Data Structures in Python
Chapter 5

- **Bubble sort**
- Selection sort
- Insertion sort
- Merge sort
- Quick sort Algorithm
- Quick sort Analysis
- Empirical Analysis

Agenda & Readings

- Agenda
  - Motivation
  - Python sorted() function and sort() method
  - Bubble sort algorithm
  - Time complexity - Big O
- Reference:
  - Problem Solving with Algorithms and Data Structures
    - Chapter 5 Search, Sorting and Hashing

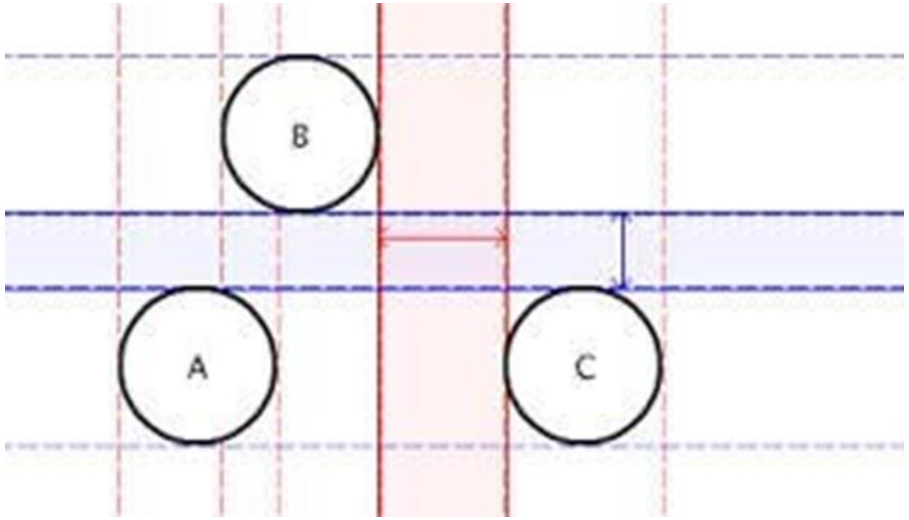
Sorting: One of the Most Common Activities on Computers

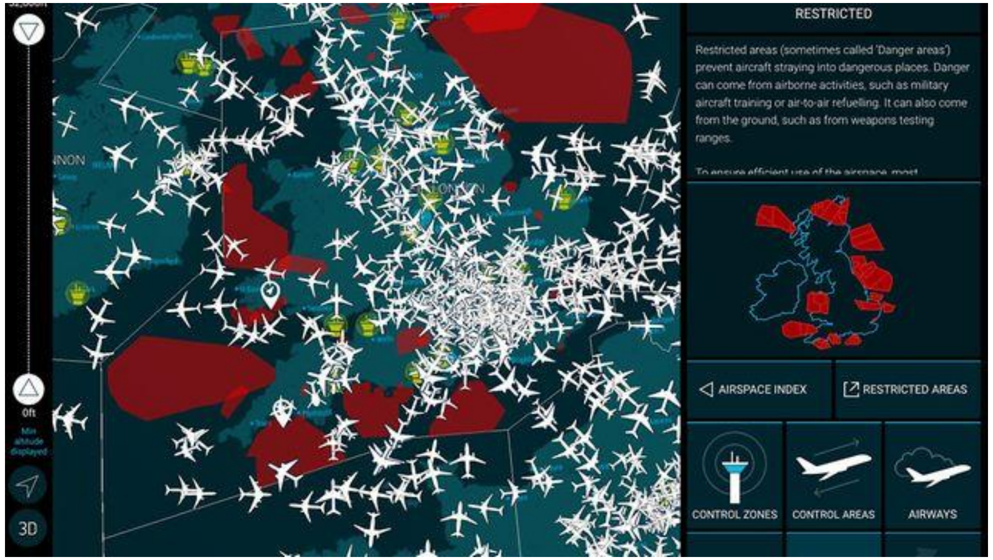
- **Example 1:**
  - **Alphabetically sorted names:**
    - e.g., names in phone book, street names in map, , file names in a folder
  - Advantages:
    - Can use efficient search algorithms:
    - Binary search finds item in $O(\log n)$ time

- **Example 2:**
  - **Sorted numbers:**
    - e.g., house prices, student IDs, grades, rankings
  - Advantages:
    - Can use efficient search algorithms (see example 1)
    - Easy to find position or range of values in sorted list, e.g., minimum value, median value, quartile values, all students with A grades, all houses within a certain price range etc.

