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| Basic Sorting Algorithms Implemented In Python – Danish's Blog  Project: Benchmarking Sorting Algorithms  COMPUTATIONAL THINKING WITH ALGORITHMS MODULE -46887 | Clodagh Murphy  **Higher Diploma in Data Analytics 2019/2020** |

Contents

[Introduction to sorting, sorting algorithms and related concepts. 2](#_Toc39388476)

[i. Bubble Sort 5](#_Toc39388477)

[ii. Merge Sort 7](#_Toc39388478)

[iii. Counting Sort 9](#_Toc39388479)

[iv. Insertion Sort 11](#_Toc39388480)

[v. Timsort 13](#_Toc39388481)

[Discuss the benchmarking process. 16](#_Toc39388482)

[Observations on the results of benchmarking process. 20](#_Toc39388483)

[Summary of the Project 20](#_Toc39388484)

[BIBLIOGRAPHY 21](#_Toc39388485)

# Introduction to sorting, sorting algorithms and related concepts.

*Sorting is at the very heart of what computers do. In fact, in many ways it was sorting that brought the computer into being.*

(Christian & Griffiths, 2016)

Sorting is what happens when an arbitrary arrangement of *n* items is rearranged into a particular order with the contents of the collection unaffected.

**Why is it important?**

Sorting is important in Data Science because information is rarely required in an adhoc or random manner. Instead it is needed in categories for example: chronological, alphabetised or listed in terms from smallest to largest. Identifying duplicates and analysing distribution patterns are made easier when data is sorted. Sorting is an intrinsically important task, in addition to supporting other functions e.g. searching.

The larger that datasets become, the greater importance lies with sorting.

Christian & Griffiths set out an important principal of sorting: *Scale hurts.* This means that the cost (computing and otherwise) of sorting grows exponentially based on the *n* of items in the original collection. This tallies with the estimation that 25% of all CPU cycles are devoted to sorting. Therefore, in a data driven society, such as the one we inhabit, efficient methods of sorting are crucial.

**What are algorithms?**

*A set of rules that must be followed when solving a particular problem.*

*A well-designed algorithm should:*

* *Produce a “correct" solution for a given input*
* *Use computational resources efficiently*

(Computational Thinking with Algorithms - Introduction Lecture, Dominic Carr)

These smart scripts are an important tool for one of computing’s mort important challenges- that of sorting.

The early days of computing (from the 1940s onwards) were an important time for developing efficient sorting algorithms. A program for sorting was the first code specifically designed to be stored in the memory of a computer by John von Neumann in 1945. His mergesort algorithm underpins many comparison algorithms that are used today.

**In-place sorting**

In-place sorting is advantageous if the availability of computational memory is a concern because it uses a set amount of working memory regardless of the input size. In place sorting is a property rather than a stand-alone algorithm. Bubble Sort, Insertion Sort and Timsort have this property. Other algorithms may require more memory dependent on the size of *n*.

**Stable vs Unstable sorting**

Stable sort algorithms ensure items that are identical appear in the same order after sorting e.g. Bubble Sort whereas an unstable sort does not guarantee this result e.g. QuickSort. An example is sorting playing cards: an unstable sort outputs cards in order of number regardless of suit but a stable sort outputs cards with the same number *and suit* in the original order. Unstable sorting algorithms provide results faster and are easier to code and are therefore an efficient option for those reasons and if stability is not an issue.

**Comparator functions**

When an algorithm is created the logic of comparison must be decided on, this can be numerical, lexigraphical (based on the alphabet) or some other custom scheme based on business needs.

The specific details of the comparator function used when designing sorting algorithms does not require particular attention because they are independent of the definition of “less than” used. (Sorting Algorithms Part 1 Lecture Notes, Patrick Mannion GMIT)

**Comparison-based V non-comparison-based sorts**

A comparison sort is based on comparing a pair of elements against one another via the order ≤ as the starting point to sort the entire array.

A principal of algorithm analysis is that

*no algorithm that sorts by comparing elements can do better than 𝑛log𝑛 performance in the average or worst cases.*

(Sorting Algorithms Part 1 Lecture Notes, Patrick Mannion GMIT)

Comparison-based sorts are the most widely applicable algorithms for diverse categories of data. The most well-known are of this type and form the majority of algorithms explored in this project.

