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COMP201

Computer Systems & Programming

Lecture #10 – C Generics – `void *`

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2025

Recap: Heap allocation interface:

```c
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

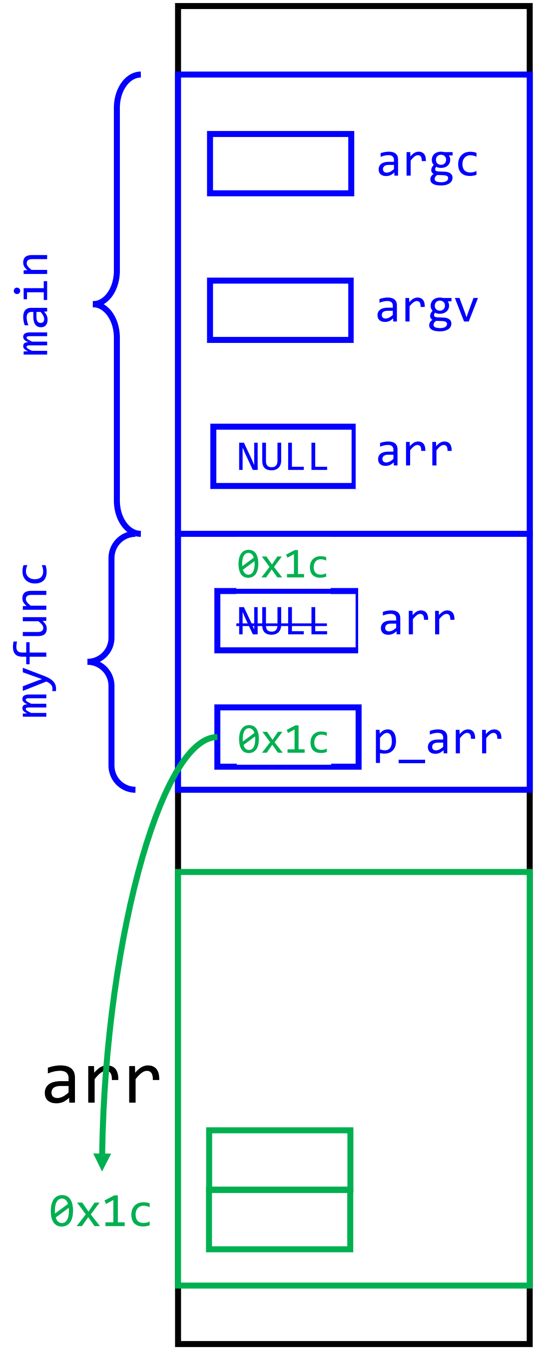
```c
void myfunc(int *arr) {
  int *p_arr = (int*) malloc(2*sizeof(int));
  p_arr[0] = 42;
  p_arr[1] = 24;
  arr = p_arr;
}

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

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  int *p_arr = (int*) malloc(2*sizeof(int));
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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

```
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

```
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

```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);

  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

```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);

  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

```
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

```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;
}
```

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(param1);`
   no way to free memory originally pointed by `ptr`

The Guardian

Microsoft IT outage

CrowdStrike global outage to cost US Fortune 500 companies $5.4bn

Banking and healthcare firms, major airlines expected to suffer most losses, according to insurer Parametrix

Nick Robins-Early

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@Perpetualmaniac

Crowdstrike Analysis:

It was a NULL pointer from the memory unsafe C++ language.

Since I am a professional C++ programmer, let me decode this stack trace dump for you.

```
EXCEPTION_RECORD:  fffffb0d18d3ec28 -- (.exr 0xfffffb0d18d3ec28)
ExceptionAddress: fffff8021df335a1 (csagent+0x00000000000e35a1)
   ExceptionCode: c0000005 (Access violation)
  ExceptionFlags: 00000000
NumberParameters: 2
   Parameter[0]: 0000000000000000
   Parameter[1]: 000000000000009c
Attempt to read from address 000000000000009c

CONTEXT:  fffffb0d18d3e460 -- (.cxr 0xfffffb0d18d3e460)
rax=fffffb0d18d3f2b0 rbx=0000000000000000 rcx=0000000000000003
rdx=fffffb0d18d3f280 rsi=ffff9a81b596f9a4 rdi=ffff9a81b596605c
rip=fffff8021df335a1 rsp=fffffb0d18d3ee60 rbp=fffffb0d18d3ef60
 r8=000000000000009c  r9=0000000000000000 r10=0000000000000000
r11=0000000000000014 r12=fffffb0d18d3ef28 r13=fffffb0d18d3f0d0
r14=000000000000001a r15=0000000000000004
iopl=0         nv up ei pl nz na po nc
cs=0010  ss=0018  ds=002b  es=002b  fs=0053  gs=002b             efl=00050206
csagent+0xe35a1:
fffff802`1df335a1 458b08          mov     r9d,dword ptr [r8] ds:002b:00000000`0000009c=????????
Resetting default scope

BLACKBOXBSD: 1 (!blackboxbsd)


BLACKBOXNTFS: 1 (!blackboxntfs)


BLACKBOXPNP: 1 (!blackboxpnp)


BLACKBOXWINLOGON: 1

PROCESS_NAME:  System

READ_ADDRESS:  000000000000009c

ERROR_CODE: (NTSTATUS) 0xc0000005 - The instruction at 0x%p referenced memory at 0x%p. The memory could not

EXCEPTION_CODE_STR:  c0000005

EXCEPTION_PARAMETER1:  0000000000000000

EXCEPTION_PARAMETER2:  000000000000009c

EXCEPTION_STR:  0xc0000005

STACK_TEXT:
fffffb0d`18d3ee60 fffff802`1df09152     : 00000000`00000000 00000000`e01f008d fffffb0d`18d3f202 fffff802`1e
fffffb0d`18d3f000 fffff802`1df0a3e9     : 00000000`00000000 00000000`00000010 00000000`00000000 ffff9a81`b5
fffffb0d`18d3f130 fffff802`1e14954f     : 00000000`00000000 00000000`00000000 00000000`00000000 00000000`00
fffffb0d`18d3f260 fffff802`1e145d9b     : ffff9a81`93735280 fffffb0d`18d3f5d0 00000000`00000000 00000000`00
fffffb0d`18d3f4d0 fffff802`1deb8fd0     : 00000000`000030f1 fffffb0d`18d3f790 ffff9a81`992cbb30 ffffe409`b7
```

10:08 PM · Jul 19, 2024 · **34.7M** Views

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.

