

Carleton University  
Department of Systems and Computer Engineering  
SYSC 2006 - Foundations of Imperative Programming - Fall 2019

**Lab 4 - C Arrays**

**Demo/Grading**

After you finish the exercises, a TA will review your solutions, ask you to run the test harness provided on cuLearn, and assign a grade. For those who don't finish early, a TA will grade the work you've completed, starting about 30 minutes before the end of the lab period. **Any unfinished exercises should be treated as "homework"; complete these on your own time, before your next lab.**

**Prerequisite Reading**

*C Arrays* (provided on cuLearn).

*How to Think Like a Computer Scientist, C Version 1.09*, Chapter 7 (Arrays). The URL for this book is in the course outline.

**General Requirements**

You have been provided with four files:

- `exercises.c` contains incomplete definitions of five functions you have to design and code.
- `exercises.h` contains the declarations (function prototypes) for the functions you'll implement. **Do not modify `exercises.h`.**
- `main.c` and `sput.h` implement a *test harness* (functions that will test your code, and a `main` function that calls these test functions). **Do not modify `main` or any of the test functions.**

For those students who already know C or C++: do not use structs or pointers. They aren't necessary for this lab.

Your functions must not be recursive. **Repeated actions must be implemented using C's `while`, `for` or `do-while` loop structures.**

None of the functions you write should perform console input; for example, contain `scanf` statements. None of your functions should produce console output; for example, contain `printf` statements.

**Your functions must not declare local variables that are arrays; in other words, they must not have declarations similar to:**

```
int temp[n];
```

Use the indexing (`[]`) operator to access array elements. Do not use pointers and pointer arithmetic (which have not yet been covered in lectures). This means your functions should not contain statements of the form `*ptr = ...` or `*(ptr + i) = ...`, where `ptr` is a pointer to an element in an array.

## Code style matters!

You must format your C code so that it adheres to one of two commonly-used conventions for indenting blocks of code and placing braces (K&R style or BSD/Allman style). Instructions for selecting the formatting style and formatting blocks of code are in the Lab 1 handout.

Spacing is also essential. Examples:

- Leave a space around each operator, e.g., use “`c = a + b;`” instead of “`c=a+b;`”
- Leave a space between variable declaration and the beginning of statements.
- Leave a space before and after a logical block, e.g., **while**, **for**, or **if** statement

Finish each exercise (i.e., write the function and verify that it passes all its tests) before you move on to the next one. Don't leave testing until after you've written all the functions.

## Getting Started

**Step 1:** Launch Pelles C and create a new project named `array_exercises`. (Instructions for creating projects are in the handout for Lab 1.) If you're using the 64-bit edition of Pelles C, select Win 64 Console program (EXE) as the project type. If you're using the 32-bit edition of Pelles C, select Win32 Console program (EXE). **Don't click the icons for Console application wizard, Win32 Program (EXE) or Win64 Program (EXE) - these are not correct types for this project.**

**Step 2:** Download files `main.c`, `exercises.c`, `exercises.h` and `sput.h` from cuLearn. Move these files into your `array_exercises` folder.

**Step 3:** Add `main.c` and `exercises.c` to your project. (Instructions for doing this are in the handout for Lab 1.) You don't need to add `exercises.h` and `sput.h` to the project. Pelles C will do this after you've added `main.c`.

**Step 4:** Build the project. It should build without any compilation or linking errors.

**Step 5: Read this step carefully. To use the test harness, you need to understand the output it displays.**

File `main.c` contains five *test suites*, one for each of the functions you'll write in Exercises 1-5.

Execute the project. The test harness will report errors as it runs, which is what we'd expect, because you haven't started working on the functions the harness tests. The console output will be similar to this:

```
== Entering suite #1, "Exercise 1: avg_magnitude()" ==

[1:1] test_avg_magnitude:#1 "avg_magnitude({5.7, 2.3, -1.9, 4.5,
6.2, -8.1, 9.7, 3.1}, 8)" FAIL
!   Type:      fail-unless
!   Condition: fabs(avg_magnitude(samples, 8) - 5.19) < 0.01
!   Line:      25
Expected result: 5.19 (approximately), actual result: -1.00

--> 1 check(s), 0 ok, 1 failed (100.00%)
Tests for remaining exercises won't be run until avg_magnitude passes
```

all tests.

```
==> 1 check(s) in 1 suite(s) finished after 0.00 second(s),
    0 succeeded, 1 failed (100.00%)
```

