CS107, Lecture 13
C Generics and Function Pointers

Reading: K&R 5.11

Announcements

- Midterm exam **Tues 5/5 7-9PM in CEMEX Auditorium** - exam webpages posted with review materials and exam information. Review session being scheduled, time TBD!
  - Seating assignments and date/time (for OAE + conflict exams) available on the midterm page, or at cs107.stanford.edu/cgi-bin/exam_seating.
- **Mid-Quarter Evaluation available:** open through Sun 5/3 at 11:59PM PDT. We greatly appreciate any feedback!

CS107 Topic 4

How can we use our knowledge of memory and data representation to write code that works with any data type?

Why is answering this question important?

- Writing code that works with any data type lets us write more generic, reusable code while understanding potential pitfalls (last time)
- Allows us to learn how to pass functions as parameters, a core concept in many languages (today)

assign4: implement your own version of the **ls** command, a function to generically find and insert elements into a sorted array, and a program using that function to sort the lines in a file like the **sort** command.

Learning Goals

- Learn how to write C code that works with any data type
- Learn how to pass functions as parameters
- Learn how to write functions that accept functions as parameters

Lecture Plan

- Generics So Far
- Generic Array Swap
- **Motivating Example:** Bubble Sort
- Function Pointers
- Generic Function Pointers

```
cp -r /afs/ir/class/cs107/lecture-code/lect13 .
```

Lecture Plan

- **Generics So Far**
- Generic Array Swap
- **Function Pointers Motivating Example:** Bubble Sort
- Function Pointers
- Generic Function Pointers

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```

Generics So Far

- **`void *`** is a variable type that represents a generic pointer “to something”.
- We cannot directly dereference a **`void *`**.
- We can use **`memcpy`** or **`memmove`** to copy data from one memory location to another.
- **`void *`** and generics are powerful but dangerous because of the lack of type checking, so we must be extra careful when working with generic memory.

Generic Swap

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

We can use **void *** to represent a pointer to any data, and **memcpy/memmove** to copy arbitrary bytes.

Void * Pitfalls

void *s are powerful, but dangerous - C cannot do as much checking!

- E.g. with **int**, C would never let you swap *half* of an int. With **void *s**, this can happen!

```
int x = 0xffffffff;
int y = 0xeeeeeeee;
swap(&x, &y, sizeof(short));

// now x = 0xffffeeee, y = 0xeeeeffff!
printf("x = 0x%x, y = 0x%x\n", x, y);
```

Void * Pitfalls

void *s are powerful, but dangerous - C cannot do as much checking!

- E.g. with **int**, C would never let you swap *half* of an int with a short. With **void *s**, this can happen!

```
int x = 0xffffffff;
short y = 0xeeee;
swap(&x, &y, sizeof(short));

// now x = 0xfffeeee, y = 0xffff!
printf("x = 0x%x, y = 0x%x\n", x, y);
```

Void *Pitfalls

Void * has more room for error because it manipulates arbitrary bytes without knowing what they represent. This can result in some strange memory Frankensteins!

http://i.ytimg.com/vi/10gPoYjq3EA/hqdefault.jpg

NEW: memset

memset is a function that sets a specified number of bytes starting at an address to a certain value.

```
void *memset(void *s, int c, size_t n);
```

It fills n bytes starting at memory location **s** with the byte **c**. (It also returns **s**).

```
int counts[5];
memset(counts, 0, 3);      // zero out first 3 bytes at counts
memset(counts + 3, 0xff, 4)    // set index 3 entry's bytes to 1s
```

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```

Swap Ends

You're asked to write a function that swaps the first and last elements in an array of numbers.

```
void swap_ends_int(int *arr, size_t nelems) {
    int tmp = arr[0];
    arr[0] = arr[nelems - 1];
    arr[nelems - 1] = tmp;
}

int main(int argc, char *argv[]) {
    int nums[] = {5, 2, 3, 4, 1};
    size_t nelems = sizeof(nums) / sizeof(nums[0]);
    swap_ends_int(nums, nelems);
    // want nums[0] = 1, nums[4] = 5
    printf("nums[0] = %d, nums[4] = %d\n", nums[0], nums[4]);
    return 0;
}
```

Wait – we just wrote a generic swap function. Let's use that!

Swap Ends

You're asked to write a function that swaps the first and last elements in an array of numbers.

```
void swap_ends_int(int *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}

int main(int argc, char *argv[]) {
    int nums[] = {5, 2, 3, 4, 1};
    size_t nelems = sizeof(nums) / sizeof(nums[0]);
    swap_ends_int(nums, nelems);
    // want nums[0] = 1, nums[4] = 5
    printf("nums[0] = %d, nums[4] = %d\n", nums[0], nums[4]);
    return 0;
}
```

Wait – we just wrote a generic swap function. Let's use that!

Swap Ends

Let's write out what some other versions would look like (just in case).

```
void swap_ends_int(int *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}

void swap_ends_short(short *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}

void swap_ends_string(char **arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}

void swap_ends_float(float *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}
```

The code seems to be the same regardless of the type!

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}
```

Is this generic? Does this work?

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}
```

Is this generic? Does this work?

Unfortunately not. First, we no longer know the element size. Second, pointer arithmetic depends on the type of data being pointed to. With a void *, we lose that information!

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems) {
    swap(arr, arr + nelems - 1, sizeof(*arr));
}
```

We need to know the element size, so let's add a parameter.

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, arr + nelems - 1, elem_size_bytes);
}
```

We need to know the element size, so let's add a parameter.

Pointer Arithmetic

```
arr + nelems - 1
```

Let's say nelems = 4. How many bytes beyond arr is this?

If it's an array of…

Int?

