CS107, Lecture 9
C Generics – Function Pointers

Reading: K&R 5.11

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

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

Plan For Today

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

Generics

- We always strive to write code that is as general-purpose as possible.
- Generic code reduces code duplication, and means you can make improvements and fix bugs in one place rather than many.
- Generics is used throughout C for functions to sort any array, search any array, free arbitrary memory, and more.

Generic Swap

Wouldn't it be nice if we could write *one* function that would work with any parameter type, instead of so many different versions?

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

Generic Swap

```c
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);
}
```

We can use **void *** to represent a pointer to any data, and **memcpy** 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);
```

Swap Ends

Let's write a function that swaps the first and last elements in an array. How can we make this generic?

```
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));
}
```

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 <u>places</u> to arr, and 3 * sizeof(int) = 12 bytes

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

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

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

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 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);
}
```

Plan For Today

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

Stacks

- C generics are particularly powerful in helping us create generic data structures.
- Let's see how we might go about making a generic Stack in C.

Stack Structs

```
typedef struct int_node {
    struct int_node *next;
    int data;
} int_node;


typedef struct int_stack {
    int nelems;
    int_node *top;
} int_stack;
```

Stack Structs

```
typedef struct int_node {
    struct int_node *next;
    int data;
} int_node;


typedef struct int_stack {
    int nelems;
    int_node *top;
} int_stack;
```

Problem: each node can no longer store the data itself, because it could be any size!

Generic Stack Structs

```
typedef struct int_node {
    struct int_node *next;
    void *data;
} int_node;


typedef struct stack {
    int nelems;
    int elem_size_bytes;
    node *top;
} stack;
```

Solution: each node stores a pointer, which is always 8 bytes, to the data somewhere else. We must also store the data size in the Stack struct.

Stack Functions

- **`int_stack_create()`**: creates a new stack on the heap and returns a pointer to it
- **`int_stack_push(int_stack *s, int data)`**: pushes data onto the stack
- **`int_stack_pop(int_stack *s)`**: pops and returns topmost stack element

int_stack_create

```
int_stack *int_stack_create() {
    int_stack *s = malloc(sizeof(int_stack));
    s->nelems = 0;
    s->top = NULL;
    return s;
}
```

Generic stack_create

```
stack *stack_create(int elem_size_bytes) {
    stack *s = malloc(sizeof(stack));
    s->nelems = 0;
    s->top = NULL;
    s->elem_size_bytes = elem_size_bytes;
    return s;
}
```

int_stack_push

```
void int_stack_push(int_stack *s, int data) {
    int_node *new_node = malloc(sizeof(int_node));
    new_node->data = data;

    new_node->next = s->top;
    s->top = new_node;
    s->nelems++;
}
```

Generic stack_push

```
void int_stack_push(int_stack *s, int data) {
    int_node *new_node = malloc(sizeof(int_node));
    new_node->data = data;

    new_node->next = s->top;
    s->top = new_node;
    s->nelems++;
}
```

Problem 1: we can no longer pass the data itself as a parameter, because it could be any size!

Generic stack_push

```
void int_stack_push(int_stack *s, const void *data) {
    int_node *new_node = malloc(sizeof(int_node));
    new_node->data = data;

    new_node->next = s->top;
    s->top = new_node;
    s->nelems++;
}
```

Solution 1: pass a pointer to the data as a parameter instead.

Generic stack_push

```c
void int_stack_push(int_stack *s, const void *data) {
    int_node *new_node = malloc(sizeof(int_node));
    new_node->data = data;

    new_node->next = s->top;
    s->top = new_node;
    s->nelems++;
}
```

Problem 2: we cannot copy the existing data pointer into new_node. The data structure must manage its own copy that exists for its entire lifetime. The provided copy may go away!

Generic stack_push

```
int main() {
    stack *int_stack = stack_create(sizeof(int));
    add_one(int_stack);
    // now stack stores pointer to invalid memory for 7!
}

void add_one(stack *s) {
    int num = 7;
    stack_push(s, &num);
}
```

Generic stack_push

```
void stack_push(stack *s, const void *data) {
    node *new_node = malloc(sizeof(node));
    new_node->data = malloc(s->elem_size_bytes);
    memcpy(new_node->data, data, s->elem_size_bytes);

    new_node->next = s->top;
    s->top = new_node;
    s->nelems++;
}
```

Solution 2: make a heap-allocated copy of the data that the node points to.

int_stack_pop

```
int int_stack_pop(int_stack *s) {
    if (s->nelems == 0) {
        error(1, 0, "Cannot pop from empty stack");
    }
    int_node *n = s->top;
    int value = n->data;

    s->top = n->next;

    free(n);
    s->nelems--;

    return value;
}
```

Generic stack_pop

```
int int_stack_pop(int_stack *s) {
    if (s->nelems == 0) {
        error(1, 0, "Cannot pop from empty stack");
    }
    int_node *n = s->top;
    int value = n->data;

    s->top = n->next;

    free(n);
    s->nelems--;

    return value;
}
```

Problem: we can no longer return the data itself, because it could be any size!

