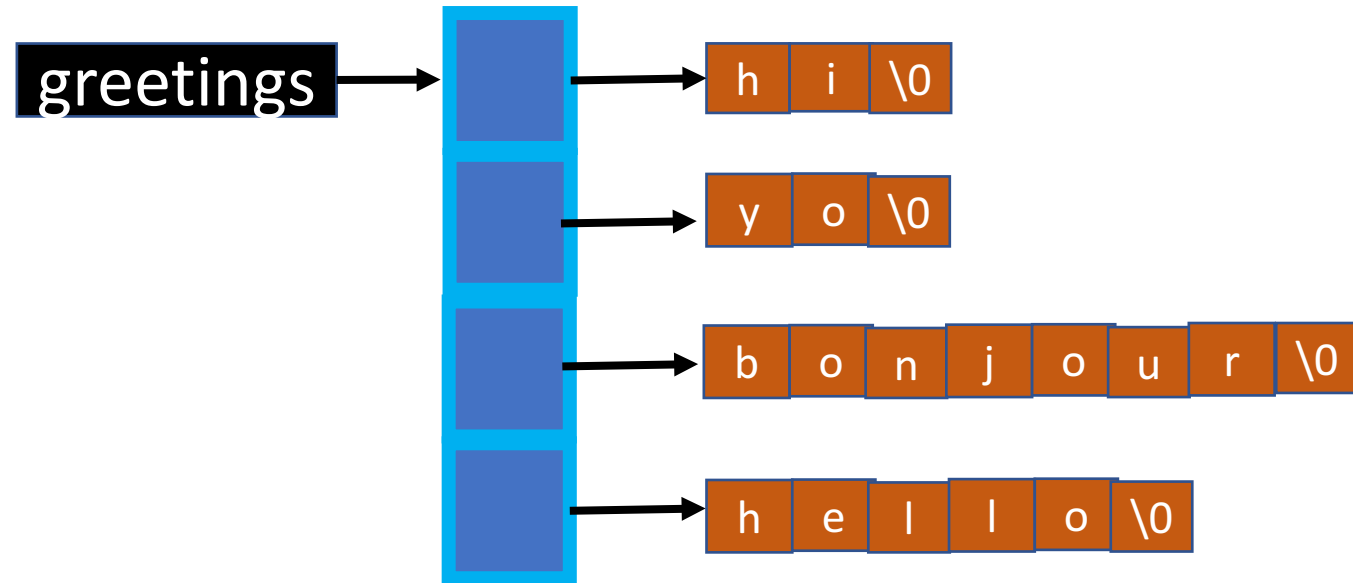


Another solution: Array of pointers

- `char *greetings[4] = { "hi", "yo", "bonjour", "hello" };`

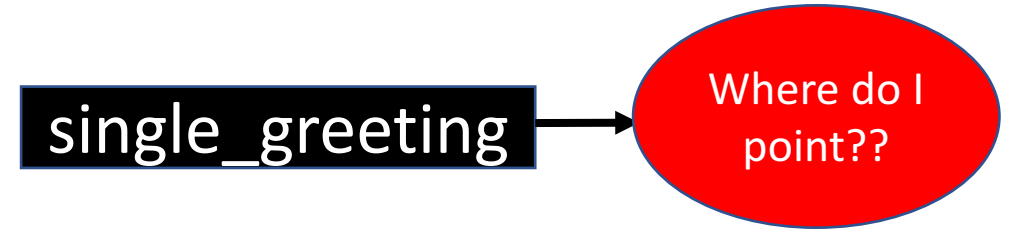
- The type of each entry is now "char*", a single character pointer

