CS 31: Intro to Systems
C Programming

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Swarthmore College
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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
What is C?

Dennis Ritchie worked at Bell Labs back in 1972.

C was created for systems programming.

C was created to write Unix.
Why C in this course?

Did you ever see the wizard of Oz?
What was going on behind the curtains?
More than what you would think!
The mystery revealed!
Python versus C: Paradigms

Python and C follow different programming paradigms.

• **C:**
  – is procedure-oriented.
  – breaks down to functions.

• **Python:**
  – follows an object-oriented paradigm.
  – allows Python to break down objects and methods.
So, the point(er) is….?

• Programming languages are tools
  – Python is one language and it does its job well
  – C is another language and it does its job well

• Pick the right tool for the job
  – C is a good language to explore how the system works under-the-hood.
  – C is the Language of Systems Programmers: Fast running OS code that exposes the details of the hardware is really important!

• It’s the right tool for the job we need to accomplish in this course!
<table>
<thead>
<tr>
<th><strong>Python</strong></th>
<th><strong>C</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td># hello world</td>
<td>// hello world</td>
</tr>
<tr>
<td>import math</td>
<td>#include &lt;stdio.h&gt;</td>
</tr>
<tr>
<td>def main():</td>
<td>int main() {</td>
</tr>
<tr>
<td>print “hello world”</td>
<td>printf(“hello world\n”);</td>
</tr>
<tr>
<td>main()</td>
<td>return 0;</td>
</tr>
<tr>
<td></td>
<td>}</td>
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</tbody>
</table>
# Hello World

## Python

```python
# hello world
import math

def main():
    print "hello world"

main()
```

## C

```c
// hello world
#include <stdio.h>

int main( ) {
    printf("hello world\n");
    return 0;
}
```

```c
//: single line comment
```

```python
#: single line comment
```
**Hello World**

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#: single line comment

import libname: include Python libraries

//: single line comment

#include<libname>: include C libraries
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# single line comment  // single line comment

**import libname:** include Python libraries

**include<libname>:** include C libraries

**Blocks:** indentation

Blocks: {   } (indentation for readability)
“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.
Are these the same program?

A. Yes

B. No

C. I can’t tell...
# Hello World

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<td># hello world import math</td>
<td>// hello world #include &lt;stdio.h&gt;</td>
</tr>
</tbody>
</table>
| def main(): print “hello world” | int main() {
| main() | 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( ): 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.
Type Matters!

• No self-identifying data
  – Looking at a sequence of bits doesn’t tell you what they mean
  – Could be signed, unsigned integer
  – Could be floating-point number
  – Could be part of a string

• The machine interprets what those bits mean!
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;          float temperature;
  humidity = 20;         temperature = 32.5
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:
  ```c
  int humidity;
  humidity = 20;
  ```
- Only represents integers
- Small range, high precision
- Faster arithmetic
- (Maybe) less space required

Floating Point (float, double)
- Example:
  ```c
  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

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Operators: consider the type

- **Arithmetic**: +, -, *, /, % (numeric type operands)
  
  /: operation and result type depends on operand types:
  - Two `int` operands: `int` division truncates the result → 3/2 is 1
  - One or two `float` or `double` operands: floating-point 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: consider the type

- **Relational** (operands any type, result integer “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 integer “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. #1: (!10) || (5 > 2)
   - A True True
   - B True False
   - C False True
   - D False False

2. #2: (-1) && (!5 > -1)
   - A True True
   - B True False
   - C False True
   - D False False
## Conditional Statements

<table>
<thead>
<tr>
<th>Basic if statement:</th>
<th>With optional else:</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>if (&lt;boolean expr&gt;) {</code></td>
<td><code>if (&lt;boolean expr&gt;) {</code></td>
</tr>
<tr>
<td><code>  if-true-body</code></td>
<td><code>  if-true-body</code></td>
</tr>
<tr>
<td><code>}</code></td>
<td><code>}</code></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chaining if-else if</th>
<th>With optional else:</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>if (&lt;boolean expr1&gt;) {</code></td>
<td><code>if (&lt;boolean expr1&gt;) {</code></td>
</tr>
<tr>
<td><code>  if-expr1-true-body</code></td>
<td><code>  if-expr1-true-body</code></td>
</tr>
<tr>
<td><code>} else if (&lt;bool expr2&gt;) {</code></td>
<td><code>} else if (&lt;bool expr2&gt;) {</code></td>
</tr>
<tr>
<td><code>  else-if-expr2-true-body</code></td>
<td><code>  else-if-expr2-true-body</code></td>
</tr>
<tr>
<td><code>  (expr1 false)</code></td>
<td><code>  (expr1 false)</code></td>
</tr>
<tr>
<td><code>}</code></td>
<td><code>}</code></td>
</tr>
<tr>
<td><code>...</code></td>
<td><code>...</code></td>
</tr>
<tr>
<td><code>} else if (&lt;bool exprN&gt;) {</code></td>
<td><code>} else if (&lt;bool exprN&gt;) {</code></td>
</tr>
<tr>
<td><code>  else-if-exprN-true-body</code></td>
<td><code>  else-if-exprN-true-body</code></td>
</tr>
<tr>
<td><code>}</code></td>
<td><code>}</code></td>
</tr>
</tbody>
</table>

Very similar to Python, just remember `{ }` are blocks
While Loops

• Basically identical to Python while loops:

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

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

