CS 134:
Dictionaries and Sets

Announcements & Logistics

- **Lab 5** is today/tomorrow
  - Expect most people to finish it during scheduled lab period
- **Midterm**: Thu Mar 17th
  - Attend one slot: **6 - 7:30pm or 8 - 9:30pm** in **Wachenheim B11**
  - **Wachenheim 002** at 6pm for reduced distractions/extra time
- **Midterm review**: Tue Mar 15th
  - **7 - 8:30 pm** in **TPL 203** (bring your questions!)
- **Practice midterm** on Glow
- Please fill out the **CS134 TA feedback form** by Friday

Do You Have Any Questions?

Last Time

- A **dictionary** is a **mutable** collection that maps **keys** to **values**
  - **Keys** must be unique & **immutable, values** can any Python object
- Iterating over a dictionary: what do we iterate over?
  - Iterate over the ***keys*** of a dictionary directly (by default)
- Dictionary comprehensions: similar to list comprehensions
- Useful dictionary method:
  - `dict.get(key, defaultVal)`:
    returns `dict[key]` if key exists, else returns `defaultVal`.
    If no `defaultVal` provided: returns `None` if key does not exist.

Today's Plan

- Wrap up dictionaries
- Investigate **sorting** with dictionaries
- Discuss a new unordered data structure: **sets**
- Review all data structures so far and when to use each

Recap: Dictionaries and Mutability

- Dictionaries are **mutable**
  - Has implications for aliasing!

```
>>> myDict = {1: 'a', 2: 'b', 3: 'c'}
>>> newDict = myDict # alias!
>>> newDict[4] = ‘d'
>>> myDict # changes as well
{1: 'a', 2: 'b', 3: 'c', 4: 'd'}
```

- Note: dictionary keys **must be immutable**
  - Cannot have keys of mutable types such as list
- Dictionary values can be any type (mutable values such as lists)

Recap: Dictionary Comprehensions

- Similar to list comprehensions, useful for mapping and filtering
- Remember: when iterating over a dictionary, we are iterating over its **keys** (in the order of creation)

```
calendar = {'Jan': 31, 'Feb': 28, 'Mar': 31, 'Apr': 30,
            'May': 31, 'Jun': 30, 'Jul': 31, 'Aug': 31,
            'Sep': 30, 'Oct': 31, 'Nov': 30, 'Dec': 31}
```

```
days30 = {k: calendar[k] for k in calendar if calendar[k] == 30}
```

```
days30
```

```
{'Apr': 30, 'Jun': 30, 'Sep': 30, 'Nov': 30}
```

Sorting Operations with Dictionaries

- Let's say we're developing a Scrabble app
- We can store the score for each letter as a dictionary as below

```
scrabbleScore = {'a':1 , 'b':3, 'c':3, 'd':2, 'e':1,
                 'f':4, 'g':2, 'h':4, 'i':1, 'j':8,
                 'k':5, 'l':1, 'm':3, 'n':1, 'o':1,
                 'p':3, 'q':10, 'r':1, 's':1, 't':1,
                 'u':1, 'v':8, 'w':4, 'x':8, 'y':4, 'z': 10}
```

- If we call the `sorted()` function on a dictionary, it returns an **ordered list of all the keys**.

Sorting Operations with Dictionaries

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                 'f':4, 'g':2, 'h':4, 'i':1, 'j':8,
                 'k':5, 'l':1, 'm':3, 'n':1, 'o':1,
                 'p':3, 'q':10, 'r':1, 's':1, 't':1,
                 'u':1, 'v':8, 'w':4, 'x':8, 'y':4, 'z': 10}
```

- If we call the `sorted()` function on a dictionary, it returns an **ordered list of all the keys**.

```
print(sorted(scrabbleScore))
```

```
['a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j', 'k', 'l', 'm', 'n', 'o', 'p', 'q', 'r',
's', 't', 'u', 'v', 'w', 'x', 'y', 'z']
```

Sorting By Value

- This behavior isn't super useful for Scrabble
- What if we wanted to sort based on the scores of the letters (from highest to lowest) instead?
- This known as a **sort-by-value** as opposed to **sort-by-key**
- As before, using `sorted()` with a `key` function (not be confused with the keys in the dictionary!) comes in handy.
- We'll need to spend just a little more effort to come up with a suitable `key` function
- Ex: Jupyter notebook

Sorting By Value

- We first use the `items()` method to generate a list of tuples, where each tuple is a key-value pair
- We then sort this list based on value (*second* element of each tuple)

```
def getScrabbleScore(letterScoreTuple):
    """
    Takes a tuple corresponding to (letter, score) and returns the score
    """
    return letterScoreTuple[1]


# first use the items method to get a list of (key, value) tuples
# and then sort using a key function
scrabbleItems = scrabbleScore.items()
sortedScrabbleItems = sorted(scrabbleItems, key=getScrabbleScore, reverse=True)
print(sortedScrabbleItems[0:3], '...', sortedScrabbleItems[-3:])
```

