
# COMP201

# Computer Systems & Programming

## Lecture #13 – C Generics – `void *`

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2020

# Recap

- Other heap allocations
- `realloc`

# Plan for Today

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

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

# Lecture plan

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

# COMP201 Topic 5: How can we use our knowledge of memory and data representation to write code that works with any data type?

# Learning Goals

- Learn how to write C code that works with any data type.
- Learn about how to use `void *` and avoid potential pitfalls.

# 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?

# Lecture Plan

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

# Swap

You're asked to write a function that swaps two numbers.

```
void swap_int(int *a, int *b) {
    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);
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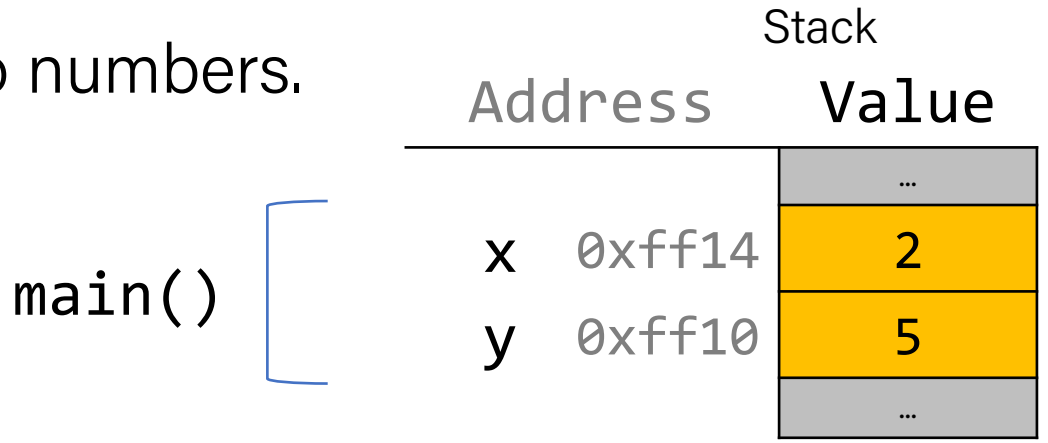

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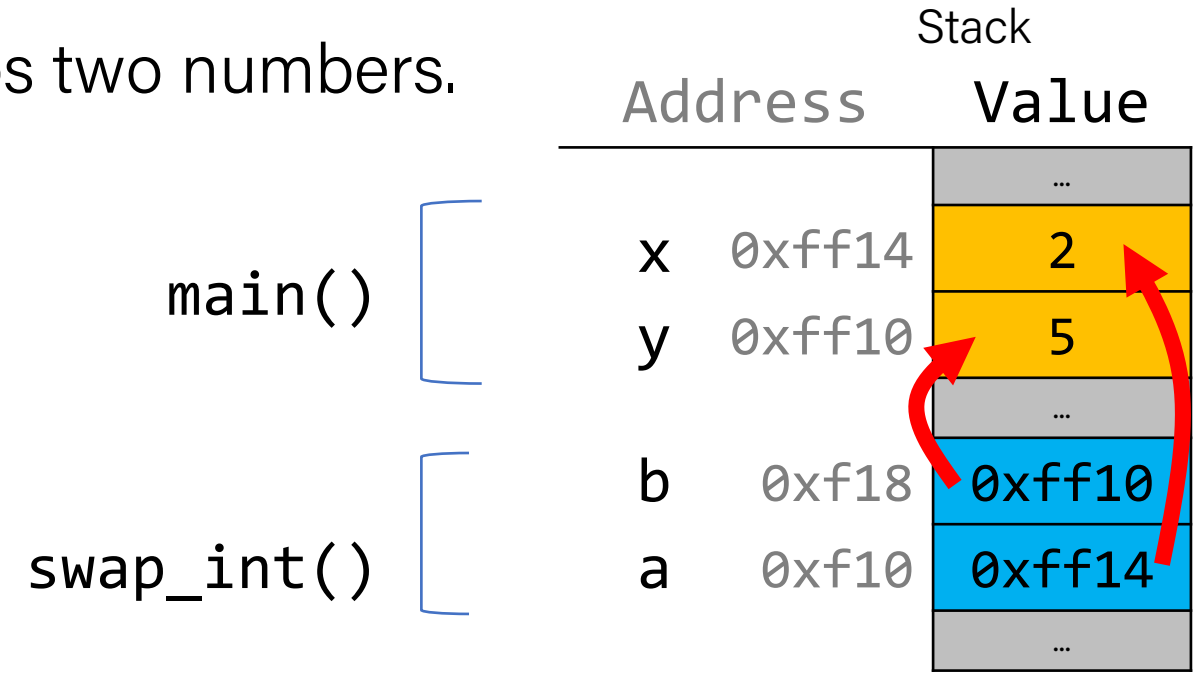

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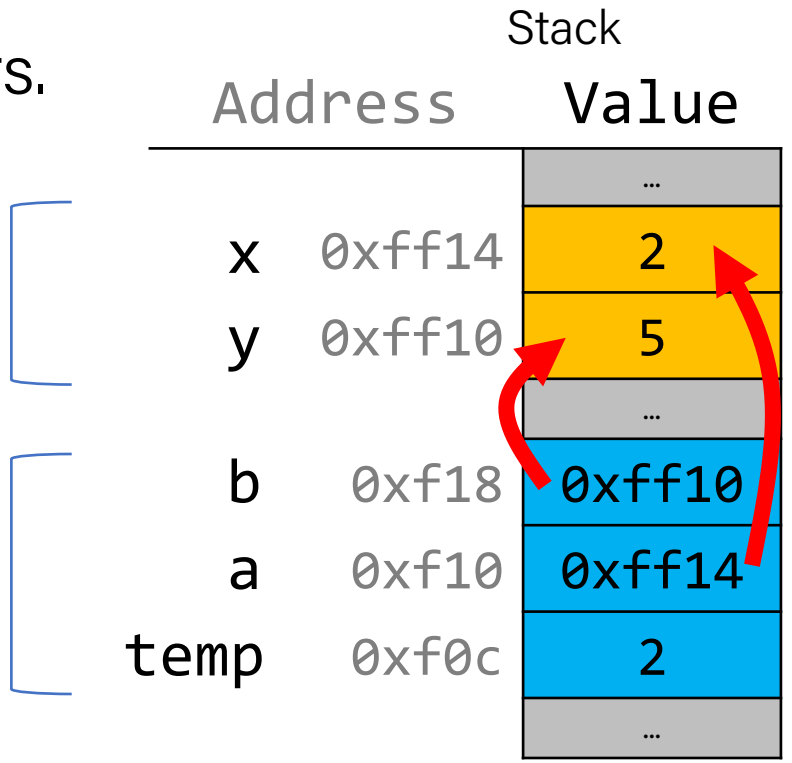

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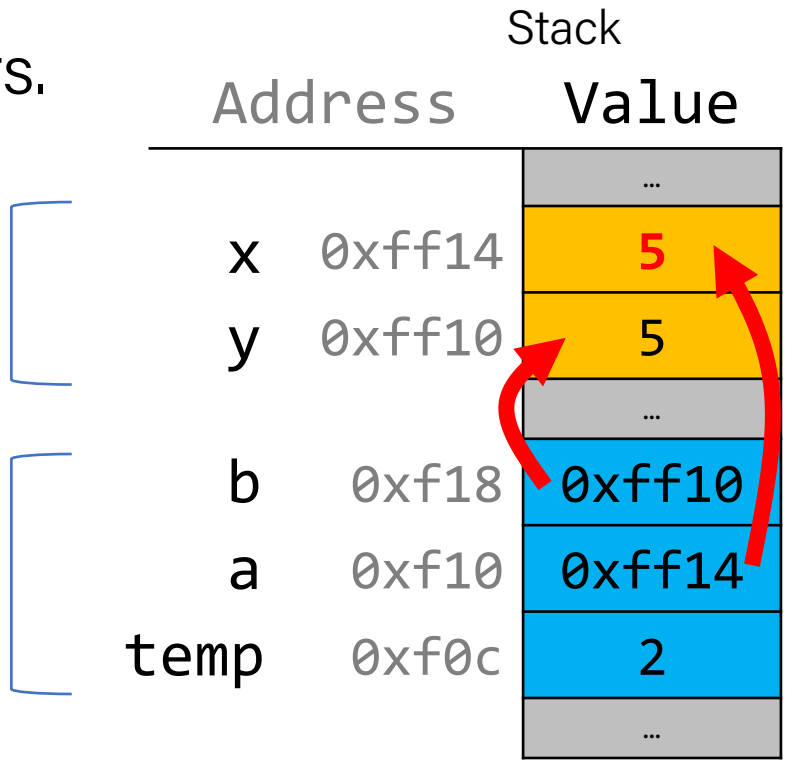

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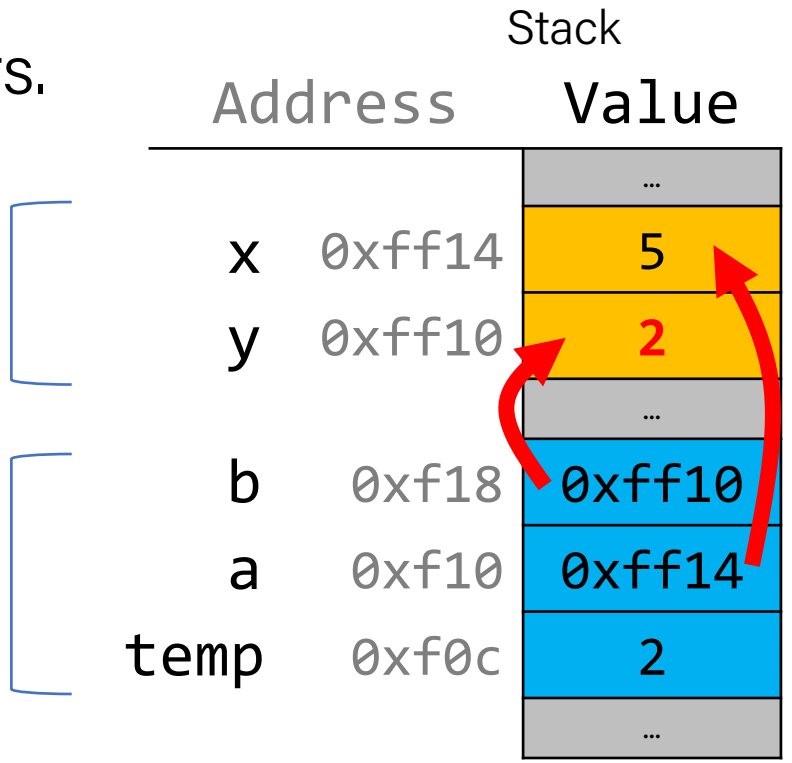

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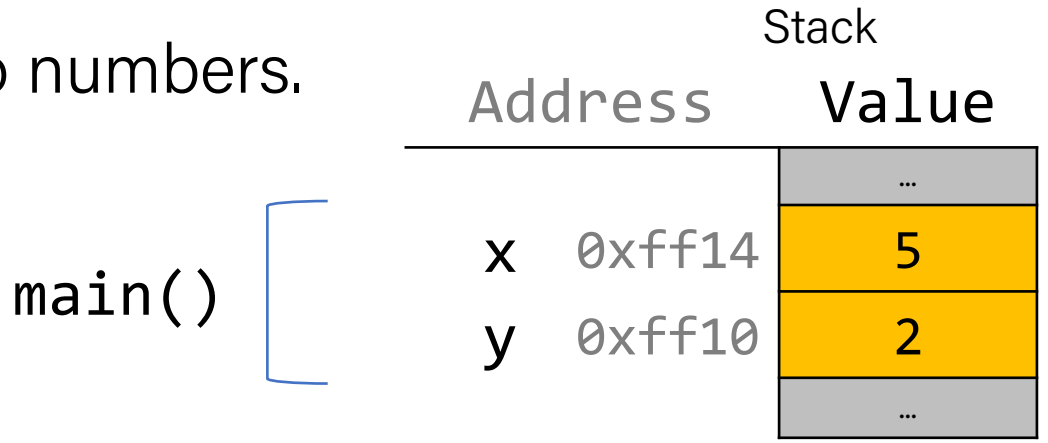

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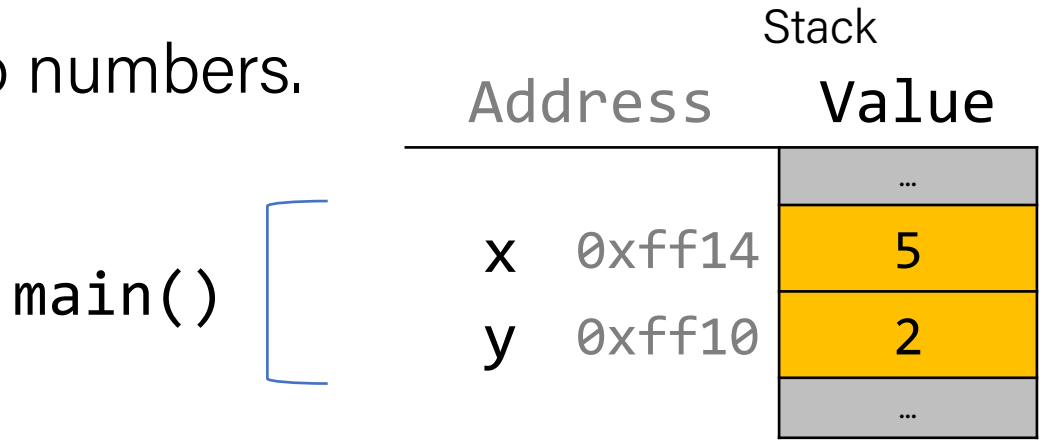

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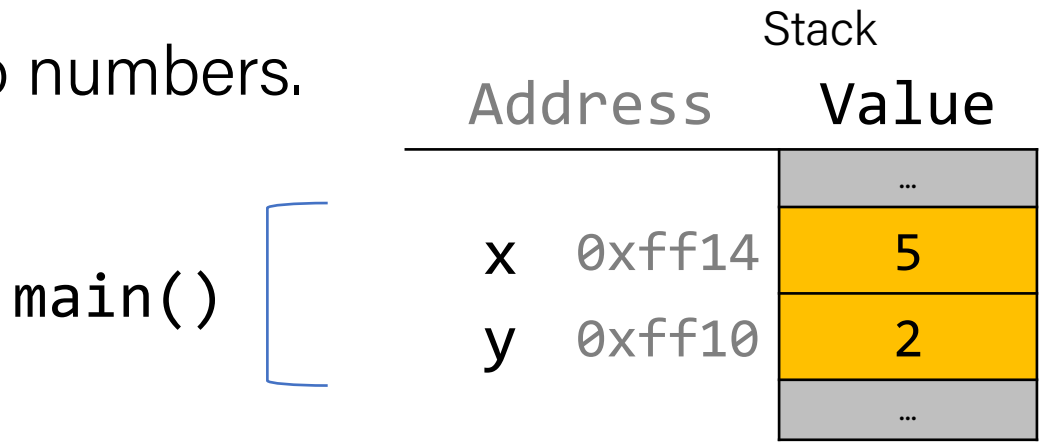

“Oh, when I said ’numbers’ I meant `shorts`, not `ints`.”

# Swap