```
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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    printf("x = %d, y = %d\n", x, y);
    return 0;
}
```

Stack

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

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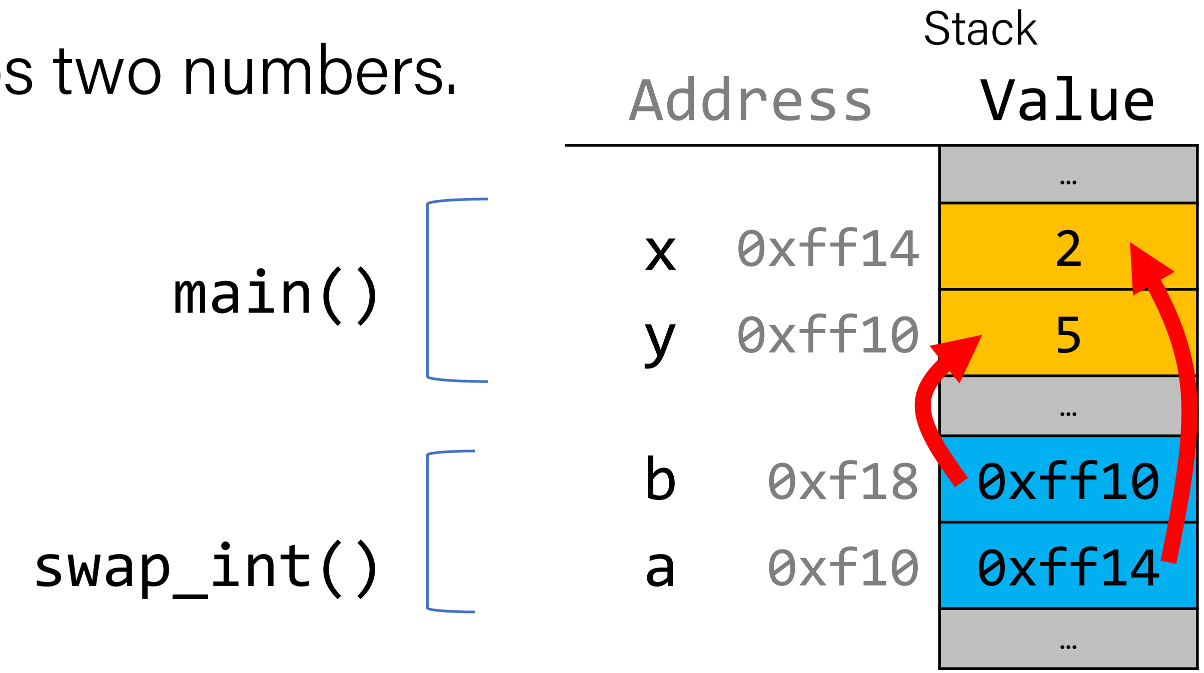

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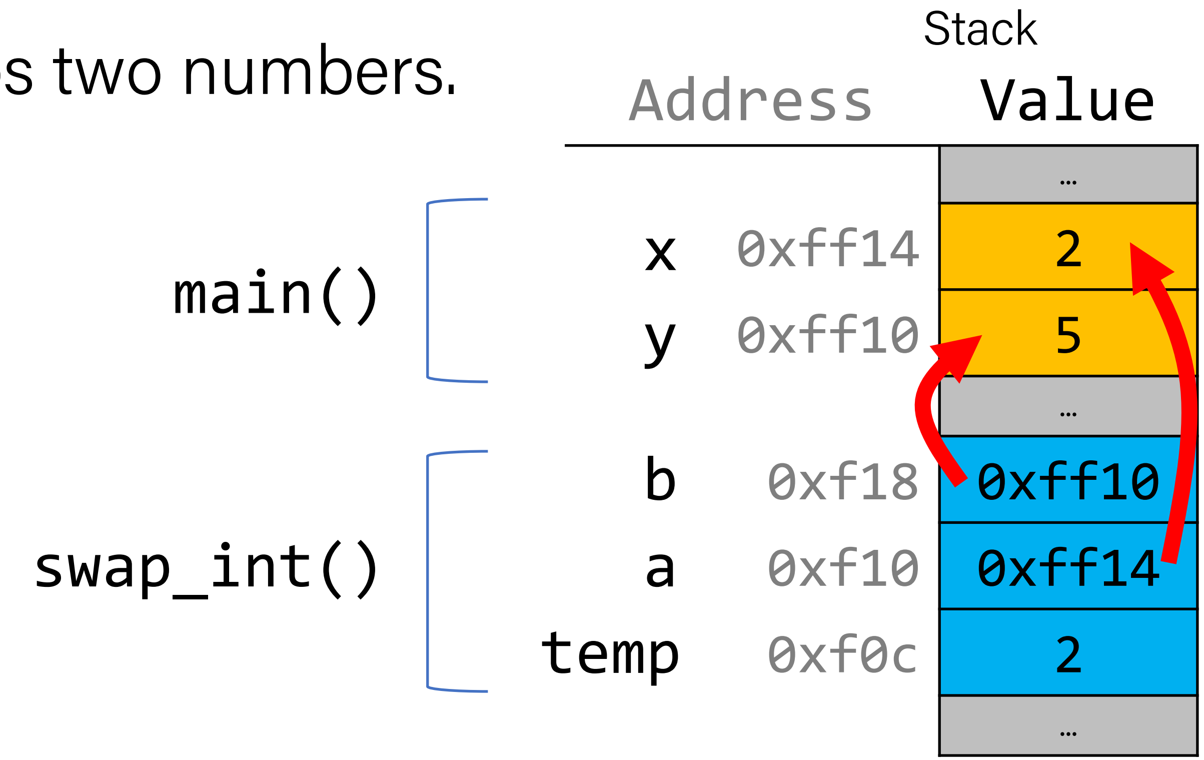

