COMP201

Computer Systems & Programming

Lecture #11 – Function Pointers

KOÇ UNIVERSITY

Aykut Erdem // Koç University // *Spring 2025*

Good news, everyone!

Image: Professor Farnsworth (Futurama)

- No lab this week.

Recap

- Overview: Generics
- Generic Swap
- Generics Pitfalls
- Generic Array Swap

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

Plan for Today

- Generics So Far
- Motivating Example: Bubble Sort
- Function Pointers
- Example: Generic Printing
- Example: Counting Matches

Disclaimer: Slides for this lecture were borrowed from
—Nick Troccoli's Stanford CS107 class

Lecture Plan

- Generics So Far
- Motivating Example: Bubble Sort
- Function Pointers
- Example: Generic Printing
- Example: Counting Matches

Generics So Far

- **`void *`** is a variable type that represents a generic pointer "to something".
- We cannot perform pointer arithmetic with or dereference a **`void *`**.
- We can use **`memcpy`** or **`memmove`** to copy data from one memory location to another.
- To do pointer arithmetic with a **`void *`**, we must first cast it to a **`char *`**.
- **`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.

Recap: 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.

Recap: Generic Swap

```
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    memcpy(temp, data1ptr, nbytes);
    // copy data2 to location of data1
    memcpy(data1ptr, data2ptr, nbytes);
    // copy data in temporary storage to location of data2
    memcpy(data2ptr, temp, nbytes);
}
```

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

Recap: Generic Swap

```
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    memcpy(temp, data1ptr, nbytes);
    // copy data2 to location of data1
    memcpy(data1ptr, data2ptr, nbytes);
    // copy data in temporary storage to location of data2
    memcpy(data2ptr, temp, nbytes);
}
```

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

Recap: Generic Swap

```
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    memcpy(temp, data1ptr, nbytes);
    // copy data2 to location of data1
    memcpy(data1ptr, data2ptr, nbytes);
    // copy data in temporary storage to location of data2
    memcpy(data2ptr, temp, nbytes);
}
```

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

Recap: Generic Array Swap

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

We can cast to a **`char *`** in order to perform manual byte arithmetic with void * pointers.

Recap: 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_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_bytes, elem_bytes);
}
```

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

Recap: 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_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_bytes, elem_bytes);
}
```

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

Recap: 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_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_bytes, elem_bytes);
}
```

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

Array Rotation

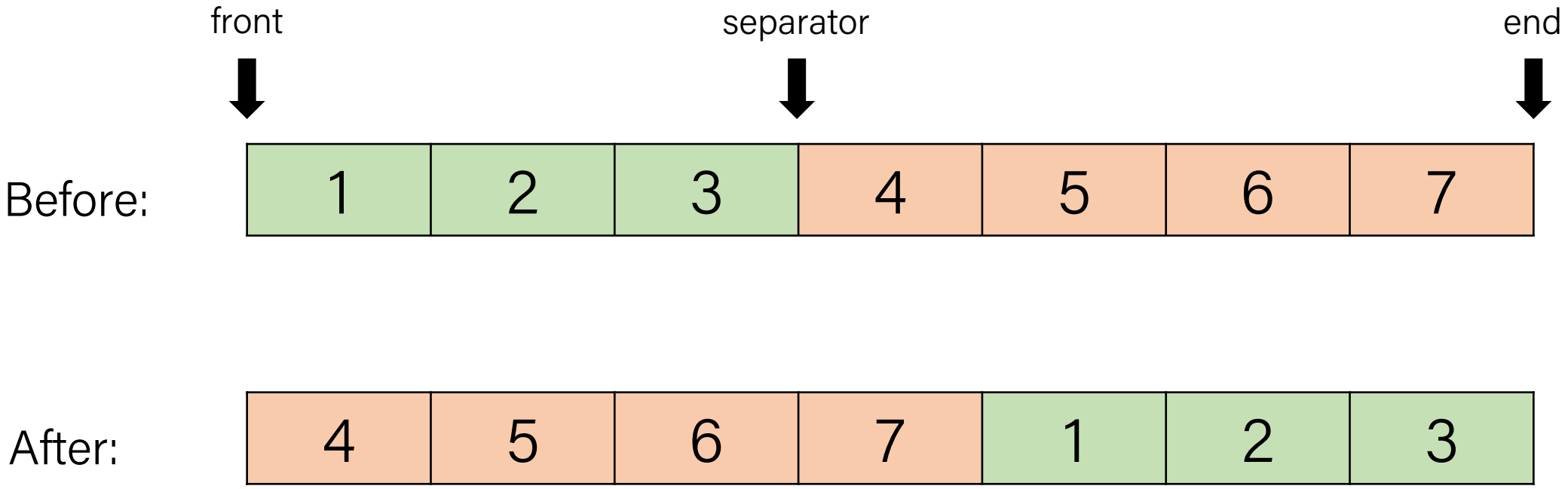
You're asked to provide an implementation for a function called **`rotate`** with the following prototype:

```
void rotate(void *front, void *separator, void *end);
```

The expectation is that **`front`** is the base address of an array, **`end`** is the past-the-end address of the array, and **`separator`** is the address of some element in between. **`rotate`** moves all elements in between **`front`** and **`separator`** to the end of the array, and all elements between **`separator`** and **`end`** move to the front.

Array Rotation

```
int array[7] = {1, 2, 3, 4, 5, 6, 7};
rotate(array, array + 3, array + 7);
```



Demo: Array Rotation

`rotate.c`

Array Rotation

A properly implemented **`rotate`** will prompt the following program to generate the provided output.

```
int main(int argc, char *argv[]) {
    int array[10] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
    print_int_array(array, 10); // intuitive implementation ☺
    rotate(array, array + 5, array + 10);
    print_int_array(array, 10);
    rotate(array, array + 1, array + 10);
    print_int_array(array, 10);
    rotate(array + 4, array + 5, array + 6);
    print_int_array(array, 10);
    return 0;
}
```

```
Output:
linuxpool :~/lect11$ ./rotate
Array: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Array: 6, 7, 8, 9, 10, 1, 2, 3, 4, 5
Array: 7, 8, 9, 10, 1, 2, 3, 4, 5, 6
Array: 7, 8, 9, 10, 2, 1, 3, 4, 5, 6
linuxpool:~/lect11$
```

Array Rotation

A properly implemented **`rotate`** will prompt the following program to generate the provided output.

And here's that properly implemented function!

```
void rotate(void *front, void *separator, void *end) {
    int width = (char *)end - (char *)front;
    int prefix_width = (char *)separator - (char *)front;
    int suffix_width = width - prefix_width;

    char temp[prefix_width];
    memcpy(temp, front, prefix_width);
    memmove(front, separator, suffix_width);
    memcpy((char *)end - prefix_width, temp, prefix_width);
}
```

memset

memset is a function that sets a specified number of bytes at one 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 3rd entry's bytes to 1s
```

Why are `void *` pointers useful?

Because each parameter and return type must be a *single type* with a *single size*.

