Sorting Algorithms in Java

Sorting data means arranging it in a certain order, often in an array-like data structure. You can use various ordering criteria, common ones being sorting numbers from least to greatest or vice-versa, or sorting strings lexicographically.

1. Bubble Sort :-

Explanation

Bubble sort works by swapping adjacent elements if they're not in the desired order. This process repeats from the beginning of the array until all elements are in order.

We know that all elements are in order when we manage to do the whole iteration without swapping at all - then all elements we compared were in the desired order with their adjacent elements, and by extension, the whole array.

Here are the steps for sorting an array of numbers from least to greatest:

- **4 2** 1 5 3: The first two elements are in the wrong order, so we swap them.
- 2 **4 1** 5 3: The second two elements are in the wrong order too, so we swap.
- 2 1 **4 5** 3: These two are in the right order, 4 < 5, so we leave them alone.
- 2 1 4 **5 3**: Another swap.
- 2 1 4 3 5: Here's the resulting array after one iteration.

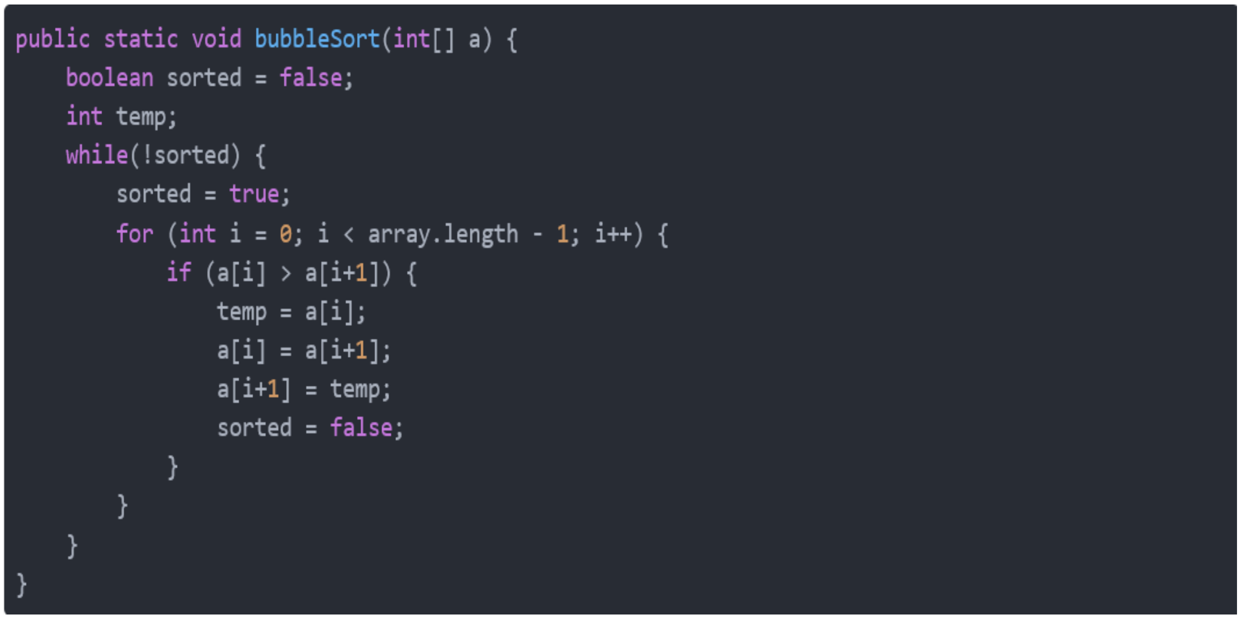
Because at least one swap occurred during the first pass (there were actually three), we need to go through the whole array again and repeat the same process.

By repeating this process, until no more swaps are made, we'll have a sorted array.

The reason this algorithm is called Bubble Sort is because the numbers kind of "bubble up" to the "surface." If you go through our example again, following a particular number (4 is a great example), you'll see it slowly moving to the right during the process.

Implementation

We assume the array is sorted, but if we're proven wrong while sorting (if a swap happens), we go through another iteration. The while-loop then keeps going until we manage to pass through the entire array without swapping:



```java
public static void bubbleSort(int[] a) {
    boolean sorted = false;
    int temp;
    while(!sorted) {
        sorted = true;
        for (int i = 0; i < array.length - 1; i++) {
            if (a[i] > a[i+1]) {
                temp = a[i];
                a[i] = a[i+1];
                a[i+1] = temp;
                sorted = false;
            }
        }
    }
}
```

When using this algorithm, we have to be careful how we state our swap condition.

For example, if I had used a[i] >= a[i+1] it could have ended up with an infinite loop, because for equal elements this relation would always be true, and hence always swap them.

2. Insertion Sort :-

Explanation

The idea behind Insertion Sort is dividing the array into the *sorted* and *unsorted* subarrays.

