Array Lesson 2 Outline

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#include <stdio.h>

int main ()
{ /* main */
    const int z_length = 6;
    const int program_success_code = 0;
    float z[z_length], z_squared[z_length];
    int index;

    for (index = 0; index < z_length; index++) {
        printf("Input z[%d]:\n", index);
        scanf("%f", &z[index]);
    } /* for index */
    for (index = 0; index < z_length; index++) {
        z_squared[index] = z[index] * z[index];
    } /* for index */
    for (index = 0; index < z_length; index++) {
        printf("%19.7f^2 = %19.7f\n", z[index], z_squared[index]);
    } /* for index */
    return program_success_code;
} /* main */

“Use at least 19 spaces total, 7 of which are to the right of the decimal point.”
Reading Array Values Using for Loop #2

```bash
% gcc -o array_for_read_square array_for_read_square.c
% array_for_read_square

Input z[0]:
  5
Input z[1]:
  1.1
Input z[2]:
-33.33333
Input z[3]:
1.5e+05
Input z[4]:
0.0033333
Input z[5]:
1.5e-05

  5.0000000^2 =          25.0000000
  1.1000000^2 =           1.2100000
-33.3333282^2 =        1111.1107178
  150000.0000000^2 = 22499999744.0000000
  0.0033333^2 =           0.0000111
  0.0000150^2 =           0.0000000
```
#include <stdio.h>

int main ()
{ /* main */
  const int z_length = 6;
  const int program_success_code = 0;
  float z[z_length], z_squared[z_length];

  printf("Input z[%d]:\n", 0);
  scanf("%f", &z[0]);
  printf("Input z[%d]:\n", 1);
  scanf("%f", &z[1]);
  printf("Input z[%d]:\n", 2);
  scanf("%f", &z[2]);
  printf("Input z[%d]:\n", 3);
  scanf("%f", &z[3]);
  printf("Input z[%d]:\n", 4);
  scanf("%f", &z[4]);
  printf("Input z[%d]:\n", 5);
  scanf("%f", &z[5]);
for Loop: Like Many Statements #2

```c
z_squared[0] = z[0] * z[0];
z_squared[1] = z[1] * z[1];
printf("%19.7f^2 = %19.7f\n", 
z[0], z_squared[0]);
printf("%19.7f^2 = %19.7f\n", 
z[1], z_squared[1]);
printf("%19.7f^2 = %19.7f\n", 
z[2], z_squared[2]);
printf("%19.7f^2 = %19.7f\n", 
z[3], z_squared[3]);
printf("%19.7f^2 = %19.7f\n", 
z[4], z_squared[4]);
printf("%19.7f^2 = %19.7f\n", 
z[5], z_squared[5]);
return program_success_code;
} /* main */
```
for Loop: Like Many Statements #3

```bash
% gcc -o array_no_for_read_square array_no_for_read_square.c
% array_no_for_read_square
Input z[0]: 5
Input z[1]: 1.1
Input z[2]: -33.333333
Input z[3]: 1.5e+05
Input z[4]: 0.0033333
Input z[5]: 1.5e-05

5.0000000^2 = 25.0000000
1.1000000^2 = 1.2100000
-33.3333282^2 = 1111.1107178
150000.0000000^2 = 22499999744.0000000
0.0033333^2 = 0.0000011
0.0000150^2 = 0.0000000
```
Reading Array on One Line of Input #1

Instead of having to explicitly prompt for each array element, you can have a single prompt, and then the user can input all of the array elements’ values in a single line of input text.
Reading Array on One Line of Input #2

```c
#include <stdio.h>

int main ()
{ /* main */
    const int z_length = 6;
    const int program_success_code = 0;
    float z[z_length], z_squared[z_length];
    int index;

    printf("Input all %d values of z:\n", z_length);
    for (index = 0; index < 6; index++) {
        scanf("%f", &z[index]);
    } /* for index */
    for (index = 0; index < 6; index++) {
        z_squared[index] = z[index] * z[index];
    } /* for index */
    for (index = 0; index < 6; index++) {
        printf("%19.7f^2 = %19.7f\n",
                z[index], z_squared[index]);
    } /* for index */
    return program_success_code;
} /* main */
```
Reading Array on One Line of Input #3