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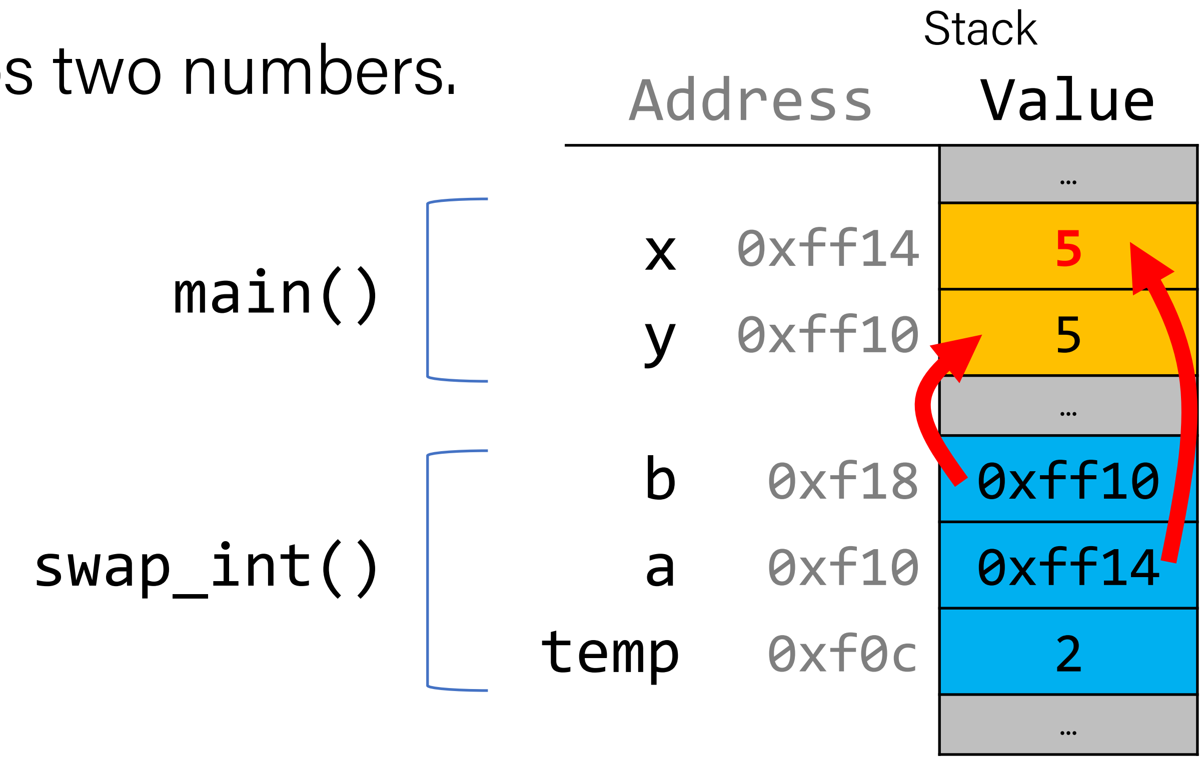

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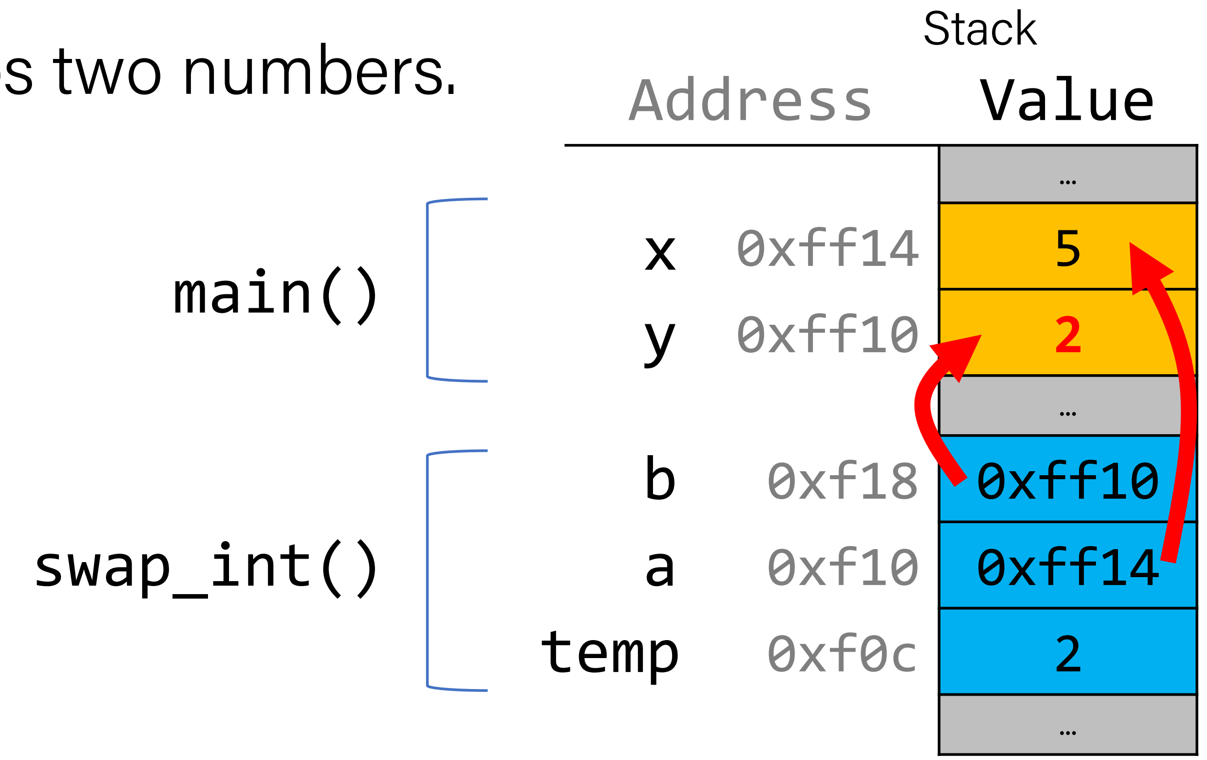

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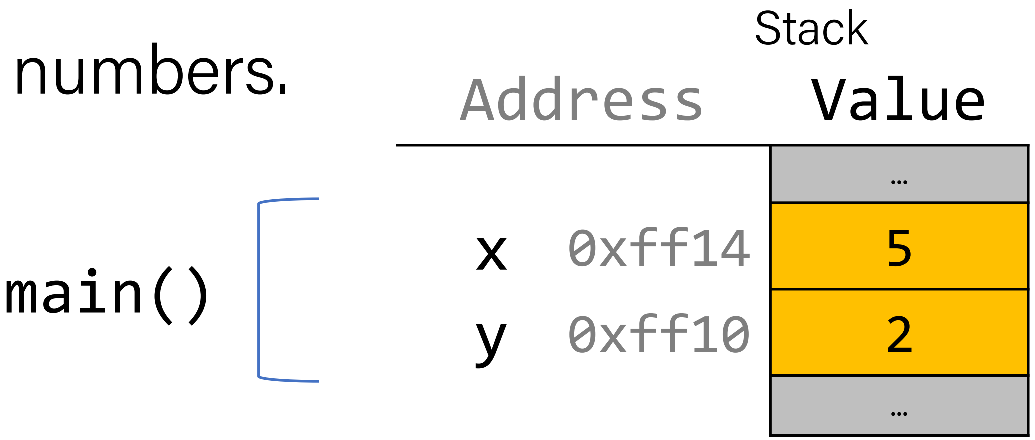

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    return 0;
}
```