Pointer Arithmetic

```
arr + nelems - 1
```

Let's say nelems = 4. How many bytes beyond arr is this?

If it's an array of…

Int: adds 3 places to arr, and 3 * sizeof(int) = 12 bytes

Pointer Arithmetic

```
arr + nelems - 1
```

Let's say nelems = 4. How many bytes beyond arr is this?

If it's an array of…

Int: adds 3 places to arr, and 3 * sizeof(int) = 12 bytes

Short?

Pointer Arithmetic

```
arr + nelems - 1
```

Let's say nelems = 4. How many bytes beyond arr is this?

If it's an array of…

Int: adds 3 places to arr, and 3 * sizeof(int) = 12 bytes

Short: adds 3 places to arr, and 3 * sizeof(short) = 6 bytes

Pointer Arithmetic

```
arr + nelems - 1
```

Let's say nelems = 4. How many bytes beyond arr is this?

If it's an array of…

Int: adds 3 places to arr, and 3 * sizeof(int) = 12 bytes

Short: adds 3 places to arr, and 3 * sizeof(short) = 6 bytes

Char *: adds 3 places to arr, and 3 * sizeof(char *) = 24 bytes

In each case, we need to know the element size to do the arithmetic.

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, arr + nelems - 1, elem_size_bytes);
}
```

How many bytes past arr should we go to get to the last element?

(nelems – 1) * elem_size_bytes

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, arr + (nelems - 1) * elem_size_bytes, elem_size_bytes);
}
```

How many bytes past arr should we go to get to the last element?

(nelems – 1) * elem_size_bytes

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, arr + (nelems - 1) * elem_size_bytes, elem_size_bytes);
}
```

But C still can't do arithmetic with a void*. We need to tell it to not worry about it, and just add bytes. **How can we do this?**

Swap Ends

Let's write a version of swap_ends that works for any type of array.

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
         elem_size_bytes);
}
```

But C still can't do arithmetic with a void*. We need to tell it to not worry about it, and just add bytes. **How can we do this?**

char * pointers already add bytes!

Swap Ends

You're asked to write a function that swaps the first and last elements in an array of numbers. Well, now it can swap for an array of anything!

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
         elem_size_bytes);
}
```

```
int nums[] = {5, 2, 3, 4, 1};
size_t nelems = sizeof(nums) / sizeof(nums[0]);
swap_ends(nums, nelems, sizeof(nums[0]));
```

Swap Ends

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```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
         elem_size_bytes);
}
```

```
short nums[] = {5, 2, 3, 4, 1};
size_t nelems = sizeof(nums) / sizeof(nums[0]);
swap_ends(nums, nelems, sizeof(nums[0]));
```

Swap Ends

You're asked to write a function that swaps the first and last elements in an array of numbers. Well, now it can swap for an array of anything!

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
         elem_size_bytes);
}
```

```
char *strs[] = {"Hi", "Hello", "Howdy"};
size_t nelems = sizeof(strs) / sizeof(strs[0]);
swap_ends(strs, nelems, sizeof(strs[0]));
```

Swap Ends

You're asked to write a function that swaps the first and last elements in an array of numbers. Well, now it can swap for an array of anything!

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
         elem_size_bytes);
}
```

```
mystruct structs[] = …;
size_t nelems = …;
swap_ends(structs, nelems, sizeof(structs[0]));
```

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Bubble Sort

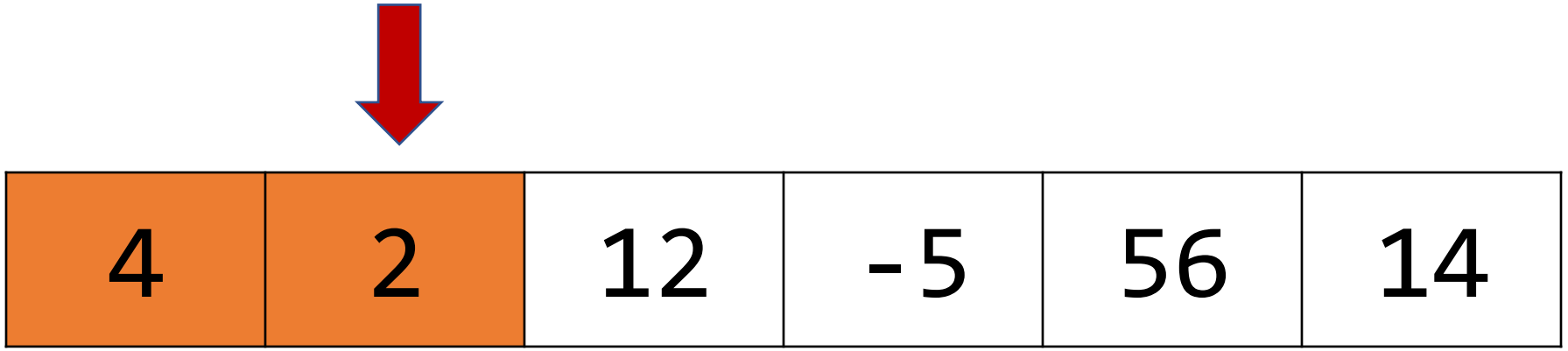
Let's write a function **`bubble_sort_int`** to sort a list of integers using the **bubble sort algorithm**.

4	2	12	-5	56	14

Bubble sort repeatedly goes through the array, swapping any pairs of elements that are out of order. When there are no more swaps needed, the array is sorted!

Bubble Sort

Let's write a function **`bubble_sort_int`** to sort a list of integers using the **bubble sort algorithm**.



