L14: Sorting

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CompSci 201: Spring 2024

2/28/2024: LEAP DAY EVE

Announcements, Coming up

- Today, Wednesday 2/28
  - APT 5 (linked list problems) due
- Next Monday 3/4
  - Project P3: DNA (linked list project) due
- Next Wednesday 3/6
  - APT 6 (sorting problems) due
- Then…Spring Break!

Today's outline

1. Announce Midsemester Survey
    1. Invaluable for staff, especially UTAs ⇒ for you!
    2. Look for Canvas announcement from Violet

2. Sorting in Java: Comparing objects with **`Comparable`** and **`Comparator`**

3. Efficient sorting algorithms
    1. Insertion sort
    2. Recursive Mergesort

Sorting in Java: Comparable, Comparator

Sorting w/ Java.util: Put elements of Array/List in non-decreasing order

- **Arrays.sort** / **Collections.sort** are void – they sort the array/list passed as an argument.
- Default order is non-decreasing (least to greatest).

```
67      int[] elements = {5, 3, 9, 2, 4, 1};
68      Arrays.sort(elements);
69      System.out.println(Arrays.toString(elements));
```

- Prints [1, 2, 3, 4, 5, 9]

Java API Sort Algorithms

- `Collections.sort` (for a List)
- `Arrays.sort` (for an Array)

- Both O(N log(N)), ***nearly linear*** runtime complexity.
- Sorts in-place, mutates the input rather than return a new List/Array.
- *Stable*, does not reorder elements if not needed (e.g., if two elements are equal).

What can be compared and sorted in Java?

- Objects of a Class that implements `Comparable` interface. Has a **`naturalOrder`**.
- Requires implementing a **`.compareTo()`** method

Should return an int:

- < 0 if **`this`** comes before the parameter.
- 0 if **`this`** and the parameter are equal.
- > 0 if **`this`** comes after the parameter.

```
private static class Person implements Comparable<Person> {
    String first;
    String last;
    public Person(String s) {...}
    public String getLast() { return last; }
    public String getFirst() { return first; }
    public String toString() { return first + " " + last; }
    @Override
    public int compareTo(Person p){
        int diff = last.compareTo(p.last);
        if (diff != 0) return diff;
        return first.compareTo(p.first);
    }
}
```

Strings are Comparable

- What is the equivalent of < for Strings?
- Use the **`compareTo`** method for the natural lexicographic (dictionary/sorted) ordering.

```
jshell> "a".compareTo("b");
$30 ==> -1

jshell> "b".compareTo("b");
$31 ==> 0

jshell> "b".compareTo("a");
$32 ==> 1

jshell> "az".compareTo("cb");
$37 ==> -2
```

Negative for “less than”

Zero for “equal”

Positive for “less than”

Lexicographic, check first character, second if equal, third if still equal, …

Sorting `Comparable` objects by `naturalOrder`

`[sloth, house, owl, ant, mice, kelp]`

```
String[] a = {"sloth", "house", "owl", "ant", "mice", "kelp"};
System.out.println(Arrays.toString(a));

String[] copy = Arrays.copyOf(a, a.length);
Arrays.sort(copy);
System.out.println(Arrays.toString(copy));
```

`[ant, house, kelp, mice, owl, sloth]`

- `naturalOrder` for Strings is lexicographic (alphabetical or dictionary order)

Comparable for other classes?

All Blob comparing code available here

- Can implement **`Comparable`** interface when defining your own class.

```
3   public class Blob implements Comparable<Blob> {
4       String name;
5       String color;
6       int size;
```

- Must implement a **`compareTo`** method

```
14      @Override
15      public int compareTo(Blob other) {
16          return this.name.compareTo(other.name);
17      }
```

Compares blobs by their names

Sorting Comparable Objects

- Running code in a main method…

```
40        System.out.println(myBlobs);
```

Original: [(bo, blue, 4), (al, red, 2), (cj, green, 1), (di, red, 4)]

```
42        Collections.sort(myBlobs);
43        System.out.println(myBlobs);
```

Sorted: [(al, red, 2), (bo, blue, 4), (cj, green, 1), (di, red, 4)]

- Formal guarantee: Element **`e1`** will come before **`e2`** (after sorting) if **`e1.compareTo(e2) < 0`**.

Defining a Comparator

- What if…
  - The class doesn't implement Comparable?
  - Or you want to sort a different way?