```
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;
}
```

# Swap

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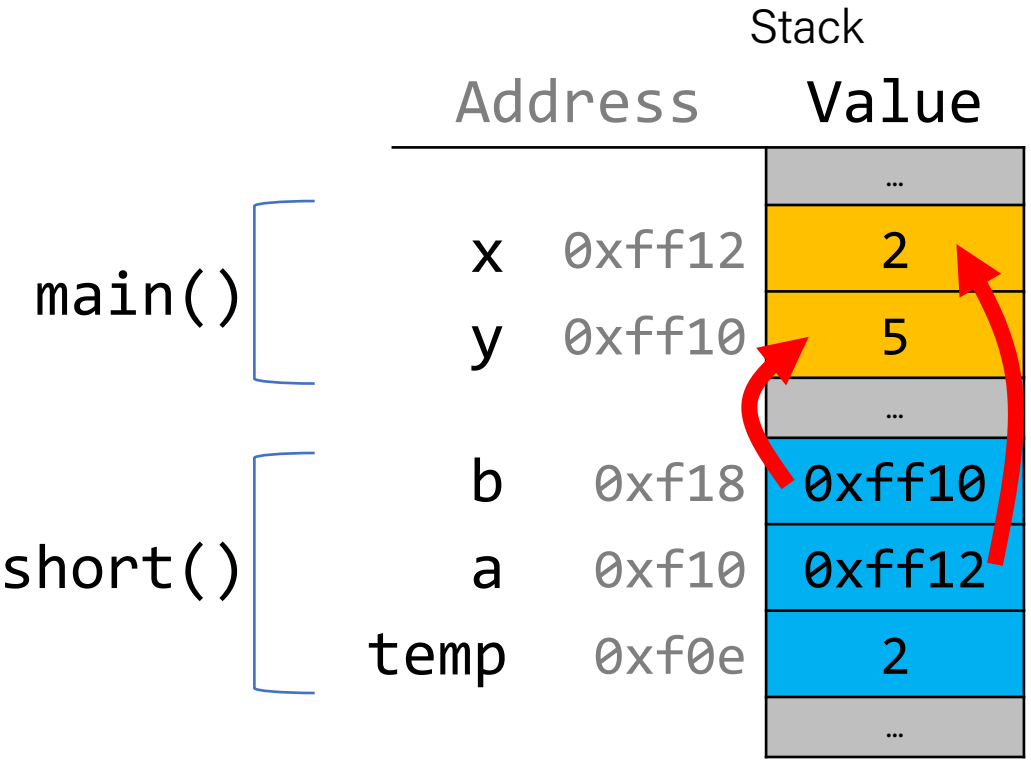

“You know what, I goofed. We’re going to use strings. Could you write something to swap those?”

# Swap

```
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);
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# Swap