Why Are `void *` Pointers Useful?

- Each parameter and return type must be a *single* type with a *single* size.
- **Problem #1:** for a function parameter to accept multiple data types, it needs to be able to accept data of different sizes.
  - **Key Idea #1:** pointers are all the same size regardless of what they point to. To pass different sizes of data via a single parameter type, make the parameter be a pointer to the data instead.
- **Problem #2:** we still might pass either a `char *`, `int *`, etc. These are the same size, but still different declared types. What should the parameter type be?
  - **Key Idea #2:** A `void *` encompasses all these types – it represents a "pointer to something". A `char *`, `int *`, etc. all implicitly cast to `void *`.
- **Solution:** to pass one of multiple types via a single parameter/return, that parameter/return's type can be **`void *`**, and we can pass a pointer to the data.

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Bubble Sort

- Let's write a function to sort a list of integers. We'll use 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

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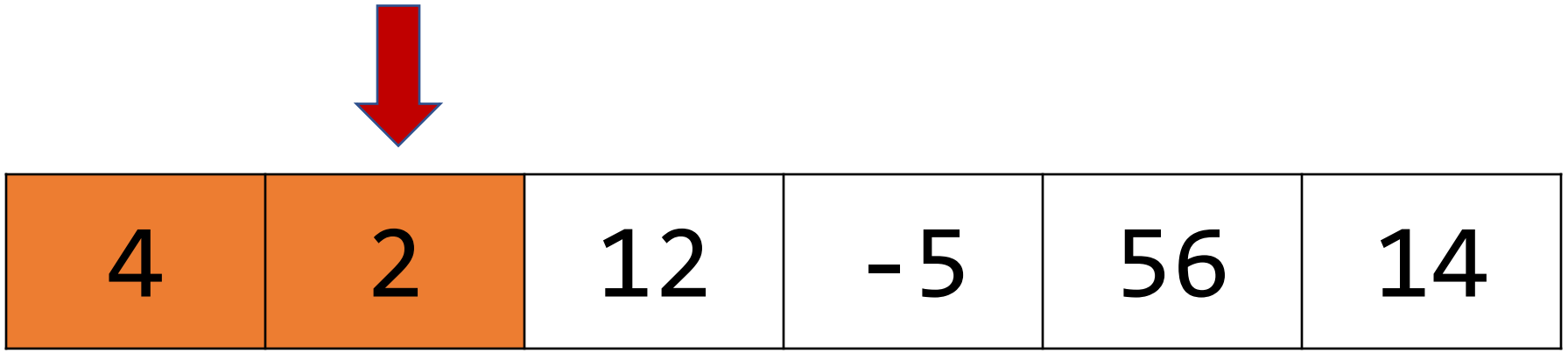

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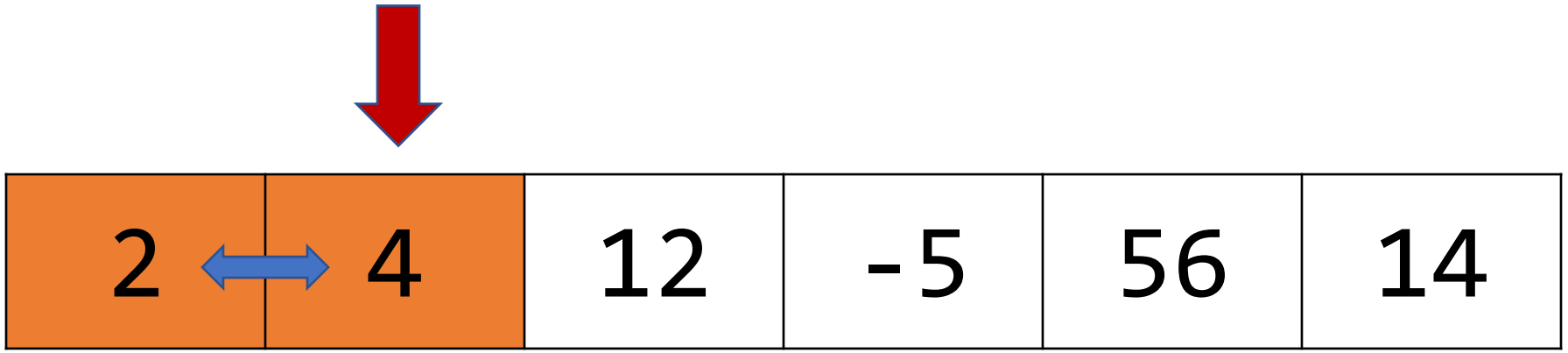

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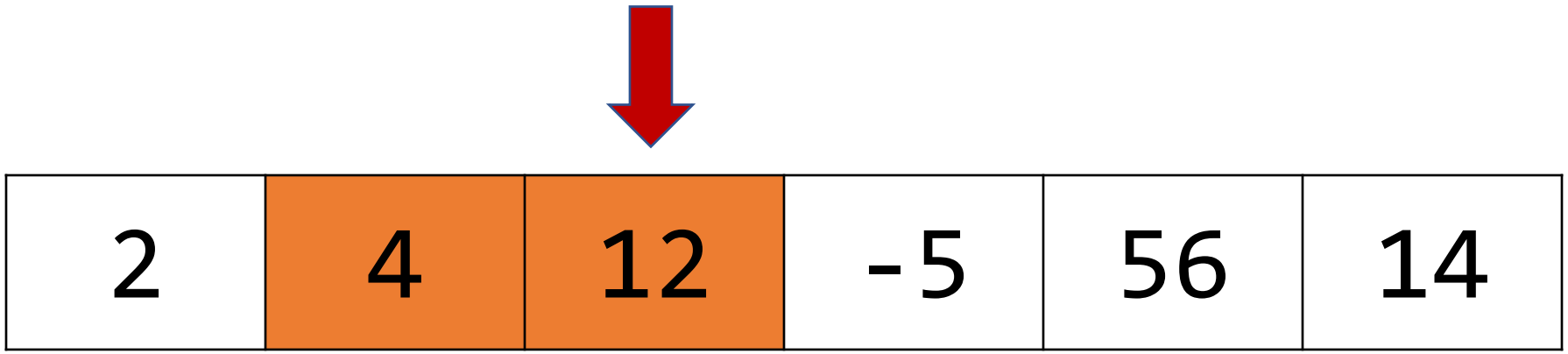

