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Arrays and Pointers (Part 2)

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Assignment advice

- Use `gcc` for the linking step, not `ld`
- Pay close attention to the function parameters and descriptions in the table!
- Ask questions – the TAs and I are happy to help!
  - Office hours
  - Email

What are pointers?

- Address of some bytes in virtual memory
  - Can point to any segment: stack, heap, data, code (!)
  - Need to understand these segments to avoid pointer bugs
    - Stack memory goes away when the function returns
    - Heap memory goes away when you free() it
    - Code and data (static/global) stick around
- Has an associated type at compile time

Declaring pointers

```
int *head, *tail;
```

- Here the type of head or tail is "pointer to `int`"
- Note the * is repeated for multiple declarations
  - Sometimes you see
    `int* head;`
  - This looks like it declares two pointers, but it doesn't:
    `int* head, tail;`
  - Actually declares *one pointer and one integer*!
  - Recommended style: put the * next to the variable name

Getting an address

- The & operator gives us the virtual address of many things
  - Variables
  - Arrays
  - Array elements
  - Functions (!)
- If `var` is of type `foo`, then `&var` is of type `foo *` ("pointer to foo")

```c
#include <stdio.h>

int foo(int x) {
  return x + 1;
}

int main(int argc, char *argv[]) {
  int x, y;
  int a[2];

  printf("x    is at %p\n", &x);
  printf("y    is at %p\n", &y);
  printf("a    is at %p\n", &a);
  printf("a[0] is at %p\n", &a[0]);
  printf("a[1] is at %p\n", &a[1]);
  printf("foo  is at %p\n", &foo);
  printf("main is at %p\n", &main);
  return 0;
}
```

Setting pointers

- We can then store this address in a matching pointer!

```
int *p = &x;
```

  - We now have a pointer to x that we can use, pass to functions, etc.

```
int *q = p;
```

  - Now both p and q point to x
  - Can point to a different address later:

```
p = &y;
```

  - Now p points to y, and q still points to x

Dereferencing pointers

- To access the *value that is pointed at*, use the * operator:

```
int *p = &x;
```

  - Read: `int y = *p;`
  - Write: `*p = 5;`
  - Called "dereferencing"... which just means follow the arrow

- The * and & operators are complementary

```
*(&x) == x
```

Pointer types

- At runtime, a pointer is just a number
  - But then so is everything else!
- At compile time, it has an associated type
  - Pointer to _____
  - So the compiler can do type checking on & and *

```
int *p = &x;
```

  - What is the type of *p?

Pointer arithmetic

- Caution: addition and subtraction work slightly differently on pointers
  - One of C's more unusual features

```
int *p = &x;
p = p + 1;
```

  - This is legal and useful
  - Moves p forward, not by one byte, but by `sizeof(int)`!
- Why might this be?

Arrays are pointers!

- Suppose we have

```
int a[10];
int *p = &a[0];
```

  - What is `p + 1`?
  - What is `*(p + 5)`?

Arrays are pointers!

- Suppose we have

```
int a[10];
int *p = &a[0];
```

  - What is `p + 1`?
  - What is `*(p + 5)`?
- This is what the `[]` operator does!
  - Syntactic sugar