- Create a helper class that implements the `Comparator` interface.
  - One method: `compare`: indicates how to compare two objects

- Then pass a Comparator object to your call to sort.

Defining a `Comparator<Blob>`

```
1   import java.util.Comparator;
```

Separate class:

- implements Comparator<TypeToCompare>,
- and implements a single method compare

```
 8   public class BlobComparator implements Comparator<Blob> {
 9       @Override
10       public int compare(Blob a, Blob b) {
11           int sizeDiff = a.size - b.size;
12           if (sizeDiff != 0) {
13               return (-1) * sizeDiff;
14           }
15           return a.compareTo(b);
16       }
17   }
```

Takes 2 parameters, Should return:

- < 0 if a comes before b,
- > 0 if a comes after b,
- 0 if equal in order

Flipping the sign reverses the comparison, large to small

Breaking ties by the natural order

Sorting with a Comparator

- Running code in a main method…

```
40        System.out.println(myBlobs);
```

Original: [(bo, blue, 4), (al, red, 2), (cj, green, 1), (di, red, 4)]

Create a `BlobComparator` object, pass it to the sort.

```
48      Collections.sort(myBlobs, new BlobComparator());
49      System.out.printf(format: "%s\n\n", myBlobs);
```

Sorted: [(bo, blue, 4), (di, red, 4), (al, red, 2), (cj, green, 1)]

- Element `e1` will come before `e2` (after sorting) if `compare(e1, e2) < 0`.

Private Inner Comparator

- Can define a Comparator class as a private inner class if only used inside the class.
- Useful for APTs, here is an example:

SimpleSort APT

Problem Statement

Sometimes sorting helps in recognizing patterns. Given an array of strings, write the method `recognize` that returns an array of the same strings, but sorted by length with the shortest strings first and the longest strings last in the returned array. You can create a new array or sort the array parameter `value`, but you must return a sorted array containing the same strings that are in `values`.

In the returned array, strings that are the same length should be sorted in alphabetical order. See the examples for details.

Class

```
public class LengthSort {
    public String[] rearrange(String[] values){
        // you write code here and replace statement below
        return null;
    }
}
```

Private Inner Comparator

- Can define a Comparator class as a private inner class if only used inside the class.
- Useful for APTs, here is an example:

- Given `String[] values`:
  - Sort first in ***non-decreasing order of length***,
  - then sort same-length in ***alphabetical order***.

- [“a”, “b”, “c”, “an”, “be”, “pi”, “test”, “quiz”]

Template for Solving LengthSort with a Private Inner Comparator

Can see this code here

```
1   import java.util.Arrays;
2   import java.util.Comparator;
3
4   public class LengthSort {
5       private class LengthSortComp implements Comparator<String> {
6           @Override
7           public int compare(String a, String b) {
8               // Need to modify this to solve the problem
9               return a.compareTo(b);
10          }
11      }
12
13      public String[] rearrange(String[] values){
14          Arrays.sort(values, new LengthSortComp());
15          return values;
16      }
17  }
```

`Comparable` vs. `Comparator`

- `Comparable a`: use `a.compareTo(b)`
  - What is method signature? One parameter
  - Method in class of which object `a` is an instance
  - `a` is `this`, `b` is a parameter
- `Comparator c`, use `c.compare(a,b)`
  - Method has two parameters
  - Part of `Comparator` (Java API link)
- Both return an int:
    - < 0 (means `a` comes before `b`)
    - == 0 (means `a` equals `b`)
    - > 0 (means `a` comes after `b`)

Runtime Complexity of Sort and Comparator?

- `Arrays.sort`, `Collections.sort`, call either `compareTo` (default) or `compare` (if you give a `Comparator`)…

- O(N log(N)) `compareTo/compares`, on an Array/List of N elements.

- Exists theoretical proof that this many comparisons is ***necessary*** for any comparison-based sorting.

When is comparing once not constant time?

```
4   public class ListComp implements Comparator<List<Integer>> {
5       @Override
6       public int compare(List<Integer> list1, List<Integer> list2) {
7           int minLength = Math.min(list1.size(), list2.size());
8           for (int i=0; i<minLength; i++) {
9               int diff = list1.get(i) - list2.get(i);
10              if (diff != 0) {
11                  return diff;
12              }
13          }
14          return 0;
15      }
16  }
```

Runtime complexity of this Comparator may depend on the length of the two Lists being compared.