The sorted part is of length 1 at the beginning and is corresponding to the first (left-most) element in the array. We iterate through the array and during each iteration, we expand the sorted portion of the array by one element.

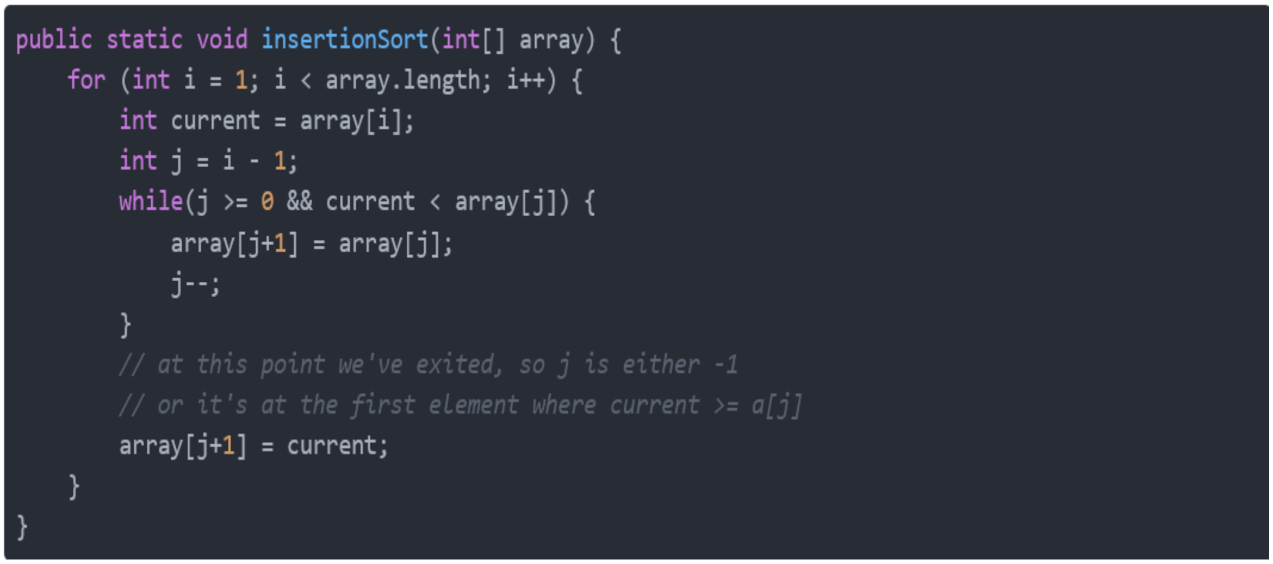
Upon expanding, we place the new element into its proper place within the sorted subarray. We do this by shifting all of the elements to the right until we encounter the first element we don't have to shift.

For example, if in the following array the bolded part is sorted in an ascending order, the following happens:

- **3 5 7 8** 4 2 1 9 6: We take 4 and remember that that's what we need to insert. Since 8 > 4, we shift.
- **3 5 7 x 8** 2 1 9 6: Where the value of x is not of crucial importance, since it will be overwritten immediately (either by 4 if it's its appropriate place or by 7 if we shift). Since 7 > 4, we shift.
- **3 5 x 7 8** 2 1 9 6
- **3 x 5 7 8** 2 1 9 6
- **3 4 5 7 8** 2 1 9 6

After this process, the sorted portion was expanded by one element, we now have five rather than four elements. Each iteration does this and by the end we'll have the whole array sorted.

Implementation



```
public static void insertionSort(int[] array) {
    for (int i = 1; i < array.length; i++) {
        int current = array[i];
        int j = i - 1;
        while(j >= 0 && current < array[j]) {
            array[j+1] = array[j];
            j--;
        }
        // at this point we've exited, so j is either -1
        // or it's at the first element where current >= a[j]
        array[j+1] = current;
    }
}
```

