```
#include "hashTable.h"
#include<iostream>
#include<climits>
#include<fstream>
#include<vector>
#include<string>

using namespace std;



void testHash(){
        cout << "Test Hash Function" << endl;
        int numSlots = 13001; //prime
        str s1("Tung Luu");
        assert(s1.hash(numSlots) == 1821);
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        str s2("Wilson Le");
        assert(s2.hash(numSlots) == 3402);
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
}

void testHtTostring(){
        cout << "Test Hash Table toString" << endl;
        int numSlots = 13001; //prime
        HashTable<Data<str, int> > ht(numSlots);
        assert(ht.toString(0) == "[]");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        assert(ht.toString(2) == "[]");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        assert(ht.toString(13001) == "[]");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
}

void testHtConstructor(){
        cout << "Test Hash Table Constructor" << endl;
        int numSlots1 = 13001; //prime
        HashTable<Data<str, int> > ht1(numSlots1);
        assert(ht1.slots == numSlots1);
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        assert(ht1.table->length() == 0);
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        assert(ht1.table->toString() == "[]");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
        int numSlots2 = 13381; //prime
        HashTable<Data<str, int> > ht2(numSlots2);
        assert(ht2.slots == numSlots2);
        cout << "\tTest 4 Passed â\234\224ï¸\216" << endl;
        assert(ht2.table->length() == 0);
        cout << "\tTest 5 Passed â\234\224ï¸\216" << endl;
        assert(ht2.table->toString() == "[]");
        cout << "\tTest 6 Passed â\234\224ï¸\216" << endl;
}

void testHtInsert(){
        cout << "Test Hash Table Insert" << endl;
        int numSlots = 13001; //prime
        HashTable<Data<str, string> > ht1(numSlots);
        Data<str, string> *d1 = new Data<str, string>(str("Hello"), "world");
        Data<str, string> *d2 = new Data<str, string>(str("CS271"), "Wilson Le");
        Data<str, string> *d3 = new Data<str, string>(str("CS271"), "Tung Luu");
        ht1.insert(d1);
        ht1.insert(d2);
        ht1.insert(d3);
        assert(ht1.toString(d1->hash(numSlots)) == "[world]");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        assert(ht1.toString(d2->hash(numSlots)) == "[Wilson Le, Tung Luu]");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        assert(ht1.toString(d3->hash(numSlots)) == "[Wilson Le, Tung Luu]");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
}

void testHtRemove(){
        cout << "Test Hash Table Remove" << endl;
        int numSlots = 13001; //prime
        HashTable<Data<str, string> > ht1(numSlots);
        Data<str, string> *d1 = new Data<str, string>(str("Hello"), "world");
        Data<str, string> *d2 = new Data<str, string>(str("CS271"), "Wilson Le");
        Data<str, string> *d3 = new Data<str, string>(str("CS271"), "Tung Luu");
        ht1.insert(d1);
        ht1.insert(d2);
        ht1.insert(d3);
        ht1.remove(*d1);
        assert(ht1.toString(d1->hash(numSlots)) == "[]");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        ht1.remove(*d2);
        assert(ht1.toString(d2->hash(numSlots)) == "[Tung Luu]");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        ht1.remove(*d3);
        assert(ht1.toString(d3->hash(numSlots)) == "[]");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
}

void testHtClone(){
        cout << "Test Hash Table Clone" << endl;
        int numSlots = 11; //prime
        HashTable<Data<str, string> > ht1(numSlots);
        Data<str, string> *d1 = new Data<str, string>(str("Hello"), "world");
        Data<str, string> *d2 = new Data<str, string>(str("CS271"), "Wilson Le");
        Data<str, string> *d3 = new Data<str, string>(str("CS271"), "Tung Luu");
        ht1.insert(d1);
        ht1.insert(d2);
        ht1.insert(d3);
        HashTable<Data<str, string> > ht2 = ht1;
        HashTable<Data<str, string> > ht3(ht1);
        ht2.remove(*d1);
        ht3.remove(*d2);
        assert(ht1.toString(d1->hash(numSlots)) == "[world]");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        assert(ht1.toString(d2->hash(numSlots)) == "[Wilson Le, Tung Luu]");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        assert(ht1.toString(d3->hash(numSlots)) == "[Wilson Le, Tung Luu]");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
        assert(ht2.toString(d1->hash(numSlots)) == "[]");
        cout << "\tTest 4 Passed â\234\224ï¸\216" << endl;
        assert(ht2.toString(d2->hash(numSlots)) == "[Wilson Le, Tung Luu]");
        cout << "\tTest 5 Passed â\234\224ï¸\216" << endl;
        assert(ht3.toString(d1->hash(numSlots)) == "[world]");
