Pointers and dynamic data structures

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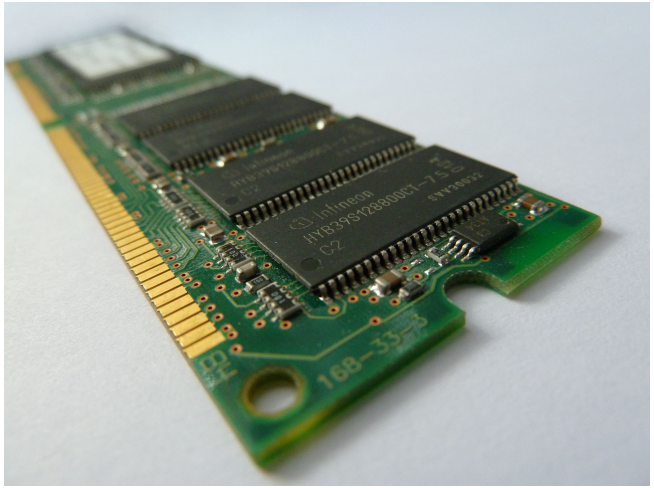
Pointers

Your computer needs memory to run programs

Variables must be loaded and stored from memory in order for things to happen



https://upload.wikimedia.org/wikipedia/commons/b/b6/Ram_chip.jpg

Every object resides somewhere in memory

- **Objects** include variables, functions, and other things we haven't defined yet
  - Anything that's a "thing" in your code
- How do we know where an object is in memory?

This is an address

1600 Amphitheatre Pkwy,
Mountain View, CA 94043,
United States

screenshot from Google Maps

Objects in code also have addresses

- **Address:** where an object resides in memory
- We can create a special kind of object that stores the address of another object
  - This is called a pointer

Visualization of addresses, variables, and values from EECS 280

We often say that a pointer "points to" an object, and that the * operator "follows" the pointer to the object it is pointing at. In keeping with this terminology, a pointer is often pictured as an arrow from the pointer to the object it is pointing at, as shown in Figure 13.