% gcc -o array_for_read_1line_square array_for_read_1line_square.c
% array_for_read_1line_square

Input all 6 values of z:

5  1.1  -33.3333  1.5e+05  0.003333  1.5e-05

5.0000000^2 = 25.0000000
1.1000000^2 = 1.2100000
-33.3333282^2 = 1111.1107178
150000.0000000^2 = 22499999744.0000000
0.0033333^2 = 0.0000111
0.0000150^2 = 0.0000000
Aside: Why Named Constants Are Good

Consider the previous program.
What if we decide that we want to change the array length? Then we’d have to go in and change every for statement in the program.
That may not seem like much work in the previous program, but it can be a lot of work with large programs.
For example, the Advanced Regional Prediction System (ARPS), the numerical weather prediction program created by the Center for Analysis & Prediction of Storms, is a Fortran 90 program that is almost 150,000 lines long, with over 5,800 loops. Changing the loop bounds on such a program would take a huge amount of work.
#include <stdio.h>

int main ()
{ /* main */
    const int z_length = 6;
    const int lower_bound = 0;
    const int program_success_code = 0;
    float z[z_length], z_squared[z_length];
    int index;

    for (index = lower_bound; index < z_length; index++) {
        printf("Input z[%d]:\n", index);
        scanf("%f", &z[index]);
    } /* for index */

    for (index = lower_bound; index < z_length; index++) {
        z_squared[index] = z[index] * z[index];
    } /* for index */

    for (index = lower_bound; index < z_length; index++) {
        printf("%19.7f^2 = %19.7f\n",
            z[index], z_squared[index]);
    } /* for index */
    return program_success_code;
} /* main */
% gcc -o array_for_read_named array_for_read_named.c

% array_for_read_named
Input z[0]:
5
Input z[1]:
1.1
Input z[2]:
-33.33333
Input z[3]:
1.5e+05
Input z[4]:
0.0033333
Input z[5]:
1.5e-05

5.0000000^2 = 25.0000000
1.1000000^2 = 1.2100000
-33.3333282^2 = 1111.1107178
150000.0000000^2 = 22499999744.0000000
0.0033333^2 = 0.0000111
0.0000150^2 = 0.0000000
#include <stdio.h>

int main ()
{ /* main */
    const float initial_sum = 0.0;
    const int length = 10;
    const int lower_bound = 0;
    const int upper_bound = length - 1;
    const int program_success_code = 0;
    int a[length];
    int sum;
    int index;

    printf("Input values #%d to #%d:
", lower_bound, upper_bound);
    for (index = lower_bound; index < length; index++) {
        scanf("%d", &a[index]);
    } /* for index */
    sum = initial_sum;
    for (index = lower_bound; index < length; index++) {
        sum = sum + a[index];
    } /* for index */
    printf("The sum of those values is %d.\n", sum);
    return program_success_code;
} /* main */
Computing with Arrays #2

% gcc -o array_sum array_sum.c
% array_sum
Input values #0 to #9:
1 4 9 16 25 36 49 64 81 100
The sum of those values is 385.
```c
#include <stdio.h>

int main ()
{ /* main */
    const int length               = 10;
    const int lower_bound =  0;
    const int upper_bound = length - 1;
    const int program_success_code =  0;
    int a[length], b[Length], c[length];
    int index;

    printf("Input a values #\%d to #\%d:\n",
            lower_bound, upper_bound);
    for (index = lower_bound; index < length; index++) {
        scanf("%d", &a[index]);
    } /* for index */

    printf("Input b values #\%d to #\%d:\n",
            lower_bound, upper_bound);
    for (index = lower_bound; index < length; index++) {
        scanf("%d", &b[index]);
    } /* for index */

    printf("Input c values #\%d to #\%d:\n",
            lower_bound, upper_bound);
    for (index = lower_bound; index < length; index++) {
        scanf("%d", &c[index]);
    } /* for index */
} /* main */
```
for (index = lower_bound; index < length; index++) {
    c[index] = a[index] + b[index];
} /* for index */

printf("The pairwise sums of the ");
printf("%d array elements are:\n", length);
for (index = lower_bound; index < length; index++) {
    printf("%d ", c[index]);
} /* for index */
printf("\n");
return program_success_code;
} /* main */
Computing with Arrays #5