Generic stack_pop

```
void *int_stack_pop(int_stack *s) {
    if (s->nelems == 0) {
        error(1, 0, "Cannot pop from empty stack");
    }
    int_node *n = s->top;
    void *value = n->data;

    s->top = n->next;

    free(n);
    s->nelems--;

    return value;
}
```

While it's possible to return the heap address of the element, this means the client would be responsible for freeing it. Ideally, the data structure should manage its own memory here.

Generic stack_pop

```
void stack_pop(stack *s, void *addr) {
    if (s->nelems == 0) {
        error(1, 0, "Cannot pop from empty stack");
    }
    node *n = s->top;
    memcpy(addr, n->data, s->elem_size_bytes);
    s->top = n->next;

    free(n->data);
    free(n);
    s->nelems--;
}
```

Solution: have the caller pass a memory location as a parameter, and copy the data value to that location.

Using Generic Stack

```
int_stack *intstack = int_stack_create();
for (int i = 0; i < TEST_STACK_SIZE; i++) {
    int_stack_push(intstack, i);
}
```

We must now pass the *address* of an element to push onto the stack, rather than the element itself.

Using Generic Stack

```
stack *intstack = stack_create(sizeof(int));
for (int i = 0; i < TEST_STACK_SIZE; i++) {
    stack_push(intstack, &i);
}
```

We must now pass the *address* of an element to push onto the stack, rather than the element itself.

Using Generic Stack

```
int_stack *intstack = int_stack_create();
int_stack_push(intstack, 7);
```

We must now pass the *address* of an element to push onto the stack, rather than the element itself.

Using Generic Stack

```
stack *intstack = stack_create(sizeof(int));
int num = 7;
stack_push(intstack, &num);
```

We must now pass the *address* of an element to push onto the stack, rather than the element itself.

Using Generic Stack

```
// Pop off all elements
while (intstack->nelems > 0) {
    printf("%d\n", int_stack_pop(intstack));
}
```

We must now pass the *address* of where we would like to store the popped element, rather than getting it directly as a return value.

Using Generic Stack

```
// Pop off all elements
int popped_int;
while (intstack->nelems > 0) {
    int_stack_pop(intstack, &popped_int);
    printf("%d\n", popped_int);
}
```

We must now pass the *address* of where we would like to store the popped element, rather than getting it directly as a return value.

Plan For Today

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

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

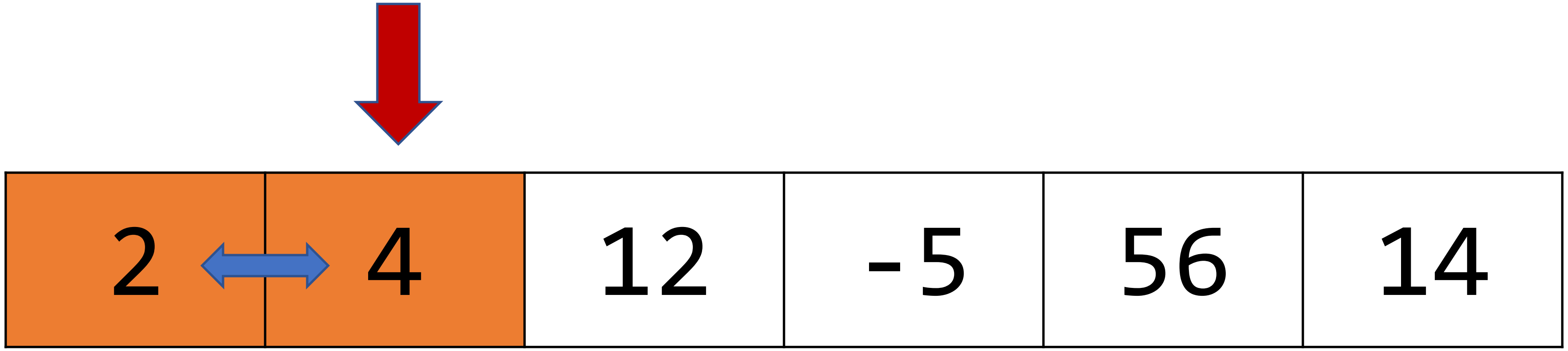
- Let's write a function to sort a list of integers. We'll use the **bubble sort algorithm**.