Returning pointers

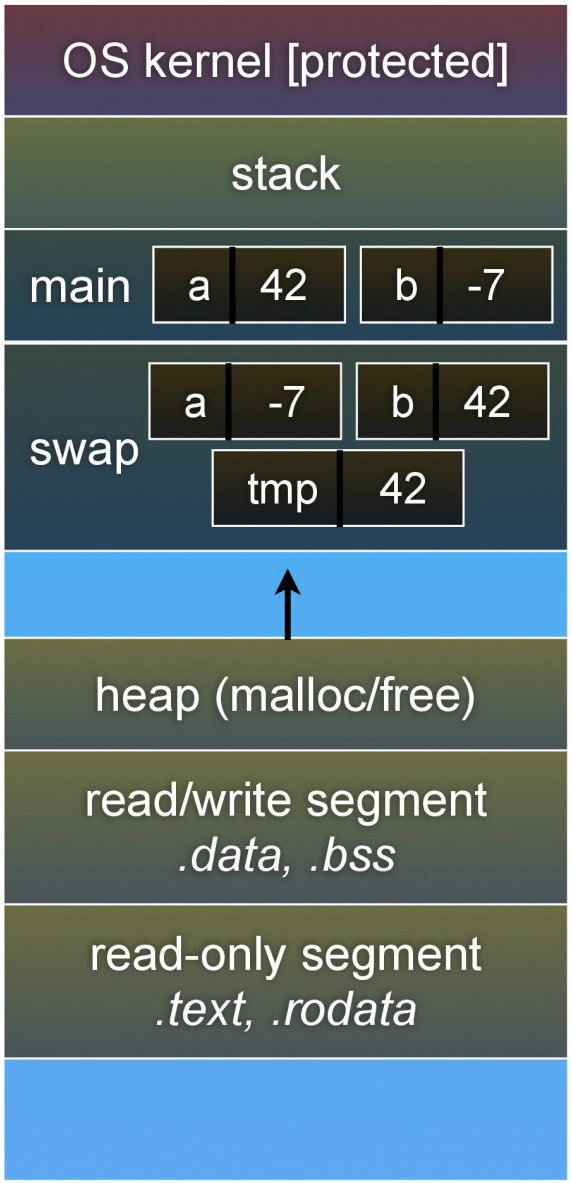
- Functions can *return a pointer* just like any other type
  - Usually returning NULL means failure
  - Not checking this can lead to dereferencing a NULL pointer
    - Segfault!
  - Example: malloc()

```c
#include <stdio.h>

int *find(int arr[], int len, int x) {
  int i;

  for (i = 0; i < len; i++)
    if (arr[i] == x)
      return &arr[i];

  // Didn't find it
  return NULL;
}

int main(int argc, char *argv[]) {
  int arr[20];

  // ...

  int *p = find(arr, 20, -3);
  if (p == NULL) {
    // print an error
    return 1;
  }
  return 0;
}
```

Passing by reference

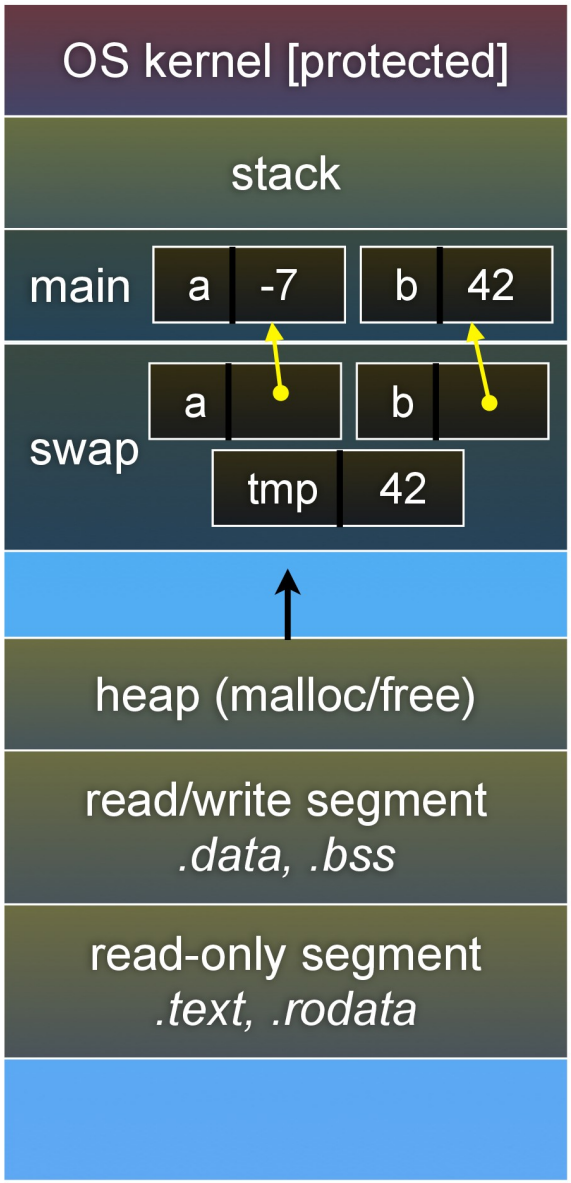
- C makes a copy of each function parameter on the stack
  - But if the parameter is an address, you get a copy of the address
  - Can still get at the original variable
- To jog your memory...

