CS 31: Intro to Systems
C Programming

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September 1, 2022

Agenda

- Basics of C programming
  - Comments, variables, print statements, loops, conditionals, etc.
  - NOT the focus of this course
  - Ask questions if you have them!

- Comparison of C vs. Python
  - Data organization and strings
  - Functions

Hello World

Python	C

`# hello world`
`import math`
 	
`def main():`
`  print "hello world"`
 	
`main()`
	`// hello world`
	`#include <stdio.h>`
	
	`int main(void) {`
	`  printf("hello world\n");`
	`  return 0;`
	`}`

#: single line comment	**//**: single line comment
import libname: include Python libraries	**#include <libname>**: include C libraries
Blocks: **indentation**	Blocks: **{ }** (indentation for readability)
print: statement to printout string	**printf**: function to print out format string
statement: each on separate line	**statement**: each ends with **;**

“White Space”

- Python cares about how your program is formatted. Spacing has meaning.

- C compiler does NOT care. Spacing is ignored.
  - This includes spaces, tabs, new lines, etc.
  - Good practice (for your own sanity):
    - Put each statement on a separate line.
    - Keep indentation consistent within blocks.

These are the same program…

```
#include <stdio.h>

int main(void) {
    int number = 7;
    if (number > 10) {
        do_this();
    } else {
        do_that();
    }
}
```

```
#include <stdio.h>
int main(void) { int number
= 7; if (number > 10) {
do_this();
   } else
{
do_that();}}
```

Hello World

Python	C

`# hello world`
`import math`
 	
`def main():`
`  print "hello world"`
 	
`main()`
	`// hello world`
	`#include <stdio.h>`
	
	`int main(void) {`
	`  printf("hello world\n");`
	`  return 0;`
	`}`

#: single line comment	**//**: single line comment
import libname: include Python libraries	**#include<libname>**: include C libraries
Blocks: **indentation**	Blocks: **{ }** (indentation for readability)
print: statement to printout string	**printf**: function to print out format string
statement: each on separate line	**statement**: each ends with **;**
def main(): : the main function definition	**int main(void)** : the main function definition (int specifies the **return type** of main)

Types

- Everything is stored as bits.
- Type tells us how to interpret those bits.
- “What type of data is it?”
  - integer, floating point, text, etc.

Types in C

- All variables have an explicit type!

- You (programmer) must declare variable types.
  - Where: at the beginning of a block, before use.
  - How: <variable type> <variable name>;

- Examples:

```
int humidity;
humidity = 20;
```

```
float temperature;
temperature = 32.5
```

Discussion question

- Green border

- Recall the sequence
  - Answer individually
  - Discuss in your group
  - Answer as a group
  - Class-wide discussion

We have to explicitly declare variable types ahead of time? Lame! Python figured out variable types for us, why doesn't C?

We have to explicitly declare variable types ahead of time? Lame! Python figured out variable types for us, why doesn't C?

A. C is old.
B. Explicit type declaration is more efficient.
C. Explicit type declaration is less error prone.
D. Dynamic typing (what Python does) is imperfect.
E. Some other reason (explain)

Numerical Type Comparison

Integers (int)

- Example:

```
int humidity;
humidity = 20;
```

- Only represents integers
- Small range, high precision
- Faster arithmetic
- (Maybe) less space required

Floating Point (float, double)

- Example:

```
float temperature;
temperature = 32.5;
```

- Represents fractional values
- Large range, less precision
- Slower arithmetic

I need a variable to store a number, which type should I use?