Stack

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

Swap

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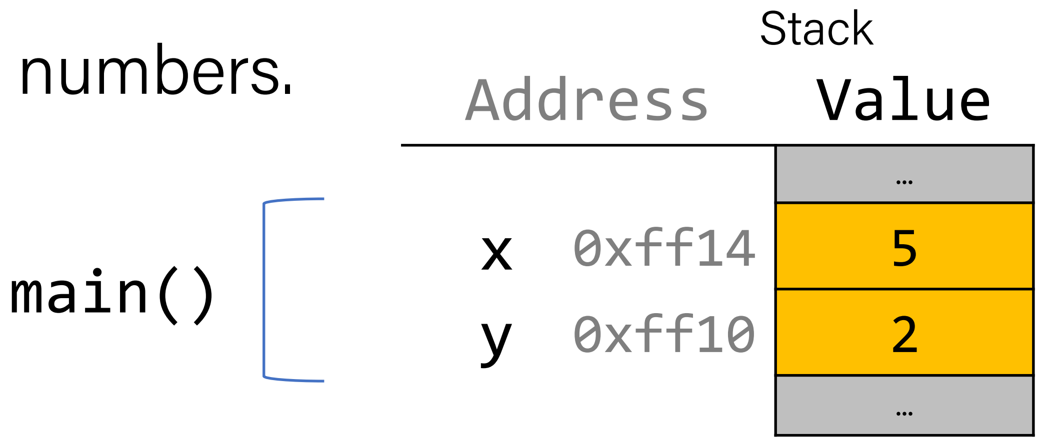


"Oh, when I said 'numbers' I meant `shorts`, not `ints`."

😑

Swap

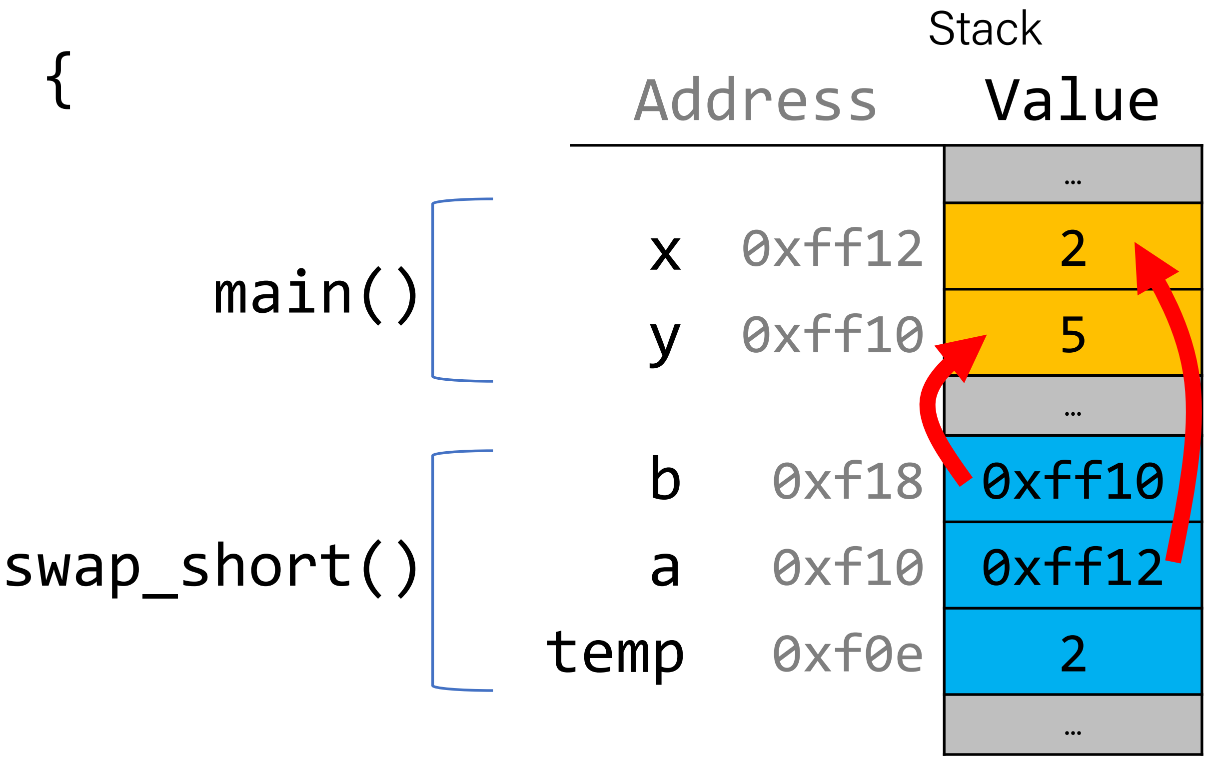
```
void swap_short(short *a, short *b) {
    short temp = *a;
    *a = *b;
    *b = temp;
}

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

```
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?”