Overall runtime complexity to sort N **`ArrayList`**s, each with M elements, is O(MN log(N)) in the worst case with this **`Comparator`**.

java.util.Comparator: Convenient Shorthands

- `Comparator.naturalOrder` and `reversed()`

```
jshell> Comparator<String> c = Comparator.naturalOrder()
c ==> INSTANCE

jshell> c.compare("a","b")
$12 ==> -1

jshell> c.reversed().compare("a","b")
$13 ==> 1
```

Must be `Comparable`

- `Comparator.comparing`

```
jshell> Comparator<String> c = Comparator.comparing(String::length)
c ==> java.util.Comparator$$Lambda$27/0x0000000800b97c[illegible]@2b71fc7e

jshell> c.compare("this", "is")
$15 ==> 1

jshell> c.compare("is", "it")
$16 ==> 0
```

Syntax is: `<Type>::<method name>` to sort something of the Type by the result of some getter method that returns something Comparable.

`Comparator`-generating shorthands

`[sloth, house, owl, ant, mice, kelp]`

```
copy = Arrays.copyOf(a, a.length);
Arrays.sort(copy, Comparator.comparing(String::length));
System.out.println(Arrays.toString(copy));
```

`[owl, ant, mice, kelp, sloth, house]`

- Why does "owl" come before "ant"?
  - Stable sort respects order of equal keys

Using `.thenComparing` shorthand

`[sloth, house, owl, ant, mice, kelp]`

```
Arrays.sort(copy, Comparator.
                      comparing(String::length).
                          thenComparing(Comparator.naturalOrder()));
```

`[ant, owl, kelp, mice, house, sloth]`

- First compare by length
  - if same? Compare naturally

Comparator with “lambdas”

- Can also define a comparator with a ***“lambda expression.”***

```
Integer[] nums = {2, 0, 1};

Comparator<Integer> comp = (a, b) -> (b-a);
```

Type we want to compare

Given an **a** and a **b** of that type…

`comp.compare(a,b)` should return this expression

```
Arrays.sort(nums, comp);
```

nums is now { 2, 1, 0 }

What is printed by the following line of code?

```
System.out.println("duke".compareTo("devils"));
```

- true
- false
- an integer less than 0
- 0
✓- an integer greater than 0

After sorting, ar will be...

```
String[] ar = {"bird", "dog", "cat", "snake"};
Comparator<String> comp = Comparator.comparing(String::length);
Arrays.sort(ar, comp);
```

Ans: [dog, cat, bird, snake]

Suppose you have the following list of lists of integers:

[[2, 0, 1], [1, 0, 1], [1, 6]]. After sorting, the list would be ordered as…

```
4   public class ListComp implements Comparator<List<Integer>> {
5       @Override
6       public int compare(List<Integer> list1, List<Integer> list2) {
7           int minLength = Math.min(list1.size(), list2.size());
8           for (int i=0; i<minLength; i++) {
9               int diff = list1.get(i) - list2.get(i);
10              if (diff != 0) {
11                  return diff;
12              }
13          }
14          return 0;
15      }
16  }
```

Ans: [[1, 0, 1], [1, 6], [2, 0, 1]]

Suppose you have an **ArrayList** myLists of N **ArrayLists**, each of size at most M. The worst-case runtime complexity to compare any two elements of myLists would be….

```
4   public class ListComp implements Comparator<List<Integer>> {
5       @Override
6       public int compare(List<Integer> list1, List<Integer> list2) {
7           int minLength = Math.min(list1.size(), list2.size());
8           for (int i=0; i<minLength; i++) {
9               int diff = list1.get(i) - list2.get(i);
10              if (diff != 0) {
11                  return diff;
12              }
13          }
14          return 0;
15      }
16  }
```

Ans: O(M)

Given an Array of N Strings, each of length at most M, the worst case runtime complexity to sort the Array with java.util.Arrays.sort is..