Use the one that fits your specific need best…

An Example with Local Variables

```
/* a multiline comment:
   anything between slashdot and dotslash */

#include <stdio.h> // C's standard I/O library (for printf)

int main(void) {
   // first: declare main's local variables
   int x, y;
   float z;

   // followed by: main function statements
   x = 6;
   y = (x + 3)/2;
   z = x;
   z = (z + 3)/2;

   printf(…)  // Print x, y, z
}
```

What values will we see for x, y, and z?

```
/* a multiline comment:
   anything between slashdot and dotslash */

#include <stdio.h> // C's standard I/O library (for printf)

int main(void) {
   // first: declare main's local variables
   int x, y;
   float z;

   // followed by: main function statements
   x = 6;
   y = (x + 3)/2;
   z = x;
   z = (z + 3)/2;

   printf(…)  // Print x, y, z
}
```

Clicker choices

	X	Y	Z
A	4	4	4
B	6	4	4
C	6	4.5	4
D	6	4	4.5
E	6	4.5	4.5

Operators: need to think about type

- **Arithmetic**: +, -, *, /, % (numeric type operands)

  /: operation and result type depends on operand types:

  - 2 int operands: int division truncates: 3/2 is 1
  - 1 or 2 float or double operands: float or double division: 3.0/2 is 1.5

  %: mod operator: (only int or unsigned types)

  - Gives you the (integer) remainder of division.

    13 % 2 is 1 27 % 3 is 0

  Shorthand operators :

  - var **op=** expr; (var = var op expr):
    x += 4 is equivalent to x = x + 4
  - var**++**; var**--**; (var = var+1; var = var-1):
    x++ is same as x = x + 1 x-- is same as x = x -1;

Boolean values in C?

- There is no “boolean” type in C!
- Instead, **integer expressions** used in conditional statements are interpreted as true or false
- **Zero (0) is false, any non-zero value is true**
- Questions?
- “Which non-zero value does it use?”

Operators: need to think about type

- **Relational** (operands any type, result int “boolean”):
  - <, <=, >, >=, ==, !=
  - 6 != (4+2) is 0 (false)
  - 6 > 3 some non-zero value (we don’t care which one) (true)
- **Logical** (operands int “boolean”, result int “boolean”):
  - ! (not): !6 is 0 (false)
  - && (and): 8 && 0 is 0 (false)
  - || (or): 8 || 0 is non-zero (true)

Boolean values in C

- **Zero (0) is false, any non-zero value is true**
- **Logical** (operands int "boolean"->result int "boolean"):
  - ! (not): inverts truth value
  - && (and): true if both operands are true
  - || (or): true if either operand is true

Do the following statements evaluate to True or False?

#1: (!10) || (5 > 2)

#2: (-1) && ((!5) > -1)

Clicker choices

	#1	#2
A	True	True
B	True	False
C	False	True
D	False	False

Conditional Statements

Basic if statement:

```
if(<boolean expr>) {
  if-true-body
}
```

With optional else:

```
if(<boolean expr>) {
  if-true-body
} else {
  else body(expr-false)
}
```

Chaining if-else if

```
if(<boolean expr1>) {
  if-expr1-true-body
} else if (<bool expr2>){
  else-if-expr2-true-body
  (expr1 false)
}
...
} else if (<bool exprN>){
  else-if-exprN-true-body
}
```

With optional else:

```
if(<boolean expr1>) {
  if-expr1-true-body
} else if (<bool expr2>){
  else-if-expr2-true-body
}
...
} else if (<bool exprN>){
  else-if-exprN-true-body
} else {
  else body
  (all exprX's false)
}
```

Very similar to Python, just remember { } are blocks

While Loops

- Basically identical to Python while loops:

```
while (<boolean expr>) {
    while-expr-true-body
}
```

```
x = 20;
while (x < 100) {
  y = y + x;
  x += 4;  //  x = x + 4;
}
<next stmt after loop>;
```

```
x = 20;
while (1) {  // while true
  y = y + x;
  x += 4;
  if(x >= 100) {
     break;  // break out of loop
  }
}
<next stmt after loop>;
```

For loops: different than Python's

```
for (<init>; <cond>; <step>) {
   for-loop-body-statements
}
<next stmt after loop>;
```

1. Evaluate <init> one time, when first eval **for** statement
2. Evaluate <cond>, if it is false, drop out of the loop (<next stmt after>)
3. Evaluate the statements in the for loop body
4. Evaluate <step>
5. Goto step (2)

```
for (i = 1; i <= 10; i++) {  // example for loop
   printf("%d\n", i*i);
}
```

printf function

- Similar to Python's formatted print statement:

```
Python:   print  "%d %s\t %f"  % (6, "hello", 3.4)
    C:   printf("%d %s\t %f\n",  6, "hello", 3.4);

         printf(<format string>, <values list>);
```

