- This lab will cover Hash Tables, Maps, and Sets
- It is assumed that you have reviewed chapter 10 of the textbook. You may want to refer to the text and your lecture notes during the lab as you solve the problems.
- When approaching the problems, think before you code. Doing so is good practice and can help you lay out possible solutions.
- Think of any possible test cases that can potentially cause your solution to fail!
- If you finish early, you may leave early after showing the TA your work. Or you may stay and help other students. If you don't finish by the end of the lab, we recommend you complete it on your own time. Ideally you should not spend more time than suggested for each problem.
- Your TAs are available to answer questions in lab, during office hours, and on Piazza.

Vitamins

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1. Given an array of size **N = 7**, perform the following operation using **separate chaining**. Draw the abstract representation of the array on a piece of paper. Trace all the changes. Use **Multiply-Add-Divide (MAD) as the compression method**. The MAD method maps an integer i as follows:

$$[(ai \ + \ b) mod\, p] mod\, N$$

p is a prime number
a is a number within the range of [1, p-1]
b is a number within the range of [0, p-1]

For this problem, assume p = 107, a = 1, b = 2. The items don't have any values associated with them, meaning they are just integers. You will have to rehash when the number of items, n is greater than the total capacity N, i.e. when n>N.

a. Insert 37
b. Insert 47
c. Insert 51
d. Delete 37
e. Insert 65
f. Insert 104
g. Insert 8
h. Insert 5
i. Insert 10
j. Insert 7
k. Delete 8

2. Given a hash table T with 25 slots that stores 2000 elements, the load factor α for T is

   __________.

3. Analyze the worst-case and average runtime of the following function, and give it an appropriate name:

```python
def mystery(s1, s2):
    fMap = ChainingHashTableMap( ) #fMap = frequency Map

    for char in s1:
        if char not in fMap:
            fMap[char] = 0

        fMap[char] += 1

    for char in s2:
        if char not in fMap:
            return False

        fMap[char] -= 1

    for key in fMap:
        if fMap[key] != 0:
            return False

    return True
```

   What are the outputs of the following?

```python
print(mystery("cheaters", "teachers"))

print(mystery("engineering", "gnireenigne"))

print(mystery("Python", "nohtyp"))
```

Coding

In this section, it is strongly recommended that you solve the problem on paper before writing code.

Download the **ChainingHashTableMap.py** & **UnsortedArrayMap.py** file on NYU Brightspace

1.
    a. Given a list of numbers, return the number that appears most frequently in average O(n) time.
    You can assume that the most frequent number in lst is unique.

    ```
    def most_frequent(lst):
    ```

    ```
    Input: lst = [5,9,2,9,0,5,9,7]
    Output: 9

    Explanation: 9 appears the most in the array
    ```

    b. Given a list of numbers, return the first number that is not repeated in the list in average O(n) time. Use the implementation from above to assist.

    ```
    def first_unique(lst):
    ```

    ```
    Input: lst = [5,9,2,9,0,5,9,7]
    Output: 2

    Explanation: 2 is the first non-duplicate number
    ```

    c. What is the worst-case <u>extra space complexity</u> of your two functions? Suppose that instead of a list of integers, you are given a string of lower-case and upper-case letters (symbols not included). Does the extra space complexity change?

2. Given a list of *unsorted* integers and a target value, return a tuple of the indices of two numbers that sum up to the target in average O(n) time. Return (None, None) if no pair exists.

```
def two_sum(lst, target):
```

ex)
```
Input: lst =  [-2, 11, 15, 21, 20, 7], target = 22
Output: (2,5)

Explanation: Indices 2 and 5 hold numbers 15 and 7, which both sum up to 22.

Input: lst =  [-2, 11, 15, 21, 20, 20], target = 22
Output: (None, None)
```

Hint: You should use the ChainingHashTableMap class to achieve the run-time.

3. In this question, we will look at the `PlayList` ADT. This ADT is used to maintain a sequential collection of songs. Each song could be played individually, or all songs could be played sequentially (in the order they were inserted in). (35 minutes)

   Define this ADT, which supports the following behavior:
   - `pl = PlayList( )` - creates an empty PlayList object.
   - `pl.add_song(new_song_name)` - adds the song new_song_name to the end of the songs sequence
   - `pl.add_song_after(song_name, new_song_name)` - adds the song new_song_name to the songs sequence, right after song_name; or raise KeyError exception if song_name not in the play list
   - `pl.play_song(song_name)` - plays the song song_name; or raise KeyError exception if song_name not in the play list
   - `pl.play_list( )` - plays all the songs in the PlayList by their sequential order.