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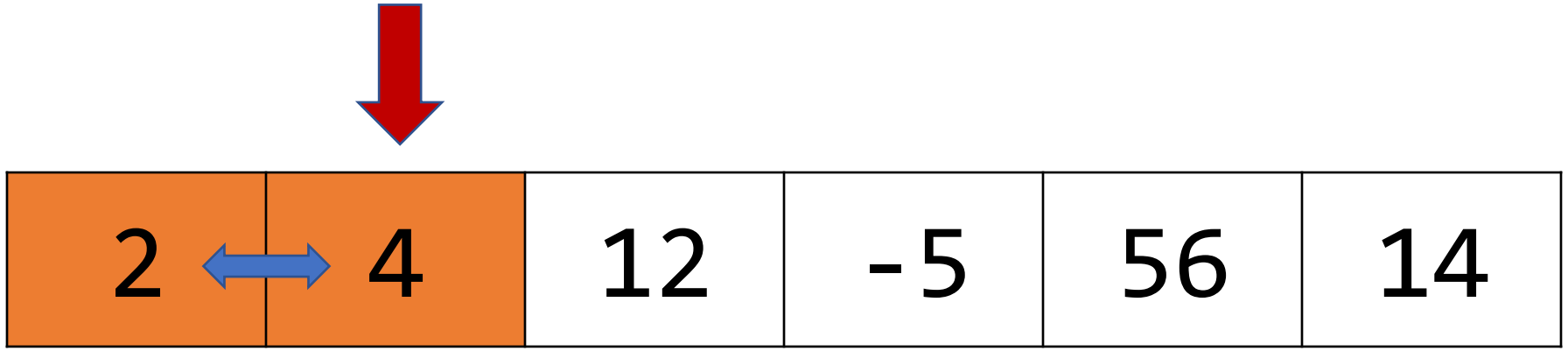

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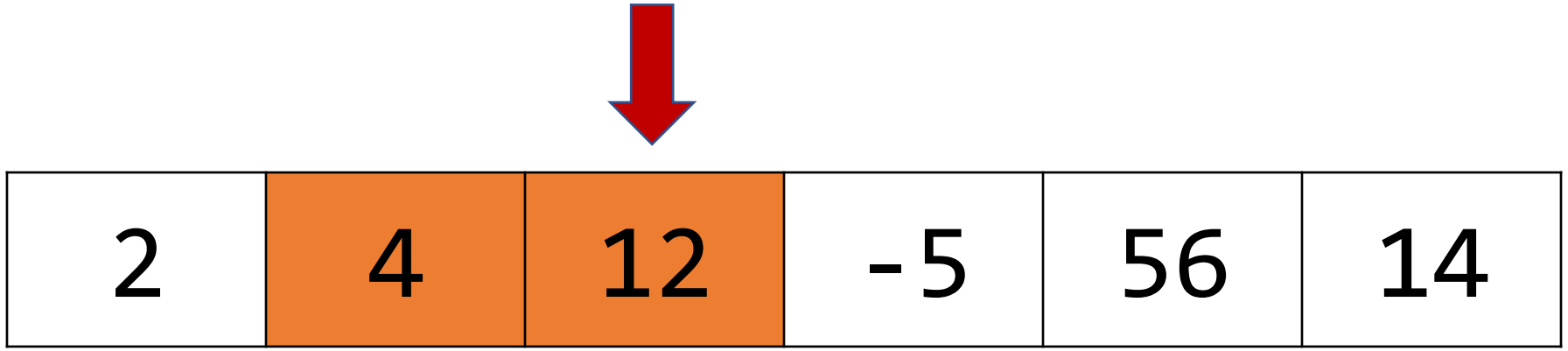

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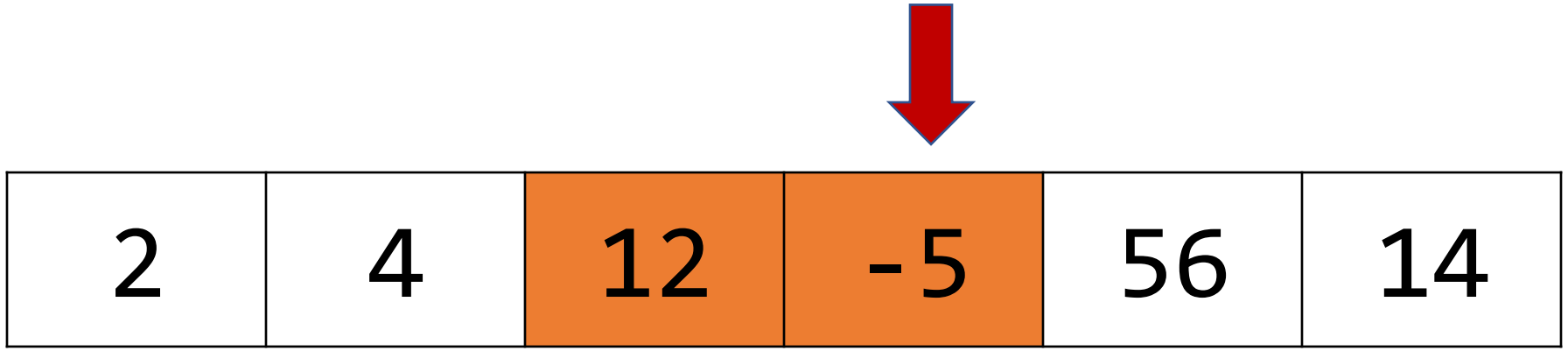