%d	int placeholder (-13)
%f or %g	float or double (higher-precision than float) placeholder (9.6)
%c	char placeholder ('a')
%s	string placeholder ("hello there")
\t \n	tab character, new line character

- Formatting Differences:
  - C: need to explicitly print end-of-line character (`\n`)
  - C: **string and char are different types**
    `'a'`: in Python is a string, in C is a **char**
    `"a"`: in Python is a string, in C is a **string**

Data Collections in C

- Many complex data types out there (CS 35)

- C has a few simple ones built-in:
  - Arrays
  - Structures (`struct`)
  - Strings (arrays of characters)

- Often combined in practice, e.g.:
  - An array of structs
  - A struct containing strings

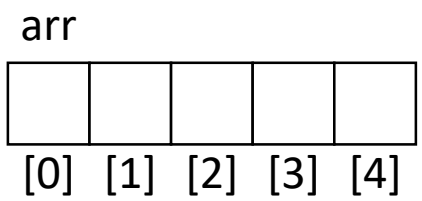
Arrays

- C's support for collections of values
  - Array buckets store a single type of value
  - Need to specify max capacity (num buckets) when you declare an array variable (single memory chunk)

```
<type> <var_name>[<num buckets>];
int arr[5];  // an array of 5 integers
float rates[40]; // an array of 40 floats
```

  - Often accessed via a loop:

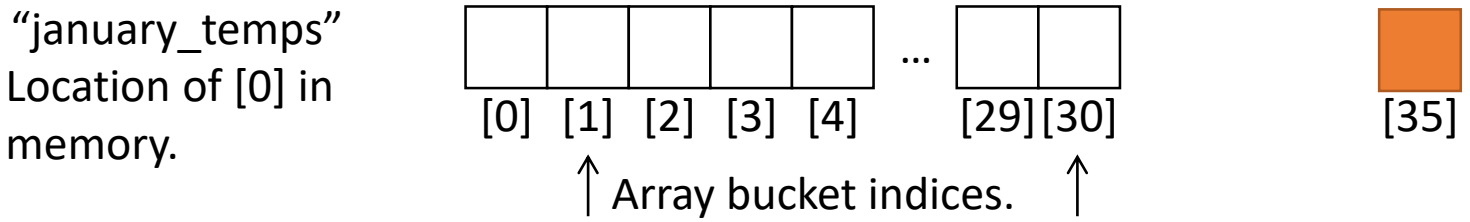
```
for(i=0; i < 5; i++) {
    arr[i] = i;
    rates[i] = (arr[i]*1.387)/4;
}
```



Get/Set value using brackets [] to index into array.

Array Characteristics

```
int january_temps[31];  // Daily high temps
```



- Indices start at 0! Why?
- Array variable name means, to the compiler, the beginning of the memory chunk. (address)
  - Keep this in mind, we'll return to it soon (functions).
- Index number is an offset from beginning.
- C does NOT do bounds checking.
  - Asking for january_temps[35]?
    - Python: error
    - C: "Ok, why not?"

Characters and Strings

- A character (type `char`) is numerical value that holds one letter.

```
char my_letter = 'w';   // Note: single quotes
```

- What is the numerical value?
  - printf("%d %c", my_letter, my_letter);
  - Would print: 119 w
- Why is 'w' equal to 119?
  - ASCII Standard says so.