% gcc -o array_add_pairwise array_add_pairwise.c
% array_add_pairwise

Input a values #0 to #9:
1  8  27  64  125  216  343  512  729  1000

Input b values #0 to #9:
1  4  9  16  25  36  49  64  81  100

The pairwise sums of the 10 array elements are:
2 12 36 80 150 252 392 576 810 1100
Static Memory Allocation

Up to now, all of the examples of array declarations that we’ve seen have involved array sizes that are explicitly stated as **constants** (named or literal), and that therefore are known at compile time.

We call this kind of declaration **static**, because the size and location of the array is set by the compiler at compile time, and they never change after compilation.
Static Memory Allocation Example #1

```c
#include <stdio.h>

int main ()
{ /* main */
    const int a_length = 5;
    const int program_success_code = 0;
    int a[a_length];
    int count;

    for (count = 0; count < a_length; count++) {
        a[count] = 2 * count;
    } /* for count */
    for (count = 0; count < a_length; count++) {
        printf("a[%2d] = %2d\n", count, a[count]);
    } /* for count */
    return program_success_code;
} /* main */
```
Static Memory Allocation Example #2

```bash
% gcc -o array_for_mult array_for_mult.c
% array_for_mult

a[ 0] =  0
a[ 1] =  2
a[ 2] =  4
a[ 3] =  6
a[ 4] =  8
```
Static Sometimes Not Good Enough #1

Often, we want to use an array – or perhaps many arrays – whose sizes aren’t specifically known at compile time.
#include <stdio.h>
#include <stdlib.h>

int main ()
{ /* main */
    const int minimum_a_length  =  1;
    const int maximum_a_length  = 15;
    const int program_failure_code = -1;
    const int program_success_code =  0;
    int a[maximum_a_length];
    int a_length;
    int count;

    printf("How long will the array be (%d to %d)?\n", 
            minimum_a_length, maximum_a_length);
    scanf("%d", &a_length);
    if ((a_length < minimum_a_length) || 
            (a_length > maximum_a_length)) {
        printf("That’s not a valid array length!\n");
        exit(program_failure_code);
    } /* if ((a_length < minimum_a_length) || ...) */
for (count = 0; count < a_length; count++) {
    a[count] = 2 * count;
} /* for count */
for (count = 0; count < a_length; count++) {
    printf("a[%2d] = %2d\n", count, a[count]);
} /* for count */
return program_success_code;
} /* main */
Static Sometimes Not Good Enough #4

```bash
$ gcc -o array_for_mult_read array_for_mult_read.c
$ array_for_mult_read
How long will the array be (1 to 15)?
5

a[ 0] = 0
a[ 1] = 2
a[ 2] = 4
a[ 3] = 6
a[ 4] = 8
```
Static Memory Allocation Can Be Wasteful

If the size of an array – or at least the number of elements that we want to use – isn’t known at compile time, we can always simply allocate an array that’s at least as big as the biggest array that we could imagine needing.

Of course, we might imagine that number to be pretty big. On the one hand, memory is very cheap these days. On the other hand, we might reach the point where we can’t have the arrays we want, because we need too many arrays, any one of which might need to be big.

But what if we could allocate space for our arrays at runtime?
Dynamic Memory Allocation #1

*Dynamic memory allocation* means allocating space for an array *at runtime*.

To use dynamic memory allocation, we have to declare our array variable, not as a static array, but rather as a *pointer* to an array of the same data type:

```c
float* quiz1_score = (float*)NULL;
```

Notice that, when we declare the pointer, we initialize it to the *null* memory location, which means that the pointer doesn’t point to anything (yet).
We use the `malloc` function ("memory allocate") to allocate the array at runtime, once we know its length:

```c
quiz1_score = (float*)malloc(sizeof(float) * number_of_students);
```

The `(float*)` is called a **type cast**, which we won’t go into detail about right now. You **MUST** use it when you use `malloc`.