😤

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);
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    printf("x = %s, y = %s\n", x, y);
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```

Swap

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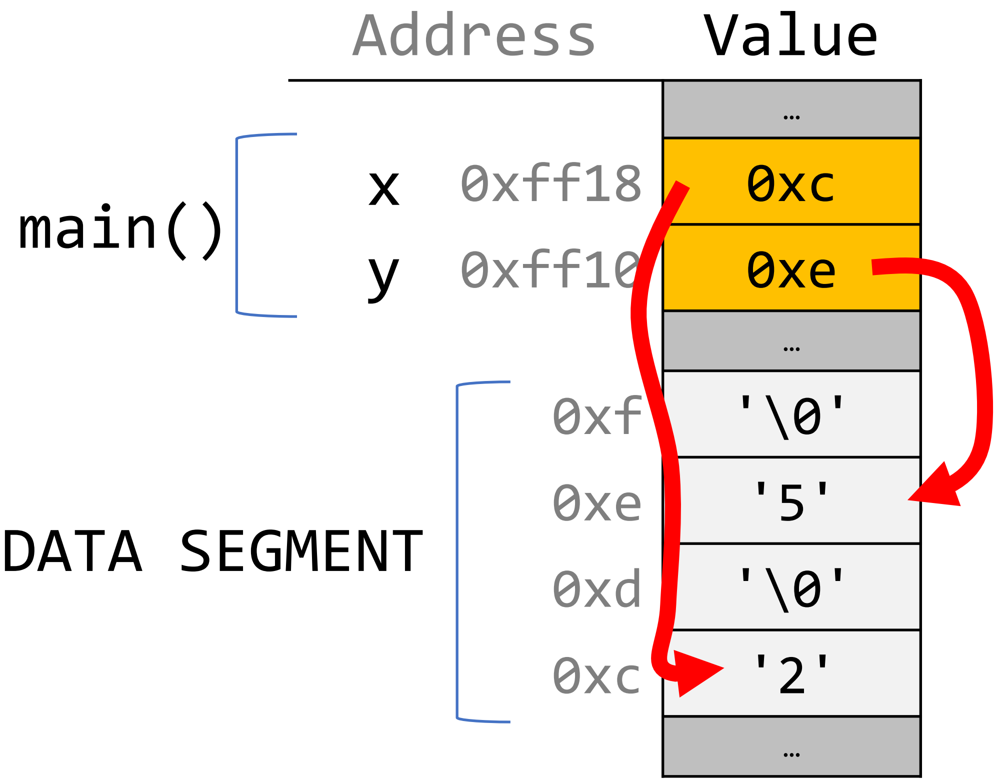

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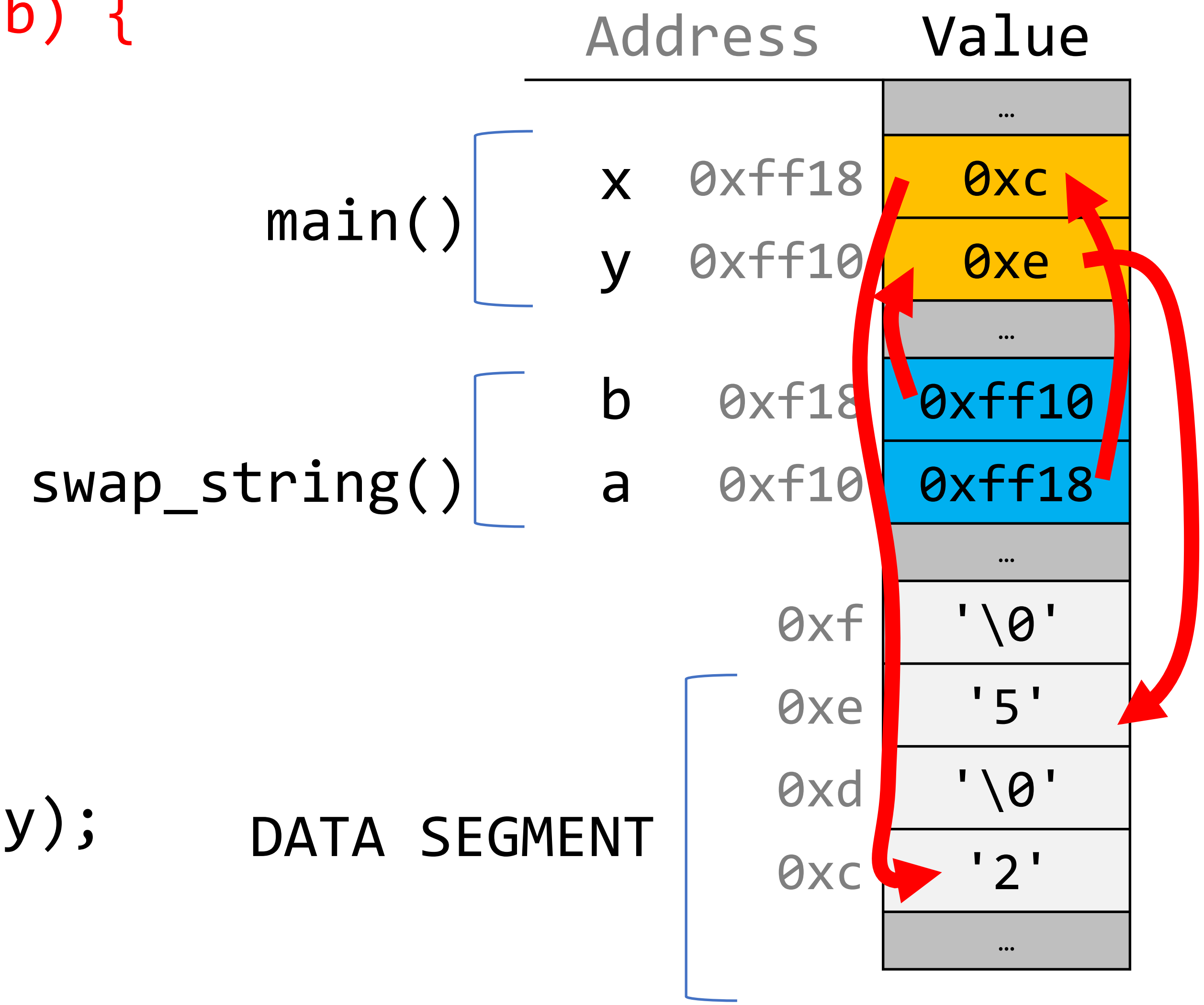

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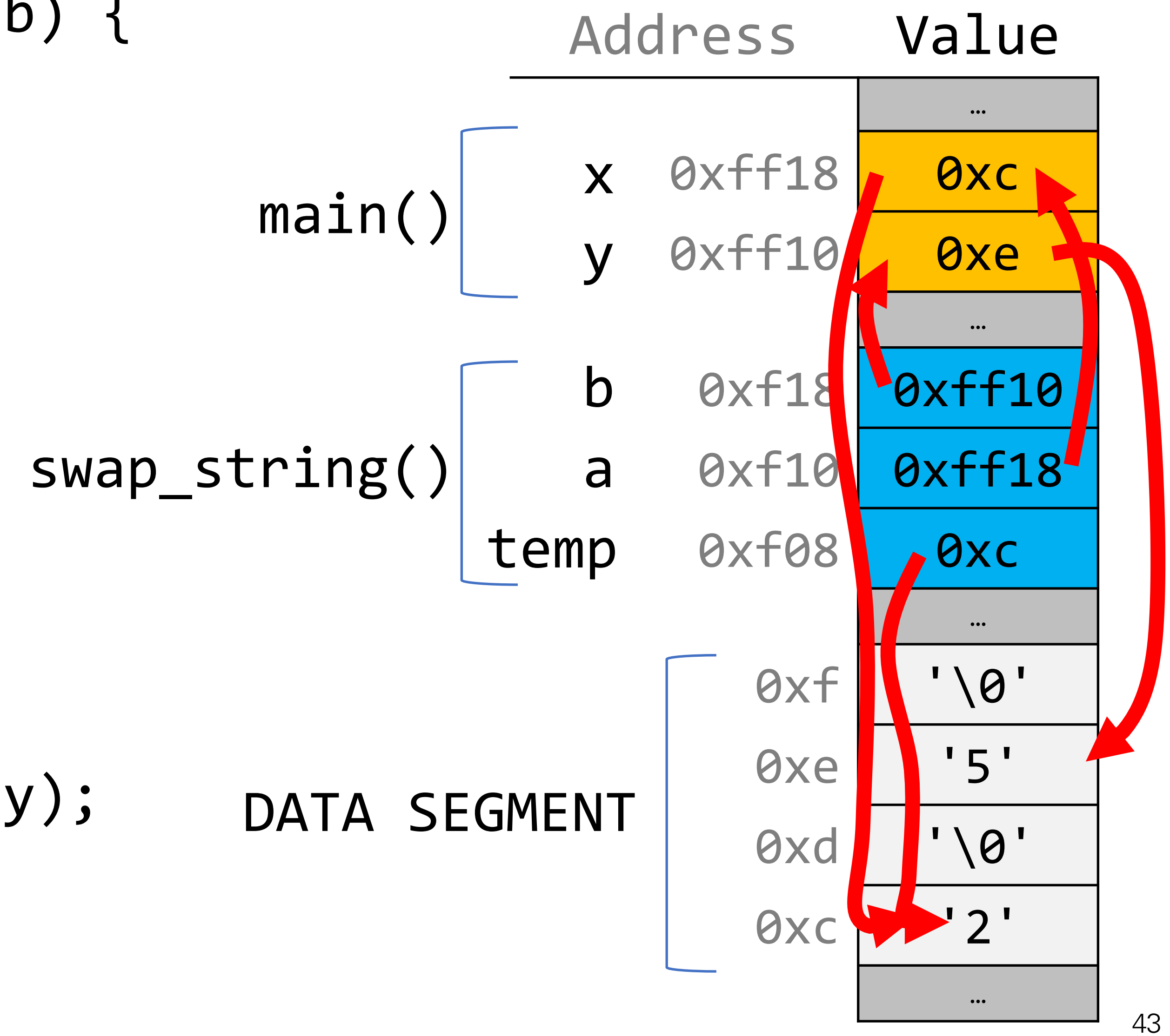

Swap

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}
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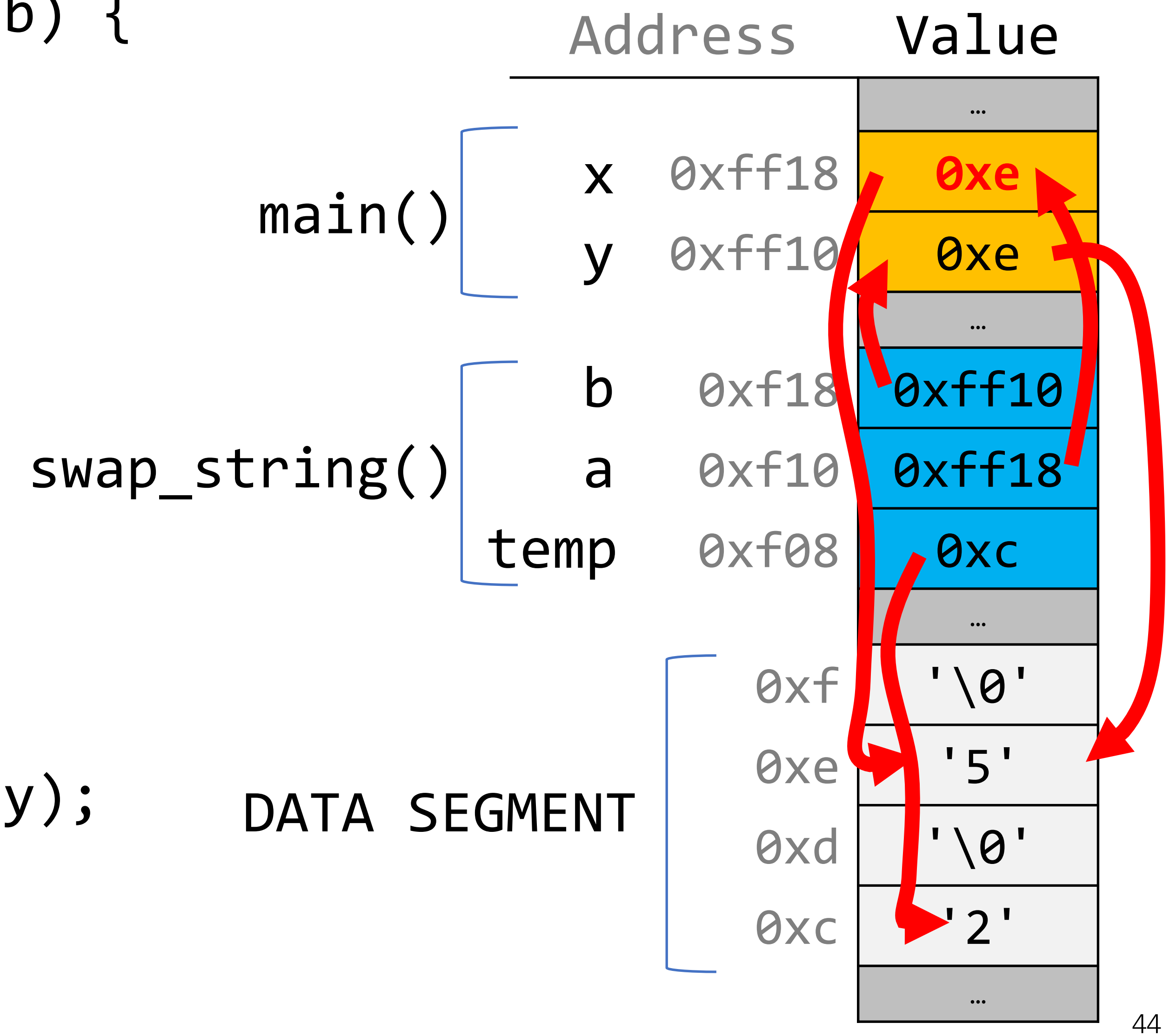

Swap

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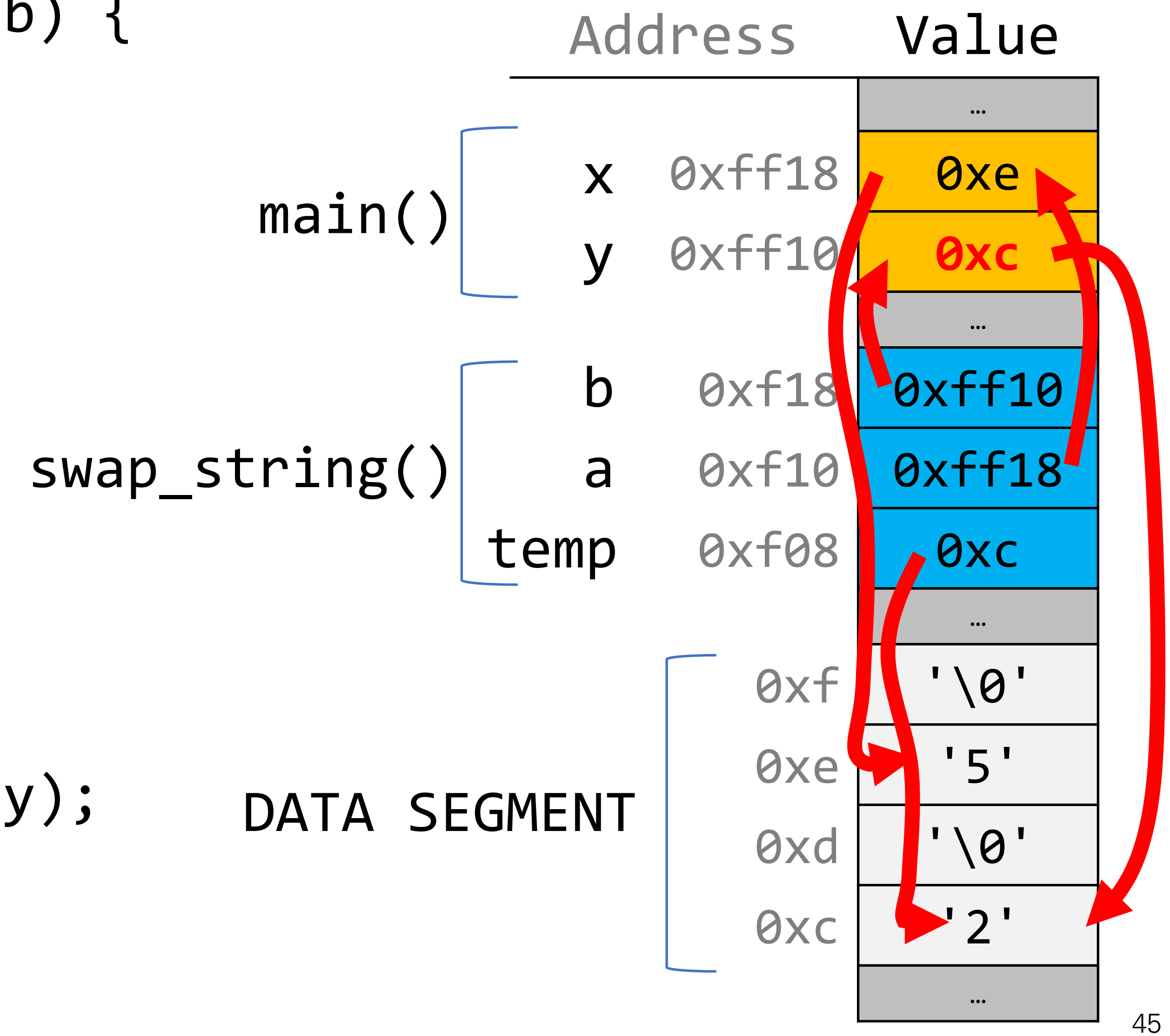

Swap

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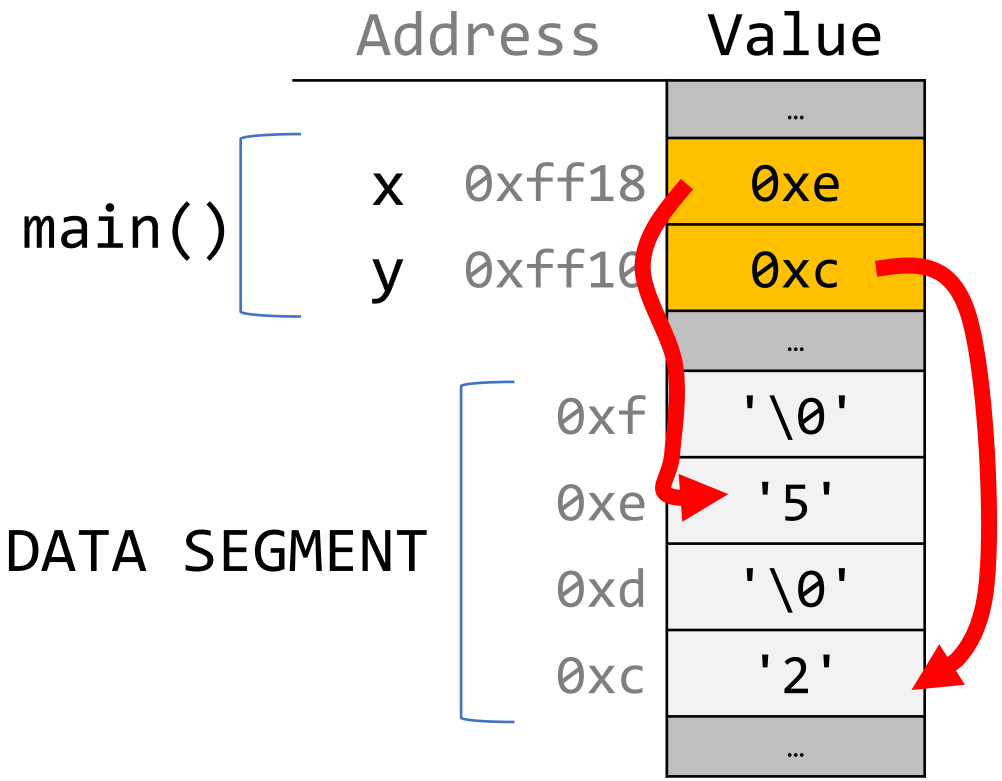
    *a = *b;
    *b = temp;
}