   To simulate playing a song, have the methods `print("Playing " + song_name)`.

   __Implementation Requirements__:

1. `add_song, add_song_after, play_song` should run in Θ(1) **average time**.
2. `play_list` should run in Θ(n) average time, n being the number of songs in the play list.
3. You may not use Python's built-in dict. Use the `ChainingHashTableMap` instead, which has the same behavior. If needed, you may use ONE additional data structure implemented in class to help you:

   ```
   ArrayStack
   ArrayQueue
   DoublyLinkedList
   BinarySearchTree
   ```

Test Code for the PlayList ADT:

```
#Feel free to listen to these itunes top hits while you code :)

p1 = PlayList( )
p1.add_song("Jana Gana Mana")
p1.add_song("Kimi Ga Yo")
p1.add_song("The Star-Spangled Banner")
p1.add_song("March of the Volunteers")
p1.add_song_after("The Star-Spangled Banner", "La Marcha Real")
p1.add_song_after("Kimi Ga Yo", "Aegukga")
p1.add_song("Arise, O Compatriots")
p1.add_song("Chant de Ralliement")
p1.add_song_after("Chant de Ralliement", "Himno Nacional Mexicano")
p1.add_song_after("Jana Gana Mana", "God Save The Queen")

p1.play_song("The Star-Spangled Banner")
p1.play_song("Jana Gana Mana")

p1.play_list( )
```

Output:

```
"Playing The Star-Spangled Banner"
"Playing Jana Gana Mana"
"Playing Jana Gana Mana"
"Playing God Save The Queen"
"Playing Kimi Ga Yo"
"Playing Aegukga"
```

```
"Playing The Star-Spangled Banner"
"Playing La Marcha Real"
"Playing March of the Volunteers"
"Playing Arise, O Compatriots"
"Playing Chant de Ralliement"
"Playing Himno Nacional Mexicano"
```

OPTIONAL

4. For this question, you will implement another data type, `Set`, which is similar to a `Map`. A set is similar to a map in that it has the following properties:

    - **all keys in the collection are unique**
    - **all keys in the collection are unordered**

    Instead of having a (key, value) pair, **sets only have keys**. Therefore, it is ideal to use a set if you only care about unique keys instead of setting the value of each key to None.

    For familiarity, Python has a built-in set (`set`) and map (`dict`).

    Using dict literals `{ }` , we can create a dictionary with the following:

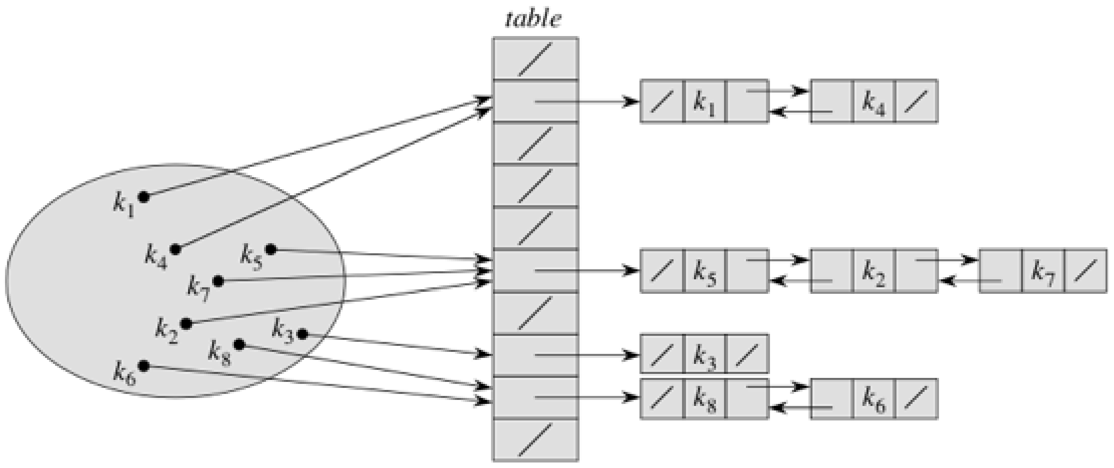
    ```
    dict1 = {1 : "apple", 2 : "banana", 3: "orange"}
    print(type(dict1)) #<class 'dict'>
    ```