Non-comparison sorts the input *without* comparing the values of the elements, this is achieved by having conditions or assumptions about the data in the arrays. For example,

Bucket sort performs best when input is uniformly distributed over a range and badly if the arrays are clustered together, as elements fall into the same bucket and are sorted slowly.

Therefore, the type of data being sorted can influence the choice of algorithm.

**How does space and time complexity impact an algorithm’s performance?**

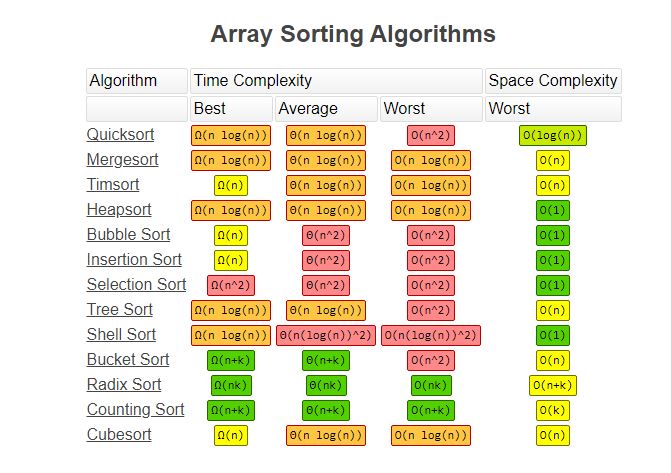
Space (memory requirements of extra space needed for the sorting to take place) and time complexity (measuring the number of operations given input size) and use case/requirements should be understood before choosing an algorithm for a particular purpose.

This project explores them in both theoretical and a practical sense using *Big O* notation and benchmarking implementations respectively.

*Big O notation represents the relationship between n and the number of steps the algorithm takes to find a solution*

(Sorting Algorithms in Python Article realpython.com)

The diagram below provides a colour coded overview of sorting algorithms’ time and space complexity. (bigocheatsheet.com)





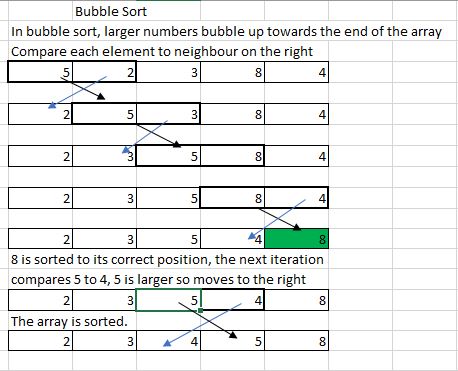
The best, worst and average cases should be explained when analysing a sorting algorithm.

This is because there is no “one size fits all” algorithmic solution and in fact as a data source changes, a once suitable algorithm may be too computationally expensive to run and require a more efficient replacement.

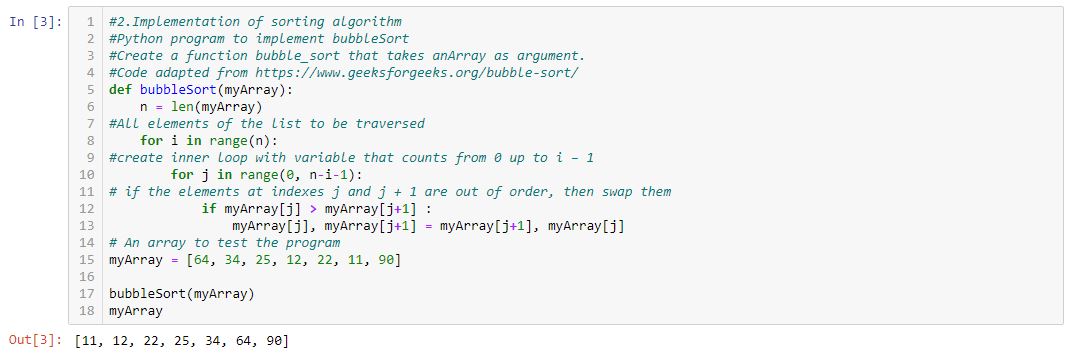
## Bubble Sort

Bubble Sort is a modest, intuitive algorithm which is also extremely inefficient. It became something of a celebrity algorithm when it was derided by Barrack Obama on a visit to Google in 2007.