Characters and Strings

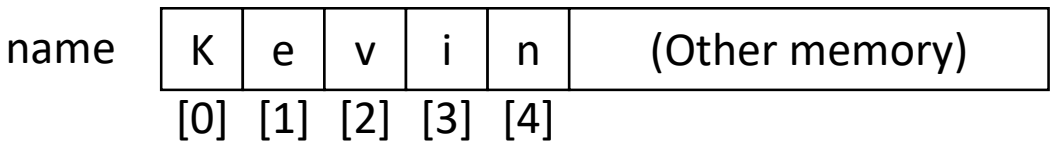
Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
0	00	Null	32	20	Space	64	40	@	96	60	`
1	01	Start of heading	33	21	!	65	41	A	97	61	a
2	02	Start of text	34	22	"	66	42	B	98	62	b
3	03	End of text	35	23	#	67	43	C	99	63	c
4	04	End of transmit	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
6	06	Acknowledge	38	26	&	70	46	F	102	66	f
7	07	Audible bell	39	27	'	71	47	G	103	67	g
8	08	Backspace	40	28	(	72	48	H	104	68	h
9	09	Horizontal tab	41	29	)	73	49	I	105	69	i
10	0A	Line feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage return	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift out	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	47	2F	/	79	4F	O	111	6F	o
16	10	Data link escape	48	30	0	80	50	P	112	70	p
17	11	Device control 1	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	50	32	2	82	52	R	114	72	r
19	13	Device control 3	51	33	3	83	53	S	115	73	s
20	14	Device control 4	52	34	4	84	54	T	116	74	t
21	15	Neg. acknowledge	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	54	36	6	86	56	V	118	76	v
23	17	End trans. block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitution	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	63	3F	?	95	5F	_	127	7F	□

Characters and Strings

- A character (type `char`) is numerical value that holds one letter.
- A string is a memory block containing characters, one after another…

- Examples:

  char name[6] = “Kevin”;



Hmm, suppose we used printf and %s to print name.

How does it know where the string ends and other memory begins?

How can we tell where a string ends?

A. Mark the end of the string with a special character.

B. Associate a length value with the string, and use that to store its current length.

C. A string is always the full length of the array it's contained within (e.g., `char name[20]` must be of length 20).

D. All of these could work (which is best?).

E. Some other mechanism (such as?).

Characters and Strings

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
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2	02	Start of text	34	22	"	66	42	B	98	62	b
3	03	End of text	35	23	#	67	43	C	99	63	c
4	04	End of transmit	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
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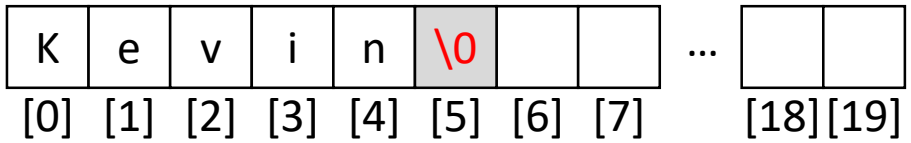
8	08	Backspace	40	28	(	72	48	H	104	68	h
9	09	Horizontal tab	41	29	)	73	49	I	105	69	i
10	0A	Line feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage return	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift out	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	47	2F	/	79	4F	O	111	6F	o
16	10	Data link escape	48	30	0	80	50	P	112	70	p
17	11	Device control 1	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	50	32	2	82	52	R	114	72	r
19	13	Device control 3	51	33	3	83	53	S	115	73	s
20	14	Device control 4	52	34	4	84	54	T	116	74	t
21	15	Neg. acknowledge	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	54	36	6	86	56	V	118	76	v
23	17	End trans. block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitution	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	63	3F	?	95	5F	_	127	7F	□

Special stuff over here in the lower values.

Characters and Strings

- A character (type `char`) is numerical value that holds one letter.
- A string is a memory block containing characters, one after another, with a null terminator (numerical 0) at the end.
- Examples:

    char name[20] = “Kevin”;



Strings in C

- C String library functions: `#include <string.h>`
  - Common functions (strlen, strcpy, etc.) make strings easier
  - Less friendly than Python strings

- More on strings later, in labs.

- For now, remember about strings:
  - Allocate enough space for null terminator!
  - If you're modifying a character array (string), don't forget to set the null terminator!
  - If you see crazy, unpredictable behavior with strings, check these two things!

structs

- Treat a collection of values as a single type:
  - C is not an object oriented language, no classes
  - A `struct` is like just the data part of a class

- Rules:
  1. Define a new struct type outside of any function
  2. Declare variables of the new struct type
  3. Use dot notation to access the different field values of the struct variable

Struct Example

- Suppose we want to represent a *student* type.

```
struct student {
        char name[20];
        int grad_year;
        float gpa;
};

struct student bob;

strcpy(bob.name, “Robert Paulson”);  // Set name (string) with strcpy()
bob.grad_year = 2023;
bob.gpa = 3.1;

printf(“Name: %s, year: %d, GPA: %f”, bob.name, bob.grad_year, bob.gpa);
```

Arrays of Structs

```
struct student {
        char name[20];
        int grad_year;
        float gpa;
};

struct student classroom[50];

strcpy(classroom[0].name, “Alice”);
classroom[0].grad_year = 2014
classroom[0].gpa = 4.0;

// With a loop, create an army of Alice clones!
int i;
for (i = 0; i < 50; i++) {
        strcpy(classroom[i].name, “Alice”);
        classroom[i].grad_year = 2014;
        classroom[i].gpa = 4.0;
}
```

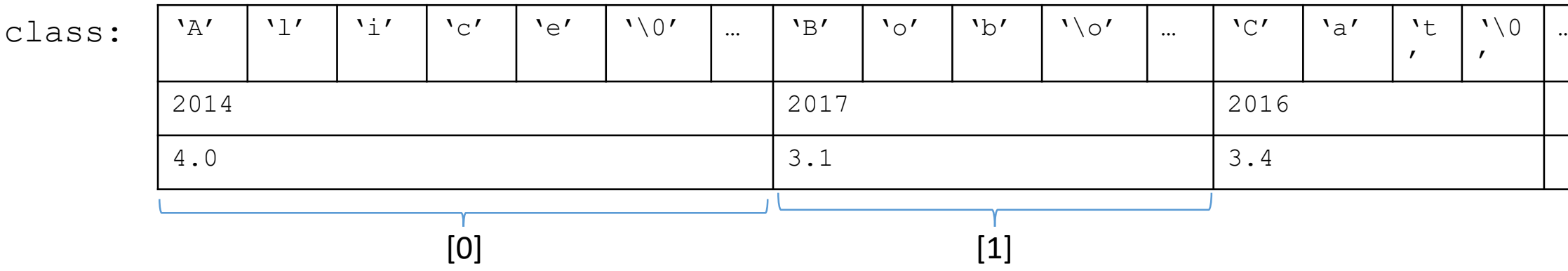
Arrays of Structs

```
struct student classroom[50];

strcpy(classroom[0].name, “Alice”);
classroom[0].grad_year = 2014;
classroom[0].gpa = 4.0;

strcpy(classroom[1].name, “Bob”);
classroom[1].grad_year = 2017;
classroom[1].gpa = 3.1

strcpy(classroom[1].name, “Cat”);
classroom[1].grad_year = 2016;
classroom[1].gpa = 3.4
```



Functions: Specifying Types

- Need to specify the return type of the function, and the type of each parameter:

```
<return type> <func name> ( <param list> ) {
    // declare local variables first
    // then function statements
       return <expression>;
}

// my_function takes 2 int values and returns an int
int my_function(int x, int y) {
  int result;
  result = x;
  if(y > x) {
    result = y+5;
  }
  return result*2;
}
```

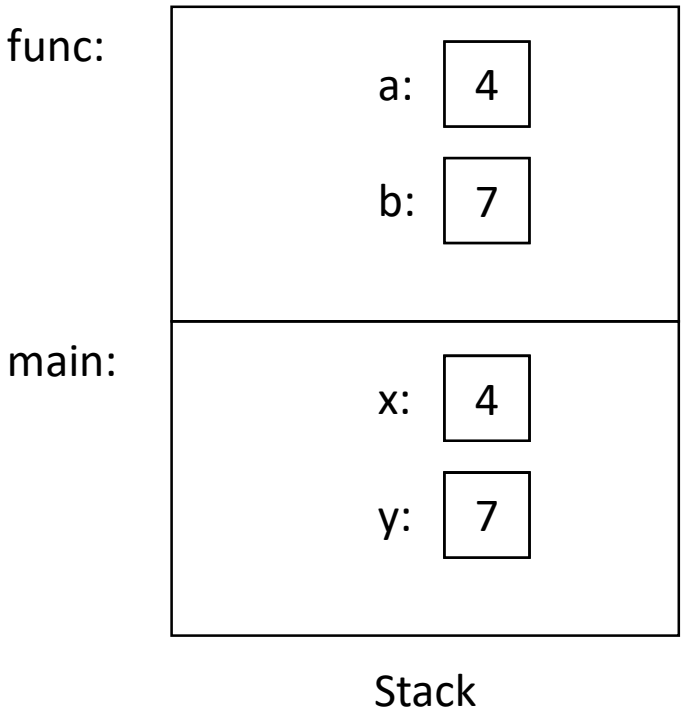
Compiler will yell at you if you try to pass the wrong type!

