User Defined Functions 1 Outline

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Often, we have a particular kind of value that we need to calculate over and over again, under a variety of circumstances. For example, in PP#5, we have to calculate the taxicab norm of the elements of each array.

\[
\text{taxicab\_norm1} = \text{initial\_sum}; \\
\text{for (element = first\_element;} \\
\quad \text{element < number\_of\_elements; element++}) \{ \\
\quad \text{taxicab\_norm1 +=} \\
\quad \quad \text{fabs(input\_value1[element]);} \\
\} /* for element */
\]
Standard Library Not Enough #2

We know that the algorithm for calculating the taxicab norm of the elements of an array is **always the same**.

So why should we have to write the same piece of code over and over and over and over and over and over?

Wouldn’t it be better if we could write that piece of code **just once** and then **reuse** it in many applications?
Calling a Function Instead

So, it’d be nice to replace this code:

```c
#define initial_sum
for (element = first_element;
    element < number_of_elements; element++) {
    taxicab_norm1 +=
        input_value1[element];
} /* for element */
```

with calls to a function that would calculate the taxicab norm for any array:

```c
taxicab_norm1 =
taxicab_norm(input_value1, number_of_elements);
```
Why User-Defined Functions?

taxicab_norm1 =
taxicab_norm(input_value1, number_of_elements);
...
taxicab_norm2 =
taxicab_norm(input_value2, number_of_elements);

Obviously, the designers of C weren’t able to anticipate the zillion things that we might need functions to do – such as calculate the taxicab norm of the elements of an array. So there are no standard library functions to calculate something that is application-specific. Instead, we as C programmers are going to have to define our own function to do it.
User Defined Functions Lesson 1

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User-Defined taxicab_norm

```c
float taxicab_norm(float* array, int number_of_elements)
{ /* taxicab_norm */
    const float initial_sum = 0.0;
    const int minimum_number_of_elements = 1;
    const int first_element = 0;
    const int program_failure_code = -1;
    float sum;
    int element;
    if (number_of_elements < minimum_number_of_elements) {
        printf("ERROR: can't have an array of length %d:
", number_of_elements);
        printf("It must have at least %d element.\n", minimum_number_of_elements);
        exit(program_failure_code);
    } /* if (number_of_elements < ...) */
    if (array == (float*)NULL) {
        printf("ERROR: can't calculate the taxicab norm of ");
        printf("a nonexistent array.\n");
        exit(program_failure_code);
    } /* if (array == (float*)NULL) */
    sum = initial_sum;
    for (element = first_element;
        element < number_of_elements; element++) {
        sum = sum + fabs(array[element]);
    } /* for element */
    return sum;
} /* taxicab_norm */
```
User-Defined Function Properties

In general, the definition of a user-defined function looks a lot like a program, except for the following things:

1. The function header begins with a return type that is appropriate for that function (for example, int, float, char).

2. The function has a name that is chosen by the programmer.

3. At the end of the function header is a list of arguments, enclosed in parentheses and separated by commas, each argument preceded by its data type.

4. The function may declare local named constants and local variables.

5. In the body of the function, the return statement tells the function what value to return to the statement that called the function.
Declarations Valid in Own Function #1

```c
float taxicab_norm (float* array, int number_of_elements) {
    /* taxicab_norm */
    const float initial_sum = 0.0;
    const int minimum_number_of_elements = 1;
    const int first_element = 0;
    const int program_failure_code = -1;
    float sum;
    int element;
    /* ... */
} /* taxicab_norm */
```

The compiler treats each function completely independently of the others.

Most importantly, the declarations inside a function – including the declarations of its arguments – apply only to that function, not to any others.
Declarations Valid in Own Function #2

```c
float taxicab_norm (float* array, int number_of_elements)
{ /* taxicab_norm */
    const float initial_sum   = 0.0;
    const int minimum_number_of_elements = 1;
    const int first_element    = 0;
    const int program_failure_code = -1;
    float sum;
    int element;
    /* ... */
} /* taxicab_norm */
```

For example:

- The declaration of `initial_sum` in the function `taxicab_norm` is visible only to the function `taxicab_norm` but not to the main function, nor to any other function.

If another function wants to have the same named constant, it has to have its own declaration of that named constant.
Return Type

float taxicab_norm (float* array, int number_of_elements)  
{  /* taxicab_norm */
    ...
}  /* taxicab_norm */

In the function header, immediately **before** the function name is a data type.