3. Selection Sort :-

Explanation

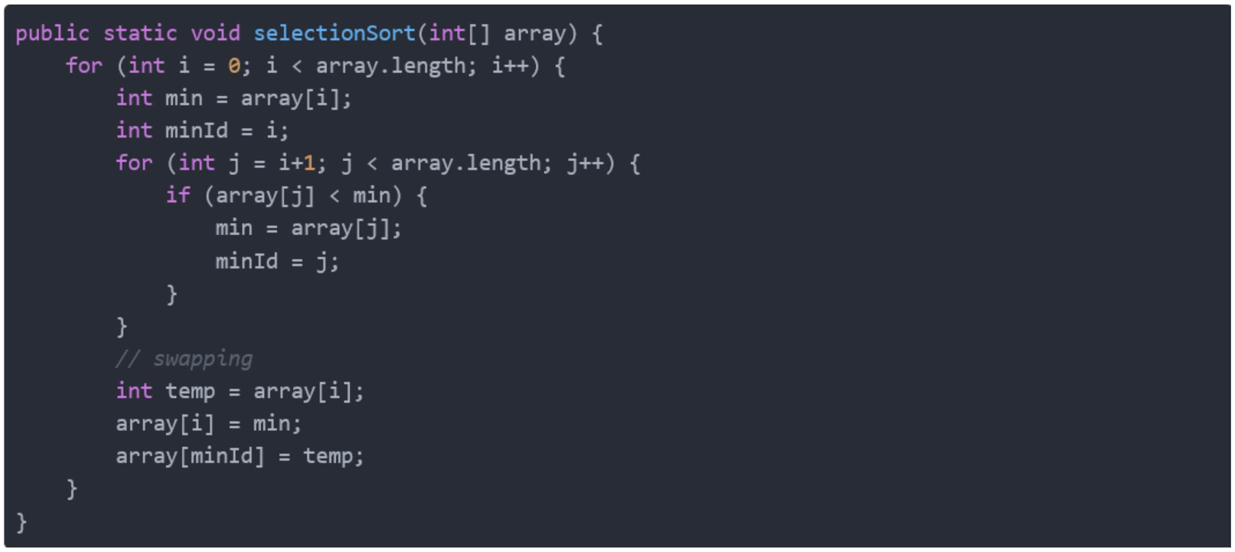
Selection Sort also divides the array into a sorted and unsorted subarray. Though, this time, the sorted subarray is formed by inserting the minimum element of the unsorted subarray at the end of the sorted array, by swapping:

- 3 5 *1* 2 4
- **1** 5 3 *2* 4
- **1 2** *3* 5 4
- **1 2 3** 5 *4*
- **1 2 3 4** *5*
- **1 2 3 4 5**

Implementation

In each iteration, we assume that the first unsorted element is the minimum and iterate through the rest to see if there's a smaller element.

Once we find the current minimum of the unsorted part of the array, we swap it with the first element and consider it a part of the sorted array:



```java
public static void selectionSort(int[] array) {
    for (int i = 0; i < array.length; i++) {
        int min = array[i];
        int minId = i;
        for (int j = i+1; j < array.length; j++) {
            if (array[j] < min) {
                min = array[j];
                minId = j;
            }
        }
        // swapping
        int temp = array[i];
        array[i] = min;
        array[minId] = temp;
    }
}
```

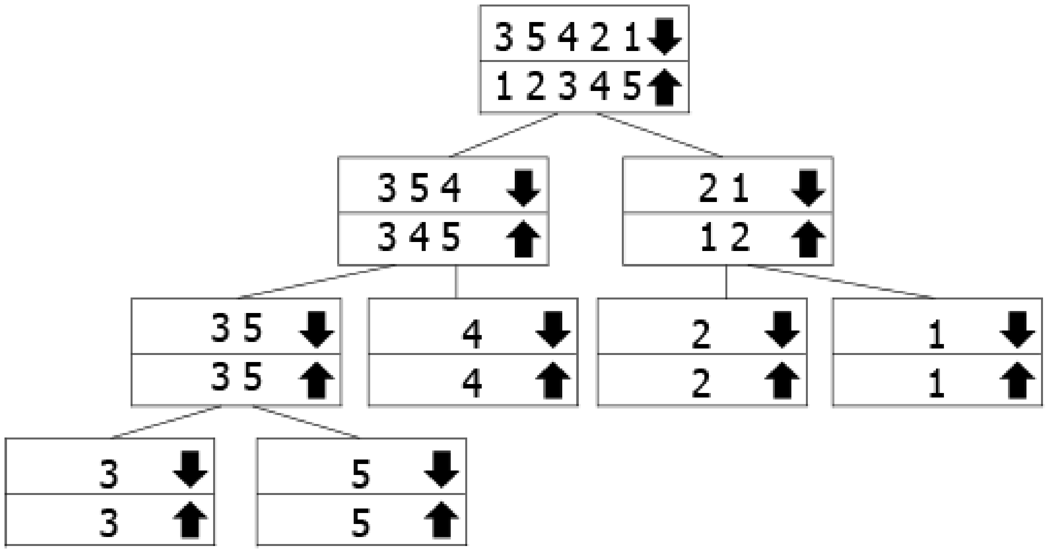
4. Merge Sort :-

Explanation

Merge Sort uses recursion to solve the problem of sorting more efficiently than algorithms previously presented, and in particular it uses a divide and conquer approach.

Using both of these concepts, we'll break the whole array down into two subarrays and then:

1. Sort the left half of the array (recursively)
2. Sort the right half of the array (recursively)
3. Merge the solutions



This tree is meant to represent how the recursive calls work. The arrays marked with the down arrow are the ones we call the function for, while we're merging the up-arrow ones going back up. So, you follow the down arrow to the bottom of the tree, and then go back up and merge.

