ECE36800 Programming Assignment #1

Due Monday, February 15, 2021, 11:59pm

This assignment covers learning objective 1: An understanding of basic data structures, including stacks, queues, and trees; learning objective 3: An ability to apply appropriate sorting and search algorithms for a given application.

This assignment is to be completed on your own. You will implement Shell sort on an array and Shell sort on a linked list. In both cases, you will use the following sequence for Shell sort:

$$\{h(1) = 1, h(2) = 4, h(3) = 13, \ldots, h(i), h(i+1) = 3 \times h(i) + 1, \ldots, h(p)$$

where $h(p)$ is the largest number in the sequence that is smaller than the size of the array to be sorted.

You are not allowed to pre-compute the sequence and store them in your program. The sequence has to be generated (but not stored) as part of your Shell sort functions.

Functions to be written

We provide you three `.h` files: `shell_array.h`, `shell_list.h`, and `list_of_list.h`. You will develop the functions declared in these `shell_array.h` and `shell_list.h` files in the corresponding `.c` files: `shell_array.c` and `shell_list.c`. These `.c` files and `pa1.c` are the only files you will submit for this assignment.

If you need additional helper functions, you should define them in the corresponding `.c` files. It is best that these helper functions be declared as static. Do not name these help functions with a prefix of two underscores "__".

You are allowed to use only structures defined in `shell_list.h` and `list_of_list.h` in this assignment. You are not allowed to define new structures.

Do not modify the provided `.h` files because you are not submitting them. Any modifications you have made to the provided `.h` will not be reflected in the `.h` files that we use to evaluate your submission.

Functions you will write for `shell_array.c`:

There are three functions that deal with performing Shell sort on an array. The first two functions `Array_Load_From_File` and `Array_Save_To_File`, are not for sorting, but are needed to transfer the `long` integers to be sorted from and to a file in **binary form** to and from an array, respectively.

```
long *Array_Load_From_File(char *filename, int *size)
```

The size of the binary file whose name is stored in the `char` array pointed to by `filename` should determine the number of `long` integers in the file. The size of the **binary** file should be a multiple of `sizeof(long)`. You should allocate sufficient memory to store all `long` integers in the file into an array and assign to `*size` the number of integers you have in the array. The function should return the address of the memory allocated for the `long` integers.

You may assume that all input files that we will use to evaluate your code will be of the correct format.

Note that we will not give you an input file that stores more than `INT_MAX` `long` integers (see `limits.h` for `INT_MAX`). If the input file is empty, an array of size 0 should still be created and `*size` be assigned 0. You should return a NULL address and assign 0 to `*size` if you could not open the file or fail to allocate sufficient memory.

It is important that the caller function, e.g., the `main` function, has an `int` variable to store the size of the array, and pass the address of this variable into `long *Array_Load_From_File(char *filename, int *size)` using the `size` parameter.

```
int Array_Save_To_File(char *filename, long *array, int size)
```

The function saves `array` to an external file specified by `filename` in **binary format**. The output file and the input file have the same format. The integer returned should be the number of `long` integers in the `array` that have been successfully saved into the file.

If `array` is NULL or `size` is 0, an empty output file should be created.

```
void Array_Shellsort(long *array, int size, long *n_comp)
```

The function takes in an `array` of `long` integers and sort them (using the Shell sorting algorithm). `size` specifies the number of integers to be sorted, and `*n_comp` should store the number of comparisons involving items in `array` throughout the entire process of sorting. This function will have to use the sequence $\{h(1) = 1, h(2) = 4, h(3) = 13, \ldots, h(i), h(i+1) = 3 \times h(i) + 1, \ldots\}$ for sorting. You may choose to use insertion sort or bubble sort to sort each sub-array. (If you use selection sort to sort each sub-array, your program will most likely have high run-time complexity. Why?)

A comparison that involves an item in `array`, e.g., `temp < array[i]` or `array[i] < temp`, corresponds to one comparison. A comparison that involves two items in `array`, e.g., `array[i] < array[i-1]`, also corresponds to one comparison. Comparisons such as `i < j` where `i` or `j` are indices are not considered as comparisons for this programming assignment.

It is important that the caller function, e.g., the `main` function, has a `long` integer variable to store the number of comparisons, and pass the address of this variable into `void Array_Shellsort(long *array, int size, long *n_comp)` using the `n_comp` parameter.

