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162. Find Peak Element

May 29, 2017 | 153.5K views

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A peak element is an element that is greater than its neighbors.

Given an input array `nums`, where `nums[i] ≠ nums[i+1]`, find a peak element and return its index.

The array may contain multiple peaks, in that case return the index to any one of the peaks is fine.

You may imagine that `nums[-1] = nums[n] = -∞`.

Example 1:

```
Input: nums = [1,2,3,1]
Output: 2
Explanation: 3 is a peak element and your function should return the index number 2.
```

Example 2:

```
Input: nums = [1,2,1,3,5,6,4]
Output: 1 or 5
Explanation: Your function can return either index number 1 where the peak element is
             or index number 5 where the peak element is 6.
```

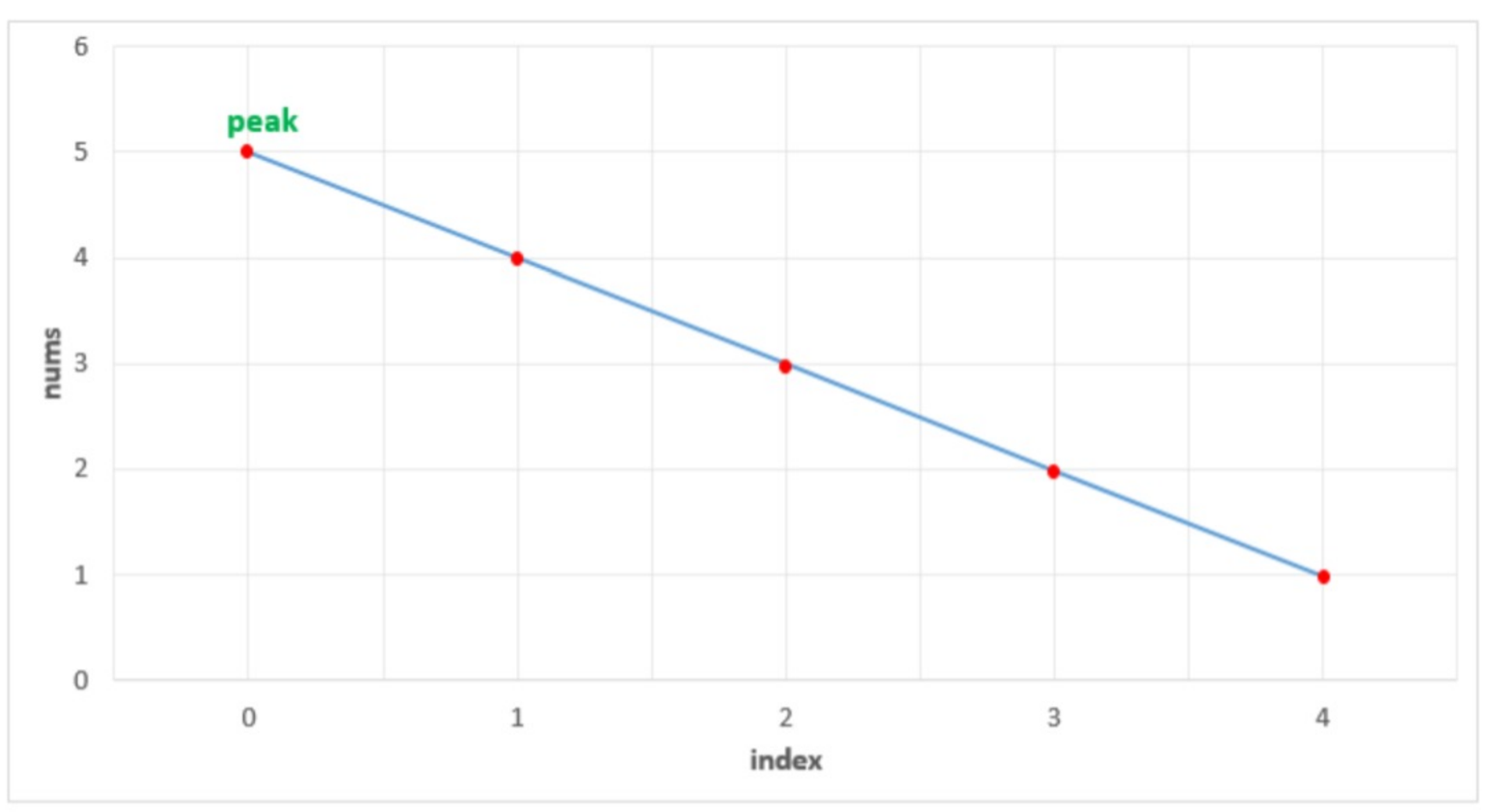
Follow up: Your solution should be in logarithmic complexity.