```
[('q', 10), ('z', 10), ('j', 8)] ... [('s', 1), ('t', 1), ('u', 1)]
```

- Note that we can also use a list comprehension after to extract just the keys if desired

Advantages of Using Dictionaries

- Easy access based on keys (some sort of named reference) rather than indices (referenced by position in the list)
- For example, to access the Scrabble score for **'p'** using a dictionary we simply ask for **scrabbleScore['p']**
- In contrast suppose the letters and scores are stored as two ordered lists (or even as a list of lists) that looks like this:

```
print(letters[0:3], '...', letters[-3:])
print(scores[0:3], '...', scores[-3:])
```

```
['a', 'b', 'c'] ... ['x', 'y', 'z']
[1, 3, 3] ... [8, 4, 10]
```

- We now have to be able to "recall" or find where **'p'** is located in these lists and then extract its corresponding score

Advantages of Using Dictionaries

- Side-by-side this is what that would look like

```
# dictionary access
scoreDict = scrabbleScore['p']
```

```
# list access
indexP = letters.index('p')
scoreList = scores[indexP]
```

```
# confirm they're the same
scoreDict == scoreList
```

```
True
```

- Though list access seems like a minor notational inconvenience, it also has **computational implications**
- Every time we try to find the position of a letter in our list using the `index()` method, we are actually looping over each letter until we find the one we're looking for (in fact, we could have re-written the list access explicitly using a loop.)
- The dictionary access on the other hand instantly knows what it's looking for

Advantages of Using Dictionaries

- Let's see how this difference plays out when we ask the computer to do 6 million queries (people across the world play a lot of Scrabble!)
- We'll use our old friend the `time` module for this

```
# random letters to query several times
randomLetters = ['a', 'l', 'q', 's', 'y', 'z']*1000000
print("Number of queries", len(randomLetters))
```

```
Number of queries 6000000
```

- Ex: Jupyter notebook

Advantages of Using Dictionaries

- Even in this really simple case, dictionaries give a 4x speed-up!

```
# generate list of letters and scores
letters = list(scrabbleScore.keys())
scores = list(scrabbleScore.values())

# time using list operations to compute total score
startTime = time.time()
totalScore = 0

for query in randomLetters:
    index = letters.index(query)
    totalScore += scores[index]

endTime = time.time()
timeList = endTime - startTime
print("Time taken using a list", round(timeList, 3), "seconds")
```

```
Time taken using a list 2.219 seconds
```

```
# time using dictionaries to compute total score
startTime = time.time()
totalScore = 0

for query in randomLetters:
    totalScore += scrabbleScore[query]

endTime = time.time()
timeDict = endTime - startTime
print("Time taken using a dictionary", round(timeDict, 3), "seconds")
```

```
Time taken using a dictionary 0.589 seconds
```

Summary: Benefits of Dictionaries

- Dictionaries can be a **more efficient** alternative to sequences for some operations
- When we **insert** into an ordered sequence like a list
  - We need to "move over" all elements to make space
  - This is an expensive operation: worst case (insert at beginning of list) takes time proportional to number of items stored in list
- When we **search** for an item in an list:
  - If we are not careful we might have to compare to every item stored
- Using a dictionary instead of a list means:
  - Can **insert more efficiently** (without having to move any other item)
  - Can support **more efficient (almost instantaneous!) queries** on average (if keys are "hashes" of values)
- To learn more about about efficiency of data structures, take CS136/CS256!

Moving on…

New Unordered Data Structure: Sets

- Dictionaries are unordered **key, value** stores
- What if we only need an unordered "***collection***" of items?
    - We can use a new data structure: **sets**
- Sets are ***mutable***, **unordered** collections of **immutable** objects
- Sets are written as comma separated values between curly braces
- Like keys in a dictionary, values in a set must be **unique** and **immutable**
    - Sets can be an effective way of **eliminating duplicate values**

```
nums = {42, 17, 8, 57, 23}
flowers = {'tulips', 'daffodils', 'asters', 'daisies'}
potters = {('Ron', 'Weasley'), ('Luna', 'Lovegood'), ('Hermione', 'Granger')}
emptySet = set() # empty set
```

New Unordered Data Structure: Sets

- **Question:** What is the potential downside of removing duplicates w/sets?

