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# COMP201

## Computer Systems & Programming

### Lecture #10 – C Generics – `void *`

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2024

# Recap: Heap allocation interface:

```
void *malloc(size_t size);
void *calloc(size_t nmemb, size_t size);
void *realloc(void *ptr, size_t size);
char *strdup(char *s);
void free(void *ptr);
```

Heap **memory allocation** guarantee:

- `NULL` on failure, so check with `assert`
- Memory is contiguous; it is not recycled unless you call free
- `realloc` preserves existing data
- `calloc` zero-initializes bytes, `malloc` and `realloc` do not

**Undefined behavior** occurs:

- If you overflow (i.e., you access beyond bytes allocated)
- If you use after `free`, or if `free` is called twice on a location.
- If you `realloc`/`free` non-heap address

# Recap: The Stack vs The Heap

## **Stack** (“local variables”)

- **Fast**
  Fast to allocate/deallocate; okay to oversize
- **Convenient.**
  Automatic allocation/ deallocation; declare/initialize in one step
- **Reasonable type safety**
  Thanks to the compiler

⚠️ **Not especially plentiful**
Total stack size fixed, default 8MB

⚠️ **Somewhat inflexible**
Cannot add/resize at runtime, scope dictated by control flow in/out of functions

## **Heap** (dynamic memory)

- **Plentiful.**
  Can provide more memory on demand!
- **Very flexible.**
  Runtime decisions about how much/when to allocate, can resize easily with realloc
- **Scope under programmer control**
  Can precisely determine lifetime

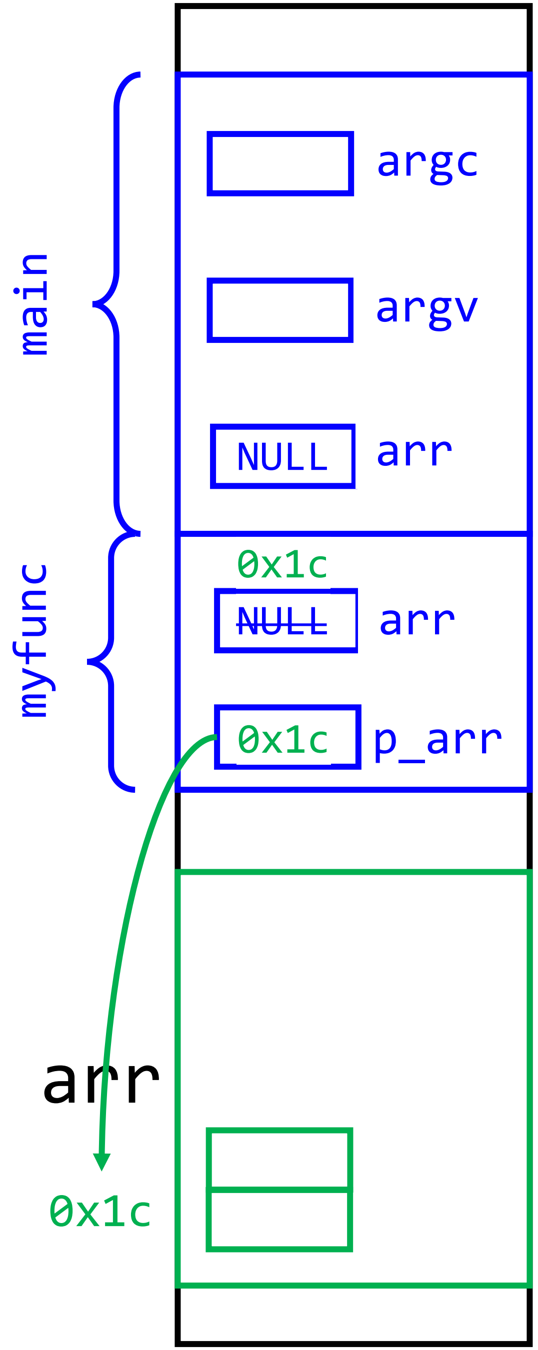
⚠️ **Lots of opportunity for error**
Low type safety, forget to allocate/free before done, allocate wrong size, etc., Memory leaks (much less critical)

# Recap: Exercise 1

```c
void myfunc(int *arr) {
  int *p_arr = (int*) malloc(2*sizeof(int));
  p_arr[0] = 42;
  p_arr[1] = 24;
  arr = p_arr;
}

int main(int argc, char *argv[]) {
  int *arr = NULL;
  myfunc(arr);
  printf("arr[0] = %d\n arr[1] = %d", arr[0], arr[1]);
  free(arr);
  return 0;
}
```

# Recap: Exercise 1

```
void myfunc(int *arr) {
  int *p_arr = (int*) malloc(2*sizeof(int));
  p_arr[0] = 42;
  p_arr[1] = 24;
  arr = p_arr;
}

int main(int argc, char *argv[]) {
  int *arr = NULL;
  myfunc(arr);
  printf("arr[0] = %d\n arr[1] = %d", arr[0], arr
  free(arr);
  return 0;
}
```



# Recap: Exercise 1

```
void myfunc(int *arr) {
  int *p_arr = (int*) malloc(2*sizeof(int));
  p_arr[0] = 42;
  p_arr[1] = 24;
  arr = p_arr;
}

int main(int argc, char *argv[]) {
  int *arr = NULL;
  myfunc(arr);
  printf("arr[0] = %d\n arr[1] = %d", arr[0], arr[1]);
  free(arr);
  return 0;
}
```

1. dereference of uninitialized or invalid pointer: `arr` in `main` is still `NULL`

# Recap: Exercise 1

```c
void myfunc(int *arr) {
  int *p_arr = (int*) malloc(2*sizeof(int));
  p_arr[0] = 42;
  p_arr[1] = 24;
  arr = p_arr;
}

int main(int argc, char *argv[]) {
  int *arr = NULL;
  myfunc(arr);
  printf("arr[0] = %d\n arr[1] = %d", arr[0], arr[1]);
  free(arr);
  return 0;
}
```

2. freeing unallocated storage!

# Recap: Exercise 2

```c
int myfunc(int **array, n) {
  int** int_array = (int**) malloc(n*sizeof(int));
  array = int_array;
  return 0;
}

int main(int argc, char *argv[]) {
  int **array = NULL;
  myfunc(array,10);
  array[0] = (int*) malloc(4*sizeof(int));
  return 0;
}
```

# Recap: Exercise 2

```
int myfunc(int **array, n) {
  int** int_array = (int**) malloc(n*sizeof(int));
  array = int_array;
  return 0;
}

int main(int argc, char *argv[]) {
  int **array = NULL;
  myfunc(array,10);
  array[0] = (int*) malloc(4*sizeof(int));
  return 0;
}
```

1. insufficient space for a dynamically allocated variable: `malloc` should use `sizeof(int*)`

# Recap: Exercise 2

```
int myfunc(int **array, n) {
  int** int_array = (int**) malloc(n*sizeof(int));
  array = int_array;
  return 0;
}

int main(int argc, char *argv[]) {
  int **array = NULL;
  myfunc(array,10);
  array[0] = (int*) malloc(4*sizeof(int));
  return 0;
}
```

2. dereference of uninitialized or invalid pointer: `array` in `main` is still `NULL`

# Exercise 3

```
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);

  while ((*ptr++ = *param1++) != '\0')
    ;

  strcat(ptr+strlen(param1)+1, param2);
  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

- Unlike other languages assignment statement has a return value – the value of rhs
- In C, `NULL` is (usually) defined as `((void *)0)`

# Exercise 3

```
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);

  while ((*ptr++ = *param1++) != 0)
    ;

  strcat(ptr+strlen(param1)+1, param2);
  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

1. Dereference of invalid pointer: `strcat` could not find end of `dest`

# Exercise 3

```
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);

  while ((*ptr++ = *param1++) != 0)
    ;

  strcat(ptr+strlen(param1)+1, param2);
  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

2. memory leakage: `ptr = NULL;` should be `free(ptr);`

# Exercise 4

```c
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);
  strcpy(ptr, param1);
  ptr += strlen(param1);

  while ((*ptr++ = *param2++) != 0)
    ;

  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

# Exercise 4

```
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);
  strcpy(ptr, param1);
  ptr += strlen(param1);

  while ((*ptr++ = *param2++) != 0)
    ;

  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

1. memory leakage: `ptr = NULL;` should be `free(ptr);`

# Exercise 4

```
int main(int argc, char *argv[]) {
  if (argc!=3) {printf("wrong number of arguments\n"); return 1;}

  char *param1 = *argv[1];
  char *param2 = *argv[2];
  char *ptr;

  ptr = (char *) malloc(strlen(param1)+strlen(param2)+1);
  strcpy(ptr, param1);
  ptr += strlen(param1);

  while ((*ptr++ = *param2++)
    ;

  printf("%s\n", ptr);
  ptr = NULL;
  return 0;
}
```

2. memory leakage:
   `ptr+=strlen(param2);`
   no way to free memory originally pointed by `ptr`

# 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.

# 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

# 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

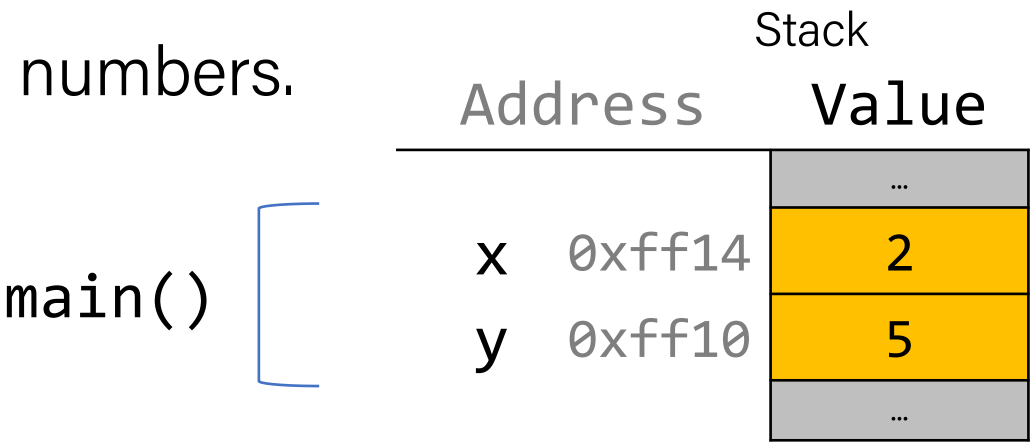
You’re asked to write a function that swaps two numbers.

```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;
}
```

# Swap

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

```
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;
}
```



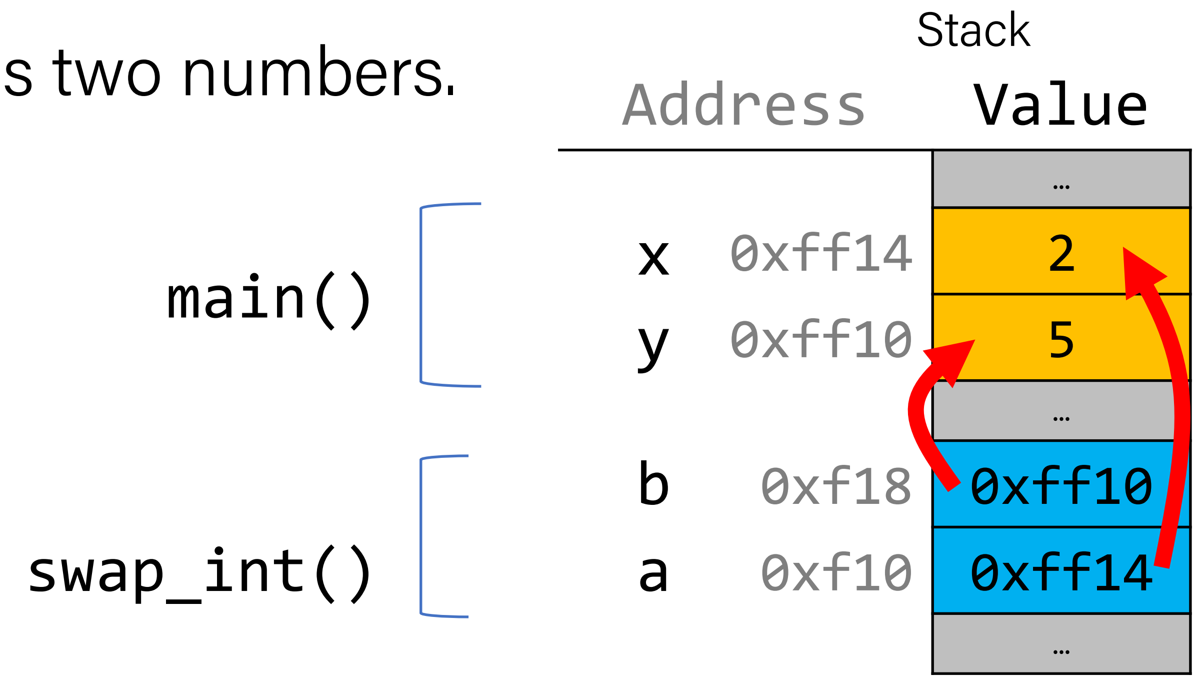
Stack

|  |  | Address | Value |
|---|---|---|---|
|  |  |  | … |
| main() | x | 0xff14 | 2 |
|  | y | 0xff10 | 5 |
|  |  |  | … |

# Swap

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

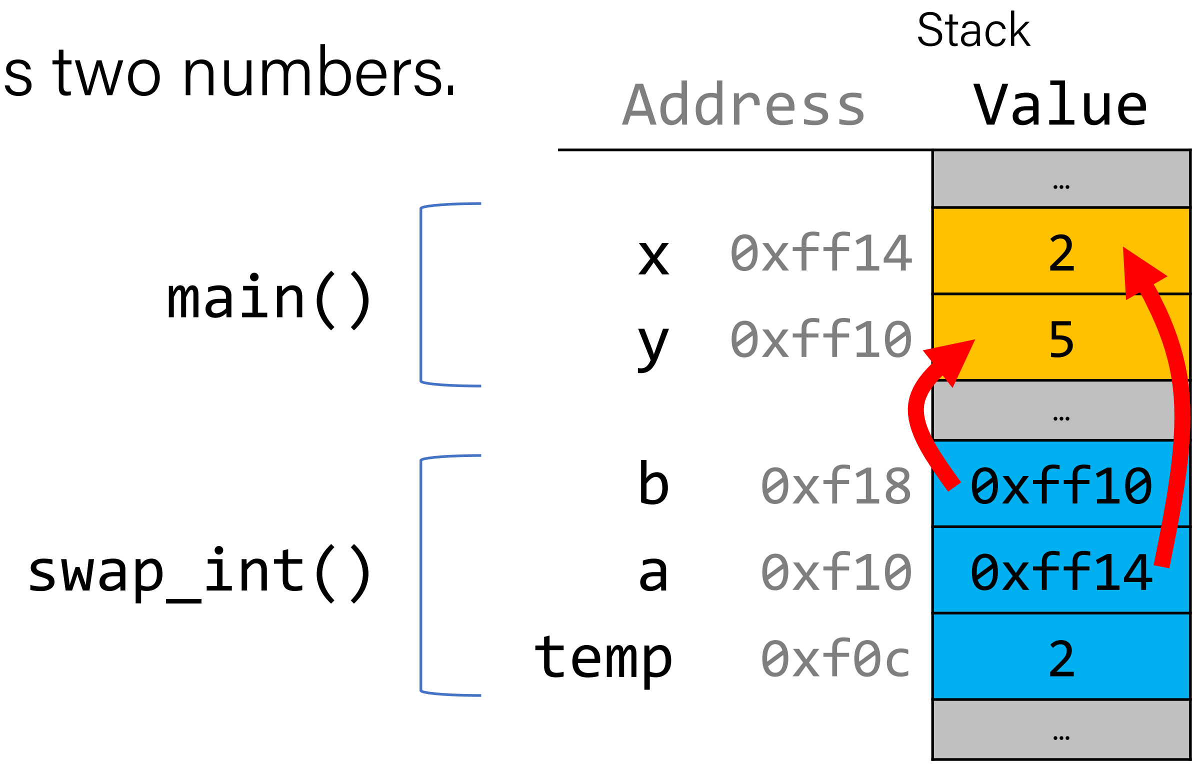
```
void swap_int(int *a, int *b) {
    int temp = *a;
    *a = *b;
    *b = temp;
}

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;
}
```



# Swap

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