Recap: pass-by-value




```c
void swap(int a, int b) {
  int tmp = a;
  a = b;
  b = tmp;
}

int main(int argc, char *argv[]) {
  int a = 42, b = -7;

  swap(a, b);
  printf("a: %d, b: %d\n", a, b);
  return 0;
}
```

Recap: pass-by-reference




```c
void swap(int *a, int *b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}

int main(int argc, char *argv[]) {
  int a = 42, b = -7;

  swap(&a, &b);
  printf("a: %d, b: %d\n", a, b);
  return 0;
}
```

Output parameters

- Pointer parameters to a function can be used both for input and output
- Functions have only one "real" return value
  - And this is often already being used for an error code
  - To return something else, use a pointer
  - To return multiple values, use pointers
- This is normal, idiomatic C

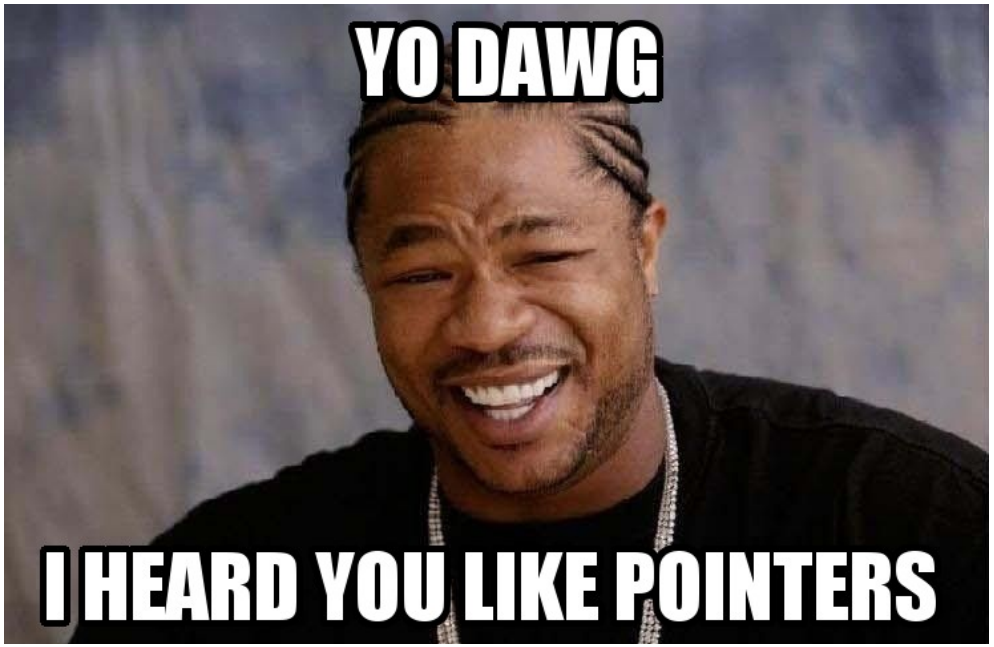
```c
#include <stdio.h>

void get_two_nums(int *a, int *b) {
  *a = 5;
  *b = 20;
}

int main(int argc, char *argv[]) {
  int x, y;

  // Two return values
  get_two_nums(&x, &y);

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

Pointers to pointers

- Pointers can point to any type... including other pointers!

```
int *p = &x;
int **q = &p;
```

- For example, what if...
  - you want to pass a *pointer* by reference?
  - you want an array of pointers?
  - you want to return multiple pointers?



Pointers to void

```
void *ray;
```

- Wait... what type does this point to??
  - No type, treated as raw bytes
  - Must *cast* to a different pointer type before it is useful:

```
int *p = (int *) ray;
```

  - Example: malloc() returns a pointer to void