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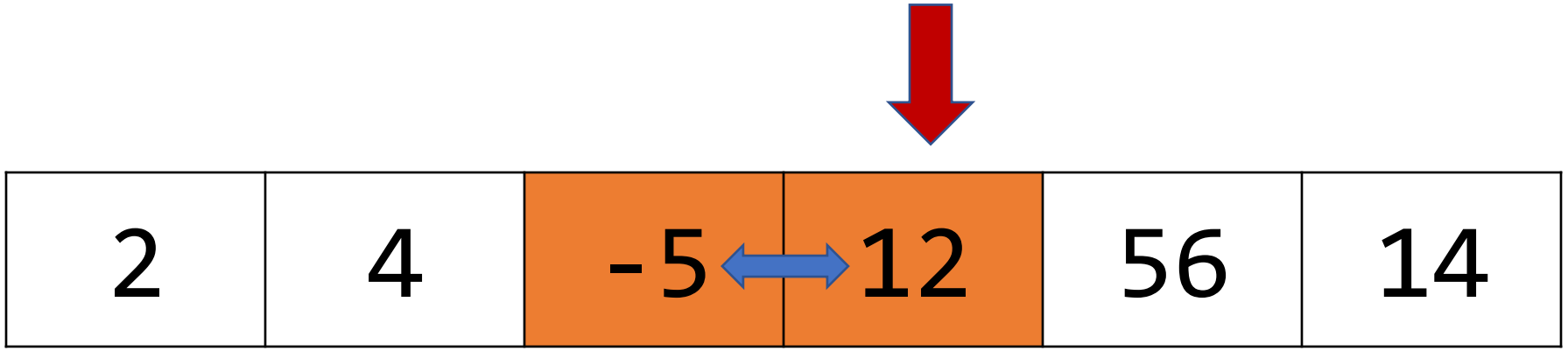

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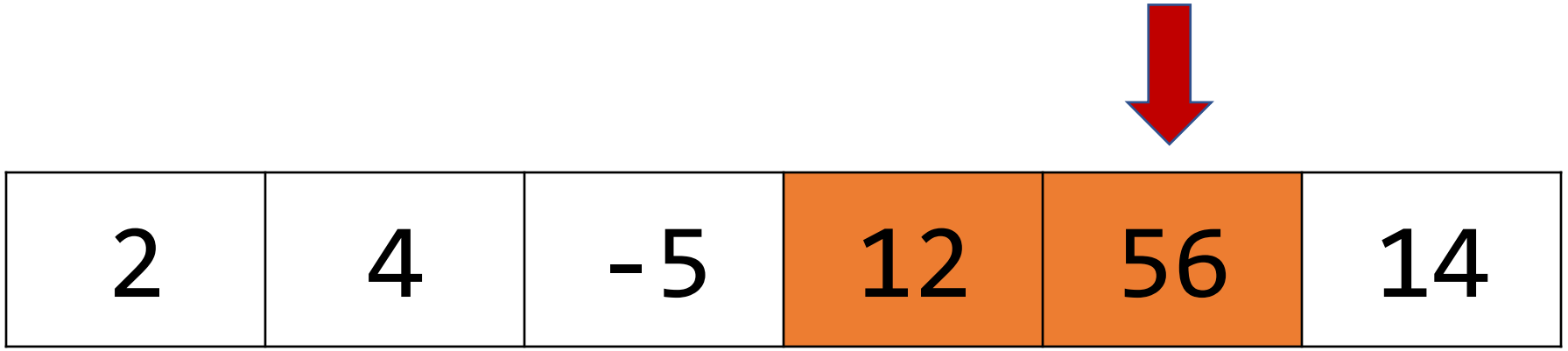

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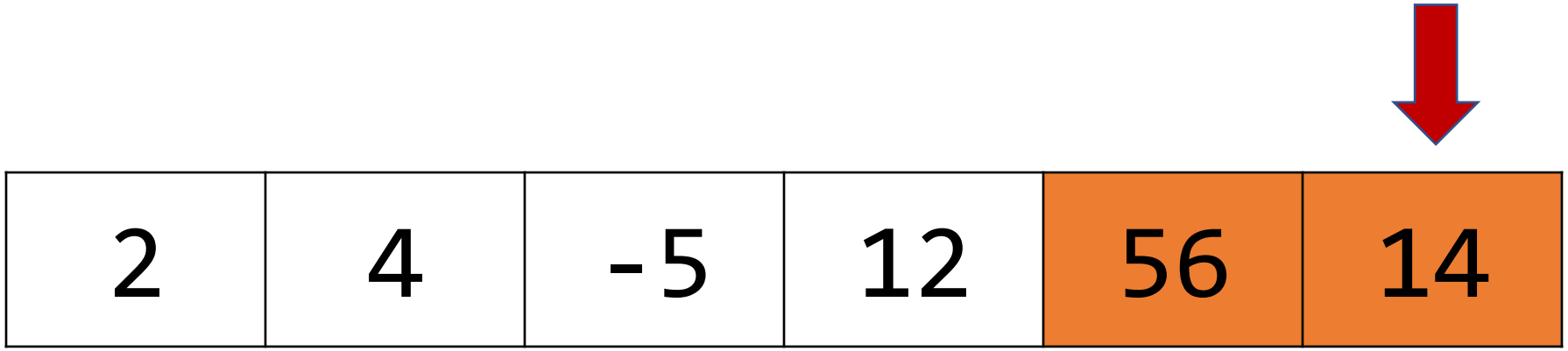

