KATHMANDU UNIVERSITY

DHULIKHEL, KAVREPALANCHOWK, NEPAL

SUBJECT CODE: COMP 314

In the partial fulfilment of "Introduction to Sorting Algorithm-Insertion and Merge Sort"

Lab Report #2

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Link to GitHub: https://github.com/KamalShrest/CE_III_49_Lab2

Lab 2: Sorting (Insertion Sort and Merge Sort)

Objectives:

- Implementation the following sorting algorithms:
  (a) Insertion sort
  (b) Merge sort
- Implementation of some test cases in the algorithms.
- Generation of random inputs for the program and applying both Insertion Sort and Merge Sort algorithms to sort the generated sequence of data.
- Record the execution times of both algorithms for best and worst cases on inputs of different size.
- Plot an input-size vs execution-time graph.
- Explanation for the observations

Introduction: Sorting Algorithms

A Sorting Algorithm is used to rearrange a given array or list elements according to a comparison operator on the elements. The comparison operator is used to decide the new order of element in the respective data structure. Some of the common sorting algorithms include Selection sort, Bubble sort, Recursive Bubble sort, **Insertion Sort, Merge sort**, Quick Sort, Heap Sort (among the comparison sorting algorithms), similarly Counting Sort, Radix Sort, Bucket Sort, Shell Sort (among the non-comparison sorting algorithms).

It is important if you need an algorithm to be *consistent* with your performance requirements. For example, if your algorithm has a best-case of O(n lg n) but a worst-case of (n^2) performance, and you might expect the amount of data input to increase ten-fold over the next year, then favouring worst-case running time will provide you with assurance that your algorithm will not lose its quality later.

Stable sort vs. Unstable sort

A stable sort is a sort which guarantees that when two items are compared and determined to be the same, their positions in the set will not be compromised. Whereas for unstable sort the positions of the items may change given the nature of the sort.

Insertion Sort Algorithm:

Features:

- It is efficient for smaller data sets, but very inefficient for larger lists. Insertion Sort is adaptive, that means it reduces its total number of steps if a partially sorted array is provided as input, making it efficient.
- It is better than Selection Sort and Bubble Sort algorithms.
- Its space complexity is less. Like bubble Sort, insertion sort also requires a single additional memory space.
- It is a **stable** sorting technique, as it does not change the relative order of elements which are equal.

Algorithm:

Step 1 − If it is the first element, it is already sorted. Return 1;
Step 2 − Pick next element
Step 3 − Compare with all elements in the sorted sub-list
Step 4 − Shift all the elements in the sorted sub-list that is greater than the Value to be sorted
Step 5 − Insert the value
Step 6 − Repeat until list is sorted

Pseudo Code:

```
procedure insertionSort( A : array of items )
   int holePosition
   int valueToInsert

   for i = 1 to length(A) inclusive do:

      /* select value to be inserted */
      valueToInsert = A[i]
      holePosition = i

      /*locate hole position for the element to be inserted */
      while holePosition > 0 and A[holePosition-1] > valueToInsert do:
         A[holePosition] = A[holePosition-1]
         holePosition = holePosition -1
      end while

      /* insert the number at hole position */
      A[holePosition] = valueToInsert
    end for

end procedure
```

Python Code:

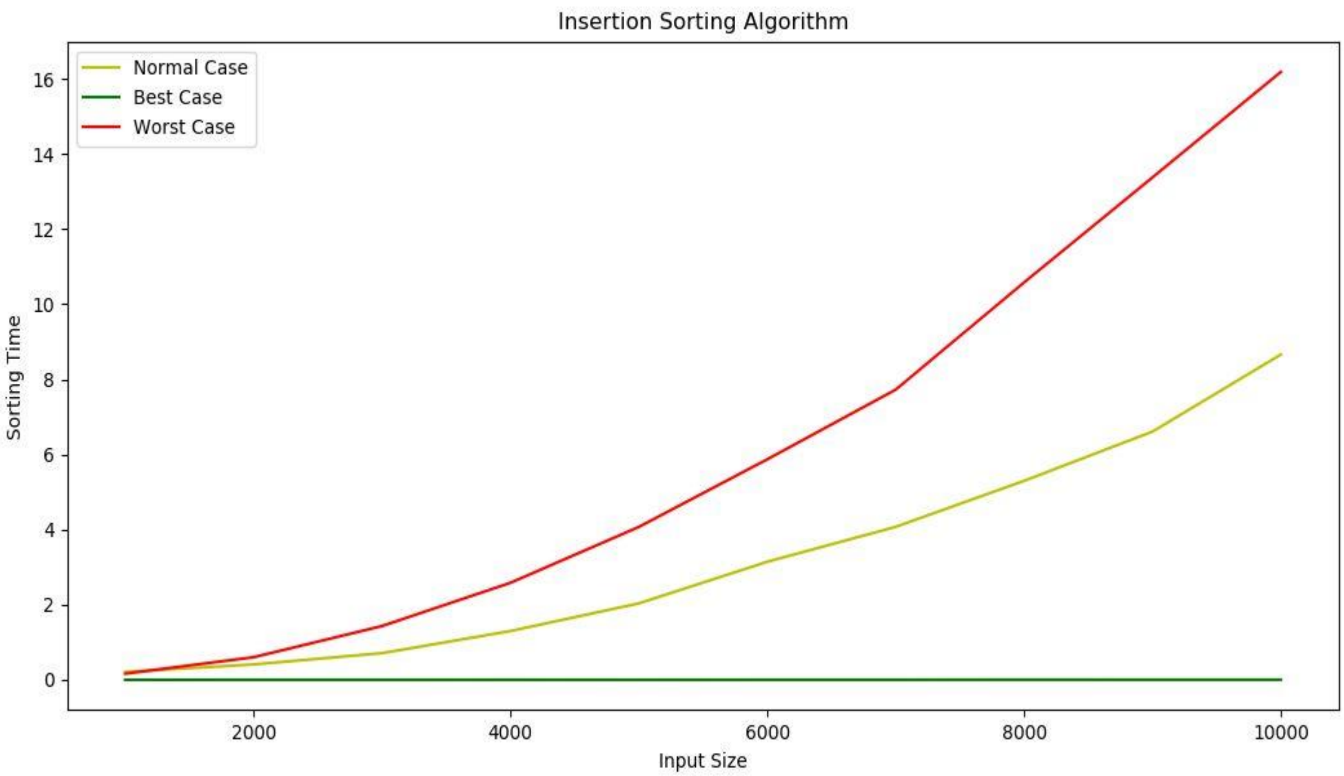
```python
def insertionSort(arr):

    for i in range(1, len(arr)):

        key = arr[i]
        j = i-1
        while j >=0 and key < arr[j] :
                arr[j+1] = arr[j]
                j -= 1
        arr[j+1] = key
    return arr
```

```python
from insertion_sorting import insertionSort
import random
from time import time
import matplotlib.pyplot as plt

randomnum=random.sample(range(100000),10000)
sortednum=sorted(randomnum)
insertion_unsorted=[]
insertion_bestcase=[]
insertion_worstcase=[]
xdomain=[]
j=0
stepsize=1000
print("*****NORMAL CASE SCENARIO******")
for i  in range(1000,11000,stepsize):
    start_time=time()
    insertionSort(randomnum[0:i])
    end_time=time()
    print(end_time-start_time)
    insertion_unsorted.insert(j,end_time-start_time)
    xdomain.insert(j,i)
    j+=1
print("********BEST CASE SCENARIO********")
for i  in range(1000,11000,stepsize):
    start_time=time()
    insertionSort(sortednum[0:i])
    end_time=time()
    print(end_time-start_time)
    insertion_bestcase.insert(j,end_time-start_time)
    j+=1

print("*****WORST CASE SCENARIO******")
for i  in range(1000,11000,stepsize):
    start_time=time()
    insertionSort(sortednum[i:0:-1])
    end_time=time()
    print(end_time-start_time)
    insertion_worstcase.insert(j,end_time-start_time)
    j+=1

print("*************************")

plt.plot(xdomain,insertion_unsorted,'y',label="Normal Case")
plt.plot(xdomain,insertion_bestcase,'g',label="Best Case")
plt.plot(xdomain,insertion_worstcase,'r',label="Worst Case")
plt.legend(loc='upper left')
plt.show()
```

