

## Radix Sort

The **lower bound for Comparison based sorting algorithm** (Merge Sort, Heap Sort, Quick-Sort .. etc) is  $\Omega(n \log n)$ , i.e., they cannot do better than  $n \log n$ . **3.3**

**Counting sort** is a linear time sorting algorithm that sort in  $O(n+k)$  time when elements are in range from 1 to k.

### ***What if the elements are in range from 1 to $n^2$ ?***

We can't use counting sort because counting sort will take  $O(n^2)$  which is worse than comparison based sorting algorithms. Can we sort such an array in linear time?

**Radix Sort** is the answer. The idea of Radix Sort is to do digit by digit sort starting from least significant digit to most significant digit. Radix sort uses counting sort as a subroutine to sort.

### ***The Radix Sort Algorithm***

**1)** Do following for each digit i where i varies from least significant digit to the most significant digit.  
 .....**a)** Sort input array using counting sort (or any stable sort) according to the i'th digit.

### **Example:**

Original, unsorted list:

170, 45, 75, 90, 802, 24, 2, 66

Sorting by least significant digit (1s place) gives: [\*Notice that we keep 802 before 2, because 802 occurred before 2 in the original list, and similarly for pairs 170 & 90 and 45 & 75.]

170, 90, 802, 2, 24, 45, 75, 66

Sorting by next digit (10s place) gives: [\*Notice that 802 again comes before 2 as 802 comes before 2 in the previous list.]

802, 2, 24, 45, 66, 170, 75, 90

Sorting by most significant digit (100s place) gives:

2, 24, 45, 66, 75, 90, 170, 802

### ***What is the running time of Radix Sort?***

Let there be  $d$  digits in input integers. Radix Sort takes  $O(d \cdot (n+b))$  time where  $b$  is the base for representing numbers, for example, for decimal system,  $b$  is 10. What is the value of  $d$ ? If  $k$  is the maximum possible value, then  $d$  would be  $O(\log_b(k))$ . So overall time complexity is  $O((n+b) \cdot \log_b(k))$ . Which looks more than the time complexity of comparison based sorting algorithms for a large  $k$ . Let us first limit  $k$ . Let  $k \leq n^c$  where  $c$  is a constant. In that case, the complexity becomes  $O(n \log_b(n))$ . But it still doesn't beat comparison based sorting algorithms.

What if we make value of  $b$  larger?. What should be the value of  $b$  to make the time complexity linear? If we set  $b$  as  $n$ , we get the time complexity as  $O(n)$ . In other words, we can sort an array of integers with range from 1 to  $n^c$  if the numbers are represented in base  $n$  (or every digit takes  $\log_2(n)$  bits).

### ***Is Radix Sort preferable to Comparison based sorting algorithms like Quick-Sort?***

If we have  $\log_2 n$  bits for every digit, the running time of Radix appears to be better than Quick Sort for a wide range of input numbers. The constant factors hidden in asymptotic notation are higher for Radix Sort and Quick-Sort uses hardware caches more effectively. Also, Radix sort uses counting sort as a subroutine and counting sort takes extra space to sort numbers.

**Recommended: Please try your approach on [{IDE}](#) first, before moving on to the solution.**

### **Implementation of Radix Sort**

Following is a simple C++ implementation of Radix Sort. For simplicity, the value of  $d$  is assumed to be 10. We recommend you to see [Counting Sort](#) for details of countSort() function in below code.