This data type specifies the **return type**, which is the data type of the value that the function will return.

The return type (for now) must be a basic scalar type (for example, int, float, char).

Notice that the return type of the function **is declared**, but **in a weird way** (in the function header, before the function name).
List of Arguments

```c
float taxicab_norm (float* array, int number_of_elements) {
    /* taxicab_norm */
} /* taxicab_norm */
```

At the end of the function header, immediately after the function name, is a list of arguments, enclosed in parentheses and separated by commas, each argument preceded by its data type.

Thus, the function’s arguments are declared, but not in the function’s declaration section.
Names of Arguments

float taxicab_norm (float* array, int number_of_elements)
{ /* taxicab_norm */
} /* 'taxicab_norm */

The names of the arguments in the function definition **DON’T** have to match the names of the arguments that are passed into the function by the `main` function (or by whatever other function) that calls the function.

They should be meaningful with respect to **the function in which they occur**, **NOT** with respect to the function(s) that call(s) that function.
Array Arguments

float taxicab_norm (float* array, int number_of_elements)

When passing an array argument, you must also pass an argument that represents the length of the array. Not surprisingly, this length argument should be of type int.

Also, when passing an array argument, you have two choices about how to express the argument’s data type. The first is above; the second is below:

float taxicab_norm (float array[], int number_of_elements)

In CS1313, we prefer * notation to [] notation.
Local Variables & Named Constants #1

float taxicab_norm (float* array, int number_of_elements)  
{ /* taxicab_norm */
    const float initial_sum = 0.0;
    const int minimum_number_of_elements = 1;
    const int first_element = 0;
    const int program_failure_code = -1;
    float sum;
    int element;
    ...
} /* taxicab_norm */

The function’s declaration section may contain declarations of

**local** named constants and **local** variables.

These names that are valid ONLY within the function that is
being defined.

On the other hand, these same names can be used with
totally different meanings by other functions (and by
the calling function).
Local Variables & Named Constants #2

```c
float taxicab_norm (float* array, int number_of_elements)
{
    /* taxicab_norm */
    const float initial_sum = 0.0;
    const int minimum_number_of_elements = 1;
    const int first_element = 0;
    const int program_failure_code = -1;
    float sum;
    int element;
    ...
} /* taxicab_norm */
```

Good programming style requires declaring:

1. **local named constants**, followed by
2. **local variables**

inside the function definition.

Note that these declarations should occur in the usual order.
Returning the Return Value #1

float taxicab_norm (float* array, int number_of_elements)
{ /* taxicab_norm */
    ...
    sum = initial_sum;
    for (element = first_element;
         element < number_of_elements; element++) {
        sum = sum + fabs(array[element]);
    } /* for element */
    return sum;
} /* taxicab_norm */

In the body of the function, the **return** statement tells the function to return the **return value**.

If the function does not return a value, then the compiler may get upset.

The return value is returned to the statement that called the function, and in some sense “replaces” the function call in the expression where the function call appears.
User Defined Functions Lesson 1

Returning the Return Value #2

float taxicab_norm (float* array, int number_of_elements) {
    /* taxicab_norm */
    ...
    sum = initial_sum;
    for (element = first_element;
        element < number_of_elements; element++) {
        sum = sum + fabs(array[element]);
    } /* for element */
    return sum;
} /* taxicab_norm */

The return value is returned to the statement that called
the function, and in some sense “replaces” the function call
in the expression where the function call appears.

taxicab_norm1 =
    taxicab_norm(input_value1, number_of_elements);
...

    taxicab_norm2 =
    taxicab_norm(input_value2, number_of_elements);
Declarations Inside Functions #1

The following point is EXTREMELY important:

For our purposes, the only user-defined identifiers that a given function is aware of – whether it’s the main function or otherwise – are those that are explicitly declared in the function’s declaration section, or in the function’s argument list.

