# Computer Science & Engineering 155E
# Problem Solving Using Computers

Lecture 06 - Modular Programming

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## Chapter 6 - Outline



## Overview

- Chapter 3: separate components – functions – of a program, corresponding to individual steps in a problem solution.
  - Provide input to a function as *parameters*
  - Returning (at most) a **single** value (output)
- Now: we learn how to connect functions to create a program system – an arrangement of parts that makes your program pass information from one function to another.

## Functions with Simple Outputs

`function([argument list])`

- Argument lists provide the communication links between the `main` function and its functions (sub-programs).
- Arguments enable a function to manipulate different data each time it is called.
- So far, we have passed inputs into a function and returned only one result value from a function.
- We can use output parameters to "return" multiple results from a function.

## Functions – Simple Outputs

How a function call works:

- When a function call executes, the computer allocates memory space on the *system stack* for each parameter.
- The value of each actual parameter is stored in the memory cell allocated to its corresponding formal parameter.
- The function body can access this value *locally*.

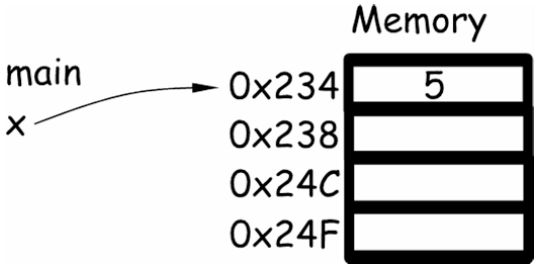
## Example Program

```
1  #include<stdio.h>
2
3  void myFunc(int arg);
4
5  int main(void) {
6      int x = 5;
7      printf("Before calling myFunc, x = %d\n", x);
8      myFunc(x);
9      printf("After calling myFunc,  x = %d\n", x);
10     return 0;
11 }
12
13 void myFunc(int arg) {
14     arg = 4;
15     printf("Inside function,       x = %d\n", arg);
16 }
```

## Passing By Value

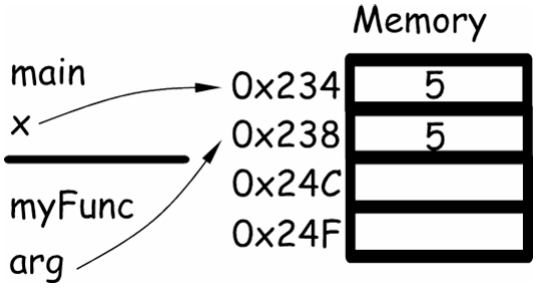
- This is known as *passing by value*
- The value of a variable is *copied* into a new memory cell for use by the function that is called
- Any changes to this new memory cell are *not* reflected in the calling function

## Functions – Simple Outputs



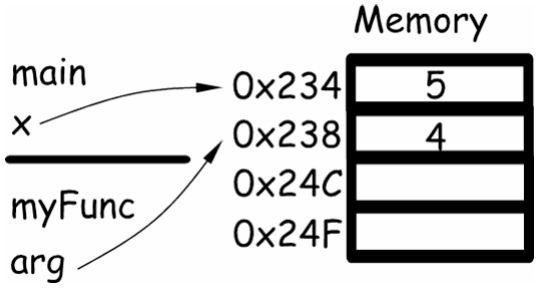

```
1 int main(void) {
2     int x = 5;
3     ...
```

## Functions – Simple Outputs



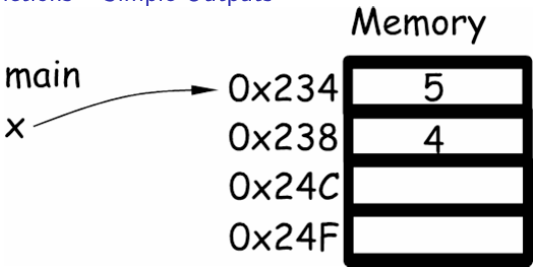

```
1     int x = 5;
2     myFunc(x);
3     ...
```

## Functions – Simple Outputs




```
1 void myFunc(int arg) {
2     arg = 4;
3 }
```

## Functions – Simple Outputs




```
1     int x = 5;
2     myFunc(x);
3     printf("%d\n", x);
4 }
```

**Output = 5**

## Pointers

- How can we allow access to variables when calling functions?
- The function needs to be told the *memory address* of the variable, not just its value
- Ultimately, the details are left to the compiler and system, but we do have to have some control in C.
- A *pointer* is a variable that holds ("points" to) a *memory address*
- A pointer must point to a memory address that holds a specific *type* of variable (`int`, `double` etc.)