```
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;
}
```



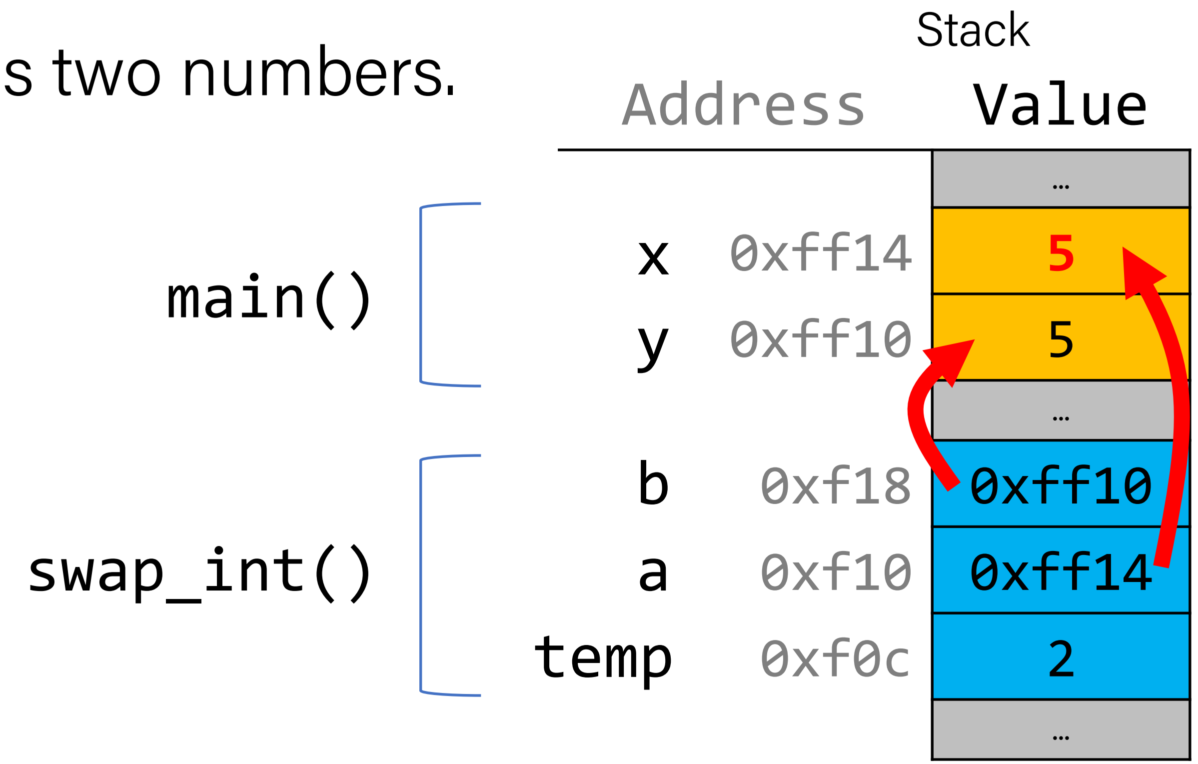
Stack

| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff14 | 2 |
| | y | 0xff10 | 5 |
| | | | … |
| swap_int() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff14 |
| | temp | 0xf0c | 2 |
| | | | … |

# Swap

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

```
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;
}
```



Stack

| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff14 | 5 |
| | y | 0xff10 | 5 |
| | | | … |
| swap_int() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff14 |
| | temp | 0xf0c | 2 |
| | | | … |

# Swap

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

```c
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);
    // want x = 5, y = 2
    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```
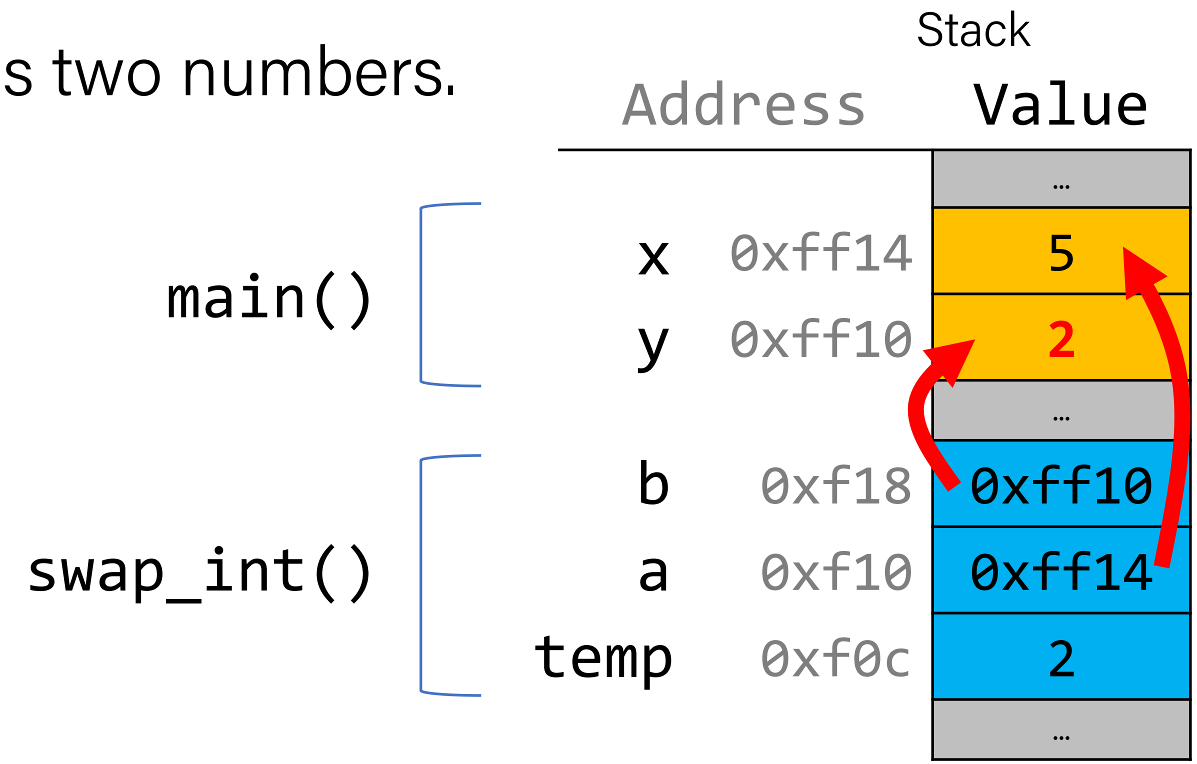



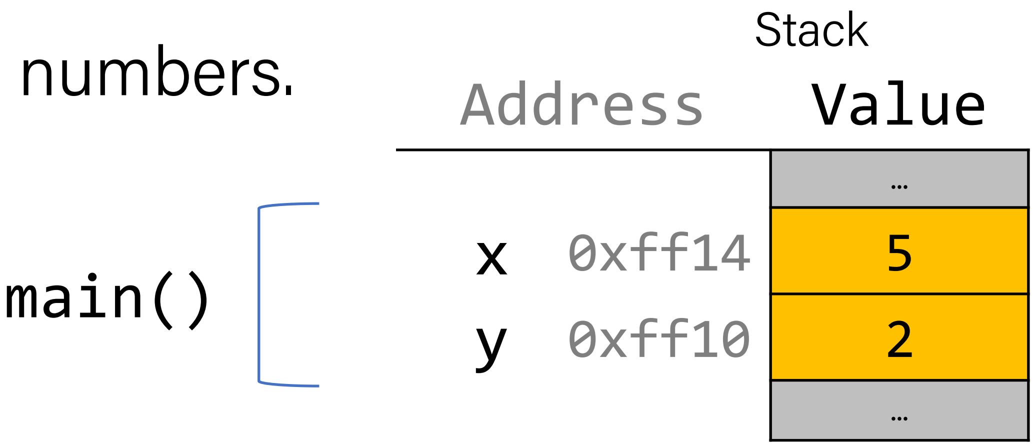
Stack

| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff14 | 5 |
| | y | 0xff10 | 2 |
| | | | … |
| swap_int() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff14 |
| | temp | 0xf0c | 2 |
| | | | … |

# Swap

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

```
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;
}
```