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| **Name of Algorithm** | Bubble Sort |
| **Date** | First mention in print was 1962. |
| **Stable/Unstable** | Stable |
| **Comparison /**  **Non Comparison** | Simple Comparison based sort. |
| **Time Complexity** | **Average**: 𝑛2  **Best:** n or Linear (doesn’t happen very often) therefore the worst or average case results are more important to note.  **Worst**: 𝑛2  Bubble Sort achieves an impressive linear time complexity when it receives an array that is already sorted. The more likely quadratic runtime 𝑛2 can be expected from this algorithm which compares consecutive numbers over and over again. |
| **Space Complexity** | 1  1 or constant is an advantageous result which derives from the in-place sorting style of Bubble Sort. |
| **How does it work?** | Bubble Sort compares consecutive numbers in an array, they are swapped around if not already in order. The highest number will “bubble” to the right-hand side of the array. The process continues until the correct order is achieved. |
| **Characteristics**  **of note** | Slow unless records already sorted when it accesses that the items are already sorted then quickly exits. |

**Diagram illustrating how Bubble Sort works.**

**Python implementation of BubbleSort**



## Merge Sort

Another legendary algorithm is merge sort, created by John von Neumann is

*as important in the history of sorting as sorting in the history of computing.*

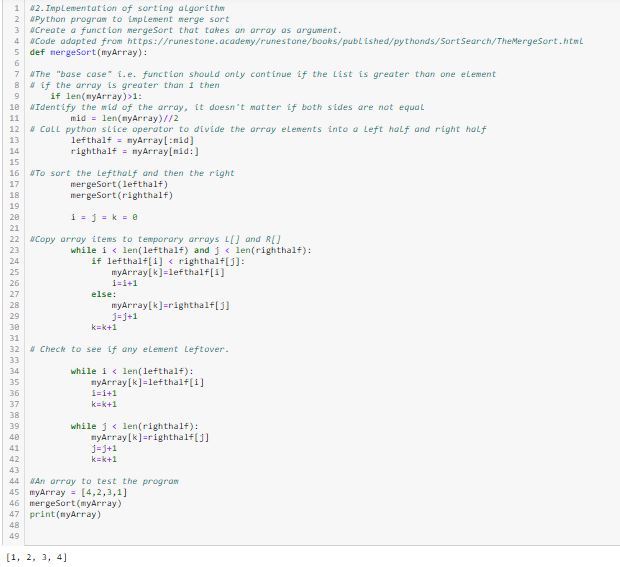
(Katajainen and Träff, 1997)

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| **Name of Algorithm** | MergeSort |
| **Date** | 1945 |
| **Attributed To** | John von Neumann |
| **Stable/Unstable** | Stable |
| **Comparison /**  **Non Comparison** | An efficient comparison-based sort |
| **Time Complexity** | **Average**: n log n  **Best**: n log n  **Worst**: n log n  MergeSort produces results that fall into the logarithmic time complexity category i.e., the runtime develops linearly where input increases rapidly.  An example is where an implementation takes a millisecond to handle and array of one hundred random numbers, it will take two ms for two hundred, three ms for three hundred and continues in that manner. |
| **Space Complexity** | 𝑂(𝑛)  Each merge step doubles the list size when the left and right parts are stored in temporary arrays of size n/2 in the worst case before the merged array is stored in place of the original array. |
| **How does it work?** | There are two parts to MergeSort implementation:  Split the list into halves followed by merging. |
| **Characteristics of note** | Divide and conquer approach- breaks problem into smaller problems in order to find a solution. Merge sort divides the supplied list in half continually by means of recursion. Once completed, the sorted lists are merged together. |

**Diagram illustrating how MergeSort works.**

![MergeSort diagram
](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDaRXhpZgAATU0AKgAAAAgABAE7AAIAAAAFAAAISodpAAQAAAABAAAIUJydAAEAAAAKAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEFjZXIAAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMxOAAAkpIAAgAAAAMxOAAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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**Python implementation of MergeSort**



## Counting Sort

Counting Sort is an example of a non-comparison sort that can only be implemented on non-negative integers in the range 0 – k-1.

It uses the fact that the range and input (only integers) is known to produce sorting in (close to) linear time.