## Pointers I

Declaring, Assigning

- Declare a pointer by giving it a type and using the asterisk:
  `int *myIntegerPointer;`
  `double *myDoublePointer;`
- Initially, you should assign a pointer to point to the `NULL` memory address: `int *myIntegerPointer = NULL;`
- Assigning values to a pointer is not the same as assigning values to a regular variable:
  `myIntegerPointer = 10;`
  means, that `myIntegerPointer` will now point to the *memory address* 10!

## Pointers II

Declaring, Assigning

- The memory address may not belong to the program, accessing or altering whatever is stored at memory address 10 is dangerous!
- Segmentation Faults, Bus errors, core dumps, etc.

## Pointers

Dereferencing

- To store a *value* at a memory address pointed to by a pointer, use the following syntax:
  `*myIntegerPointer = 10;`
- Now 10 is stored at the memory location pointed to by `myIntegerPointer`
- This is known as *dereferencing*

## Pointers

Referencing

- It is possible to get the memory address of regular variables; this is known as *referencing*
- Use the ampersand operator to get the memory address of a variable.

```
1  int k = 2;
2  int *my_pointer;
3  my_pointer = &k;
```

- Now `my_pointer` points to whatever memory address the variable `k` is located at!
- Changing the value of `k` can be accomplished by using either the variable `k` or by the reference `my_pointer`
- We have seen this when using `scanf`: the function needs the memory address in order to store the value!

## Pointers

Referencing - Example

```
1  #include<stdio.h>
2
3  int main(void)
4  {
5    int k = 10;
6    printf("The value of k = %d\n", k);
7    int *aPointerToK = &k;  /* this is a poniter to an integer
8                               type, set to the memory address
9                               of k */
10   printf("The memory address of k = %d\n", aPointerToK);
11   printf("The value stored at that memory address is %d\n", *aPointerToK);
12   *aPointerToK = 20; /* changing the value of k using its pointer */
13   printf("The value of k = %d\n",k);
14 }
```

## Pointers

Another Example

- We can use pointers as parameters to functions.
- Passing the memory address of a variable rather than its value allows the function to access and *change* the variable's value since the function now "knows" where the variable is stored
- Doesn't just have a copied value
- This is known as *passing by reference*
- Demonstration: two functions that swap values

## Pointers I

### Function Arguments

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

void swap(int a, int b);
void swap_ptr(int *a, int *b);

int main(int argc, char *argv[])
{
  int a = 42;
  int b = 2008;
  printf("a = %d, b = %d\n",a,b);
  swap(a,b);  /* doesn't work! */
  printf("a = %d, b = %d\n",a,b);
  swap_ptr(&a,&b);
  printf("a = %d, b = %d\n",a,b);
  return 0;
}

// (Ignore this)
```

## Pointers II

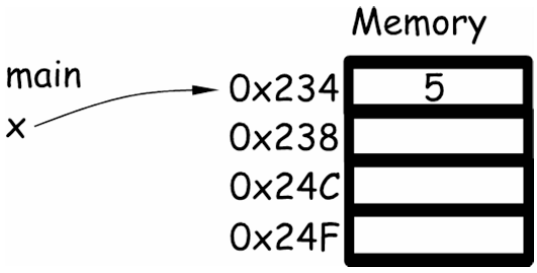
### Function Arguments

```c

void swap(int a, int b)
{
  int temp = a;
  a = b;
  b = temp;
}

void swap_ptr(int *a, int *b)
{
  int temp = *a;
  *a = *b;
  *b = temp;
}
```

## Example Program

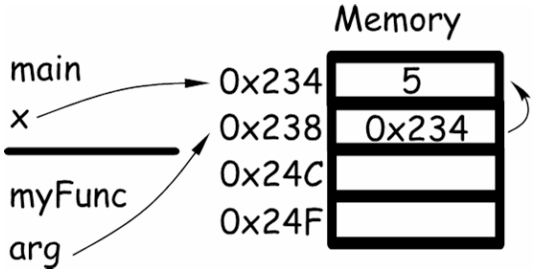
```c
void myFunc(int *arg);

int main(void) {
    int x = 5;
    myFunc(&x);
    printf("%d\n", x);
    return 0;
}

void myFunc(int *arg) {
    *arg = 4;
}
```

## Functions – Simple Outputs



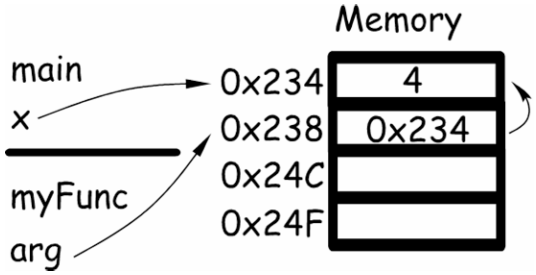

