KAIST

EE 209: Programming Structures for EE

Assignment 3: Customer Management Table

Purpose

The purpose of this assignment is to help you learn how to implement common data structures in C and how to exploit them to achieve modularity in a real-world application. It also will give you the opportunity to gain more experience with the GNU/Linux programming tools, especially `bash`, `emacs`, and `gdb`.

Rules

Dynamic resizing of an array in task 1 is "on your own" part of this assignment. This part is worth 15% of this assignment.

Background

A data structure is a way of organizing data for efficient operation. In this assignment, you will implement the required functionalities (register, unregister, and find) of a customer management program using the following data structures.

- Array: an array is a collection of the same data type, where its elements are stored linearly in memory.
- Hash table: a more efficient implementation might use a *hash table*, which reduces the complexity to search for data. Hash tables are described in Lecture 10 of this course, or Section 2.9 of *The Practice of Programming* (Kernighan & Pike) and Chapter 14 of *Algorithms in C, Parts 1-4* (Sedgewick).

Your Task

You will implement and improve the customer data management API using various data structures. Your task in this assignment is threefold:

- [Task 1] Implement an API library for the customer data management, using a dynamically resizable array.
- [Task 2] Implement the same API library using a hash table.
- [Task 3] Test the correctness of your two libraries and measure the performance.

The `customer_manager` Interface

`customer_manager` is an API library for the customer data management, where the users can register the customer information and perform lookup operations to retrieve the purchase amount information.

The `customer_manager` interface introduces a structure type definition, `DB_T`:

- Conceptually, the `DB_T` structure is used for saving the pointer(s) to the entire customer data.

    - The per-customer data includes the customer name, ID, and purchase amount.

The `customer_manager` interface is described in a file named [`customer_manager.h`](customer_manager.h), and it contains these function declarations:

```
DB_T CreateCustomerDB(void);
void DestroyCustomerDB(DB_T d);
int RegisterCustomer(DB_T d, const char *id, const char *name, const
int purchase);
int UnregisterCustomerByID(DB_T d, const char *id);
int UnregisterCustomerByName(DB_T d, const char *name);
int GetPurchaseByID(DB_T d, const char *id);
int GetPurchaseByName(DB_T d, const char *name);
typedef int (*FUNCPTR_T)(const char* id, const char* name, const int
purchase);
int GetSumCustomerPurchase(DB_T d, FUNCPTR_T fp);
```

What each function does is as follows:

- `CreateCustomerDB` should allocate memory for a new `DB_T` object and any underlying objects.
    - On success, it should return a pointer to the memory block for the new `DB_T` object.
    - If the function fails to allocate the memory, it should return `NULL`.
- `DestroyCustomerDB` should free all memory occupied by the `DB_T` object and all the underlying objects.
    - If the given pointer to the `DB_T` object is `NULL`, it should do nothing.
- `RegisterCustomer` registers a new item, that is, a new user whose ID is `id`, name is `name`, and purchase amount is `purchase` to the `DB_T` object `d`.

- This function should store a new user item with her customer information with `d`.
- The new item should _own_ the id and name strings by copying them to new buffers. Consider using `strdup()`. If you use `strdup()`, please add `-D_GNU_SOURCE` after `gcc209`.
  (e.g., `$ gcc209 -D_GNU_SOURCE -o testclient testclient.c`)
- On success, it should return 0. Otherwise (e.g., on failure), it should return -1.
- If any of `d`, `id`, or `name` is `NULL`, it is a failure. If `purchase` is zero or a negative number, it is a failure.
- If an item with the same id _or_ with the same name already exists, it is a failure. You should not modify the existing item in this case, and should not leak memory for the new item. A good strategy is to check if such an item already exists, and allocate the new item only if it does not exist.

- `UnregisterCustomerByID` unregisters a user whose ID is `id` from the `DB_T` object, `d`.
  - On success, it should return 0. Otherwise, it should return -1.
  - If `d` or `id` is `NULL`, it is a failure. If no such item exists, it is a failure.
  - Make sure that you free all the memory allocated for the item being unregistered.
- `UnregisterCustomerByName` unregisters a user whose name is `name` from the `DB_T` object, `d`.
  - It is identical to `UnregisterCustomerByID` except that it matches `name` instead of `id`.
  - On success, it should return 0. Otherwise, it should return -1.
  - If `d` or `name` is `NULL`, it is a failure. If no such item exists, it is a failure.