```java
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
}

<nest 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 (<nest 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, with a few 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**

<table>
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<tr>
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<tbody>
<tr>
<td><code>print &quot;%d %s\t%f&quot; % (6, &quot;hello&quot;, 3.4)</code></td>
<td><code>printf(&quot;%d %s\t%f\n&quot;, 6, &quot;hello&quot;, 3.4);</code></td>
</tr>
</tbody>
</table>

| %d       | int placeholder (-13)     |
| %f or %g | float or double placeholder (9.6) |
| %c       | char placeholder (‘a’)    |
| %s       | string placeholder ("hello there") |
| \t \n   | tab character, new line character |
Data Collections in C

• Many complex data types out there (CS 35)

• C has a few simple ones built-in:
  – Arrays
  – Structures \texttt{(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
  – **Specify max capacity** (num buckets) when you declare an array variable (single memory chunk)

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

• C’s support for collections of values

• Often accessed via a loop:

```c
int arr[5];  // an array of 5 integers
float rates[40]; // an array of 40 floats
for (i=0; i < 5; i++) {
    arr[i] = i;
    rates[i] = (arr[i]*1.5)/4;
}
```

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

```c
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. (The memory **address**)**
  - `january_temps` (without brackets!) **Location of [0] in memory.**
  - Keep this in mind, we’ll return to it soon (functions).
Array Characteristics

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

- Indices start at 0! Why?
- The index refers to an **offset** from the start of the array
  - e.g., [3] means “three integers forward from the starting address”
int january_temps[31]; // Daily high temps

"january_temps"
Location of [0] in memory.

[0] [1] [2] [3] [4] ... [29] [30] [35]

↑ Array bucket indices. ↑

• Asking for january_temps[35]?

C does NOT do bounds checking.

• Python: error
• C: “Sure! I don’t care ..” <ominous silence while bad things happen>
Characters and Strings

• A character (type `char`) is numerical value that holds one letter.
  ```c
  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?
  – American Standard Code for Information Interchange (ASCII) standard says so.
<table>
<thead>
<tr>
<th>Dec</th>
<th>Hex</th>
<th>Char</th>
<th>Dec</th>
<th>Hex</th>
<th>Char</th>
<th>Dec</th>
<th>Hex</th>
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<th>Dec</th>
<th>Hex</th>
<th>Char</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>00</td>
<td>Null</td>
<td>32</td>
<td>20</td>
<td>Space</td>
<td>64</td>
<td>40</td>
<td>B</td>
<td>96</td>
<td>60</td>
<td>'</td>
</tr>
<tr>
<td>1</td>
<td>01</td>
<td>Start of heading</td>
<td>33</td>
<td>21</td>
<td>!</td>
<td>65</td>
<td>41</td>
<td>A</td>
<td>97</td>
<td>61</td>
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<td>02</td>
<td>Start of text</td>
<td>34</td>
<td>22</td>
<td>&quot;</td>
<td>66</td>
<td>42</td>
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<td>104</td>
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<td>Horizontal tab</td>
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<td>29</td>
<td>)</td>
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<td>105</td>
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<td>0A</td>
<td>Line feed</td>
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<td>2A</td>
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<td>4A</td>
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<td>106</td>
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<td>13</td>
<td>0D</td>
<td>Carriage return</td>
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<td>4D</td>
<td>M</td>
<td>109</td>
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<tr>
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<td>Shift out</td>
<td>46</td>
<td>2E</td>
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<td>4E</td>
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<td>n</td>
</tr>
<tr>
<td>15</td>
<td>0F</td>
<td>Shift in</td>
<td>47</td>
<td>2F</td>
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<td>79</td>
<td>4F</td>
<td>O</td>
<td>111</td>
<td>6F</td>
<td>o</td>
</tr>
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<td>Data link escape</td>
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<td>30</td>
<td>0</td>
<td>80</td>
<td>50</td>
<td>P</td>
<td>112</td>
<td>70</td>
<td>p</td>
</tr>
<tr>
<td>17</td>
<td>11</td>
<td>Device control 1</td>
<td>49</td>
<td>31</td>
<td>1</td>
<td>81</td>
<td>51</td>
<td>Q</td>
<td>113</td>
<td>71</td>
<td>q</td>
</tr>
<tr>
<td>18</td>
<td>12</td>
<td>Device control 2</td>
<td>50</td>
<td>32</td>
<td>2</td>
<td>82</td>
<td>52</td>
<td>R</td>
<td>114</td>
<td>72</td>
<td>r</td>
</tr>
<tr>
<td>19</td>
<td>13</td>
<td>Device control 3</td>
<td>51</td>
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</table>
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...