Function Arguments

- Arguments are **passed by value**
  - The function gets a separate copy of the passed variable

```
int func(int a, int b) {
        a = a + 5;
        return a - b;
}

int main() {
    ⟶  int x, y;  // declare two integers
        x = 4;
        y = 7;
        y = func(x, y);
        printf("%d, %d", x, y);
}
```

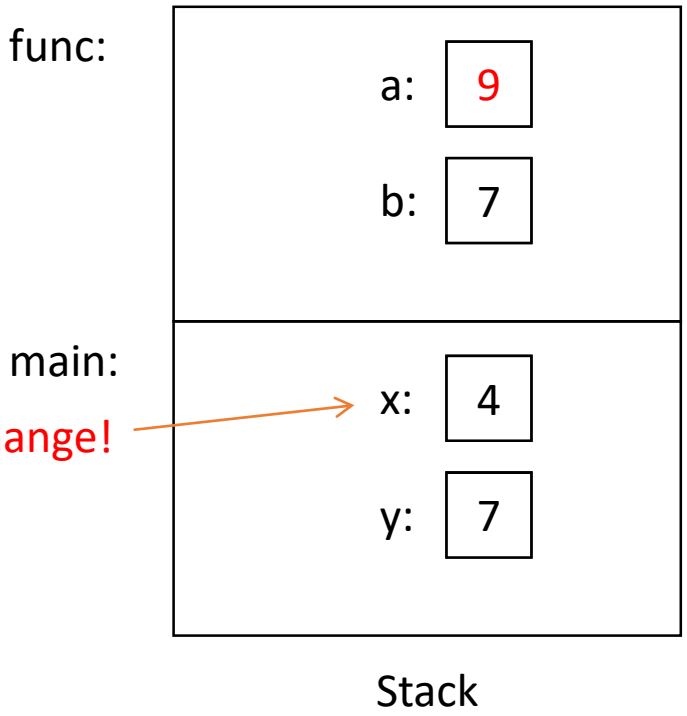


Function Arguments

- Arguments are **passed by value**
  - The function gets a separate copy of the passed variable

```
int func(int a, int b) {
    → a = a + 5;
      return a - b;
}

int main() {
      int x, y;  // declare two integers
      x = 4;
      y = 7;
    → y = func(x, y);
      printf("%d, %d", x, y);
}
```



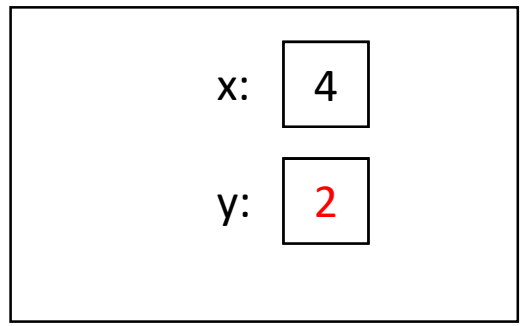
Note: This doesn't change!