Any support functions for these three functions, if any, must reside in `shell_array.c`. It is best that these helper functions be declared as static. Do not name these help functions with a prefix of two underscores "__".

Functions you will have to write for `shell_list.c`:

There are also three functions that deal with performing Shell sort on a linked list. In this assignment, you will use the following user-defined type to store integers in a linked list:

```
typedef struct _Node {
   long value;
   struct _Node *next;
} Node;
```

This structure has been defined in `shell_list.h`. Given the definition of the structure `Node`, these are the three functions you have to write to deal with performing Shell sort on a linked list:

```
Node *List_Load_From_File(char *filename)
```

The load function should read all (`long`) integers in the input file into a linked-list and return the address pointing to the first node in the linked-list. *The linked-list must contain as many nodes as the number of `long` integers in the file.* You should not have additional nodes in the linked list. **Moreover, the `long` integers should be stored in the same order in the linked-list as they are stored in the file.** In other words, the first (last) `long` integer in the input file is the `long` integer stored in the first (last) node of the list.

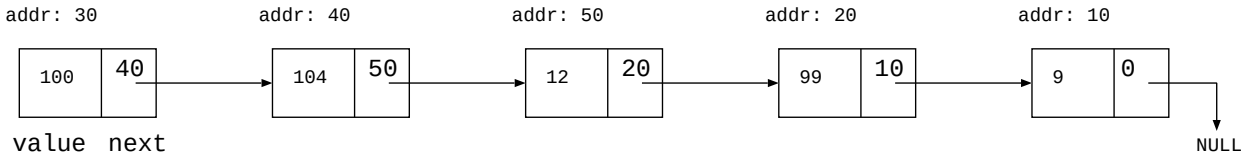
```
int List_Save_To_File(char *filename, Node *list)
```

The save function should write all (`long`) integers in a linked-list into the output file in the order in which they are stored in the linked list. This function returns the number of integers successfully written into the file.

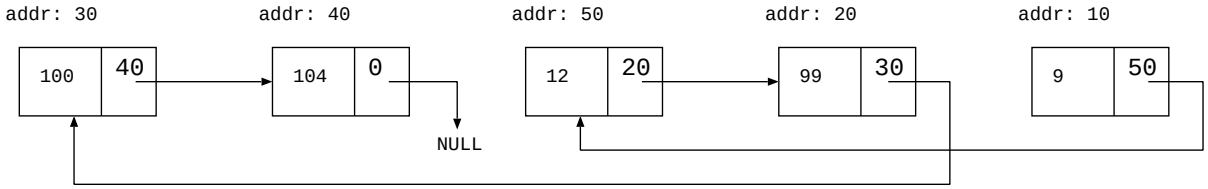
```
Node *List_Shellsort(Node *list, long *n_comp)
```

The Shell sort function takes in a `list` of long integers and sort them. To correctly apply Shell sort, you would have to know the number of elements in the `list` and compute the sequence used for sorting accordingly. The address pointing to the first node of the sorted list is returned by the function. Similar to the case of an array, a comparison here is defined to be any comparison that involves the field `value` in the structure `Node`. Note that if you are given a list of *n* `Nodes`, you should return a sorted list of *n* `Nodes`.

(a) Original list



(b) Sorting by manipulating addresses of Nodes



The `List_Shellsort` function must perform sorting by manipulating the `next` fields of the `Nodes`. Figure (a) shows an original list that is unsorted. Figure (b) shows how the list is sorted by storing the correct addresses in the `next` fields. The `long` integers stored in the `value` fields remain in the original `Nodes`. For example, the integer `99` is stored in a `Node` with an address `20` in the original list. The `field` of the same `Node` stores the address `10`, allowing it to point to the `Node` storing the value `9`.

After sorting, 99 is still stored in the value field of the Node with address 20. However, the next field of the Node now stores 30, allowing it to point to the Node storing the value 100.

In other words, each long integer must reside in the same Node in the original list before and after sorting.

