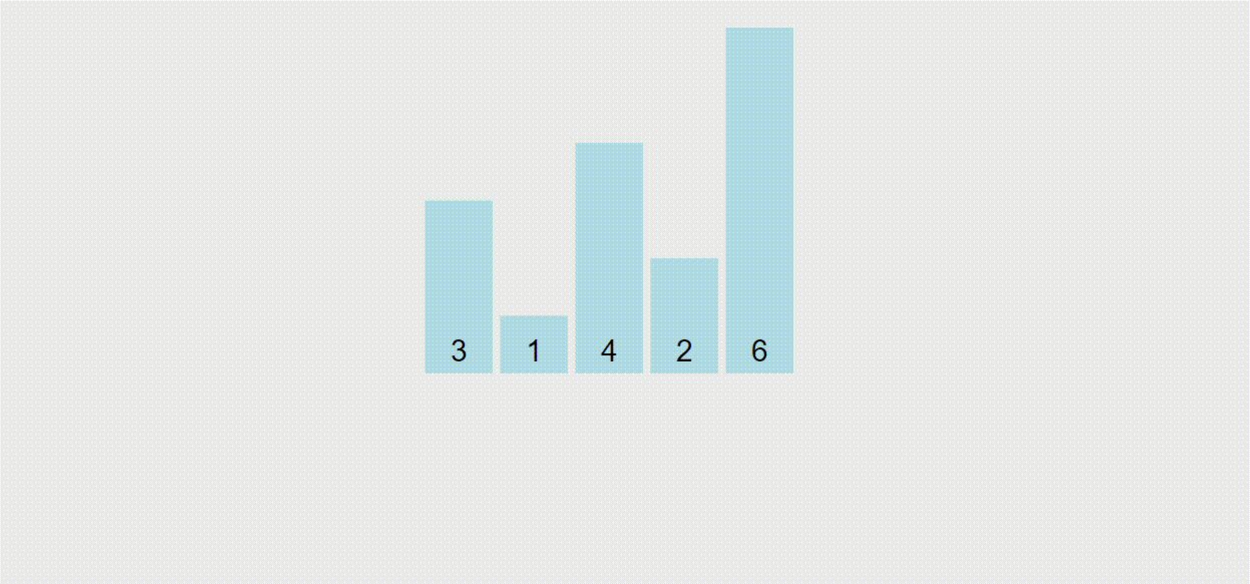
Sorting II - Advanced

Part II

Quick Sort

Quick Sort



Similar to merge sort, Quicksort follows the **divide-and-conquer approach** that was first introduced.

`visualization from: VisuAlgo`

A2SV

Quick Sort

```
if length of array is less than or equal to 1:
  return array
else:
  select an element from the array to use as a pivot
  partition the elements of the array into two sub-arrays:
    - elements less than or equal to pivot
    - elements greater than pivot
  quicksort the sub-array of elements less than or equal to pivot
  quicksort the sub-array of elements greater than pivot
  concatenate the sorted sub-arrays and return the result
```

Quick Sort

Example input

R

[**4**, 2, 6, 8, 1, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 6, 8, 1, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 6, 8, 1, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 6, 8, 1, 5, 9]

P W

P: pivot
W: write index
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Quick Sort

Example input

R

[4, 2, 1, 8, 6, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 1, 8, 6, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 1, 8, 6, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

R

[4, 2, 1, 8, 6, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

[1, 2, 4, 8, 6, 5, 9]

P W

P: pivot
W: write index
R: read index

Quick Sort

Example input

[1, 2, 4, 8, 6, 5, 9]

quicksort ([1, 2])

quicksort ([8, 6, 5, 9])

Combine the answer

Visualization Link

Can you implement the function **partition** ?

[**Implement Here**]

Implementation

```python
def partition(nums, left, right) -> int:
    """
    Picks the first element left as a pivot
     and returns the index of pivot value in the sorted array
    """
    pivot_val = nums[left]
    store_index = left + 1
    for j in range(store_index, right + 1):
        if nums[j] < pivot_val:
            nums[store_index], nums[j] = nums[j], nums[store_index]
            store_index += 1

    nums[store_index - 1], nums[left] = nums[left], nums[store_index - 1]
    return store_index - 1
```

Implementation

```
def quick_sort(nums, left, right):
    # if length of array is less than or equal to 1
    if left >= right:
        return

    pivot_index = partition(nums, left, right)
    quick_sort(nums, left, pivot_index - 1)
    quick_sort(nums, pivot_index + 1, right)
```

Q: What do you think is the time complexity for the aforementioned sorting Algorithm?

?