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

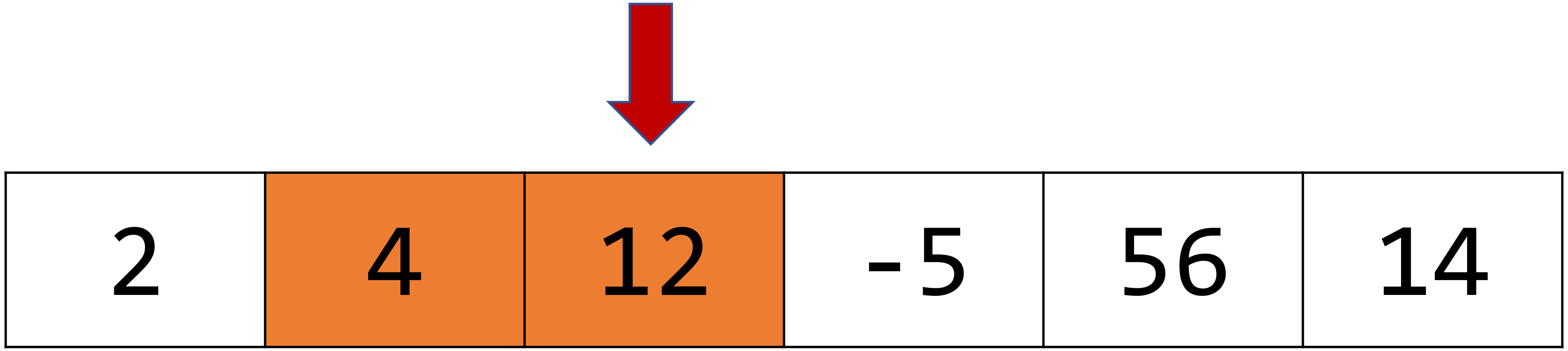
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



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



- 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

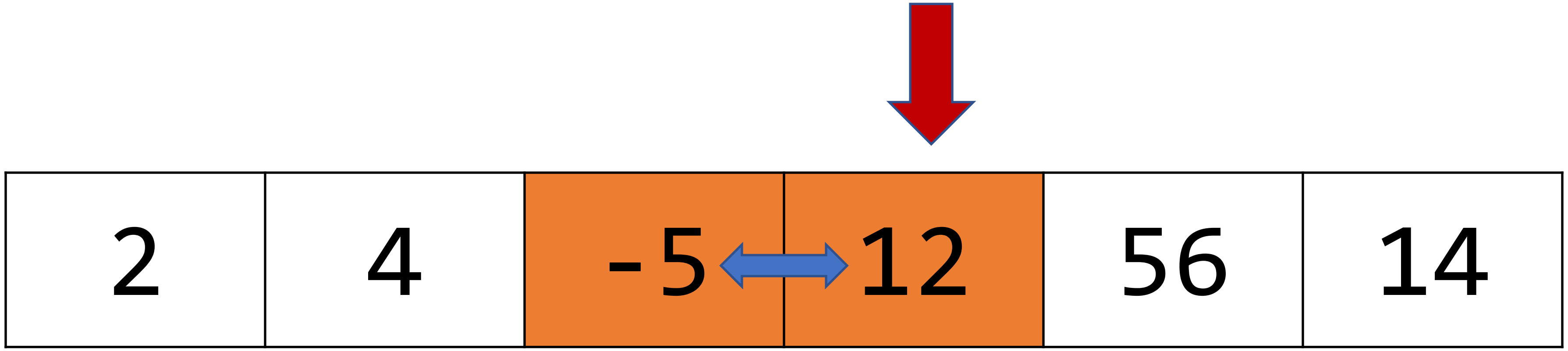
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

2	4	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 to sort a list of integers. We’ll use the **bubble sort algorithm**.