- This avoids wasting the space



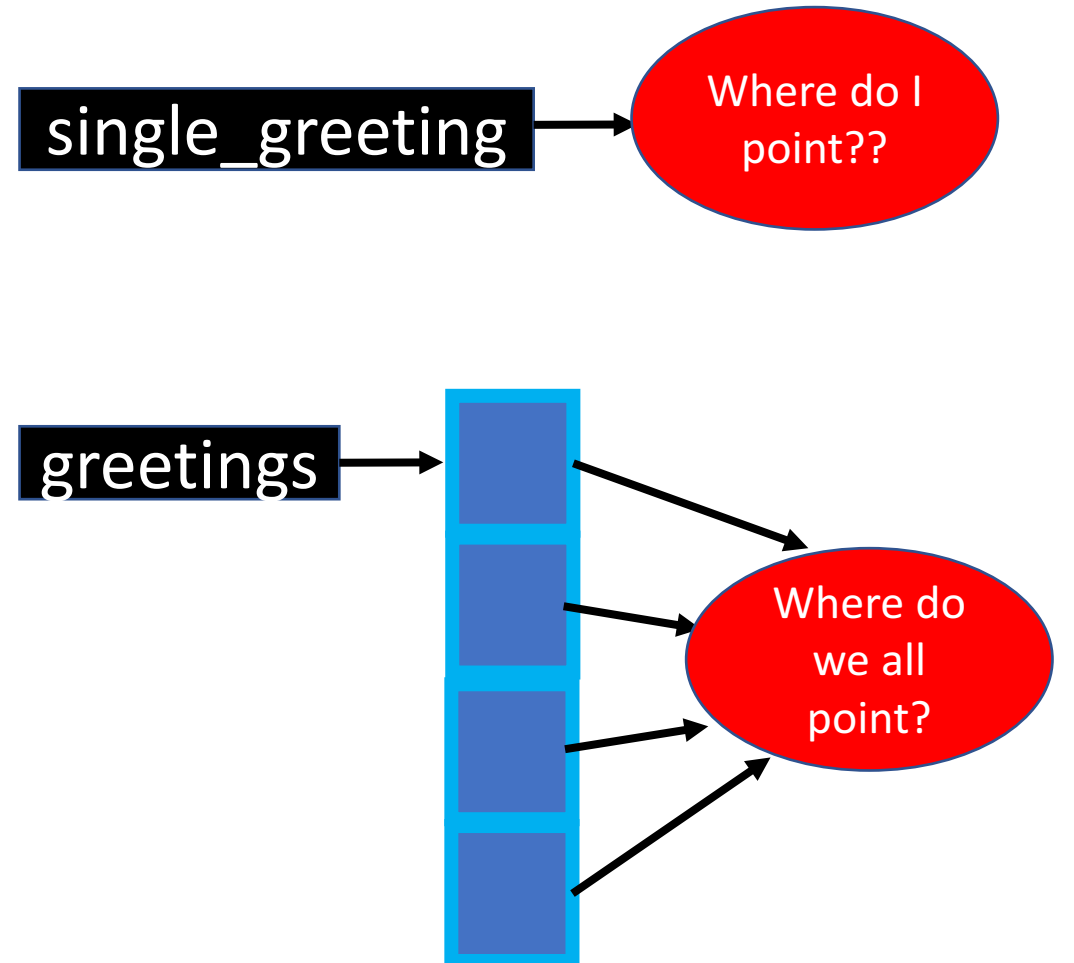
Array of pointers gotcha!

- Recall, where does an uninitialized pointer point?
 - E.g., `char* single_greeting;`
 - If we are lucky it might be NULL leading to segfault on use
 - We should be smart and set it to NULL ourselves
 - Otherwise, we will learn how to debug the hard way...



Array of pointers gotcha!

- The same story holds for arrays of pointers:
 - E.g., `char *greetings[4];`
 - All of the pointers are now undefined
- The declaration on it's own does not create any memory to hold words
- Must ensure to assign each pointer before its use:
 - To a literal like "hello"
 - To an existing pointer or array



What about calling functions: with 2D array

- Following our example, `char ttt[3][3]`
 - Suppose we'd like a function that we can call like `f(ttt)`
1. `void f(char current_board[3][3]){ /* function code */ }`
 - Match the types exactly: it must work!

What about calling functions: with 2D array

- Following our example, `char ttt[3][3]`
 - Suppose we'd like a function that we can call like `f(ttt)`
1. `void f(char current_board[3][3]){ /* function code */ }`
 2. `void f(char current_board[][3]){ /* function code */ }`
 - C needs to know the entry type to read the data correctly, so the char array of length 3 must be present
 - C does not need the length of the outer array: remember, it doesn't take care of this for us anyhow!

What about calling functions: with 2D array

- Following our example, `char ttt[3][3]`
 - Suppose we'd like a function that we can call like `f(ttt)`
1. `void f(char current_board[3][3]){ /* function code */ }`
 2. `void f(char current_board[][3]){ /* function code */ }`
 3. `void f((char*)current_board[3]){ /* function code */ }`
 - This says “pointer to data of type 3-length char array”
 - Same reasoning, as we can note the outer array with unknown size is equivalent to pointer
 - The brackets around `(char*)` are essential to distinguish this from an array of pointers (It is a good sanity check for you to be really sure you now know the difference yourself!)