Output:

Input Size	Normal Case	Best Case	Worst Case
1000	0.08395099639892578	0.0010006427764892578	0.1599104404449463
2000	0.2788405418395996	0.0019996166229248047	0.625640869140625
3000	0.6806111335754395	0.0019981861114501953	1.335254192352295
4000	1.147357702255249	0.0029969215393066406	3.163175344467163
5000	1.9129068851470947	0.003998756408691406	4.023701429367065
6000	2.683483600616455	0.001997232437133789	5.981588363647461
7000	4.000710964202881	0.0019989013671875	8.226300716400146
8000	5.708739519119263	0.0029990673065185547	10.973678588867188
9000	6.714166164398193	0.0049970149993896484	13.931021451950073
10000	8.52612566947937	0.0029964447021484375	17.432392835617065

Graph:



Interpretation of Observations:

Hence the time complexities for insertion sorting algorithm are: O (n^2) in Average and Worst case where as O(n) in best case scenario.

Merge Sort Algorithm:

Divide and Conquer in Merge Sort:

- **Divide** by finding the number q of the position midway between p and r Do this step the same way we found the midpoint in binary search: add p and r divide by 2, and round down.
- **Conquer** by recursively sorting the subarrays in each of the two sub problems created by the divide step. That is, recursively sort the subarray `array[p..q]` and recursively sort the subarray `array[q+1..r]`.
- **Combine** by merging the two sorted subarrays back into the single sorted subarray `array[p..r]`.

Algorithm:

Step 1 − if it is only one element in the list it is already sorted, return.
Step 2 − divide the list recursively into two halves until it can no more be divided.
Step 3 − merge the smaller lists into new list in sorted order.

Pseudo Code:

```
procedure mergesort( var a as array )
  if ( n == 1 ) return a

  var l1 as array = a[0] ... a[n/2]
  var l2 as array = a[n/2+1] ... a[n]

  l1 = mergesort( l1 )
  l2 = mergesort( l2 )

  return merge( l1, l2 )
end procedure

procedure merge( var a as array, var b as array )

  var c as array
  while ( a and b have elements )
    if ( a[0] > b[0] )
      add b[0] to the end of c
      remove b[0] from b
    else
      add a[0] to the end of c
      remove a[0] from a
    end if
  end while
```

```
    while ( a has elements )
       add a[0] to the end of c
       remove a[0] from a
    end while

    while ( b has elements )
       add b[0] to the end of c
       remove b[0] from b
    end while

    return c

end procedure
```

Python Code:

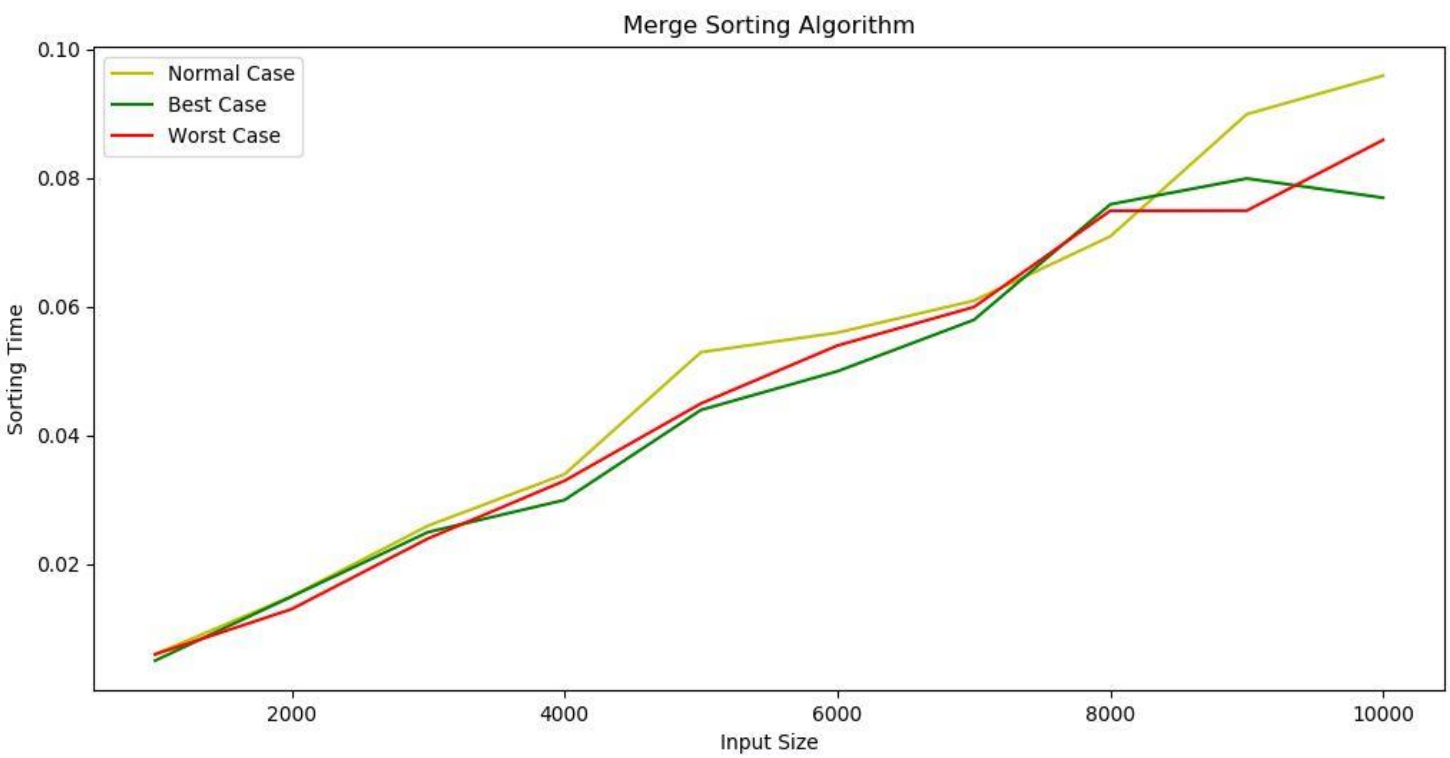
```python

def mergeSort(alist):

    if len(alist)>1:
        mid = len(alist)//2
        lefthalf = alist[:mid]
        righthalf = alist[mid:]

        mergeSort(lefthalf)
        mergeSort(righthalf)

        i=0
        j=0
        k=0
        while i < len(lefthalf) and j < len(righthalf):
            if lefthalf[i] < righthalf[j]:
                alist[k]=lefthalf[i]
                i=i+1
            else:
                alist[k]=righthalf[j]
                j=j+1
            k=k+1

        while i < len(lefthalf):
            alist[k]=lefthalf[i]
            i=i+1
            k=k+1

        while j < len(righthalf):
            alist[k]=righthalf[j]
            j=j+1
            k=k+1
    return alist


```

```python
from merge_sorting import mergeSort
import random
from time import time
import matplotlib.pyplot as plt
randomnum=random.sample(range(100000),10000)
sortednum=sorted(randomnum)
merge_unsorted=[]
merge_bestcase=[]
merge_worstcase=[]
xdomain=[]
j=0
stepsize=1000
print("*************************")
# NORMAL CASE SCENARIO
for i  in range(1000,11000,stepsize):
    start_time=time()
    mergeSort(randomnum[0:i])
    end_time=time()
    print(end_time-start_time)
    merge_unsorted.insert(j,end_time-start_time)
    xdomain.insert(j,i)
    j+=1
print("*************************")

# BEST CASE SCENARIO
for i  in range(1000,11000,stepsize):
    start_time=time()
    mergeSort(sortednum[0:i])
    end_time=time()
    print(end_time-start_time)
    merge_bestcase.insert(j,end_time-start_time)
    j+=1
print("*************************")

# WORST CASE SCENARIO
for i  in range(1000,11000,stepsize):
    start_time=time()
    mergeSort(sortednum[i:0:-1])
    end_time=time()
    print(end_time-start_time)
    merge_worstcase.insert(j,end_time-start_time)
    j+=1
print("*************************")
plt.plot(xdomain,merge_unsorted,'y',label="Normal Case")
plt.plot(xdomain,merge_bestcase,'g',label="Best Case")
plt.plot(xdomain,merge_worstcase,'r',label="Worst Case")
plt.legend(loc='upper left')
plt.title("Merge Sorting Algorithm")
plt.xlabel('Input Size')
```