[FAILURE]

\*\*\* Process returned 1 \*\*\*

In Exercise 1, you'll complete the implementation of a function named `avg_magnitude`. The test suite for this function is named "Exercise 1: `avg_magnitude()`". This test suite has one *test function*, named `test_avg_magnitude`:

```
static void test_avg_magnitude(void)
{
    // The first statement declares an array and
    // initializes the elements

    double samples[] = { 5.7, 2.3, -1.9, 4.5, 6.2, -8.1, 9.7, 3.1 };

    sput_fail_unless(fabs(avg_magnitude(samples, 8) - 5.19) < 0.01,
                     "avg_magnitude({5.7, 2.3, -1.9, 4.5, 6.2, -8.1,
                     9.7, 3.1}, 8)");
    printf("Expected result: 5.19 (approximately), actual result:
           %.2f\n", avg_magnitude(samples, 8));
}
```

This function checks if `avg_magnitude` calculates the average magnitude of array `samples`, which contains eight doubles.

The condition that determines if `avg_magnitude` returns the correct value (5.19, approximately) may appear a bit strange:

$$\text{fabs}(\text{avg\_magnitude}(\text{samples}, 8) - 5.19) < 0.01$$

Because of the way floating-point numbers are represented in a computer, we should never use the `==` operator to compare them for equality. Two floating-point numbers are considered to be equal if they differ by a small amount. So, we subtract 5.19 (the expected result) from the value returned by `avg_magnitude`, and call `fabs` to obtain the absolute value of this difference. If this value is small (less than 0.01), we consider the value returned by `avg_magnitude` to be close enough to 5.19, and the test passes.

The incomplete implementation of `avg_magnitude` in `exercises.c` always returns -1.0, so this condition is `false`, and the test fails. The harness then displays the expected and actual results.

After the first suite has been executed, a message is displayed, indicating that the tests performed by test suite #1 failed:

```
--> 1 check(s), 0 ok, 1 failed (100.00%)
Tests for remaining exercises won't be run until avg_magnitude passes
all tests.
```

A summary is displayed as the test harness finishes:

```
==> 1 check(s) in 1 suite(s) finished after 1.00 second(s),
    0 succeeded, 1 failed (100.00%)
```

```
[FAILURE]
```

```
*** Process returned 1 ***
```

After you have correctly implemented `avg_magnitude`, the output displayed by `sput` should be:

```
== Entering suite #1, "Exercise 1: avg_magnitude()" ==
```

```
[1:1] test_avg_magnitude:#1 "avg_magnitude({5.7, 2.3, -1.9, 4.5,
6.2, -8.1, 9.7, 3.1}, 8)" pass
```

```
Expected result: 5.19 (approximately), actual result: 5.19
```

```
--> 1 check(s), 1 ok, 0 failed (0.00%)
```

When you review the output, you can quickly determine that your `avg_magnitude` function passes the test performed by `test_avg_magnitude`.

**Step 6:** Open `exercises.c` in the editor.

## Exercise 1

A sound (for example; a note played on a guitar or a spoken word) is recorded by using a microphone to convert the acoustical signal into an electrical signal. The electrical signal can be converted into a list of numbers that represent the amplitudes of *samples* of the electrical signal measured at equal time intervals. If we have  $n$  samples, we refer to the samples as  $x_0, x_1, x_2, \dots, x_{n-1}$ .

The *average magnitude*, or average absolute value, of a signal is given by the formula:

$$\text{average magnitude} = (|x_0| + |x_1| + |x_2| + \dots + |x_{n-1}|) / n = \sum |x_k| / n; \quad k = 0, 1, 2, \dots, n - 1$$

An incomplete implementation of a function named `avg_magnitude` is provided in `exercises.c`. The function prototype is:

```
double avg_magnitude(double x[], int n);
```

This function returns the average magnitude of the signal represented by an array of `doubles` containing  $n$  elements.

Finish the definition of this function. Your function should assume that  $n$  is positive; i.e., **it should not verify that  $n$  is  $> 0$  before calculating the average magnitude of the first  $n$  array elements.**

C's math library (`math.h`) contains a function that calculate the absolute values of real numbers. The function prototype is:

```
// Return the absolute value of x.
double fabs(double x);
```

Build the project, correcting any compilation errors, then execute the project. The test harness will run. Use the console output to help you identify and correct any flaws. Verify that your function passes all the tests in test suite #1 before you start Exercise 2.