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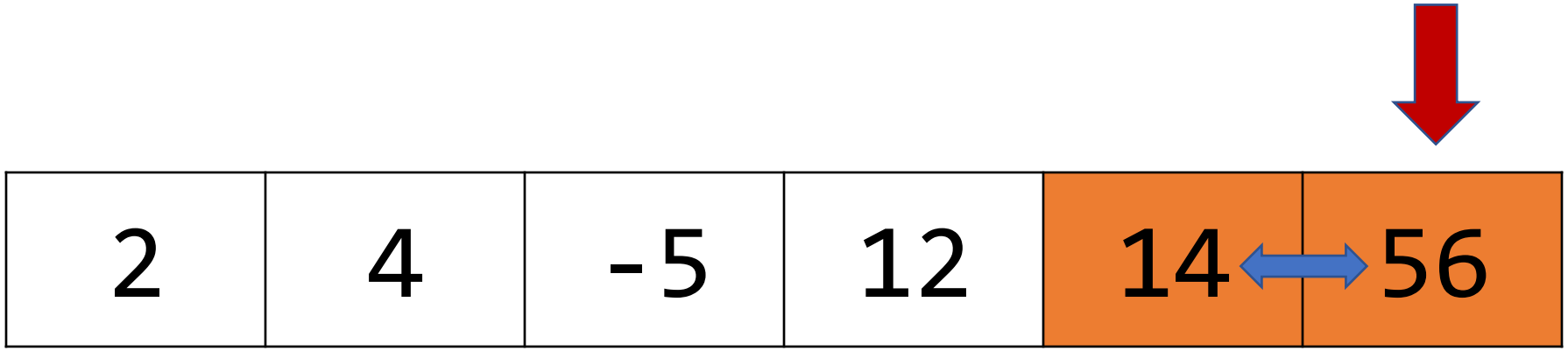

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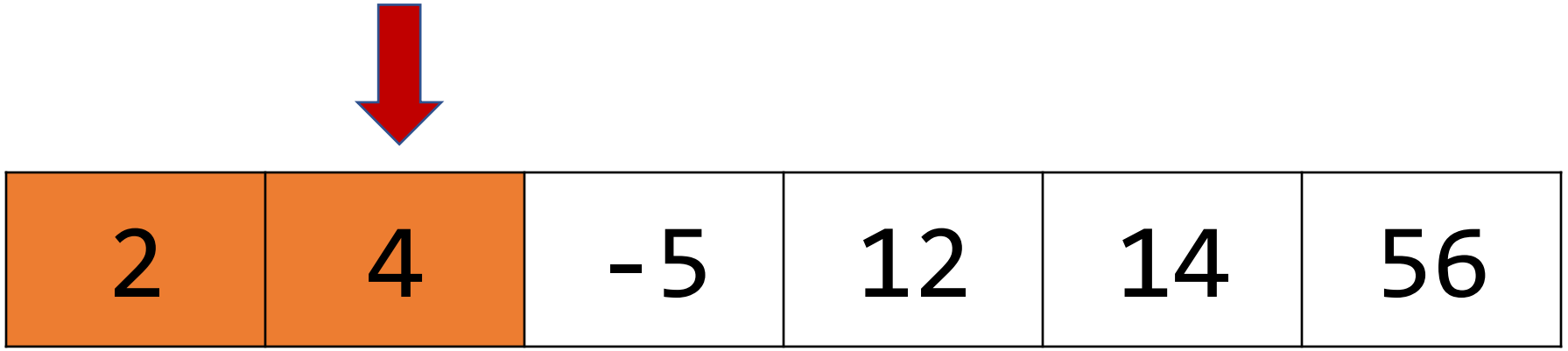

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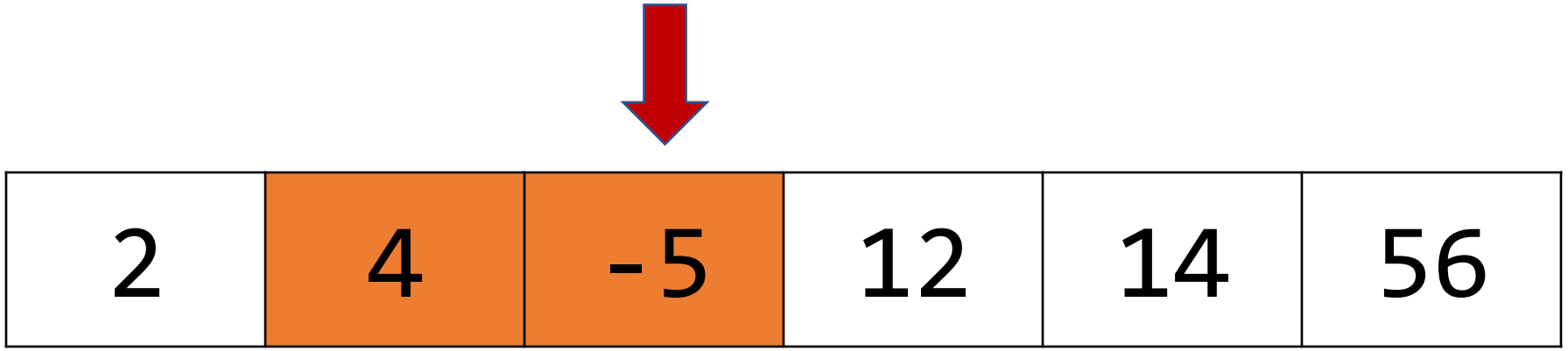