Output:

Input Size	Average Case	Best Case	Worst Case
1000	0.008983850479125977	0.007961511611938477	0.008978843688964844
2000	0.01898789405822754	0.019970417022705078	0.018988847732543945
3000	0.031975507736206055	0.020008563995361328	0.021990537643432617
4000	0.034993648529052734	0.029983043670654297	0.035979270935058594
5000	0.044974327087402344	0.036978960037231445	0.04398822784423828
6000	0.052987098693847656	0.0479741096496582	0.05098772048950195
7000	0.06094765663146973	0.050973415374755860	0.0579831600189209
8000	0.08095383644104004	0.08698058128356934	0.06696200370788574
9000	0.0919656753540039	0.08093881607055664	0.08095359802246094
10000	0.09094762802124023	0.08295106887817383	0.08393406867980957

Graph:



Interpretation of Observations:

Hence the time complexities for insertion sorting algorithm are: O (nlogn) in Average and Worst case and best case scenario.

Test Cases:

```python


import unittest
import random
from insertion_sorting  import insertionSort
from merge_sorting import mergeSort

numberoftestcases=10000
class SearchTestCase(unittest.TestCase):
    # test for linear Search

    def test_insertionSort(self):

        randomnum=random.sample(range(100000),numberoftestcases)
        sortednum=sorted(randomnum)
        self.assertEqual(insertionSort(randomnum),sortednum)

    def test_mergeSort(self):
        randomnum=random.sample(range(100000),numberoftestcases)
        sortednum=sorted(randomnum)
        self.assertEqual(mergeSort(randomnum),sortednum)


if __name__=='__main__':
    unittest.main()


```

Output:

```
(base) C:\Users\pc\Desktop\Algorithm Lab 2>python test_cases.py
..
----------------------------------------------------------------------
Ran 2 tests in 8.701s

OK

(base) C:\Users\pc\Desktop\Algorithm Lab 2>
```

Comparison between the sorting algorithms:

Comparison between the sorting algorithms were done on the same range and same elements for average case scenario:

```
import random
from time import time
import matplotlib.pyplot as plt
from insertion_sorting import insertionSort
from merge_sorting import mergeSort

randomnum=random.sample(range(100000),100000)

insertion_sort=[]
merge_sort=[]
xdomain=[]
j=0


for i in range(10000,100000,10000):
    start_time_merge=time()
    mergeSort(randomnum[0:i])
    end_time_merge=time()
    print(end_time_merge-start_time_merge)
    merge_sort.insert(j,end_time_merge-start_time_merge)
    xdomain.insert(j,i)
    j+=1


print("********************")


for i in range(10000,100000,10000):
    start_time_insertion=time()
    insertionSort(randomnum[0:i])
    end_time_insertion=time()
    print(end_time_insertion-start_time_insertion)
    insertion_sort.insert(j,end_time_insertion-start_time_insertion)
    j+=1



plt.plot(xdomain,insertion_sort,'r',label="Insertion Sort")
plt.plot(xdomain,merge_sort,'g',label="Merge Sort")
plt.title("Comparison Between Merge and Insertion Sorting Algorithm")
plt.xlabel('Input Size')
plt.ylabel('Sorting Time')
plt.legend(loc='upper left')
plt.show()
```

Output Graph