Solution

Approach 1: Linear Scan

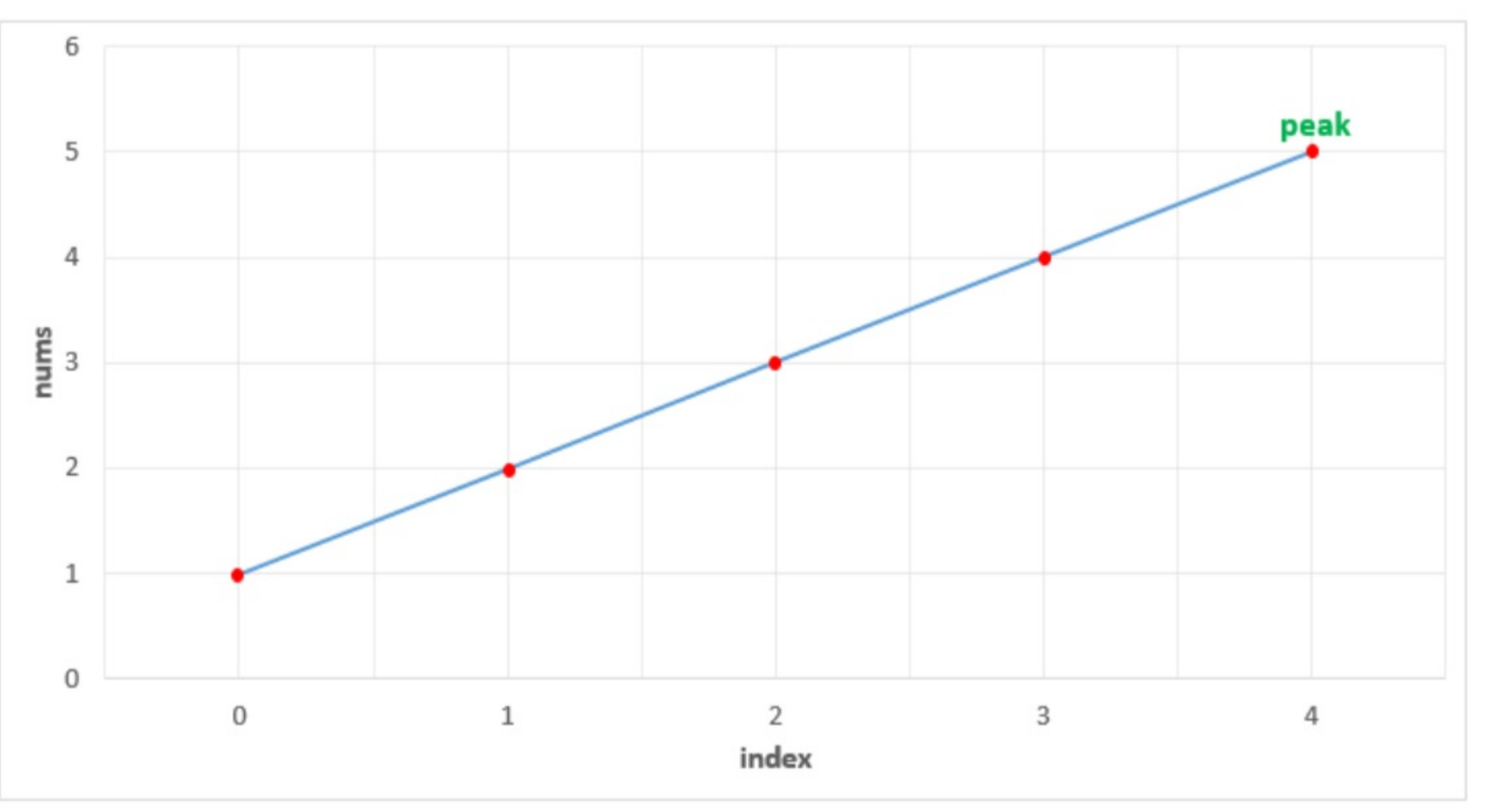
In this approach, we make use of the fact that two consecutive numbers $nums[j]$ and $nums[j+1]$ are never equal. Thus, we can traverse over the $nums$ array starting from the beginning. Whenever, we find a number $nums[i]$, we only need to check if it is larger than the next number $nums[i+1]$ for determining if $nums[i]$ is the peak element. The reasoning behind this can be understood by taking the following three cases which cover every case into which any problem can be divided.