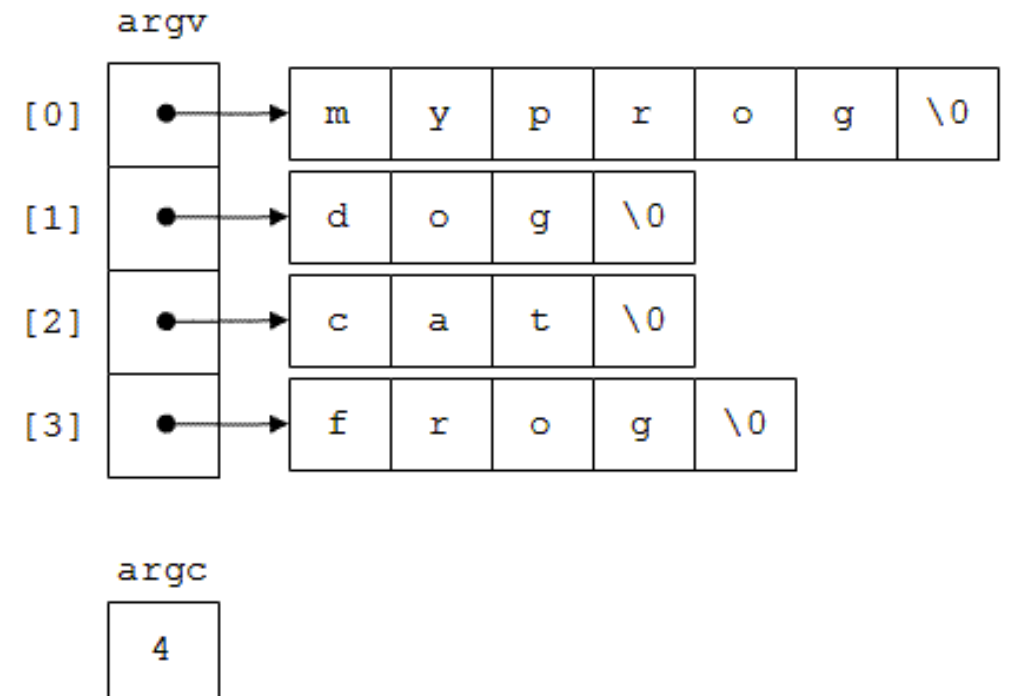
Calling functions with arrays of pointers

- Suppose we have our `char* greetings[4];`
 - And would like to be able to call `f(greetings);`
1. `void f(char *greetings[4]){ /* function code */ }`
 2. `void f(char *greetings[]) { /* function code */ }`
- Same reasoning as the above, we only have 1 array to track now and C can do that without the size

Final example for today, sort argv

- Type is `char* argv[]`, an array of pointers, each to one of the argument words
- We want the user to be able to type any number of arguments, each of any length and have the result end up properly sorted
- We can sort “in place” by working only on the pointer values within `argv`, no need to create a new variable

```
23456@turing:~$ myprog dog cat frog
```



Dave's solution on Github ExampleCode

- `Lecture11-2Darrays/sort_argv.c`
- I recommend you try this yourself as an exercise and compare
- At minimum, go over and understand each component

```
#include <stdio.h>
#include <string.h>

int main( int argc, char *argv[] ){

    // Consider one argument at a time
    for( int pos=0; pos<argc; pos++ ){

        // Find the "first" word alphabetically from here on
        char *current_min = argv[pos];
        int min_pos = -1;
        for( int pos2=pos+1; pos2<argc; pos2++ ){
            // Recall, str1 < str2 not OK, need strcmp
            if( strcmp( argv[pos2], current_min ) < 0 ){
                current_min = argv[pos2];
                min_pos = pos2;
            }
        }

        // If the initial min changed, we found a word out of order, swap
        if( current_min != argv[pos] ){
            char *temp = argv[pos];
            argv[pos] = current_min;
            argv[min_pos] = temp;
        }
    }

    // Print the result, should be sorted!
    for( int pos=0; pos<argc; pos++ )
        printf( "%s\n", argv[pos] );

    return 0;
}
```