CS107, Lecture 8
C Generics – Void *

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Based on slides created by Marty Stepp, Cynthia Lee, Chris Gregg, and others.
Why We ❤️ The Stack

• **It is fast.** Your program already has that memory reserved for it!

• **It is convenient.** Memory is handled automatically, and is fast because old memory is left in place and marked as usable for future function calls.

• **It is safe.** You specify variable types, and the compiler can therefore do checks on the data. We’ll see later this is not necessarily true on the heap.
Why We ❤ The Heap

• **It is plentiful.** The stack has at most 8MB by default. The heap can provide more on demand!

• **Allocations are resizable.** Unlike on the stack, if you allocate something (e.g. an array), you can change the size of it later using `realloc`.

• **Scope.** The memory is not cleaned up when its function exits; instead, you control when the memory is freed.
• As a general rule of thumb, unless a situation requires dynamic allocation, stack allocation is preferred. Often both techniques are used together in a program.

• Heap allocation is a necessity when:
  • you have a very large allocation that could blow out the stack
  • you need to control the memory lifetime, or memory must persist outside of a function call
  • you need to resize memory after its initial allocation
Learning Goals

• Learn how to write C code that works with any data type.
• Learn about how to use void * and avoid potential pitfalls.
Plan For Today

• **Overview:** Generics
• Generic Swap
• Generics Pitfalls
• Generic Array Swap
• Generic Stack
Plan For Today

- **Overview**: Generics
- Generic Swap
- Generics Pitfalls
- Generic Array Swap
- Generic Stack
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.
• How can we write generic code in C?
• **Overview**: Generics

• Generic Swap

• Generics Pitfalls

• Generic Array Swap

• Generic Stack
You’re asked to write a function that swaps two numbers.

```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
You’re asked to write a function that swaps two numbers.

```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
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void swap_int(int *a, int *b) {
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}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
You’re asked to write a function that swaps two numbers.

```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char **argv) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
You’re asked to write a function that swaps two numbers.

```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
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    int temp = *a;
    *a = *b;
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int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
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You’re asked to write a function that swaps two numbers.

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    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
You’re asked to write a function that swaps two numbers.

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void swap_int(int *a, int *b) {
    int temp = *a;
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    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
You’re asked to write a function that swaps two numbers.

```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    int x = 2;
    int y = 5;
    swap_int(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
“Oh, when I said ‘numbers’ I meant shorts, not ints.”
void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    short x = 2;
    short y = 5;
    swap_short(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    short x = 2;
    short y = 5;
    swap_short(&x, &y);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
“You know what, I goofed. We’re going to use strings. Could you write something to swap those?”
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
  char *temp = *a;
  *a = *b;
  *b = temp;
}

int main(int argc, char *argv[]) {
  char *x = "2";
  char *y = "5";
  swap_string(&x, &y);
  // want x = 5, y = 2
  printf("x = %s, y = %s\n", x, y);
  return 0;
}
```c
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
“Awesome! Thanks.”
“Awesome! Thanks. We also have 20 custom struct types. Could you write swap for those too?”
Wouldn’t it be nice if we could write *one* function that would work with any parameter type, instead of so many different versions?

```c
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) { ... }
...
```c
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}
```
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}
void swap(pointer to data1, pointer to data2) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}
void swap(pointer to data1, pointer to data2) {
  store a copy of data1 in temporary storage
  copy data2 to location of data1
  copy data in temporary storage to location of data2
}

int temp = *data1ptr;  // 4 bytes
short temp = *data1ptr; // 2 bytes
char *temp = *data1ptr; // 8 bytes

**Problem:** each type may need a different size temp!
void swap(pointer to data1, pointer to data2) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}

*data1 = *data2ptr;

Problem: each type needs to copy a different amount of data!
void swap(pointer to data1, pointer to data2) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}

Problem: each type needs to copy a different amount of data!

*data2ptr = temp;  
4 bytes

*data2ptr = temp;  
2 bytes

*data2ptr = temp;  
8 bytes

Generic Swap
C knows the size of temp, and knows how many bytes to copy, because of the variable types.
Is there a way to make a version that doesn’t care about the variable types?
void swap(pointer to data1, pointer to data2) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}
void swap(pointer to data1, pointer to data2) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}

Generic Swap
void swap(void *data1ptr, void *data2ptr) {
    store a copy of data1 in temporary storage
    copy data2 to location of data1
    copy data in temporary storage to location of data2
}

Generic Swap
void swap(void *data1ptr, void *data2ptr) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
void swap(void *data1ptr, void *data2ptr) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

If we don’t know the data type, we don’t know how many bytes it is. Let’s take that as another parameter.
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

Let’s start by making space to store the temporary value. How can we make this temp space?
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    void temp; ???
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

Let’s start by making space to store the temporary value. How can we make this temp space?
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

**temp** is **nbytes** of memory, since each **char** is 1 byte!
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

Now, how can we copy in what `data1ptr` points to into `temp`?
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    temp = *data1ptr; ???
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
    char temp[nbytes];
    // store a copy of data1 in temporary storage
    temp = *data1ptr; ???
    // copy data2 to location of data1
    // copy data in temporary storage to location of data2
}

We can’t dereference a void * (or set an array equal to something). C doesn’t know what it points to! Therefore, it doesn’t know how many bytes there it should be looking at.
memcpy is a function that copies a specified amount of bytes at one address to another address.

`void *memcpy(void *dest, const void *src, size_t n);`

It copies the next n bytes that `src` points to to the location contained in `dest`. (It also returns `dest`.) It does not support regions of memory that overlap.