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

2	4	-5	12	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

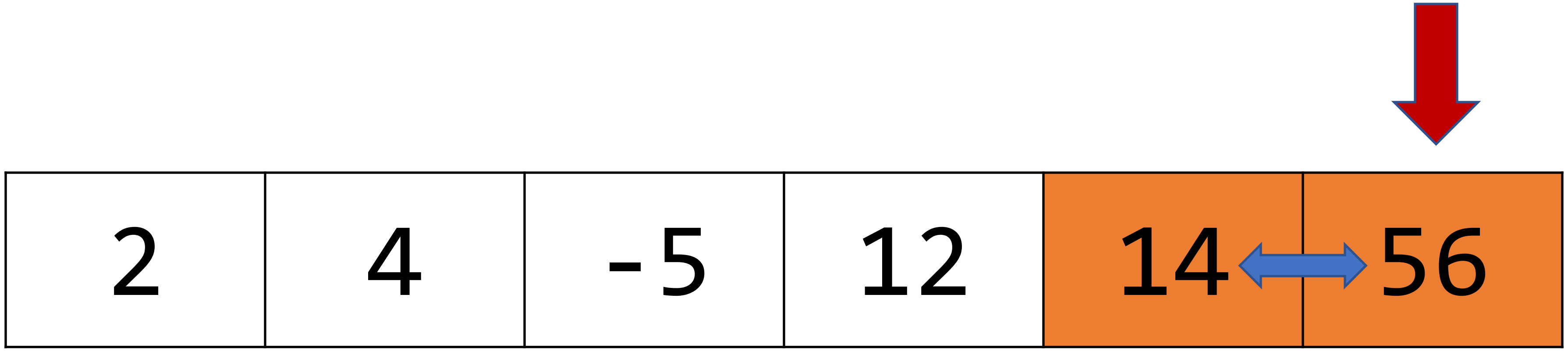
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

2	4	-5	12	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 to sort a list of integers. We’ll use the **bubble sort algorithm**.



- 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

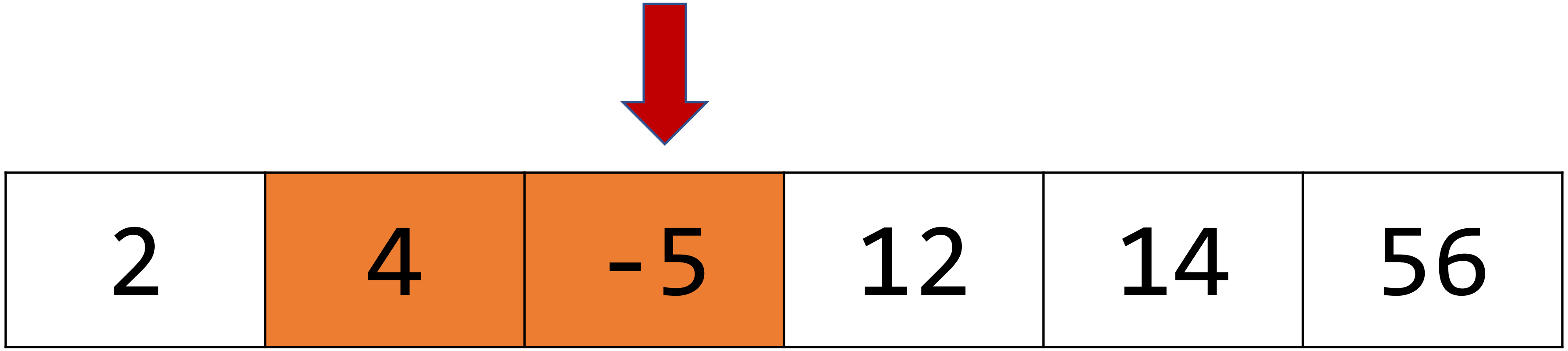
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

2	4	-5	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!

Bubble Sort

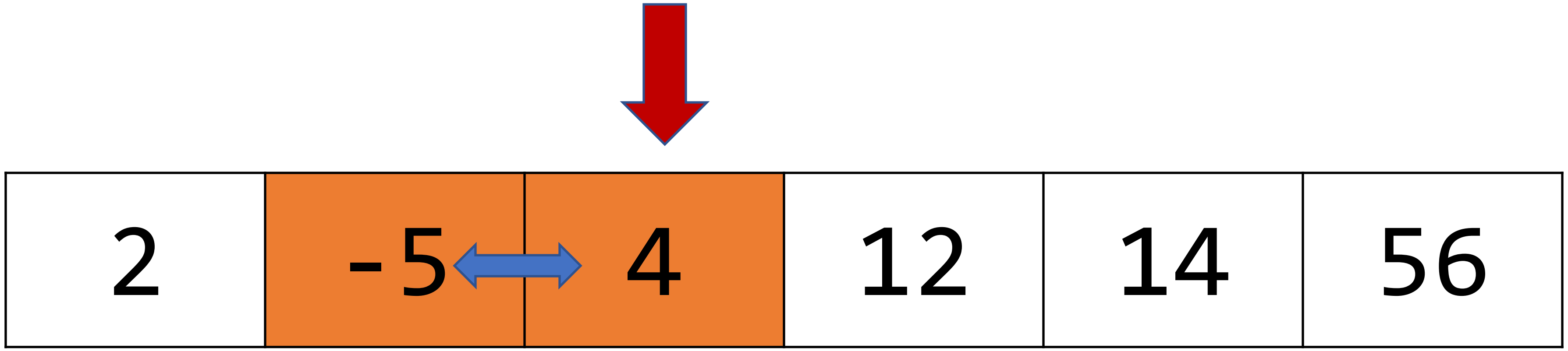
- Let's write a function to sort a list of integers. We'll use the **bubble sort algorithm**.