In our example, we have the array 3 5 3 2 1, so we divide it into 3 5 4 and 2 1. To sort them, we further divide them into their components. Once we've reached the bottom, we start merging up and sorting them as we go.

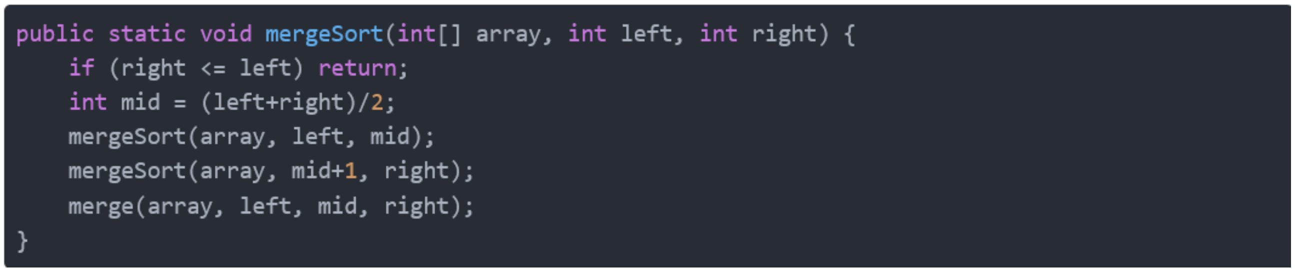
Implementation

The core function works pretty much as laid out in the explanation. We're just passing indexes left and right which are indexes of the left-most and right-most element of the subarray we want to sort. Initially, these should be 0 and array.length-1, depending on implementation.

The base of our recursion ensures we exit when we've finished, or when right and left meet each other. We find a midpoint mid, and sort subarrays left and right of it recursively, ultimately merging our solutions.

If you remember our tree graphic, you might wonder why don't we create two new smaller arrays and pass them on instead. This is because on really long arrays, this would cause huge memory consumption for something that's essentially unnecessary.

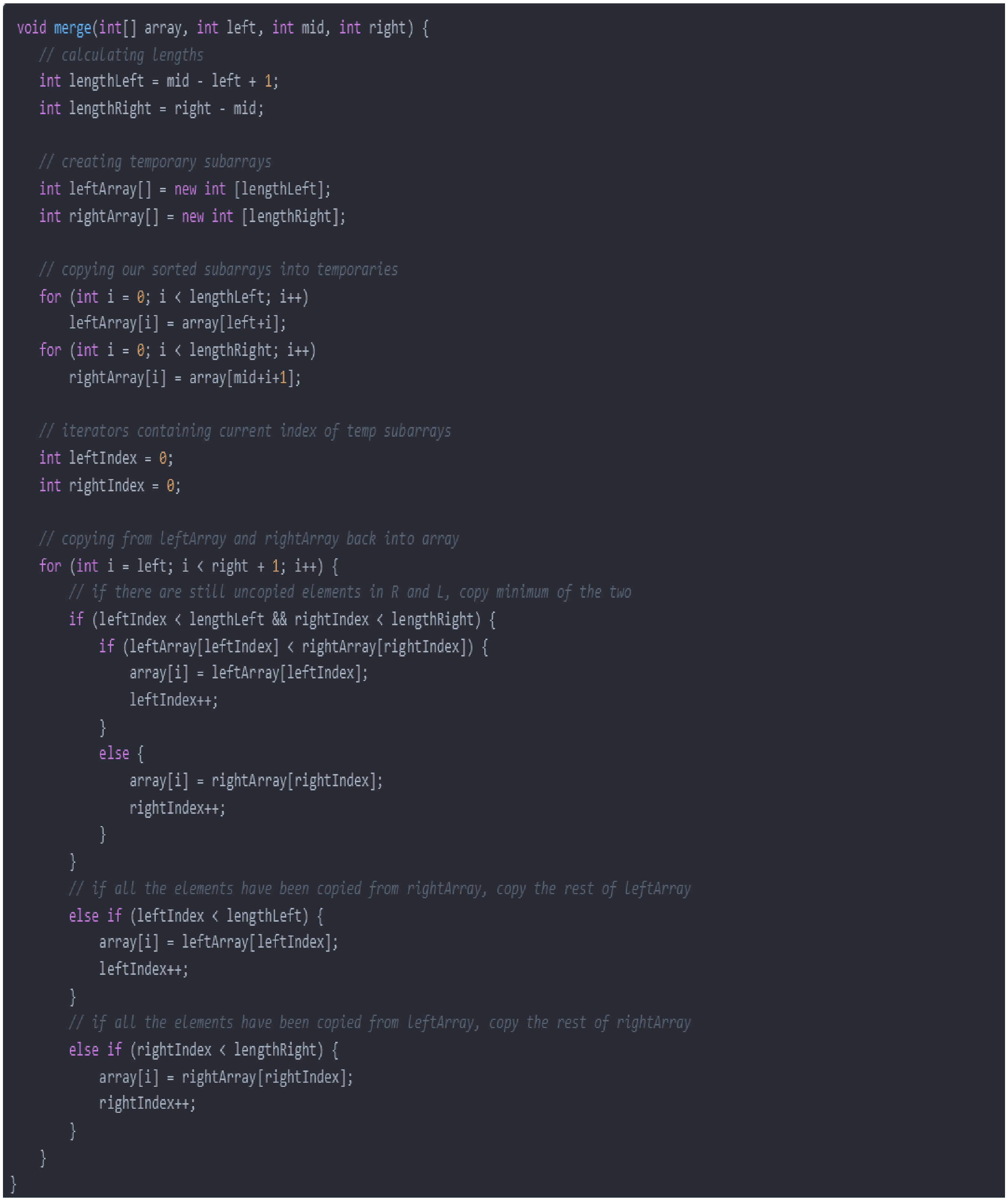
Merge Sort already doesn't work in-place because of the merge step, and this would only serve to worsen its memory efficiency. The logic of our tree of recursion otherwise stays the same, though, we just have to follow the indexes we're using:



```java
public static void mergeSort(int[] array, int left, int right) {
    if (right <= left) return;
    int mid = (left+right)/2;
    mergeSort(array, left, mid);
    mergeSort(array, mid+1, right);
    merge(array, left, mid, right);
}
```