        cout << "\tTest 6 Passed â\234\224ï¸\216" << endl;
        assert(ht3.toString(d2->hash(numSlots)) == "[Tung Luu]");
        cout << "\tTest 7 Passed â\234\224ï¸\216" << endl;
}

int main(){
        testHash();
        testHtTostring();
        testHtConstructor();
        testHtInsert();
        testHtRemove();
        testHtClone();
        return 0;
}
```

```
#ifndef DICT_H
#define DICT_H
#include "hashTable.h"
#include "data.h"
template <class Key, class Value>
class Dict{
        friend void testDictDestructor();
        public:
                Dict();

                // insert data into list
                void insert(Data<Key, Value> *d);

                // get data from list
                Data<Key, Value> * get(const Data<Key, Value>& d) const;

                // remove data from list
                void remove(const Data<Key, Value>& d);

                // return string representation of dictionary
                string toString();

        private:
                HashTable<Data<Key, Value> > ht;
                int size;
};

#include "dict.cpp"
#endif
```

```
#include <sstream>
#include "hashTable.h"
#include "dict.h"
using namespace std;

template <class Key, class Value>
Dict<Key, Value>::Dict(){
        this->size = 13001;
        this->ht = HashTable<Data<Key, Value> >(size);
}

template <class Key, class Value>
void Dict<Key, Value>::insert(Data<Key, Value> *d){
        this->ht.insert(d);
}

template <class Key, class Value>
Data<Key, Value> * Dict<Key, Value>::get(const Data<Key, Value>& k) const {
    return this->ht.get(k);
}

template <class Key, class Value>
void Dict<Key, Value>::remove(const Data<Key, Value>& k){
        this->ht.remove(k);
}

template <class Key, class Value>
string Dict<Key, Value>::toString(){
    return ht.toString();
}
```

```
#include "dict.h"
#include<iostream>
#include<climits>
#include<fstream>
#include<vector>
#include<string>

using namespace std;

void testDictToString(){
        cout << "Test Dict toString" << endl;
        Dict<str, string> d;
        d.insert(new Data<str, string>(str("test"), "testValue1"));
        assert(d.toString() == "{\n[test: testValue1]\n}");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        d.insert(new Data<str, string>(str("test"), "testValue2"));
        assert(d.toString() == "{\n[test: testValue1, test: testValue2]\n}");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        d.insert(new Data<str, string>(str("test1"), "testValue2"));
        assert(d.toString() == "{\n[test1: testValue2]\n[test: testValue1, test: testValu
e2]\n}");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
}

void testDictInsert(){
        cout << "Test Dict Insert" << endl;
        Dict<str, string> d;
        d.insert(new Data<str, string>(str("test"), "testValue1"));
        assert(d.toString() == "{\n[test: testValue1]\n}");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        d.insert(new Data<str, string>(str("test"), "testValue2"));
        assert(d.toString() == "{\n[test: testValue1, test: testValue2]\n}");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
        d.insert(new Data<str, string>(str("test1"), "testValue2"));
        assert(d.toString() == "{\n[test1: testValue2]\n[test: testValue1, test: testValu
e2]\n}");
        cout << "\tTest 3 Passed â\234\224ï¸\216" << endl;
}

void testDictGet(){
        cout << "Test Dict Insert" << endl;
        Dict<str, string> d;
        d.insert(new Data<str, string>(str("A"), "hello"));
        assert(d.get(Data<str, string>(str("A"), ""))->toString() == "A: hello");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        d.insert(new Data<str, string>(str("B"), "world"));
        assert(d.get(Data<str, string>(str("B"), ""))->toString() == "B: world");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
}

void testDictRemove(){
        cout << "Test Dict Insert" << endl;
        Dict<str, string> d;
        d.insert(new Data<str, string>(str("A"), "hello"));
        d.insert(new Data<str, string>(str("A"), "helloo"));
        d.insert(new Data<str, string>(str("B"), "world"));
        d.insert(new Data<str, string>(str("B"), "worldd"));
        d.remove(Data<str, string>(str("A"), ""));
        d.remove(Data<str, string>(str("B"), ""));
        assert(d.get(Data<str, string>(str("A"), ""))->toString() == "A: helloo");
        cout << "\tTest 1 Passed â\234\224ï¸\216" << endl;
        assert(d.get(Data<str, string>(str("B"), ""))->toString() == "B: worldd");
        cout << "\tTest 2 Passed â\234\224ï¸\216" << endl;
}

int main(){
        testDictToString();
        testDictInsert();
        testDictGet();
        testDictRemove();
        return 0;
}
```

```
#ifndef DATA_H
#define DATA_H
#include <string>
#include <iostream>
#include <climits>