You are not allowed to have arrays (of any types) in this file. Therefore, you cannot divide a list into sub-lists and use an array to store these sub-lists. This restriction also applies to all helper functions of List_Shellsort**.**

If you want to divide a list into sub-lists, you must use a list of linked-lists to maintain these sub-lists. You may use the following user-defined type to store a linked-list of linked-lists. To be exact, the following structure can be used to implement a linked-list of addresses pointing to the Node structure.

```
typedef struct _List {
    Node *node;
    struct _List *next;
} List;
```

This structure is probably useful for you to maintain k linked-lists, where k is a number in your sequence. However, it is not necessary that you use this structure in your implementation. My implementation uses only the structure Node. You may have a faster run-time if you use a list of linked-lists. Using only the structure Node may slow down the sorting.

If you want to use the List structure in shell_list.c, you must include the file list_of_list.h in the shell_list.c.

Any additional helper functions should be defined in shell_list.c file. It is best that these helper functions be declared as static. Do not name these helper functions with a prefix of two underscores "__".

It is important that the linked list returned from and/or passed into these three functions in shell_list.c *contain only nodes that store valid values.*

main **function you will write in** pa1.c**:**

You have to write another file called pa1.c that would contain the main function to invoke the functions in shell_array.c and shell_list.c.

You should be able to obtain the executable pa1 with the following command:

```
gcc -O3 -std=c99 -Wall -Wshadow -Wvla -pedantic shell_array.c shell_list.c pa1.c -o pa1
```

The flags used are very similar to the flags used in ECE264, except that the -Werror flag has been taken out. Also, the optimization flag -O3 is used. It is recommended that while you are developing your program, you use the "-g" flag instead of the "-O3" flag for compilation so that you can use a debugger if necessary. **It is your responsibility to make sure that your submission can be complied successfully on** ecegrid. Just to be sure, you should type in alias gcc at the command line and check whether your gcc uses the correct set of flags.

When the following command is issued,

```
./pa1 -a input.b output.b
```

the program should load from `input.b` the `long` integers to be sorted and store them in an array, run Shell sort on the array, and save the sorted `long` integers in `output.b`. The program should also print the number of comparisons performed to the standard output with the format "`%ld\n`".

When the following command is issued,

```
./pa1 -l input.b output.b
```

the program should load from `input.b` the `long` integers to be sorted and store them in a linked-list, run Shell sort on the linked-list, and save the sorted `long` integers in `output.b`. The program should also print the number of comparisons performed to the standard output with the format "`%ld\n`".

What should the `main` function do when an empty file or an invalid file is given?

For the "-a" option, the load function (`Array_Load_From_File`) returns a NULL address if you could not open the file or fail to allocate sufficient memory. The `main` function should exit with `EXIT_FAILURE` when the returned address of the load function is `NULL`.

For an empty file, the load function should return a valid array of size 0. Therefore, an empty output file should be created.

For the "-l" option, the current setup does not allow you to distinguish between an empty file or an invalid input filename (they both will result in an empty linked list from the load function (`List_Load_From_File`) for linked-lists). Therefore, you should continue to perform sorting and writing (an empty output file).

You may declare and define other (static) helper functions in `pa1.c`.

Submission and Grading:

The assignment requires the submission (electronically) of a zip file called `pa1.zip` through Brightspace. The zip file should contain `shell_array.c`, `shell_list.c`, and `pa1.c`. We do not expect you to turn in a `Makefile` because we are going to evaluate your functions individually. *Any other files in the zip file will be discarded.* **Your zip file should not contain a folder (that contains the source files)**. Assuming that your folder contains `shell_array.c`, `shell_list.c`, and `pa1.c`, you can create `pa1.zip` as follows:

```
zip pa1.zip shell_array.c shell_list.c pa1.c
```

It is important that if the instructor has a working version of `pa1.c`, it should be compilable with your `shell_array.c` and `shell_list.c` to produce an executable. Similarly, if the instructor has a working version of `shell_array.c`, it should be compilable with your `pa1.c` and `shell_list.c` to produce an executable. For evaluation purpose, we will use different combinations of your submitted `.c` files and our `.h` and `.c` files to generate different executables. If a particular combination does not allow an executable to be generated, you do not get any credit for the function(s) that the executable is supposed to evaluate.

The loading and saving functions will account for 20 points. The Shellsort function for arrays will account for 30 points. The Shellsort function for lists will account for 50 points. The main function does not account for any points. However, if your main function does not work properly, we will deduct up to 5 points.