To merge the sorted subarrays into one, we'll need to calculate the length of each and make temporary arrays to copy them into, so we could freely change our main array.

After copying, we go through the resulting array and assign it the current minimum. Because our subarrays are sorted, we just chose the lesser of the two elements that haven't been chosen so far, and move the iterator for that subarray forward:



```java
void merge(int[] array, int left, int mid, int right) {
    // calculating lengths
    int lengthLeft = mid - left + 1;
    int lengthRight = right - mid;

    // creating temporary subarrays
    int leftArray[] = new int [lengthLeft];
    int rightArray[] = new int [lengthRight];

    // copying our sorted subarrays into temporaries
    for (int i = 0; i < lengthLeft; i++)
        leftArray[i] = array[left+i];
    for (int i = 0; i < lengthRight; i++)
        rightArray[i] = array[mid+i+1];

    // iterators containing current index of temp subarrays
    int leftIndex = 0;
    int rightIndex = 0;

    // copying from leftArray and rightArray back into array
    for (int i = left; i < right + 1; i++) {
        // if there are still uncopied elements in R and L, copy minimum of the two
        if (leftIndex < lengthLeft && rightIndex < lengthRight) {
            if (leftArray[leftIndex] < rightArray[rightIndex]) {
                array[i] = leftArray[leftIndex];
                leftIndex++;
            }
            else {
                array[i] = rightArray[rightIndex];
                rightIndex++;
            }
        }
        // if all the elements have been copied from rightArray, copy the rest of leftArray
        else if (leftIndex < lengthLeft) {
            array[i] = leftArray[leftIndex];
            leftIndex++;
        }
        // if all the elements have been copied from leftArray, copy the rest of rightArray
        else if (rightIndex < lengthRight) {
            array[i] = rightArray[rightIndex];
            rightIndex++;
        }
    }
}
```

