Assignment 6
The Great Firewall of Santa Cruz: Bloom Filters, Linked Lists and Hash Tables

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CSE 13S – Winter 2021

Due: February 28th at 11:59 pm PST

1 Introduction

> *War is peace. Freedom is slavery. Ignorance is strength.*
>
> —George Orwell, 1984

You have been selected through thoroughly democratic processes (and the machinations of your friend and hero Ernst Blofeld) to be the Dear and Beloved Leader of the Glorious People's Republic of Santa Cruz following the failure of the short-lived anarcho-syndicalist commune, where each person in turn acted as a form of executive officer for the week. In order to promote virtue and prevent vice, and to preserve social cohesion and discourage unrest, you have decided that the Internet content must be filtered so that your beloved children are not corrupted through the use of unfortunate, hurtful, offensive, and far too descriptive language.

2 Bloom Filters

> *The Ministry of Peace concerns itself with war, the Ministry of Truth with lies, the Ministry of Love with torture and the Ministry of Plenty with starvation. These contradictions are not accidental, nor do they result from from ordinary hypocrisy: they are deliberate exercises in* ***doublethink****.*
>
> —George Orwell, 1984

The Internet is very large, very fast, and full of *badthink*. The masses spend their days sending each other cat videos and spewing *oldspeak*—very bad indeed. You decide, as the newly elected Dear and Beloved Leader of the Glorious People's Republic of Santa Cruz (GPRSC), that a more neutral *newspeak* is required to keep the citizens of the GPRSC content, pure, and from thinking too much. But how do you process and store so many words as they flow in and out of the GPRSC at 10 Gbits/second? The solution comes to your brilliant and pure mind—a *Bloom filter*.

A Bloom filter is a space-efficient probabilistic data structure, conceived by Burton H. Bloom in 1970, and is used to test whether an element is a member of a set. False-positive matches are possible, but false negatives are not—in other words, a query for set membership returns either "possibly in the set" or "definitely not in the set." Elements can be added to the set but not removed from it; the more elements added, the higher the probability of false positives.

A Bloom filter can be represented as an array of m bits, or a **bit vector**. A Bloom filter should utilize k different hash functions. Using these hash functions, a set element added to the Bloom filter is mapped to at most k of the

m bit indices, generating a uniform pseudo-random distribution. Typically, k is a small constant which depends on the desired false error rate ϵ, while m is proportional to k and the number of elements to be added.

Assume you are adding an word w to your Bloom filter and are using $k = 3$ hash functions, $f(x)$, $g(x)$, and $h(x)$. To add w to the Bloom filter, you simply set the bits at indices $f(w)$, $g(w)$, and $h(w)$. To check if some word w' has been added to the same Bloom filter, you check if the bits at indices $f(w')$, $g(w')$, and $h(w')$ are set. If they are all set, then w' has *most likely* been added to the Bloom filter. If any one of those bits was cleared, then w' has definitely *not* been added to the Bloom filter. The fact that the Bloom filter can only tell if some word has *most likely* been added to the Bloom filter means that *false positives* can occur. The larger the Bloom filter, the lower the chances of getting false positives.

So what do Bloom filters mean for you as the Dear and Beloved Leader? It means you can take a list of proscribed words, *oldspeak* and add each word into your Bloom filter. If any of the words that your citizens use seem to be added to the Bloom filter, then this is very ungood and further action must be taken to discern whether or not the citizen did transgress. You decide to implement a Bloom filter with *three* salts for *three* different hash functions. Why? To reduce the chance of a *false positive*.