// class str is a string that has a hash function
class str {
        public:
                str(){
                        this->data = "";
                }
                str(string s){
                        this->data = s;
                }
                int hash(int numSlots) const{
                        // The maximum value of numSlots should be INT_MAX
                        numSlots = min(numSlots, INT_MAX);

                        // Since the char type has 8-bits, which can represents 256 chara
cters,
                        // we will choose 257 as our base because 257 is a prime which is
 close to 256.
                        int base = 257;
                        int powOfBase = 1;
                        int mod = numSlots;

                        int hashRes = 0; // The hash result
                        for(int i = 0; i < this->data.length(); i++) {
                                unsigned char c = this->data[i];
                                // Using the property (a+b) mod n=(a mod n + b mod n) mod
 n
                                // and the property (ab) mod p = ( (a mod p) (b mod p) )
mod p,
                                // we can use the following formulas to calculate the sam
e result as
                                // (hashing a string by expressing it as radix-257 and th
en mod by a number)
                                hashRes = (hashRes + (c * powOfBase)) % mod;
                                powOfBase = (powOfBase * base) % mod;
                        }

                        return hashRes;
                }
                friend ostream& operator<<(ostream& os, const str& s){
                        os << s.data;
                        return os;
                }
                friend bool operator<(const str& s1, const str& s2){
                        return s1.data < s2.data;
                }
                friend bool operator>(const str& s1, const str& s2){
                        return s1.data > s2.data;
                }
                friend bool operator==(const str& s1, const str& s2){
                        return s1.data == s2.data;
                }
        private:
                string data;
};

template <class K, class V>
class Data {
        public:
                Data(K k, V v){
                        this->key = k;
                        this->value = v;
                };
                int hash(int numSlots) const{
                        return this->key.hash(numSlots);
                }
        string toString() const {
            stringstream ss;
            ss << this->key << ": " << this->value;
            return ss.str();
        }
                friend ostream & operator<< (ostream& output, const Data &D ){
                        output << D.toString();
                        return output;
                }
                friend bool operator<(const Data& Data1, const Data& Data2){
                        return Data1.key < Data2.key;
                }
                friend bool operator>(const Data& Data1, const Data& Data2){
                        return Data1.key > Data2.key;
                }
                friend bool operator==(const Data& Data1, const Data& Data2){
                        return Data1.key == Data2.key;
                }
        private:
                K key;
                V value;
};
#endif
```

```
#include<iostream>
#include <fstream>
#include <string>
#include <sys/time.h>
#include "dict.h"
#include "data.h"
using namespace std;

int main()
{
        Dict<str, string> movieDict;
        ifstream movieData("movies_mpaa.txt");

        if(movieData.is_open()) {
                string movie;
                // start timer
                timeval timeBefore, timeAfter;
                long diffSeconds, diffUSeconds;
                gettimeofday(&timeBefore, NULL);

                while(getline(movieData, movie)){
                        int titleEnd = movie.find("\t");
                        string title = movie.substr(0, titleEnd);
                        string cast = movie.substr(titleEnd + 1, movie.size() - titleEnd
 - 1);
                        Data<str, string>* movie = new Data<str, string>(str(title), cast
);
                        movieDict.insert(movie);
                }
                movieData.close();

                // stop timer
                gettimeofday(&timeAfter, NULL);
                diffSeconds = timeAfter.tv_sec - timeBefore.tv_sec;
                diffUSeconds = timeAfter.tv_usec - timeBefore.tv_usec;
                cout << diffSeconds + diffUSeconds/1000000.0 << endl;

        }
        string title = "\"A Woman of Independent Means\" (1995)";
        Data<str, string>* sample = new Data<str, string>(str(title), "");
        Data<str, string>* movie = movieDict.get(*sample);
    cout<< *movie << endl;
}
```