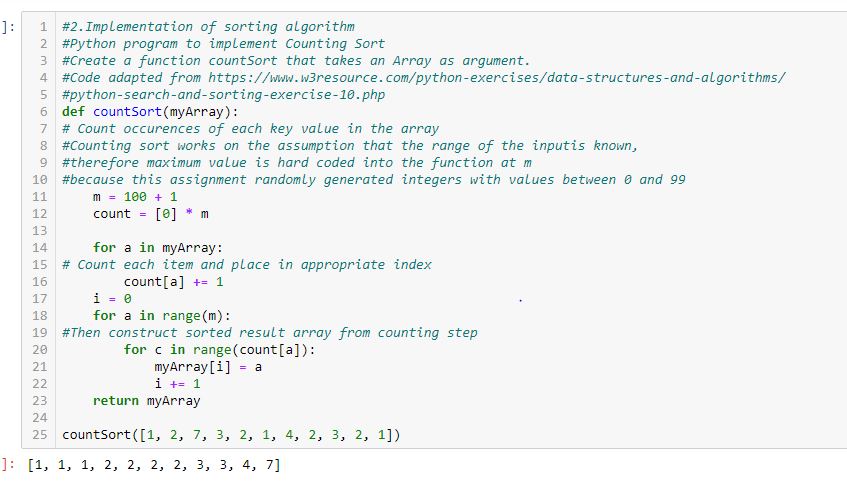
|  |  |
| --- | --- |
| **Name of Algorithm** | Counting Sort |
| **Date** | 1954 |
| **Attributed To** | Harold H. Seward |
| **Stable/Unstable** | Stable |
| **Comparison / Non Comparison** | A non-comparison sort |
| **Time Complexity** | **Average**: O(n +k)  **Best**: (n +k).  **Worst**: (n +k)  Counting Sort provides time complexity of n+k in all scenarios. This excellent time complexity comes as a result of the conditions that must be met by the data passed into the Counting Sort implementation in the first instance. This advantage must be traded off against the fact it is not as widely applicable as the other algorithms featured in this assignment. |
| **Space Complexity** | (n +k)  Counting Sort provides effective space complexity if the variance between the different key values remains small. |
| **How does it work?** | Initially works out the range of input data to assign keys, e.g., elements 1-5 = 5 keys. Counts instances of each key. The largest key value is entered at the end of output array and algorithm continues to work through the original array. |
| **Characteristics of note** | Allows sorting in (close to) linear time.  Non-comparison sorts work on a set of assumptions.  If this condition is met, it delivers a running time advantage and can be transferred to sorting data with label rather than integers if non-negative integers are assigned as sort keys. |

**Diagram illustrating how Counting Sort works.**

![A screenshot of a cell phone

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDaRXhpZgAATU0AKgAAAAgABAE7AAIAAAAFAAAISodpAAQAAAABAAAIUJydAAEAAAAKAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEFjZXIAAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMwOQAAkpIAAgAAAAMwOQAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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**Python implementation of Counting Sort**

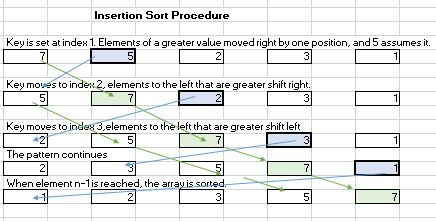
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## Insertion Sort

Simple, intuitive (i.e. the way you might sort items yourself) and easy to implement Insertion sort is very slow on large arrays

|  |  |
| --- | --- |
| **Name of Algorithm** | Insertion Sort |
| **Date** | Referenced by John Mauchly in the first published discussion of computer sorting in 1946. |
| **Stable/Unstable** | Stable |
| **Comparison / Non Comparison** | Comparison |
| **Time Complexity** | **Average**: 𝑛2  **Best:** n  doesn’t happen very often therefore the worst or average case results are more important to note.  **Wors**t: 𝑛2  Insertion Sort performs slowly unless the array is small. A partially sorted array will produce the best results.  This 𝑛2 quadratic runtime is a result of the fact that the elements are checked twice when each item is compared with the rest of the array. |
| **Space Complexity** | 1  1 or constant is an advantageous result which derives from the in-place sorting style of Insertion Sort. |
| **How does it work?** | Similar to how you might shuffle a hand of cards, Insertion Sort compares each item with the rest of the list to build the sorted array one items at a time. |
| **Characteristics of note** | At its most inefficient used on large arrays of random numbers, like the samples used in this project.  Used by Timsort to internally sort small portions of the input array. |

