Assignment 4: Symbol Table

1. Introduction

In this assignment you will write a sixth implementation of the storage system used by the word frequency program shown in lecture. We provide a file containing main() and also some shell scripts that will feed data to main. You write a file that implements the functions to do the filing.

This assignment gives you practice using structs, arrays, and pointers in C. This assignment also gives you practice using malloc() and free() to manage memory.

Start by linking to our version of main, some scripts, and some data files. All these files are in the directory *~lib113/hw/wf/files*. Link to them by typing

```
% ln -s ~lib113/hw/wf/files/*  .     <-- there is a dot at the end
```

You now have *symbolic links* to all these files. The files appear to be in your current directory, but they are just pointers to our read-only files. For information about what links are and how they work, see the Unix book or search the Internet for *symbolic link*.

2. Building a Frequency Table with Unix Tools

We have been building frequency tables with Unix tools for several weeks. For example, this pipeline produces a list of the lines for all trains leaving South Station:

```
grep "stn=south station" sched | grep "dir=o" | cut -d";" -f6 | cut -d= -f2
```

The output looks something like:

```
needham
fairmount
needham
greenbush
kingston
..etc..
```

We want a list that looks like

```
108 fairmount
 69 franklin
 56 greenbush
 ..etc..
```

That is, we want a list of the words that appear, we want the number of times each word appears in the input (the *frequency*), and we want the list sorted in alphabetical order.

We can use the Unix tools sort and uniq to produce this frequency table. Try this:

```
grep "stn=south station" sched|grep "dir='o'|cut -d";" -f6|cut -d= -f2|sort | uniq -c
```

The sort command reads in all the input lines and outputs them in alphabetical order, and the uniq -c command replaces each sequence of repeated lines with a count and the line.

This method has two problems. The first problem is that the input may not be split into one word per line. The second problem is that sorting takes time. A long list of words can take a long time to sort, but the sorting is only being done to prepare the input for uniq -c.

3. A Proposal for a New Tool : wordfreq

The solution to these problems is to write a new C program, one that reads standard input, splits the input into words, counts the words, and prints an alphabetical list of all the words with their frequencies. That is, it produces the same result as sorting then uniq -c'ing, but without the time required to sort all the input.

4. Five Solutions So Far

In lecture, we saw five implementations of the wordfreq filing system. All the programs implement a storage system that holds words and associated integers. A table that associates values with strings is called a *symbol table*. The programs provide functions to insert new symbols into the table, retrieve data from the table, update values in the table, and to cursor through the table to see what is there.

All five solutions work but, but some have limitations or wasted memory. The fifth solution uses memory efficiently and has no artificial limitations. It has one problem: it was the slowest by far.

Your project is to write a sixth version of wlfiler, one uses linked lists but runs much faster than version 5.

5. Speeding Up the Linked List Version

Version 5 uses a single, unsorted linked list to store all the 'rows' in the table. Any search for a word must traverse this list. The list is unsorted, so the program has to go all the way to the end to make sure a word is not on the list.

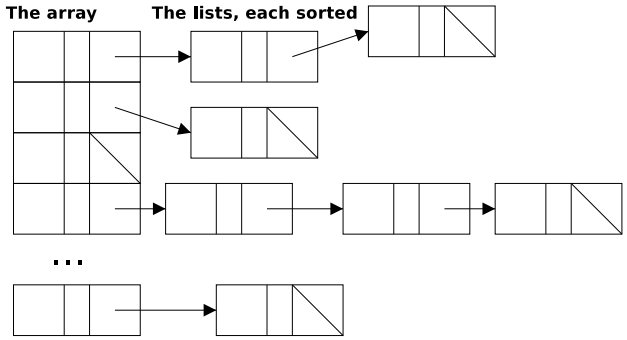
Your faster version will run about 50 times faster by making the following changes to the storage:

1. The single linked list will be replaced with 26 linked lists, one for each letter of the alphabet. All the words that start with the letter 'a' will be on the first list, all the words that start with 'b' will be on the second list, etc. This change will reduce the search time by, on average, a factor of 26.
2. Each of those linked lists will be kept in alphabetical order. By doing so, you can write code that will know when to stop looking for a word without going to the end of the list. On average, you will stop searching halfway through the list, further reducing your search time by a factor of 2.

Details of the structures and code follow.

6. An Array of 26 Linked Lists

What does an array of linked lists look like? A diagram is:



The entries in the table are *structs* that contain the word, the frequency, and a pointer to the next item in the list. If there is no next item in that list, the pointer has the value NULL.

The lists of items are organized into an array. The array, seen at the left of the diagram, is an array of structs. Each struct is the head of the list. It does *not* contain a word. The `next` member of that struct points to the list. If there are no words on that list, that head struct contains a NULL pointer.