5. Heapsort :-

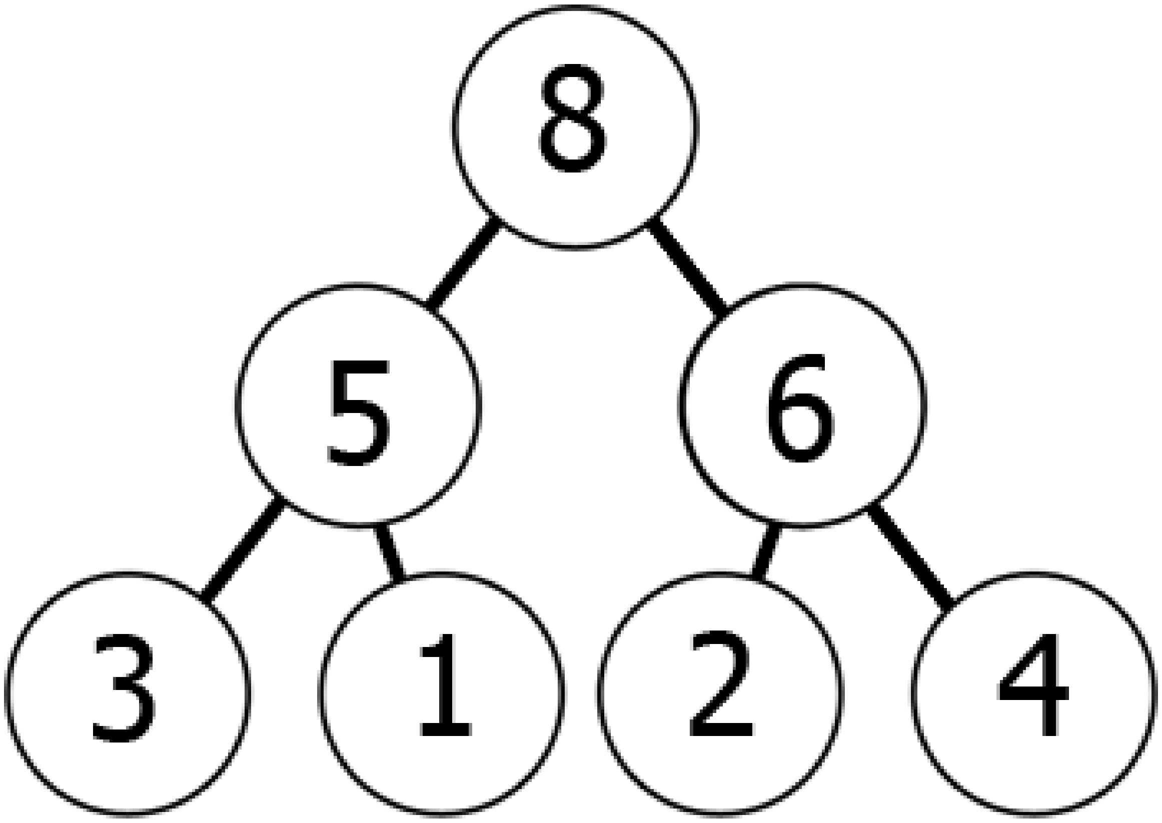
Explanation

To properly understand why Heapsort works, you must first understand the structure it's based on - *the heap*. We'll be talking in terms of a binary heap specifically, but you can generalize most of this to other heap structures as well.

A heap is a tree that satisfies the heap property, which is that for each node, all of its children are in a given relation to it. Additionally, a heap must be almost complete. An almost complete binary tree of depth d has a subtree of depth d-1 with the same root that is complete, and in which each node with a left descendent has a complete left subtree. In other words, when adding a node, we always go for the leftmost position in the highest incomplete level.

If the heap is a *max-heap*, then all of the children are smaller than the parent, and if it's a *min-heap* all of them are larger.

In other words, as you move down the tree, you get to smaller and smaller numbers (min-heap) or greater and greater numbers (max-heap). Here's an example of a max-heap:



We can represent this max-heap in memory as an array in the following way:

8 5 6 3 1 2 4

You can envision it as reading from the graph level by level, left to right. What we have achieved by this is that if we take the kth element in the array, its children's positions are 2*k+1 and 2*k+2 (assuming the indexing starts at 0). You can check this for yourself.

Conversely, for the kth element the parent's position is always (k-1)/2.

Knowing this, you can easily *"max-heapify"* any given array. For each element, check if any of its children are smaller than it. If they are, swap one of them with the parent, and recursively repeat this step with the parent (because the new large element might still be bigger than its other child).

Leaves have no children, so they're trivially *max-heaps* of their own:

- 6 1 *8* 3 5 **2 4**: Both children are smaller than the parent, so everything stays the same.
- 6 *1* 8 **3 5** 2 4: Because 5 > 1, we swap them. We recursively heapify for 5 now.
- 6 *5* 8 **3 1** 2 4: Both of the children are smaller, so nothing happens.
- *6* **5 8** 3 1 2 4: Because 8 > 6, we swap them.
- 8 5 6 3 1 2 4: We got the heap pictured above!