When the `malloc` function is called, it returns a pointer to a location in memory that is the first byte of an array whose size is the number of elements of the array that is being allocated, times the size of each of the elements – that is, exactly enough space to fit the array being allocated.
Dynamic Memory Allocation #3

Notice the `sizeof` function; it returns the number of bytes in a scalar of the given data type.

For example, on an Intel/AMD x86 computer under the `gcc` compiler, `sizeof(float)` returns 4.
After the call to `malloc`:

- If the allocation is **unsuccessful**, then the pointer will still be **null**.
- If the allocation is **successful**, then the pointer will be **something other than null**.

```c
quiz1_score = (float*)malloc(sizeof(float) * number_of_students);
if (quiz1_score == (float*)NULL) {
    printf("ERROR: the attempt to allocate
    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    \n    exit(program_failure_code);
} /* if (quiz1_score == (float*)NULL) */
```
Dynamic Memory Deallocation

Dynamic memory deallocation means freeing up the space for an array that has been dynamically allocated at runtime. Often, this is done at the end of the program, though not always.

In C, the deallocate command is named `free`.

For example, to deallocate a `float` array named `quiz1_score`, do this:

```c
free(quiz1_score);
quiz1_score = (float*)NULL;
```

Notice that, after deallocating the array pointed to by `quiz1_score`, we have to set `quiz1_score` to null. We sometimes refer to this as **nullifying** the pointer.
Dynamic Memory Allocation Example #1

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

int main ()
{ /* main */
    const int minimum_array_length = 1;
    const int program_failure_code = -1;
    const int program_success_code = 0;
    int* array = (int*)NULL;
    int array_length;
    int count;

    printf("How long will the array be (at least %d)?\n",
           minimum_array_length);
    scanf("%d", &array_length);
    if (array_length < minimum_array_length) {
        printf("That's not a valid array length!\n");
        exit(program_failure_code);
    } /* if (array_length < minimum_array_length) */
```
Dynamic Memory Allocation Example #2

```c
array = (int*)malloc(sizeof(int) * array_length);
if (array == (int*)NULL) {
    printf("ERROR: the attempt to allocate\n");
    printf(" array failed.\n");
    exit(program_failure_code);
} /* if (array == (int*)NULL) */
for (count = 0; count < array_length; count++) {
    array[count] = 2 * count;
} /* for count */
for (count = 0; count < array_length; count++) {
    printf("array[%2d] = %2d\n", count, array[count]);
} /* for count */
free(array);
array = (int*)NULL;
return program_success_code;
} /* main */
```
Dynamic Memory Allocation Example #3

```bash
% gcc -o array_for_mult_read_dynamic array_for_mult_read_dynamic.c
% array_for_mult_read_dynamic
How long will the array be (at least 1)? 0
That’s not a valid array length!
% array_for_mult_read_dynamic
How long will the array be (at least 1)? 5
array[ 0] =  0
array[ 1] =  2
array[ 2] =  4
array[ 3] =  6
array[ 4] =  8
```
Exercise: Mean #1

Given a list of $n$ real numbers

$$x_1, x_2, \ldots, x_n$$

the **mean** of the values in the list is an **average**, which is a value that is typical of the values in the list.

The mean, here denoted $\bar{x}$ (pronounced “x-bar”), is calculated as the sum of all the values in the list, divided by the number of values in the list:

$$\bar{x} = (x_1 + x_2 + \ldots + x_n) / n$$
Exercise: Mean #2

Write a program that:
1. greets the user;
2. prompts for, inputs and idiotproofs the number of elements to be used;
3. dynamically allocates an array of appropriate length and type;
4. prompts for and inputs all of the elements of the array (note that idiotproofing isn’t needed for this step);
5. calculates the mean;
6. outputs the list of values in the array;
7. outputs the mean;
8. deallocates the array.

The program should work for any positive number of float elements.

The body of the program must not have any numeric literal constants; all constants must be declared using appropriate user-defined identifiers. Don’t worry about comments, except for labeling block closes.