Purpose

The goal of this assignment is to get you programming with more complex allocation patterns than you have previously.

Preliminaries

Login to the server of your choice and cd to the directory where you keep your CS 211 work. Then download and unarchive the starter code, and change into the project directory:

```
% cd cs211
% curl $HW211/hw03.tgz | tar zvxk
:.
% cd hw03
```

If you have correctly downloaded and configured everything then the project should build cleanly:

```
% make
:.
cc -o test_vc test/test_vc.o src/libvc.o -l211 -fsaniti...
%
```

Introduction

In this project, you will implement a library vc for counting votes and a small client program count that exercises the library.

An important idea throughout this assignment is to adhere to the specified ownership protocol for managing memory. In the library, you will implement operations for an abstract type vote_count_t that points to a mapping from candidate names to their vote counts. A vote_count_t object owns the strings that hold the names of the candidates, so whoever frees the vote_count_t object is responsible for freeing its strings as well.
Orientation

As in previous homeworks, your code is divided into three .c files:

- Most significant functionality will be defined in the “vc library,” src/libvc.c.
- Tests for those functions will be written in test/test_vc.c.
- The main() function that implements the count program will be defined in src/count.c.

Function signatures for src/libvc.c are provided for you in src/libvc.h; since the grading tests expect to interface with your code via this header file, you must not modify src/libvc.h in any way. All of your code will be written in the three .c files.

The project also provides a Makefile with several targets:

<table>
<thead>
<tr>
<th>target</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>builds everything * &amp;</td>
</tr>
<tr>
<td>test</td>
<td>builds and runs the tests &amp;</td>
</tr>
<tr>
<td>test_vc</td>
<td>builds (but doesn’t run) the tests</td>
</tr>
<tr>
<td>count</td>
<td>builds the count program</td>
</tr>
<tr>
<td>clean</td>
<td>removes all build products &amp;</td>
</tr>
</tbody>
</table>

* default & phony

Specifications

The project comprises two functional components, which are specified in the next two subsections.

The count program

The count program reads candidate names, one per line, from the standard input. It counts the number of occurrences of each candidate name, and when the input ends, it prints a table of candidate names and counts to the standard output, like so:

```
% ./count
kennedy
nixon
nixon
kennedy
kennedy
^D
```

In the terminal, pressing Control-D (only at the beginning of a line) sends the end-of-file signal.
The *count* program is limited in how many different candidates it can handle, and the limit is defined using a C preprocessor macro `MAX_CANDIDATES` in the `src/libvc.h` header file. When *count* is given more different candidates than it can handle, it begins dropping votes. Each time it sees a candidate that it hasn’t seen before and doesn’t have room for, it prints a message to `stderr`. At the end, it prints the total count of dropped votes to `stderr` before terminating with exit code 2.

So for example, if `MAX_CANDIDATES` were only 2, it would behave like this:

```
% ./count
perot
bush
cinton
./count: vote dropped: clinton
clinton
./count: vote dropped: clinton
clinton
./count: vote dropped: clinton
bush
^D
perot 1
bush 2
./count: 3 vote(s) dropped
[2] % echo $status
2
%
```

I’m using underlining to indicate what the program prints to the standard error.

In *fish*, the special shell variable `$status` contains the exit code of the most recently run command. (Most other shells use `$?` for the exit code.)

If the program fails to allocate memory, it exits with a message printed to `stderr` and an exit code of 1.

*The vc library*

The header `src/libvc.h` defines one type, intended to represent a mapping from candidate names to vote counts:

```
typedef struct vote_count* vote_count_t;
```

This type is abstract in the sense that other files that include `src/libvc.h` will know that type `vote_count_t` is a pointer to some struct type, but they won’t know anything about the definition of that struct. This means that they can create, manipulate, and destroy `struct vote_count` objects only via the functions declared in the same header.

We will refer to the object that a `vote_count_t` points to as a *vote count map*. The `src/libvc.h` header declares eight functions for working
with vote count maps: two for managing their lifecycles, one for modifying them, and five for querying them. The functions are:

- **vote_count_t vc_create(void)** allocates a new, empty vote count map on the heap and returns a pointer to it. Every successful call to vc_create() allocates a new object that must subsequently be deallocated exactly once using vc_destroy.
  
  **Ownership:** The caller takes ownership of the result.
  
  **Errors:** Returns **null** if memory cannot be allocated.

- **void vc_destroy(vote_count_t vc)** deallocates all memory associated with vc. vc may be **NULL**, in which case this function does nothing.
  