CS 271 Project 6

Tung Luu, Wilson Le

November 20, 2021

1 Hash function

Our hash function hashes string by first interpreting the all characters in the string using radix notation. Since the char type has 8-bits, which can represent 256 characters, I choose 257 as a radix, because 257 is a prime that is close to 256. Let's call the number of slots in our hash table m. With a string s, the formula to calculate the hash of s is:

$$h(s) = (\sum_{i=0}^{s.length()} s[i] * 257^i) \mod m$$

Here's the implementation of my program using the above hash function to hash all words in /usr/share/dict/words into 1000 slots:

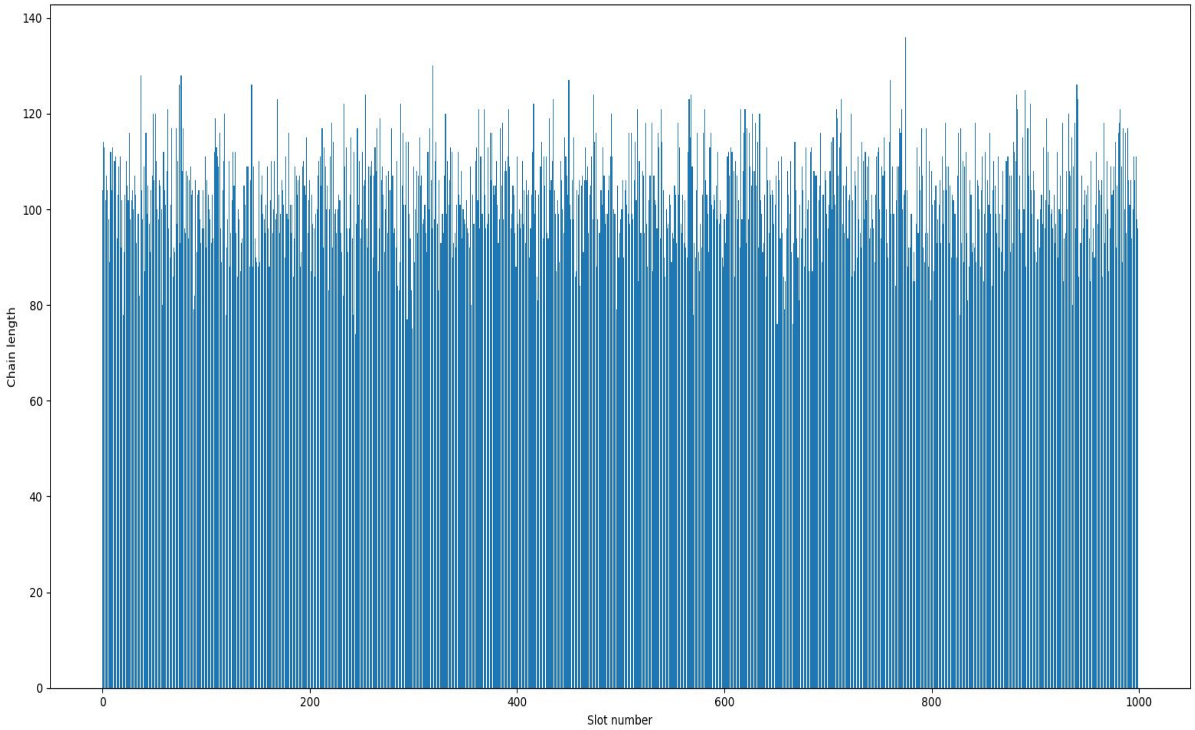
```
#include <iostream>
#include <climits>
#include <fstream>
#include <vector>
#include <string>
using namespace std;

/*
A hash functions that map strings to integer in {0,1,...,numSlots - 1}
*/
int hashString(string s, int numSlots) {
    // The maximum value of numSlots should be INT_MAX
    numSlots = min(numSlots, INT_MAX);

    // Since the char type has 8-bits, which can represents 256 characters,
    // we will choose 257 as our base because 257 is a prime which is close to 256.
    int base = 257;
    int powOfBase = 1;
    int mod = numSlots;

    int hashRes = 0; // The hash result
    for(int i = 0; i < s.length(); i++) {
        unsigned char c = s[i];
        // Using the property (a+b) mod n=(a mod n + b mod n) mod n
        // and the property (ab) mod p = ( (a mod p) (b mod p) ) mod p,
        // we can use the following formulas to calculate the same result as
        // (hashing a string by expressing it as radix-257 and then mod by a number)
        hashRes = (hashRes + (c * powOfBase)) % mod;
        powOfBase = (powOfBase * base) % mod;
    }

    return hashRes;
}

int main() {
    vector<int> freq(1000, 0);
    ifstream dict("/usr/share/dict/words");
    string line;

    if(dict.is_open()) {
        while(getline(dict, line)) {
            int hashCode = hashString(line, 1000);
            freq[hashCode] += 1;
        }
        dict.close();
    }

    ofstream output("./data.csv");
    if(output.is_open()) {
        output << "slot,length" << "\n";
        for(int i = 0; i < 1000; i++) {
            output << i << "," << freq[i] << "\n";
        }
    }
    output.flush();
    output.close();
}
```

