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Project Report

Topic: SORTING ALGORITHMS

Subject: Data Structures and Algorithms

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List of Algorithms

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1 Algorithms Presentation

1.1 Heap Sort

1.1.1 Ideas

The heap sort is comparison-based sorting technique base on Binary Heap data structure - a complete Binary Tree, as we only sort the data in ascending order so the Max Binary Heap, whose the key at the root is maximum among all keys, is taken in to use. It is similar to the selection sort where we find the minimum element and place it at the beginning then repeat the same process for the remaining elements.

1.1.2 Descriptions

Using these following steps to perform the heap sort:

- Step 1: Build a heap data structure from the given input array using heapify.
- Step 2: Swap the root element, which is now the largest element, with the last element of the heap.
- Step 3: Heapify the remaining elements of the heap except for the last element.

Repeat Step 2 and Step 3 until the heap contains only 1 element.

Algorithm 1 Heap Sort

```
1: function SWAP(a, b)
2:     temp ← a
3:     a ← b
4:     b ← temp
5: end function

6: function HEAPIFY(array, n, i)
7:     largest ← i
8:     left ← 2 * i + 1
9:     right ← 2 * i + 2
10:
11:    if left < n && array[largest] < array[left] then
12:        largest ← left
13:    end if
14:
15:    if right < n && array[largest] < array[right] then
16:        largest ← right
17:    end if
18:
19:    if largest ≠ i then
20:        SWAP(array[largest], array[i])
21:        HEAPIFY(array, n, largest)
22:    end if
23: end function
```

```
24: function HEAPSORT(array, n)
25:     for i ← 0 to n − 1 do
26:         HEAPIFY(array, n, i)
27:     end for
28:
29:     for i ← n − 1 to 0 do
30:         SWAP(array[0], array[i])
31:         HEAPIFY(array, i, 0)
32:     end for
33: end function
```

1.1.3 Time Complexity

The problem size is: n - the number of elements of the array.
The process of converting an array of n elements to a heap data structure takes $O(logn)$ logarithmic time - the $O(logn)$ factor is the height of the binary tree, then the last element will be extracted from the array so the size is now $n-1$ and the converting process will continue until the array only has 1 element left. So the total time complexity is:

$$O(logn) + O(log(n-1)) + ... + O(log1) = O(log(n!))$$

Time complexity:

- **Best case:** $O(nlogn)$
- **Average case:** $O(nlogn)$
- **Worst case:** $O(nlogn)$

1.1.4 Space Complexity

Since heap sort is an in-place sorting algorithm, it does not require additional storage.
Space complexity: $O(n)$

1.2 Radix Sort

1.2.1 Ideas

The radix sort is a non comparison-based sorting technique. To achieve the finally sorted order, the radix sort distributes the elements into buckets based on each digit's value and repeatedly sorting the elements by their significant digits, from the least significant digit to the most significant digit. The radix sort uses the counting sort to sort the list considering a certain digit.

1.2.2 Descriptions

Using these following steps to perform the radix sort:

- Step 1: Find the largest value in the array.
- Step 2: Iterate *exp* times, *exp* is the number of digits of the largest value, once for each significant place. In each iteration, performing the counting sort to sort the elements.

Algorithm 2 Radix Sort

```
1: function getMax(array, n)
2:     Max ← array[0]
3:
4:     for i ← 0 to n − 1 do
5:         if Max < array[i] then
6:             Max ← array[i]
7:         end if
8:     end for
9:
10:    return Max
11: end function

12: function countSort(array, n, exp)
13:    output is an array of n integers
14:    count is an array of 10 integers, the value of each element is 0
15:
16:    for i ← 0 to n − 1 do
17:        count[⌊array[i]/exp⌋ mod 10] ← count[⌊array[i]/exp⌋ mod 10] + 1
18:    end for
19:
20:    for i ← 1 to 10 do
21:        count[i] ← count[i] + count[i − 1]
22:    end for
23:
24:    for i ← n − 1 to 0 do
25:        output[count[⌊array[i]/exp⌋ mod 10] − 1] = array[i]
26:
27:        count[⌊array[i]/exp⌋ mod 10] ← count[⌊array[i]/exp⌋ mod 10] − 1
28:    end for
29:
30:    for i ← 0 to n − 1 do
31:        array[i] ← output[i]
32:    end for
33: end function

34: function radixSort(array, n)
35:    max ← getMax(array, n)
36:
37:    for exp ← 1 to ⌊max/exp⌋ > 1 do
38:        countSort(array, n, exp)
39:    end for
40: end function
```

1.2.3 Time Complexity

The problem size are:

- k - the number of digits of the largest value.
- n - the number of elements of the array.

