

Data Structures in Python

Chapter 5

- Bubble sort
- Selection sort
- Insertion sort
- Merge sort
- **Quick sort Algorithm**
- Quick sort Analysis
- Empirical Analysis

Agenda & Readings

- Agenda
 - Quick sort algorithm
 - $n \log(n)$ algorithm,
 - Divide and conquer algorithm
- Reference:
 - Problem Solving with Algorithms and Data Structures
 - Chapter 5 Search, Sorting and Hashing: [Quick sort](#)
 - Wikipedia [Quick sort](#)
 - [\[알고리즘\] 퀵정렬](#)

Quick sort

- Quick sort invented by British computer scientist C.A.R. Hoare in 1960
- Quick sort is another divide and conquer algorithm.
- Time complexity is $O(n \log n)$ average, $O(n^2)$ worst case, faster than merge sort in general.

Quick sort - Algorithm

- Choose a pivot element from the array. Although we can choose any element in the array as a pivot, it's easy to implement if we choose the rightmost element of the subarray.

index	0	1	2	3	4	5	6	7	8	9
value	32	23	81	43	92	39	57	16	75	65

pivot

- Partition or reorder the array so that all values smaller than the pivot are moved before it and all values larger (or equal) than the pivot are moved after it.

32	23	43	39	57	16	92	81	75	65
----	----	----	----	----	----	----	----	----	----

pivot

- When this is done, the pivot is in its final position.

32	23	43	39	57	16	65	81	75	92
----	----	----	----	----	----	----	----	----	----

sorted

- Conquer by repeating steps above for the left side and right side of the pivot recursively, except the pivot itself since it is sorted and positioned at the right place,

Quick sort - Partition

- Choose a pivot element and partition the array in place such that all elements to the left of the pivot element are smaller, while all elements to the right are greater than the pivot.

index	0	1	2	3	4	5	6	7	8	9
value	32	23	81	43	92	39	57	16	75	65
j=lo i=lo-1	j=0 i=0	j=1 i=1	j=2 i=1	j=3 i=2	j=4 i=2	j=5 i=3	j=6 i=4	j=7 i=5	j=8 i=5	pivot

while j traverses from **low** to **hi-1**
i increments only when **a[j] < pivot**

```
def partition(a, lo, hi):  
    pivot = a[hi]  
    i = lo - 1;  
    j = lo  
    while j <= hi - 1: scan  
        if a[j] < pivot:  
            i += 1  
            if i != j: swap  
                a[j], a[i] = a[i], a[j]  
            j += 1  
    a[hi], a[i+1] = a[i+1], a[hi] sorted  
    return i + 1
```

Quick sort - Partition

- Choose a pivot element and partition the array in place such that all elements to the left of the pivot element are smaller, while all elements to the right are greater than the pivot.

index	0	1	2	3	4	5	6	7	8	9
value	32	23	81	43	92	39	57	16	75	65
j=lo i=lo-1	j=0 i=0	j=1 i=1	j=2 i=1	j=3 i=2	j=4 i=2	j=5 i=3	j=6 i=4	j=7 i=5	j=8	pivot
				swap		swap	swap	swap		

Now, find elements to swap.

while j traverses from low to hi-1
i increments only when a[j] < pivot

```
def partition(a, lo, hi):
    pivot = a[hi]
    i = lo - 1;
    j = lo
    while j <= hi - 1:
        if a[j] < pivot:
            i += 1
            if i != j:
                a[j], a[i] = a[i], a[j]
        j += 1
    a[hi], a[i+1] = a[i+1], a[hi]
    return i + 1
```

Quick sort - Partition

- Choose a pivot element and partition the array in place such that all elements to the left of the pivot element are smaller, while all elements to the right are greater than the pivot.

index	0	1	2	3	4	5	6	7	8	9
value	32	23	81	43	92	39	57	16	75	65

j=lo	j=0	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	pivot
i=lo-1	i=0	i=1	i=1	i=2	i=2	i=3	i=4	i=5	i=5	
				swap		swap	swap	swap		

swap(2,3)

32	23	43	81	92	39	57	16	75	65
----	----	----	----	----	----	----	----	----	----

swap(3,5)

32	23	43	39	92	81	57	16	75	65
----	----	----	----	----	----	----	----	----	----

swap(4,6)

32	23	43	39	57	81	92	16	75	65
----	----	----	----	----	----	----	----	----	----

swap(5,7)

32	23	43	39	57	16	92	81	75	65
----	----	----	----	----	----	----	----	----	----

↑

not sorted

while j traverses from low to hi-1

i increments only when a[j] < pivot

```
def partition(a, lo, hi):
    pivot = a[hi]
    i = lo - 1;
    j = lo
    while j <= hi - 1:
        if a[j] < pivot:
            i += 1
            if i != j:
                a[j], a[i] = a[i], a[j]
            j += 1
    a[hi], a[i+1] = a[i+1], a[hi]
    return i + 1
```

Quick sort - Partition

- Choose a pivot element and partition the array in place such that all elements to the left of the pivot element are smaller, while all elements to the right are greater than the pivot.