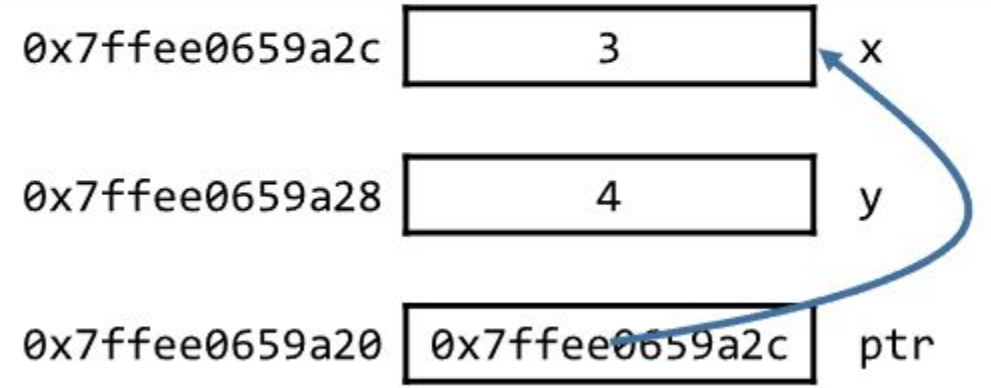


Figure 13 *An arrow indicates the object whose address a pointer holds.*

https://eecs280staff.github.io/notes/03_Pointers.html

Declaring a pointer

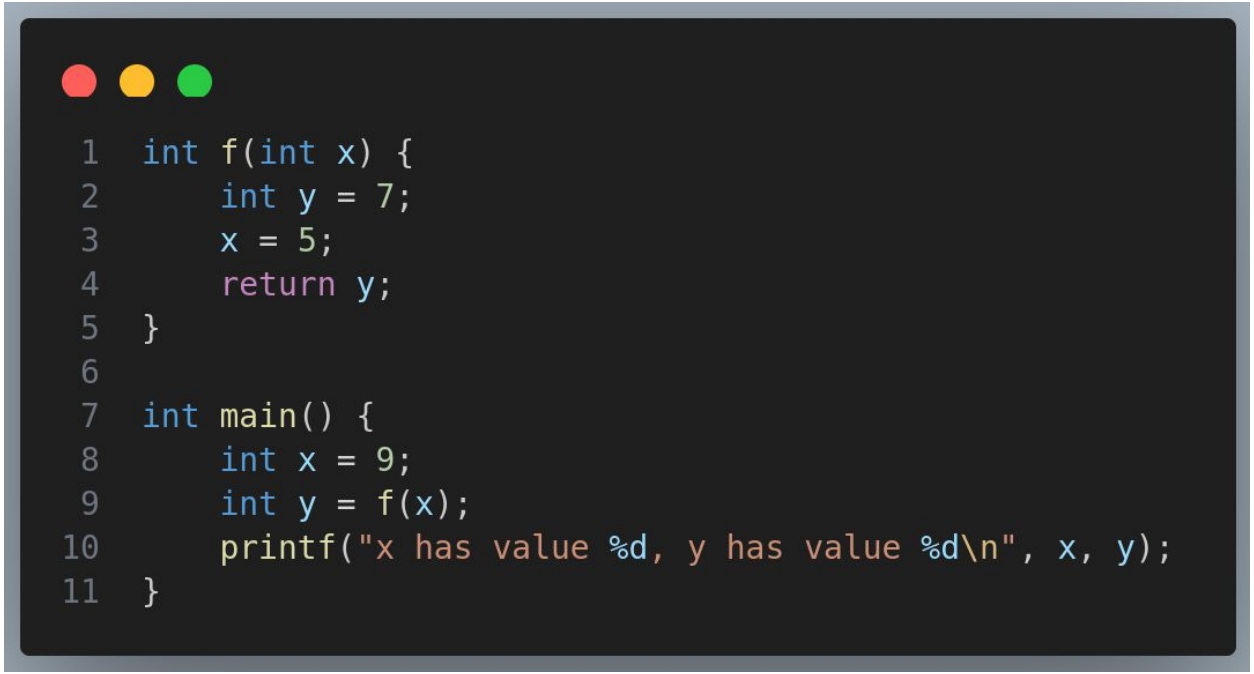
- <type> * <variable name> = & <other variable you want address of>
  - You can also point to arrays
  - For placeholder value, use NULL
- Examples:

```
1  int* ptr_to_integer = &some_int;
2  double* ptr_to_double = &some_double;
3  char* string = "hello";
4  int** ptr_to_integer_ptr = &ptr_to_integer;
```

Pass by value vs pass by pointer

Let's run the following program

What value do you think will be printed?



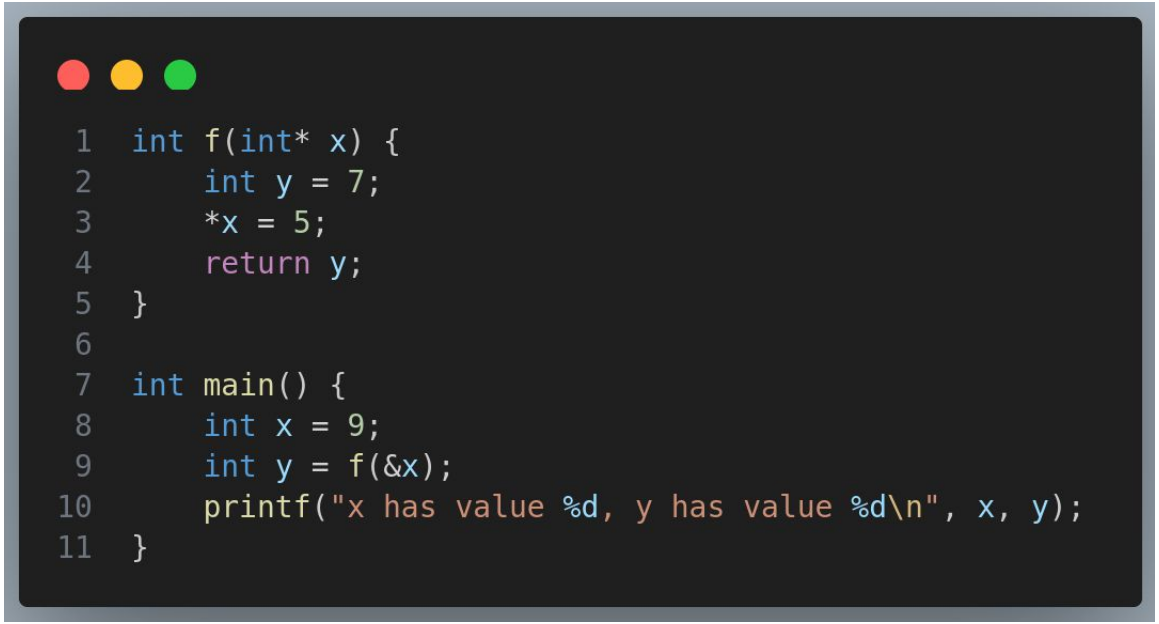
```c
int f(int x) {
    int y = 7;
    x = 5;
    return y;
}

int main() {
    int x = 9;
    int y = f(x);
    printf("x has value %d, y has value %d\n", x, y);
}
```

