CS 137 Week 2

Loops, Functions, Recursion, Arrays

September 18th, 2017

Loops

- We will finish this week with looping statements
- We already discussed one such structure, namely while loops.
- `while (expr) statement` can run 0 or more times
- A `do while` loop will execute at least once
- `do {statements} while (expr);`

Example

```c
#include <stdio.h>
int main(void) {
  int a=1920, b = 1080;
  int r; //Why is this declaration here?
  do{
    r = a % b;
    a = b;
    b = r;
  } while (r != 0);
  printf("%d", a);
  return 0;
}
```

For Loop

Syntax: `for(expr1; expr2; expr3) { statements }`

- Expression 1 is usually an initializer before the loop is executed
- Expression 2 is usually a condition
- Expression 3 is usually an incrementer/decrementer.
- In C99 and beyond, Expression 1 can be a initialization of a new variable whose scope is only the for loop.

Example

Print the numbers from 0 to 9

```
#include <stdio.h>
int main(void) {
  for(int i = 0; i < 10; i = i+1){
    printf("%d\n", i);
  }
  //Note: i=2 here would result in an error.
  return 0;
}
```

Breaks and Continues

- Like with switch statements, you can use the break; command to end the termination of a while, do or for statement early.
- C also has continue statements which allows you to exit the loop body early and go to just before the end of the loop body
- There is also a goto command that can jump to any labelled part of the program.
- Using these statements almost always makes code harder to read and so most programmers avoid or limit the use of these as much as possible.

Example - Sum Three Nonzero Integers

```
#include <stdio.h>
int main(void) {
   int n=0, sum=0, i=0;
   while (n < 3){
      scanf("%d",&i);
      if (i==0) continue;
      sum += i;
      n++;
   }
   printf("%d", sum);
}
```

Example

Write a program that asks the user for an integer and determines if it is a prime number. Print "Not Prime" if it is not prime and "Prime" otherwise.

- Recall: A prime number is an integer greater than 1 whose only positive divisors are 1 and itself.

Idea 1

Count all the divisors of the given number and if it is 2, we have a prime number.

```
#include <stdio.h>
int main(void) {
  int n, div=1, c=0;
  scanf("%d",&n);
  if (n<=1) printf("Not Prime");
  else {
    while(div <= n){
      if (n%div == 0) c++;
      div++;
    }
    if (c==2) printf("Prime");
    else printf("Not Prime");
  }
  return 0;
}
```

Optimization

There are a few ways we can make this code run faster

- If we have a non-prime number, then it has a divisor between the number itself and 1 (not including endpoints). If we find this, we can immediately break the code and print not prime
- If it has such a divisor d, there must be one less than $\sqrt{n}$ where n is the given number for one of d or n/d is bounded above by $\sqrt{n}$.
- Let's rewrite the code to account for these changes.

Idea 2

Search for a single divisor not 1 or n and if we find one return false.

```
#include <stdio.h>
int main(void) {
  int n, div=2;
  scanf("%d",&n);
  if (n<=1) printf("Not Prime");
  else {
    while(div*div <= n){
      if (n%div == 0) break;
      div++;
    }
    if (div*div <= n) printf("Not Prime");
    else printf("Prime");
  }
  return 0;
}
```

Comments

- This code now works but isn't very reuseable.
- You would have to embed this code every time inside the main function if you wanted to determine if a number is prime.
- It would be nice if we could create a function that would return true or false depending on if the given number is prime or not.

Functions

- We've actually already seen functions;

  ```
  int main(void)
  ```

  is a function!
- Syntax:

  ```
  return-type fcn_name (parameter[s]) {}
  ```
- The return-type must be specified in C99 and later; it is `void` if the function does not return anything
- `fcn_name` follows the same rules as variable names
- `parameters` must have their types declared per variable, eg. `int fun(int a, int b)` vs `int fun(int a, b)`
- Calling a function with no parameters: `fcn_name();`
- `return` ends the function and returns the value after it.