#### **C/C++**

```
// C++ implementation of Radix Sort
#include<iostream>
using namespace std;

// A utility function to get maximum value in arr[]
int getMax(int arr[], int n)
{
    int mx = arr[0];
    for (int i = 1; i < n; i++)
        if (arr[i] > mx)
            mx = arr[i];
    return mx;
}

// A function to do counting sort of arr[] according to
// the digit represented by exp.
void countSort(int arr[], int n, int exp)
```

```

{
    int output[n]; // output array
    int i, count[10] = {0};

    // Store count of occurrences in count[]
    for (i = 0; i < n; i++)
        count[ (arr[i]/exp)%10 ]++;

    // Change count[i] so that count[i] now contains actual
    // position of this digit in output[]
    for (i = 1; i < 10; i++)
        count[i] += count[i - 1];

    // Build the output array
    for (i = n - 1; i >= 0; i--)
    {
        output[count[ (arr[i]/exp)%10 ] - 1] = arr[i];
        count[ (arr[i]/exp)%10 ]--;
    }

    // Copy the output array to arr[], so that arr[] now
    // contains sorted numbers according to current digit
    for (i = 0; i < n; i++)
        arr[i] = output[i];
}

// The main function to that sorts arr[] of size n using
// Radix Sort
void radixsort(int arr[], int n)
{
    // Find the maximum number to know number of digits
    int m = getMax(arr, n);

    // Do counting sort for every digit. Note that instead
    // of passing digit number, exp is passed. exp is 10^i
    // where i is current digit number
    for (int exp = 1; m/exp > 0; exp *= 10)
        countSort(arr, n, exp);
}

// A utility function to print an array
void print(int arr[], int n)
{
    for (int i = 0; i < n; i++)
        cout << arr[i] << " ";
}

// Driver program to test above functions
int main()
{
    int arr[] = {170, 45, 75, 90, 802, 24, 2, 66};
    int n = sizeof(arr)/sizeof(arr[0]);
    radixsort(arr, n);
    print(arr, n);
    return 0;
}

```

[Run on IDE](#)

## Java

```

// Radix sort Java implementation
import java.io.*;
import java.util.*;

class Radix {

```

```

// A utility function to get maximum value in arr[]
static int getMax(int arr[], int n)
{
    int mx = arr[0];
    for (int i = 1; i < n; i++)
        if (arr[i] > mx)
            mx = arr[i];
    return mx;
}

// A function to do counting sort of arr[] according to
// the digit represented by exp.
static void countSort(int arr[], int n, int exp)
{
    int output[] = new int[n]; // output array
    int i;
    int count[] = new int[10];
    Arrays.fill(count, 0);

    // Store count of occurrences in count[]
    for (i = 0; i < n; i++)
        count[(arr[i]/exp)%10]++;

    // Change count[i] so that count[i] now contains
    // actual position of this digit in output[]
    for (i = 1; i < 10; i++)
        count[i] += count[i - 1];

    // Build the output array
    for (i = n - 1; i >= 0; i--)
    {
        output[count[(arr[i]/exp)%10] - 1] = arr[i];
        count[(arr[i]/exp)%10]--;
    }

    // Copy the output array to arr[], so that arr[] now
    // contains sorted numbers according to current digit
    for (i = 0; i < n; i++)
        arr[i] = output[i];
}

// The main function to that sorts arr[] of size n using
// Radix Sort
static void radixsort(int arr[], int n)
{
    // Find the maximum number to know number of digits
    int m = getMax(arr, n);

    // Do counting sort for every digit. Note that instead
    // of passing digit number, exp is passed. exp is 10^i
    // where i is current digit number
    for (int exp = 1; m/exp > 0; exp *= 10)
        countSort(arr, n, exp);
}

// A utility function to print an array
static void print(int arr[], int n)
{
    for (int i=0; i<n; i++)
        System.out.print(arr[i]+" ");
}

/*Driver function to check for above function*/
public static void main (String[] args)
{
    int arr[] = {170, 45, 75, 90, 802, 24, 2, 66};
    int n = arr.length;

```

```
        radixsort(arr, n);
        print(arr, n);
    }
}
/* This code is contributed by Devesh Agrawal */
```

[Run on IDE](#)