You can think of a "salt" as an initialization vector or a key. Using different salts with the same hash function results in a different, unique hash. Since you are equipping your Bloom filter with three different salts, you are effectively getting three different hash functions: $f(x)$, $g(x)$, and $h(x)$. Hashing a word w, with extremely high probability, should result in $f(w) \neq g(w) \neq h(w)$. These salts are to be used for the SPECK cipher, which requires a 128-bit key, so we have used MD5 [1] "message-digest" to reduce three books down to 128 bits each. You will use the SPECK cipher as a hash function, which will be explained in §5.1,

2.1 `BloomFilter`

The following `struct` defines the `BloomFilter` ADT. The three salts will be stored in the `primary`, `secondary`, and `tertiary` fields. Each salt is 128 bits in size. To hold these 128 bits, we use an array of two `uint64_t`s. This `struct` definition *must* go in `bf.c`.

```
1 struct BloomFilter {
2   uint64_t primary[2];   // Primary hash function salt.
3   uint64_t secondary[2]; // Secondary hash function salt.
4   uint64_t tertiary[2];  // Tertiary hash function salt.
5   BitVector *filter;
6 };
```

2.2 `BloomFilter *bf_create(uint32_t size)`

The constructor for a Bloom filter. Working code for the constructor, complete with primary, secondary, and tertiary salts that you will use, is shown below. Note that you will also have to implement the bit vector ADT for your Bloom filter, as it will serve as the array of bits necessary for a proper Bloom filter.

[1] Rivest, R.. "The MD5 Message-Digest Algorithm." RFC 1321 (1992): 1-21.

```
BloomFilter *bf_create(uint32_t size) {
  BloomFilter *bf = (BloomFilter *) malloc(sizeof(BloomFilter));
  if (bf) {
    // Fear & Loathing in Las Vegas
    bf->primary[0] = 0x02d232593fbe42ff;
    bf->primary[1] = 0x3775cfbf0794f152;
    // A Moveable Feast
    bf->secondary[0] = 0xc1706bc17ececc04;
    bf->secondary[1] = 0xe9820aa4d2b8261a;
    // The Cremation of Sam McGee
    bf->tertiary[0] = 0xd37b01df0ae8f8d0;
    bf->tertiary[1] = 0x911d454886ca7cf7;
    bf->filter = bv_create(size);
    if (!bf->filter) {
      free(bf);
      bf = NULL;
    }
  }
  return bf;
}
```

2.3 `void bf_delete(BloomFilter **bf)`

The destructor for a Bloom filter. As with all other destructors, it should free any memory allocated by the constructor and null out the pointer that was passed in.

2.4 `uint32_t bf_size(BloomFilter *bf)`

Returns the size of the Bloom filter. In other words, the number of bits that the Bloom filter can access. Hint: this is the length of the underlying bit vector.

2.5 `void bf_insert(BloomFilter *bf, char *oldspeak)`

Takes `oldspeak` and inserts it into the Bloom filter. This entails hashing `oldspeak` with each of the three salts for three indices, and setting the bits at those indices in the underlying bit vector.

2.6 `bool bf_probe(BloomFilter *bf, char *oldspeak)`

Probes the Bloom filter for `oldspeak`. Like with `bf_insert()`, `oldspeak` is hashed with each of the three salts for three indices. If all the bits at those indices are set, return `true` to signify that `oldspeak` was most likely added to the Bloom filter. Else, return `false`.

2.7 `void bf_print(BloomFilter *bf)`

A debug function to print out a Bloom filter.

Pre-lab Part 1

1. Write down the pseudocode for inserting and deleting elements from a Bloom filter.

3 Bit Vectors

Symmetrical equations are good in their place, but 'vector' is a useless survival, or offshoot from quaternions, and has never been of the slightest use to any creature.

—Lord Kelvin

Bit vectors are a rarely taught but essential tool in the kit of all computer scientists and engineers. A bit vector is an ADT that represents an array of bits, the bits in which are used to denote if something is true or false (1 or 0). This is an efficient ADT since, in order to represent the truth or falsity of an array of n items, we can use $n/8$ if $n \equiv 0 \pmod 8$ else $\lfloor n/8 \rfloor + 1$ `uint8_t`'s instead of n, and being able to access 8 indices with a single integer access is extremely cost efficient.

```
1 struct BitVector {
2   uint32_t length;
3   uint8_t *vector;
4 };
```

You must implement each of the functions specified in the header file. Most of them are just a line of two of **C** code, but their implementation can be subtle. Since, you have already implemented a bit matrix, you will find that their implementations are similar. You are warned *again* against using code that you may find on the Internet.