In the above implementation, we use some property of modulo operation to calculate the hash result of a string without getting integer overflow, achieving the same result as our original formula for hashing.

2 Analysis

We also plot a bar graph that displays how evenly our hash function assigns words to 1000 slots, in which the x-axis is slot number and y-axis is chain length. We write the a short python snippet to create this graph and calculate the standard deviation:

```
import matplotlib.pyplot as plt
import pandas as pd
import math

data = pd.read_csv("./data2.csv")

def stdDev(data):
    n = len(data)
    mean = sum(data) / n
    total = 0
    for x in data:
        total += (x - mean) ** 2
    return math.sqrt(total / n)

def plot():
    plt.bar(data["slot"], data["length"])

    plt.xlabel("Slot number")
    plt.ylabel("Chain length")
    plt.show()

print(stdDev(data["length"]))
plot()
```



The standard deviation of our hash function when apply to the dictionary is 9.86286971423632.

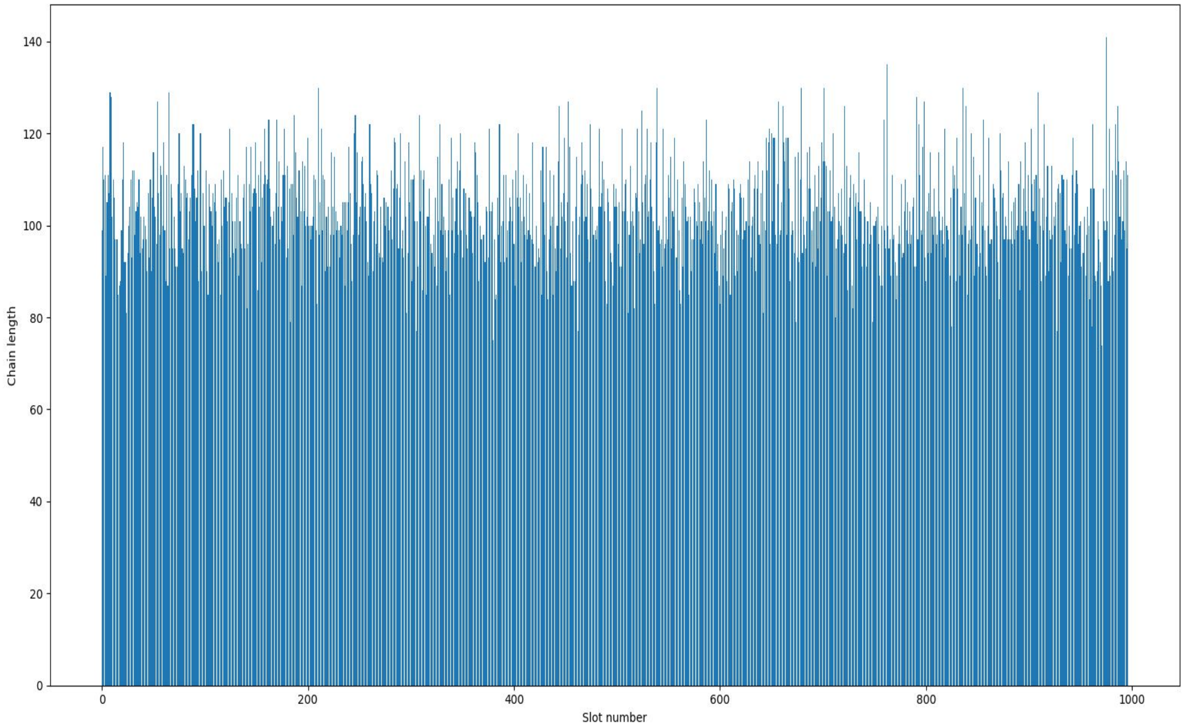
3 Improvement

Our choice of 1000 as our number of slots might not be the best choice. I made a slightly different version of my hash function, where the number of slots is a maximum prime number that is smaller or equal to the numSlots parameter passed into the function. I think choosing a prime number as the number of slots can increase uniform of our hash function.

```
#include<iostream>
#include<climits>
#include<fstream>
#include<vector>
#include<string>
using namespace std;

/*
isPrime[i] = true if i is a prime number, false otherwise. This function
fills the isPrime vector from 0 to maxNum;
```

```
*/
void sieveOfEratosthenes(int maxNum, vector<int>& isPrime) {
    for(int num = 2; num * num <= maxNum; num++) {
        if(isPrime[num]) {
            for(int multiples = num * num; multiples <= maxNum; multiples += num) {
                isPrime[multiples] = false;
            }
        }
    }
}

/*
let's call m the biggest prime number less or equal than numSlots.