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



- 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

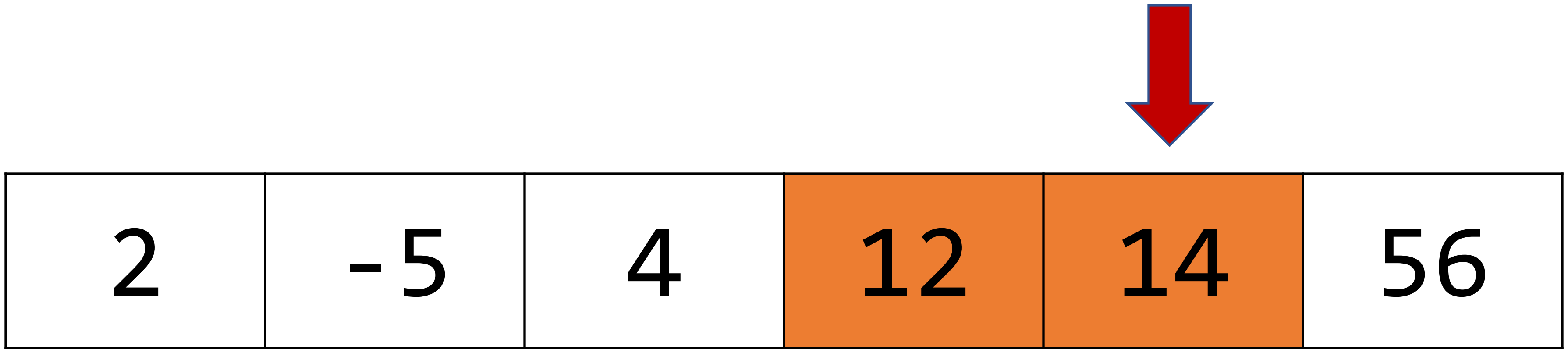
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

2	-5	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!

Bubble Sort

- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



- 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

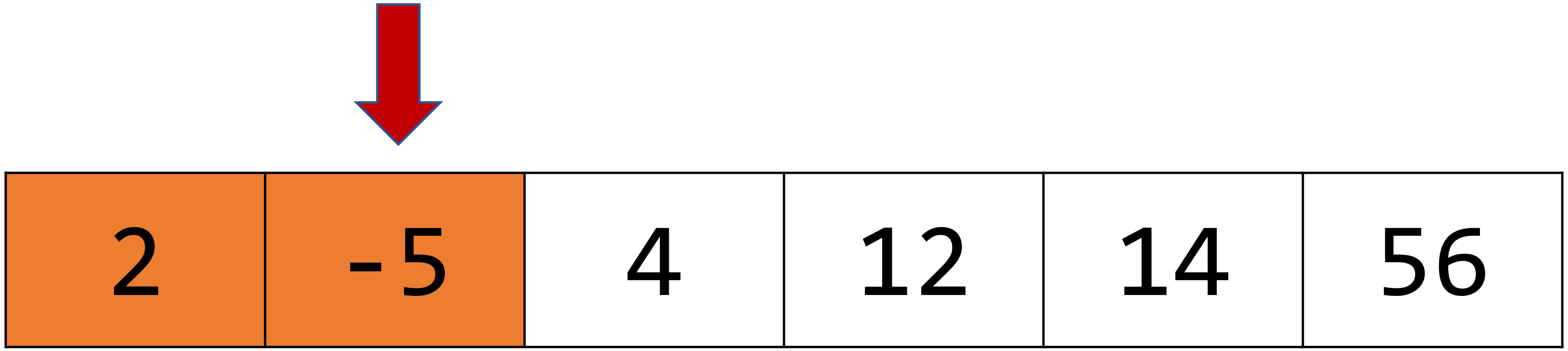
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

2	-5	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!