Be aware that we set a time-limit for each test case based on the size of the test case. If your program does not complete its execution before the time limit for a test case, it is deemed to have failed the test case. We will not announce the time-limits that we will use. You should instead analyze whether your implementation has the expected time complexity through the numbers of comparisons or the runtimes for various test cases. You can obtain the runtime using the command `time`, e.g., `time ./pa1 -l input.b output.b`.

It is important all the files that have been opened are closed and all the memory that have been allocated are freed before the program exits. A caller function that receives heap memory should be responsible for freeing it. For example, if the instructor's `main` function calls the `Array_Load_From_File` function, it is the responsibility of the `main` function to free the returned array. It is not the responsibility of the `Array_Shellsort` or `Array_Save_To_File` to free the array. Memory issues will result in 50-point penalty.

Given:

We provide the `.h` files and sample input files in `pa1_examples.zip`. All ".b" files are binary files. The number in the name refers to the number of `long` integers the file is associated with. For example, `15.b` contains 15 `long` integers, `15sa.b` contains 15 sorted `long` integers from `15.b`. In particular, `15sa.b` is created by `pa1` by the following command:

```
./pa1 -a 15.b 15sa.b
```

My implementation of `pa1` prints the following output to the screen when the above command is issued:

```
60
```

My implementation of `pa1` prints the following output to the screen when the following command is issued:

```
./pa1 -l 15.b 15sl.b
121
```

My implementation of `pa1` also created `1Ksa.b` and `1Ksl.b`. Of course, `15sa.b` and `15sl.b` are identical and `1Ksa.b` and `1Ksl.b` are also identical. For the input files `10K.b`, `100K.b`, and `1M.b`, the output files of my implementation of `pa1` are not included.

Your implementation should not try to match the number of comparisons that my implementation reported. That is not the purpose of the assignment.

Getting started:

Copy over the files from the Brightspace website. Any updates to these instructions will be announced through Brightspace.

Given that the input files are in binary format, you probably want to write some helper functions to print the array of `long` integers before and after sorting in text (instead of binary) for debugging purpose. Keep in mind that `fread` and `fwrite` for binary files are analogous to `fscanf` and `fprintf` for text files.

If you want to perform Shell sort on a linked list without dividing the list into several sub-lists, it is easier to implement bubble sort in your Shell sort routine. (This is a rare example when bubble sort is more useful than insertion sort.)

To perform insertion sort on a linked list, ask yourself whether it is easier to form a complete list and then perform insertion sort, or it is easier to insert an item into a sorted list in the right order.

If you want to divide a linked list into several sub-lists, you should ask yourself the question of how the "sortedness" of a linked list affect the time complexity of insertion sort.

You also have to ask the question of whether you have performed (Shell) sorting correctly. If the array of `long` integers is in ascending order after sorting, have you sorted correctly?

As you have to generate the sequence for Shell sort in `shell_array.c` and `shell_list.c`, there will be similar lines of code in both `.c` files. While we do not encourage that in general, for the purpose of this assignment, we will reluctantly allow you to copy-and-paste these lines of code.

This assignment is about performing Shell sort. If you implement other sorting algorithms, your submission does not meet the specifications of the assignment. Your program will not earn the relevant credits if it does not meet the specifications.

Other than the required output to `stdout` as specified, do not print other messages to `stdout`. If you want to print error messages for debugging purposes, use `fprint` to print the messages to `stderr`. If your program produces messages that are not expected, your submission does not meet the specifications of the assignment and it will not earn the relevant credits.

We will use `valgrind` to check for memory issues. While you are most familar with memory leaks, `valgrind` can be useful in helping you find the cause of a segmentation fault and identify allocated memory locations that have not been initialized properly. The tool is useful only when you pay attention to all messages that valgrind reports. One useful programming habit is to keep your code `valgrind`-clean at any stage of programming. In other words, do not leave any memory issues unresolved at any stage of programming.

Another good habit to cultivate is to pay attention to the number of memory allocations made by your program. Does the number of memory allocations reported by `valgrind` match your expectation? For example, I expect my `pa1` to make 3 allocations for Shell sorting an array, and 18 allocations for Shell sorting a list of 15 integers (without splitting the linked list into sublists). Why do we need 3 and 17 allocations, respectively?