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

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

Examples:

```c
char food[6] = "Pizza";
```

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>i</th>
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</table>

(Other memory)
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?).
0 is the “Null character”

Special stuff over here in the lower values.

<table>
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</table>
A character (type `char`) is a 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:

```c
char name[20] = "Pizza";
```
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 field values of a struct variable
Suppose we want to represent a student type.

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

// Variable bob is of type struct student
struct student bob;

// Set name (string) with strcpy()
strcpy(bob.name, "Robert Paulson");
bob.grad_year = 2019;
bob.gpa = 3.1;

printf("Name: %s, year: %d, GPA: %f", bob.name, bob.grad_year, bob.gpa);
```
Arrays of Structs

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

//create an array of struct students!
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

```c
struct student classroom[50];
strcpy(classroom[0].name, "Alice");
classroom[0].grad_year = 2019;
classroom[0].gpa = 4.0;
strcpy(classroom[1].name, "Bob");
classroom[1].grad_year = 2020;
classroom[1].gpa = 3.1
strcpy(classroom[2].name, "Cat");
classroom[2].grad_year = 2021;
classroom[2].gpa = 3.4
```
Struct: Layout in Memory

classroom:

<table>
<thead>
<tr>
<th>'A'</th>
<th>'l'</th>
<th>'i'</th>
<th>'c'</th>
<th>'e'</th>
<th>\0</th>
<th>...</th>
<th>'B'</th>
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<th>'C'</th>
<th>'a'</th>
<th>'t'</th>
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<td>3.4</td>
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</tr>
</tbody>
</table>
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;
}
```
Function Arguments

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

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

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

```
main:
  x:  
  y:  
```

Stack
Function Arguments

Arguments are **passed by value**

– The function gets a separate **copy** of the passed variable

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

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

```
Stack

main:

x: 4
y: 7
```
Arguments are **passed by value**

– The function gets a separate **copy** of the passed variable

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

int main() {
    // declare two integers
    int x, y;
    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

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int func(int a, int b) {
    a = a + 5;
    return a - b;
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int main() {
    // declare two integers
    int x, y;
    x = 4;
    y = 7;
    y = func(x, y);
    printf("%d, %d", x, y);
}
```
Arguments are **passed by value**

- The function gets a separate copy of the passed variable

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

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

![Stack diagram]

**Note:** This doesn’t change!

**No impact on values in main!**
Function Arguments

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

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

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

```
main:
 Stack
 x: 4
 y: 2
```
Function Arguments

Arguments are **passed by value**

- The function gets a separate **copy** of the passed variable

```c
int func(int a, int b) {
    a = a + 5;
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int main() {
    // declare two integers
    int x, y;
    x = 4;
    y = 7;
    y = func(x, y);
    printf("%d, %d", x, y);
}
```

Output: 4, 2
```c
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?

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?

```c
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    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]);
}
```
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    y = 1;
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What will this print?

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    values[0] = 5;
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    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)