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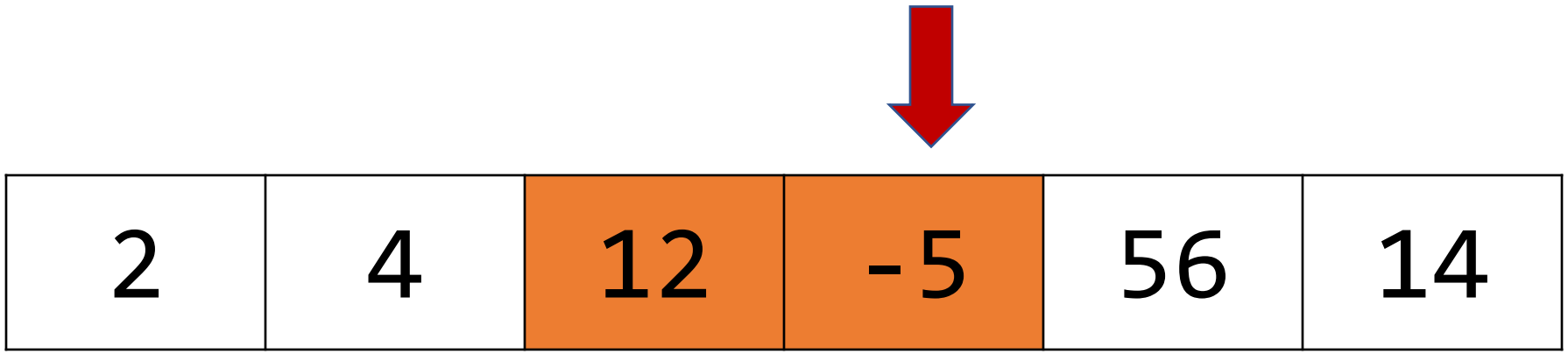

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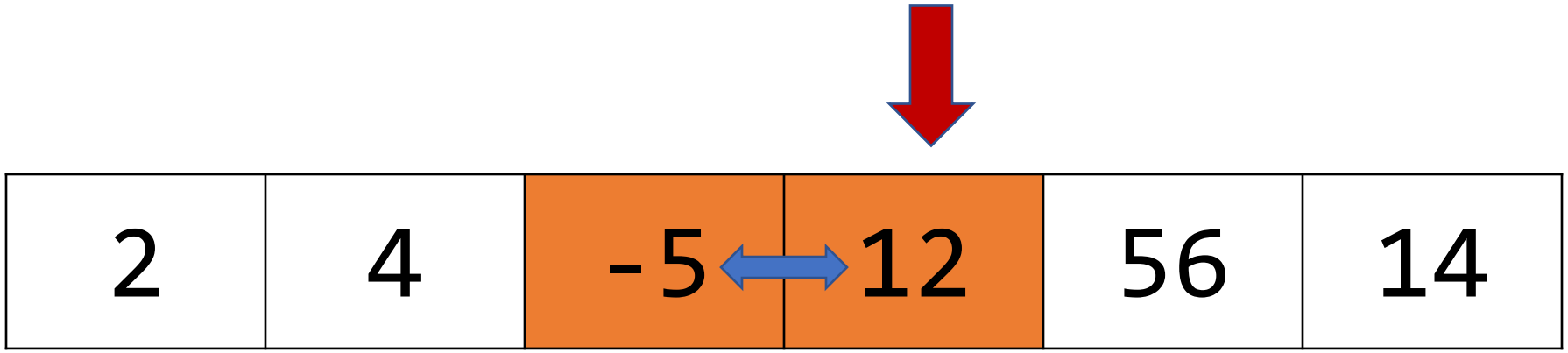

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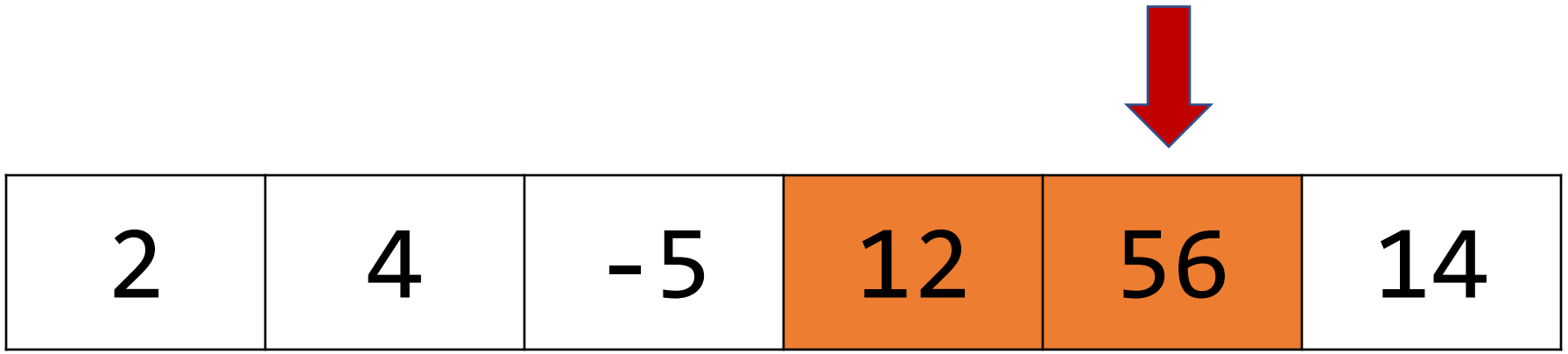

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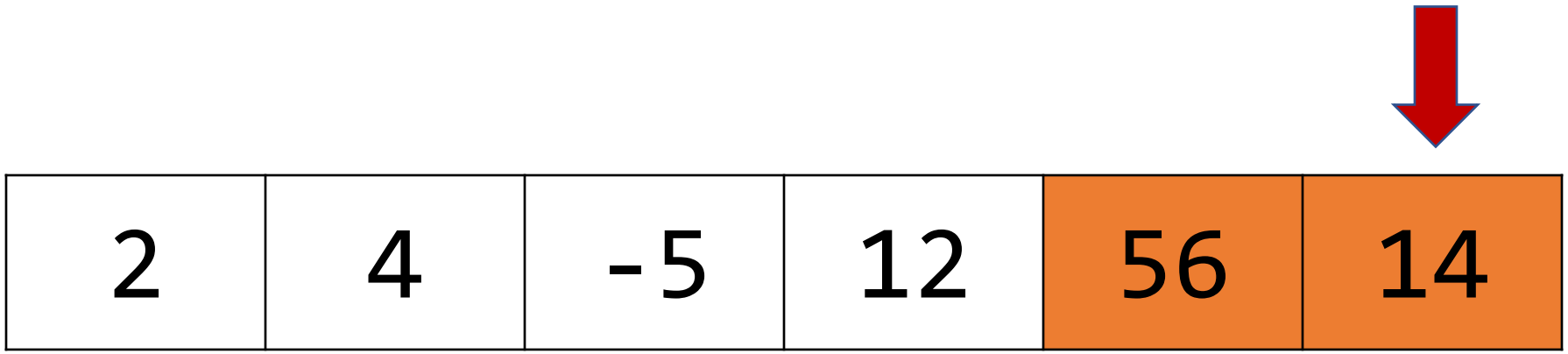