Basic Example

```
#include <stdio.h>
int max(int a, int b){
  return a > b ? a : b;
}
int main(void) {
  printf("%d", max(5,10));
  return 0;
}
```

Boolean Variables

- One more quirk about C is that there are no boolean variables.
- In C99 and later, there is a library `<stdbool.h>` that gives you boolean variables.
- It turns out that these `bool` variables are secretly unsigned integers in disguise (so even with this really aren't boolean variables!) and these take up a full byte like a `char`.
- These types can only take 0 and 1 as values (all non-zero values are just 1). You can also use the words `true` and `false` with this library.

Code Page 1

```
#include <stdbool.h>
#include <stdio.h>

bool isPrime(int n){
  int div=2;
  if (n<=1) return false;
  while(div*div <= n){
    if (n%div == 0) return false;
    div++;
  }
  return true;
}
```

Code Page 2

```
int main(void) {
   int n;
   scanf("%d",&n);
   bool is_prime = isPrime(n);
   if (is_prime) printf("Prime\n");
   else printf("Not Prime\n");
   return 0;
}
```

A Bit About Local Variables

- The variable `n` inside isPrime is what we call a local variable.
- The value from main is copied into the local variable in the `isPrime` function.
- Changing the local variable inside `isPrime` does not affect the variable in main (Thankfully!)
- Returning a local variable returns a copy of the value.

Passing By Value

Functions in C pass by value. What is printed below?

```
#include <stdio.h>
void foo(int n){
  n = 10;
}
int main(void) {
  int n = 4;
  foo(n);
  printf("%d\n",n);
  return 0;
}
```

Function Declarations

- In our example, we defined the function before using it.
- Strictly speaking, C doesn't force us to do this.
- However, C will be guessing at what the return type is of the function which it will default to `int`.
- To correct this, we can include a function declaration - a sort of promise to C that eventually we'll be defining this function that has this given return type.
- The declaration is the first line of the function but ends with a semicolon.
- The declaration needn't include the parameters, though it is advised to do so.

Rewritten

```c
#include <stdbool.h>
#include <stdio.h>

bool isPrime(int num);

int main(void) {
  //Same Code
}

bool isPrime(int num){
  //Same Code
}
```

New Topic - Recursion

- Simply put, recursion occurs when a function calls itself.
- Two golden rules of recursion:
  1. Must have a base case.
  2. Must make progress towards that base case.

GCD

Below is the recursive version of computing the GCD of two numbers.

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```
int gcd(int a, int b){
  if (b==0)
    return a;
  return gcd(b, a%b);
}
```

How This Looks on the Stack

gcd	a = 26, b=0	returns 26
gcd	a = 52, b=26	returns gcd(26, 0)
gcd	a = 78, b=52	returns gcd(52, 26)
gcd	a = 130, b=78	returns gcd(78, 52)
gcd	a = 338, b=130	returns gcd(130, 78)
gcd	a = 806, b=338	returns gcd(338, 130)
main	...	

Sample

- Write a recursive function `power` that takes two non-negative integer parameters `b` and `n` and returns b^n.
- Write a recursive function `geometric_sum` that takes two non-negative integer parameters `b` and `n` and returns the sum

$$1 + b + b^2 + b^3 + ... + b^n.$$

If you finish quickly, also do this iteratively.

Example - Leap Years

- Gregorian calendar replaced the Julian calendar in most of Europe in 1582.
- North America (ie. England and its colonies) adopted this calendar in September of 1752.
- A leap year, that is, a year containing an extra day occurs every 4 years that are not multiples of 100 unless they are also multiples of 400.
- Examples: 2016, 2000, 1804 were all leap years.
- Non-Examples: 2017, 1900, 1950 were not leap years.
- Write a function `is_leap_year` that returns `true` if a given year was a leap year and returns `false` otherwise.

Exceptions

- This works well but gives us some problems if the year were say negative.
- In fact, since we are in North America, we probably want the year to be at least 1752.
- We can accomplish this by using `assert` statements.
- First, add `#include <assert.h>` to the beginning then include `assert(year > 1752);`

Assert

- In general, `assert(expr);`
- If `expr` is true, this line does nothing
- Otherwise, it terminates the program with a message containing the filename, line number, function and expression.
- This is great for debugging.
- Also great to leave it in (so long as `expr` is not computationally expensive). Helps to remember assumptions, causes program to fail "loudly" vs "quietly", advises other programmers if code undergoes modifications.
- Good for regression testing as well, that is checking that changes haven't broken anything in another part of the code.

Separate Compilation

- In the "real world", programs are coded by many programmers.
- It is often inefficient to all be working on the same file, not to mention it can get very confusing when you have millions of lines of code.
- We would like to modularize the design and reduce compile time.

powers.h

Below are the contents of `powers.h` - a header file with some function definitions.