Case 1. All the numbers appear in a descending order. In this case, the first element corresponds to the peak element. We start off by checking if the current element is larger than the next one. The first element satisfies this criteria, and is hence identified as the peak correctly. In this case, we didn't reach a point where we needed to compare $nums[i]$ with $nums[i-1]$ also, to determine if it is the peak element or not.



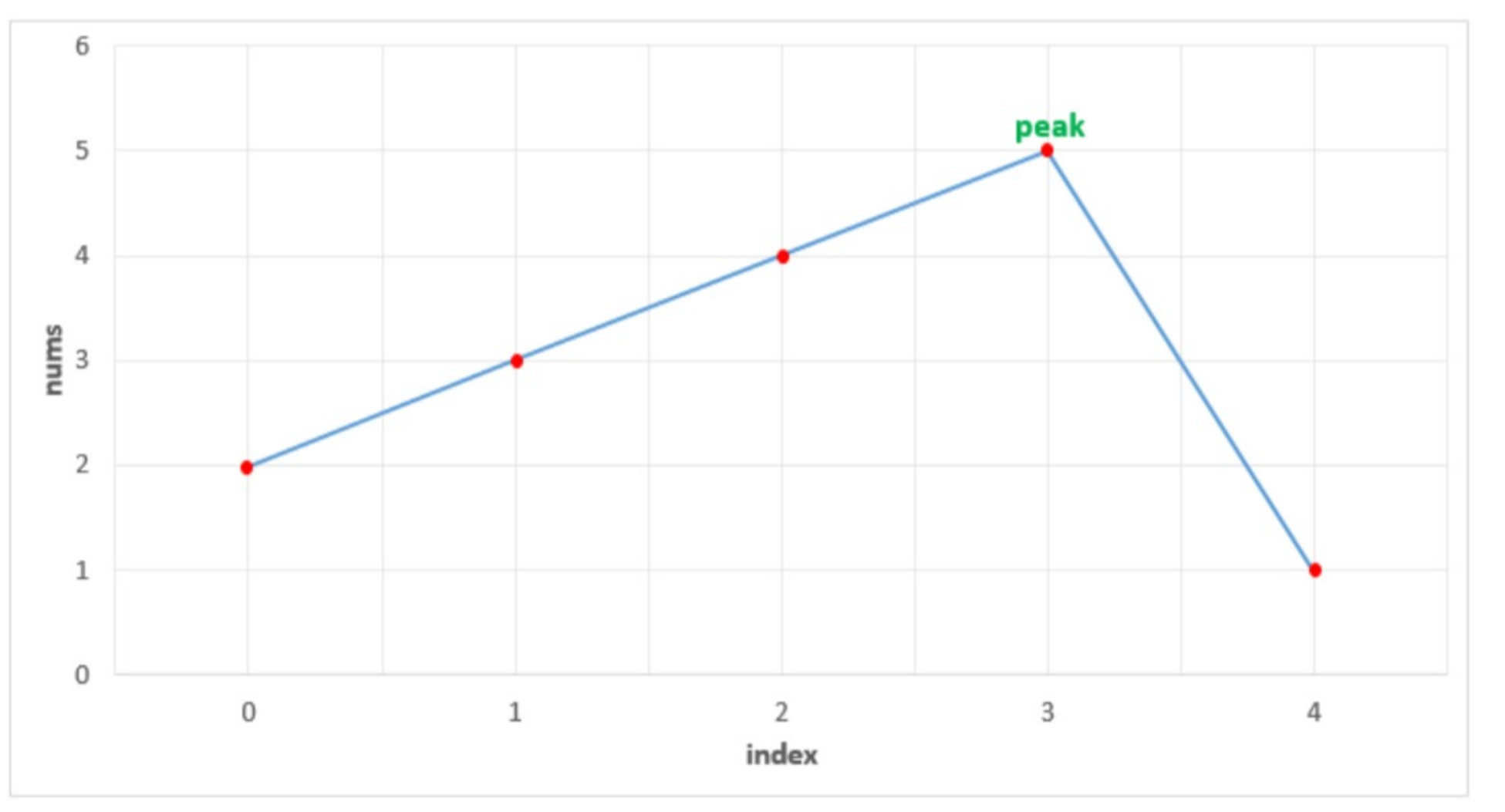
Case 1

Case 2. All the elements appear in ascending order. In this case, we keep on comparing $nums[i]$ with $nums[i+1]$ to determine if $nums[i]$ is the peak element or not. None of the elements satisfy this criteria, indicating that we are currently on a rising slope and not on a peak. Thus, at the end, we need to return the last element as the peak element, which turns out to be correct. In this case also, we need not compare $nums[i]$ with $nums[i-1]$, since being on the rising slope is a sufficient condition to ensure that $nums[i]$ isn't the peak element.



Case 2