Stack

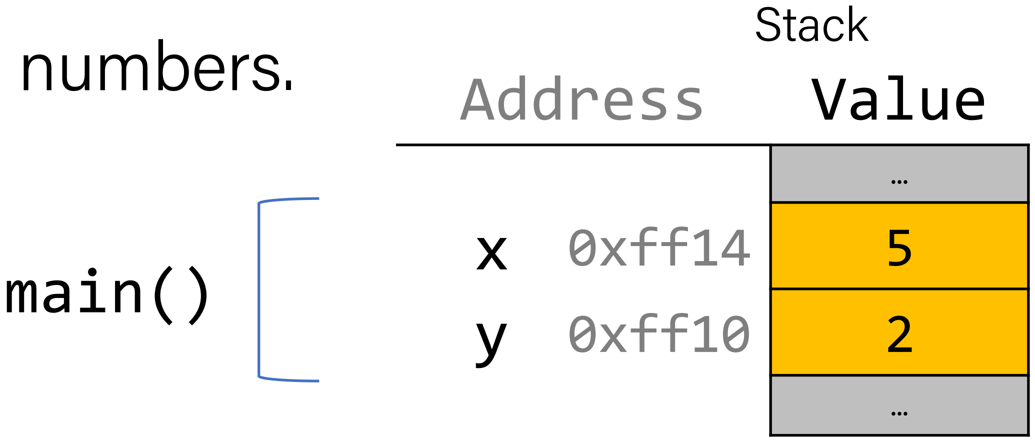
main()

| | Address | Value |
|---|---|---|
| | | … |
| x | 0xff14 | 5 |
| y | 0xff10 | 2 |
| | | … |

# Swap

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

```
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;
}
```



main()

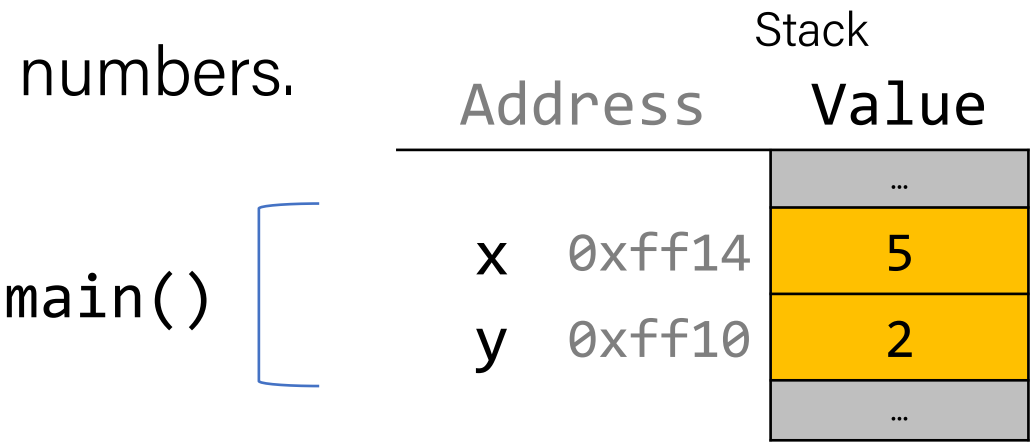
Stack

| | Address | Value |
|---|---|---|
| | | … |
| x | 0xff14 | 5 |
| y | 0xff10 | 2 |
| | | … |

# Swap

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

```
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`.”

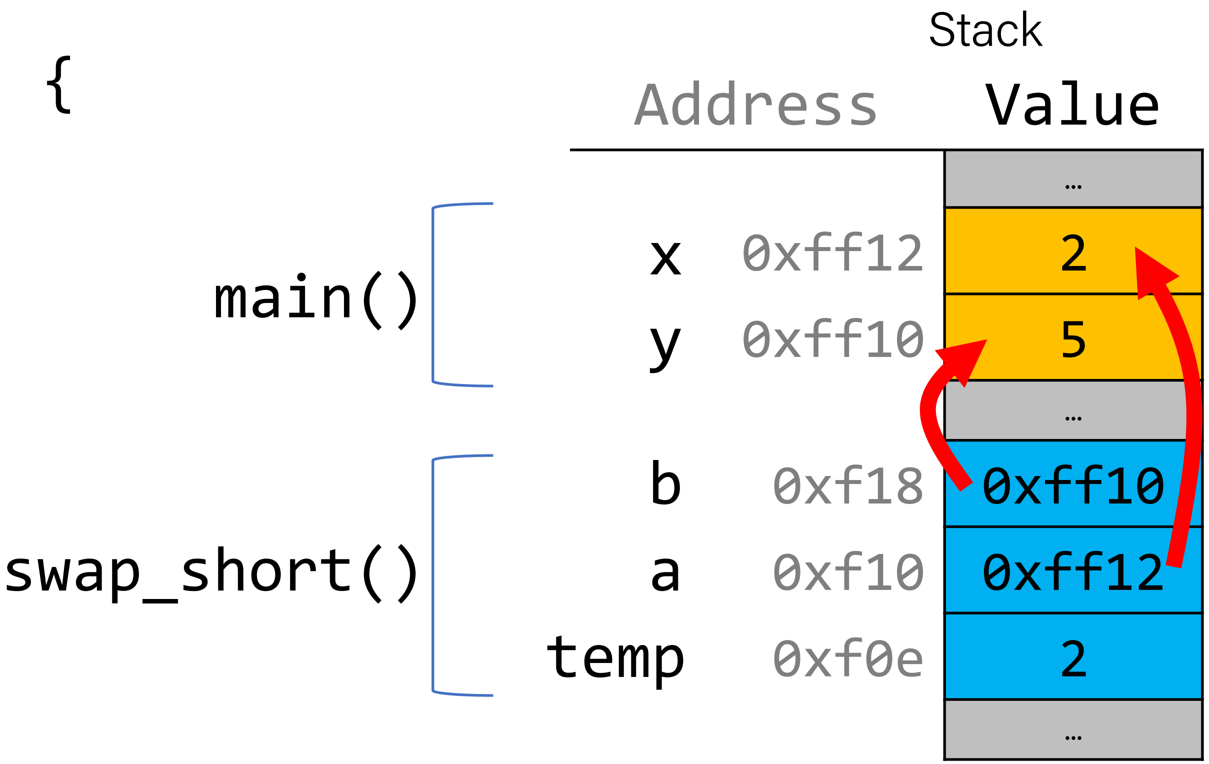
😑

# 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

```
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;
}
```



Stack

| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff12 | 2 |
| | y | 0xff10 | 5 |
| | | | … |
| swap_short() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff12 |
| | temp | 0xf0e | 2 |
| | | | … |

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

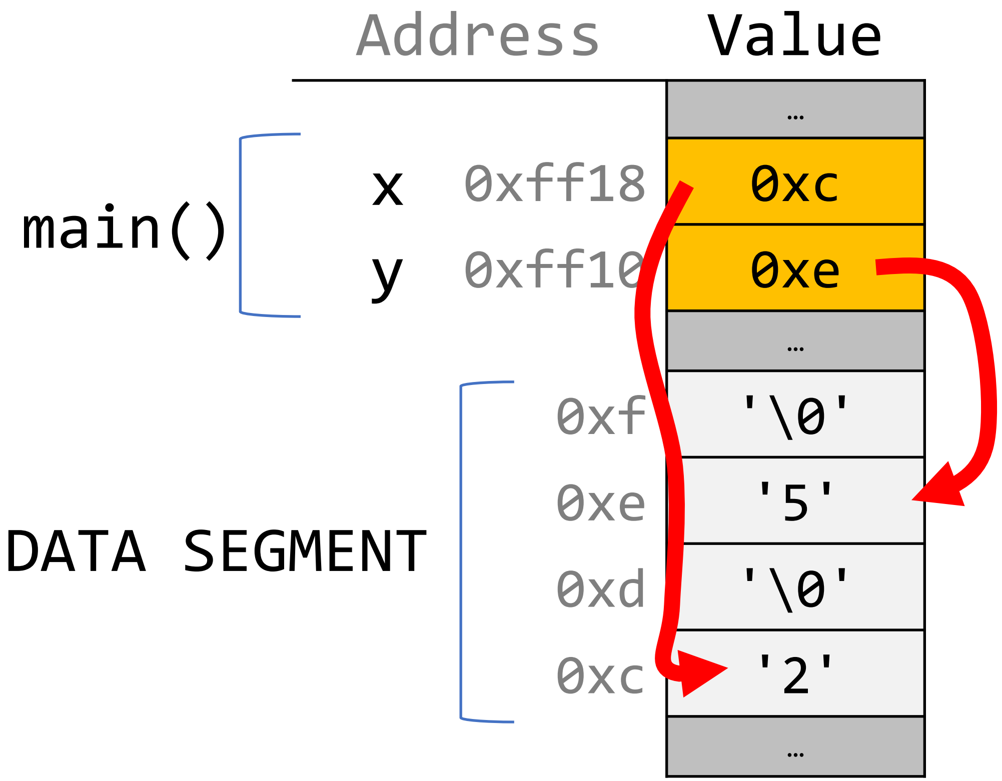
😤

# 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);
    return 0;
}
```

# Swap

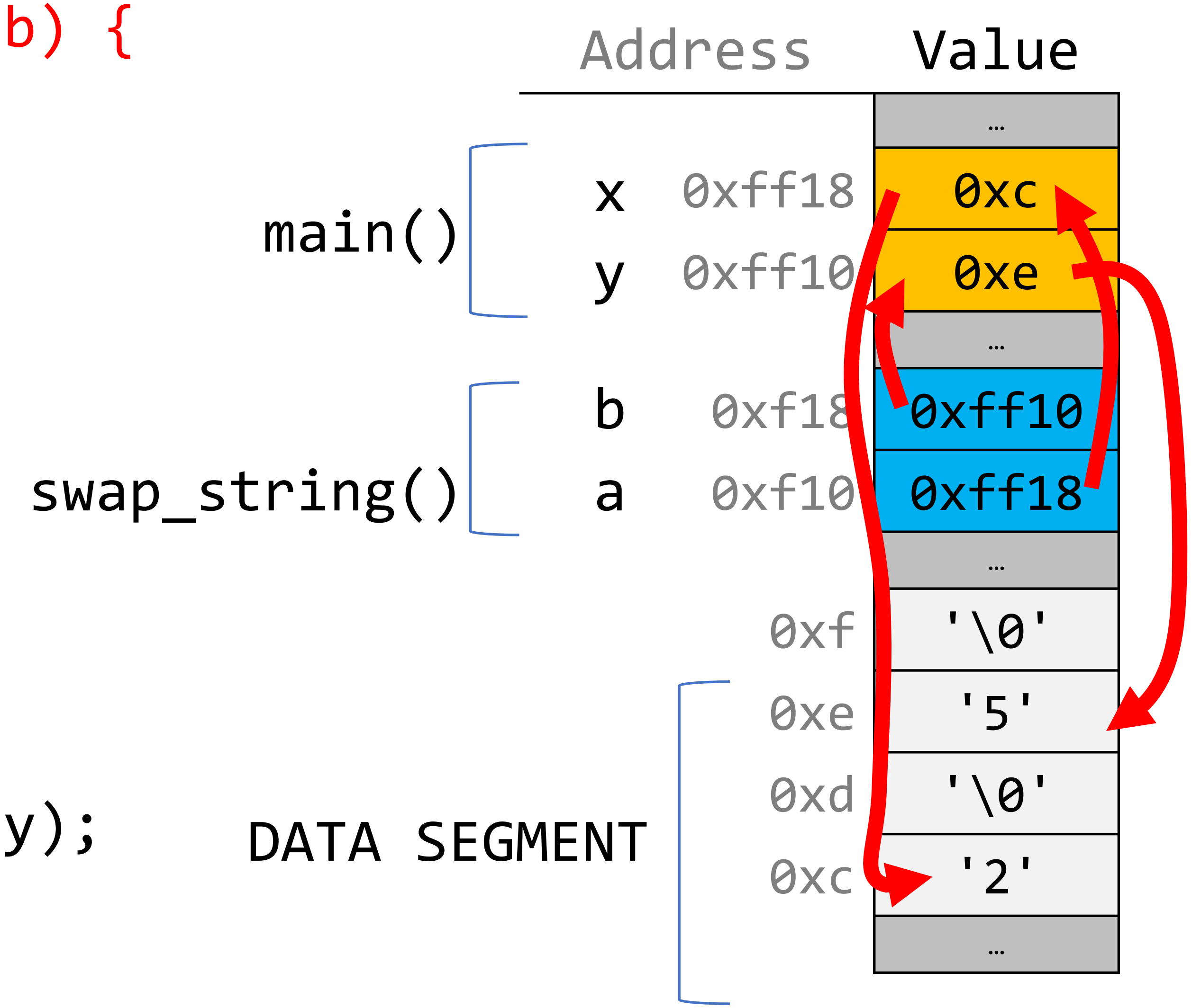
```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

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);
    return 0;
}
```



| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff18 | 0xc |
| | y | 0xff10 | 0xe |
| | | | … |
| DATA SEGMENT | | 0xf | '\0' |
| | | 0xe | '5' |
| | | 0xd | '\0' |
| | | 0xc | '2' |
| | | | … |

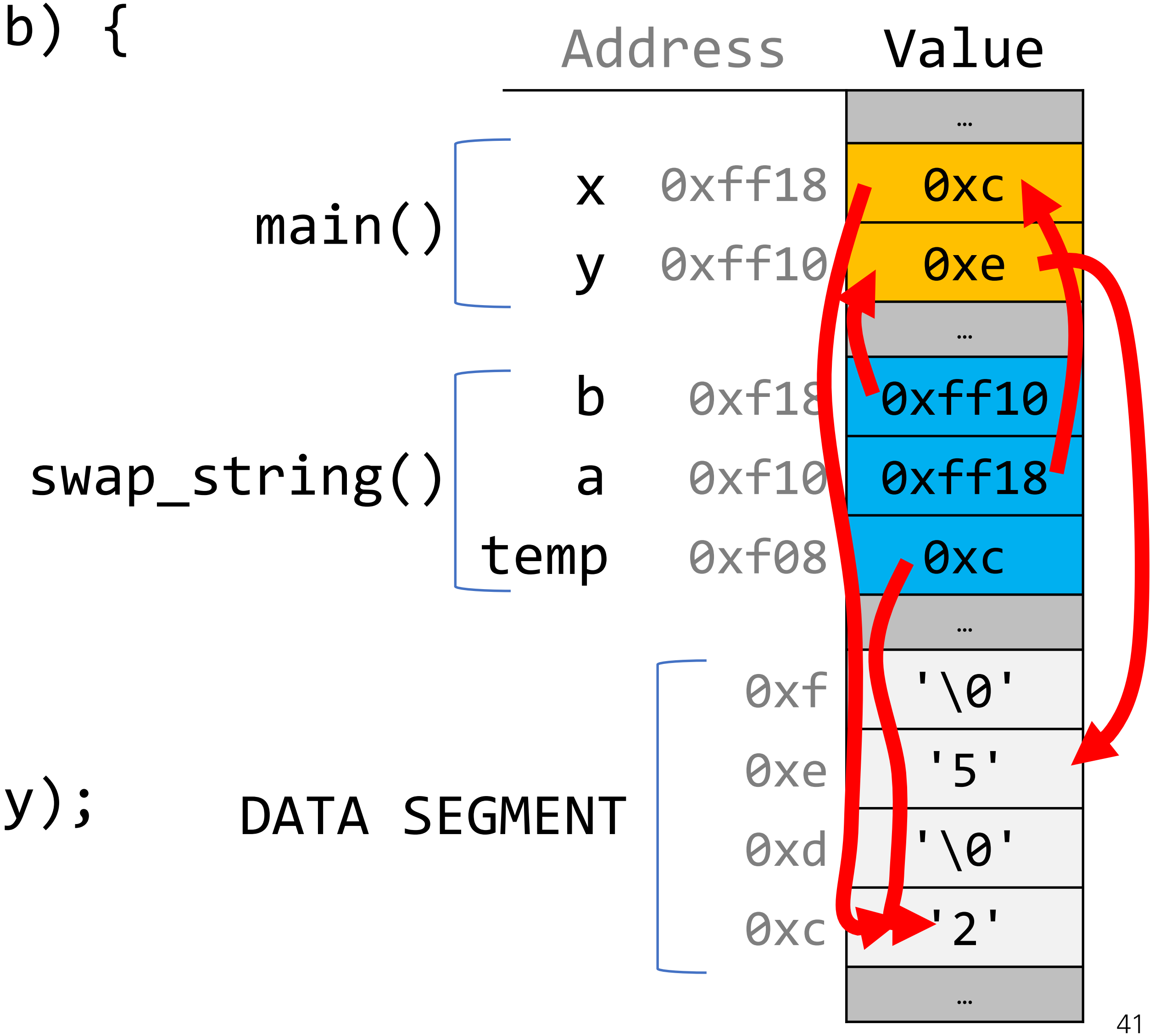
# Swap

```
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);
    return 0;
}
```



# Swap

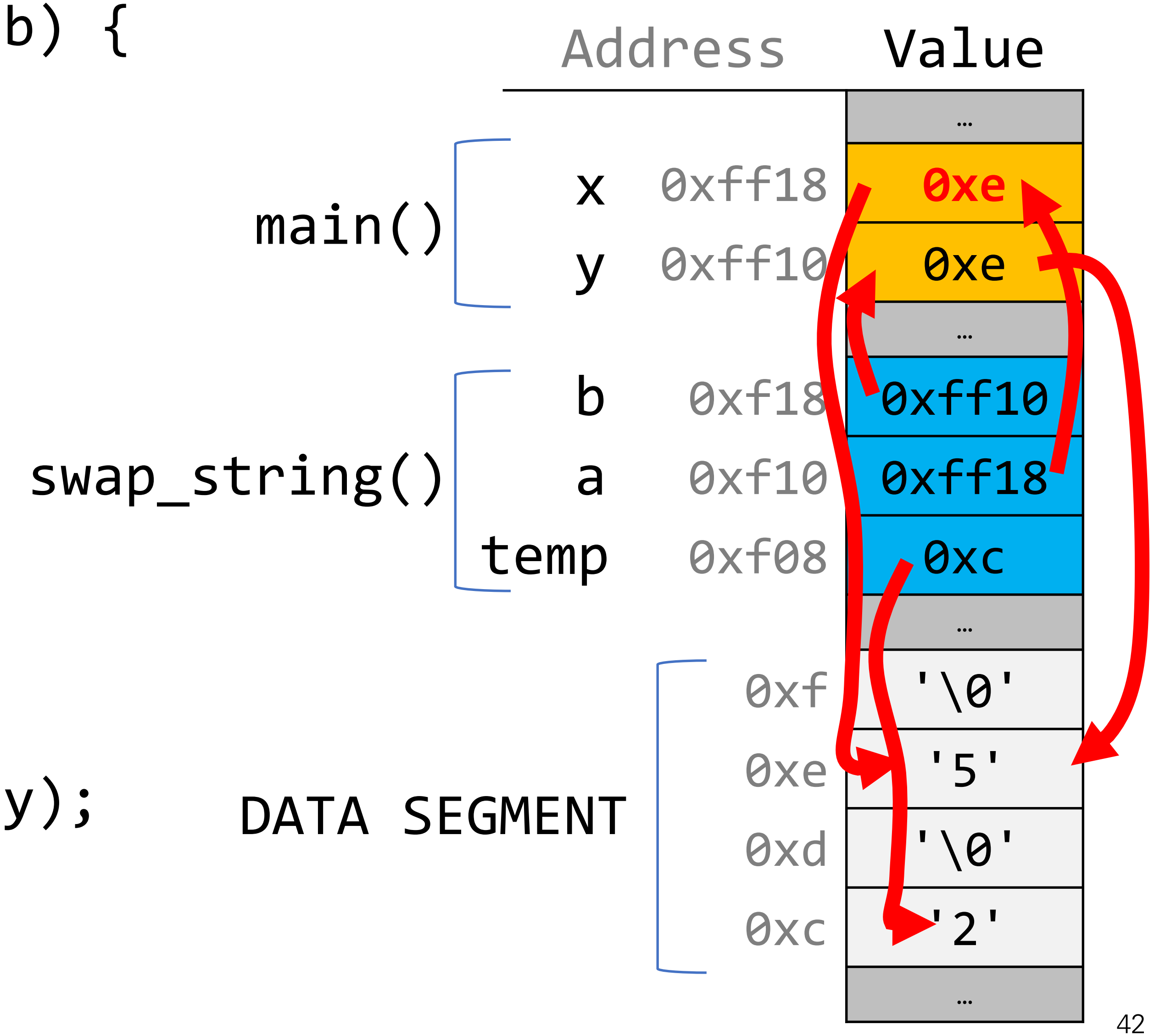
```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

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);
    return 0;
}
```



| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff18 | 0xc |
| | y | 0xff10 | 0xe |
| | | | … |
| swap_string() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff18 |
| | temp | 0xf08 | 0xc |
| | | | … |
| DATA SEGMENT | | 0xf | '\0' |
| | | 0xe | '5' |
| | | 0xd | '\0' |
| | | 0xc | '2' |
| | | | … |

# Swap

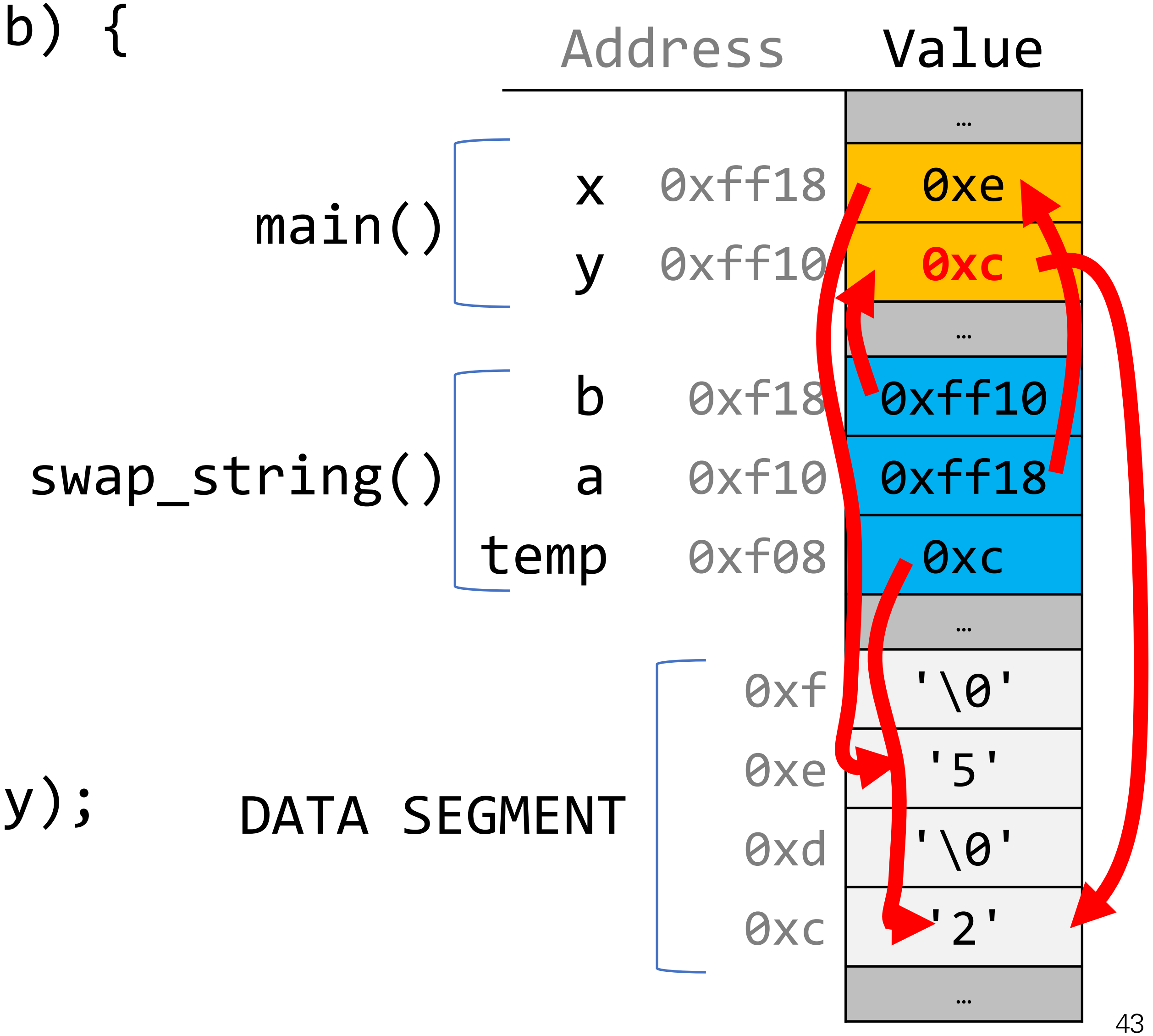
```c
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

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;
}
```



| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff18 | 0xe |
| | y | 0xff10 | 0xe |
| | | | … |
| swap_string() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff18 |
| | temp | 0xf08 | 0xc |
| | | | … |
| DATA SEGMENT | | 0xf | '\0' |
| | | 0xe | '5' |
| | | 0xd | '\0' |
| | | 0xc | '2' |
| | | | … |

# Swap

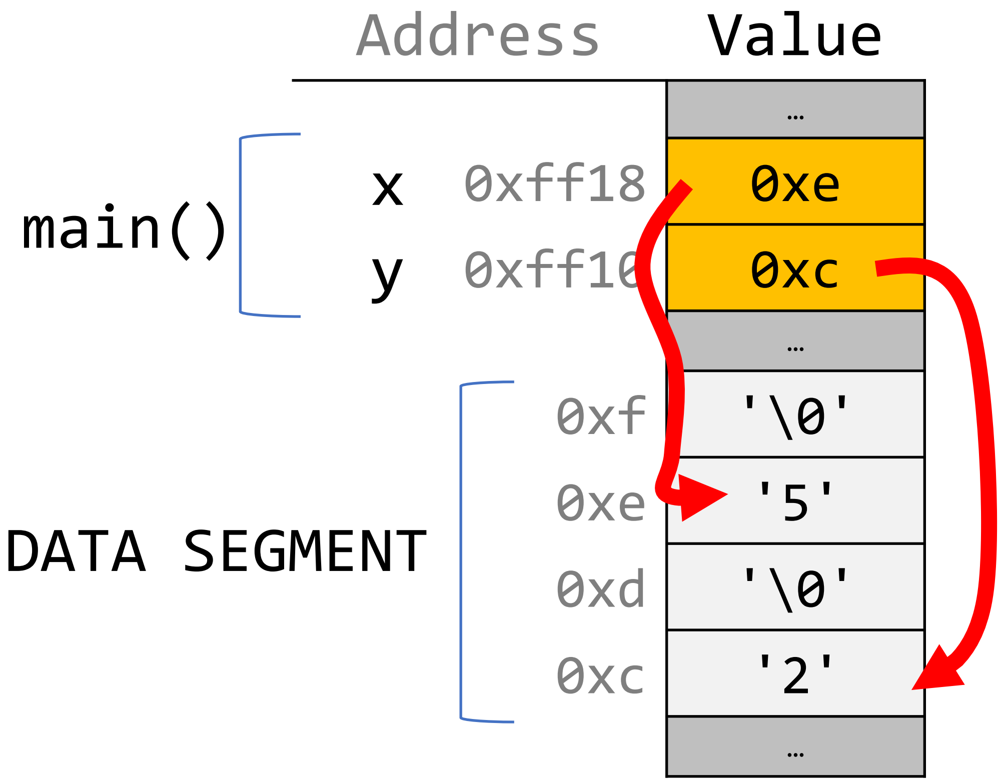
```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

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);
    return 0;
}
```



| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff18 | 0xe |
| | y | 0xff10 | 0xc |
| | | | … |
| swap_string() | b | 0xf18 | 0xff10 |
| | a | 0xf10 | 0xff18 |
| | temp | 0xf08 | 0xc |
| | | | … |
| DATA SEGMENT | | 0xf | '\0' |
| | | 0xe | '5' |
| | | 0xd | '\0' |
| | | 0xc | '2' |
| | | | … |

# Swap

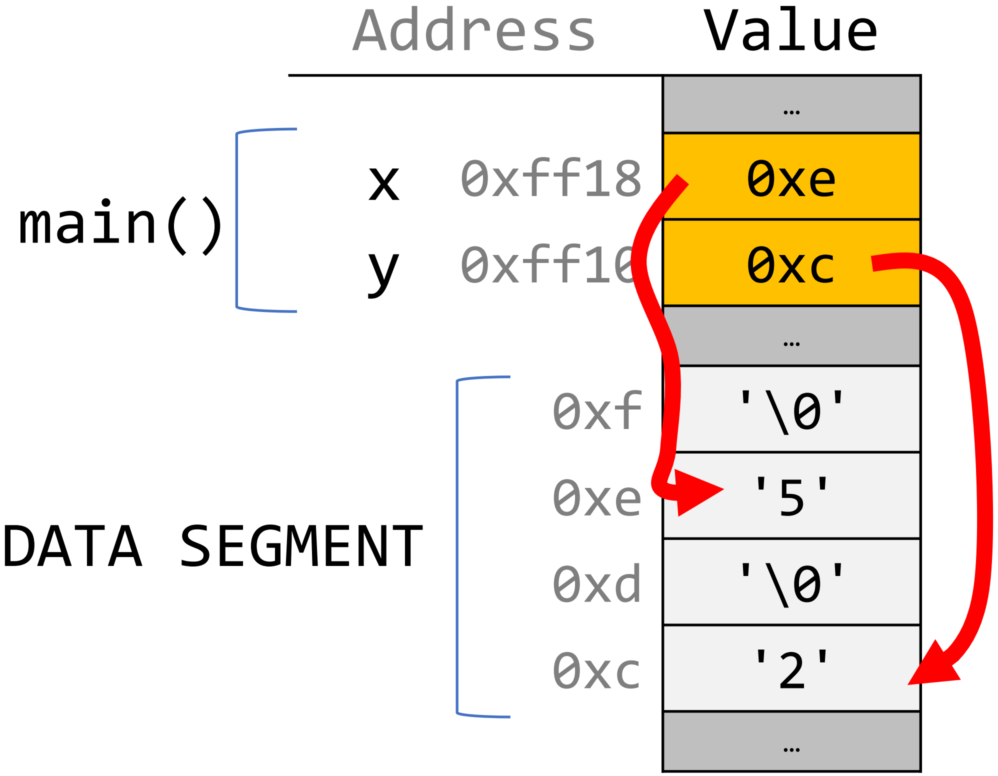
```
void swap_string(char **a, char **b) {
    char *temp = *a;
    *a = *b;
    *b = temp;
}

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);
    return 0;
}
```



| | | Address | Value |
|---|---|---|---|
| | | | … |
| main() | x | 0xff18 | 0xe |
| | y | 0xff10 | 0xc |
| | | | … |
| DATA SEGMENT | | 0xf | '\0' |
| | | 0xe | '5' |
| | | 0xd | '\0' |
| | | 0xc | '2' |
| | | | … |

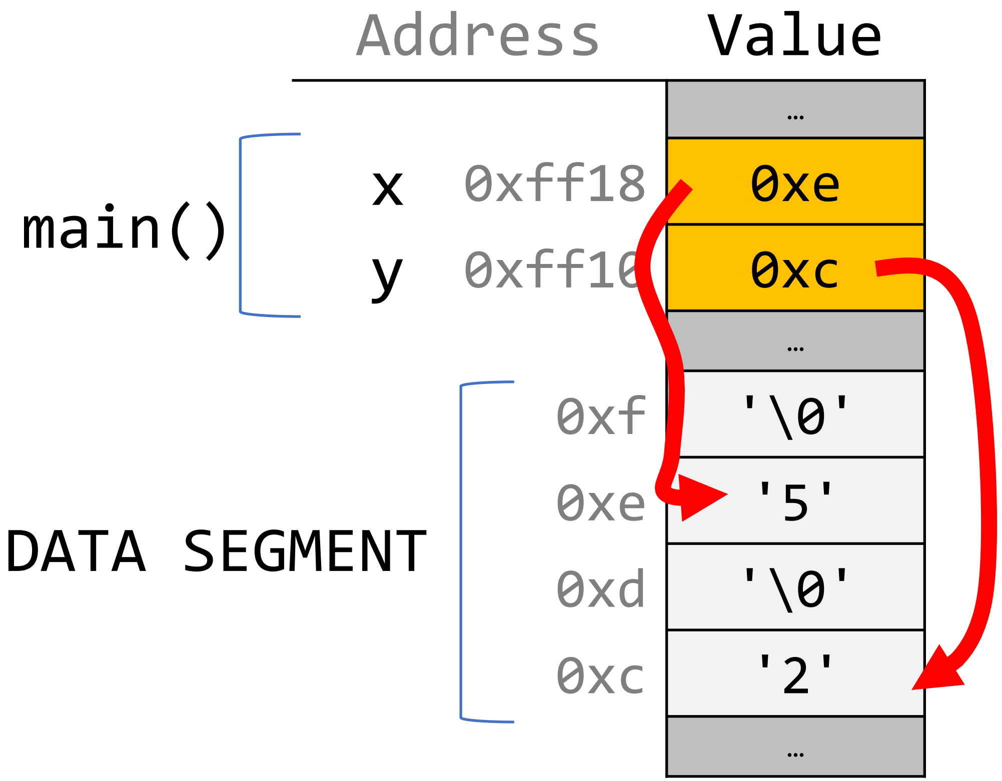
# Swap

```
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);
    return 0;
}
```



# 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);
    return 0;
}
```



“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;
    *a = *b;
    *b = temp;
}
```

# 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;
    *a = *b;
    *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
}
```

# 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
}
```

| | |
|---|---|
| `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

```
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
}
```

```
*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

```
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(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
}
```

# 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
}
```

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
    // 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.

# 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
    // 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) {
    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) {
    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

**`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`

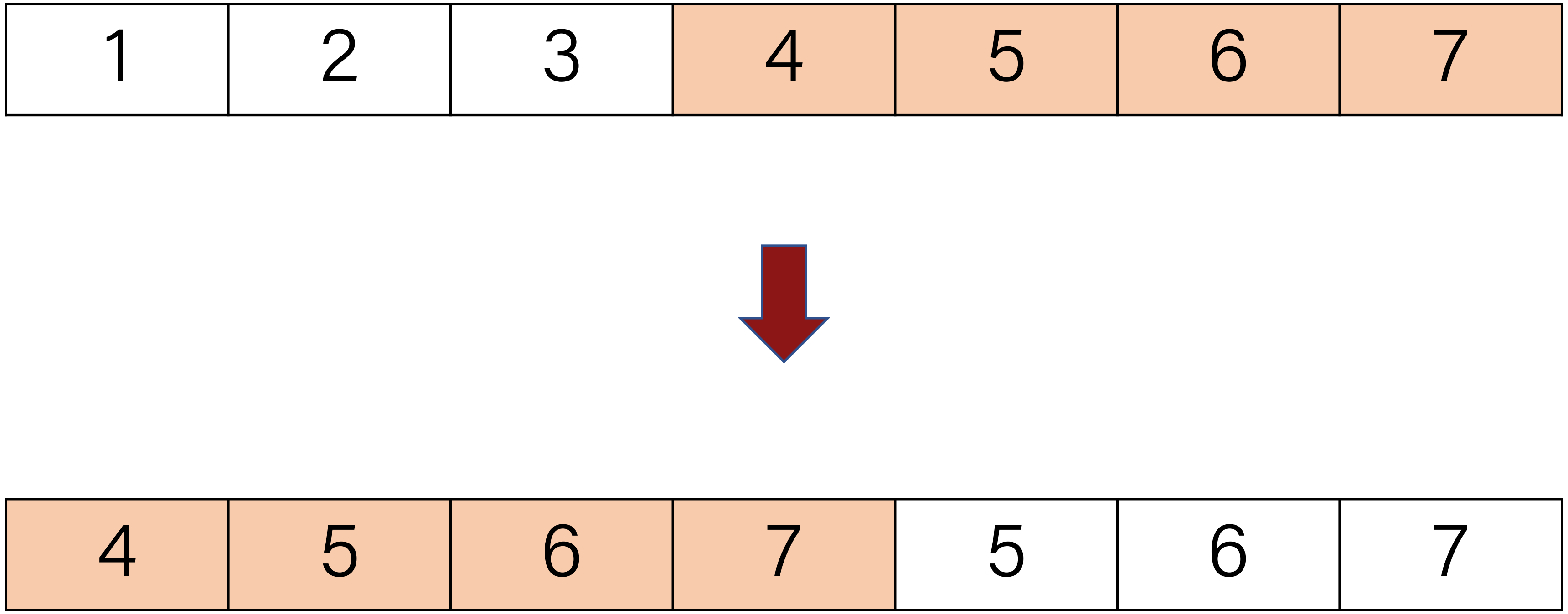
**`memmove`** is the same as `memcpy`, but supports overlapping regions of memory. (Unlike its name implies, it still "copies").

```
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?



| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | 5 | 6 | 7 | 5 | 6 | 7 |

# 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

```
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

```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);
}
```

```c
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

# 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 <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

# 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.

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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!

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    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

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```
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`

# 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));

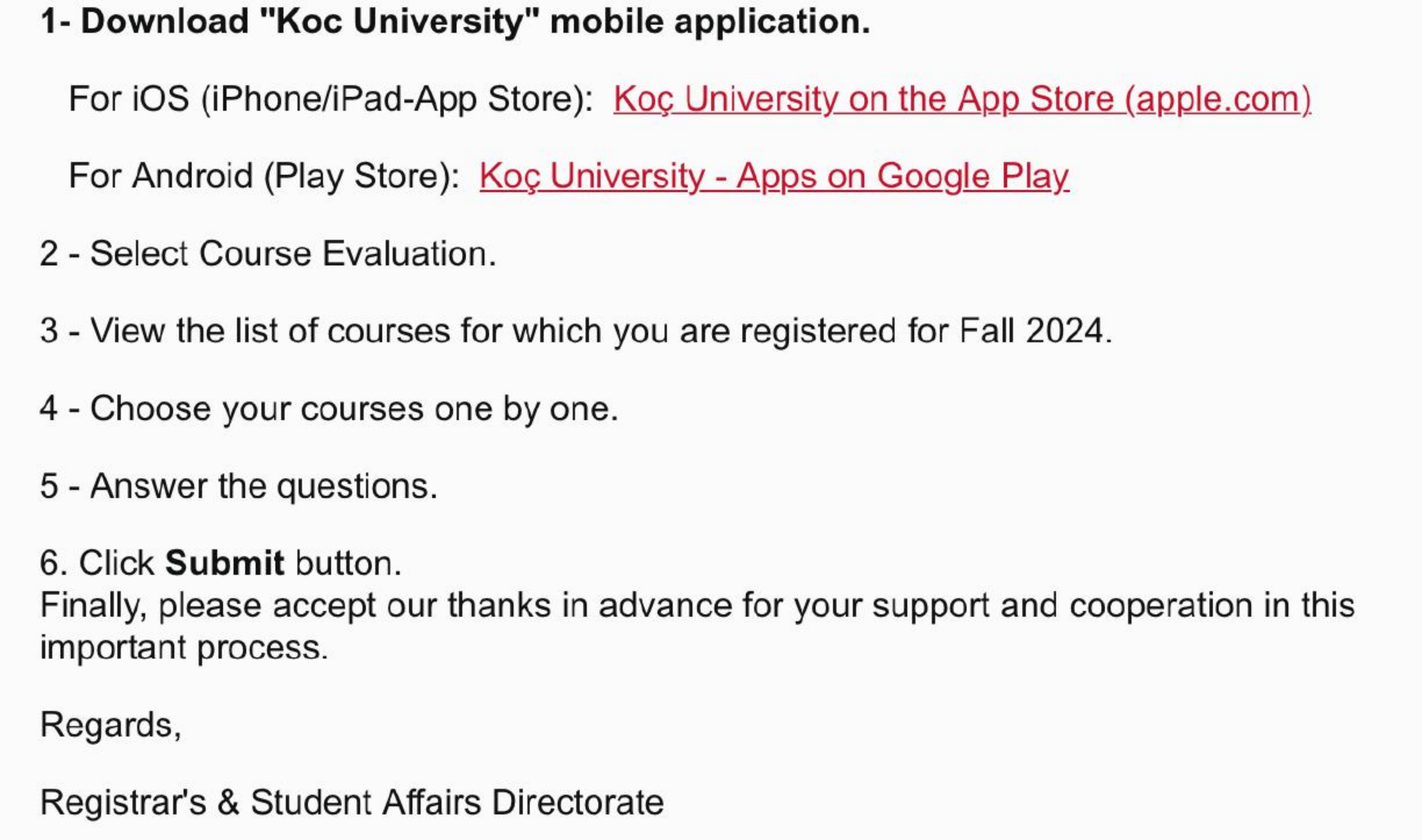
// now x = 0xffffeeee, y = 0xeeeeffff!
printf("x = 0x%x, y = 0x%x\n", x, y);
```

# 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.

# Start Term Course Evaluation

- November 6 through November 17 (until midnight) 2024



**1- Download "Koc University" mobile application.**

For iOS (iPhone/iPad-App Store): Koç University on the App Store (apple.com)

For Android (Play Store): Koç University - Apps on Google Play

2 - Select Course Evaluation.

3 - View the list of courses for which you are registered for Fall 2024.

4 - Choose your courses one by one.

5 - Answer the questions.

6. Click **Submit** button.
Finally, please accept our thanks in advance for your support and cooperation in this important process.

Regards,

Registrar's & Student Affairs Directorate

# Recap

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

**Next time:** *Function Pointers*