Sorting: One of the Most Common Activities on Computers

- **Example 3:**
  - Sort objects in space.
    - e.g., Objects in a street, Objects in space
  - Advantages:
    - Can use efficient search algorithms, e.g., for collision detection





Sorting: Important Properties to Investigate

- **How efficient** is the sorting algorithm?
  - Note: can depend on order of input data set, e.g., is it almost sorted or completely unsorted?
- **How much memory** does sort algorithm require?

- **How easy** is algorithm to implement?
  - for simple problems and small data sets, simple sorting algorithm usually sufficient

Sorting: Need a comparison operator

- Any information which needs to be kept in sorted order will involve the **comparison** of items (<, =, >), e.g., strings and numbers:
  - ints/floats
    - $-34 < -1 < 0 < 1 < 245$
  - Characters
    - $A < \ldots < \ldots < Y < Z < a < b < c \ldots < y < z$
  - Strings
    - $'Hungry' < 'Money' < \text{‘}More\text{’} < 'money' < 'work'$

- Any information which needs to be kept in sorted order will have a key, the sort **key** (e.g., id, name, code number, ⋯).
  - The key determines the position of the individual object in the collection.
  - Commonly the key is a number.
  - When comparing keys which are strings, the Unicode (ASCII) values of the string are used (e.g., 'a' is Ox00061, 'A' is Ox00041 and ' ' is Ox00020).

Python sorted() function – 1

- Python has an inbuilt sort function: `sorted()`
  - The `sorted()` function takes any iterable and returns a list containing the sorted elements. (Note that all sequences are iterable.)

```
a= [5, 2, 3, 1, 4]
b= sorted(a)
print("a: ", a)
print("b: ", b)
print(b == a)
```

```
a: [5, 2, 3, 1, 4]
b: [1, 2, 3, 4, 5]
False
```

Python sorted() function – 2

- Python has an inbuilt sort function: `sorted()`
  - The `sorted()` function takes any iterable and returns a list containing the sorted elements. (Note that all sequences are iterable.)
  - Example: List

```
a = [5, 2, 3, 1, 4]
b = sorted(a)
print("a: ", a)
print("b: ", b)
print(b == a)
```

```
a: [5, 2, 3, 1, 4]
b: [1, 2, 3, 4, 5]
False
```

  - Example: String

```
a = "think"
b= sorted(a)   # sorted always returns a list
print("a:", a)
print("b:", b)
print(b == a)
```

```
a: think
b: ['h', 'i', 'k', 'n', 't']
False
```

Python sorted() function – 2

- Python has an inbuilt sort function: `sorted()`
  - Example: Dict
    - For dictionary, `sorted()` returns **sorted list of keys**, and sorts output by **keys**.

```
a = {4:5, 2:9, 1:6, 3:7}
b = sorted(a)
print("a: ", a)
print("b: ", b)
print(b == a)
```

```
a: {1: 6, 2: 9, 3: 7, 4: 5}
b: [1, 2, 3, 4]
False
```

```
a = {'kiwi':5, 'banana':9, 'apple':6, 'orange':7}
b = sorted(a)
print("a: ", a)
print("b: ", b)
print(b == a)
```

```
a:  {'kiwi': 5, 'banana': 9, 'apple': 6, 'orange': 7}
b:  ['apple', 'banana', 'kiwi', 'orange']
False
```

Python list method, sort()

- As well as the Python built-in `sorted()` **function**, the `sort()` **method** can be used to sort the elements of a list **in place**.

```
a = [5, 2, 3, 1, 4]
print("a: ", a)
a.sort()
print("a: ", a)
```

```
a: [5, 2, 3, 1, 4]
a: [1, 2, 3, 4, 5]
```

Python sorted() function, list sort() method

- We already have the Python sorting functions.
  Why bother looking at sorting algorithms?
  - It gives us a greater understanding of how our programs work.
  - Best sorting function depends on application.
  - Useful for developing sorting algorithms for specific applications

- In particular, we are interested in how much processing it takes to sort a collection of items (i.e., the Big O).
  - Also, as Wikipedia says: "useful new algorithms are still being invented, with the now widely used Timsort dating to 2002, and the library sort being first published in 2006."
  - In Python, Timsort is used (for both `sorted()` and `sort()`).

Sorting: The Expensive Bits

- In order to sort items, we will need to **compare** items and swap them if they are out of order.

- Number of **comparisons** and the number of **swaps** are the costly operations in the sorting process, and these affect the efficiency of a sorting algorithm.

Sorting Considerations

- An **internal sort** requires that the collection of data fit entirely in the computer's main memory.
- An **external sort**: the collection of data will not fit in the computer's main memory all at once but must reside in secondary storage.
- For very large collections of data it is costly to create a new structure (list) and fill it with the sorted elements so we will look at sorting **in place**.
- **One pass** is defined as one trip through the data structure (or part of the structure) comparing and, if necessary, swapping elements along the way. (In these examples the data structure is a list of ints.)
- In these discussions we sort from smallest (on the left of the list) to largest (on the right of the list).