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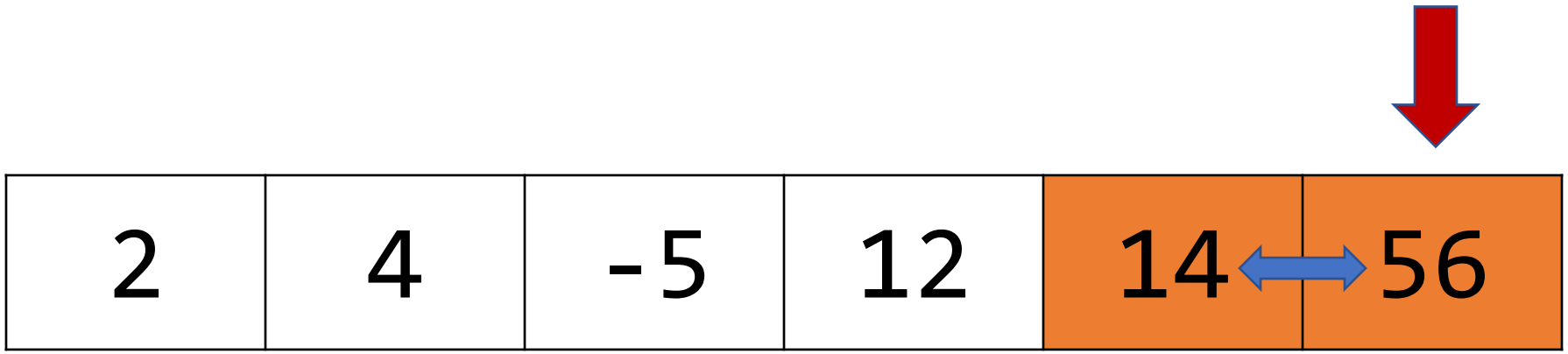

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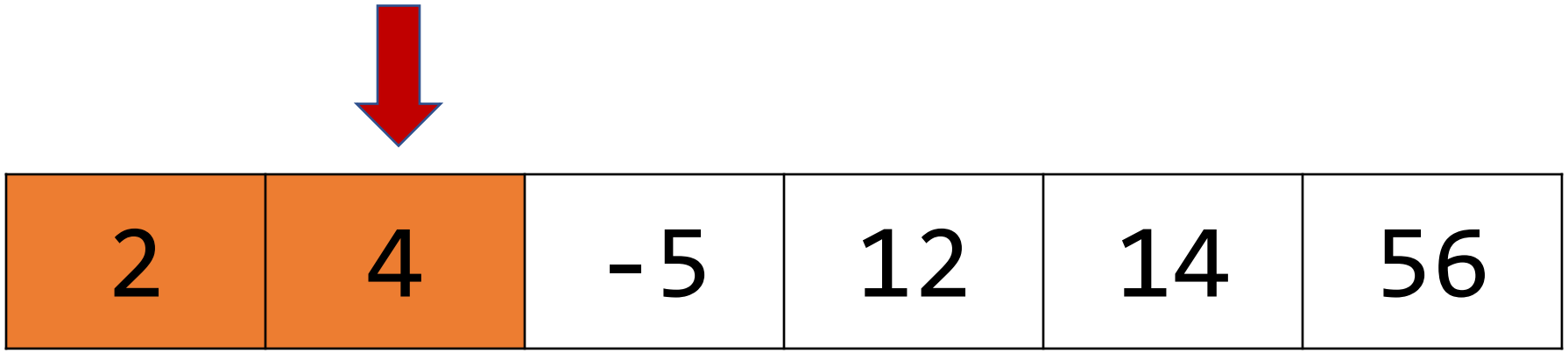

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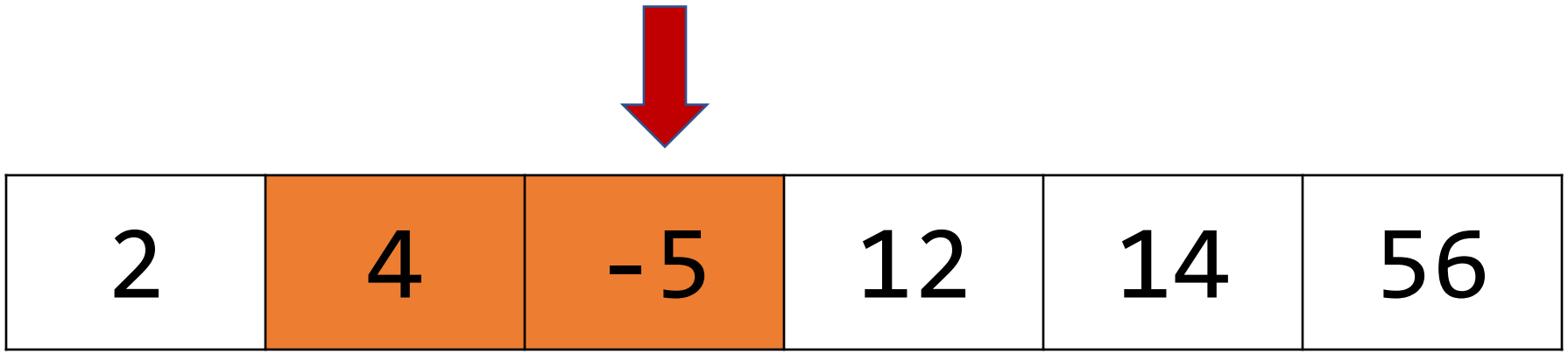

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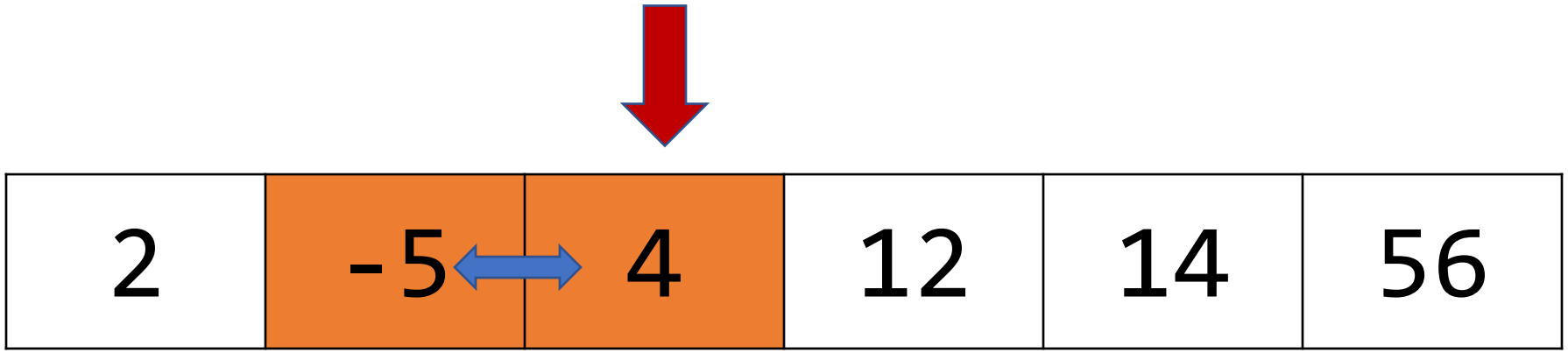