```c
int main(void) {
    int x = 5;
    ...
```

## Functions – Simple Outputs



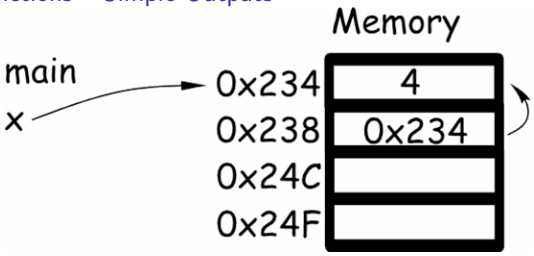

```c
    int x = 5;
    myFunc(&x);
    ...
```

## Functions – Simple Outputs




```c
void myFunc(int *arg) {
    *arg = 4;
}
```

## Functions – Simple Outputs




```
1      int x = 5;
2      myFunc(&x);
3      printf("%d\n", x);
4  }
```

**Output = 4**

## Returning Multiple Values

- C only allows *one* value to be returned by any function
- Sometimes its useful to have a function "return" more than one value
- Not directly possible, but we can use pointers as function parameters
- This allows the function to modify the values stored in the passed variables
- Calling function can then access these values
- In effect, multiple values are "returned" by the function

## Additional Example I

Sorting Three Numbers

```
1  #include <stdio.h>
2  void order(double *smp, double *lgp);
3
4  int main(void)
5  {
6     double num1, num2, num3;
7
8     printf("Enter three numbers separated by blanks> ");
9     scanf("%lf %lf %lf", &num1, &num2, &num3);
10
11    order(&num1, &num2);
12    order(&num1, &num3);
13    order(&num2, &num3);
14
15    printf("The numbers in ascending order are: ");
16    printf("%.2f %.2f %.2f\n", num1, num2, num3);
17    return 0;
18 }
```

## Additional Example II

Sorting Three Numbers

```
19
20 void order( double *a, double *b) {
21    double temp;
22    if (*a > *b) {
23       temp = *a;
24       *a = *b;
25       *b = temp;
26    }
27 }
```

## Exercise

**Exercise**

*Recall a previous exercise where we used two functions to compute the roots of a quadratic equation,*

$$ax^2 + bx + c$$

*using the quadratic equation:*

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

*Repeat this exercise, but pass $r_1, r_2$ parameters by reference so that only one function is necessary.*

## Answer I

```
1  #include<stdio.h>
2  #include<math.h>
3
4  void computeQuadraticRoots(double a, double b, double c, double *root1, double *root2);
5
6  int main(void)
7  {
8    double a, b, c;
9    printf("Enter a>");
10   scanf("%lf",&a);
11   printf("Enter b>");
12   scanf("%lf",&b);
13   printf("Enter c>");
14   scanf("%lf",&c);
15
16   double r1, r2;
17   computeQuadraticRoots(a,b,c,&r1,&r2);
18   printf("Equation: %.2fx^2 + %.2fx + %.2f\n",a,b,c);
19   printf("1st Root: %f\n",r1);
20   printf("2nd Root: %f\n",r2);
21
22   return 0;
23 }
24
25 /*
26  * We pass root1, root2 by reference so that we can store both values and the calling
27  * function has access to them.  Variables a, b, and c are passed by value because the
28  * function does not need to modify them.
29  */
30
```

## Answer II

```
31 void computeQuadraticRoots(double a, double b, double c, double *root1, double *root2)
32 {
33     *root1 = (-b + sqrt(b*b - 4*a*c)) / (2*a);
34     *root2 = (-b - sqrt(b*b - 4*a*c)) / (2*a);
35     return;
36 }
```

## Scope of Names

The **scope** of an identifier (variable name) refers to the region of a program (code block) where the identifier can be referenced (its value accessed).

- A variable declared inside a function is *local* to that function.
- Its value cannot be accessed or changed by other functions without a reference to its location
- You can use the same identifier (variable name) for different local variables in different functions

## Global Variables I

- Variables declared outside any function are *global* in scope.
- Any function can access or change their value
- The same identifier *cannot* be used in any other function
- Not the same thing as preprocessor macros (`#define PI 3.14`)

## Scope Example