The counting sort used in the radix sort takes $O(n + b)$ logarithmic time with b is the base of the number system but in this case b is a constant, and since we have to perform the counting sort k times so the time complexity will be $O(k * n)$ in all cases.
Time complexity:

- **Best case:** $O(k * n)$
- **Average case:** $O(k * n)$
- **Worst case:** $O(k * n)$

1.2.4 Space Complexity

Since we have to create an auxiliary space to store each digit value and copy the elements back to the original array so the space complexity will be $O(n + b)$.
Space complexity: $O(n + b)$

1.3 Flash Sort

1.3.1 Ideas

The flash sort is a comparison-based sorting technique, a more efficient way to implement the bucket sort as it creates buckets and rearrange all elements according to buckets. Lastly, sorting each bucket using the insertion sort.

1.3.2 Descriptions

Using these following steps to perform the flash sort:

- Step 1: Find the positions of the minimum and the maximum value in the array.
- Step 2: Divide the array into m buckets.
- Step 3: Count the number of elements in each bucket.
- Step 4: Convert the counts of each bucket into prefix sum.
- Step 5: Rearrange all the elements of each bucket in a position $array_{\text{i}}$ where $bucketId - 1 < i < bucketId$.
- Step 6: Sort each bucket using the insertion sort.

Algorithm 3 Flash Sort

```
1: function FLASHSWAP(array, n, bucket, m, maxPos, minPos, c)
2:     bucketId ← m − 1
3:     move ← 0, i ← 0, flash ← 0
4:
5:     SWAP(array[maxPos], array[0])
6:     while move < n − 1 do
7:         while i > bucketId − 1 do
```

```
            i ← i + 1
            bucketId ← c * (array[i] − array[minPos])
        end while

        flash ← a[i]
        while i ≠ bucketID do
            bucketId ← c * (array[i] − arrray[minPos]
            bucketId ← bucketId − 1
            Swap(flash, a[bucketId])
            move ← move + 1
        end while
    end while
end function

function flashSort(array, n)
    m ← 0.45 * n
    bucket is an array of m integers, the value of each element is 0
    maxPos ← 0, minPos ← 0

    for i ← 0 to n − 1 do
        if array[maxPos] < array[i] then
            maxPos ← i
        end if

        if array[minPos] > array[i] then
            minPos ← i
        end if
    end for

    c ← (m−1) / (array[maxPos]−array[minPos])
    for i ← 0 to n − 1 do
        k ← c * (array[i] − array[minPos])
        bucket[k] ← bucket[k] + 1
    end for

    for i ← 1 to m − 1 do
        bucket[k] ← bucket[k] + bucket[k − 1]
    end for

    flashSwap(array, n, bucket, m, maxPos, minPos, c)
    insertionSort(array, n)
end function
```

1.3.3 Time Complexity

The problem size is: n - the number of elements of the array.
The best and average time complexity is $O(n)$. However, there is a possibility that nearly all the elements are belong to one bucket which can make the time complexity go up to the worst time

complexity of the insertion sort, which is $O(n^2)$.
Time complexity:

- **Best case:** $O(n)$
- **Average case:** $O(n)$
- **Worst case:** $O(n^2)$

1.3.4 Space Complexity

Since the flash sort is an in-place sorting algorithm, it does not require additional storage.
Space complexity: $O(n)$

2 Chart Draw and Comment

2.1 Random Data

Bar Chart:

Comments:

2.2 Sorted Data

Bar Chart:

Comments:

2.3 Reversed Data

Bar Chart:

Comments:

2.4 Nearly Sorted Data

Bar Chart:

Comments: