

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

Lab 7 - Developing a List Collection, First Iteration

Objective

In this lab, you'll begin the development of a C module that implements a list collection that is similar to a Python `list` or a Java `ArrayList`. You'll learn how we can build useful data structures in C by using pointers to connect dynamically allocated arrays and structs.

Attendance/Demo

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.**

Background

C (and C++) arrays have several limitations:

- An array's capacity is specified when the array is declared; for example, this statement declares an array named `numbers` that holds 10 integers: `int numbers[10];`

This capacity is fixed when the code is compiled; there is no way to increase the array's capacity at run-time.
- C doesn't provide an operator or standard library function that returns an array's capacity.
- C doesn't check for out-of-bounds array indices, which means code can access memory outside the array by using an out-of-bounds index. If `numbers` is declared this way:

`int numbers[10];`

the expressions `numbers[-1]` or `numbers[10]` will compile without error (even though the declared capacity of the array is 10). At run-time, these expressions will not cause the program to terminate with an error, even though they access memory outside of the array.

Many modern programming languages have addressed these limitations by providing a collection known as a *list*. Java provides a class named `ArrayList` and Python has a built-in type (class) named `list`. Although C++ supports C-style arrays for backwards compatibility, many C++ programmers instead use the `vector` class that is part of the C++ Standard Template Library.

Here are the important differences between C arrays and the lists provided by many

programming languages:

- A list increases its capacity as required. As you append items to a list or insert items in a list, the list will automatically grow (increase its capacity) when it becomes full.
- A list keeps track of its *length* or *size* (that is, the number of items currently stored in the list). Python has a built-in `len` function that takes one argument, a list, and returns the list's length. Java's `ArrayList` class provides a *method* (another name for a function) named `size`, which returns the number of items in the list.
- List operations will often generate a run-time error if you specify an out-of-range list index. By default, this normally results in an error message being displayed, then the program terminates.
- In Python, many common list operations are provided by built-in operators, functions and methods. Java's `ArrayList` class defines several methods that provide similar operations. Compare this with C and C++ arrays, which provide very few built-in array operations.

Over the next couple of labs, you're going to develop a C module that implements a list collection. This collection will provide many of the same features as Python's `list`, Java's `ArrayList` and C++'s `vector`, and will be a useful module to have in your "toolbox" if you end up doing a lot of C programming.

In the first version of the list module, we won't attempt to implement all the features of Python or Java lists. Although our list will be based on a dynamically-allocated array, in this first iteration it will have fixed capacity; in other words, it won't grow when it becomes full. We're going to focus on developing functions that provide the core list operations. You'll refine and extend your module in a subsequent lab.

We'll use the following terms when working with lists:

- list *length*: the number of items currently stored in a list
- list *size*: a synonym for length
- list *capacity*: the maximum number of items that can be stored in a list

Make sure you understand the difference between a list's length (size) and its capacity.

General Requirements

You have been provided with four files:

- `array_list.c` contains incomplete definitions of several functions you have to design and code;
- `array_list.h` contains the declaration of the `list_t` structure, as well as declarations

(function prototypes) for the functions you'll implement. **Do not modify `array_list.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.**

None of the functions you write should call `calloc`, `realloc` or `free`. Only `list_construct` (Exercise 1) is permitted to call `malloc`.

None of the functions you write should perform console input; i.e., contain `scanf` statements. Unless otherwise specified, none of your functions should produce console output; i.e., contain `printf` statements.

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.

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

Getting Started

Step 1: Launch Pelles C and create a new project named `array_list`. (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`, `array_list.c`, `array_list.h` and `sput.h` from cuLearn. Move these files into your `array_list` folder.

Step 3: Add `main.c` and `array_list.c` to your project. (Instructions for doing this are in the handout for Lab 1.) You don't need to add `array_list.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: Execute the project. The test harness (the functions in `main.c`) will report several errors as it runs, which is what we'd expect, because you haven't started working on the functions the harness tests.

Step 6: Open `array_list.c` in the editor and do Exercises 1 through 7.

Exercise 1

In a recent lecture, you learned how dynamically allocate an array from the heap; for example, this code fragment allocates an array that has the capacity to hold 100 integers and stores the pointer to the array in variable `pa`. It then initializes all the array elements to 0:

```
int *pa;
pa = malloc(100 * sizeof(int)); // pa points to the first
                                // element in the array
assert(pa != NULL);
for (int i = 0, i < 100; i += 1) {
    pa[i] = 0;
}
```

In another lecture, you learned how to dynamically allocate a `struct` from the heap; for example, this code fragment allocates a `struct` that stores the Cartesian coordinates of a point:

```
typedef struct {
    int x;
    int y;
} point_t;

point_t *pt;
pt = malloc(sizeof(point_t)); // pt points to the point_t
                               // struct in the heap
assert(pt != NULL);
```

The data structure that underlies our list collection will combine these two concepts. It will consist of a dynamically-allocated `struct`, and one of `struct`'s members will be a pointer to a dynamically-allocated array.

Open `array_list.h`. This file contains the declaration for a `struct` named `list_t`:

```
typedef struct {
    int *elems; // Pointer to the backing array.
    int capacity; // Maximum number of elements in the list.
    int size; // Current number of elements in the list.
} list_t;
```

Notice that the type of member `elems` is "pointer to `int`". This member will be initialized with the pointer to an array of integers that has been allocated from the heap.

In `array_list.c` (not `array_list.h`) you have been provided with an incomplete definition of a function named `list_construct` that, when completed, will return a pointer to a new, empty list of integers with a specified capacity. The function prototype is:

```
list_t *list_construct(int capacity);
```

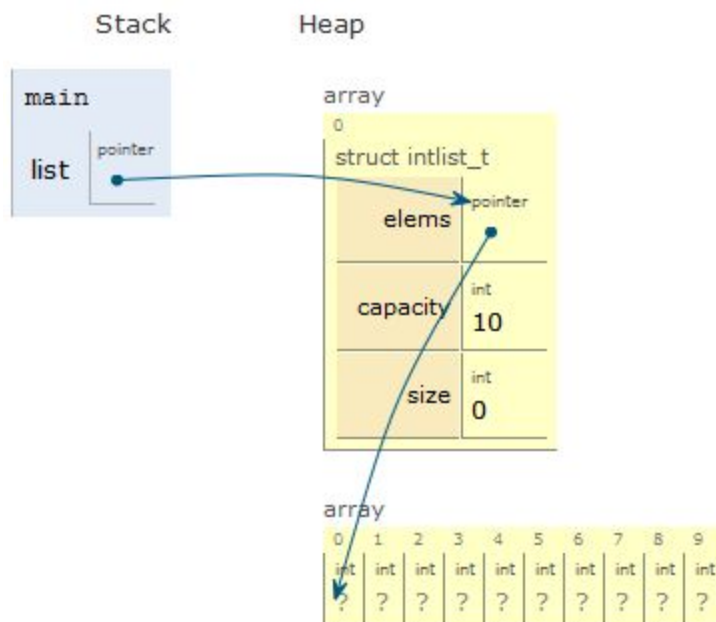
You must modify the function so that it correctly implements all of the following requirements:

- The function terminates (via `assert`) if `capacity` is less than or equal to 0.
- The function allocates two blocks of memory from the heap:
 - One block is the list's backing array; that is, a dynamically-allocated array with the specified capacity.
 - The other block is the dynamically-allocated `list_t` struct. Your `list_construct` function will return the pointer to this struct.
- The function terminates (via `assert`) if memory cannot be allocated for the struct or the array.
- The function initializes the struct's `elems`, `capacity` and `size` members.

Suppose `main` contains this statement:

```
list_t *list = list_construct(10);
```

Here's a C Tutor diagram that depicts memory after this statement is executed:



Complete the function definition.

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 `list_construct` passes all the tests in test suite #1.

Before attempting the remaining exercises, consider using C Tutor to visualize the execution of your `list_construct` function, step-by-step. Copy the definition of `list_construct` to the C Tutor editor. You'll also need to copy/paste the declaration of the `list_t` struct (from `array_list.h`) to C Tutor and write a short main function that calls `list_construct`.

Completing the remaining exercises will be easier if you can visualize how the functions use the list's data structure.

Interlude (read this before attempting the remaining exercises)

All the functions in Exercises 2 through 7 have a parameter of type `list_t *`:

```
return_type fn_name(list_t *list, ...);
```

In other words, the first argument passed to these functions is a pointer to a list.

The function can access element `i` in the list's backing array by using this expression:

```
list->elems[i]
```

This expression might appear complicated, so let's break it into pieces:

- Parameter `list` is a pointer to the list; i.e., a pointer to an `list_t` struct.
- Recall that the expression `list->elems` is equivalent to `(*list).elems`; that is, we're selecting the `elems` member in the struct pointed to by `list`. Member `elems` is a pointer to an `int`; specifically, it points to the first element in an array of integers. Therefore, the expression `list->elems` yields the pointer to the first element in the list's backing array.
- Because `elems` is a pointer to an array, we can access individual elements using the `[]` operator. So, `list->elems[i]` is the element at position `i` in the array that is pointed to by `list->elems`; in other words, element `i` in the list's backing array.

Exercise 2

File `array_list.c` contains an incomplete definition of a function named `list_append` that appends an integer to the end of a list. The function prototype is:

```
_Bool list_append(list_t *list, int element)
```

This function should terminate (via `assert`) if parameter `list` is `NULL`.

Parameter `element` contains the value that will be appended to the list if the list is not full. (In other words, `element` will be stored in the list only if it has room for at least one more element.) If `element` was appended, the function should return `true`. If the function was not successful, because the list was full, it should leave the list unchanged and return `false`.

Complete the function definition.

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 `list_append` passes all the tests in test suite #2.

Exercise 3

File `array_list.c` contains an incomplete definition of a function named `list_capacity` that returns the capacity of a list. The function prototype is:

```
int list_capacity(const list_t *list)
```

This function should terminate (via `assert`) if parameter `list` is `NULL`.

Complete the function definition.

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 `list_capacity` passes all the tests in test suite #3.

Exercise 4

File `array_list.c` contains an incomplete definition of a function named `list_size` that returns the size of a specified list. The function prototype is:

```
int list_size(const list_t *list)
```

This function should terminate (via `assert`) if parameter `list` is `NULL`.

Complete the function definition.

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 `list_size` passes all the tests in test suite #4.

Exercise 5

File `array_list.c` contains an incomplete definition of a function named `list_get` that returns the element located at a specified index (position) in a list. The function prototype is:

```
int list_get(const list_t *list, int index)
```

This function should terminate (via `assert`) if parameter `list` is `NULL` or if `index` is not in the range `0 .. list_size()-1`, inclusive.

Complete the function definition.

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 `list_get` passes all the tests in test suite #5.

Exercise 6

File `array_list.c` contains an incomplete definition of a function named `list_set` that stores an integer at a specified index (position) in a list. The function will return the integer that was previously stored at that index. The function prototype is:

```
int list_set(list_t *list, int index, int element)
```

Parameter `element` contains the value that will be stored in the list.

This function should terminate (via `assert`) if parameter `list` is `NULL` or if `index` is not in the range `0 .. list_size()-1`, inclusive.

Complete the function definition.

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 `list_set` passes all the tests in test suite #6.

Exercise 7

File `array_list.c` contains an incomplete definition of a function named `list_removeall` that empties a list. The function prototype is:

```
void list_removeall(list_t *list)
```

This function should terminate (via `assert`) if parameter `list` is `NULL`.

To illustrate the use of this function, here is a code fragment that allocates a new, empty list. It appends three integers to the list, then calls `list_removeall`:

```
list_t *my_list = list_construct(10); // list has capacity 10, size 0
_Bool success;

success = list_append(my_list, 2); // list has capacity 10, size 1
success = list_append(my_list, 4); // list has capacity 10, size 2
success = list_append(my_list, 6); // list has capacity 10, size 3
list_removeall(my_list);           // list has capacity 10, size 0
```

When `list_removeall` returns, the list has room for 10 integers.

Complete the function definition. This function should not free any of the memory that was allocated by `list_construct`, or call `malloc`.

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 `list_removeall` passes all the tests in test suite #7.

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 attendance/grading 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.
3. You'll need your `array_list` module for Lab 8. That lab assumes your module passes all the tests in the Lab 7 test harness. Remember to complete any unfinished exercises before your next lab period.

Homework Exercise - Visualizing Program Execution

In the final exam, you will be expected to be able to draw diagrams that depict the execution of short C programs that use pointers to dynamically allocated `structs` and arrays, using the same notation as C Tutor. This exercise is intended to help you develop your code tracing/visualization skills when working with programs that allocate memory from the heap.

1. The *Labs* section on cuLearn has a link, **Open C Tutor in a new window**. Click on this link.
2. Copy the `list_t` declaration from `array_list.h` and your solutions to Exercises 1-7 into the C Tutor editor.
3. Write a short `main` function that exercises your list functions.
4. *Without using C Tutor*, trace the execution of your program. Draw memory diagrams that depict the program's activation frames just before each of your list functions returns. Use the same notation as C Tutor.
5. Use C Tutor to trace your program one statement at a time, stopping just before each function returns. Compare your diagrams to the visualizations displayed by C Tutor.