Case 3. The peak appears somewhere in the middle. In this case, when we are traversing on the rising edge, as in Case 2, none of the elements will satisfy $nums[i] > nums[i+1]$. We need not compare $nums[i]$ with $nums[i-1]$ on the rising slope as discussed above. When we finally reach the peak element, the condition $nums[i] > nums[i+1]$ is satisfied. We again, need not compare $nums[i]$ with $nums[i-1]$. This is because, we could reach $nums[i]$ as the current element only when the check $nums[i] > nums[i+1]$ failed for the previous($(i-1)^{th}$ element, indicating that $nums[i-1] < nums[i]$. Thus, we are able to identify the peak element correctly in this case as well.



Case 3

Java Copy

```java
public class Solution {
    public int findPeakElement(int[] nums) {
        for (int i = 0; i < nums.length - 1; i++) {
            if (nums[i] > nums[i + 1])
                return i;
        }
        return nums.length - 1;
    }
}
```

Complexity Analysis

- Time complexity : $O(n)$. We traverse the $nums$ array of size n once only.
- Space complexity : $O(1)$. Constant extra space is used.

Approach 2: Recursive Binary Search

Algorithm

We can view any given sequence in $nums$ array as alternating ascending and descending sequences. By making use of this, and the fact that we can return any peak as the result, we can make use of Binary Search to find the required peak element.