All parameters in C are technically pass by value

- Pass by value: the parameter will be a different object with the same value
- Pointers, however, allow for something informally called pass by pointer
  - Pass by pointer lets you change the original value

Let's try that again, but with some slight modifications

- What has changed?
- What do you think will print now?



```c
int f(int* x) {
    int y = 7;
    *x = 5;
    return y;
}

int main() {
    int x = 9;
    int y = f(&x);
    printf("x has value %d, y has value %d\n", x, y);
}
```

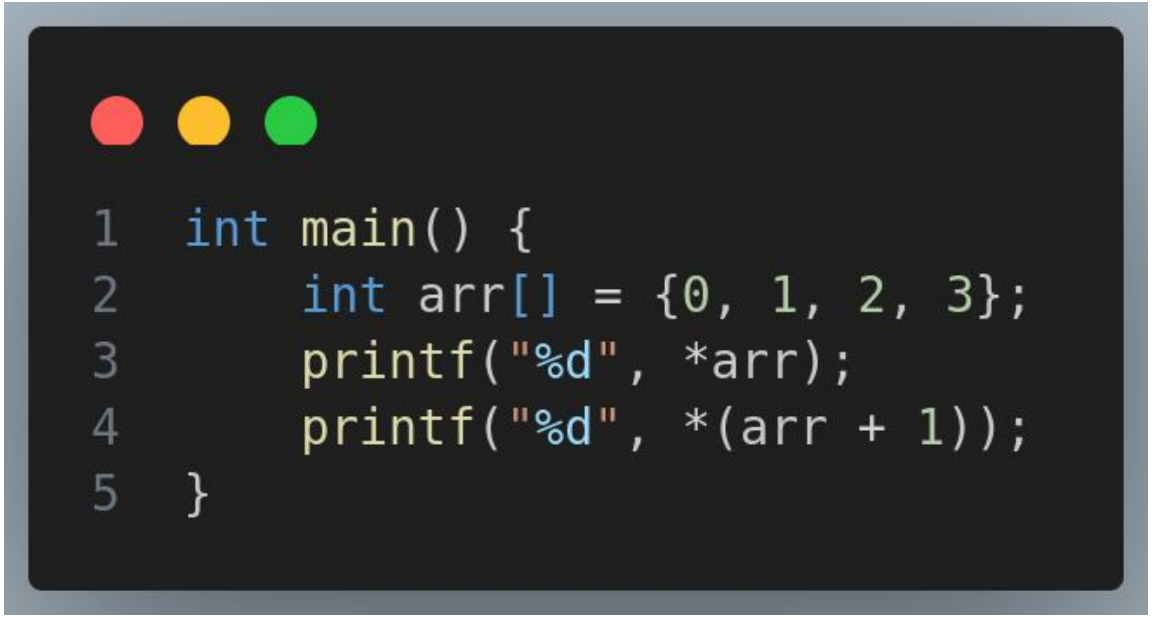
When writing larger, interconnected programs, remember how objects are passed around and copied

- C uses pass by pointer frequently - you often don’t want to make copies of large objects
- Primitives (e.g. int, char, etc.) are usually fine to leave as pass by value because they are so small

Arrays as pointers

Array variables can become pointers by **array decay**

What do you think prints here?



```c
int main() {
    int arr[] = {0, 1, 2, 3};
    printf("%d", *arr);
    printf("%d", *(arr + 1));
}
```

Array decay: arrays have a pointer value when required

- If you ask the program for the value of a variable that corresponds to an array, the program will tell you that it is a pointer
- Basically, arrays can be used like pointers

