

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

You rank players in the game from highest to lowest score. 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 function that takes:

1. an array of `unsorted_scores`
2. the `highest_possible_score` in the game

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

For example:

```
unsorted_scores = [37, 89, 41, 65, 91, 53]
HIGHEST_POSSIBLE_SCORE = 100

sort_scores(unsorted_scores, HIGHEST_POSSIBLE_SCORE)
# returns [37, 41, 53, 65, 89, 91]
```

Ruby ▼

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

And we'll treat `highest_possible_score` 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 function. 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<sup>1</sup>. 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<sup>1</sup>. We can build an array `score_counts` 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 `score_counts`. Each index represents a score and its value represents the count of appearances. So we can simply add the score to a new array `sorted_scores` as many times as count of appearances.

## Solution

We use counting sort<sup>1</sup>.

```
def sort_scores(unsorted_scores, highest_possible_score)

  # array of 0s at indices 0..highest_possible_score
  score_counts = [0] * (highest_possible_score+1)

  # populate score_counts
  unsorted_scores.each do |score|
    score_counts[score] += 1
  end

  # populate the final sorted array
  sorted_scores = []

  # for each item in score_counts
  score_counts.each_with_index do |count, score|

    # for the number of times the item occurs
    (0...count).each do |time|

      # add it to the sorted array
      sorted_scores.push(score)
    end
  end

  return sorted_scores
end
```

## 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 `sorted_scores`. How many numbers end up in `sorted_scores` in the end? Exactly how many were in our input array!  $n!$

If we didn't treat `highest_possible_score` 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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