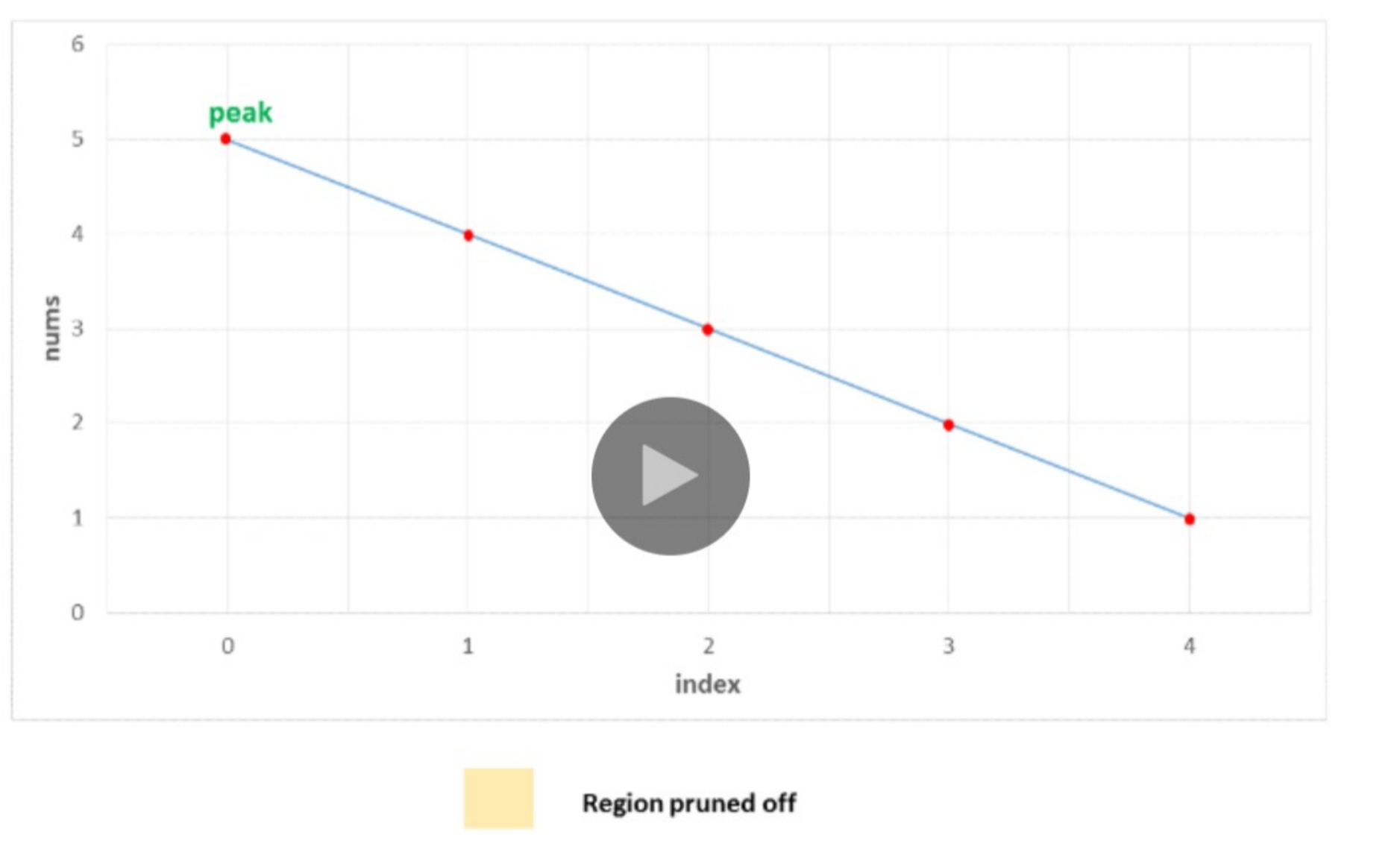
In case of simple Binary Search, we work on a sorted sequence of numbers and try to find out the required number by reducing the search space at every step. In this case, we use a modification of this simple Binary Search to our advantage. We start off by finding the middle element, mid from the given $nums$ array. If this element happens to be lying in a descending sequence of numbers. or a local falling slope(found by comparing $nums[i]$ to its right neighbour), it means that the peak will always lie towards the left of this element. Thus, we reduce the search space to the left of mid(including itself) and perform the same process on left subarray.

If the middle element, mid lies in an ascending sequence of numbers, or a rising slope(found by comparing $nums[i]$ to its right neighbour), it obviously implies that the peak lies towards the right of this element. Thus, we reduce the search space to the right of mid and perform the same process on the right subarray.

In this way, we keep on reducing the search space till we eventually reach a state where only one element is remaining in the search space. This single element is the peak element.

To see how it works, let's consider the three cases discussed above again.

Case 1. In this case, we firstly find 3 as the middle element. Since it lies on a falling slope, we reduce the search space to `[1, 2, 3]`. For this subarray, 2 happens to be the middle element, which again lies on a falling slope, reducing the search space to `[1, 2]`. Now, 1 acts as the middle element and it lies on a falling slope, reducing the search space to `[1]` only. Thus, 1 is returned as the peak correctly.