Function Arguments

- Arguments are **passed by value**
  - The function gets a separate copy of the passed variable

```
int func(int a, int b) {
        a = a + 5;
        return a - b;
}

int main() {
        int x, y;  // declare two integers
        x = 4;
        y = 7;
        y = func(x, y);
        printf("%d, %d", x, y);
}
```



Output: 4, 2

What will this print?

```
int func(int a, int y, int my_array[]) {
        y = 1;
        my_array[a] = 0;
        my_array[y] = 8;
        return y;
}

int main() {
        int x;
        int values[2];

        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```

A. 0, 5, 8
B. 0, 5, 10
C. 1, 0, 8
D. 1, 5, 8
E. 1, 5, 10

Hint: What does the name of an array mean to the compiler?

What will this print?

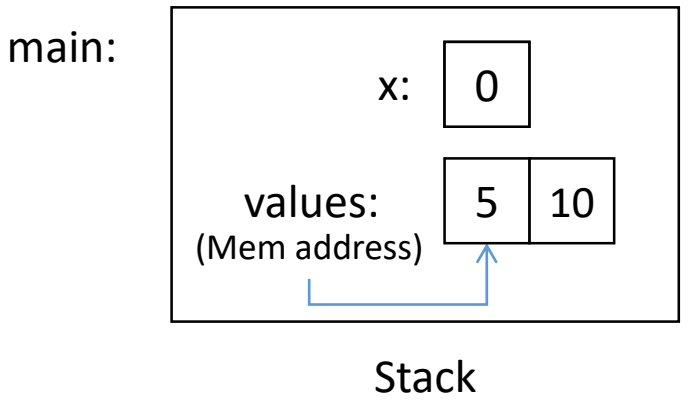
```
int func(int a, int y, int my_array[]) {
        y = 1;
        my_array[a] = 0;
        my_array[y] = 8;
        return y;
}

int main() {
        int x;
        int values[2];

        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```



What will this print?

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int func(int a, int y, int my_array[]) {
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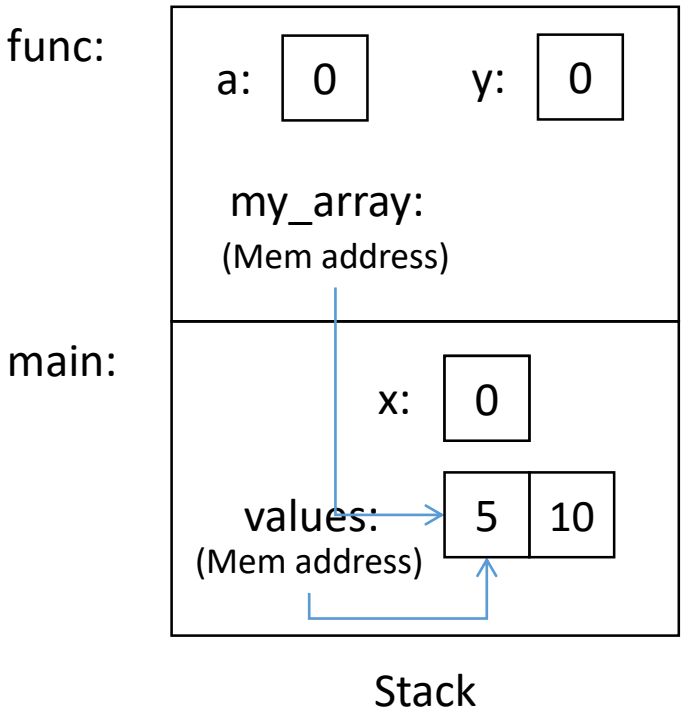
        my_array[a] = 0;
        my_array[y] = 8;
        return y;
}

int main() {
        int x;
        int values[2];

        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```



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        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```