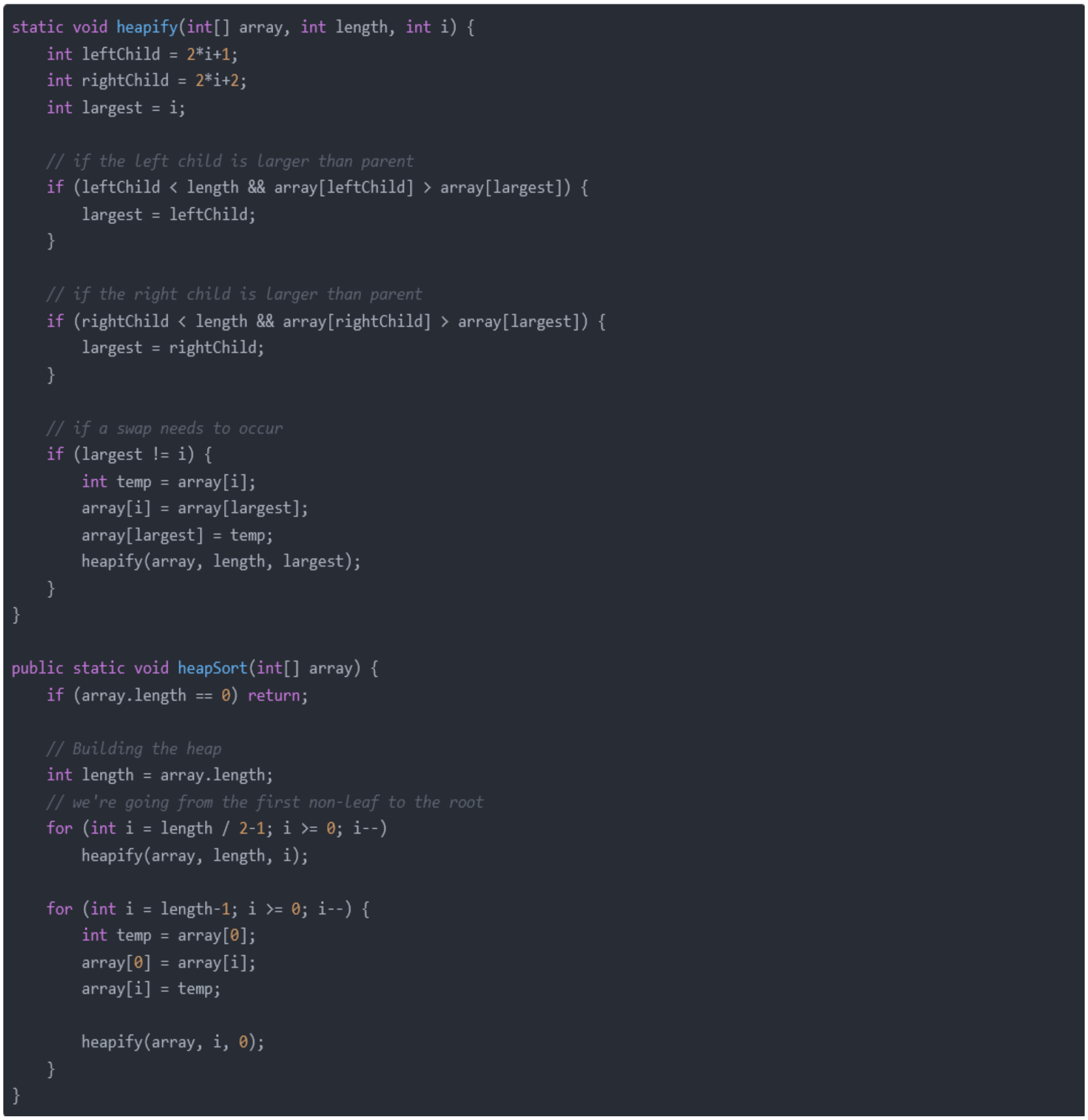
Once we've learned to heapify an array the rest is pretty simple. We swap the root of the heap with the end of the array, and shorten the array by one.

We heapify the shortened array again, and repeat the process:

- *8* 5 6 3 1 2 *4*
- *4* 5 6 3 1 2 **8**: swapped
- *6* 5 4 3 1 *2* **8**: heapified
- 2 5 4 3 1 **6 8**: swapped
- *5* 2 4 2 *1* **6 8**: heapified
- 1 2 4 2 **5 6 8**: swapped

And so on, I'm sure you can see the pattern emerging.

Implementation



```java
static void heapify(int[] array, int length, int i) {
    int leftChild = 2*i+1;
    int rightChild = 2*i+2;
    int largest = i;

    // if the left child is larger than parent
    if (leftChild < length && array[leftChild] > array[largest]) {
        largest = leftChild;
    }

    // if the right child is larger than parent
    if (rightChild < length && array[rightChild] > array[largest]) {
        largest = rightChild;
    }

    // if a swap needs to occur
    if (largest != i) {
        int temp = array[i];
        array[i] = array[largest];
        array[largest] = temp;
        heapify(array, length, largest);
    }
}

public static void heapSort(int[] array) {
    if (array.length == 0) return;

    // Building the heap
    int length = array.length;
    // we're going from the first non-leaf to the root
    for (int i = length / 2-1; i >= 0; i--)
        heapify(array, length, i);

    for (int i = length-1; i >= 0; i--) {
        int temp = array[0];
        array[0] = array[i];
        array[i] = temp;

        heapify(array, i, 0);
    }
}
```