Ans: O(M N log N)

Efficient sorting algorithms

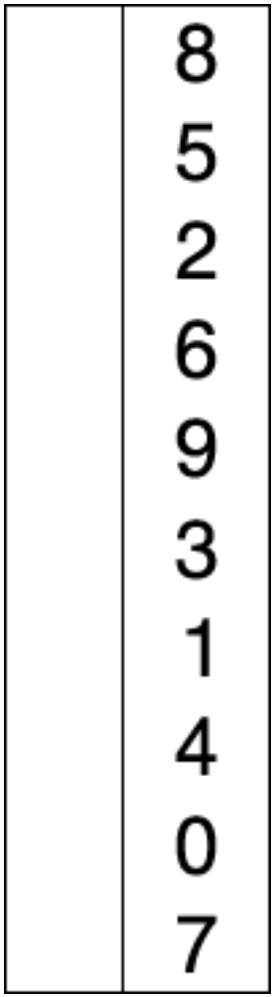
See example implementations here

Selection Sort with a Loop Invariant

- Loop invariant: On iteration `i`, the first `i` elements are the smallest `i` elements in sorted order.

- On iteration `i`…
  - Find the smallest element from index `i` onward
    - *(By loop invariant, must be the **next smallest** element)*
  - Swap that with the element at index `i`

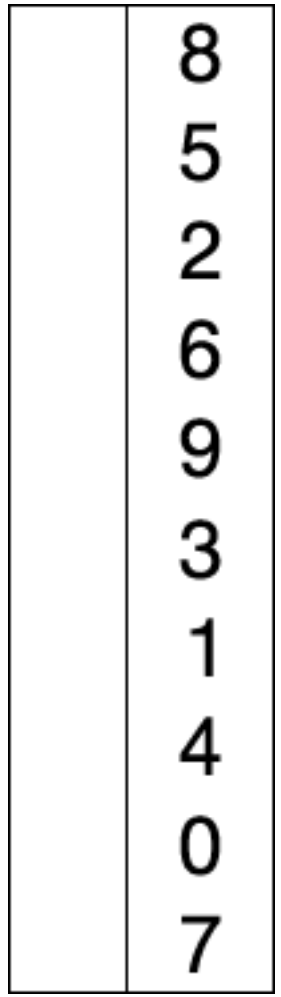
- Algorithm is called ***Selection Sort***.



Selection Sort Code and Runtime

```
3    public static void selectSort(int[] ar) {
4        for (int i=0; i<ar.length; i++) {
5            int minDex = i;
6            for (int j=i+1; j<ar.length; j++) {
7                if (ar[j] < ar[minDex]) {
8                    minDex = j;
9                }
10           }
11           int temp = ar[i];
12           ar[i] = ar[minDex];
13           ar[minDex] = temp;
14       }
15   }
```