3.1 `BitVector *bv_create(uint32_t length)`

This constructor will allocate memory for the bit vector. The number of bits that `vector` should hold is `length`. If at any point allocating memory with `calloc()` fails, the function must return `NULL`, else it must return a `BitVector *` or a pointer to a `BitVector`.

3.2 `void bv_delete(BitVector **bv)`

The destructor will free the memory allocated for the bit vector. This requires freeing memory for the array, `vector`, followed by freeing the structure itself. It is best practice to set a pointer to `NULL` once it has been freed to avoid dereferencing a `NULL` pointer in the future (in reality you should check if a pointer is valid before dereferencing it). In order to set `bv` to `NULL`, we need the address of the pointer to the bit vector, hence the reason for a double pointer as a parameter.

3.3 `uint32_t bv_length(BitVector *bv)`

Returns the bit vector's length.

3.4 `void bv_set_bit(BitVector *bv, uint32_t i)`

Upon creation, the elements of a bit vector will be initialized to 0. Since we cannot directly access a bit in a `uint8_t`, we instead need to perform bitwise operations on bytes in order to set a specific bit. The location of

the byte where the bit in question, `i`, resides is given by the following: `vector[⌊i/8⌋]`. Then a bitwise operation is needed to set the correct bit, `i`. Setting a bit should not interfere with any of the other bits' values.

3.5 `void bv_clr_bit(BitVector *bv, uint32_t i)`

In some cases it may be necessary to clear a bit or element in a bit vector. Similarly to setting a bit, it is necessary to access the byte where the bit specified by `i` is located. The location of the byte is given by the following: `vector[⌊i/8⌋]`. Then bitwise operations are needed to clear the correct bit, `i`. Clearing a bit should not interfere with any of the other bits' values.

3.6 `uint8_t bv_get_bit(BitVector *bv, uint32_t i)`

As mentioned in §3, it is necessary to be able to get specific bits from the Bloom filter to determine if one of your dear citizens has used improper oldspeak. Thus, we need a function get a bit from a bit vector. Just like setting and clearing a bit, we need to access the $\lfloor i/8 \rfloor^{\text{th}}$ byte in `vector` to retrieve the value of the i^{th} bit. Then bitwise operations are needed to get the value of the bit. This function should return a 1 if the bit is set and 0 otherwise.

3.7 `void bv_print(BitVector *bv)`

For debugging purposes it is helpful to print out a bit vector. *Do this first.*

4 Hash Tables

> *To send men to the firing squad, judicial proof is unnecessary . . . These procedures are an archaic bourgeois detail.*
>
> Ernesto Ché Guevara

Armed with a Bloom filter, you now exercise the power to catch and punish those who practice wrongthink and continue to use oldspeak. It comes to mind however, that a Bloom filter is probabilistic and that it is better to exercise mercy and counsel the oldspeakers so that they may atone and use *newspeak*. To remedy this, another solution pops into your brilliant and pure mind—a *hash table*.

A hash table is a data structure that maps keys to values and provides fast, O(1), look-up times. It does so typically by taking a key k, hashing it with some hash function $h(x)$, and placing the key's corresponding value in an underlying array at index $h(k)$. This is the perfect way not only to store translations from oldspeak to newspeak, but also as a way to store all prohibited oldspeak words without newspeak translations. We will refer to oldspeak without newspeak translations as *badspeak*. So what happens when two *oldspeak* words have the same hash value? This is called a *hash collision*, and must be resolved. Rather than doing *open addressing* (as will be discussed in lecture), we will be using *linked lists* to resolve *oldspeak* hash collisions. First, however, we must discuss the hash function.