Bubble Sort

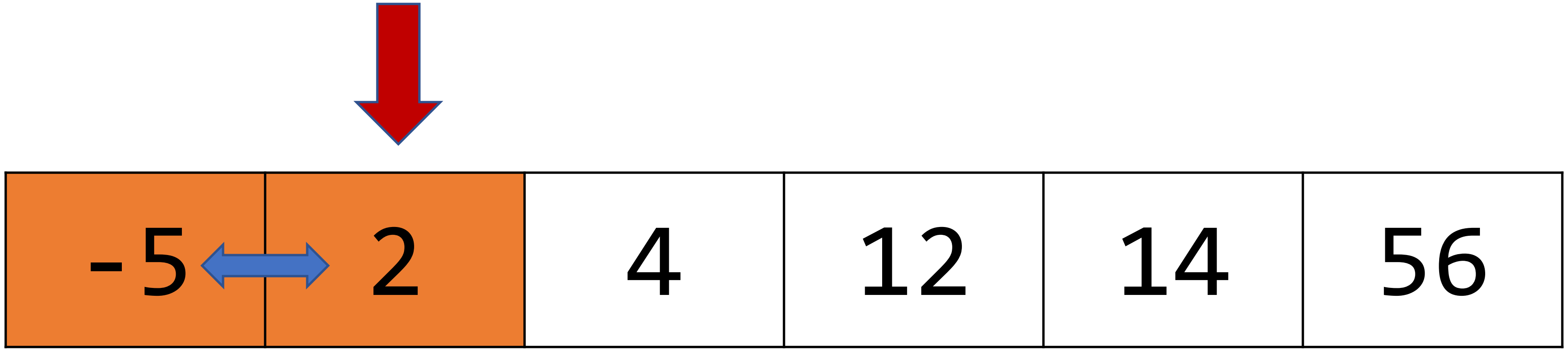
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



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



- 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

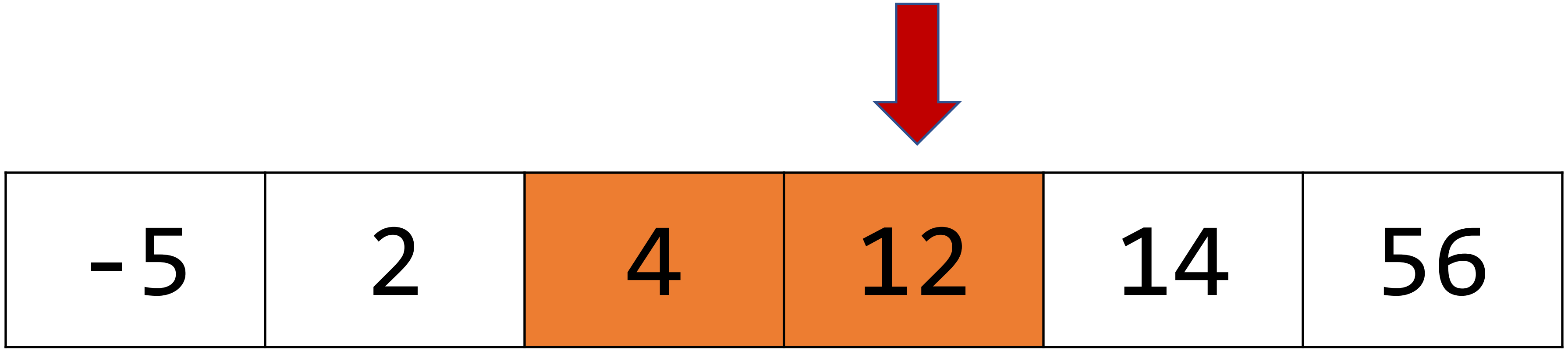
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.

-5	2	4	12	14	56

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

Bubble Sort

- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



- 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 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 elements that are out of order. When there are no more swaps needed, the array is sorted!