## Python

```
# Python program for implementation of Radix Sort

# A function to do counting sort of arr[] according to
# the digit represented by exp.
def countingSort(arr, exp1):

    n = len(arr)

    # The output array elements that will have sorted arr
    output = [0] * (n)

    # initialize count array as 0
    count = [0] * (10)

    # Store count of occurrences in count[]
    for i in range(0, n):
        index = (arr[i]/exp1)
        count[ (index)%10 ] += 1

    # Change count[i] so that count[i] now contains actual
    # position of this digit in output array
    for i in range(1,10):
        count[i] += count[i-1]

    # Build the output array
    i = n-1
    while i>=0:
        index = (arr[i]/exp1)
        output[ count[ (index)%10 ] - 1] = arr[i]
        count[ (index)%10 ] -= 1
        i -= 1

    # Copying the output array to arr[],
    # so that arr now contains sorted numbers
    i = 0
    for i in range(0,len(arr)):
        arr[i] = output[i]

# Method to do Radix Sort
def radixSort(arr):

    # Find the maximum number to know number of digits
    max1 = max(arr)

    # Do counting sort for every digit. Note that instead
    # of passing digit number, exp is passed. exp is 10^i
    # where i is current digit number
    exp = 1
    while max1/exp > 0:
        countingSort(arr,exp)
        exp *= 10

# Driver code to test above
arr = [ 170, 45, 75, 90, 802, 24, 2, 66]
radixSort(arr)
```

```
for i in range(len(arr)):
    print(arr[i]),

# This code is contributed by Mohit Kumra
```

[Run on IDE](#)

Output:

2 24 45 66 75 90 170 802

## Radix Sort | GeeksforGeeks



**Snapshots:**

Consider this input array

|     |    |    |    |     |    |   |    |
|-----|----|----|----|-----|----|---|----|
| 170 | 45 | 75 | 90 | 802 | 24 | 2 | 66 |
|-----|----|----|----|-----|----|---|----|

First consider the one's place

Consider this input array


|             |            |            |            |             |            |          |            |
|-------------|------------|------------|------------|-------------|------------|----------|------------|
| 17 <u>0</u> | 4 <u>5</u> | 7 <u>5</u> | 9 <u>0</u> | 80 <u>2</u> | 2 <u>4</u> | <u>2</u> | 6 <u>6</u> |
|-------------|------------|------------|------------|-------------|------------|----------|------------|

|     |    |     |   |    |    |    |    |
|-----|----|-----|---|----|----|----|----|
| 170 | 90 | 802 | 2 | 24 | 45 | 75 | 66 |
|-----|----|-----|---|----|----|----|----|

Consider this input array

|     |    |    |    |     |    |   |    |
|-----|----|----|----|-----|----|---|----|
| 170 | 45 | 75 | 90 | 802 | 24 | 2 | 66 |
|-----|----|----|----|-----|----|---|----|

|     |    |     |   |    |    |    |    |
|-----|----|-----|---|----|----|----|----|
| 170 | 90 | 802 | 2 | 24 | 45 | 75 | 66 |
|-----|----|-----|---|----|----|----|----|



Observe that 170 has come before 90 this is because it appeared before in the original list.

Consider this input array

|     |    |    |    |     |    |   |    |
|-----|----|----|----|-----|----|---|----|
| 170 | 45 | 75 | 90 | 802 | 24 | 2 | 66 |
|-----|----|----|----|-----|----|---|----|

|     |    |     |   |    |    |    |    |
|-----|----|-----|---|----|----|----|----|
| 170 | 90 | 802 | 2 | 24 | 45 | 75 | 66 |
|-----|----|-----|---|----|----|----|----|

|     |   |    |    |    |     |    |    |
|-----|---|----|----|----|-----|----|----|
| 802 | 2 | 24 | 45 | 66 | 170 | 75 | 90 |
|-----|---|----|----|----|-----|----|----|

Now consider the 100's place.



# Array is Now sorted

|   |    |    |    |    |    |     |     |
|---|----|----|----|----|----|-----|-----|
| 2 | 24 | 45 | 66 | 75 | 90 | 170 | 802 |
|---|----|----|----|----|----|-----|-----|

## Quiz on Radix Sort

### Other Sorting Algorithms on GeeksforGeeks/GeeksQuiz:

- Selection Sort
- Bubble Sort
- Insertion Sort
- Merge Sort
- Heap Sort
- QuickSort
- Counting Sort
- Bucket Sort
- ShellSort

### References:

[http://en.wikipedia.org/wiki/Radix\\_sort](http://en.wikipedia.org/wiki/Radix_sort)

<http://alg12.wikischolars.columbia.edu/file/view/RADIX.pdf>

MIT Video Lecture

Introduction to Algorithms 3rd Edition by Clifford Stein, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest

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3.3

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