  - Make sure that you free all the memory allocated for the item being unregistered.
- `GetPurchaseByID` searches for the purchase amount of the customer whose ID is `id` from a `DB_T` object `d`.
  - On success, it should return the purchase amount. Otherwise, it should return -1
  - If `d` or `id` is `NULL`, it is a failure. If there is no customer whose ID matches the given one, it is a failure.
- `GetPurchaseByName` searches for the purchase amount of the customer whose name is `name` from a `DB_T` object `d`.
  - It is identical to `GetPurchaseByID` except that it matches `name` instead of `id`.
  - On success, it should return the purchase amount. Otherwise, it should return -1
  - If `d` or `name` is `NULL`, it is a failure. If there is no customer whose name matches the given one, it is a failure.
- `GetSumCustomerPurchase` calculates the sum of the numbers returned by `fp` by calling `fp` for each user item. That is, this function iterates every user item in `d`, calls `fp` once for each user item, and returns the sum of the numbers returned by `fp`.
  - On success, `GetCustomerPurchase` should return the sum of all numbers returned by `fp` by iterating each user item in `d`.
  - If `d` or `fp` is NULL, it should return -1.
  - Note that `fp` is provided by the caller of `GetSumCustomerPurchase`. `fp` is a function pointer that takes user's id, name, and purchase as parameters, evaluates a specific condition on it, and returns a non-negative number. For example, the following code snippet shows the example

of the function pointed by `fp`, which returns the half of the purchase amount of the user whose name contains "Gorilla".

```
int GetHalfAmountOfUserWhoseNameContainsGorilla(const char
*id, const char *name, const int purchase) {

   if (strstr(name, "Gorilla") != NULL)
      return (purchase/2);
   return 0;
}
...

// call of GetSumCustomerPurchase() with the above function
int value = GetSumCustomerPurchase(d,
GetHalfAmountOfUserWhoseNameContainsGorilla);
printf("Half the purchase amount of the users whose name
contains Gorilla is %d₩n", value);
```

[Task 1] The `customer_manager` Array Implementation

The goal of the first task is to implement the customer_manager API using a dynamically resizable array. Array is the simplest data structure that works well for a small number of user items.

Your first `customer_manager` implementation should be as follows:

- Follow the function prototype described in customer_manager.h.
- Write your code in a file named `customer_manager1.c` (skeleton code).
- Avoid any memory leaks. Your `customer_manager` implementation should use a dynamically-allocated memory (i.e., in `CreateCustomerDB()` and `DestroyCustomerDB()`). It should make sure to free all dynamically-allocated memory when the memory is no longer needed.

- Whenever is possible, validate function parameters by calling the `assert` macro. Determining which invariant should be maintained is a part of your task.

Implementation tips:

- Define the structure for a user item, and allocate an array of the user item structure when `CreateCustomerDB` is called. You may start with the initial array size as 1024.
- A reasonable user item structure, a DB structure, and `CreateCustomerDB` is as follows. You can use the following code or define your own structure differently.

```
#define UNIT_ARRAY_SIZE 1024

struct UserInfo {
  char *name;     // user name
  char *id;       // user ID
  int purchase;   // purchase amount
};

struct DB {
  struct UserInfo *pArray;   // pointer to the array
  int curArrSize;            // current array size (max # of elements)
  int numItems;              // # of stored items,
                             // needed to determine when the array
should be expanded

  // add more records below if needed
  ...
};

...
DB_T CreateCustomerDB(void)
{
  DB_T d;

  d = (DB_T) calloc(1, sizeof(struct DB));
  if (d == NULL) {
     fprintf(stderr, "Can't allocate a memory for DB_T₩n");
```

- `      return NULL;`
- `    }`
- `    d->curArrSize = UNIT_ARRAY_SIZE; // start with 1024 elements`
- `    d->pArray = (struct UserInfo *)calloc(d->curArrSize, sizeof(struct UserInfo));`
- `    if (d->pArray == NULL) {`
- `      fprintf(stderr, "Can't allocate a memory for array of size %d₩n", d->curArrSize);`
- `      free(d);`
- `      return NULL;`
- `    }`
- `    return d;`
- `}`
- Using `calloc()` to allocate the array is often helpful since it initializes all elements (and their fields) to `0`.
- For `RegisterCustomer`, find an empty element in the array, and store the new user data in it. Make sure that you copy id and name strings instead of only their pointers. If there is no empty element, expand the array by calling `realloc()`. The increment amount should be 1024 elements each time you expand.
- In `UnregisterCustomerByID` or `UnregisterCustomerByName`, you search for the matching item, and deallocate the name and id. Optionally, you can set the name to `NULL`. This way, you can easily know which element is empty by checking each element's `name` with `NULL`.
- For `GetSumCustomerPurchase`, scan the array from index 0 till the max index, and call `fp` for each _valid_ element.
- Feel free to deviate from the above implementation tips if you have your own idea to make the code run faster or more efficiently

[Task 2] The customer_manager Hash Table Implementation

Unfortunately, using an array is slow when you deal with a large number of user items. Frequent registration and unregisteration of a user item creates many holes (empty elements) scattered across the array, which, in turn, makes these operations slow. Adding, deleting, and searching of a user item would eventually depend on linear search (unless you take extra measures to manage the holes separately).