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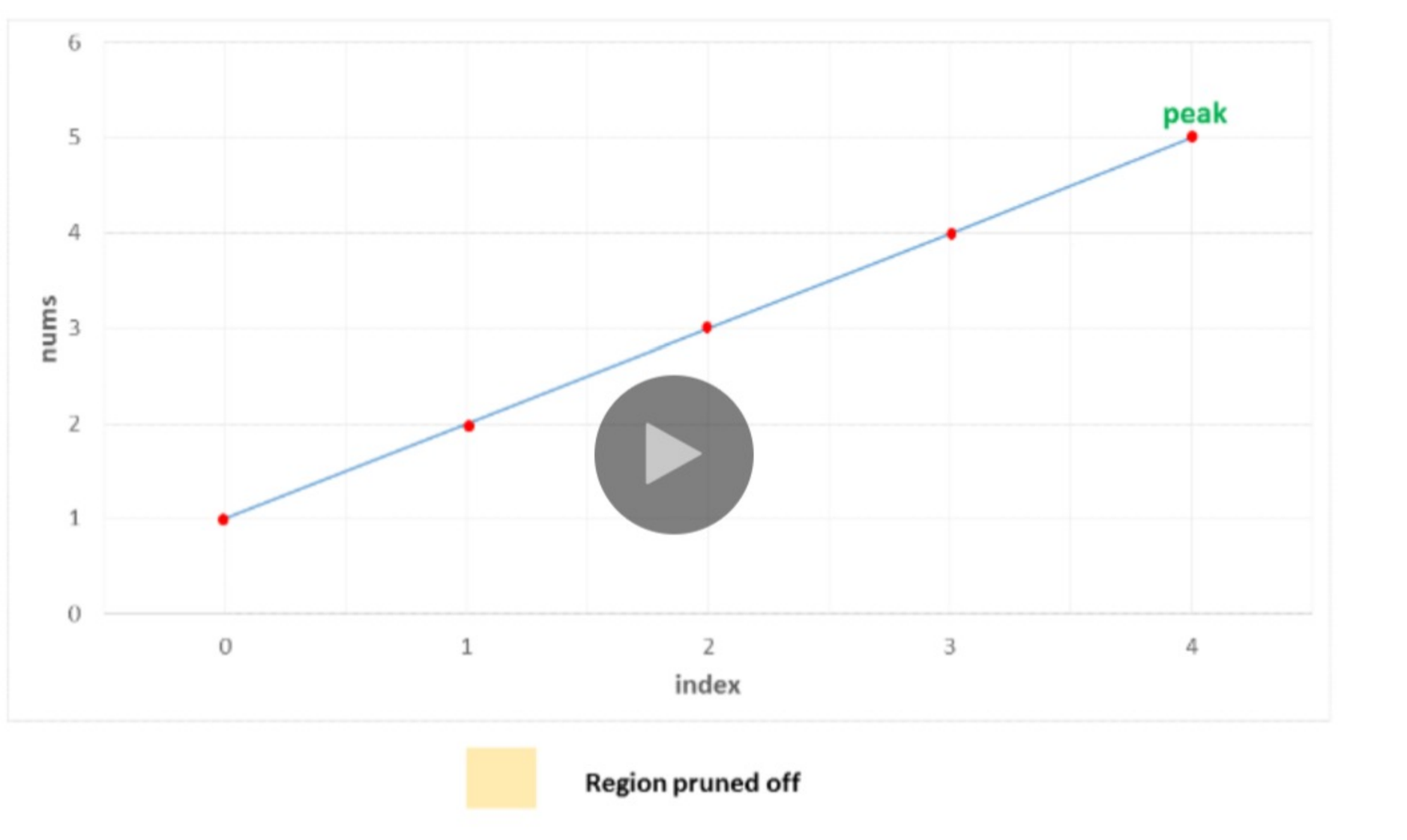
Case 2. In this case, we firstly find 3 as the middle element. Since it lies on a rising slope, we reduce the search space to `[4, 5]`. Now, 4 acts as the middle element for this subarray and it lies on a rising slope, reducing the search space to `[5]` only. Thus, 5 is returned as the peak correctly.