    However, if we use the same literals with only keys, we end up creating a set:

    ```
    set1 = {1, 2, 3}
    print(type(set1)) #<class 'set'>
    ```

Note: Since we only have unique keys, we do not need the item class. Instead of using the UnsortedArrayMap file, we will just use a **DoublyLinkedList** as our secondary collections.

Here is a representation of the `ChainingHashTableSet`:



Each key is mapped to a slot (index) in the hash table using a hash function, and is then placed into the doubly linked list bucket in the respective slot.

Download the **ChainingHashTableMap.py** file on NYU Brightspace

The `ChainingHashTableSet` will use the same hash function that was implemented in lectures.

Your task is to modify the existing methods in the ChainingHashTableMap file for a ChainingHashTableSet and additionally define the add, remove methods. (35 minutes)

```
class ChainingHashTableSet:

      def __init__(self, N=64):
      #modify this to support the set ADT

      def rehash(self, new_size):
      #modify this to support the set ADT

      def __iter__(self):
      #modify this to support the set ADT

      def __contains__(self, key):
      #modify this to support the set ADT


      def add(self, key): #replace __setitem__
      ''' Adds a key to the set. If the key already exists, do
      nothing. You may want to refer to the __setitem__
      implementation of the ChainingHashTableMap. '''


      def remove(self, key): #replace __delitem__
      ''' Removes a key from the set. If the key doesn't exist, raise
      a KeyError. You may want to refer to the __delitem__
      implementation of the ChainingHashTableMap  '''

      #remove __getitem___


def print_hash_table(hset):
#modify this to support the set ADT
```

Sets are commonly used with logic operations: **AND, OR**. You will learn more about sets when you take your Discrete Mathematics course; here is a head start with some extra credit for you!

The **AND** operation, also called the **intersection of 2 sets** is a set containing keys that exist in **BOTH** sets. We use the ∩ or & to denote the operator.

ex)

```
set1 = {1, 2, 3, "apple", "banana"}
set2 = {1, 3, "orange"}

set1 & set2 returns {1, 3}
set1.intersection(set2) returns {1, 3}


#commutative property: a & b == b & a
set2 & set1 returns {1, 3}
```

The **OR** operation, also called **the union of 2 sets** is a set containing keys that exist in **EITHER** sets. We use the ∪ or **|** to denote the operator.

ex)

```
set1 = {1, 2, 3, "apple", "banana"}
set2 = {1, 3, "orange"}

set1 | set2 returns {1, 2, 3, "apple", "banana", "orange"}
set1.union(set2) returns {1, 2, 3, "apple", "banana", "orange"}


#commutative property: a | b == b | a
set2 | set1 returns {1, 2, 3, "apple", "banana", "orange"}
```

Finally, there is the **difference of 2 sets**, which is a set containing keys that exist in **ONE SET BUT NOT THE OTHER**. We use the - to denote the operator.____

ex)

```
set1 = {1, 2, 3, "apple", "banana"}
set2 = {1, 3, "orange"}

#notice that unlike with OR and AND, the operation is not commutative!

set1 - set2 returns {2, "apple", "banana"}
set2 - set1 returns {"orange"}

set1.difference(set2) returns {2, "apple", "banana"}
set2.difference(set1) returns {"orange"}
```

Add the following methods to your `ChainingHashTableSet` class:

```
def intersection(self, other):
#returns a new set containing the intersection of the two sets
#self is set1, and other is set2

def __and__(self, other):
#same as intersection, but allows you to do set1 & set2


def union(self, other):
#returns a new set containing the union of the two sets
#self is set1, and other is set2

def __or__(self, other):
#same as union, but allows you to do set1 | set2


def difference(self, other):
#returns a new set containing the difference of the two sets
#self is set1, and other is set2


def __sub__(self, other):
#same as difference, but allows you to do set1 - set2
```

Hint: the operators implementations __and__, __or__, and __sub__ should only be driver methods. You should use the methods implemented in part 4.