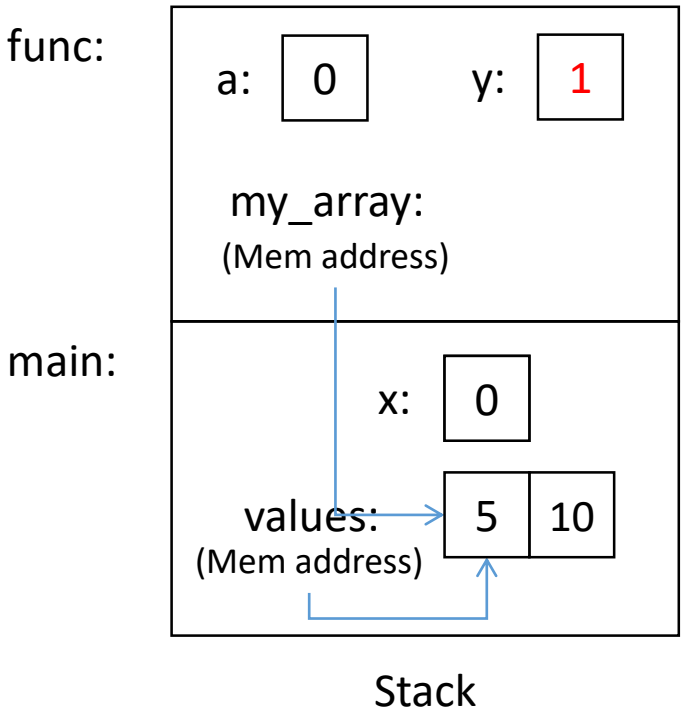

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        int x;
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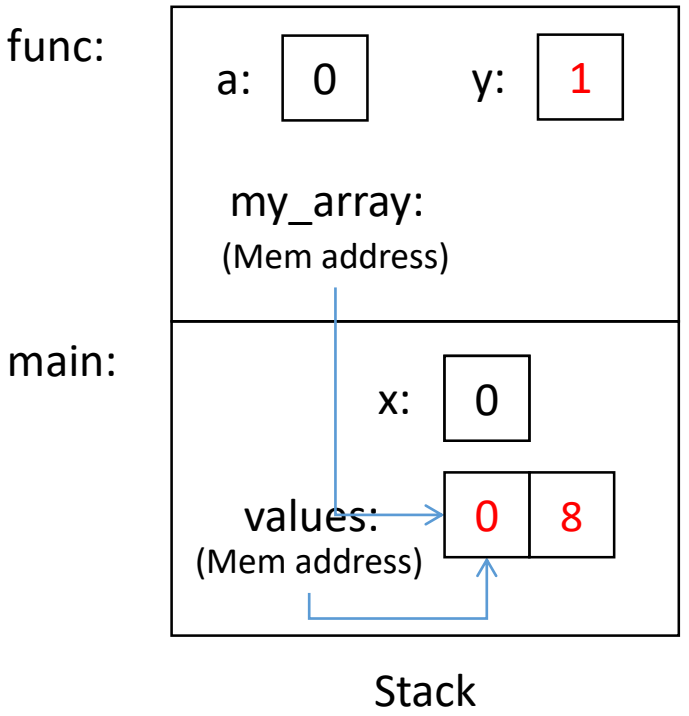
        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```



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        x = 0;
        values[0] = 5;
        values[1] = 10;

        x = func(x, x, values);

        printf("%d, %d, %d", x, values[0], values[1]);
}
```

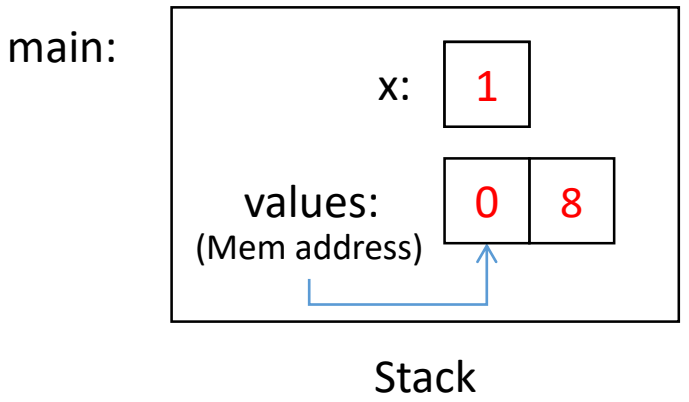

Fear not!

- Don’t worry, I don’t expect you to have mastered C.
- It’s a skill you’ll pick up as you go.
- We’ll revisit these topics when necessary.

- When in doubt: solve the problem in English, whiteboard pictures, whatever else!
  - Translate to C later.
  - Eventually, you’ll start to think in C.

Up next…

- Bits, Bytes, Binary (data representation)