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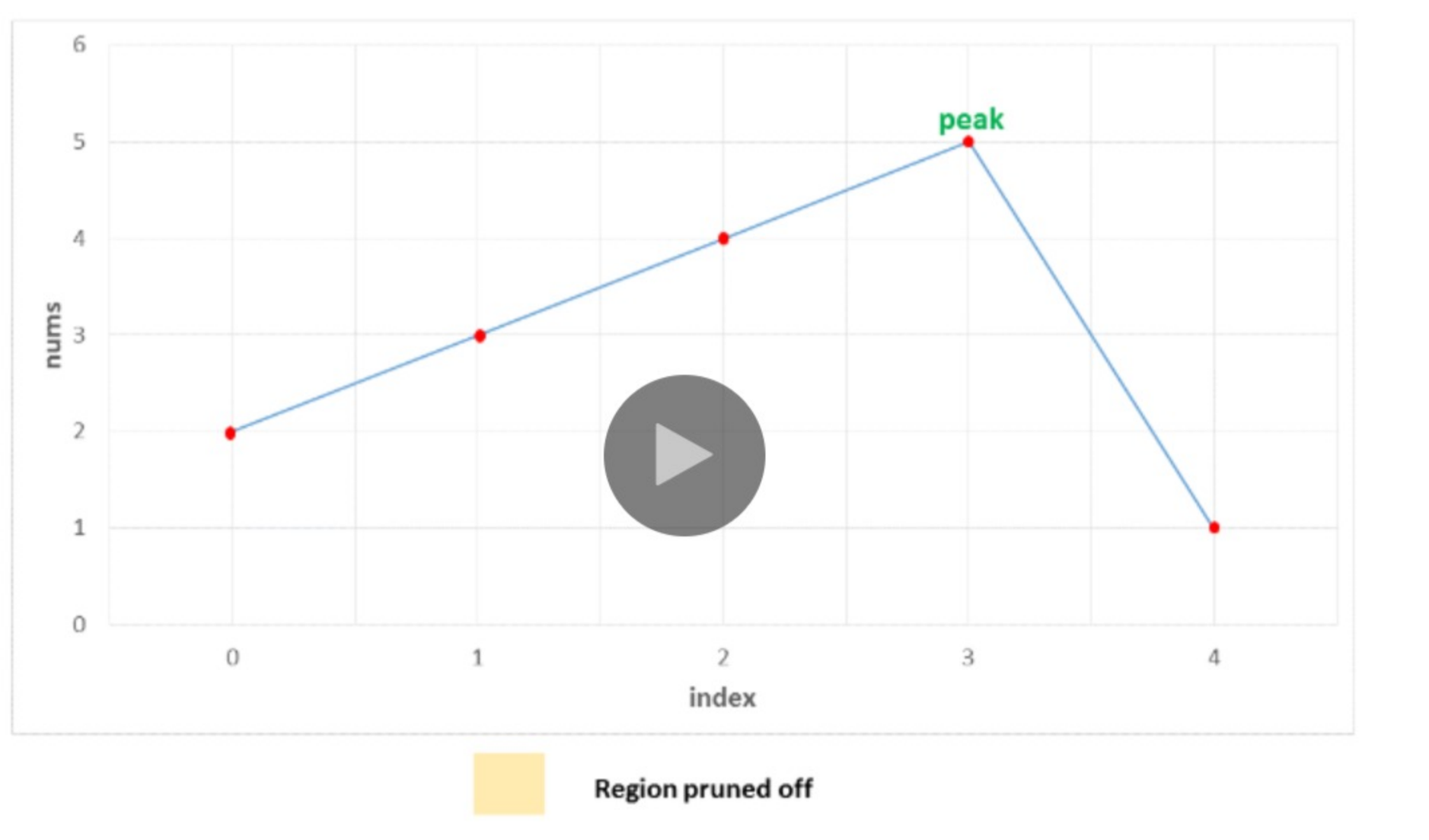
Case 3. In this case, the peak lies somewhere in the middle. The first middle element is 4. It lies on a rising slope, indicating that the peak lies towards its right. Thus, the search space is reduced to `[5, 1]`. Now, 5 happens to be the on a falling slope(relative to its right neighbour), reducing the search space to `[5]` only. Thus, 5 is identified as the peak element correctly.