**Diagram illustrating how Insertion Sort works.**



**Python implementation of Insertion Sort**

![A screenshot of a social media post

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDaRXhpZgAATU0AKgAAAAgABAE7AAIAAAAFAAAISodpAAQAAAABAAAIUJydAAEAAAAKAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEFjZXIAAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAMzMgAAkpIAAgAAAAMzMgAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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## Timsort

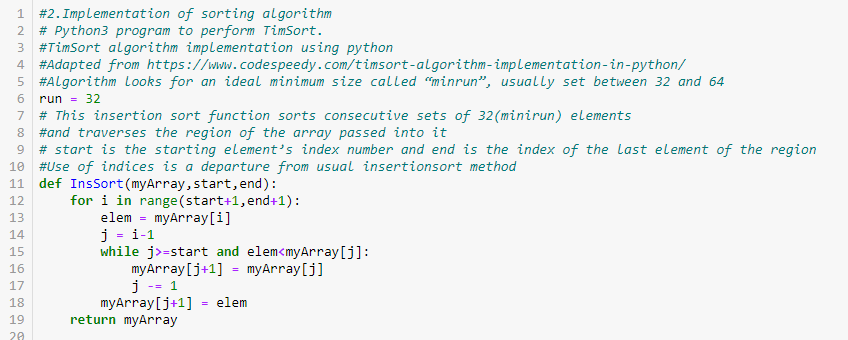
*The fastest sorting algorithm you’ve never heard of.*

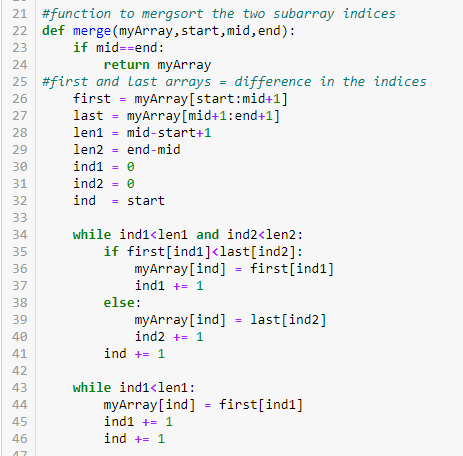
(Brandon Skerritt, 2019)

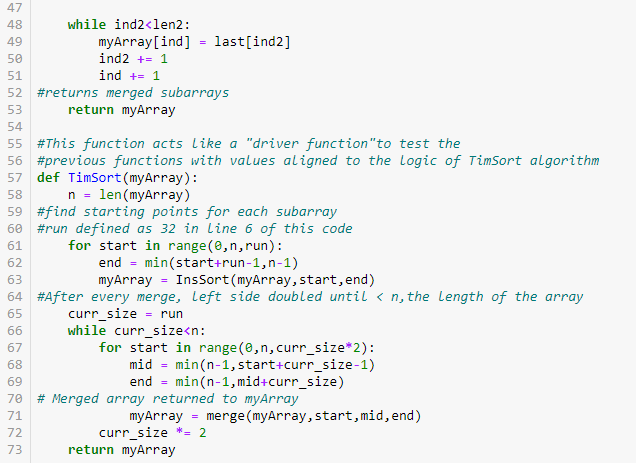
Although it is a complex sorting algorithm, I wish to include Timsort in this assignment because it is built in to python’s (the language used in this project) sorted() and sort() functions.

|  |  |
| --- | --- |
| **Name of Algorithm** | Timsort |
| **Date** | 2002 |
| **Attributed to** | Tim Peters, prominent Python developer |
| **Stable/Unstable** | Stable |
| **Time Complexity** | **Average**: O(n Log n)  **Best**: n  The best result doesn’t happen very often therefore the worst or average case results are more important to note.  **Worst**: n log n  Timsort matches Merge sort in terms of time complexity. |
| **Space Complexity** | 𝑂(𝑛)  The space complexity of Timsort is “fair” in the worst case. |
| **How does it work?** | The algorithm first finds subsets of the data that are partially or already sorted with binary insertion sort.  Then merge sort takes over merging an identified subset, called a run, with other sub-arrays until sorting has completed. |
| **Characteristics of note** | It is a hybrid of Merge and Insertion sort.  Timsort leverages the sequencing patterns that occur in real-world data. |

Implementation of timsort









# Discuss the benchmarking process.

**Why Benchmark?**

Benchmarking compares the performance of algorithm using an empirical method (a type of a posteori analysis) that is verified by observation rather than based on theory.