4.1 Hashing with the SPECK Cipher

You will need a good hash function to use in your Bloom filter and hash table. We will have discussed hash functions in class, and rather than risk having a poor one implemented, we will simply provide you one. The SPECK[2] block cipher is provided for use as a hash function.

SPECK is a family of lightweight block ciphers publicly released by the National Security Agency (NSA) in June 2013. SPECK has been optimized for performance in software implementations, while its sister algorithm, SIMON, has been optimized for hardware implementations.

[2] Ray Beaulieu, Stefan Treatman-Clark, Douglas Shors, Bryan Weeks, Jason Smith, and Louis Wingers, "The SIMON and SPECK lightweight block ciphers." In Proceedings of the 52nd ACM/EDAC/IEEE Design Automation Conference (DAC), pp. 1–6. IEEE, 2015.

SPECK is an add-rotate-xor (ARX) cipher. The reason a cipher is used for this is because encryption generates random output given some input; exactly what we want for a hash.

Encryption is the process of taking some file you wish to protect, usually called plaintext, and transforming its data such that only authorized parties can access it. This transformed data is referred to as ciphertext. Decryption is the inverse operation of encryption, taking the ciphertext and transforming the encrypted data back to its original state as found in the original plaintext. Encryption algorithms that utilize the same key for both encryption and decryption, like SPECK, are symmetric-key algorithms, and algorithms that don't, such as RSA, are asymmetric-key algorithms.

You will be given two files, `speck.h` and `speck.c`. The former will provide the interface to using the SPECK hash function which has been named `hash()`, and the latter contains the implementation. The hash function `hash()` takes two parameters: a 128-bit salt passed in the form of an array of two `uint64_t`s, and a key to hash. The function will return a `uint32_t` which is exactly the index the key is mapped to.

```
1 uint32_t hash(uint64_t salt[], char *key);
```

4.2 HashTable

Below is the `struct` definition for a hash table. Similar to a Bloom filter, a hash table contains a salt which is passed to `hash()` whenever a new oldspeak entry is being inserted. As mentioned in §5, we will be using linked lists to resolve oldspeak hash collisions, which is why a hash table contains an array of linked lists. The `mtf` field indicates whether or not the linked lists should use the *move-to-front* technique, which will be discussed in §5.6.

```
1 struct HashTable {
2   uint64_t salt[2];
3   uint32_t size;
4   bool mtf;
5   LinkedList **lists;
6 };
```

4.3 HashTable *ht_create(uint32_t size, bool mtf)

The constructor for a hash table. The `size` parameter denotes the number of indices, or linked lists, that the hash table can index up to. The salt for the hash table has been supplied in the constructor as well.

```c
HashTable *ht_create(uint32_t size, bool mtf) {
  HashTable *ht = (HashTable *) malloc(sizeof(HashTable));
  if (ht) {
    ht->salt[0] = 0x85ae998311115ae3; // Il nome della rosa
    ht->salt[1] = 0xb6fac2ae33a40089;
    ht->size = size;
    ht->mtf = mtf;
    ht->lists = (LinkedList **) calloc(size, sizeof(LinkedList *));
    if (!ht->lists) {
      free(ht);
      ht = NULL;
    }
  }
  return ht;
}
```

4.4 `void ht_delete(HashTable **ht)`

The destructor for a hash table. Each of the linked lists in `lists`, the underlying array of linked lists, is freed. The pointer that was passed in should be set to `NULL`.

4.5 `uint32_t ht_size(HashTable *ht)`

Returns the hash table's size.

4.6 `Node *ht_lookup(HashTable *ht, char *oldspeak)`

Searches for an entry, a node, in the hash table that contains `oldspeak`. A node stores oldspeak and its newspeak translation. The index of the linked list to perform a look-up on is calculated by hashing the `oldspeak`. If the node is found, the pointer to the node is returned. Else, a `NULL` pointer is returned.