index	0	1	2	3	4	5	6	7	8	9
value	32	23	81	43	92	39	57	16	75	65

j=lo	j=0	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	pivot
i=lo-1	i=0	i=1	i=1	i=2	i=2	i=3	i=4	i=5	i=5	
			swap			swap	swap	swap		

swap(2,3)	32	23	43	81	92	39	57	16	75	65
-----------	----	----	----	----	----	----	----	----	----	----

swap(3,5)	32	23	43	39	92	81	57	16	75	65
-----------	----	----	----	----	----	----	----	----	----	----

swap(4,6)	32	23	43	39	57	81	92	16	75	65
-----------	----	----	----	----	----	----	----	----	----	----

swap(5,7)	32	23	43	39	57	16	92	81	75	65
-----------	----	----	----	----	----	----	----	----	----	----

swap(6,9)	32	23	43	39	57	16	65	81	75	92
swap(i+1,hi)										

recursively sort left $a[] \leq \text{pivot}$ sorted $a[] \geq \text{pivot}$ sort right

while j traverses from low to hi-1
i increments only when $a[j] < \text{pivot}$

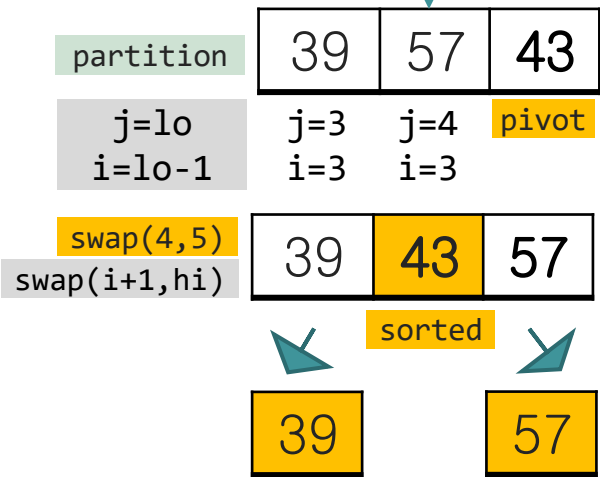
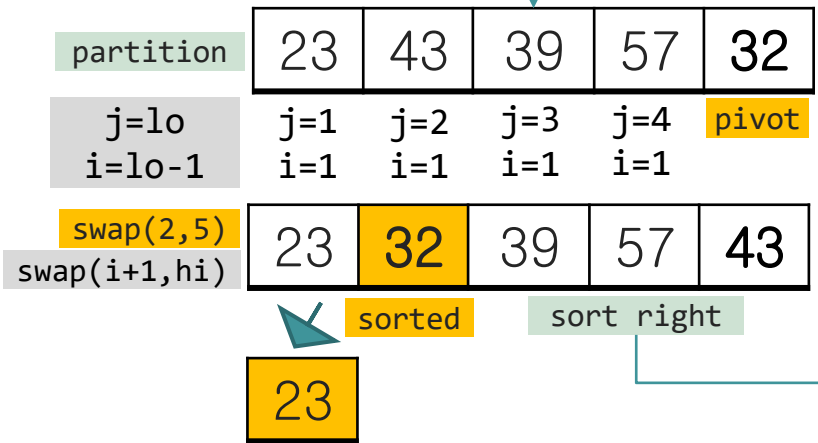
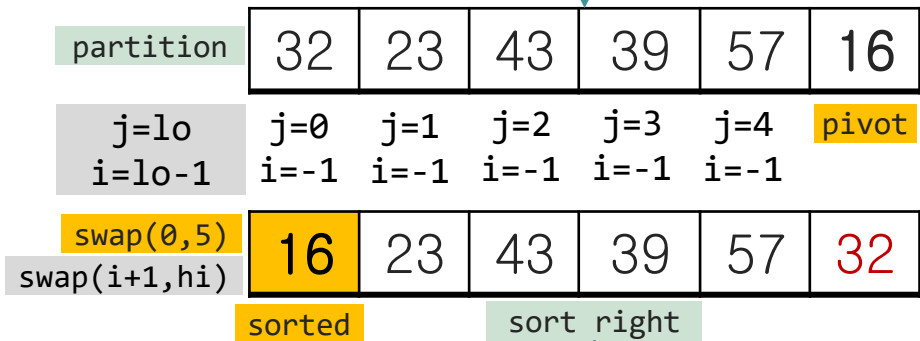
```
def partition(a, lo, hi):
    pivot = a[hi]
    i = lo - 1;
    j = lo
    while j <= hi - 1:
        if a[j] < pivot:
            i += 1
            if i != j:
                a[j], a[i] = a[i], a[j]
            j += 1
    a[hi], a[i+1] = a[i+1], a[hi]
    return i + 1
```


Quick sort - Partition

Repeat this process recursively:

index	0	1	2	3	4	5	6	7	8	9
value	32	23	43	39	57	16	65	81	75	92

sort left $a[] \leq \text{pivot}$ sorted $a[] \geq \text{pivot}$ sort right



The rest of this part is left as an exercise.

Summary

- Quick sort is one of the most efficient sorting algorithms.
- It is based on the splitting of an array (**partition**) into smaller ones and rearrange based on the comparison with '**pivot**' element selected.
- Like merge sort, quick sort also falls into the category of **divide and conquer** approach of problem-solving methodology.

Unsorted Array



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- Quick sort Coding & Analysis