

Sorting Algorithms

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Bubble sort

```
class Base:
    def BubbleSort(self, arr):
        n=len(arr)
        for i in range(n):
            for j in range(n-i-1):

                if arr[j]>arr[j+1]:
                    arr[j],arr[j+1]=arr[j+1],arr[j]

        return arr
obj=Base()
arr=[9,4,7,1,5,7,4]
print(obj.BubbleSort(arr))
```

Selection sort

```
class Base:
    def selectionSort(self, arr):
        n=len(arr)
        for i in range(n):
            min_idx=i
            for j in range(i+1,n):
                if arr[j]<arr[min_idx]:
                    min_idx=j

            arr[i],arr[min_idx]=arr[min_idx],arr[i]

        return arr

arr=[7,1,5,9,3,8]
obj=Base()
print(obj.selectionSort(arr))
```

Insertion Sort

```
def insertionSort(arr):  
    n=len(arr)  
    for i in range(1,n):  
        j=i-1  
        key_element=arr[i]  
        while j>=0 and arr[j]>key_element:  
            arr[j+1]=arr[j]  
            j-=1  
        arr[j+1]=key_element  
if __name__=="__main__":  
    n=int(input())  
    arr=list(map(int,input().split()))  
    insertionSort(arr)  
    print("["+','+'.join(map(str,arr))+"]")
```

Quick Sort

```
def quickSort_naive(arr):
    if len(arr) <= 1:
        return arr
    pivot = arr[0]
    left = [x for x in arr[1:] if x <= pivot]
    right = [x for x in arr[1:] if x > pivot]
    return quickSort_naive(left) + [pivot] +
quickSort_naive(right)

def quickSort_lomuto(arr, low, high):
    if low < high:
        pivot_index = lomuto_partition(arr, low, high)
        quickSort_lomuto(arr, low, pivot_index - 1)
        quickSort_lomuto(arr, pivot_index + 1, high)

def lomuto_partition(arr, low, high):
    pivot = arr[high]
    i = low - 1
    for j in range(low, high):
        if arr[j] <= pivot:
            i += 1
            arr[i], arr[j] = arr[j], arr[i]
    arr[i + 1], arr[high] = arr[high], arr[i + 1]
    return i + 1

def quickSort_hoare(arr, low, high):
    if low < high:
        pivot_index = hoare_partition(arr, low, high)
        quickSort_hoare(arr, low, pivot_index)
        quickSort_hoare(arr, pivot_index + 1, high)
```

```

def hoare_partition(arr, low, high):
    pivot = arr[low]
    i = low - 1
    j = high + 1
    while True:
        i += 1
        while arr[i] < pivot:
            i += 1
        j -= 1
        while arr[j] > pivot:
            j -= 1
        if i >= j:
            return j
        arr[i], arr[j] = arr[j], arr[i]

if __name__ == "__main__":
    n = int(input("enter the size of thr array:"))
    arr = list(map(int, input("enter the elements
:").split()))
    sorted_arr = quickSort_naive(arr)
    print("sorted array_naive:", sorted_arr)
    quickSort_hoare(arr, 0, len(arr) - 1)
    print("sorted array_hoare:", arr)
    quickSort_lomuto(arr, 0, len(arr) - 1)
    print("sorted array_lomuto:", arr)

```

Merge Sort

```
def mergeSort(arr):
    n=len(arr)
    if n>1:
        mid=n//2
        left_half=arr[:mid]
        right_half=arr[mid:]
        mergeSort(left_half)
        mergeSort(right_half)
        merge(arr,left_half,right_half)
def merge(arr,left_half,right_half):
    i=j=k=0
    while i<len(left_half) and j<len(right_half):
        if left_half[i]<right_half[j]:
            arr[k]=left_half[i]
            i+=1
        else:
            arr[k]=right_half[j]
            j+=1
        k+=1
    while i<len(left_half):
        arr[k]=left_half[i]
        i+=1
        k+=1
    while j<len(right_half):
        arr[k]=right_half[j]
        j+=1
        k+=1
if __name__=="__main__":
    n=int(input())
    arr=list(map(int,input().split()))
    mergeSort(arr)
    print "[" + ', '.join(map(str,arr)) + "]"
```

Counting Sort

```
def countingSort(arr):  
    if not arr:  
        return arr  
    max_val=max(arr)  
    count=[0]*(max_val+1)  
    for num in arr:  
        count[num]+=1  
    for i in range(1, len(count)):  
        count[i]+=count[i-1]  
    res=[0]*len(arr)  
    for i in range(len(arr)-1,-1,-1):  
        num=arr[i]  
        res[count[num]-1]=num  
        count[num]-=1  
    return res  
if __name__=="__main__":  
    n=int(input("enter size of array:"))  
    arr=list(map(int,input().split()))  
    sorted_arr=countingSort(arr)  
    print("sorted array:",sorted_arr)
```

Radix Sort

```
def digitSort(arr, exp):
    n=len(arr)
    output=[0]*n
    count=[0]*10
    for num in arr:
        digit=(num//exp)%10
        count[digit]+=1
    for i in range(1,10):
        count[i]+=count[i-1]
    for i in range(n-1,-1,-1):
        num=arr[i]
        digit=(num//exp)%10
        output[count[digit]-1]=num
        count[digit]-=1
    for i in range(n):
        arr[i]=output[i]

def radixSort(arr):
    if not arr:
        return arr
    max_val=max(arr)
    exp=1
    while max_val//exp>0:
        digitSort(arr,exp)
        exp*=10
    return arr

if __name__=="__main__":
    n=int(input("enter size of array:"))
    arr=list(map(int,input().split()))
    sorted_arr=radixSort(arr)
    print("sorted array:",sorted_arr)
```

Bucket Sort

```
def insertion_sort(bucket):
    for i in range(1, len(bucket)):
        key = bucket[i]
        j = i - 1
        while j >= 0 and bucket[j] > key:
            bucket[j + 1] = bucket[j]
            j -= 1
        bucket[j + 1] = key

def bucket_sort(arr):
    n = len(arr)
    buckets = [[] for _ in range(n)]

    # Put array elements in different buckets
    for num in arr:
        bi = int(n * num)
        buckets[bi].append(num)

    # Sort individual buckets using insertion sort
    for bucket in buckets:
        insertion_sort(bucket)

    # Concatenate all buckets into arr[]
    index = 0
    for bucket in buckets:
        for num in bucket:
            arr[index] = num
            index += 1

arr = [0.897, 0.565, 0.656, 0.1234, 0.665, 0.3434]
bucket_sort(arr)
print("Sorted array is:")
print(" ".join(map(str, arr)))
```

Pan Cake Sort

```
def pancake_sort(arr):  
    n = len(arr)  
  
    # Work from end of array  
    for curr_size in range(n, 1, -1):  
  
        # Find index of maximum element  
        max_index = arr.index(max(arr[:curr_size]))  
  
        # If max element is not already at its place  
        if max_index != curr_size - 1:  
  
            # Step 1: Bring max element to front  
            arr[:max_index + 1] =  
reversed(arr[:max_index + 1])  
  
            # Step 2: Move max element to its correct position  
            arr[:curr_size] = reversed(arr[:curr_size])  
  
    return arr
```

Heap Sort

```
def heapify(arr, n, i):
    largest = i          # Initialize largest as root
    left = 2 * i + 1     # Left child
    right = 2 * i + 2     # Right child

    # If left child exists and is greater than root
    if left < n and arr[left] > arr[largest]:
        largest = left

    # If right child exists and is greater than largest
    # so far
    if right < n and arr[right] > arr[largest]:
        largest = right

    # If largest is not root
    if largest != i:
        arr[i], arr[largest] = arr[largest], arr[i]
        heapify(arr, n, largest) # Recursively
heapify

def heap_sort(arr):
    n = len(arr)

    # Step 1: Build a max heap
    for i in range(n // 2 - 1, -1, -1):
        heapify(arr, n, i)

    # Step 2: Extract elements one by one
    for i in range(n - 1, 0, -1):
        arr[0], arr[i] = arr[i], arr[0] # Move max to
end
        heapify(arr, i, 0) # Heapify reduced heap
```

Time & Space Complexity Comparison:

Algorithm	Best	Average	Worst	Space	Stable	In-Place
Bubble Sort	$O(n)$	$O(n^2)$	$O(n^2)$	$O(1)$	✓	✓
Selection Sort	$O(n^2)$	$O(n^2)$	$O(n^2)$	$O(1)$	✗	✓
Insertion Sort	$O(n)$	$O(n^2)$	$O(n^2)$	$O(1)$	✓	✓
Merge Sort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(n)$	✓	✗
Quick Sort	$O(n \log n)$	$O(n \log n)$	$O(n^2)$	$O(\log n)$	✗	✓
Heap Sort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(1)$	✗	✓
Counting Sort	$O(n + k)$	$O(n + k)$	$O(n + k)$	$O(k)$	✓	✗
Radix Sort	$O(nk)$	$O(nk)$	$O(nk)$	$O(n + k)$	✓	✗
Bucket Sort	$O(n)$	$O(n)$	$O(n^2)$	$O(n)$	Depends	✗

Where k is the range of elements
 $k = (\max_ele - \min_ele + 1)$

Real-World Use Cases & Significance

Bubble Sort

Used where?

- Almost **never in production**

- Used in **teaching & debugging**

Significance

- Simplest sorting logic

Pros

- Easy to understand
- Detects already sorted arrays

Cons

- Extremely slow
-

Selection Sort

Used where?

- When **memory writes are costly**
- Embedded systems (very limited cases)

Significance

- Minimum number of swaps

Pros

- In-place
- Simple

Cons

- Always $O(n^2)$

- Not stable
-

Insertion Sort

Used where?

- **Small datasets**
- **Nearly sorted data**
- Used inside **TimSort** (Python)

Significance

- Adaptive algorithm

Pros

- Fast for small inputs
- Stable
- In-place

Cons

- Slow for large data
-

Merge Sort

Used where?

- **External sorting** (large files)
- Databases

- Linked lists

Significance

- Guaranteed $O(n \log n)$

Pros

- Stable
- Predictable performance

Cons

- Extra memory required
-

Quick Sort

Used where?

- **Most real-world systems**
- C/C++ standard libraries

Significance

- Fastest in practice (cache-friendly)

Pros

- In-place
- Very fast average case

Cons

- Worst case $O(n^2)$

- Not stable
-

Heap Sort

Used where?

- Priority queues
- Systems needing **guaranteed $O(n \log n)$**

Significance

- No worst-case degradation

Pros

- In-place
- Consistent performance

Cons

- Slower than quick sort in practice
 - Not stable
-

Counting Sort

Used where?

- Sorting marks, ages, IDs
- When range is small

Significance

- Linear time sorting

Pros

- Very fast
- Stable

Cons

- Works only for integers
 - High memory for large ranges
-

Radix Sort

Used where?

- Sorting large integers
- Phone numbers, ZIP codes

Significance

- Non-comparison sorting

Pros

- Linear time
- Stable

Cons

- Complex
- Needs stable sub-sort

Bucket Sort

Used where?

- Floating-point numbers
- Uniformly distributed data

Significance

- $O(n)$ average time

Pros

- Very fast for uniform data

Cons

- Poor for skewed data
- Range dependent

Scenario	Best Choice
Nearly sorted data	Insertion Sort
Large data, stable	Merge Sort
Fast general purpose	Quick Sort
Guaranteed worst case	Heap Sort
Small integer range	Counting Sort
Floating numbers	Bucket Sort
Large integers	Radix Sort