We improve the performance of customer_manager operations with a hash table in this task. Actually, you would need two hash tables. One is for looking up a user item with ID as a key, and the other is for a lookup with a name as a key.

Your hash table-based customer_manager implementation should:

- Follow the function prototype described in customer_manager.h.
- Reside in a file named customer_manager2.c.
- Avoid any memory leaks. For each call of malloc or calloc in any object, eventually there should be exactly one call of free.
- Use a reasonable hash function. You are welcome to use this one. Feel free to modify it or define your own hash function if you'd like.

```
enum {HASH_MULTIPLIER = 65599};
...
static int hash_function(const char *pcKey, int iBucketCount)

/* Return a hash code for pcKey that is between 0 and iBucketCount-
1,
   inclusive. Adapted from the EE209 lecture notes. */
{
   int i;
```

```
    unsigned int uiHash = 0U;
    for (i = 0; pcKey[i] != '₩0'; i++)
       uiHash = uiHash * (unsigned int)HASH_MULTIPLIER
                + (unsigned int)pcKey[i];
    return (int)(uiHash % (unsigned int)iBucketCount);
}
```

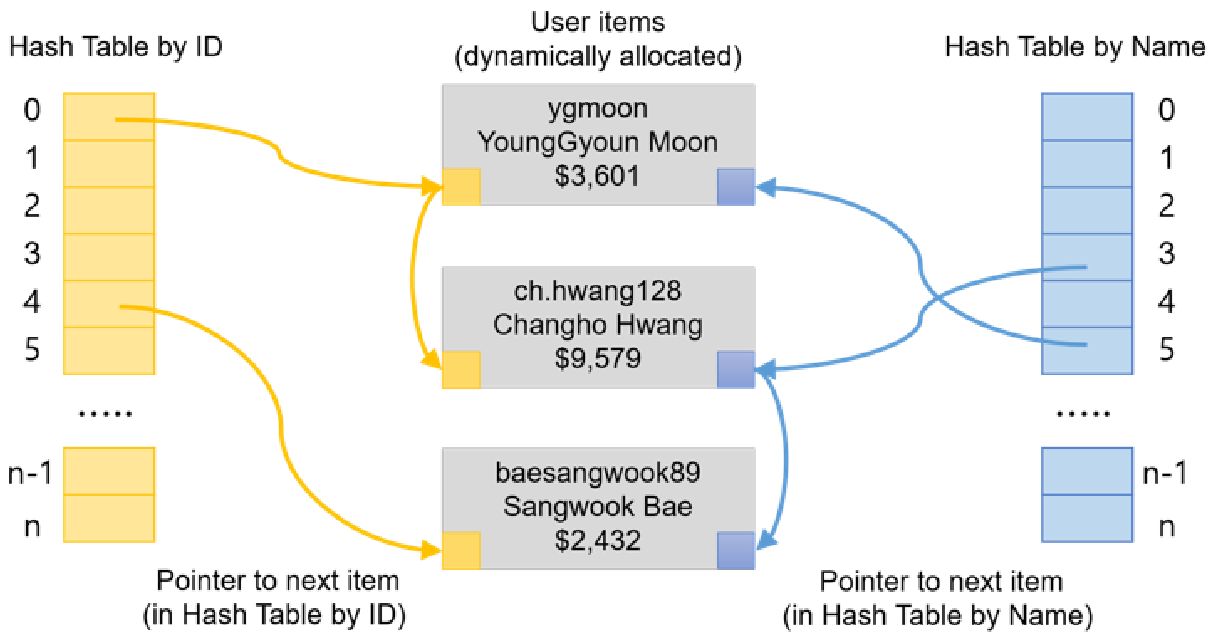
Implementation tips:

- Reuse the user item data structure that you defined in task 1, but add proper fields to keep track of the next node in a hash table. You would need two such pointers in the new user item data structure since you will need to maintain two hash tables.
- Unlike the array-based implementation, each new registration would require memory allocation of a user item structure. Please review the code in Lecture 10 since your implementation could be similar to it except that you need to maintain two hash tables here.
- Avoid gross inefficiencies. In particular, it would be grossly inefficient to hash the given key multiple times when a single time would suffice.
- Start the hash table bucket size as 1024 entries.
- (**Extra credit: 15%**) Implement hash table expansion. When the number of nodes (user items) in a hash table reaches 75% of the number of buckets, expand the hash table to double the number of buckets. That is, your initial number of buckets is 1024. When the number of nodes reaches (0.75 * 1024), you expand the number of buckets to 2048. Again, when the number of nodes reaches (0.75 * 2048), the next number of buckets should be 4086. The max number of buckets is 1 million (1,048,576 = 2^20), so even if the number of nodes exceeds 1 million, don't expand the hash table. Note that even after hash table expansion, you should be able to retrieve all existing user items already registered before

hash table expansion. Mark if you implement hash table expansion in your `readme` file.