7. The Data Structures to Implement the Symbol Table

How does this diagram translate into C code ? Since there are two things in the picture, structs and the array, there must be two definitions:

The table consists of words and their frequencies. Each item in the table, then, consists of a string and an integer. The items are strung together in a linked list. The links in the list are therefore structs that look like:

```
struct link
   {
       char        *word;   /* a ptr to the word, in malloc()ed memory */
       int         value;   /* an integer value; the frequency         */
       struct link *next;  /* points to next in list                   */
   } ;
   typedef struct link LINK;  /* LINK is shorthand for 'struct link'   */
```

Having thus defined the data type, the array of head structs is created with:

```
LINK table[ARRAY_SIZE];   /* an array of head structs */
```

This statement defines an array of structs. The *next* member of each struct points to a list of structs of type LINK. There are ARRAY_SIZE structs in the array.

8. Code to Implement the Symbol Table

The statement that defines the array of ARRAY_SIZE structs creates the array of head structs, but does not create any symbols.

You only need to create storage for words when the main program asks your package to `insert` a new symbol in the table.

The library subroutine *malloc()* gets memory from the operating system and tells you where that memory is. You tell it how much you need. Typical code looks like:

```
LINK *lp;       /* plan to hold address in lp */

lp = (LINK *) malloc( sizeof(LINK) ) ;
if ( lp == NULL )
     error-condition-code;
```

This asks for a chunk of memory large enough to hold a link struct. The pointer `lp` contains the address of this chunk of memory.

You will then need memory for the word that will be stored in that link.

```
char *cp;       /* plan to hold address in cp  */

cp = malloc( strlen(the_name) + 1 );      /* room for null */
if ( cp == NULL )
     error-condition-here;
strcpy(cp, the_name);                     /* store name */
```

You then need to put the pointer to the name in the symbol:

```
lp->word = cp ;
```

The last part, figuring out where the symbol goes, and inserting it in its list is discussed below.

9. The Assignment

The symbol table manager you will write will have a symbol table that consists of 26 lists, one for each letter of the alphabet. A symbol will be assigned to a list based on its initial letter. Each of these 26 lists will be kept in alphabetical order.

9.1. Functionality: Three Main Parts

[1] Using this array of linked lists, implement all the functions in the sample programs (`wlfiler1.c`...) from lecture. The arguments, action, and return values for those functions are all documented in the code for `wlfiler1.c`.

[2] One additional Function: `word_delete(char str[])` This function is passed a string, and the function removes from the table the item containing that string. Your function must call the system function `free()` to recycle the memory used by the struct and by the string.

[3] Correct the main() function to prevent buffer overflow. The file wlmain.c uses scanf(%s) to read in a white-space delimited string of characters from standard input. This is a problem. Explain why this use of scanf allows buffer overflow. Modify the program so it prevents buffer overflow.

In particular, write a new function called `read_word()` that reads in a word of arbitrary length and returns a pointer to the new string. This function should use the growable array technique (using realloc) we saw in wlfiler4.c. You will have to free the string after adding it to the table.

Your word filing functions may assume that all the strings it is given begin with a lower case letter. Your functions do not have to check for valid data.

Your program will be linked with the program `wlmain.c` from lecture and must work with test data we shall provide.

The program will also be linked with another test program, one that will exercise its delete function.

[4] Note: The project asks you to write versions of the functions provided by the wlfiler files. You are not allowed to change main except to solve the problem mentioned in the previous section.

9.2. Getting Started

Make sure you understand the operation of the sample programs from class and the purpose of the functions. You may notice as you study those programs that many of the functions are similar.

For your next step, think about how to design a better system. Good programming style leads one to eliminate duplicate code by calling a common helper function. For example, the in_table(), lookup(), and update() functions all do similar things. Why not have a single function to search the table for a string, and return a pointer to the struct? The caller can then decide what to do with that struct.

Finally, think through how to implement each of the operations in this new data structure. Use the fact that the lists are sorted to speed up searches. That is, do not search further than you need to.

9.3. Creating and Testing wordfreq

You need to include "wl.h" in your file or files. You need to compile wlmain.c with your program wlfiler6.c and build wl6

```
% cc wlmain.c wlfiler6.c -o wl6
```

To see if your program works, run the following shell script:

```
% ~lib113/hw/wf/wf.test
```

9.4. To Hand In

Clean Code Part of your grade will be based on your code passing *gcc -Wall* with no warnings or errors. You will lose two points for *each* warning that gcc reports about your program.

typescript Submit a typescript of your program being compiled with gcc and being tested by the test script.

Digital Handin From the directory containing your work, type

```
~lib113/handin wf
```