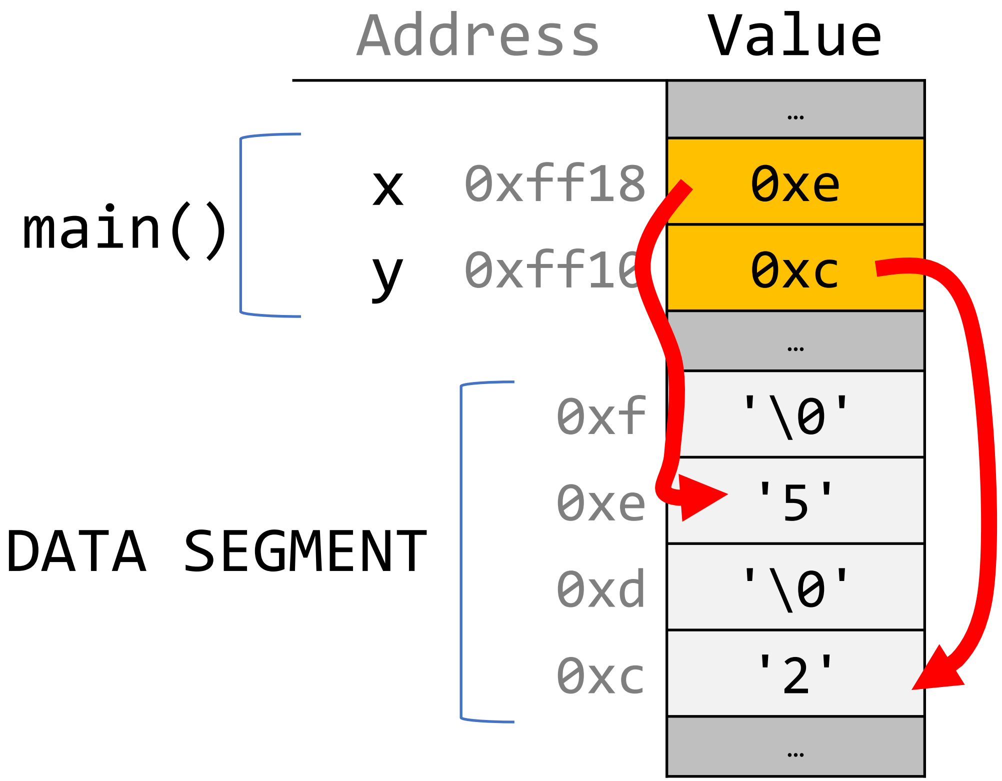
int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
```



Swap

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

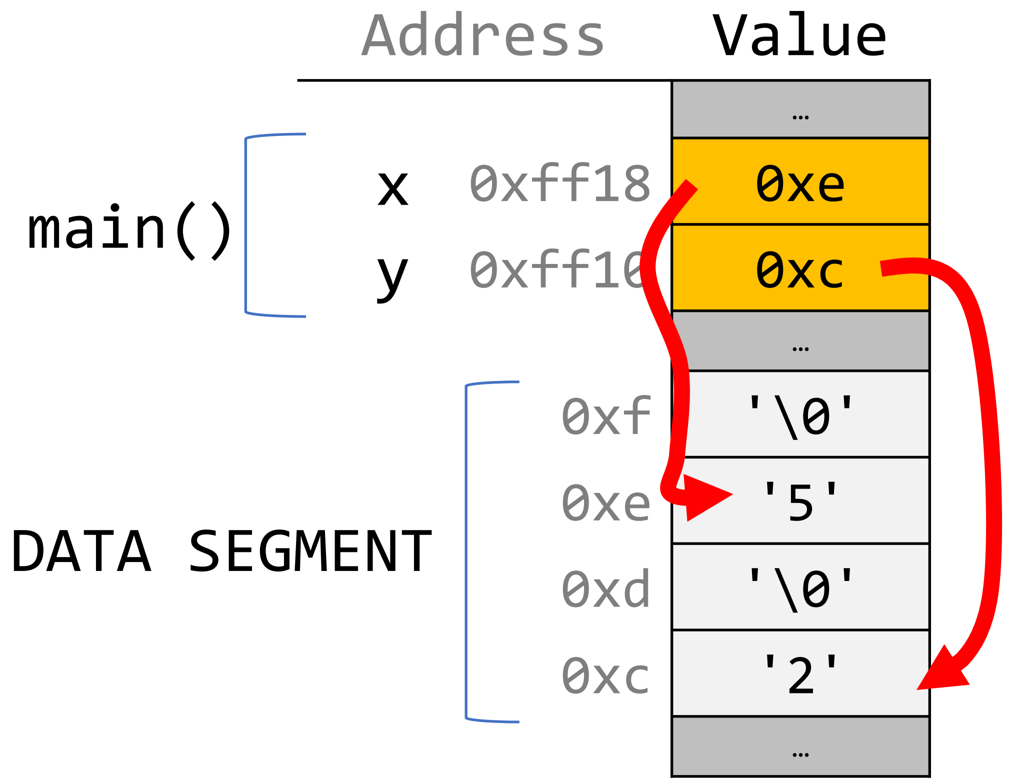
int main(int argc, char *argv[]) {
    char *x = "2";
    char *y = "5";
    swap_string(&x, &y);
    // want x = 5, y = 2
    printf("x = %s, y = %s\n", x, y);
    return 0;
}
```



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

```
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

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 <u>places</u> 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 <u>places</u> 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.

```
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 <u>anything</u>!

```
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 <u>anything</u>!

```
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.

Recap

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

Next time: *Function Pointers*