Bubble Sort

- IDEA:
  - Given is a list L of n value **`{L[0], … , L[n-1]}`**

  - Divide list into unsorted (left) and sorted part (right - initially empty):
    `Unsorted: {L[0], … , L[n-1]}      Sorted: {}`
  - In each pass compare adjacent elements and swap elements not in correct order
    → largest element is "bubbled" to the right of the unsorted part
  - Reduce size of unsorted part by one and increase size of sorted part by one.
    After i-th pass:
    `Unsorted: {L[0], … , L[n-1-i]}    Sorted: {L[n-i],…,L[n-1]}`
  - Repeat until unsorted part has a size of 1 - then all elements are sorted

Bubble Sort Algorithm

- Given is a list L of n value **`{L[0], … , L[n-1]}`**
  - Divide list into unsorted (left) and sorted part (right - initially empty):
    `Unsorted: {L[0], … , L[n-1]}` **`Sorted: {}`**
  - In each pass compare adjacent elements and swap elements not in correct order
    → largest element is "bubbled" to the right of the unsorted part
  - Reduce size of unsorted part by one and increase size of sorted part by one.
    After i-th pass:
    `Unsorted: {L[0], … , L[n-1-i]}` **`Sorted: {L[n-i],…,L[n-1]}`**
  - Repeat until unsorted part has a size of 1, then all elements are sorted

29	10	14	37	13	`List to sort`
10	14	29	13	37	PASS 1 (4 Comp, 3 Swap)
10	14	13	29	37	PASS 2 (3 Comp, 1 Swap)
10	13	14	29	37	PASS 3 (2 Comp, 1 Swap)
10	13	14	29	37	PASS 4 (1 Comp, 0 Swap)

Bubble Sort – Exercise

54	26	93	17	77	31	44	55	20	List to sort
26	54	17	77	31	44	55	20	93	PASS 1 (8 Comp, 7 Swap)
27	17	54	31	44	55	20	77		PASS 2 (7 Comp, 5 Swap)
17	26	31	44	54	20	55			PASS 3 (6 Comp, 4 Swap)
17	26	31	44	20	54				PASS 4 (5 Comp, 1 Swap)
17	26	31	20	44					PASS 5 (4 Comp, 1 Swap)
17	26	20	31						PASS 6 (3 Comp, 1 Swap)
17	20	26							PASS 7 (2 Comp, 1 Swap)
17	20								PASS 8 (1 Comp, 0 Swap)

Some Useful Python Features - print_part(), swap()

```
def print_part(a, i, j):
    print(i, j, a[i:j])

a = [54, 26, 93, 17, 77, 31, 44, 55, 20]
for x in range(0, len(a), 3):
    print(a[x], end=" ")
print_part(a, 2, 5)
print_part(a, 0, 9)
```

```
54 17 44
2 5 [93, 17, 77]
0 9 [54, 26, 93, 17, 77, 31, 44, 55, 20]
```

```
def swap(a, i, j):
    temp = a[i]
    a[i] = a[j]
    a[j] = temp
```

```
def swap(a, i, j):
    a[i], a[j] = a[j], a[i]
```

Bubble Sort Code

- Code

```
def swap(a, i, j):
    a[i], a[j] = a[j], a[i]

def bubble_sort(a):
    for pass in range(len(a)-1, 0, -1):
        for i in range(0, pass):
            if a[i] > a[i+1]:
                swap(a, i, i+1)
                #print(pass, "-", a)

if __name__ == '__main__':
    a = [54, 26, 93, 17, 77, 31, 44, 55, 20]
    print("before: ", a)
    bubble_sort(a)
    print(" after: ", a)
```

```
before:  [54, 26, 93, 17, 77, 31, 44, 55, 20]
 after:  [17, 20, 26, 31, 44, 54, 55, 77, 93]
```

Bubble Sort - Big O

- For a list with n elements:
  - The number of comparisons?
  - pass 1   pass 2   pass 3   …   last pass
    n–1   n–2   n–3   ⋯   1

    $1 + 2 + \cdots + (n-3) + (n-2) + (n-1) = \frac{1}{2}(n^2 - n)$

- Big O of the bubble sort is $O(n^2)$
  - The number of data increases 10 times, then it takes a 100 times longer.
- On average, the number of swaps is half the number of comparisons.

Bubble Sort - Summary

- Sorting is a necessary tool in computing.
- The bubble sort algorithm is simple, but slow.
  - It performs lots of comparisons ($O(n^2)$) and many swaps in each pass additionally.