## Exercise 2

The *average power* of a signal is the average squared value, which is given by the formula:

$$\text{average power} = (x_0^2 + x_1^2 + x_2^2 + \dots + x_{n-1}^2) / n = \sum x_k^2 / n; \quad k = 0, 1, 2, \dots, n - 1$$

An incomplete implementation of a function named `avg_power` is provided in `exercises.c`. The function prototype is:

```
double avg_power(double x[], int n);
```

This function returns the average power of the signal represented by an array of `doubles` containing  $n$  elements.

Finish the definition of this function. Your function should assume that  $n$  is positive; i.e., **it should not verify that  $n$  is  $> 0$  before calculating the average power of the first  $n$  array elements.**

Build the project, correcting any compilation errors, then execute the project. The test harness will run. Use the console output to help you identify and correct any flaws. Verify that your function passes all the tests in test suite #2 before you start Exercise 3.

## Exercise 3

An incomplete implementation of a function named `max` is provided in `exercises.c`. The function prototype is:

```
double max(double arr[], int n);
```

This function returns the maximum value in an array of `doubles` containing  $n$  elements.

Finish the definition of this function. Your function should assume that  $n$  is positive; i.e., **it should not verify that  $n$  is  $> 0$  before calculating the maximum value in the first  $n$  array elements.** Your function **cannot** assume that all elements in the array will be greater than any particular value; in other words, each element could be any one of the double-precision floating point numbers that can be represented in C.

Build the project, correcting any compilation errors, then execute the project. The test harness will run. Use the console output to help you identify and correct any flaws. Verify that your function passes all the tests in test suite # 3 before you start Exercise 4.

## Exercise 4

An incomplete implementation of a function named `min` is provided in `exercises.c`. The function prototype is:

```
double min(double arr[], int n);
```

This function returns the minimum value in an array of `doubles` containing  $n$  elements.

Finish the definition of this function. Your function should assume that  $n$  is positive; i.e., **it should not verify that  $n$  is  $> 0$  before calculating the minimum value in the first  $n$  array elements**. Your function **cannot** assume that all elements in the array will be smaller than any particular value; in other words, each element could be any one of the double-precision floating point numbers that can be represented in C.

Build the project, correcting any compilation errors, then execute the project. The test harness will run. Use the console output to help you identify and correct any flaws. Verify that your function passes all the tests in test suite #4 before you start Exercise 5.

### Exercise 5

There are several different ways to *normalize* a list of data. One common technique scales the values so that the minimum value in the list becomes 0, the maximum value in the list becomes 1, and the other values are scaled in proportion. For example, consider the values in this unnormalized list:

```
[-2.0, -1.0, 2.0, 0.0]
```

The normalization technique described above changes the list to:

```
[0.0, 0.25, 1.0, 0.5]
```

The formula for calculating the normalized value of the  $k^{\text{th}}$  value in a list,  $x_k$ , is:

$$\text{normalized value of } x_k = (x_k - \min_x) / (\max_x - \min_x)$$

where  $\min_x$  and  $\max_x$  represent the minimum and maximum values in the list, respectively. If you substitute  $\min_x$  for  $x_k$  in this formula, the dividend becomes 0, so the normalized value of  $\min_x$  is 0.0. If you substitute  $\max_x$  for  $x_k$  in this formula, the dividend and divisor have the same value, so the normalized value of  $\max_x$  is 1.0.

An incomplete implementation of a function named `normalize` is provided in `exercises.c`. This function is passed an array containing  $n$  real numbers, and normalizes the array using the technique described above.

Finish the definition of this function. Your function should assume that the array will contain at least two different numbers, so the expression  $\max_x - \min_x$  will never be 0. Your function must call the `max` and `min` functions you wrote for Exercises 3 and 4.

Build the project, correcting any compilation errors, then execute the project. The test harness will run. Use the console output to help you identify and correct any flaws. Verify that your function passes all the tests in test suite #5.

## **Wrap-up**

1. Remember to have a TA review your solutions to the exercises, assign a grade (Satisfactory, Marginal or Unsatisfactory) and have you initial the grading/sign-out sheet.
2. Remember to backup your project folder before you leave the lab; for example, copy it to a flash drive and/or a cloud-based file storage service. All files you've created on the hard disk will be deleted when you log out.