```
1  #include<stdio.h>
2
3  /* global variables */
4  double pi = 3.14;
5  int globalInt = 42;
6
7  void changeVariables();
8
9  int main(void)
10 {
11   int a = 50; /* a is local to main */
12   printf("pi        = %f\n", pi);
13   printf("globalInt = %d\n", globalInt);
14   changeVariables();
15   printf("pi        = %f\n", pi);
16   printf("globalInt = %d\n", globalInt);
17   return 0;
18 }
19
20 void changeVariables()
21 {
22     int b = 20; /* b is local to changeVariables */
23     /* we cannot access the variable a in this function */
24     /* we can change pi and globalInt here though */
25     pi = 3.1415;
26     globalInt = 21;
27     return;
28 }
```

## Local Scope

- Variables declared inside nested *code blocks* are local to that code block
- Cannot be accessed outside the code block even within the same function
- Relevant when writing loops or conditions: you can declare a variable local to that code block

## Local Scope

```
1  int main(void)
2  {
3      int x = 10;   /* local to main, but any
4                       sub-program block can use it */
5      {
6          /* nested program block */
7          printf("inner block: x = %d\n",x);
8          /* y is local to the inner block */
9          int y = 10;
10         printf("inner block: y = %d\n",y);
11     }
12     printf("outer block: x = %d\n",x);
13     printf("outer block: y = %d\n",y); ← illegal
14
15     return 0;
16 }
```

## Using a function to read input

- Reading input and validating that it is correct can take a non-trivial amount of code.
- Convenient to use a function to read-validate-reread input
- Requires pointers

## Example

```
1  #include<stdio.h>
2
3  void getInput(int *evenNumber);
4
5  int main(void)
6  {
7    int myNumber;
8    getInput(&myNumber);
9    printf("Your number: %d\n",myNumber);
10   return 0;
11 }
12
13 void getInput(int *evenNumber)
14 {
15    int error;
16    do {
17       error = 0;
18       printf("Enter an even integer> ");
19       scanf("%d", evenNumber);
20
21       if(*evenNumber % 2 != 0)
22       {
23         printf("You did not enter an even number!\n");
24         error = 1;
25       }
26
27    } while (error);
28 }
```

## Program Notes

- Notice line 19:
  `scanf("%d", evenNumber);`
- No ampersand! That's because `evenNumber` is a *pointer*!
- `scanf` expects a pointer, using the ampersand gives the reference (memory address) of the variable
- Notice line 21:
  `if(*evenNumber % 2 != 0)`
- Asterisk dereferences the number, invalid without it!

## Debugging and Testing I

- As the number of statements in a program grows, the possibility of error also increases.
  - Reducing the number of operations each function performs also reduces the likelihood of errors.
  - Small functions are also much easier to read and test.
- **top-down testing** is the process of testing a program starting at `main` function and testing each function thereafter.
- We test a function with a **unit test** by writing a short driver function to call it.
  - This can be done in the main function by commenting out other function calls (comment out the head and legs of stickman to see if the body is correctly made).

## Debugging and Testing II

- **Bottom-up testing** is the process of separately testing individual functions before inserting them in a program system.
- **System integration tests** are tests of the entire system
- Try both top-down and bottom-up to make sure the program is fully tested

## Common Programming Errors I

- Many opportunities for errors arise when you use functions with parameter lists
  - Ensuring that the actual argument list has the same number of items as the formal parameter list.
  - Each input argument must be of a type that can be assigned to its corresponding formal parameter.
  - An actual output argument must be of the same pointer data type as the corresponding formal parameter.
- Proper use of parameters is difficult for beginning programmers to master, but it is an essential skill.

## Common Programming Errors II

- It is easy to introduce errors in a function that produces multiple results.
  - The output parameter must be of a pointer type (*)
  - The calling function neglects to send a correct variable address (using &)
- An identifier referenced outside of its scope will return an undeclared symbol syntax error.
- Commonly occurs if brackets {} are misplaced, or if too many open or close brackets are present in the program