Bubble Sort

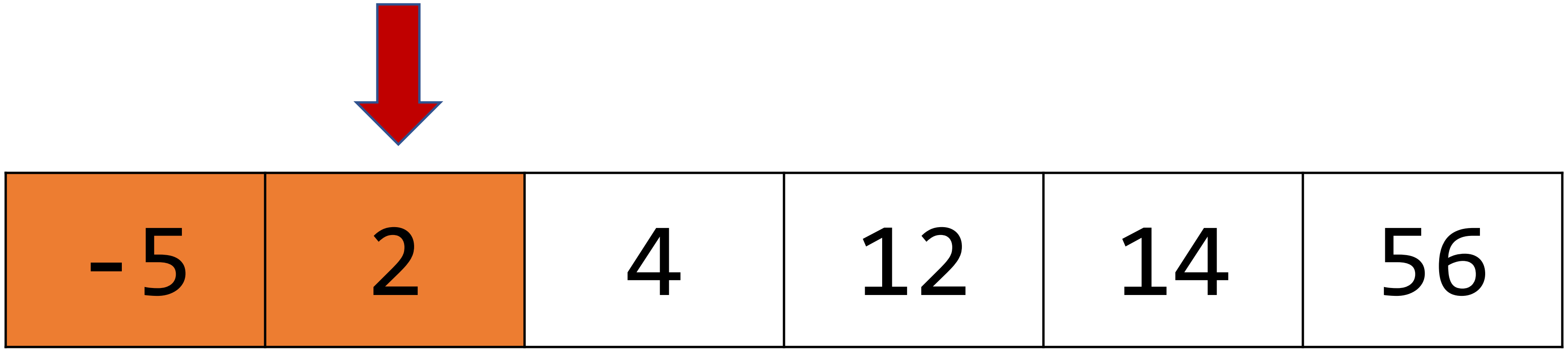
- Let's write a function to sort a list of integers. We'll use the **bubble sort algorithm**.

-5	2	4	12	14	56

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

Bubble Sort

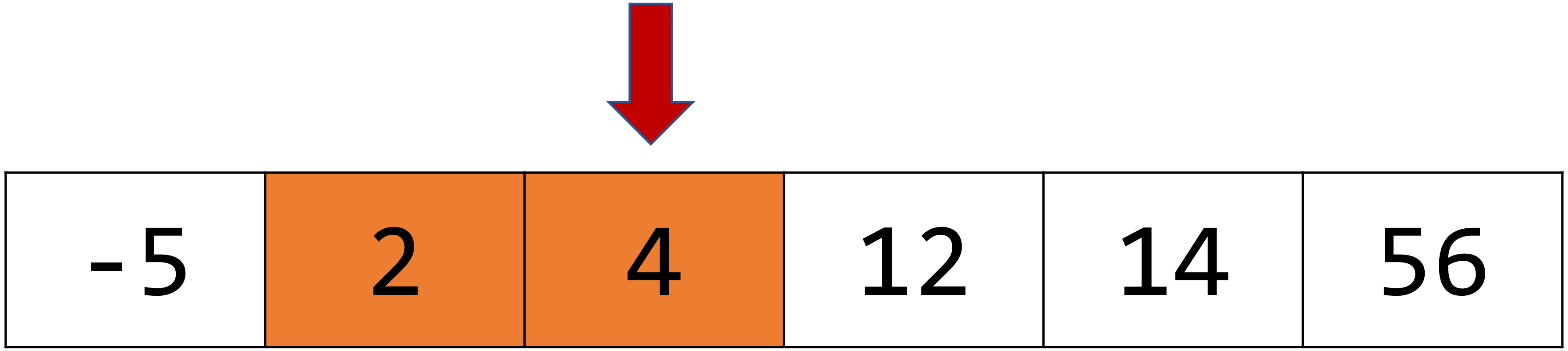
- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



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



- 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 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 elements that are out of order. When there are no more swaps needed, the array is sorted!

Bubble Sort

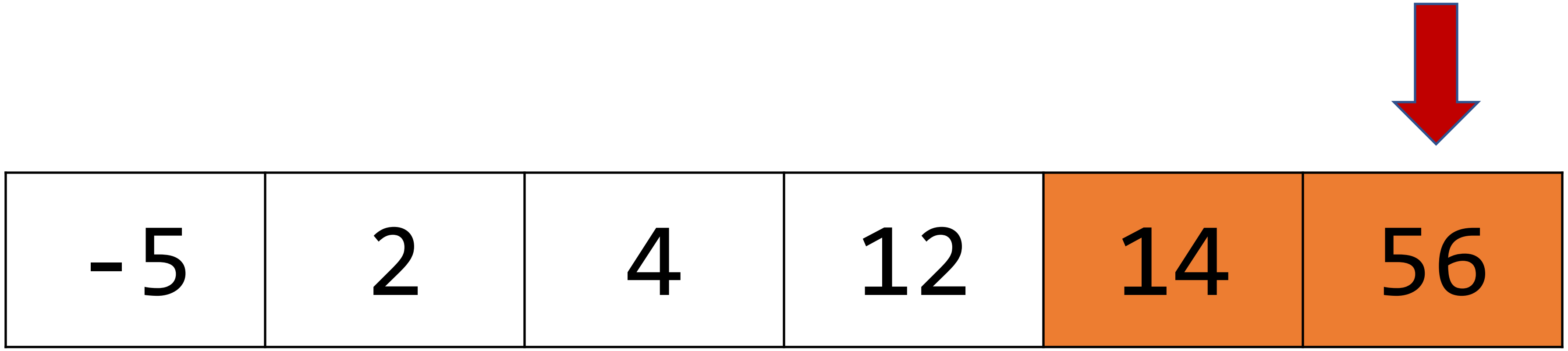
- Let's write a function to sort a list of integers. We'll use the **bubble sort algorithm**.