```
#ifndef POWERS_H //Prevents multiple inclusion
#define POWERS_H

/* Pre: num is a valid integer
   Post: returns the square of num.
*/
int square(int num);
int cube(int num);
int quartic(int num);
int quintic(int num);
#endif
```

powers.c

Below are the contents of `powers.c` - the file defining the header functions.

```
#include "powers.h" //notice the quotes!
int square(int num) {return num * num;}
int cube(int num) {return num*square(num);}
int quartic(int num) {
  return square(num)*square(num);}
int quintic(int num) {
  return square(num)*cube(num);}
```

Note - we separate these to help reduce compile time.

main.c

Below are the contents of `main.c` - the file defining the header functions.

```
#include <stdio.h>
#include "powers.h"
int main(void){
   int num=3;
   printf("%d^4 = %d\n", num, quartic(num));
   num = 2;
   printf("%d^5 = %d\n", num, quintic(num));
   return 0;
}
```

Note - we separate these to help reduce compile time.

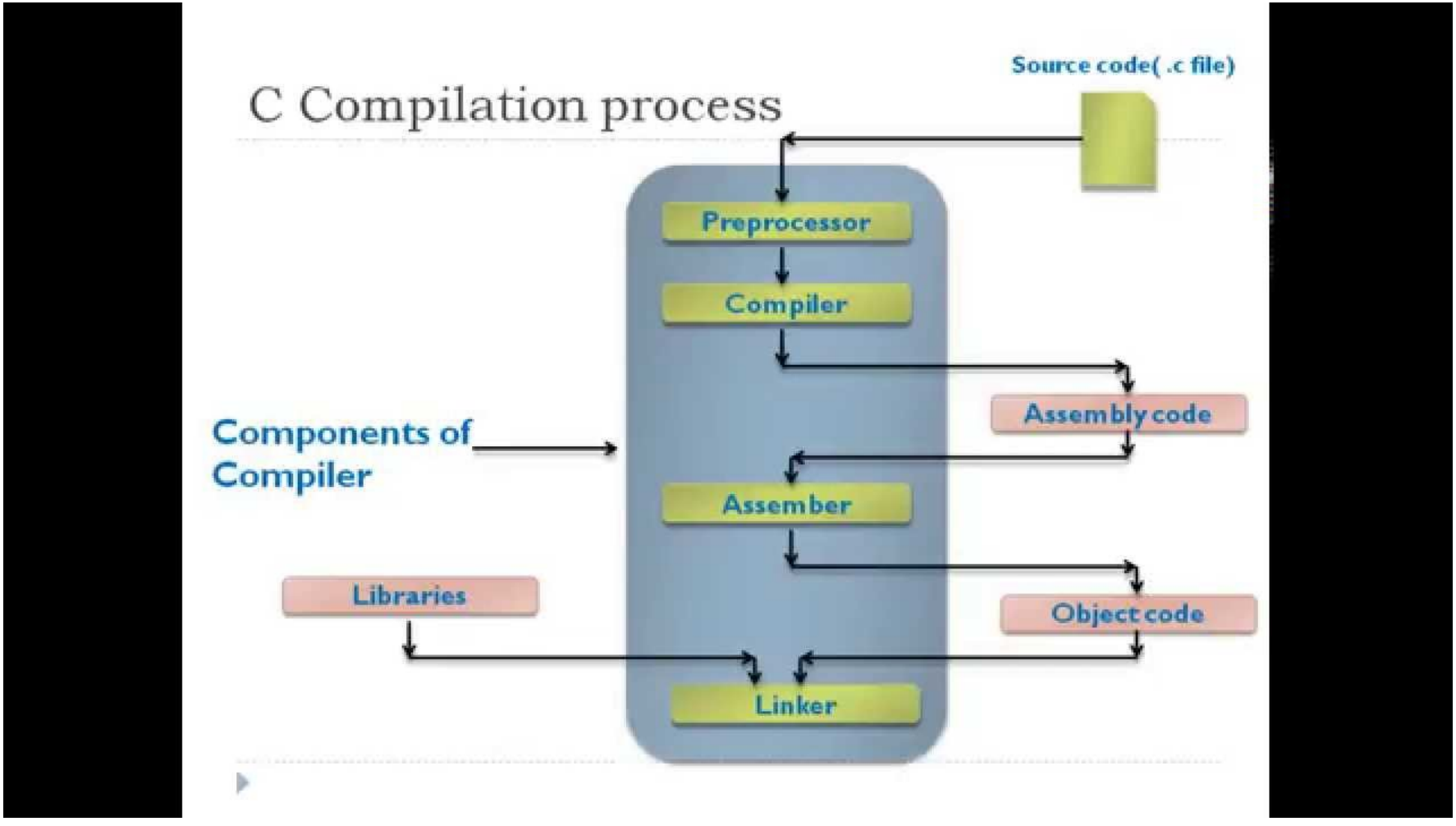
Compiling

- To compile, use