4.7 `void ht_insert(HashTable *ht, char *oldspeak, char *newspeak)`

Inserts the specified `oldspeak` and its corresponding `newspeak` translation into the hash table. The index of the linked list to insert into is calculated by hashing the `oldspeak`. If the linked list that should be inserted into hasn't been initialized yet, create it first before inserting the oldspeak and newspeak.

4.8 `void ht_print(HashTable *ht)`

A debug function to print out the contents of a hash table.

5 Linked Lists

> *Education is a weapon, whose effect depends on who holds it in his hands and at whom it is aimed.*
>
> —Joseph Stalin

A *linked list* will be used to resolve hash collisions. Each node of the linked list contains *oldspeak* and its *newspeak* translation if it exists. The *key* to search with in the linked list is *oldspeak*. Each node will also contain a pointer to the previous node *and* the next node in the linked list. This is because you will be implementing *doubly linked lists*.

5.1 `Node`

A node is defined with the following `struct`:

```
1 struct Node {
2   char *oldspeak;
3   char *newspeak;
4   Node *next;
5   Node *prev;
6 };
```

If the `newspeak` field is `NULL`, then the oldspeak contained in this node is badspeak, since there is no newspeak translation. This `struct` definition and interface for the node ADT will be provided for you in `node.h`. The node ADT is not opaque in order to simplify the rest of the linked list implementation.

5.2 `Node *node_create(char *oldspeak, char *newspeak)`

The constructor for a node. You will want to make a *copy* of the `oldspeak` and its `newspeak` translation that are passed in. What this means is *allocating memory* and copying over the characters for both `oldspeak` and `newspeak`. There was a function `strdup()` that did precisely that, but it has been deprecated. You will find it helpful to implement your own function to mimic `strdup()`.

5.3 `void node_delete(Node **n)`

The destructor for a node. Only the node `n` is freed. The previous and next nodes that `n` points to *are not* deleted. Since you have allocated memory for `oldspeak` and `newspeak`, remember to free the memory allocated to both of those as well. The pointer to the node should be set to `NULL`.

5.4 `void node_print(Node *n)`

While helpful as debug function, you will use this function to produce correct program output. Thus, it is imperative that you print out the contents of a node in the following manner:

- If the node `n` contains oldspeak *and* newspeak, print out the node with this print statement:

```
1 printf("%s -> %s\n", n->oldspeak, n->newspeak);
```

- If the node `n` contains *only* oldspeak, meaning that newspeak is null, then print out the node with this print statement:

```
printf("%s\n", n->oldspeak);
```

5.5 LinkedList

The `struct` definition of a linked list is given below. A linked list, when constructed, will initially have two *sentinel* nodes, which will be further explained in §6.6 where the constructor function is discussed along with the rationale and usage of the sentinel nodes. The field `mtf` signifies the *move-to-front* technique, which will be further explained in §6.6 and §6.10.

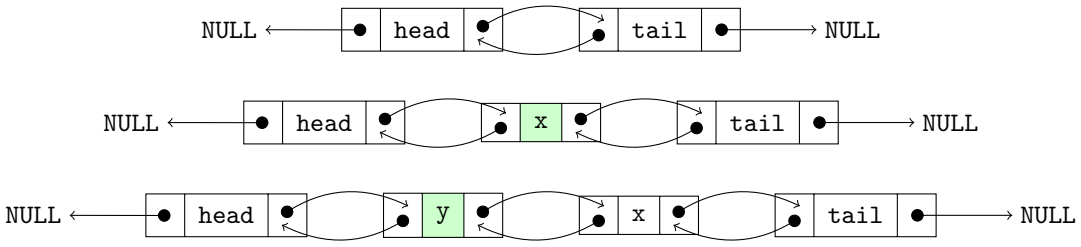
```
struct LinkedList {
  uint32_t length;
  Node *head; // Head sentinel node.
  Node *tail; // Tail sentinel node.
  bool mtf;
};
```

5.6 LinkedList *ll_create(bool mtf)

The constructor for a linked list. The only parameter that this function takes is a boolean, `mtf`. If `mtf` is `true`, that means any node that is found in the linked list through a look-up is *moved to the front* of the linked list. To simplify the code to insert nodes into the linked list, your linked lists will be initialized with exactly two *sentinel nodes*. They will serve as the head and the tail of the linked list.