  **Ownership:** Takes ownership of vc.
  
  **Errors:** If vc has already been destroyed or wasn’t returned by vc_create() in the first place then this function has undefined behavior.

- **size_t* vc_update(vote_count_t vc, const char* name)** does not update a count. Rather, returns a pointer to the count for candidate name, so that the caller can use that pointer to update the count. If name is already present in vc the returned pointer will point to the existing count for candidate name; otherwise, vc is extended to map name to a count of 0 before returning the pointer to that count.
  
  **Ownership:**
  
  - Borrows name transiently, which means that it does not store it anywhere. (In other words, vc must still be valid even after name is not.)
  - Borrows vc transiently.
  - The returned pointer is borrowed from vc and is valid until vc is destroyed.

  **Errors:**
  
  - Returns **NULL** if name is not present in vc and cannot be added because vc is full.
  - Prints a message to **stderr** and exits with code 1 if we need to allocate a copy of name and allocation fails.

- **size_t vc_lookup(vote_count_t vc, const char* name)** looks up the count for candidate name; returns 0 if not found.

  **Ownership:** Borrows both arguments transiently.
• **size_t vc_total(vote_count_t vc)** returns the total number of votes cast.
  
  **Ownership:** Borrows vc transiently.
  
• **const char* vc_max(vote_count_t vc)** returns the name of the candidate with the most (non-zero) votes. In case of a tie, returns the candidate who was added to vc earlier.
  
  Returns **NULL** if vc contains no candidates with more than zero votes.
  
  **Ownership:**
  
  – Borrows vc transiently.
  
  – The returned pointer is borrowed from vc and is valid until vc is destroyed.
  
• **const char* vc_min(vote_count_t vc)** returns the name of the candidate with the fewest (non-zero) votes. In case of a tie, returns the candidate who was added to vc later.
  
  Returns **NULL** if vc contains no candidates with more than zero votes.
  
  **Ownership:**
  
  – Borrows vc transiently.
  
  – The returned pointer is borrowed from vc and is valid until vc is destroyed.
  
• **void vc_print(vote_count_t vc)** prints a summary of the vote counts on stdout. The counts are printed one candidate per line in the order they first were added. The candidate names are left-aligned in a 20-character column, followed by a single space, and then the counts right-aligned in a 9-character column.
  
  **Ownership:** Borrows vc transiently.

  Note that libvc is not responsible for maintaining any information about dropped votes. That counting must be handled by the client program.

**Reference**

**Alignment using printf(3)**

For printing the table of counts, you will want to use printf(3)’s padding and alignment capabilities. In particular:
• A field may be padded to \( n \) characters by adding the number \( n \) between the \% and the type specifier (e.g., \( s \), \( d \), or \( zu \)). For example, \"%8d\" formats an \texttt{int} using (at least) eight characters.

• By default, fields are padded with spaces on the left, in order to right align them. Using a negative number will left align the field instead. For example, \"%-8d\" will format \texttt{ints} left-aligned in an eight-character column.

\textit{Formatting to strings with \texttt{snprintf}(3)}

For testing \texttt{libvc}'s behavior when full, you will need to generate \texttt{MAX_CANDIDATES + 1} different candidate names. (Your tests should still work when I redefine \texttt{MAX_CANDIDATES}.) The \texttt{snprintf(3)} function is like \texttt{printf()}, but instead of printing to \texttt{stdout}, it takes a \texttt{char*} and prints into the buffer that it points to. See its \texttt{manual page} for more information.

\textit{Hints}

In this section we provide suggestions, such as some useful helper functions and help interpreting the specification.

\textit{Iterating over a vote count map}

Most of the functions in \texttt{src/libvc.c} need to iterate over the array that their given \texttt{vote_count_t} points to. Be careful, because this iteration requires different termination conditions in different places. In particular, it always needs to stop before \texttt{MAX_CANDIDATES}, but often it is also necessary to stop when reaching a \texttt{NULL} candidate name.

\textit{Representation invariant}

If there are \( n \) candidates mapped in \texttt{vc} then the candidate fields of the first \( n \) elements of \texttt{vc} must contain their names, and the remaining candidate fields (if \( n < \texttt{MAX_CANDIDATES} \)) must be \texttt{NULL}. This is so that you know when to stop when searching for a candidate or for a free slot.

The first \( n \) count fields, corresponding to the \( n \) candidate names, must contain those candidates’ counts. It does not matter what the remaining \((\texttt{MAX_CANDIDATES} - n)\) count fields contain (or even whether they are initialized), since they do not store any information until their corresponding candidate fields are non-\texttt{NULL}.