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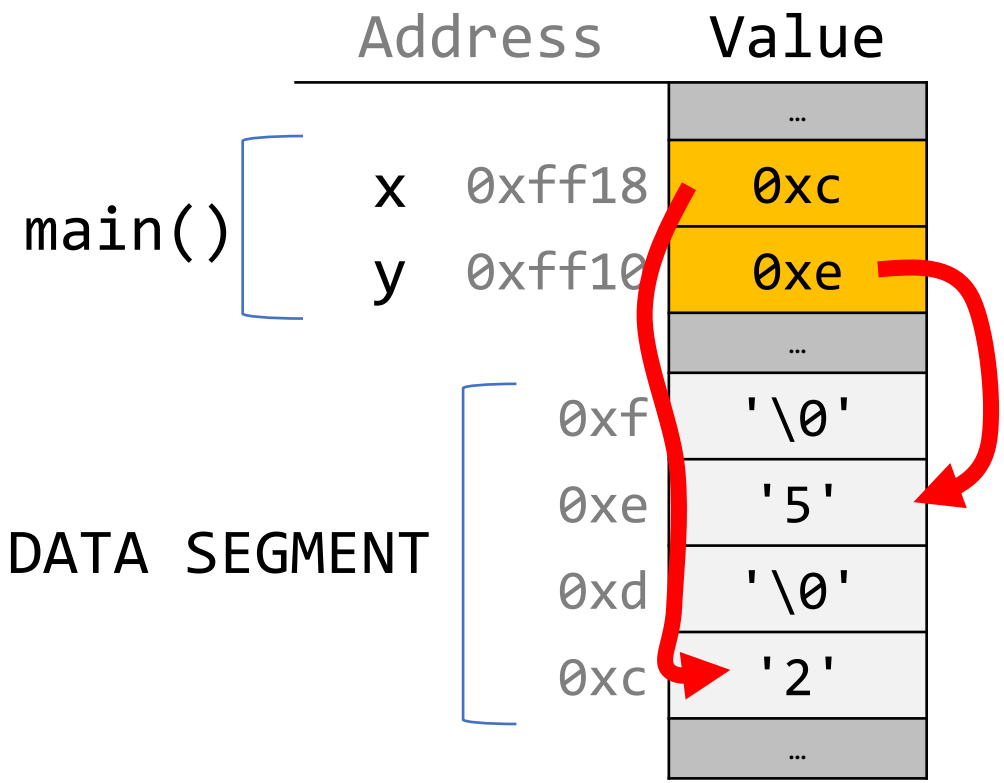

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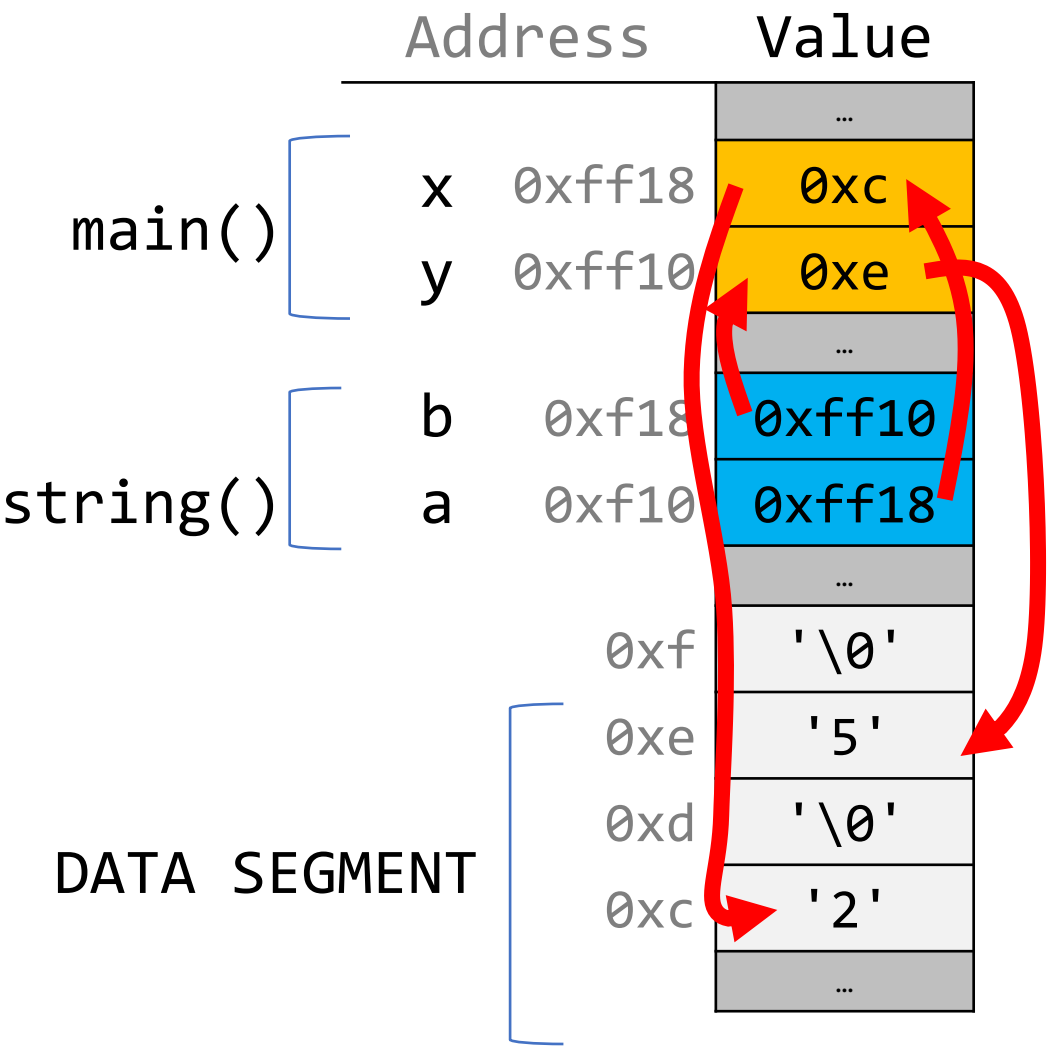

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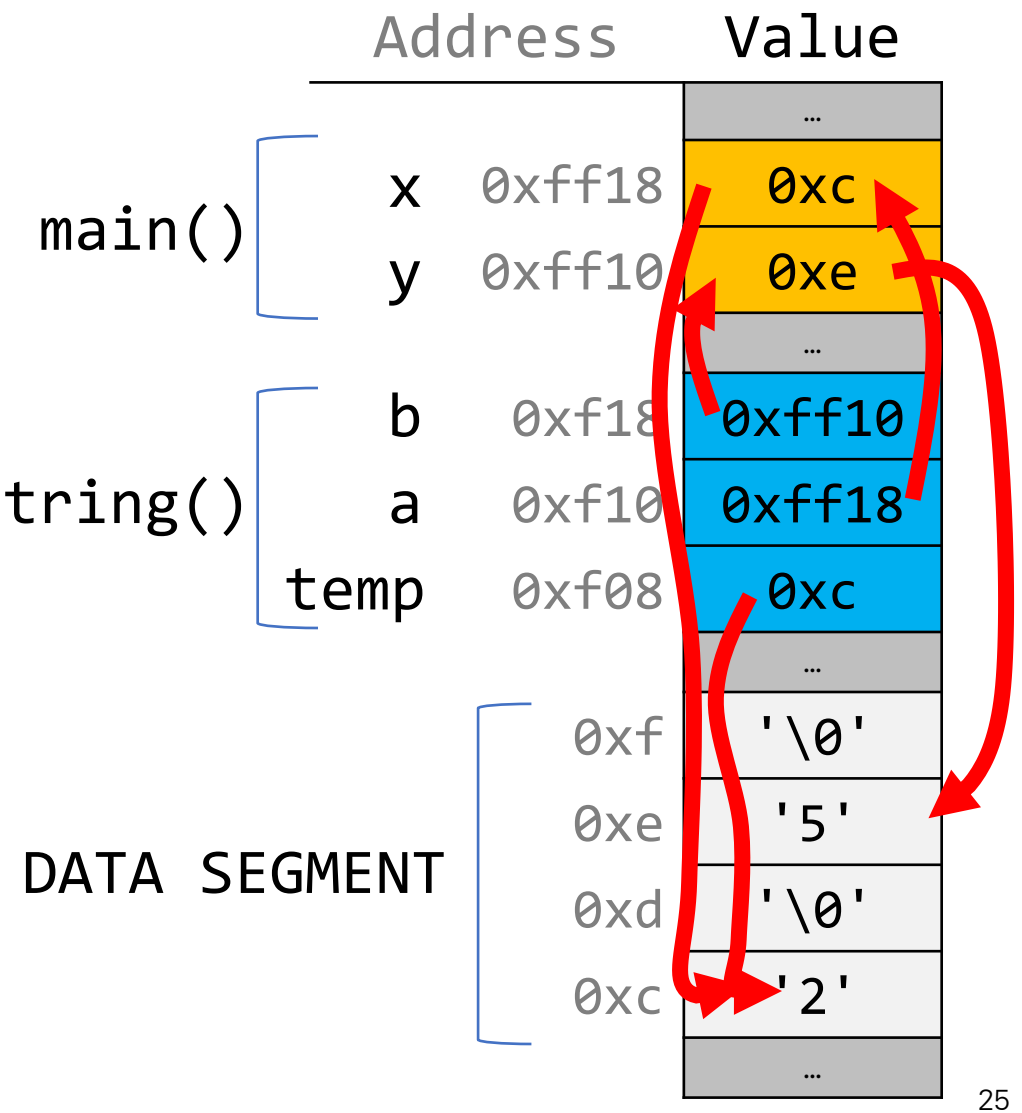

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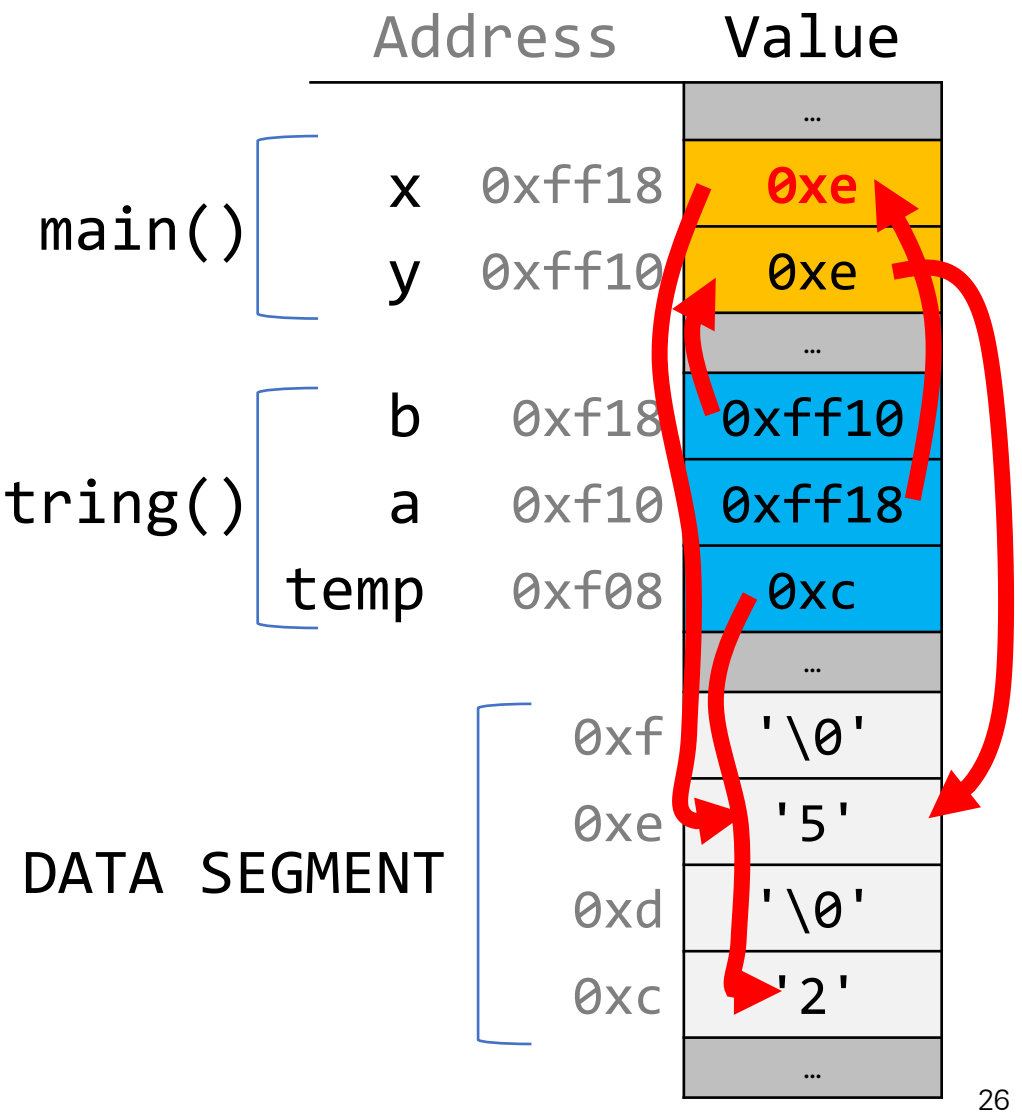

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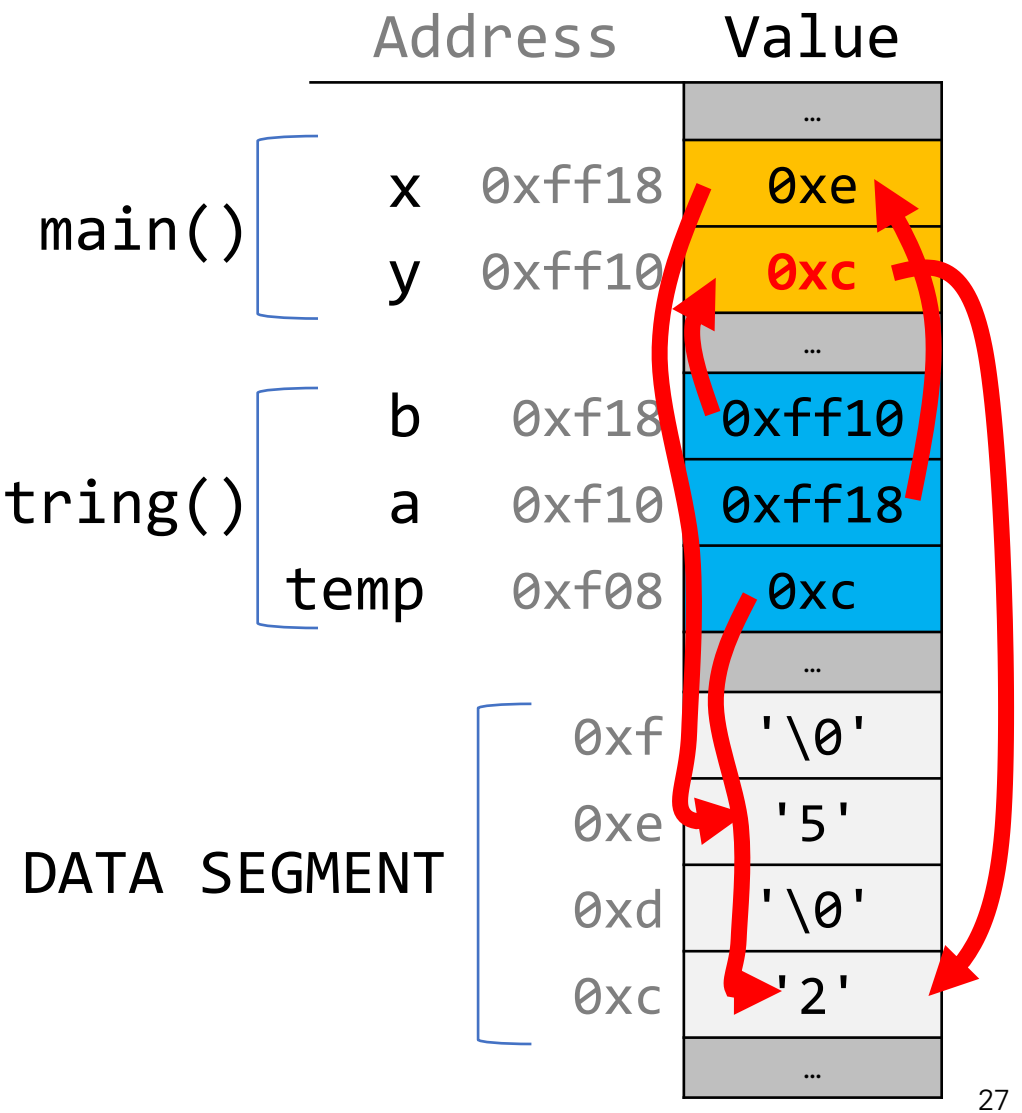

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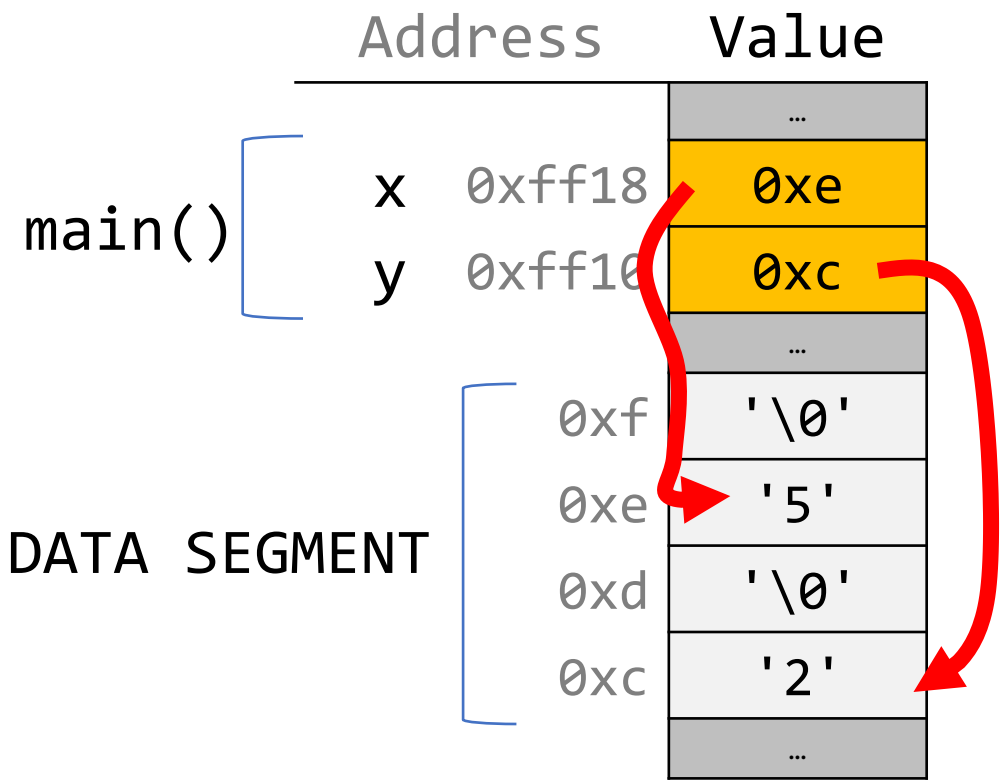

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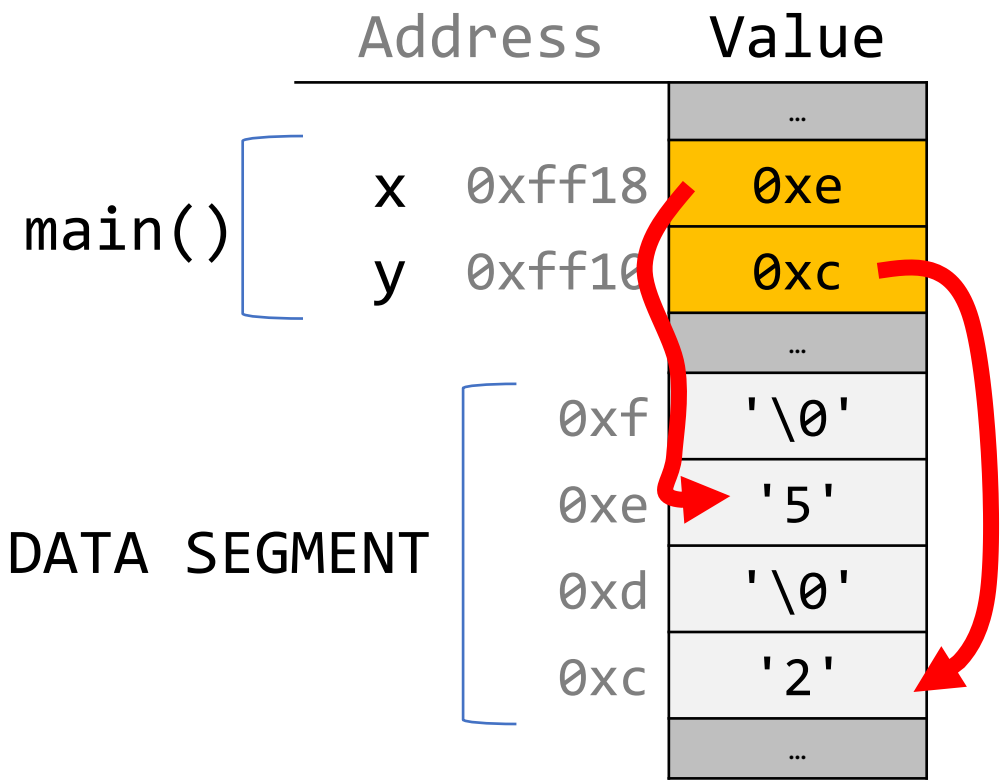

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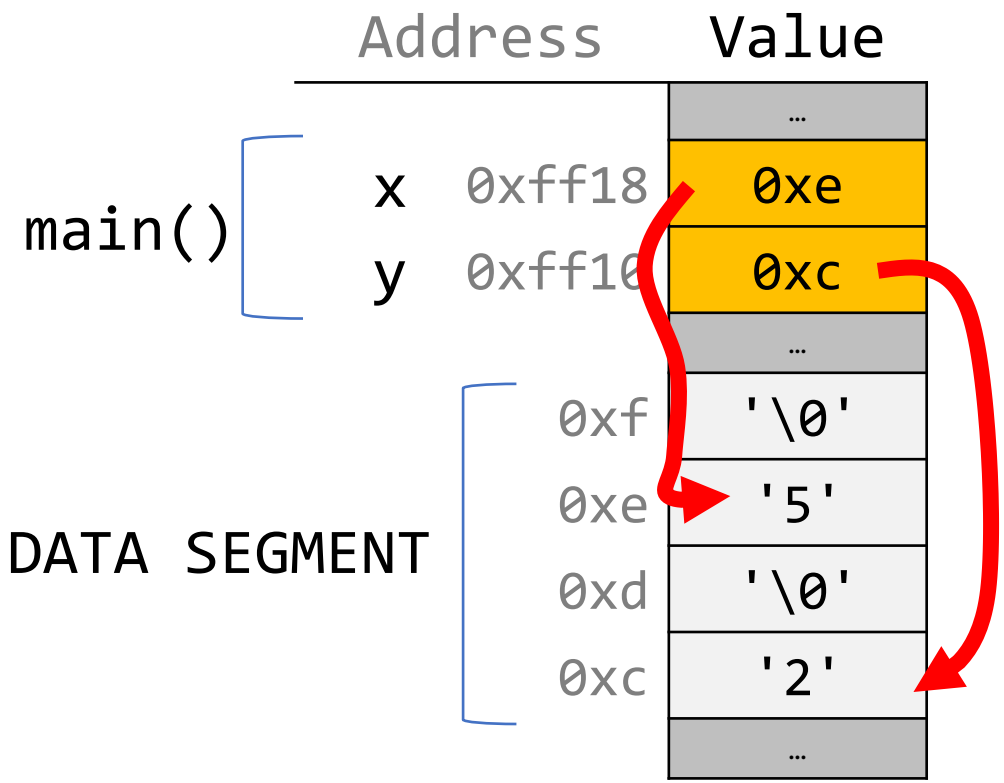

“Awesome!  Thanks.”

“Awesome! Thanks. We also have 20 custom `struct` types. Could you write swap for those too?”

“Awesome! Thanks. We also have 20 custom `struct` types. Could you write swap for those too?”


A user-defined structured data type in C (will be covered next week)

# Generic Swap

What if we could write *one* function to swap two values of any single type?

```
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

```
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;
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    char *temp = *a;
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    *b = temp;
}
```

All 3:

- Take pointers to values to swap
- Create temporary storage to store one of the values
- Move data at **b** into where **a** points
- Move data in temporary storage into where **b** points

# Generic Swap

```
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
}
```

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}
```

```
int temp = *data1ptr;
```
4 bytes

```
short temp = *data1ptr;
```
2 bytes

```
char *temp = *data1ptr;
```
8 bytes

**Problem:** each type may need a different size temp!

# Generic Swap

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void swap(pointer to data1, pointer to data2) {
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}
```

```
*data1Ptr = *data2ptr;
```
4 bytes

```
*data1Ptr = *data2ptr;
```
2 bytes

```
*data1Ptr = *data2ptr;
```
8 bytes

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

# Generic Swap

```
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
}
```

```
*data2ptr = temp;
```
4 bytes

```
*data2ptr = temp;
```
2 bytes

```
*data2ptr = temp;
```
8 bytes

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

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?

# Generic Swap

```
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void swap(void *data1ptr, void *data2ptr) {
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void swap(void *data1ptr, void *data2ptr) {
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}
```

If we don't know the data type, we don't know how many bytes it is. Let's take that as another parameter.

# Generic Swap

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

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# Generic Swap

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    // store a copy of data1 in temporary storage
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}
```

Let's start by making space to store the temporary value. How can we make **`nbytes`** of temp space?

# Generic Swap

```
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 **`nbytes`** of temp space?

# Generic Swap

```
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!

# Generic Swap

```
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`**?

# Generic Swap

```
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
}
```

Now, how can we copy in what **`data1ptr`** points to into **`temp`**?

# Generic Swap

```
void swap(void *data1ptr, void *data2ptr, size_t nbytes) {
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    // store a copy of data1 in temporary storage
    temp = *data1ptr; ???
    // copy data2 to location of data1
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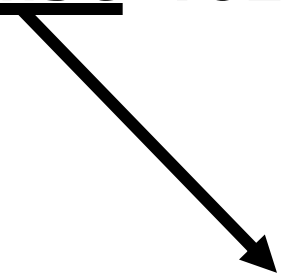
}
```

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

**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);
```



`const` is a type qualifier which indicates that the data is read only (will be covered next week)

# memcpy

**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.

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

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

# memmove

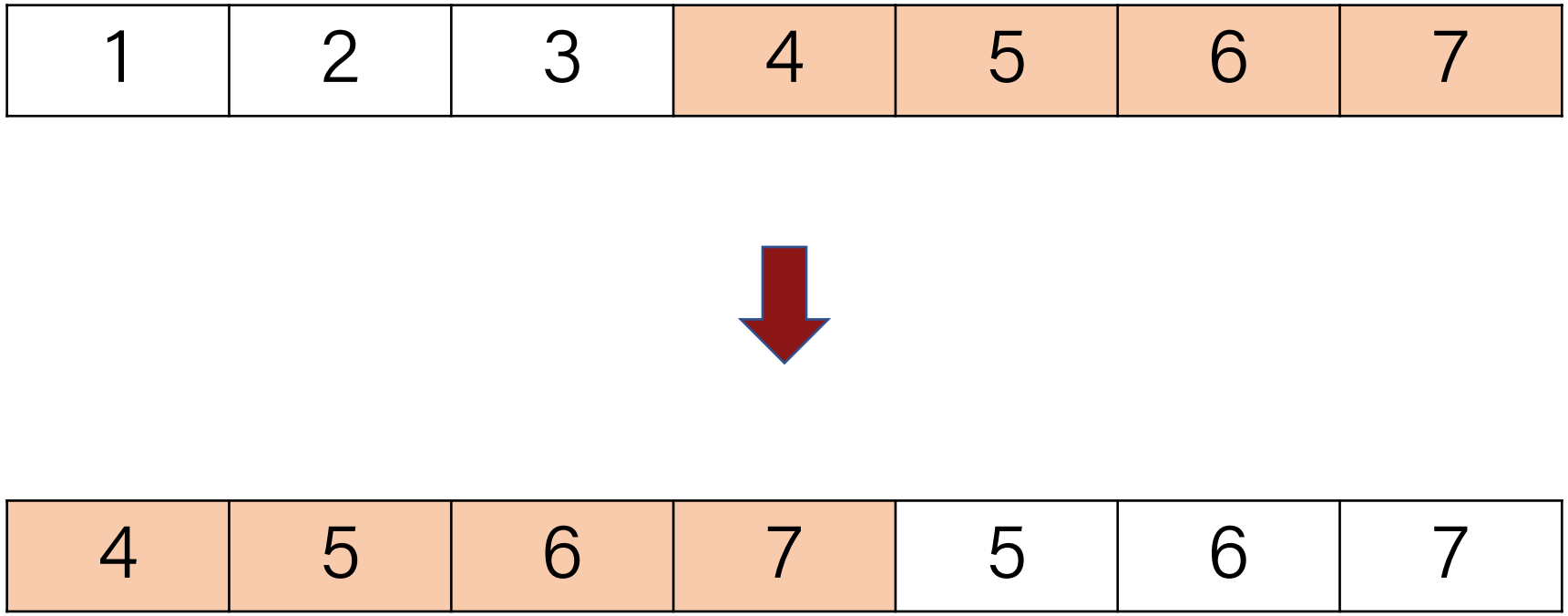
**memmove** is the same as memcpy, but supports overlapping regions of memory. (Unlike its name implies, it still "copies").

```
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**).

# memmove

When might memmove be useful?



# Generic Swap

```
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.

# Generic Swap

slido Event code: 73165

```
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
}
```

How can **memcpy** or **memmove** help us here?

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

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

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

# 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
    // 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.

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

How can we copy data2 to the location of data1?

# 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
    *data1ptr = *data2ptr; ???
    // copy data in temporary storage to location of data2
}
```

How can we copy data2 to the location of data1?

# 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
}
```

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

# 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
}
```

How can we copy temp's data to the location of data2?

# 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);
}
```

How can we copy temp's data to the location of data2? **memcpy**!

# 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));
```

# 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));
```

# 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));
```

# 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);
}
```

```
mystruct x = {…};
mystruct y = {…};
swap(&x, &y, sizeof(x));
```

# C Generics

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

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

# Lecture Plan

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

# 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

`swap.c`

# Void *Pitfalls

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

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

# Mid-Lecture Check-In

We can now answer the following questions:

1. What variable type represents a “generic pointer”?
2. What variable type can we use to create a specific number of bytes of space on the stack?
3. How can we copy generic memory from one location to another?
4. What is the difference between **`memcpy`** and **`memmove`**?
5. What are the benefits of generic functions in C? What are the challenges?

# Lecture Plan

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

# Swap Ends

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

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

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

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

# Swap Ends

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

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

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

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

# Swap Ends

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

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

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

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

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

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

# Swap Ends

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

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

Is this generic? Does this work?

# Swap Ends

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

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

Is this generic? Does this work?

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

# Swap Ends

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

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

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

# Swap Ends

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

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

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

# Pointer Arithmetic

```
arr + nelems - 1
```

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

If it's an array of...

**`Int?`**

# Pointer Arithmetic

```
arr + nelems - 1
```

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

If it's an array of...

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

# Pointer Arithmetic

```
arr + nelems - 1
```

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

If it's an array of...

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

**`Short?`**

# Pointer Arithmetic

```
arr + nelems - 1
```

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

If it's an array of...

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

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

# Pointer Arithmetic

```
arr + nelems - 1
```

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

If it's an array of...

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

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

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

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

# Swap Ends

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

```
void swap_ends(void *arr, size_t nelems, size_t elem_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**

# Swap Ends

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

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

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

**(nelems - 1) * elem_bytes**

# Swap Ends

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

```
void swap_ends(void *arr, size_t nelems, size_t elem_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?**

# Swap Ends

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

```
void swap_ends(void *arr, size_t nelems, size_t elem_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!

# 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);
}
```

# 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]));
```

# 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]));
```

# 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]));
```

# 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);
}
```

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

# Demo: Void *s Gone Wrong

`swap_ends.c`

# Recap

- **`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

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

**Next time:** Function Pointers