A linked list that is not initialized with sentinel nodes exhibits two different cases when inserting a node. The first case is when the linked list is empty and contains no nodes. This means the inserted node becomes the head of the linked list. The second case is when the linked list contains at least one node, which means the inserted node becomes the new head of the linked list and must point to the old head of the linked list. The old head of the linked list must also point back to the new head to preserve the properties of a doubly linked list.

Using two sentinel nodes reduces the insertion cases down to one: every inserted node will go between two nodes. Why? Because there are already two nodes to start with. The following diagrams showcase, in order, a linked list when initialized, the linked list when a node containing `x` is inserted, and then the linked list when a node containing `y` is inserted. Note that inserting a node into a linked list means inserting it *at the head*.



5.7 `void ll_delete(LinkedList **ll)`

The destructor for a linked list. Each node in the linked list should be freed using `node_delete()`. The pointer to the linked list should be set to `NULL`.

5.8 `uint32_t ll_length(LinkedList *ll)`

Returns the length of the linked list, which is equivalent to the number of nodes in the linked list, *not* including the head and tail sentinel nodes.

5.9 `Node *ll_lookup(LinkedList *ll, char *oldspeak)`

Searches for a node containing `oldspeak`. If a node is found, the pointer to the node is returned. Else, a `NULL` pointer is returned. If a node was found and the move-to-front option was specified when constructing the linked list, then the found node is moved to the front of the linked list. The move-to-front technique decreases look-up times for nodes that are frequently searched for. You will learn more about optimality in your future classes.

5.10 `void ll_insert(LinkedList *ll, char *oldspeak, char *newspeak)`

Inserts a new node containing the specified `oldspeak` and `newspeak` into the linked list. Before inserting the node, a look-up is performed to make sure the linked list *does not* already contain a node containing a matching `oldspeak`. If a duplicate exists, a new node is not inserted into the linked list. Else, the new node is inserted *at the head* of the linked list. This means that the new node comes directly after the head sentinel node.

5.11 `void ll_print(LinkedList *ll)`

Prints out each node in the linked list *except* for the head and tail sentinel nodes. This will require the use of `node_print()`.

Pre-lab Part 2

1. Write down the pseudocode for each of the functions in the interface for the linked list ADT.

6 Lexical Analysis with Regular Expressions

> *Ideas are more powerful than guns. We would not let our enemies have guns, why should we let them have ideas.*
>
> —Joseph Stalin

Back to regulating your citizens of the GPRSC. You will need a function to parse out the words that they speak, which will be passed to you in the form of an input stream. The words that they will use are valid words, which can include *contractions* and *hyphenations*. A valid word is any sequence of one or more characters that are part of your regular expression word character set. Your word character set should contain characters from $a-z$, $A-Z$, $0-9$, including the underscore character. Since you also accept contractions like "don't" and "y'all've" and hyphenations like "pseudo-code" and "move-to-front", your word character set should include apostrophes and hyphens as well.

You will need to write your own *regular expression* for a word, utilizing the `regex.h` library to lexically analyze the input stream for words. You will be given a parsing module that lexically analyzes the input stream using your regular expression. You are not required to use the module itself, but it is *mandatory* that you parse through

an input stream for words using at least one regular expression. The interface for the parsing module will be in `parser.h` and its implementation will be in `parser.c`.

The function `next_word()` requires two inputs, the input stream `infile`, and a pointer to a compiled regular expression, `word_regex`. Notice the word *compiled*: you must first compile your regular expression using `regcomp()` before passing it to the function. Make sure you remember to call the function `clear_words()` to free any memory used by the module when you're done reading in words. Here is a small program that prints out words input to `stdin` using the parsing module. In the program, the regular expression for a word matches one or more lowercase and uppercase letters. The regular expression you will have to write for your assignment will be more complex than the one displayed here, as it is just an example.