```
In [1]: firstChoice = ['a', 'b', 'a', 'a', 'b', 'c']

In [2]: uniques = set(firstChoice)
        uniques

Out[2]: {'a', 'b', 'c'}

In [3]: set("aabrakadabra")

Out[3]: {'a', 'b', 'd', 'k', 'r'}
```

New Unordered Data Structure: Sets

- **Question:** What is the potential downside of removing duplicates w/sets?
  - Loses ordering of elements

```
In [1]: firstChoice = ['a', 'b', 'a', 'a', 'b', 'c']

In [2]: uniques = set(firstChoice)
        uniques

Out[2]: {'a', 'b', 'c'}

In [3]: set("aabrakadabra")

Out[3]: {'a', 'b', 'd', 'k', 'r'}
```

Sets: Membership and Iteration

- Can check membership in a **set** using `in`, `not in`
- Can check length of a set using `len()`
- Can iterate over values in a loop (order will be arbitrary)

```
In [14]: nums = {42, 17, 8, 57, 23}
         flowers = {'tulips', 'daffodils', 'asters', 'daisies'}

In [15]: 16 in nums

Out[15]: False

In [16]: 'asters' in flowers

Out[16]: True

In [17]: len(flowers)

Out[17]: 4

In [18]: # iterable
         for f in flowers:
             print(f, end=" ")

tulips daisies daffodils asters
```

end = " " prevents new line

Sets are Unordered

- Therefore we **cannot**:
  - Index into a set (no notion of "position")
  - Concatenate two sets (concatenation implies ordering)
  - Create a set of ***mutable*** objects:
    - Such as lists, sets, and dictionaries

```
In [21]: {[3, 2], [1, 5, 4]}

---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
/var/folders/h8/n5myy3jd1d7cfv42cw42flt80000gn/T/ipykernel_10595/3548805500.py in <module>
----> 1 {[3, 2], [1, 5, 4]}

TypeError: unhashable type: 'list'
```

Set Methods Summary

- `s.add(item)`: changes the set `s` by adding item to it
- `s.remove(item)`: changes the set `s` by removing item from `s`.
  - If item is not in `s`, a `KeyError` occurs

The following operations return a new set.

- `s1.union(s2)` or `s1 | s2`: returns a new set that has all elements that are either in `s1` or `s2`
- `s1.intersection(s2)` or `s1 & s2`: returns a new set that has all the elements that are in both sets.
- `s1.difference(s2)` or `s1 - s2`: returns a new set that has all the elements of `s1` that are not in `s2`
- `s1 |= s2`, `s1 &= s2`, `s1 -= s2` are versions of `|, &, -` that mutate `s1` to become the result of the operation on the two sets.

An Overview of Python Data Structures (so far!)

Python Data Structures at a Glance

	Lists	Tuples	Dictionaries	Sets
Order	Yes	Yes	No	No
Mutability	Yes	No	Yes (keys are immutable)	Yes (items are immutable)
Iterable	Yes	Yes	Yes	Yes
Comprehensions	Yes	Yes (need to enclose in `tuple`)	Yes	Yes
Methods	`.append()`, `.extend()`, `.count()`, `.index()`, `etc`	`.count()`, `.index()`,	`.get()`, `.pop()`, `etc`	`.add()`, `.remove()`, `etc`

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	Lists	Tuples	Dictionaries	Sets
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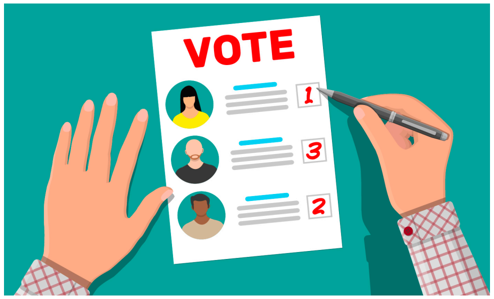
Mutability	Yes	No	Yes (keys are immutable)	Yes (items are immutable)
Iterable	Yes	Yes	Yes	Yes
Comprehensions	Yes	Yes (need to enclose in `tuple`)	Yes	Yes
	`d(), d(), (),`	`.count(),`	`.get(), .pop(),`	`.add(), .remove(), etc`

Which to use when?

Does Order Matter?



- Examples where **order** in data is important:
  - Ranked ballots
  - Queues
  - Words in a sentence
  - Tables/Matrices

- Tuples or lists?
  - Do we need to **add/remove items dynamically**?
    - If yes, use **lists** (they are mutable!)
  - If data stays same (no changes), use **tuples** (more space efficient)
  - Even though you can concatenate items to tuples, it is not efficient, as it requires "copying over all the data" and creating a new tuple

Unordered Collections

- When storing a collection of data with ***no implicit ordering***:
  - Use **dictionaries** or **sets**
  - Dictionaries are more appropriate when there is a ***key, value pair***
  - Better performance in general as compared to ordered structures
- Suppose we want to store student data in this course and quickly look up info for a given unix ID. Which data structure should we use?
  - Info may contain student name, class year, section, etc
  - Can store a **dictionary of dictionaries** (just like lists of lists!)

```
hpDict = { 'hp23': {'name': 'Harry James Potter',
      'house':'Gryffindor', 'patronus': 'Stag'},
            'hg3': {'name': 'Hermione Jean Granger',
      'house': 'Gryffindor', 'patronus': 'Otter'},
            'll4': {'name': 'Luna Lovegood',
      'house': 'Ravenclaw', 'patronus': 'Hare'}}
```