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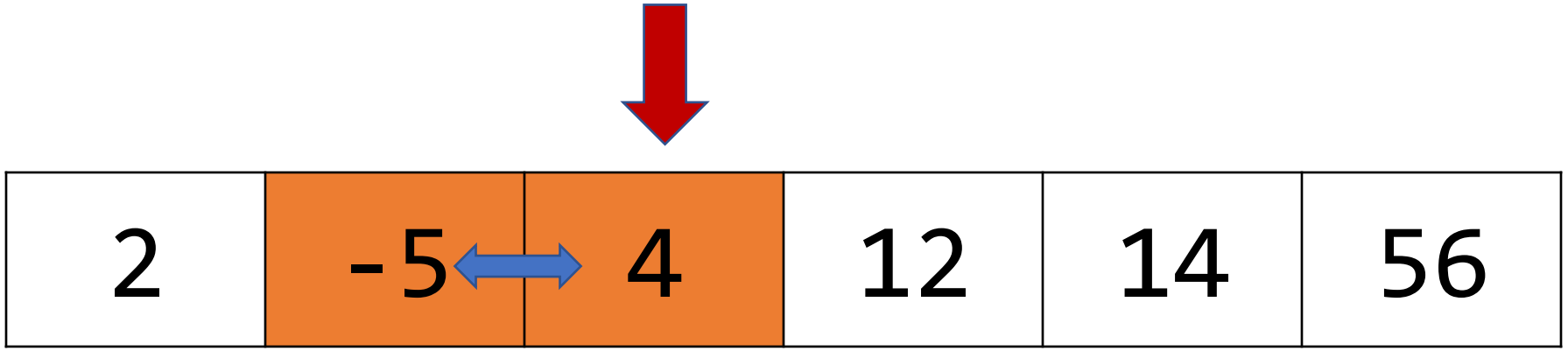

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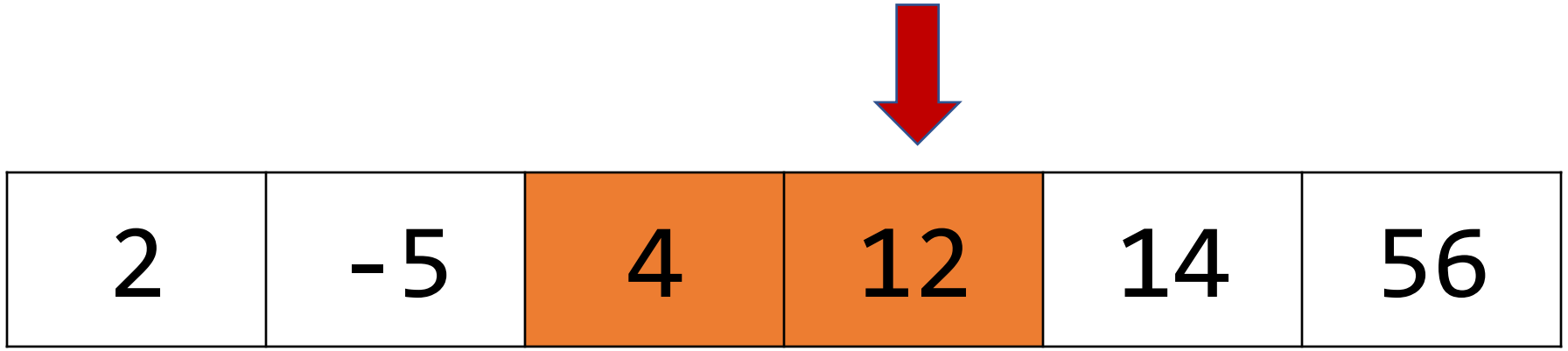

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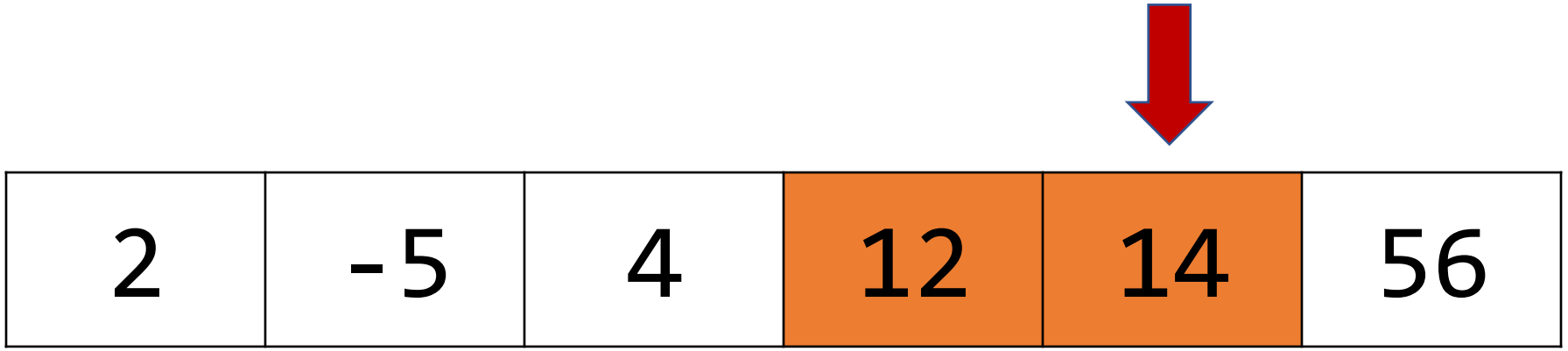

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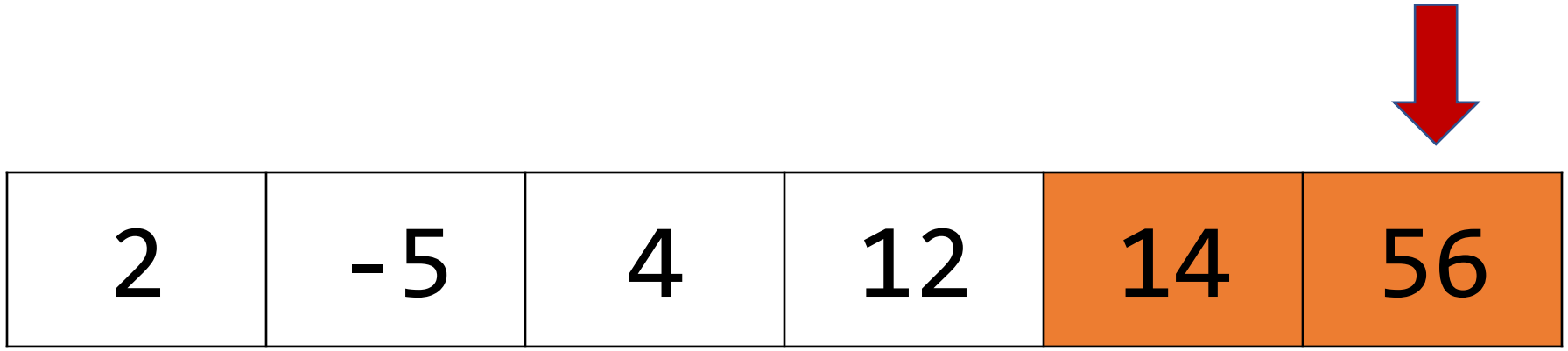

Bubble sort repeatedly goes through the array, swapping any pairs of elements that are out of order. When there are no more swaps needed, the array is sorted!

In general, bubble sort requires up to n - 1 passes to sort an array of length n, though it may end sooner if a pass doesn't swap anything.

Bubble Sort

Let's write a function **`bubble_sort_int`** to sort a list of integers using the **bubble sort algorithm**.

-5	2	4	12	14	56

Bubble sort repeatedly goes through the array, swapping any pairs of elements that are out of order. When there are no more swaps needed, the array is sorted!

Only two more passes are needed to arrive at the above. The first exchanges the 2 and the -5, and the second leaves everything as is.

Goal: Generic Bubble Sort

file_that_sorts_ints.c

```
#include "bubblesort.h"

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

file_that_sorts_strings.c

```
#include "bubblesort.h"

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

file_that_sorts_structs.c

```
#include "bubblesort.h"

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

Goal: write 1 implementation of bubblesort that any program can use to sort data of any type.

bubblesort.h/c

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (arr[i - 1] > arr[i]) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

How can we make this function more generic? To start, this function always sorts in ascending order. What about other orders?

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n, bool ascending) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if ((ascending && arr[i - 1] > arr[i]) ||
                (!ascending && arr[i] > arr[i – 1])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

We can add parameters, but they only help so much. What about other orders we can't anticipate? (odd-before-even, etc.)

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

What we really want is this – but we don't know how to implement this function…the person calling this function does, though!

Key Idea: have the caller pass a function as a parameter that takes two `int`s and tells us whether we should swap them.

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n, type?? should_swap) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

Lecture Plan

- Generics So Far
- Generic Array Swap
- **Function Pointers Motivating Example:** Bubble Sort
- **Function Pointers**
- Generic Function Pointers

```
cp -r /afs/ir/class/cs107/lecture-code/lect13 .
```

Function Pointers

A *function pointer* is the variable type for passing a function as a parameter. Here is how the parameter's type is declared in this case.

```
bool (*should_swap)(int, int)
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```
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```

Return type
(bool)

Function Pointers

A *function pointer* is the variable type for passing a function as a parameter. Here is how the parameter's type is declared in this case.

```
bool (*should_swap)(int, int)
```

Function pointer name
(should_swap)

Function Pointers

A *function pointer* is the variable type for passing a function as a parameter. Here is how the parameter's type is declared in this case.

```
bool (*should_swap)(int, int)
```

Function parameters
(two ints)

Function Pointers

Here's the general variable type syntax:

```
[return type] (*[name])([parameters])
```

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n, bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

bubble_sort_int lets the caller specify any sort order they want via the **should_swap** function.

Function Pointers

```c
// my_program.c
#include "bubblesort.h"

bool sort_ascending(int first_num,
                    int second_num) {
    return first_num > second_num;
}

int main(int argc, char *argv[]) {
    int nums[] = {4, 2, -5, 1, 12, 56};
    int nums_count = sizeof(nums) /
                     sizeof(nums[0]);
    bubble_sort_int(nums, nums_count,
                    sort_ascending);
    ...
}
```

```c
// bubblesort.c

void bubble_sort_int(int *arr, size_t
n, bool (*should_swap)(int, int)) {
    ...
}
```

bubble_sort_int is written generically. When someone imports our function into their program, they will call it specifying the sort ordering they want that time.

Function Pointers

```c
// my_program.c
#include "bubblesort.h"

bool sort_descending(int first_num,
                     int second_num) {
    return first_num < second_num;
}

int main(int argc, char *argv[]) {
    int nums[] = {4, 2, -5, 1, 12, 56};
    int nums_count = sizeof(nums) /
                     sizeof(nums[0]);
    bubble_sort_int(nums, nums_count,
                    sort_descending);
    ...
}
```

```c
// bubblesort.c

void bubble_sort_int(int *arr, size_t
n, bool (*should_swap)(int, int)) {
    ...
}
```

bubble_sort_int is written generically. When someone imports our function into their program, they will call it specifying the sort ordering they want that time.

Function Pointers

```c
// my_program.c
#include "bubblesort.h"

bool sort_odd_then_even(int first_num,
                        int second_num) {
    return (second_num % 2 != 0) &&
           (first_num % 2 == 0);
}

int main(int argc, char *argv[]) {
    int nums[] = {4, 2, -5, 1, 12, 56};
    int nums_count = sizeof(nums) /
                     sizeof(nums[0]);
    bubble_sort_int(nums, nums_count,
                    sort_odd_then_even);
    ...
}
```

```c
// bubblesort.c

void bubble_sort_int(int *arr, size_t
n, bool (*should_swap)(int, int)) {
    ...
}
```

bubble_sort_int is written generically. When someone imports our function into their program, they will call it specifying the sort ordering they want that time.

Function Pointers

Passing a non-function as a parameter allows us to *pass data around our program*. Passing a function as a parameter allows us to *pass logic around our program*. **We can implement code where a piece of the logic can be customized by the caller**.

- When writing a generic function, if we don't know how to do something in the way the caller wants, we can ask them to pass in a function parameter that can do it for us.
- Also called a "callback" function – function "calls back to" the caller.
  - **Function writer:** writes generic algorithmic functions, relies on caller-provided data
  - **Function caller**: knows the data, doesn't know how the algorithm works

Lecture Plan

- Generics So Far
- Generic Array Swap
- **Function Pointers Motivating Example:** Bubble Sort
- Function Pointers
- **Generic Function Pointers**

```
cp -r /afs/ir/class/cs107/lecture-code/lect13 .
```

Integer Bubble Sort

```
void bubble_sort_int(int *arr, size_t n, bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

bubble_sort_int now supports any possible sort ordering. But it's not fully generic - it still only supports arrays of ints. What about arrays of other types?

Generic Bubble Sort

```
void bubble_sort(int *arr, size_t n,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                int tmp = arr[i - 1];
                arr[i - 1] = arr[i];
                arr[i] = tmp;
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

Let's start by making the parameters and swap generic.

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(&arr[i - 1], &arr[i], elem_size_bytes);
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

Let's start by making the parameters and swap generic.

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(&arr[i - 1], &arr[i], elem_size_bytes);
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

Problem: we can't do pointer arithmetic / indexing with **void *s**!

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(arr + i - 1, arr + i, elem_size_bytes);
            }
        }

        if (!swapped) {
            return;
        }
    }
}
```

Problem: we can't do pointer arithmetic / indexing with **void *s**!

Key Idea: Locating i-th Elem

A common generics idiom is getting a pointer to the i-th element of a generic array. From previously, we know how to locate the **last** element:

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
elem_size_bytes);
}
```

What can we use as an expression to get the location of the i-th element?

Respond on PollEv:
pollev.com/cs107

L13. What is the expression to get a pointer to the i-th element of a generic array?

Nobody has responded yet.

Hang tight! Responses are coming in.

Key Idea: Locating i-th Elem

A common generics idiom is getting a pointer to the i-th element of a generic array. We know how to locate the **last** element:

```
void swap_ends(void *arr, size_t nelems, size_t elem_size_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_size_bytes,
elem_size_bytes);
}
```

What can we use as an expression to get the location of the i-th element?

```
void *ith_elem = (char *)arr + i * elem_size_bytes;
```

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

Let's start by making the parameters and swap generic.

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(int, int)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

How do we make the comparison function generic?

Generic Bubble Sort

To write one generic bubblesort function, we must create one function signature that works for any scenario with any type – this includes the comparison function. We must pick **one** comparison function signature.

```
void bubble_sort(int *arr, size_t n, bool (*should_swap)(int, int));
```

Generic Bubble Sort

To write one generic bubblesort function, we must create one function signature that works for any scenario with any type.

```
void bubble_sort(void *arr, size_t n,
    size_t elem_size_bytes, bool (*should_swap)(??, ??));
```

Any functions passed in as the **should_swap** parameter must exactly match this signature.

Challenge: for **should_swap** parameters, C has no way to specify "a variable of any type".

Generic Parameters

```
void bubble_sort(void *arr, size_t n,
    size_t elem_size_bytes,
    bool (*should_swap)(type param1, type param2));
```

Problem: C needs every parameter to be a single specified size. **int** is 4 bytes, **char *** is 8; how do we solve this?

Solution: pointers are the same size, regardless of what they point to. Let's have the compare function take ***pointers to the elements*** to compare. To make it generic, they will be **void *** pointers.

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(void *, void *)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (should_swap(arr[i - 1], arr[i])) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

The comparison function must work with pointers *to the elements,* not the elements themselves.

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 bool (*should_swap)(void *, void *)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (should_swap(p_prev_elem, p_curr_elem)) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

The comparison function must work with pointers *to the elements,* not the elements themselves.

Comparison Functions

Function pointers are used often in cases like this to compare two values of the same type. These are called **comparison functions**.

C has a standard format for comparison function, returning an **int** instead of a **bool** to provide more information about order. It's like **strcmp** - it should return:

- < 0 if first value should come before second value
- > 0 if first value should come after second value
- 0 if first value and second value are equivalent

```
int (*compare_fn)(void *, void *)
```

Generic Bubble Sort

```
void bubble_sort(void *arr, size_t n, size_t elem_size_bytes,
                 int (*should_swap)(void *, void *)) {
    while (true) {
        bool swapped = false;
        for (size_t i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (should_swap(p_prev_elem, p_curr_elem) > 0) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }
        if (!swapped) {
            return;
        }
    }
}
```

Passing Functions as Parameters

1. Taking a function as a parameter lets us implement code where a piece of the logic can be customized by the caller.
   - **Example: bubble sort** – a function anyone can import to sort an array. Doesn't know how to order a given pair of elements – asks caller to pass in a function that can take in two elements and specify intended order.
2. When calling e.g. **bubble sort**, the caller passes in the name of a function as a parameter that they implemented specifically for what they want to do that time. (We'll see examples next time!)
3. To write a fully-generic version of bubble sort that works with any data type, we must pick *one* signature for our comparison function – the standard comparison function signature takes in 2 **void *s** and returns an **int.**

```
void bubble_sort(void *arr, size_t n, size_t
elem_size_bytes, int (*cmp_fn)(void *, void *))
```

Recap

- Generics So Far
- Generic Array Swap
- **Function Pointers Motivating Example:** Bubble Sort
- Function Pointers
- Generic Function Pointers

Lecture 13 takeaway: We can do pointer arithmetic with a **void** * by casting it to char * and adding/subtracting # bytes. A function pointer is a type of variable that stores a function, and we can pass them as parameters. A common use case is to pass comparison functions to generic functions like bubble sort that need to compare elements.