Example program using the parsing module.

```c
#include "parser.h"
#include <regex.h>
#include <stdio.h>

#define WORD "[a-zA-Z]+"

int main(void) {
    regex_t re;
    if (regcomp(&re, WORD, REG_EXTENDED)) {
        fprintf(stderr, "Failed to compile regex.\n");
        return 1;
    }

    char *word = NULL;
    while ((word = next_word(stdin, &re)) != NULL) {
        printf("Word: %s\n", word);
    }

    clear_words();
    regfree(&re);
    return 0;
}
```

Pre-lab Part 3

1. Write down the regular expression you will use to match words with. It should match hyphenations and contractions as well. The regular expression refers to the pattern you will be using. For example, a regular expression to match strings consisting of only lowercase characters would be: `"[a-z]+"`.

7 Your Task

The people will believe what the media tells them they believe.

—George Orwell

- Initialize your Bloom filter and hash table.
- Read in a list of *badspeak* words with `fscanf()`. Again, badspeak is simply oldspeak without a newspeak translation. Badspeak is strictly forbidden. Each badspeak word should be added to the Bloom filter and the hash table. The list of proscribed words will be in `badspeak.txt`, which can be found in the `resources` repository.
- Read in a list of *oldspeak* and *newspeak* pairs with `fscanf()`. Only the oldspeak should be added to the Bloom filter. The oldspeak *and* newspeak are added to the hash table. The list of oldspeak and newspeak pairs will be in `newspeak.txt`, which can also be found in the `resources` repository.
- Now that the lexicon of badspeak and oldspeak/newspeak translations has been populated, you can start to filter out words. Read words in from `stdin` using the supplied parsing module.
- For each word that is read in, check to see if it has been added to the Bloom filter. If it has not been added to the Bloom filter, then no action is needed since the word isn't a proscribed word.
- If the word has most likely been added to the Bloom filter, meaning `bf_probe()` returned `true`, then further action needs to be taken.
    1. If the hash table contains the word and the word *does not* have a newspeak translation, then the citizen who used this word is guilty of `thoughtcrime`. Insert this badspeak word into a list of badspeak words that the citizen used in order to notify him of his errors later.
    2. If the hash table contains the word, and the word *does* have a newspeak translation, then the citizen requires counseling on proper *Rightspeak*. Insert this oldspeak word into a list of oldspeak words with newspeak translations in order to notify the citizen of the revisions needed to be made in order to practice Rightspeak.
    3. If the hash table does not contain the word, then all is good since the Bloom filter issued a false positive. No disciplinary action needs to be taken.
- If the citizen is accused of thoughtcrime *and* requires counseling on proper *Rightspeak*, then they are given a reprimanding message notifying them of their transgressions and promptly sent off to *joycamp*. The message should both contain the list of badspeak words and oldspeak words with newspeak translations that were used.

```
Dear Comrade,

You have chosen to use degenerate words that may cause hurt
feelings or cause your comrades to think unpleasant thoughts.
This is doubleplus bad. To correct your wrongthink and
preserve community consensus we will be sending you to joycamp
administered by Medellin's Miniluv. Beware of the hippos.

Your errors:

kalamazoo
antidisestablishmentarianism

Think of these words on your vacation!

sad -> happy
liberty -> badfree
music -> noise
read -> papertalk
write -> papertalk
```

- If the citizen is accused solely of thoughtcrime, then they are issued a thoughtcrime message and also set off to *joycamp*. The message should contain the list of badspeak words that were used.

```
Dear Comrade,

You have chosen to use degenerate words that may cause hurt
feelings or cause your comrades to think unpleasant thoughts.
This is doubleplus bad. To correct your wrongthink and
preserve community consensus we will be sending you to joycamp
administered by Medellin's Miniluv. Beware of the hippos.

Your errors:

kalamazoo
antidisestablishmentarianism
```