The following figure represents an example hash table-based `customer_manager` implementation (it uses the `hash_function` mentioned above).

- `hash_function("ygmoon", n)` and `hash_function ("ch.hwang128", n)` are 0.
- `hash_function("baesangwook89", n)` is 4.
- `hash_function("Changho Hwang", n)` and `hash_function ("Sangwook Bae", n)` are 3.
- `hash_function("YoungGyoun Moon", n)` is 5.



[Task 3] Testing Your Library and Measuring the Performance

We provide [testclient.c]() to test your implementations. It first checks the correctness of your library functions and measures the performance over various user items. Note that we may use other programs for grading.

To compile your code, do the following:

```
// test your array-based implementation
$ gcc209 -o testclient1 testclient.c customer_manager1.c
$ ./testclient1

// test your hash table-based implementation
$ gcc209 -o testclient2 testclient.c customer_manager2.c
$ ./testclient2
```

(**Extra credit: 15%**) We will give an extra credit to the student whose implementation is the fastest among all students. We may use our own program to measure the performance.

Logistics

Develop in your own environment using `emacs` to create source code and `gdb` to debug. Make sure to compile with `gcc209` and test your code on lab machine before submission.

Please follow the steps through Task 1 to Task 3 to complete the `customer_manager` API, and test your libraries.

We give two opportunities for getting an extra credit (each 15%).

- (Extra credit 15%): Implement hash table expansion.
- (Extra credit 15%): Make your implementation the fastest among all submissions.

Create a `readme` text file that contains:

- Your name.

- A description of whatever help (if any) you received from others while doing the assignment, and the names of any individuals with whom you collaborated, as prescribed by the course "Policy" web page.
- Compare the implementation of `customer_manager` using array and the one using hash table respectively. Please try to provide reasonable explanation for the pros and cons of each implementaion.
- Whether you implemented hash table expansion or not. If you implemented it, state which functions implement it.
- (Optionally) An indication of how much time you spent doing the assignment.
- (Optionally) Your assessment of the assignment.
- (Optionally) Any information that will help us to grade your work in the most favorable light. In particular you should describe all known bugs.

Submission

Use [KAIST KLMS] to submit your assignments. Your submission should be one gzipped tar file whose name is

YourStudentID_assign3.tar.gz

Your submission need to include the following files:

- (Task 1) `customer_manager1.c`
- (Task 2) `customer_manager2.c`
- (Task 3) no file is needed.
- `readme` text file

- Observance of Ethics. Sign on the document, save it into a PDF file, and submit it.

Grading

We will grade your work on quality from the user's point of view and from the programmer's point of view. To encourage good coding practices, we will deduct points if `gcc209` generates warning messages.

From the user's point of view, your module has quality if it behaves as it should.

In part, style is defined by the rules given in *The Practice of Programming* (Kernighan and Pike), as summarized by the Rules of Programming Style document. These additional rules apply:

Names: You should use a clear and consistent style for variable and function names. One example of such a style is to prefix each variable name with characters that indicate its type. For example, the prefix `c` might indicate that the variable is of type `char`, `i` might indicate `int`, `pc` might mean `char*`, `ui` might mean `unsigned int`, etc. But it is fine to use another style -- a style which does not include the type of a variable in its name -- as long as the result is a readable program.

Line lengths: Limit line lengths in your source code to 72 characters. Doing so allows us to print your work in two columns, thus saving paper.

Comments: Each source code file should begin with a comment that includes your name, the number of the assignment, and the name of the file.

Comments: Each function should begin with a comment that describes what the function does from the caller's point of view. The function comment should:

- Explicitly refer to the function's parameters (by name) and the function's return value.
- State what, if anything, the function reads from standard input or any other stream, and what, if anything, the function writes to standard output, standard error, or any other stream.
- State which global variables the function uses or affects.
- Appear in both the interface (.h) file for the sake of the *clients* of the function and the implementation (.c) file for the sake of the *maintainers* of the function.

Comments: Each structure type definition and each structure field definition should have a comment that describes it.

Comments: The interface of each data structure should contain a comment that describes what an object of that type is. It would be reasonable to place that comment adjacent to the definition of the opaque pointer.