In addition to the buffer to format into, \texttt{snprintf()} takes an upper limit on the number of characters to store; an older function, \texttt{sprintf(3)}, does not take such a limit. Why might that be a bad idea?

An easy way to use \texttt{snprintf()} is to stack-allocate a sufficiently large \texttt{char} array and then use \texttt{sizeof} the array for the limit.

To work properly, all of the functions in \texttt{src/libvc.c} must collaborate to maintain each vote count map in a consistent state.
Ownership strategy

A vote count map owns the strings that store the candidate names, but the vc_update() function merely borrows the name that it is given. This has several implications:

- In order to store the name of a candidate that it has not yet seen, the implementation of the vc_update() function needs to make its own copy of the name parameter on the heap.
- Clients of vc_update() are free to deallocate or reuse the name parameter that they pass to vc_update() as soon as vc_update() returns.
- Properly deallocating the memory associated with a vote_count_t (as in vc_destroy()) means deallocating all of the strings that it owns.

Strategy for the count program

The count program should start by allocating a vote count map, terminating with an error message on stderr and exit code of 1 if allocation fails. (Use the predefined OOM_MESSAGE as your format string.)

Next, it should read a line at a time using read_line(3) until end-of-file. Each string returned by read_line() is a candidate name and should be counted in the vote count map, unless calling vc_update() indicates that the vote count map is full. (Use DROP_MESSAGE to format the required warning when dropping a vote.) Don’t forget to free each string allocated by read_line().

Once there are no more votes to count, it should print the vote summary and deallocate the vote count map.

Finally, if any votes were dropped, print a final warning (use FINAL_MESSAGE) before terminating with exit code 2. Of course, if no votes were dropped, the exit code should be 0.

Helper functions

You may factor the required functions however you like, but when writing our solution, we found the following helper functions to be, well, helpful:

```c
// Returns a pointer the first element of `vc` // whose `candidate` matches `name`, or NULL if // there is no such element.
static struct vote_count*
vc_find_name(vote_count_t vc, const char* name)
```
// Returns a pointer to the first element of
// `vc` whose `candidate` is NULL, or NULL if
// `vc` is full.
static struct vote_count *
vc_find_empty(vote_count_t vc);

// Clones a string onto the heap, printing a
// message to stderr and exiting with code 1
// if malloc() fails.
static char *
strdup_or_else(const char* src);

The storage class **static** makes a function definition local to the .c
file it is written in, so **static** should be applied to all helper func-
tions.

**Deliverables and evaluation**

For this homework you must:

1. Implement the specification for the `vc` library in `src/libvc.c`.
2. Implement the specification for the `count` program in `src/count.c`.
3. Add more test cases to `test/test_vc.c` in order to test the eight
   functions that you defined in `src/libvc.c`.

The file `test/test_vc.c` contains two test cases in order to give you an
idea how to write them, but you need to add many more tests. Try to
cover all the possibilities, because for this week’s self evaluation we
will spot-check your test coverage by asking for just a few particular
test cases. You can’t anticipate which we’ll ask about, so you should
try to cover everything.

Grading will be based on:

- the correctness of your implementations with respect to the specifi-
cations,
- the presence of sufficient test cases to ensure your code’s correct-
  ness, and
- adherance to the **CS 211 Style Manual**.

**Submission**

Homework submission and grading will use the GSC grading server.
You must include any files that you create or change. For this
homework, that will include src/libvc.c, src/count.c, and test/test_vc.c. (You should not need to modify Makefile and you must not modify src/libvc.h.)

Submit using the command-line GSC client gsc(1). Instructions are available in the submit211(7) manual page on the Unix login and lab machines. To view the manual page, run:

```
% man submit211
```

Partners

If you work with a partner then you must register your partnership before uploading to GSC. There are two steps to this: one partner must create a partner request (referring to their intended partner by NetID), and then the other partner must accept that request for it to take effect.

Partner requests are created with the gsc partner request command and accepted using using the gsc partner accept command. You can list outstanding partner requests with the gsc status command and cancel them with the gsc partner cancel command. See the gsc(1) manual page for details.

Before a partner request can be accepted, the files in the two submissions must be disjoint. (The system will not choose whose file to delete if you both have files with the same name.) Once a partner request is accepted, you and your partner’s submissions are joined together: when one partner uploads files to the GSC server or performs self evaluation, the results will be visible to both.