- If the citizen only requires counseling, then they are issued an encouraging *goodspeak message*. They will read it, correct their *wrongthink*, and enjoy the rest of their stay in the GPRSC. The message should contain the list of oldspeak words with newspeak translations that were used.

```
  Dear Comrade,

  Submitting your text helps to preserve feelings and prevent
  badthink. Some of the words that you used are not goodspeak.
  The list shows how to turn the oldspeak words into newspeak.

  sad -> happy
  liberty -> badfree
  music -> noise
  read -> papertalk
  write -> papertalk
```

- The list of the command-line options your program must support is listed below. *Any* combination of the command-line options must be supported.
  - `-h size` specifies that the hash table will have `size` entries (the default will be 10000).
  - `-f size` specifies that the Bloom filter will have `size` entries (the default will be 2^{20}).
  - `-m` will enable the *move-to-front rule*.

8 Deliverables

> *I would rather have questions that can't be answered than answers that can't be questioned.*
>
> —Richard P. Feynman

You will need to turn in:

1. `banhammer.c`: This contains `main()` and *may* contain the other functions necessary to complete the assignment.
2. `speck.h`: Defines the interface for the hash function using the SPECK cipher. Do not modify this.

3. `speck.c`: Contains the implementation of the hash function using the SPECK cipher. Do not modify this.
4. `hash.h`: Defines the interface for the hash table ADT. Do not modify this.
5. `hash.c`: Contains the implementation of the hash table ADT.
6. `ll.h`: Defines the interface for the linked list ADT. Do not modify this.
7. `ll.c`: Contains the implementation of the linked list ADT.
8. `node.h`: Defines the interface for the node ADT. Do not modify this.
9. `node.c`: Contains the implementation of the node ADT.
10. `bf.h`: Defines the interface for the Bloom filter ADT. Do not modify this.
11. `bf.c`: Contains the implementation of the Bloom filter ADT.
12. `bv.h`: Defines the interface for the bit vector ADT. Do not modify this.
13. `bv.c`: Contains the implementation of the bit vector ADT.
14. `parser.h`: Defines the interface for the regex parsing module. Do not modify this.
15. `parser.c`: Contains the implementation of the regex parsing module.
16. You may have other source and header files, but *do not make things overly complicated.*
17. `Makefile`: This is a file that will allow the grader to type `make` to compile your program.
    - `CFLAGS=-Wall -Wextra -Werror -Wpedantic` must be included.
    - `CC=clang` must be specified.
    - `make clean` must remove all files that are compiler generated.
    - `make` should build your program, as should `make all`.
    - Your program executable *must* be named `banhammer`.
    - Running `scan-build` on your program should result in no reported bugs. If there are any false positives that are reported, they should be explained in `README.md`.
18. `README.md`: This must be in Markdown. This must describe how to use your program and `Makefile`. This includes listing and explaining the command-line options that your program accepts. Any false positives reported by `scan-build` should go here as well.
19. `DESIGN.pdf`: This *must* be a PDF. The design document should contain answers to the pre-lab questions at the beginning and describe your design for your program with enough detail that a sufficiently knowledgeable programmer would be able to replicate your implementation. This does not mean copying your entire program in verbatim. You should instead describe how your program works with supporting pseudo-code. For this program, pay extra attention to how you build each necessary component.

    You *must* push the `DESIGN.pdf` before you push *any* code.

9 Submission

> *We can and must write in a language which sows among the masses hate, revulsion, and scorn toward those who disagree with us.*
>
> —Vladimir Lenin

To submit your assignment, refer back to `assignment0` for the steps on how to submit your assignment through `git`. Remember: *add, commit,* and *push*!

Your assignment is turned in *only* after you have pushed and turned in the commit ID to Canvas. If you forget to push, you have not turned in your assignment and you will get a *zero.* "I forgot to push" is not a valid excuse. It is *highly* recommended to commit and push your changes *often.*