Benchmarking is carried out in this assignment to compare the performance of each algorithm’s execution.

It is good practise to carry out benchmarking on a regular basis in order to ensure that the algorithm chosen for a particular computational problem in e.g., a business setting is still the best option when circumstances change.

Various external factors can affect the bottom line, these include energy saving technologies on the machine being used and the OS installed on it. Therefore, it is beneficial to carry out numerous executions of the same application to get a good sense of the average results produced.

The hardware installed on the laptop used for the project includes: Intel Processor 2.00GHz and 4.00GB RAM.

**Python Benchmarking Application**[**¶**](https://nbviewer.jupyter.org/github/RitRa/Algorithms-project-/blob/master/Benchmarking%20Sorting%20Algorithms.ipynb#The-Benchmarking-Application)

The script is in a separate file PythonApp.py which can be opened with a command prompt/console. Much of it is adapted from previously existing code and contains my explanatory comments. The project was written using a jupyter notebook and the tables show in this report were produced using that software.

**Part #1. Import required libraries that will be used by the application**

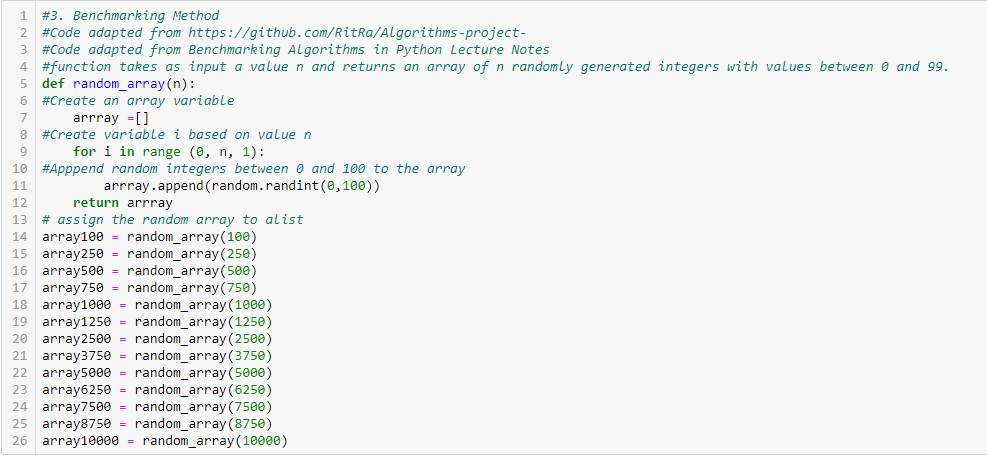
* import time, python module to provide various time related functions, used here to record the running for an implementation of an algorithm. Dates and times in Python are underpinned by the concept of the “Unix Epoch” i.e., the number of seconds that have elapsed since midnight on 1st January 1970.
* import random, the python module used to create pseudo-random number arrays
* import numpy as np, python library used for working with arrays.
* import pandas as pd, a python data analysis library its functionality used to produce dataframes and tables to view results.
* import matplotlib.pyplot as plt is used to produce data visualisation plots.
* import seaborn as sns, another data visualisation library.

**Part #2. Implementation of sorting algorithms: BubbleSort, MergeSort, InsertionSort, TimSort, CountSort.**

The commented code to implement five sorting algorithms is set out. Unlike the implementations featured earlier in this report, no arrays are introduced- this will be done as part of the benchmarking process in the next step.

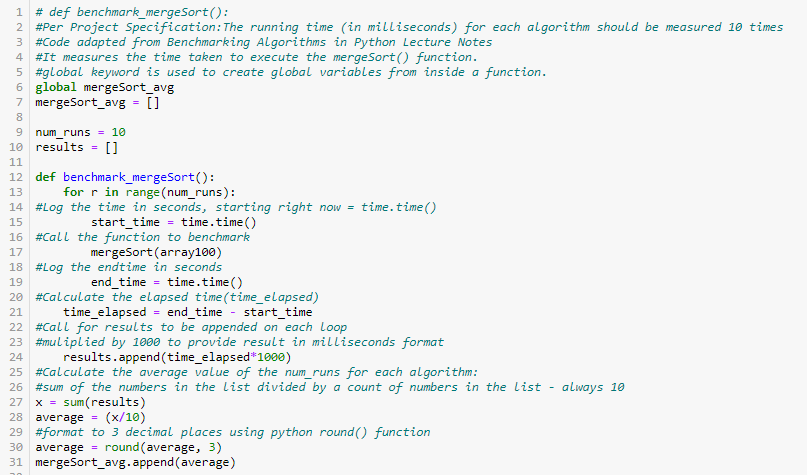
**Part #3. Benchmarking Method**

First, random integers between 1 and 100 in thirteen arrays ranging in sizes from 100 to 10,000 are created.

