



# You created a game that is more popular than Angry Birds.

Each round, players receive a score between 0 and 100, which you use to rank them from highest to lowest. So far you're using an algorithm that sorts in  $O(n \lg n)$  time, but players are complaining that their rankings aren't updated fast enough. You need a faster sorting algorithm.

Write a method that takes:

1. an array of `unsortedScores`
2. the `highestPossibleScore` in the game

and returns a sorted array of scores in less than  $O(n \lg n)$  time.

For example:

```
int[] unsortedScores = {37, 89, 41, 65, 91, 53};  
final int HIGHEST_POSSIBLE_SCORE = 100;  
  
int[] sortedScores = sortScores(unsortedScores, HIGHEST_POSSIBLE_SCORE);  
// sortedScores: [91, 89, 65, 53, 41, 37]
```

Java ▼

We're defining  $n$  as the number of `unsortedScores` because we're expecting the number of players to keep climbing.

And, we'll treat `highestPossibleScore` as a constant instead of factoring it into our big  $O$  time and space costs because the highest possible score isn't going to change. Even if we *do* redesign the game a little, the scores will stay around the same order of magnitude.

## Gotchas

**Multiple players can have the same score!** If 10 people got a score of 90, the number 90 should appear 10 times in our output array.

We can do this in  $O(n)$  time and space.

## Breakdown

$O(n \lg n)$  is the time to beat. Even if our array of scores were *already sorted* we'd have to do a full walk through the array to confirm that it was in fact fully sorted. So we have to spend *at least*  $O(n)$  time on our sorting method. If we're going to do better than  $O(n \lg n)$ , we're probably going to do exactly  $O(n)$ .

What are some common ways to get  $O(n)$  runtime?

One common way to get  $O(n)$  runtime is to use a greedy algorithm. But in this case we're not looking to just grab a specific value from our input set (e.g. the "largest" or the "greatest difference")—we're looking to reorder the whole set. That doesn't lend itself as well to a greedy approach.

Another common way to get  $O(n)$  runtime is to use counting. We can build an array `scoreCounts` where the indices represent scores and the values represent how many times the score appears. Once we have that, can we generate a sorted array of scores?

What if we did an in-order walk through `scoreCounts`. Each index represents a score and its value represents the count of appearances. So we can simply add the score to a new array `sortedScores` as many times as count of appearances.

## Solution

We use counting sort.

```
public static int[] sortScores(int[] unorderedScores, int highestPossibleScore) {  
  
    // array of 0s at indices 0..highestPossibleScore  
    int[] scoreCounts = new int[highestPossibleScore + 1];  
  
    // populate scoreCounts  
    for (int score : unorderedScores) {  
        scoreCounts[score]++;  
    }  
  
    // populate the final sorted array  
    int[] sortedScores = new int[unorderedScores.length];  
    int currentSortedIndex = 0;  
  
    // for each item in scoreCounts  
    for (int score = highestPossibleScore; score >= 0; score--) {  
        int count = scoreCounts[score];  
  
        // for the number of times the item occurs  
        for (int occurrence = 0; occurrence < count; occurrence++) {  
  
            // add it to the sorted array  
            sortedScores[currentSortedIndex] = score;  
            currentSortedIndex++;  
        }  
    }  
  
    return sortedScores;  
}
```

## Complexity

$O(n)$  time and  $O(n)$  space, where  $n$  is the number of scores.

**Wait, aren't we nesting two loops towards the bottom? So shouldn't it be  $O(n^2)$  time?** Notice *what those loops iterate over*. The *outer* loop runs once for each *unique* number in the array. The *inner* loop runs once for each *time that number occurred*.

So in essence we're just looping through the  $n$  numbers from our input array, except we're splitting it into two steps: (1) each unique number, and (2) each time that number appeared.

Here's another way to think about it: in each iteration of our two nested loops, we append one item to `sortedScores`. How many numbers end up in `sortedScores` in the end? Exactly how many were in our input array!  $n$ .

If we didn't treat `highestPossibleScore` as a constant, we could call it  $k$  and say we have  $O(n + k)$  time and  $O(n + k)$  space.

## Bonus

Note that by optimizing for time we ended up incurring some space cost! What if we were optimizing for space?

We chose to generate and return a separate, sorted array. Could we instead sort the array in place? Does this change the time complexity? The space complexity?

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