(The above statement isn’t literally true, but is true enough for our purposes.)
Declarations Inside Functions #2

Thus, a function is aware of:

1. its arguments, if any;
2. its local named constants, if any;
3. its local variables, if any;
4. other functions that it has declared prototypes for, if any (described later).
Declarations Inside Functions #3

The function knows **NOTHING AT ALL** about variables or named constants declared inside any other function. It isn’t aware that they exist and cannot use them. Therefore, the **ONLY** way to send information from one function to another is by passing arguments from the calling function to the called function.
General Form of Function Definitions

```latex
returntype funcname ( datatype1 arg1, datatype2 arg2, ... )
{
    /* funcname */
    const localconst1type localconst1 = localvalue1;
    const localconst2type localconst2 = localvalue2;
    ...
    localvar1type localvar1;
    localvar2type localvar2;
    ...
    [ function body: does stuff ]
    return retvalreturnvalue;
} /* funcname */
```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

int main ()
{
    /* main */
    const int first_element = 0;
    const int program_failure_code = -1;
    const int program_success_code = 0;
    const int minimum_number_of_elements = 1;
    float* input_value1 = (float*)NULL;
    float taxicab_norm1;
    int number_of_elements, element;

    float taxicab_norm(float* array, int number_of_elements);
}
User-Defined Function Example #2

printf("How many elements are in the array\n");
printf(" (at least %d)?\n",
        minimum_number_of_elements);
scanf("%d", &number_of_elements);
if (number_of_elements <
        minimum_number_of_elements) {
    printf(  
        "ERROR: There must be at least %d elements\n",  
        minimum_number_of_elements);
    exit(program_failure_code);
} /* if (number_of_elements < ...) */

Idiotproof as soon as you input!
User-Defined Function Example #3

```c
input_value1 =
    (float*)malloc(sizeof(float) * number_of_elements);
if (input_value1 == (float*)NULL) {
    printf("ERROR: can't allocate a float array");
    printf(" of %d elements.\n", number_of_elements);
    exit(program_failure_code);
} /* if (input_value1 == (float*)NULL) */
```

Once you know the array length, you can dynamically allocate the array.

IMMEDIATELY after dynamically allocating the array, check that the allocation succeeded.
User-Defined Function Example #4

```c
printf("What are the %d elements?\n", number_of_elements);
for (element = first_element;
    element < number_of_elements; element++) {
    scanf("%f", &input_value1[element]);
} /* for element */
taxicab_norm1 =
taxicab_norm(input_value1, number_of_elements);
printf("The taxicab norm of ");
printf("the %d elements is %f.\n", number_of_elements, taxicab_norm1);
free(input_value1);
input_value1 = (float*)NULL;
return program_success_code;
} /* main */
```

Function call
User-Defined Function Example #5

% gcc -o taxicab_norm_func_test_all \ taxicab_norm_func_test_all.c taxicab_norm.c
% taxicab_norm_func_test_all

How many elements are in the array (at least 1)?

5

What are the 5 elements?

1.5  2.5  3.5  4.5  5.5

The taxicab norm of the 5 elements is 17.500000.
Another Used-Defined Function #1

```c
float cube_root (float base)
{ /* cube_root */
    const float cube_root_power = 1.0 / 3.0;
    return pow(base, cube_root_power);
} /* cube_root */
```

What can we say about this user-defined function?

1. Its name is `cube_root`.
2. Its return type is `float`.
3. It has one argument, `base`, whose type is `float`.
4. It has one local named constant, `cube_root_power`.
5. It has no local variables.
6. It calculates and returns the cube root of the incoming argument.
Another Used-Defined Function #2

float cube_root (float base)
{ /* cube_root */
    const float cube_root_power = 1.0 / 3.0;
    return pow(base, cube_root_power);
} /* cube_root */

So, cube_root calculates the cube root of a float argument and returns a float result whose value is the cube root of the argument.

Notice that cube_root simply calls the C standard library function pow, using a specific named constant for the exponent.

We say that cube_root is a wrapper around pow, or more formally that cube_root encapsulates pow.
float cube_root (float base)  
{ /* cube_root */  
    const float cube_root_power = 1.0 / 3.0;  
    return pow(base, cube_root_power);  
} /* cube_root */

Does the name of a user-defined function have to be meaningful?

From the compiler’s perspective, absolutely not; you could easily have a function named square_root that always returns 12.

But from the perspective of programmers, that’d be a REALLY REALLY BAD IDEA, and you’d get a VERY BAD GRADE.
```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

int main ()
{
    const int number_of_elements = 3;
    const int program_success_code = 0;
    float input_value1, cube_root_value1;
    float input_value2, cube_root_value2;
    float input_value3, cube_root_value3;
    float cube_root(float base);

    printf("What %d real numbers would you
            like the cube roots of?\n", number_of_elements);
    scanf("%f %f %f",
            &input_value1, &input_value2,
            &input_value3);
```
Another Function Example #2

cube_root_value1 = cube_root(input_value1);
cube_root_value2 = cube_root(input_value2);
cube_root_value3 = cube_root(input_value3);

printf("The cube root of %f is %f.\n", input_value1, cube_root_value1);
printf("The cube root of %f is %f.\n", input_value2, cube_root_value2);
printf("The cube root of %f is %f.\n", input_value3, cube_root_value3);

return program_success_code;