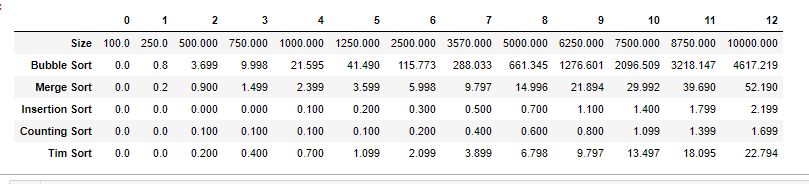


The benchmark function for each variety of sorting algorithm collects the average time (\_avg) the implementation takes to process each of the thirteen arrays. The example of code below illustrates the mergeSort implementation.

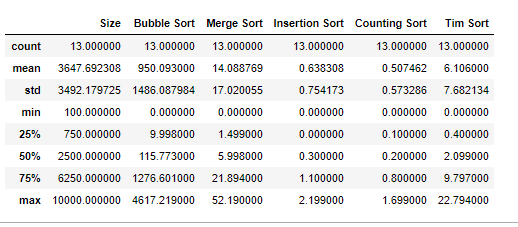
The previously defined MergeSort() function is called as part of benchmark\_mergeSort(), which is the function to record the duration of each run so that performance may be compared.



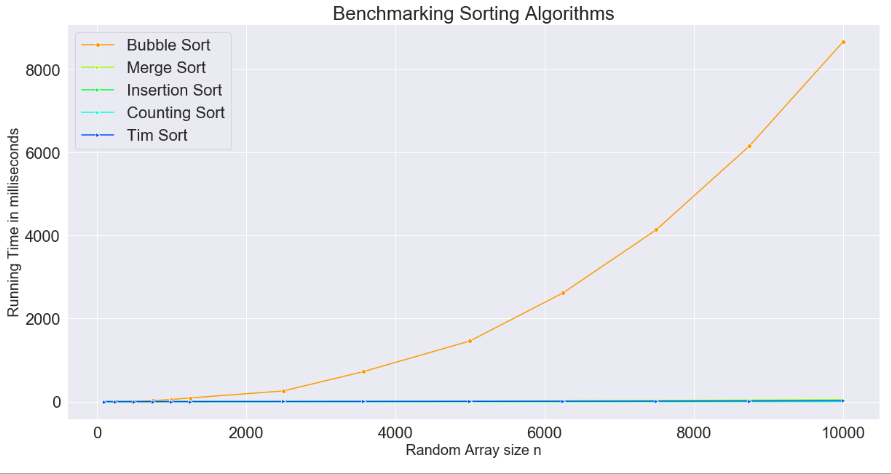
The \_avg results sitting “in the ether” must be output into a pandas DataFrame formatted to three decimal places in order to be viewed in a coherent way.