Static vs dynamic memory

Some variables live in **static memory**

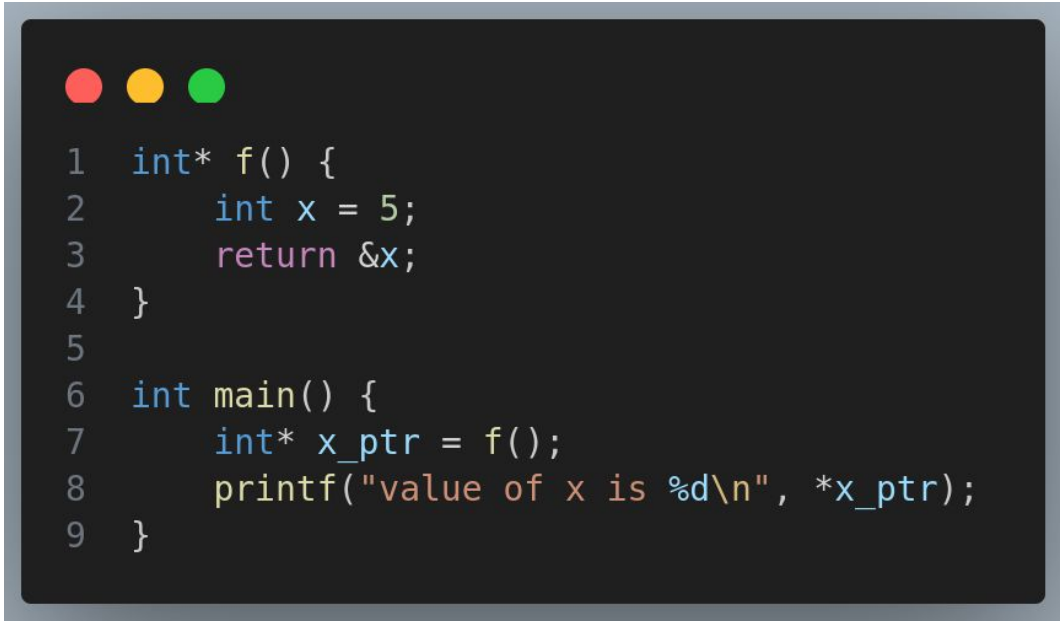
- These variables last for the program's entire lifetime
  - Global variables
  - Static variables
  - Constant variables
- You don't usually work with these in a meaningful way until OOP (object oriented programming)

Most objects live in **local memory** (aka **stack / automatic memory**)

- **Local objects** only last as long as the scope they are in
  - In this example, x only remains in memory for as long as we are in the function f
  - More efficient not to keep variables alive all the time

```
1  int* f() {
2      int x = 5;
3      return &x;
4  }
```

What happens with this code?



```c
int* f() {
    int x = 5;
    return &x;
}

int main() {
    int* x_ptr = f();
    printf("value of x is %d\n", *x_ptr);
}
```

We need **dynamic memory** (aka **heap memory**) to keep variables alive across scopes

- Lifetime of a dynamically allocated variable is controlled by the programmer
- This code will reliably work!

```c
int* f() {
    int* x_ptr = malloc(4);
    *x_ptr = 5;
    return x_ptr;
}

int main() {
    int* x_ptr = f();
    printf("value of x is %d\n", *x_ptr);
    free(x_ptr);
}
```

`malloc` and `free`

malloc = memory allocate

- **Allocate** = to make space for something
- Must specify the right number of bytes
- Use malloc to allocate space for dynamic memory

```
1  int main() {
2      int* x = malloc(4); // int is 4 bytes on my machine
3      free(x);
4  }
```

Sizes of primitive types in bytes

Data type	Size(bytes)	Range	Format String
char	1	-128 to 127	%c
unsigned char	1	0 to 255	%c
short	2	-32,768 to 32,767	%d
unsigned short	2	0 to 65535	%u
int	2	32,768 to 32,767	%d
unsigned int	2	0 to 65535	%u
long	4	-2147483648 to +2147483647	%ld
Unsinged long	4	0 to 4294967295	%lu
float	4	-3.4e-38 to +3.4e-38	%f
double	8	1.7 e-308 to 1.7 e+308	% lf
long double	10	3.4 e-4932 to 1.1 e+4932	%lf