} /* main */

Function calls
Another Function Example #3

% gcc -o cube_root_scalar \
cube_root_scalar.c cube_root.c -lm
%
cube_root_scalar

What 3 real numbers would you like the cube roots of?
1 8 25

The cube root of 1.000000 is 1.000000.
The cube root of 8.000000 is 2.000000.
The cube root of 25.000000 is 2.924018.
Function Prototype Declarations #1

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

int main ()
{
    const int number_of_elements = 3;
    const int program_success_code = 0;
    float input_value1, cube_root_value1;
    float input_value2, cube_root_value2;
    float input_value3, cube_root_value3;
    float cube_root(float base);

    /* main */
    ... 

} /* main */

Notice this declaration:
float cube_root(float base);

This declaration is a **function prototype** declaration.
```
Function Prototype Declarations #2

float cube_root(float base);

This declaration is a function prototype declaration.

The function prototype declaration tells the compiler that there’s a function named `cube_root` with a return type of `float`, and that it’s declared external to (outside of) the function that’s calling the `cube_root` function.

You MUST declare prototypes for the functions that you’re calling.

Otherwise, the compiler will assume that, by default, the function returns an `int` and has no arguments.

If that turns out not to be the case (that is, most of the time), then the compiler will become ANGRY.
User Defined Functions Lesson 1

Actual Arguments & Formal Arguments

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

int main ()
{ /* main */
  ...
  cube_root_value1 = cube_root(input_value1);
  cube_root_value2 = cube_root(input_value2);
  cube_root_value3 = cube_root(input_value3);
  ...
} /* main */

float cube_root (float base)
{ /* cube_root */
  ...
} /* cube_root */
```

When we talk about the arguments of a function, we’re actually talking about **two very different kinds** of arguments: \textit{actual arguments} and \textit{formal arguments}. 
Actual Arguments

```c
#include <stdio.h>
#include <math.h>
int main ()
{ /* main */
  ...
  cube_root_value1 = cube_root(input_value1);
  cube_root_value2 = cube_root(input_value2);
  cube_root_value3 = cube_root(input_value3);
  ...
} /* main */
```

The arguments that appear in the call to the function – for example, `input_value1`, `input_value2` and `input_value3` in the program fragment above – are known as actual arguments, because they’re the values that actually get passed to the function.

**Mnemonic:** The aCtual arguments are in the function Call.
Formal Arguments

```c
float cube_root (float base)
{ /* cube_root */
  ...
} /* cube_root */
```

The arguments that appear in the `definition` of the function – for example, `base`, in the function fragment above – are known as `formal arguments`, because they’re the names that are used in the `formal definition` of the function.

**Jargon:** Formal arguments are also known as `dummy arguments`.

**Mnemonic:** The Formal arguments are in the function definition.
Yet Another Function Example #1

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

int main ()
{ /* main */
    const int first_element = 0;
    const int number_of_elements = 5;
    const int program_success_code = 0;
    float input_value[number_of_elements];
    float cube_root_value[number_of_elements];
    int   element;
    float cube_root(float base);

    printf("What %d real numbers would you
", number_of_elements);
    printf("  like the cube roots of?\n");
    for (element = first_element;
        element < number_of_elements; element++) {
        scanf("%f", &input_value[element]);
    } /* for element */
```
Yet Another Function Example #2

for (element = first_element;
    element < number_of_elements; element++) {
    cube_root_value[element] =
        cube_root(input_value[element]);
} /* for element */

for (element = first_element;
    element < number_of_elements; element++) {
    printf("The cube root of %.1f is %.1f.\n",
        input_value[element],
        cube_root_value[element]);
} /* for element */

return program_success_code;
} /* main */
Yet Another Function Example #3

\%
\% gcc -o cube_root_array \n   cube_root_array.c cube_root.c -lm
\%
\% cube_root_array

What 5 real numbers would you like the cube roots of?

1 8 25 27 32

The cube root of 1.000000 is 1.000000.
The cube root of 8.000000 is 2.000000.
The cube root of 25.000000 is 2.924018.
The cube root of 27.000000 is 3.000000.
The cube root of 32.000000 is 3.174802.