```c
int x = 5;
int y = 4;
memcpy(&x, &y, sizeof(x)); // x = y
```
memcpy is a function that copies a specified amount of bytes at one address to another address.

```c
void *memcpy(void *dest, const void *src, size_t n);
```

It copies the next n bytes that src points to to the location contained in dest. (It also returns dest). It does not support regions of memory that overlap.

```c
int x = 5;
int y = 4;
memcpy(&x, &y, sizeof(x));
```

memcpy must take pointers to the bytes to work with to know where they live and where they should be copied to.
memmove

`memmove` is the same as `memcpy`, but supports overlapping regions of memory. (Unlike its name implies, it still “copies”).

```c
void *memmove(void *dest, const void *src, size_t n);
```

It copies the next `n` bytes that `src` points to to the location contained in `dest`. (It also returns `dest`).
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
  char temp[nbytes];
  // store a copy of data1 in temporary storage
  temp = *data1ptr; ???
  // copy data2 to location of data1
  // copy data in temporary storage to location of data2
}

We can’t dereference a void *. C doesn’t know what it points to! Therefore, it doesn’t know how many bytes there it should be looking at.
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
    // copy data in temporary storage to location of data2
}

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
    // copy data in temporary storage to location of data2
}

We can copy the bytes ourselves into temp! This is equivalent to temp = *data1ptr in non-generic versions, but this works for any type of any size.
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
    // copy data in temporary storage to location of data2
}

How can we copy data2 to the location of data1?
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
    *data1ptr = *data2ptr;  // ???
    // copy data in temporary storage to location of data2
}

How can we copy data2 to the location of data1?
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
}

How can we copy data2 to the location of data1?
memcpy!
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
}

How can we copy temp’s data to the location of data2?
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);
}

How can we copy temp’s data to the location of data2? **memcpy**!
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));
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));
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));
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);
}

mystruct x = {...};
mystruct y = {...};
swap(&x, &y, sizeof(x));
C Generics

• We can use `void *` and `memcpy` to handle memory as generic bytes.
• As long as we are given where the data of importance is, and how big it is, we can handle it!

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

• **Overview:** Generics
• Generic Swap
• Generics Pitfalls
• Generic Array Swap
• Generic Stack
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! *(How? Let’s find out!)*
Demo: Void *s Gone Wrong
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!
Plan For Today

• Overview: Generics
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• Generics Pitfalls
• Generic Array Swap
• Generic Stack
You’re asked to write a function that swaps the first and last elements in an array of numbers.

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

```c
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;
}
```
You’re asked to write a function that swaps the first and last elements in an array of numbers.

```c
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!
The code seems to be the same regardless of the type!
Let’s write a version of swap_ends that works for any type of array.

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

Is this generic? Does this work?
Let’s write a version of swap_ends that works for any type of array.

```c
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!
Let’s write a version of swap_ends that works for any type of array.

```c
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.
Let’s write a version of `swap_ends` that works for any type of array.

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

We need to know the element size, so let’s add a parameter.
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.
Let’s write a version of swap_ends that works for any type of array.

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

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

`(nelems – 1) * elem_bytes`
Let’s write a version of swap_ends that works for any type of array.

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

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

\[(\text{nelems} - 1) \times \text{elem\_bytes}\]
Let’s write a version of swap_ends that works for any type of array.

```c
void swap_ends(void *arr, size_t nelems, size_t elem_bytes) {
    swap(arr, arr + (nelems - 1) * elem_bytes, elem_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?**
Let’s write a version of swap_ends that works for any type of array.

```c
void swap_ends(void *arr, size_t nelems, size_t elem_bytes) {
    swap(arr, (char *)arr + (nelems - 1) * elem_bytes, elem_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!
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!

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

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

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

```c
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]));
```
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!

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

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

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

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

• **Overview**: Generics
• Generic Swap
• Generics Pitfalls
• Generic Array Swap
• Generic Stack
Stacks

• C generics are particularly powerful in helping us create generic data structures.
• Let’s see how we might go about making a Stack in C.
Refresher: Stacks

- A **Stack** is a data structure representing a stack of things.
- Objects can be *pushed* on top of or *popped* from the top of the stack.
- Only the top of the stack can be accessed; no other objects in the stack are visible.
- Main operations:
  - **push(value)**: add an element to the top of the stack
  - **pop()**: remove and return the top element in the stack
  - **peek()**: return (but do not remove) the top element in the stack
A stack is often implemented using a **linked list** internally.

- "bottom" = tail of linked list
- "top" = head of linked list  *(why not the other way around?)*

```cpp
Stack<int> s;
s.push(42);
s.push(-3);
s.push(17);
```

**Problem:** C is not object-oriented! We can’t call methods on variables.
Demo: Generic Stacks
Recap

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

**Next time:** More Generics, and Function Pointers