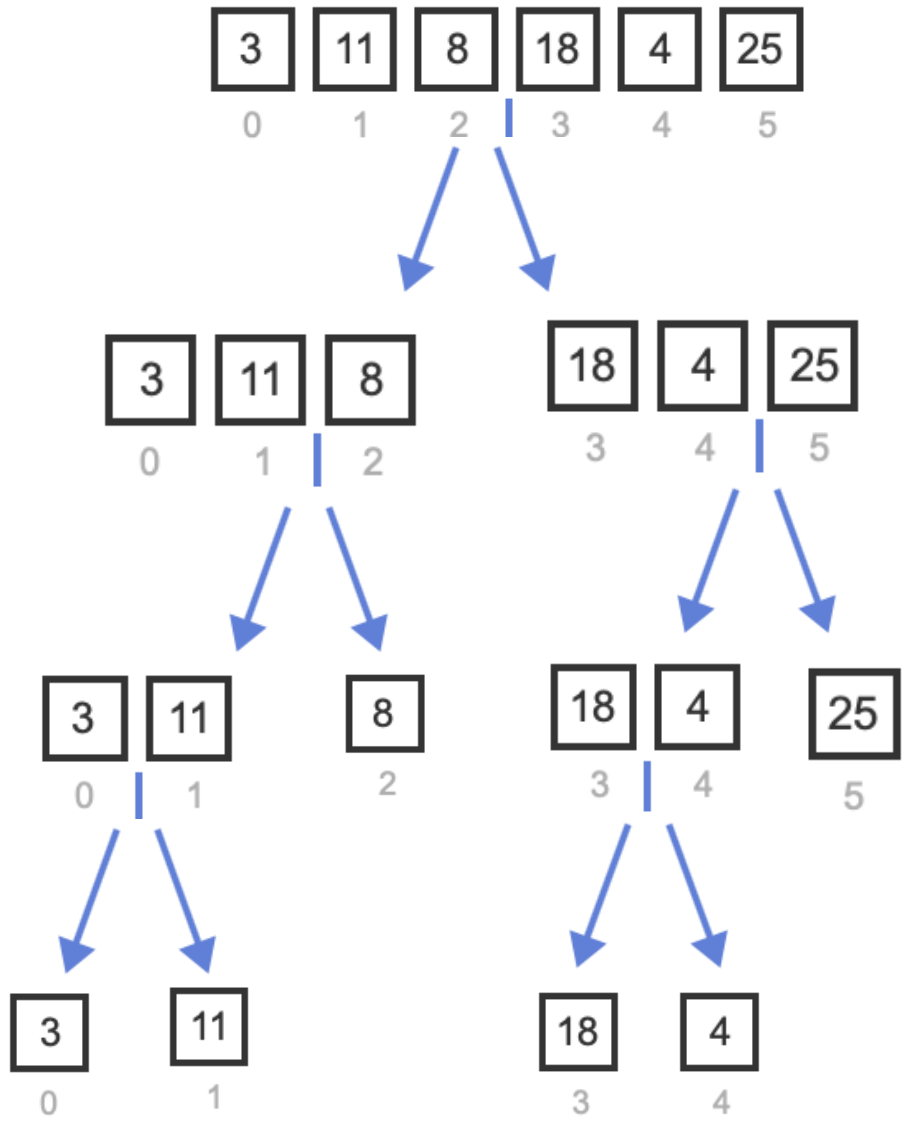
Nested O(N) loops, overall $O(N^2)$



Mergesort

High level idea:

- Base case: size 1
  - Return list
- Recursive case:
  - Mergesort(first half)
  - Mergesort(second half)
  - …



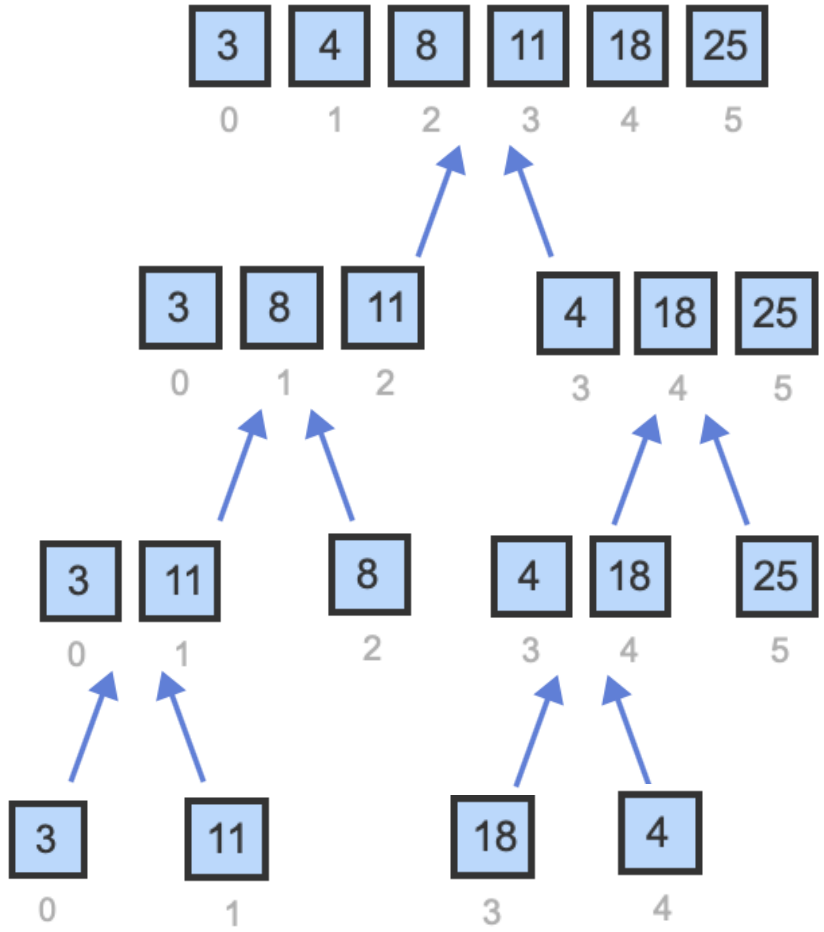
Zybook

Mergesort

High level idea:

- Base case: size 1
  - Return list
- Recursive case:
  - Mergesort(first half)
  - Mergesort(second half)
  - Merge the sorted halves
  - Return sorted

Helper method



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