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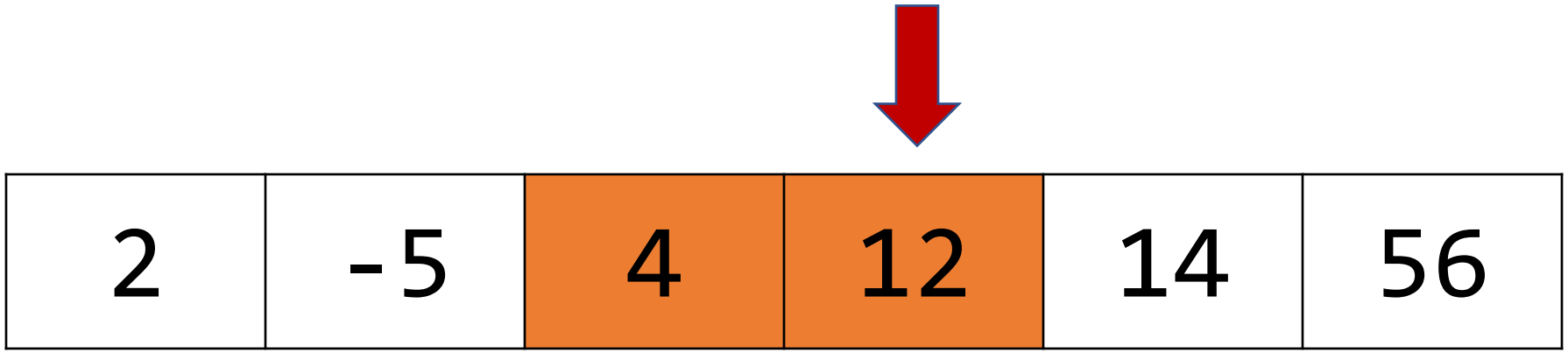

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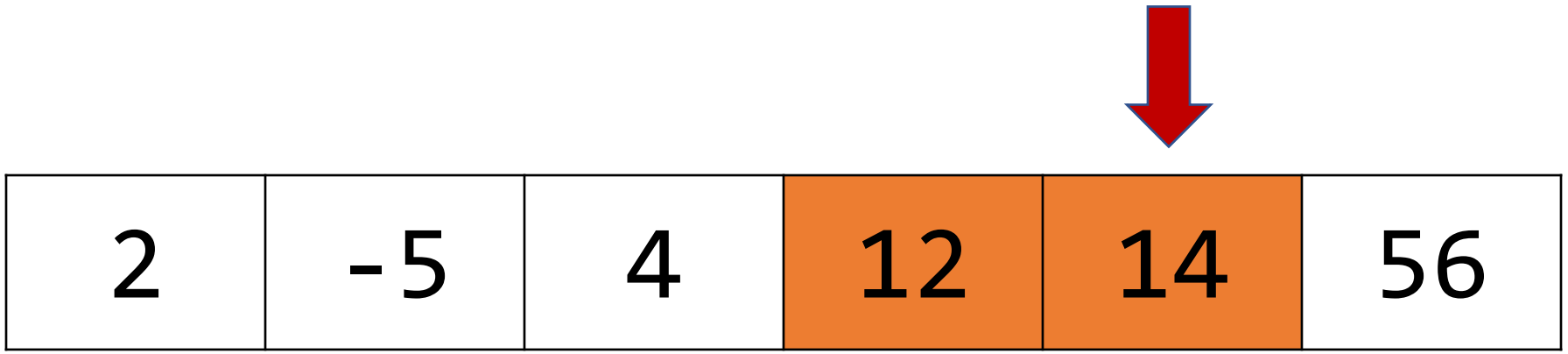

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Bubble Sort

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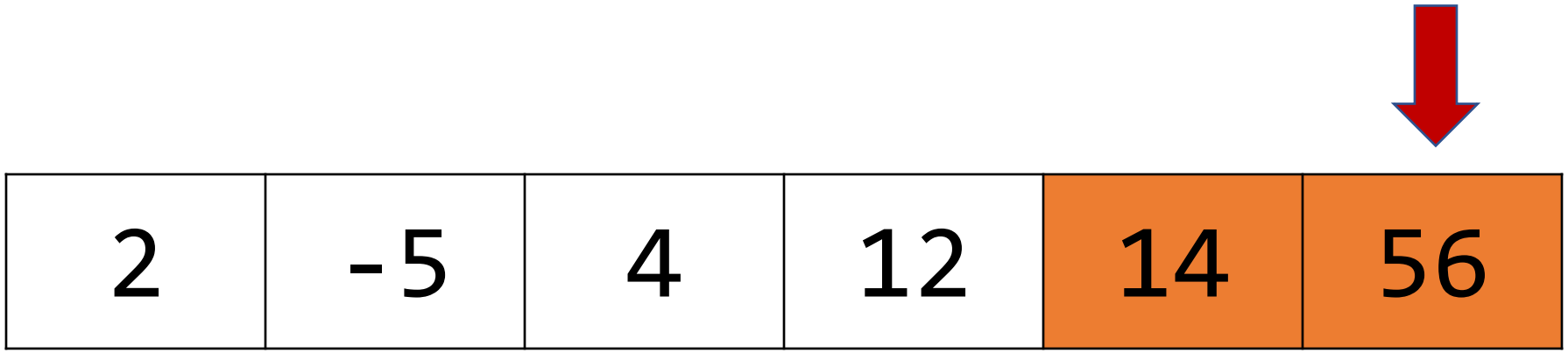

- Bubble sort repeatedly goes through the array, swapping any pairs of elem
the a

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 to sort a list of integers. We'll use the **bubble sort algorithm**.

-5	2	4	12	14	56

✅

- Bubble sort repeatedly goes through the array, swapping any pairs of ele
the

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.

Integer Bubble Sort

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

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

How can we make this function generic, to sort an array of *any type*?

Integer Bubble Sort

```
void bubble_sort_int(int *arr, int n) {
    while (true) {
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            if (arr[i - 1] > arr[i]) {
                swapped = true;
                swap_int(&arr[i - 1], &arr[i]);
            }
        }

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

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

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int i = 1; i < n; i++) {
            if (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.

Key Idea: Locating i-th Elem

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

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

How can we generalize this to get the location of the i-th element?

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

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int 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 (*p_prev_elem > *p_curr_elem) {
                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, int n, int elem_size_bytes) {
    while (true) {
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            void *p_curr_elem = (char *)arr + i * elem_size_bytes;
            if (*p_prev_elem > *p_curr_elem) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

Are we done? Is something not right?

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int 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 (*p_prev_elem > *p_curr_elem) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

Wait a minute…this doesn't work! We can't dereference `void *`s OR compare any element with >, since they may not be numbers!

A Generics Conundrum

- We've hit a snag – there is no way to generically compare elements. They could be any type and have complex ways to compare them.
- How can we write code to compare *any two elements of the same type?*
- That's not something that bubble sort can ever know how to do. **BUT** – our caller should know how to do this, because they're supplying the data….let's ask them!

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- Example: Counting Matches

Generic Bubble Sort

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                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

        if (!swapped) {
            return;
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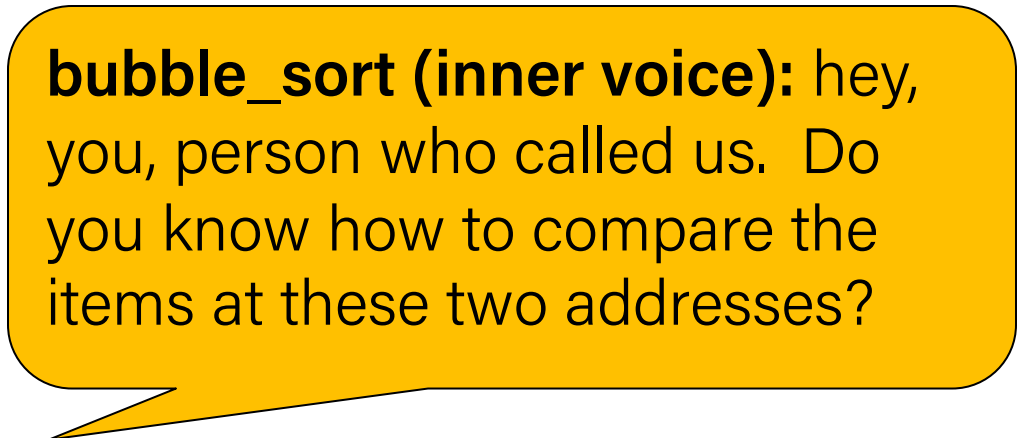

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void bubble_sort(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int i = 1; i < n; i++) {
            void *p_prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *p_curr_elem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

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

Caller: yeah, I know how to compare them. You don't know what data type they are, but I do. I have a function that can do the comparison for you and tell you the result.

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                                        function compare_fn) {
    while (true) {
        bool swapped = false;
        for (int 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 (compare_fn(p_prev_elem, p_curr_elem)) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

How can we compare these elements? They can pass us this **function as a parameter**. The function's job is to tell us how two elements compare.

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                 bool (*compare_fn)(void *a, void *b)) {
    while (true) {
        bool swapped = false;
        for (int 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 (compare_fn(p_prev_elem, p_curr_elem)) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

How can we compare these elements? They can pass us this **function as a parameter**. The function's job is to tell us how two elements compare.

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.

```
bool (*compare_fn)(void *a, void *b)
```

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```

Return type (`bool`)

Function Pointers

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```
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```

Function pointer name
(`compare_fn`)

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.

```
bool (*compare_fn)(void *a, void *b)
```

Function parameters
(two `void *`s)

Function Pointers

Here's the general variable type syntax:

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

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                 bool (*compare_fn)(void *a, void *b)) {
    while (true) {
        bool swapped = false;
        for (int 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 (compare_fn(p_prev_elem, p_curr_elem)) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

Function Pointers

```
bool integer_compare(void *ptr1, void *ptr2) {
    ...
}

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

`bubble_sort` is generic and works for any type. But the **caller** knows the specific type of data being sorted and provides a comparison function specifically for that data type.

Function Pointers

```
bool string_compare(void *ptr1, void *ptr2) {
    ...
}

int main(int argc, char *argv[]) {
    char *classes[] = {"COMP100", "COMP132", "COMP201", "COMP202"};
    int arr_count = sizeof(classes) / sizeof(classes[0]);
    bubble_sort(classes, arr_count, sizeof(classes[0]), string_compare);
    ...
}
```

`bubble_sort` is generic and works for any type. But the **caller** knows the specific type of data being sorted and provides a comparison function specifically for that data type.

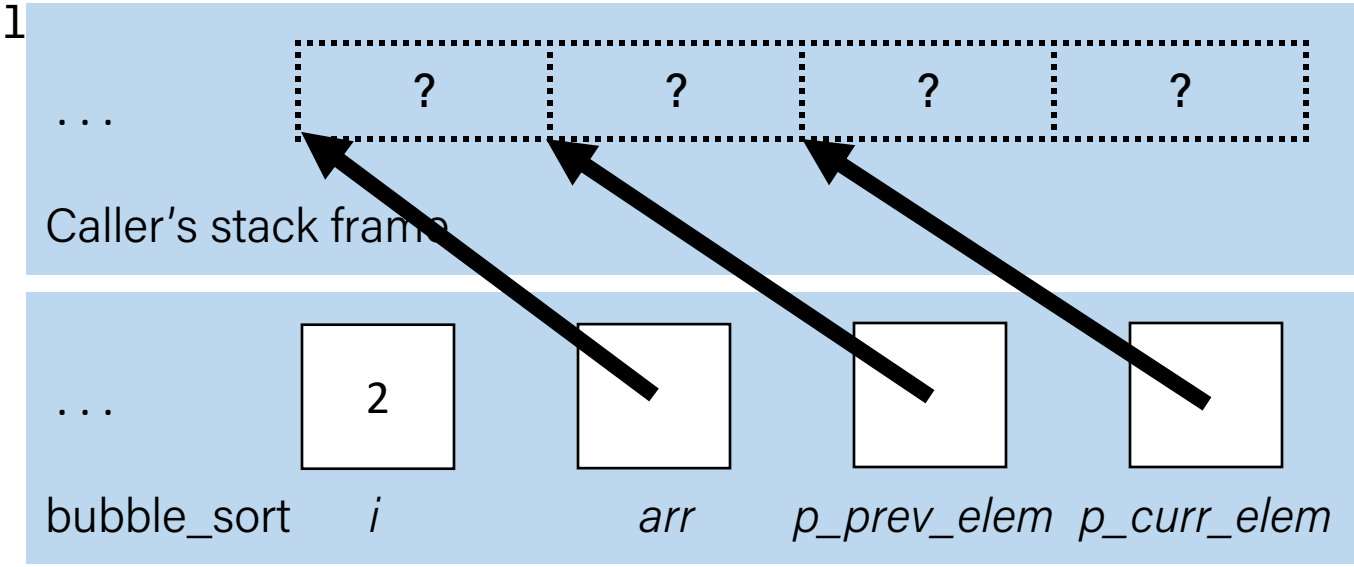
Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                 bool (*compare_fn)(void *a, void *b))
```

- Bubble Sort is written as a generic library function to be imported into potentially many programs to be used with many types. It must have a single function signature but work with any type of data.
- Its comparison function type is part of its function signature – the comparison function signature must use one set of types but accept any data of any size. How do we do this?
  - **The function will instead accept pointers to the data via `void *` parameters**
  - This means that the functions must be written to handle parameters which are *pointers to the data* to be compared

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                 bool (*compare_fn)(void *a, void *b)) {
    while (true) {
        bool swapped = false;
        for (int 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 (compare_fn(p_prev_elem, p_curr_elem)) {
                swapped = true;
                swap(p_prev_elem, p_curr_el
            }
        }

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



Function Pointers

This means that functions with generic parameters must always take *pointers to the data they care about.*

We can use the following pattern:

1) Cast the `void *`argument(s) and set typed pointers equal to them.
2) Dereference the typed pointer(s) to access the values.
3) Perform the necessary operation.

(steps 1 and 2 can often be combined into a single step)

Function Pointers