Time & Space Complexity

Worst case ? ____________

Best case ? ____________

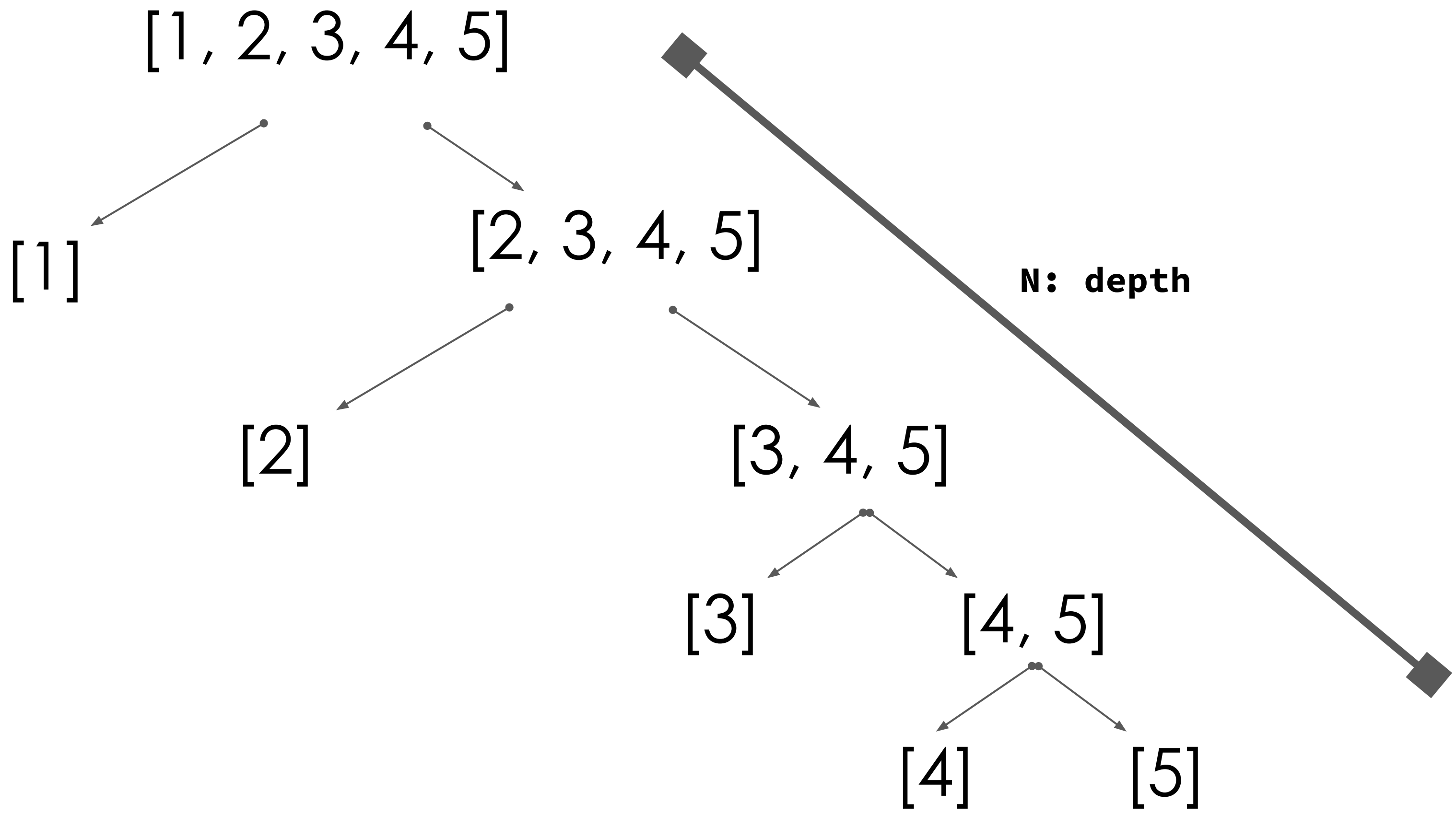
Average case ? ____________

Q: what kind of input would result in the **worst case**?

?

What happens in the worst case?

Sorted array



Q: Can we do better ? How ?

?

How can we avoid the worst case?

- Pick pivot randomly
- Median value of arr[0], arr[len//2] and arr[len - 1]

Modified Implementation

```
def partition(nums, left, right) -> int:
    # Select a random pivot_index and move the pivot in to the first
element
    pivot_index = random.randint(left, right)
    nums[pivot_index], nums[left] = nums[left], nums[pivot_index]

    pivot_val = nums[left]
    store_index = left + 1
    for j in range(store_index, right + 1):
        if nums[j] < pivot_val:
            nums[store_index], nums[j] = nums[j], nums[store_index]
            store_index += 1

    nums[store_index - 1], nums[left] = nums[left], nums[store_index - 1]
    return store_index - 1
```

Time & Space Complexity

Time complexity: **$O(n^2)$**

Space complexity: **O(1)**

Worst case	**$O(n^2)$**
Best case	**O(n log n)**
Average case	**O(n log n)**
Stable	**NO**
In-place	**YES**

Cycle/ Cyclic Sort

Cycle Sort

It is known that all comparison-based sorting algorithms have a lower bound time complexity of $\Omega(N \log N)$.