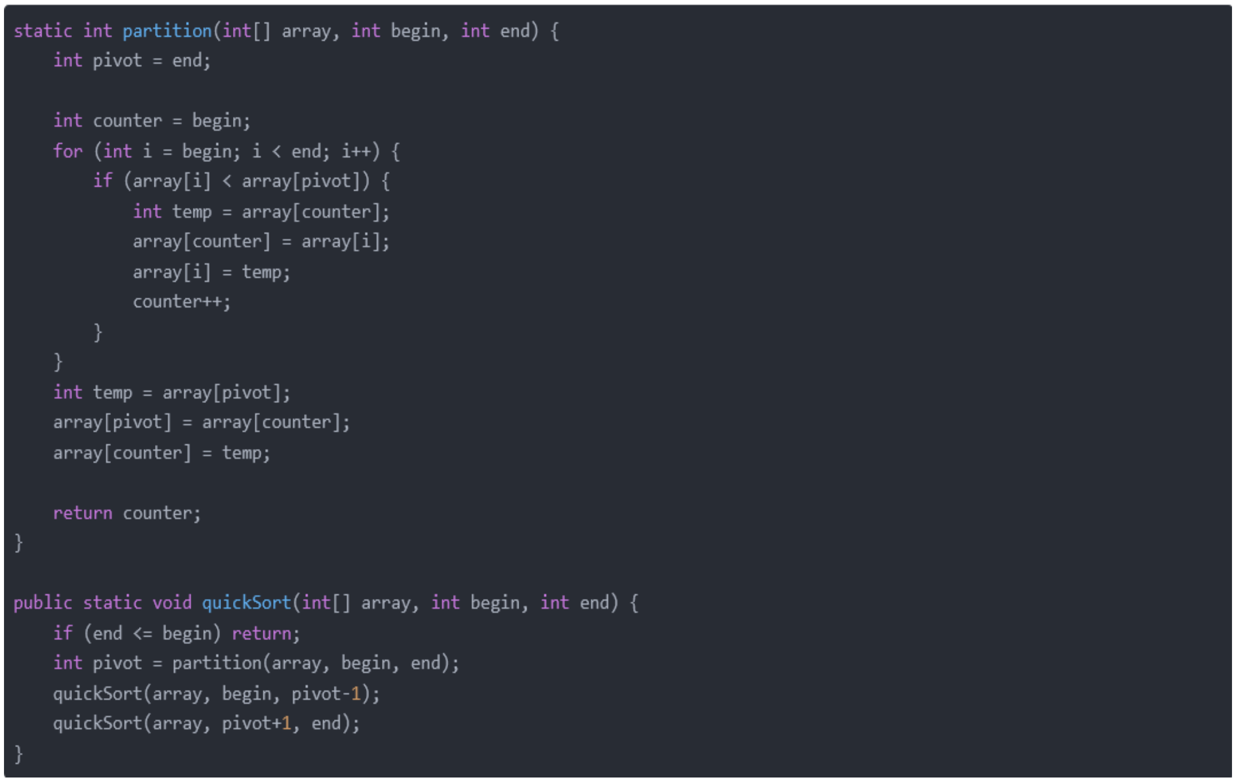
6. Quicksort :-

Explanation

Quicksort is another Divide and Conquer algorithm. It picks one element of an array as the pivot and sorts all of the other elements around it, for example smaller elements to the left, and larger to the right.

This guarantees that the pivot is in its proper place after the process. Then the algorithm recursively does the same for the left and right portions of the array.

Implementation



```
static int partition(int[] array, int begin, int end) {
    int pivot = end;

    int counter = begin;
    for (int i = begin; i < end; i++) {
        if (array[i] < array[pivot]) {
            int temp = array[counter];
            array[counter] = array[i];
            array[i] = temp;
            counter++;
        }
    }
    int temp = array[pivot];
    array[pivot] = array[counter];
    array[counter] = temp;

    return counter;
}

public static void quickSort(int[] array, int begin, int end) {
    if (end <= begin) return;
    int pivot = partition(array, begin, end);
    quickSort(array, begin, pivot-1);
    quickSort(array, pivot+1, end);
}
```

Performance Comparison :-

time(ns)	Bubble Sort	Insertion Sort	Selection Sort	MergeSort	HeapSort	QuickSort
First Run	266,089,476	21,973,989	66,603,076	5,511,069	5,283,411	4,156,005
Second Run	323,692,591	29,138,068	80,963,267	8,075,023	6,420,768	7,060,203
Third Run	303,853,052	21,380,896	91,810,620	7,765,258	8,009,711	7,622,817
Fourth Run	410,171,593	30,995,411	96,545,412	6,560,722	5,837,317	2,358,377
Fifth Run	315,602,328	26,119,110	95,742,699	5,471,260	14,629,836	3,331,834
Sixth Run	286,841,514	26,789,954	90,266,152	9,898,465	4,671,969	4,401,080
Seventh Run	384,841,823	18,979,289	72,569,462	5,135,060	10,348,805	4,982,666
Eight Run	393,849,249	34,476,528	107,951,645	8,436,103	10,142,295	13,678,772
Ninth Run	306,140,830	57,831,705	138,244,799	5,154,343	5,654,133	4,663,260
Tenth Run	306,686,339	34,594,400	89,442,602	5,601,573	4,675,390	3,148,027

We can evidently see that Bubble Sort is the *worst* when it comes to performance. Avoid using it in production if you can't guarantee that it'll handle only small collections and it won't stall the application.

HeapSort and QuickSort are the best performance-wise. Although they're outputting similar results, QuickSort tends to be a bit better and more consistent