```
bool integer_compare(void *ptr1, void *ptr2) {
    // 1) cast arguments to int *s
    int *num1ptr = (int *)ptr1;
    int *num2ptr = (int *)ptr2;

    // 2) dereference typed points to access values
    int num1 = *num1ptr;
    int num2 = *num2ptr;

    // 3) perform operation
    return num1 > num2;
}
```

This function is created by the caller specifically to compare integers, knowing their addresses are necessarily disguised as `void *` so that **`bubble_sort`** can work for any array type.

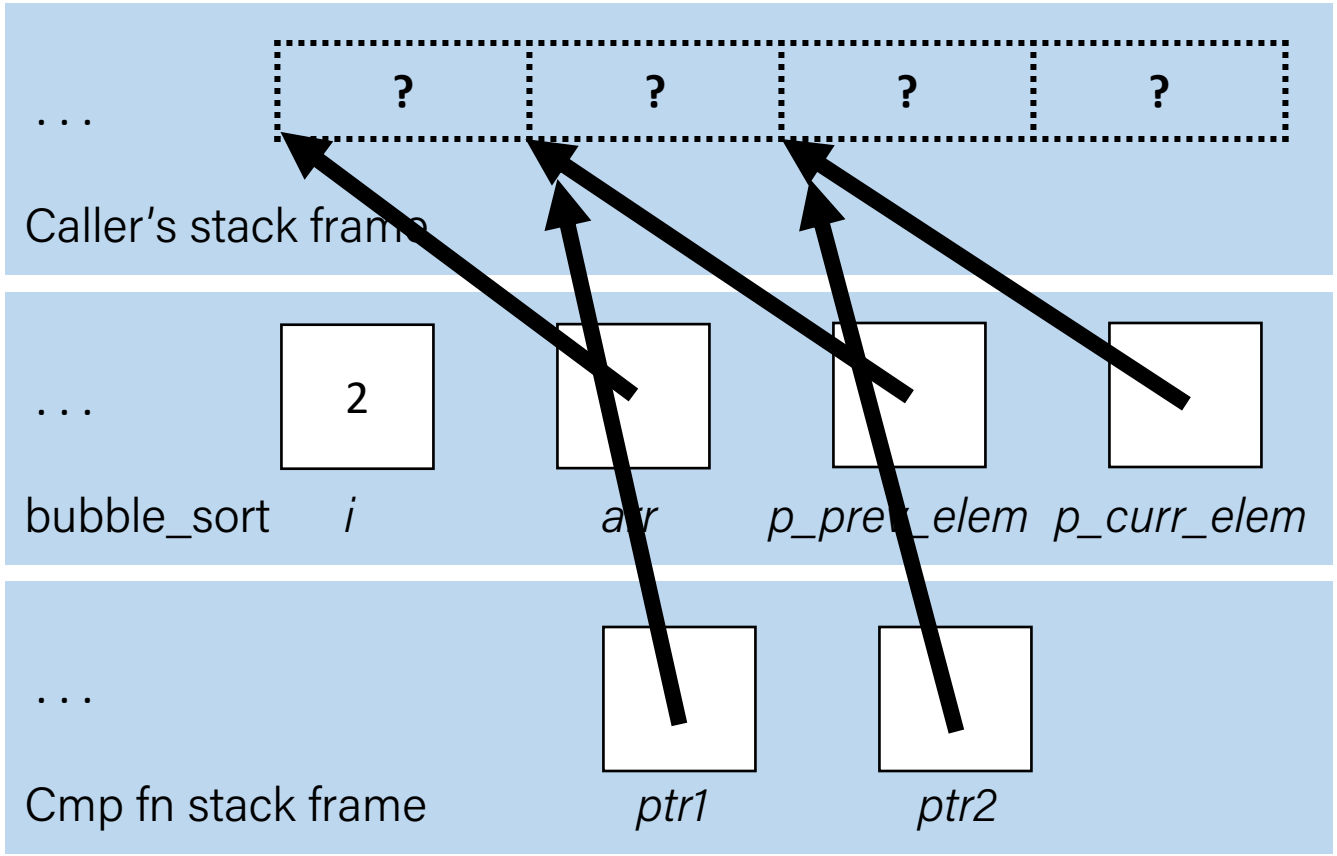
Function Pointers

```
bool integer_compare(void *ptr1, void *ptr2) {
    // 1) cast arguments to int *s
    int *num1ptr = (int *)ptr1;
    int *num2ptr = (int *)ptr2;

    // 2) dereference typed points to access values
    int num1 = *num1ptr;
    int num2 = *num2ptr;

    // 3) perform operation
    return num1 > num2;
}
```

However, the type of the comparison function that e.g. **`bubble_sort`** accepts must be generic, since we are writing one **`bubble_sort`** function to work with any data type.

Function Pointers

```
bool integer_compare(void *ptr1, void *ptr2) {
    return *(int *)ptr1 > *(int *)ptr2;
}
```



Comparison Functions

- Function pointers are used often in cases like this to compare two values of the same type. These are called **comparison functions**.
- The standard comparison function in many C functions provides even more information. 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
- This is the same return value format as **`strcmp`**!

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

Comparison Functions

```
int integer_compare(void *ptr1, void *ptr2) {
    return *(int *)ptr1 - *(int *)ptr2;
}
```

Generic Bubble Sort

```
void bubble_sort(void *arr, int n, int elem_size_bytes,
                 int (*compare_fn)(void *a, void *b)) {
    while (true) {
        bool swapped = false;
        for (int 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 (compare_fn(p_prev_elem, p_curr_elem) > 0) {
                swapped = true;
                swap(p_prev_elem, p_curr_elem, elem_size_bytes);
            }
        }