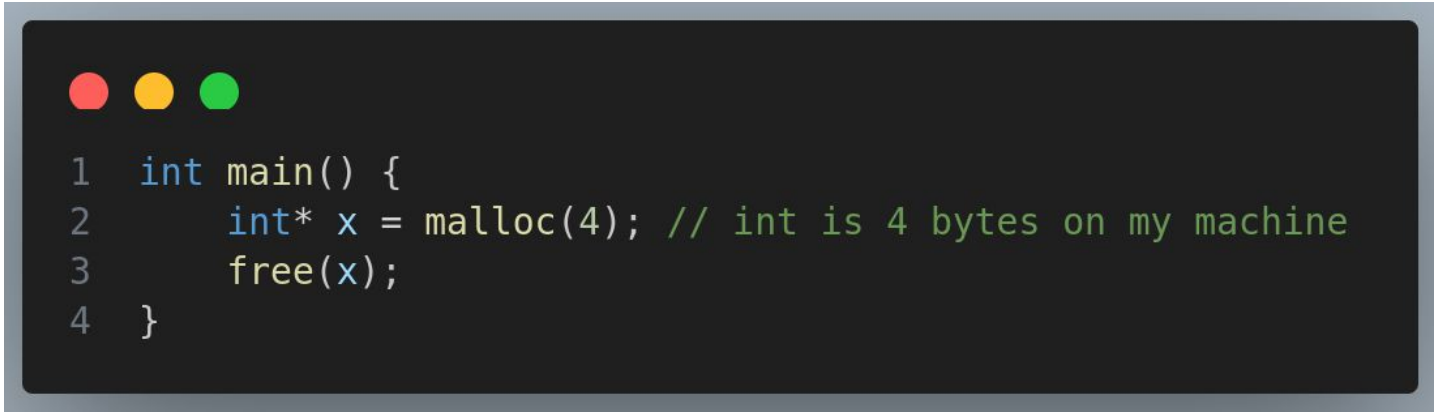
Ints can be different sizes, most systems have it as 4 bytes

Pointers can be 4 or 8 bytes depending on the system, usually 8

https://miro.medium.com/v2/resize:fit:712/1*cemNFCrMA3MK27nCuUuG_Q.png

free removes an object from dynamic memory

- Always use a free for each malloc



```c
int main() {
    int* x = malloc(4); // int is 4 bytes on my machine
    free(x);
}
```

- Don’t use the object after the free!

You can dynamically allocate arrays as well

```c
int main() {
    int* arr = malloc(20); // 5 ints
    for (size_t i = 0; i < 5; ++i) {
        arr[i] = i + 10;
    }
    for (size_t i = 0; i < 5; ++i) {
        printf("element %lu is %d\n", i, arr[i]);
    }
    free(arr);
}
```

Always use malloc and free together

- A list of problems that can happen from misusing malloc and free:
  - dangling pointer
  - double free
  - bad free
  - **memory leak** - malloc is used, but not free
  - And more...
- These errors are often hard to detect

Further English-language resources

University of Michigan, EECS 280: Memory Models and Dynamic Memory

More on static vs dynamic allocation of variables and what this looks like behind the scenes.

Some **very** important rules regarding the design of programs with dynamic memory – you should learn more in your OOP class.

Note that they use C++ and not C! (replace new with malloc, delete with free)

Stacks and queues

Data structure: any method of organizing data

- In C / C++, usually represented by a struct / class
- Arrays are the most basic data structure
- There are many fundamental data structures you will learn:
  - Arrays
  - Stacks, queues
  - Linked lists
  - Hash tables
  - Graphs
  - Trees, tries
- For today, we will introduce stacks and queues

Queue: FIFO array (first in, first out)

Think about standing in line at the grocery store

https://upload.wikimedia.org/wikipedia/commons/6/62/Covid-19_%27Alert_Level_3%27_New_World_supermarket_social_distancing_queue.jpg

Queues are just FIFO arrays

The **first** element you put **in** is the **first** element that goes **out**

```
// init. with empty stack
```

```
insert(1)
```


```
insert(2)
```


```
pop()
```


```
insert(5)
```


```
pop()
```

Stack: LIFO array (last in, first out)

Think about eating a stack of pancakes

https://live.staticflickr.com/3798/33007641255_6e01dd22e5_b.jpg

Stacks are just LIFO arrays

The last element you put in is the first element that goes out

```
// init. with empty stack
```

```
insert(1)
```


```
insert(2)
```


```
pop()
```


```
insert(5)
```


```
pop()
```

Assignments for today

Complete warmup exercises and analyze functions for errors

Go to GitHub ⇒ michigan-musicer ⇒ al.exercise_6 for code files.