-5	2	4	12	14	56

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

Bubble Sort

- Let’s write a function to sort a list of integers. We’ll use the **bubble sort algorithm**.



- 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 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 elements that are out of order. When there are no more swaps needed, the array is sorted!

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) {
        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;
        }
    }
}
```

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

Generic Bubble Sort

```
void bubble_sort_int(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_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_int(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: Generically Getting 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 get the *last* element generically:

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

We can generalize this to get the i-th element:

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

Generic Bubble Sort

```
void bubble_sort_int(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int i = 1; i < n; i++) {
            void *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            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.

Generic Bubble Sort

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

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

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

Generic Bubble Sort

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

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

Generic Bubble Sort

```
void bubble_sort_int(void *arr, int n, int elem_size_bytes) {
    while (true) {
        bool swapped = false;
        for (int i = 1; i < n; i++) {
            void *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (*prev_elem > *curr_elem) {
                swapped = true;
                swap(prev_elem, 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 wall – 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 passing in the data….let’s ask them!

Generic Bubble Sort

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

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

Us: hey, you, person who called us. Do you know how to compare these two elements? Can you help us?

Generic Bubble Sort

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

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

Caller: yeah, I know how to compare those. 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 *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (compare_fn(prev_elem, curr_elem)) {
                swapped = true;
                swap(prev_elem, curr_elem, elem_size_bytes);
            }
        }

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

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

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 *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (compare_fn(prev_elem, curr_elem)) {
                swapped = true;
                swap(prev_elem, curr_elem, elem_size_bytes);
            }
        }

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

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

Function Pointers

A function pointer is the variable type for passing a function as a parameter. Here is how the parameter's type and name are declared.

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

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)
```

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.

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

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)

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 *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (compare_fn(prev_elem, curr_elem)) {
                swapped = true;
                swap(prev_elem, 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);
    return 0;
}
```

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

- Function pointers must always take *pointers to the data they care about,* since the data could be any size!

When writing a callback, 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) {
     // cast arguments to int *s
     int *num1ptr = (int *)ptr1;
     int *num2ptr = (int *)ptr2;

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

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

This function is created by the caller *specifically* to compare integers.

Function Pointers

```
bool integer_compare(void *ptr1, void *ptr2) {
    // cast arguments to int *s and dereference
    int num1 = *(int *)ptr1;
    int num2 = *(int *)ptr2;

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

Comparison Functions

- Function pointers are used often in cases like this to compare two values of the same type.
- 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)
```

Function Pointers

```
int integer_compare(void *ptr1, void *ptr2) {
    // cast arguments to int *s and dereference
    int num1 = *(int *)ptr1;
    int num2 = *(int *)ptr2;

    // perform operation
    return num1 - num2;
}
```

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 *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (compare_fn(prev_elem, curr_elem) > 0) {
                swapped = true;
                swap(prev_elem, curr_elem, elem_size_bytes);
            }
        }

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

Tracing Bubble Sort

```
int main(int argc, char *argv[]) {
    int nums[] = {5, 2};
    bubble_sort(nums, 2, sizeof(int), int_cmp);
    return 0;
}

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 *prev_elem = (char *)arr + (i - 1) * elem_size_bytes;
            void *curr_elem = (char *)arr + i * elem_size_bytes;
            if (compare_fn(prev_elem, curr_elem) > 0) {
                swapped = true;
                swap(prev_elem, curr_elem, elem_size_bytes);
            }
        }

        ...
```

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 as long as 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?

Plan For Today

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

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…

Common Utility Callback Functions

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

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

- Cleanup function – cleans up heap memory associated with a given type.

```
void (*cleanup_fn)(void *addr)
```

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

Generic Array Printing

We would like to write a generic function that, given an array, can print out each of its elements.

- What parameters would this function need to take in?
- How can we use function pointers to help us?

Generics Overview

- 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.

Plan For Today

- **Recap:** Generics with Void *
- **Finish up:** Generic Stack
- Function Pointers
- **Example:** Bubble Sort
- More Function Pointers

Next time: Floats in C