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Java Copy

```java
public class Solution {
    public int findPeakElement(int[] nums) {
        return search(nums, 0, nums.length - 1);
    }
    public int search(int[] nums, int l, int r) {
        if (l == r)
            return l;
        int mid = (l + r) / 2;
        if (nums[mid] > nums[mid + 1])
            return search(nums, l, mid);
        return search(nums, mid + 1, r);
    }
}
```

Complexity Analysis

- Time complexity : $O\big(log_2(n)\big)$. We reduce the search space in half at every step. Thus, the total search space will be consumed in $log_2(n)$ steps. Here, n refers to the size of $nums$ array.
- Space complexity : $O\big(log_2(n)\big)$. We reduce the search space in half at every step. Thus, the total search space will be consumed in $log_2(n)$ steps. Thus, the depth of recursion tree will go upto $log_2(n)$.

Approach 3: Iterative Binary Search

Algorithm

The binary search discussed in the previous approach used a recursive method. We can do the same process in an iterative fashion also. This is done in the current approach.

Java Copy

```java
public class Solution {
    public int findPeakElement(int[] nums) {
        int l = 0, r = nums.length - 1;
        while (l < r) {
            int mid = (l + r) / 2;
            if (nums[mid] > nums[mid + 1])
                r = mid;
            else
                l = mid + 1;
        }
        return l;
    }
}
```

Complexity Analysis

- Time complexity : $O\big(log_2(n)\big)$. We reduce the search space in half at every step. Thus, the total search space will be consumed in $log_2(n)$ steps. Here, n refers to the size of $nums$ array.
- Space complexity : $O(1)$. Constant extra space is used.

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delta45724 ★165 January 14, 2019 10:45 AM
better provide a strict proof why Binary Search works here
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ygoOP ★187 July 9, 2018 6:47 PM
This line can integer overflow ```int mid = (l + r) / 2;
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akhil1311 ★177 July 25, 2019 6:10 PM
Nice solution. How do I get such solutions by myself in 30 minutes?
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xrssa ★1925 November 18, 2019 10:28 AM
Have a look at MIT 6006's 1st lecture on 'Algorithmic thinking and Peak Finding'(timestamp for divide and conquer strategy for peak finding : 27.40 min). You will understand the correctness of the algorithm(binary search in peak finding). Lecturer also showed the master theorem for this also.Never miss the 2D version of peak finding in the lecture.
https://www.youtube.com/watch?v=HtSuA80QTyo&list=PLUl4u3cNGP61Oq3tWYp6V_F-
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ddepaolo ★23 November 10, 2018 5:16 AM
The solution assumes the test cases are sorted already. However they are not. So I think it's just wrong.
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gary17 ★8 September 15, 2018 8:03 AM
The explanation is not intuitive for me, it can be super simple:
Instead of see looking for peak, try another word turn: it keeps going up, then it has to have a peak turn or reach to the end which by the definition is also what we are looking for.
The word peak is still ok, I was given "local maximum/local minimum", totally confused/mislead me.
8 Share Reply

rohitniyer ★6 March 24, 2018 4:42 PM
i guess binary search will not work for the case when we take an array nums[1,4,2,3,5,6,7,8,9,10] because if we calculate mid =(0+9)/2=4 and nums[4] is 5 and nums[4] is not greater than nums[5](that is 5 is not greater than 6) then it goes to the else condition and low becomes mid +1 that is 5. and our search range reduces by half. we could have have a possible solution at index 1 where the element 4 is greater than its neighbours.
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jasonz1121 ★11 September 4, 2018 6:14 AM
Looks like sol2 and 3 are not right. Test with case [1,2,1,1,1,1]
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quanhoang91 ★9 June 24, 2020 3:46 PM
Solution is wrong. Binary search solution always assume its either on left or right.
But thats not the case. E.g. input is [2,3,2,2,2,2,2,2,2], expected output is 7 where it should be 1
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Joseph_Zhao ★3 October 11, 2018 8:32 PM
Tested with case [1,200,3,4,5,6,7,8,9,10]. However, both sol2 and 3 returned 9...
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