However, we can achieve faster sorting algorithm — i.e., in $O(N)$ — if certain **assumptions** of the **input array exist**

Cycle Sort

Problem:

You are given an array of **size n** that only includes numbers in the range **[1, n]**, sort the array in a single pass in O(N) runtime.

0 1 2 3 4

[3, 5, 2, 1, 4]

Cycle Sort

Approach:

Let’s imagine the array was already sorted, what would be the relationship between the values and the indices ?

0 1 2 3 4

[1, 2, 3, 4, 5]

Cycle Sort

Approach:

Index = value - 1

0 1 2 3 4

[1, 2, 3, 4, 5]

Approach:

This means, we can use the **values** to know where **exactly** in the array they should be **placed**.

0 1 2 3 4

[3, 5, 2, 1, 4]

Where should 3 be placed at ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[3, 5, 2, 1, 4]

The value 3 should be placed at index 2. So we **swap**

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[2, 5, 3, 1, 4]

The value 2 is **not** in the correct place either, **where should it be ?**

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[2, 5, 3, 1, 4]

Swap

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[5, 2, 3, 1, 4]

Where should 5 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[5, 2, 3, 1, 4]

Swap

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[4, 2, 3, 1, 5]

Where should 4 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4
[4, 2, 3, 1, 5]

Swap

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4
[1, 2, 3, 4, 5]

Where should 1 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[1, 2, 3, 4, 5]

It is finally in its correct position, so we move our pointer

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

$$\begin{array}{ccccc} 0 & 1 & 2 & 3 & 4 \\ \end{array}$$

[1, 2, 3, 4, 5]

Where should 2 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4

[1, 2, 3, 4, 5]

Where should 3 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

$$\begin{array}{ccccc} 0 & 1 & 2 & 3 & 4 \\ \end{array}$$

[1, 2, 3, 4, 5]

Where should 4 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4
[1, 2, 3, 4, 5]

Where should 5 be ?

Cycle Sort

This means, we can use the values to know where exactly in the array they should be placed.

0 1 2 3 4
[1, 2, 3, 4, 5]

Array is sorted.

Can you implement the function **cycleSort** ?

Implement Here

Cycle Sort

Implementation

```
def cycleSort(arr):
    n = len(arr)
    i = 0
    while i < n:
        correct_position = arr[i] - 1
        if correct_position != i:
            arr[correct_position], arr[i] = arr[i], arr[correct_position]
        else:
            i += 1
    return arr
```

Q: What do you think is the time complexity for the aforementioned sorting Algorithm?

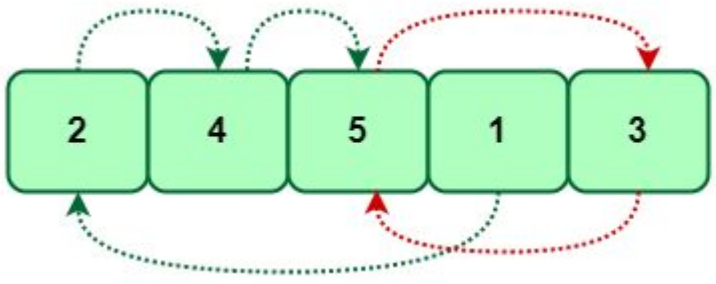
?

Cycle Sort

Worst case ________

Best case ________

Average case ________

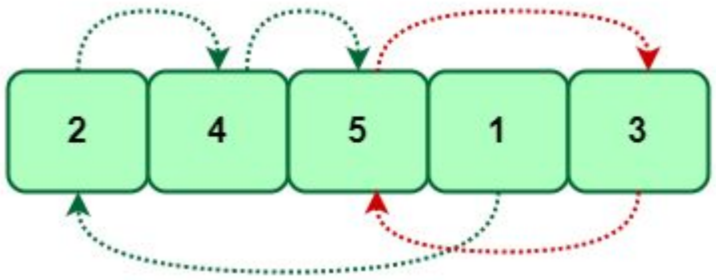


Cycle Sort

Worst case ____**O(N)**____

Best case ____**O(N)**____

Average case ____**O(N)**____



Only applies to a **constrained range** of values

Further Reading

- There are also other popular sorting algorithms such as **Radix Sort, Binary Insertion Sort**…

- Feel free to explore and share with your teammates.

Pair Programming

Practice Problems

Missing Number

Find All Numbers Disappeared in an Array

Find all duplicates in an array

Set Mismatch

Find the Duplicate Number

FIrst Missing Positive

Kth Largest Element in an Array

Resources

- Visualgo.com: is great for visualizing sorting algorithms in general
- Chatgpt: is great at re-writing and generating pseudocode
- Geeks for Geeks (GFG): has clear explanations
- A2SV Slides repo: good reference for which topics to cover and good quotes.
- Leetcode learn card Recursion II: good reference for merge sort, quick sort, and other recursion concepts
- Leetcode learn card Sorting: good reference for bucket sort, and other sorting algorithms like radix sort.

Quote of the Day

"The first law of success is concentration — to bend all the energies to one point, and to go directly to that point, looking neither to the right nor to the left."

- **William Matthews**