```
gcc -o powers powers.c main.c
```

- This compiles the code into assembly code then to object code and these files are automatically passed to the linker merging them to a single file.
- Reminder the `-o` command means to send the output to the filename immediately following.
- If you don't want to link the files (ie you just want to compile), use the command `-c`.

C Compiler



Source:
`https://i.ytimg.com/vi/VDslRumKvRA/maxresdefault.jpg`

More on Macros

- We've already seen three macros, namely `#include`, `#ifndef` and `#define`.
- In fact we can use the `#define` to define constants that we use in our code.
- Syntax: `#define identifier replacement_list`
- Notice that you don't need an equal sign or a semi colon - this is a straight replacement.
- This can be useful for constants in your code.

Example

Preprocessing turns the left into the right. (Mention floats).

```c
#include <stdio.h>
#define PI 3.1415
int main(void) {
  int r = 3;
  printf("Area:
    %f", PI*r*r);
  return 0;
}
```

```c
#include <stdio.h>
int main(void) {
  int r = 3;
  printf("Area:
    %f", 3.1415*r*r);
  return 0;
}
```

Arrays

- Up to this point we've seen ways to create variables to store data.
- What if wanted lots of variables? For example, suppose you wanted to store an office directory. Should we create a variable for each person?
- This is solved by arrays.
- Think of an array like a filing cabinet.
- Arrays start indexed at 0 (often why in CS natural numbers start at 0).

How Arrays look in Memory

`int a[5] = {10,-7,3,8,42}`

Variable Name	Memory Address	Value
a	10856	10
	10860	-7
	10864	3
	10868	8
	10872	42

We access the values via `a[0]`, `a[1]` and so on.

Creating Arrays

- `int a[5] = {10,-7,3,8,42}`
- `int a[] = {10,-7,3,8,42}` (size is inferred)
- `int a[5] = {1,2,3}` (last two entries are 0 by default)
- `int a[5] = {0}` (creates an all 0 array)
- `int a[5]` (uninitialized array contains garbage entries)
- `int a[5] = {[2] = 2, [4] = 3123}` (specified the third and fifth entries - rest are 0)

Warning

This is not allowed:

```
int a[5]; a = {1,2,3,4,5};
```

Nor is

```
int a[5]; a[5] = {1,2,3,4,5};
```

initialization is done at compile time and must be done at once (otherwise you need to manually enter entries)

Summing an Array

```
#include <stdio.h>
int main(void) {
   int a[] = {10,-7,3,8,42};
   int sum = 0;
   for(int i=0; i< 5; i++){
      sum += a[i];
   }
   printf("%d",sum);
   return 0;
}
```

Sieve of Eratosthenes

- Question: Find all prime numbers up to n.
- Idea:
  - List all the numbers from 2 to n.
  - Start at 2 and cross out all the multiples of 2.
  - Choose the next highest number not stricken out and repeat.
  - Stop when next number is greater than $\sqrt{n}$.
  - The remaining numbers are prime.
- For example, iteration 1:

	2	3	~~4~~	5	~~6~~	7	~~8~~	9	~~10~~
11	~~12~~	13	~~14~~	15	~~16~~	17	~~18~~	19	~~20~~

Sieve of Eratosthenes

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  - Start at 2 and cross out all the multiples of 2.
  - Choose the next highest number not stricken out and repeat.
  - Stop when next number is greater than $\sqrt{n}$.
  - The remaining numbers are prime.
- For example, iteration 2:

	2	3	~~4~~	5	~~6~~	7	~~8~~	~~9~~	~~10~~
11	~~12~~	13	~~14~~	~~15~~	~~16~~	17	~~18~~	19	~~20~~

main.c

```
#include <stdio.h>
#include <assert.h>
void sieve(int a[], int n);
int main(void) {
  int n; scanf("%d", &n);
  assert(n > 0);
  int a[n+1];
  sieve(a,n+1);
  for(int i=0; i<n; i++){
    if (a[i]) printf("%d\n",i);
  }
  return 0;
}
```

sieve.c

```
void sieve(int a[], int m){
  a[0] = 0;
  if (m==1) return;
  a[1] = 0;
  if (m==2) return;
  //Set potential primes
  for(int i=2; i < m; i++) a[i] = 1;
  for(int i=2; i*i <= m-1; i++){
    if (a[i]){
      //strike out multiples
      for(int j = 2*i; j < m; j += i) a[j] = 0;
    }
  }
}
```

Important Note

- Notice in the code that we passed an array and our original array was actually modified.
- What's really being passed to the function is not the array, but rather where the array exists in memory.
- Thus, when you make changes inside the array, it is actually changing the memory location that our array was specified to live in.
- Think back to the filing cabinet analogy.
- More on this later.

Exercise

Write a function `missing` that consumes an array of 99 distinct integers from 1 to 100 with one exception and returns the integer that is missing.

Array Sizes

- In all of our examples we know the size of our arrays.
- Ideally we wouldn't have to pass this information to our functions - the array itself should encode how large it is.
- We can access this information using the `sizeof()` operator, which takes as a parameter either a type or a variable and returns the number of bytes used to store a type or variable.
- Technically, it returns an unsigned integer of type `size_t`, which is an unsigned type.
- You might need to typecast this in certain situations to convince C that this is an integer (more on this later).

sizeof() Examples

Below %lu refers to "unsigned long". The %zu is preferred for cross-platform compatibility.

```
#include <stdio.h>
int main(void) {
  int a[] = {-1, 2, -1, 2, -4, 1};
  printf("%d\n", sizeof(a)/sizeof(a[0]));
  printf("%d %d %d %d\n",
    sizeof(char), sizeof(int),
      sizeof(a[0]), sizeof(a));
  printf("%lu %lu %lu %lu\n",
    sizeof(char), sizeof(int),
      sizeof(a[0]), sizeof(a));
  printf("%zu %zu %zu %zu",
    sizeof(char), sizeof(int),
      sizeof(a[0]), sizeof(a));
  return 0;
}
```

Passing Arrays to Functions

Let's take a closer look at passing an array into a function

```
#include <stdio.h>
void plusOne(int a[], int n){
  for(int i=0; i<n; i++) a[i]++;
}
int main(void) {
  int a[10] = {0,1,2,3,4,5,6,7,8,9};
  //Below, a is really a memory address.
  plusOne(a, sizeof(a)/sizeof(a[0]));
  printf("%p\n", a); //mem address
  return 0;
}
```

Pointers

- Key note: An array (by name) is a pointer to something in memory.
- `int *a;` - a pointer to an integer.
- So for example, in the function definition before,

  ```
  void plusOne(int a[], int n);
  ```

  is equivalent to

  ```
  void plusOne(int *a, int n);
  ```

Caution!

Watch out! It's a trap! What does this code print?

```
#include <stdio.h>
void sizeofArray(int a[]){
  printf("%zu\n", sizeof(a));
}
int main(void) {
  int a[] = {1,2,3,4,5,6,7,8,9,10};
  printf("%zu\n",sizeof(a));
  sizeofArray(a);
  return 0;
}
```

Probably...

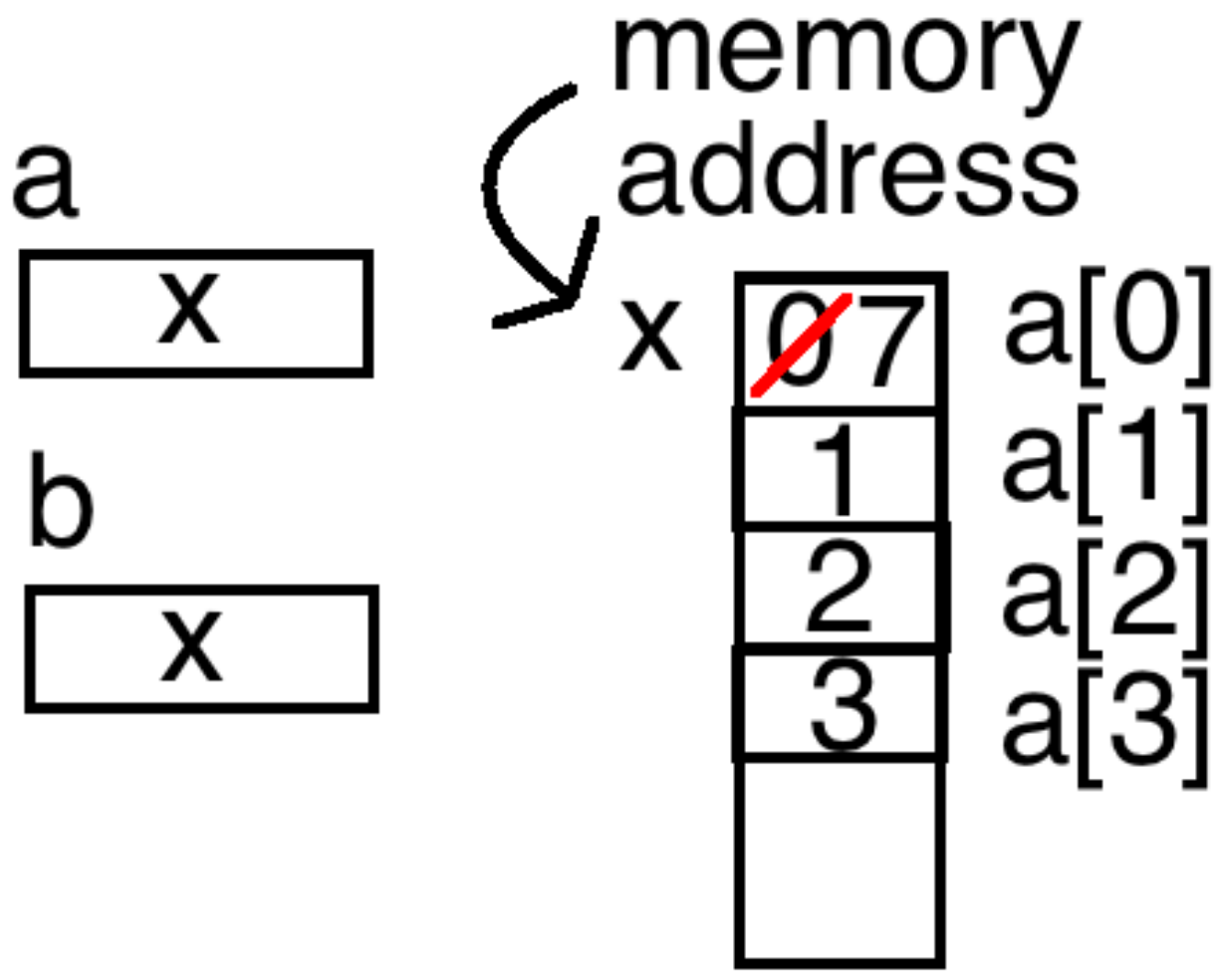
- ... not what you expected. Remember that the a in the function is really just a memory address and so has the size of a memory address location (which in this case is 8 bytes).
- The sizeof(a) inside `main` is actually the size of the array (so the size of all the elements in the array). In this case, this is 10 times `sizeof(int)`
- This awkwardness is why we need to pass the size of the array to functions.
- This is called **pointer decay**.

More Fun - References

What about this code?

```
#include <stdio.h>
int main(void) {
   int a[] = {0,1,2,3};
   int *b = a;
   printf("%d\n", a[0]);
   b[0] = 7;
   printf("%d\n", a[0]);
   return 0;
}
```

This Actually is Reasonable:



Copying Arrays

- So what if you wanted an exact but distinct copy of an array?
- For now, one way to achieve this is to create a new array of the same size and then manually copy everything into it. (Note: C99 and beyond allowed for variable length arrays)

```
#include <stdio.h>
int main(void) {
   int a[3] = {2,4,6};
   int len = sizeof(a)/sizeof(a[0]);
   int b[len];
   for(int i=0; i<len; i++) b[i] = a[i];
   a[0] = 19;
   printf("%d",b[0]);
   return 0;
}
```

Multi-Dimentional Arrays

C can also deal with arrays of arrays:

```
#include <stdio.h>
int main(void) {
  int matrix[4][3] = {{0,1,2},
      {10,11,12},{20,21,22},{30,31,32}};
  return 0;
}
```

We say this array `martix` has four **rows** and three **columns**.

Conceptually:

0	1	2
10	11	12
20	21	22
30	31	32

However...

In memory, this is stored in **row major** order:

0	$a[0][0]$
1	$a[0][1]$
2	$a[0][2]$
10	$a[1][0]$
11	$a[1][1]$
12	$a[1][2]$
20	$a[2][0]$

Example

Let's sum all the elements in a two dimensional array

```
#include <stdio.h>
int sumMulti(int a[4][3]) {
   int sum = 0;
   for (int i=0; i < 4; i++){
      for (int j=0; j < 3; j++){
         sum += a[i][j];
      }
   }
   return sum;
}
```

Final Notes

- The line

  ```
  sum += a[i][j];
  ```

  can be replaced with

  ```
  sum += a[0][i*3+j];
  ```

  (Think back to how the memory model works!
- When initializing, all dimension except possibly the first must be explicit. This holds also in function definitions.
- Example: `int a[][2] = {{1,2},{3,4}};`
- We will return in a few weeks to discuss more about pointers in more detail.