This hash functions that map strings to integer in {0,1,...,m-1}
*/
int hashString(string s, int numSlots, const vector<int>& isPrime) {
    // The maximum value of numSlots should be INT_MAX
    numSlots = min(numSlots, INT_MAX);

    int base = 257; // Since the char type has 8-bits, which can represents 256 characters,
    int powOfBase = 1;
    int mod;
    // mod is the largest prime number which is less than numSlots
    for(int num = numSlots - 1; num >=0; num--) {
        if(isPrime[num]) {
            mod = num;
            break;
        }
    }

    int hashRes = 0; // The hash result
    for(int i = 0; i < s.length(); i++) {
        unsigned char c = s[i];
        // Using the property (a+b) mod n=(a mod n + b mod n) mod n
        // and the property (ab) mod p = ( (a mod p) (b mod p) ) mod p,
        // we can use the following formulas to calculate the same result as (hashing a str
        hashRes = (hashRes + (c * powOfBase)) % mod;
        powOfBase = (powOfBase * base) % mod;
    }

    return hashRes;
}

int main() {
    vector<int> freq(1000, 0);
    ifstream dict("/usr/share/dict/words");
    string line;

    if(dict.is_open()) {
        vector<int> isPrime(1000, true);
        sieveOfEratosthenes(999, isPrime);

        while(getline(dict, line)) {
            int hashCode = hashString(line, 1000, isPrime);
            freq[hashCode] += 1;
        }
        dict.close();
    }

    ofstream output("./data2.csv");
    if(output.is_open()) {
        output << "slot,length" << "\n";
        for(int i = 0; i < 1000; i++) {
            output << i << "," << freq[i] << "\n";
        }
    }
    output.flush();
    output.close();
}
```

We also use the above python code to plot a bar graph and standard deviation that correspond to our new hash function.



The standard deviation of our new hash function when apply to the dictionary is 10.09869287254665

4 Part 4

1. Hash table time to create Dictionary from movie file: 0.201735 (s)
2. Binary search tree time to create Dictionary from movie file: 5.32387 (s)