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

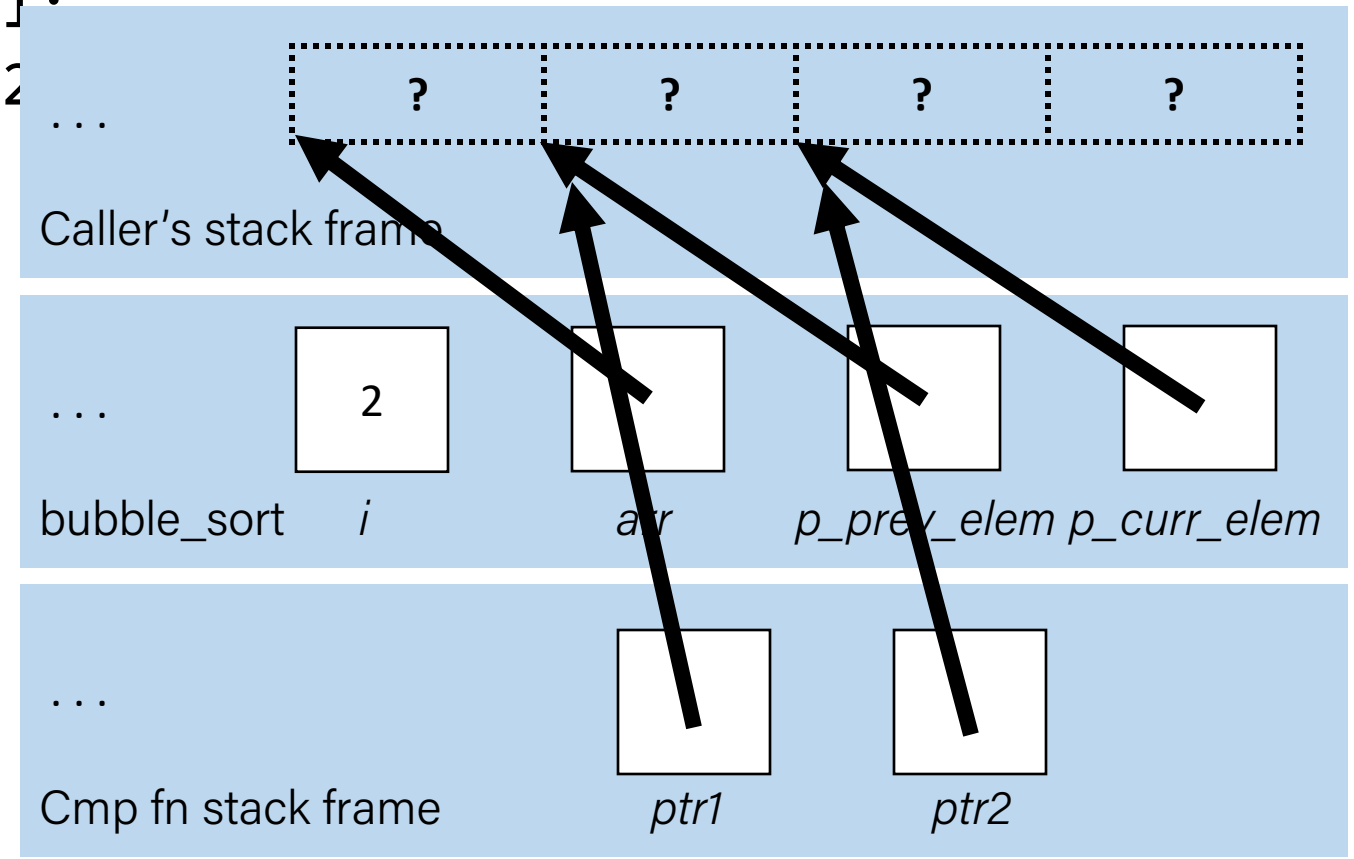
Comparison Functions

- **Exercise:** how can we write a comparison function for bubble sort to sort strings in alphabetical order?
- The common prototype provides even more information. 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 *a, void *b)
```

String Comparison Function

```
int string_compare(void *ptr1, void *ptr2) {
      // cast arguments and dereference
      char *str1 = *(char **)ptr1;
      char *str2 = *(char **)ptr2;

      // perform operation
      return strcmp(str1, str2);
}
```



Function Pointer Pitfalls

- If a function takes a function pointer as a parameter, it will accept it if it fits the specified signature.
- *This is dangerous*! E.g. what happens if you pass in a string comparison function when sorting an integer array?

Lecture Plan

- Generics So Far
- Motivating Example: Bubble Sort
- Function Pointers
- Example: Generic Printing
- Example: Counting Matches

Function Pointers

- Function pointers can be used in a variety of ways. For instance, you could have:
  - A function to compare two elements of a given type
  - A function to print out an element of a given type
  - A function to free memory associated with a given type
  - And more…

Function Pointers

- Function pointers can be used in a variety of ways. For instance, you could have:
  - A function to compare two elements of a given type
  - A function to print out an element of a given type
  - A function to free memory associated with a given type
  - And more...

Demo: Generic Printing

`print_array.c`

Common Utility Callback Functions

- Comparison function – compares two elements of a given type.

```
int (*cmp_fn)(void *addr1, void *addr2)
```

- Printing function – prints out an element of a given type

```
void (*print_fn)(void *addr)
```

- There are many more! You can specify any functions you would like passed in when writing your own generic functions.

Lecture Plan

- Generics So Far
- Motivating Example: Bubble Sort
- Function Pointers
- Example: Generic Printing
- Example: Counting Matches

Demo: Count Matches

`count_matches.c`

Count Matches

- Let's write a generic function `count_matches` that can count the number of a certain type of element in a generic array.
- It should take in as parameters information about the generic array, and a function parameter that can take in a pointer to a single array element and tell us if it's a match.

```
int count_matches(void *base, int nelems,
                  int elem_size_bytes, bool (*match_fn)(void *));
```

Count Matches

```
int count_matches(void *base, int nelems, int elem_size_bytes,
                  bool (*match_fn)(void *)) {

    int match_count = 0;

    for (int i = 0; i < nelems; i++) {
        void *curr_p = (char *)base + i * elem_size_bytes;
        if (match_fn(curr_p)) {
            match_count++;
        }
    }

    return match_count;
}
```

Function Pointers As Variables

In addition to parameters, you can make normal variables that are functions.

```
int do_something(char *str) {
    …
}

int main(int argc, char *argv[]) {
    …
    int (*func_var)(char *) = do_something;
    …
    func_var("testing");
    return 0;
}
```

Generic C Standard Library Functions

- **`qsort`** – I can sort an array of any type! To do that, I need you to provide me a function that can compare two elements of the kind you are asking me to sort.
- **`bsearch`** – I can use binary search to search for a key in an array of any type! To do that, I need you to provide me a function that can compare two elements of the kind you are asking me to search.
- **`lfind`** – I can use linear search to search for a key in an array of any type! To do that, I need you to provide me a function that can compare two elements of the kind you are asking me to search.
- **`lsearch`** - I can use linear search to search for a key in an array of any type! I will also add the key for you if I can't find it. In order to do that, I need you to provide me a function that can compare two elements of the kind you are asking me to search.

Generic C Standard Library Functions

- **`scandir`** – I can create a directory listing with any order and contents! To do that, I need you to provide me a function that tells me whether you want me to include a given directory entry in the listing. I also need you to provide me a function that tells me the correct ordering of two given directory entries.

Summary: Function Pointers

- We can pass functions as parameters to pass logic around in our programs.
- Comparison functions are one common class of functions passed as parameters to generically compare the elements at two addresses.
- Functions handling generic data must use *pointers to the data they care about*, since any parameters must have *one type* and *one size*.

Summary: Generics

- We use **`void *`** pointers and memory operations like **`memcpy`** and **`memmove`** to make data operations generic.
- We use **function pointers** to make logic/functionality operations generic.

Recap

- Generics So Far
- Motivating Example: Bubble Sort
- Function Pointers
- Example: Generic Printing
- Example: Counting Matches

Next time: `const`, *Structures*