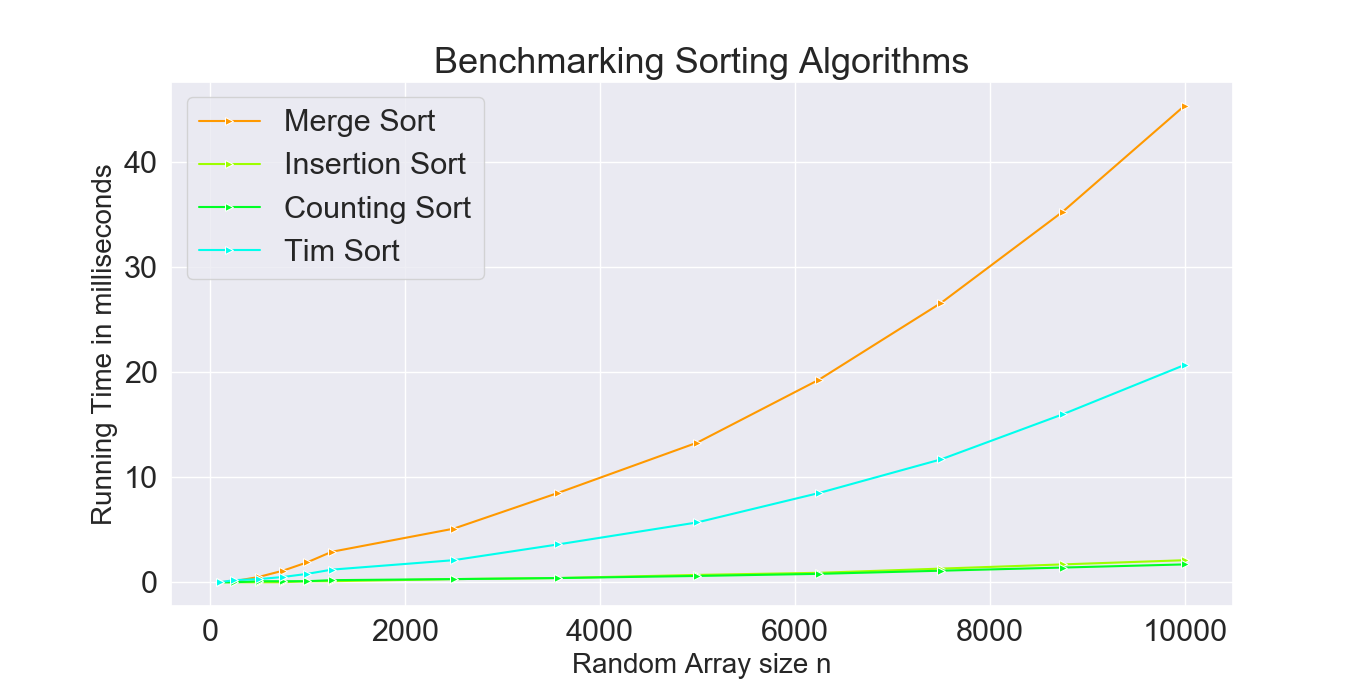
The df.describe() command is used to view statistical details e.g. mean, standard, minimum and maximum in a table.



In order to summarise the results in a colourful lineplot format, seaborn and matplotlib functionalities are called.



When bubble Sort is omitted from the plot of results, it allows a better sense of the more subtle differences to be seen.



# Observations on the results of benchmarking process.

**Bubble Sort**- its infamous poor runtime performance leaps out of the tables and data visualisation. The results are markedly worse as the size of input grows.

*Note:* The remaining four algorithms can be said to perform in a different order of magnitude and to adequately illustrate this, two plots are included.

**Merge Sort** – outside Bubble Sort, merge produces the worst run time- taking 52ms to sort 10,000 elements. The input of randomly generated number ensures that the algorithm must do the maximum number of comparisons and thus perform badly.

**Timsort** is marginally quicker than Merge (sorting the given arrays in roughly half the time). This is an expected result. Merge and timsort share a worst-case performance of *nlogn* (Big0 notation) and appear in the same order of magnitude alongside each other in the performance graph. I had expected Timsort to produce the fastest results given that it is a bespoke python algorithm built for the modern age. The data dispels my theory and supports the *nlogn* status because it is designed to excel where patterns occur in real world data and the benchmarking process is intended to almost do the opposite with randomly produced arrays. Given this handicap, I feel that Timsort gives a good account of itself under the circumstances.

**Insertion Sort** Although it has a similar worst case performance time complexity as Bubble Sort, the algorithm has performed well in this test. Earlier in the assignment, I stated that Insertion Sort is least efficient where large arrays of random numbers are concerned, hence I did not expect to see it outperforming most other sorts. I can conclude that a small *range* in an otherwise large array will get a good performance.

**Counting Sort** produces the fastest run time. It has the advantage of having its best performance needs met i.e., a maximum value of 100 hardcoded into the production of the arrays to sort.

# Summary of the Project

* This project has introduced the key concepts of sorting and explored five sorting algorithms with diagrams and examples. I have illustrated the results of the benchmarking process with data visualisations and discussed the differences between the performance of the sorting algorithms.
* PythonApp.py is attached with implementations of the five sorting algorithms, along with a main method which tests each of them and automatically outputs tables and graphs.

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