

CS61B Lecture #6: More Iteration: Sort an Array

Problem. Print out the command-line arguments in lexicographic order:

```
% java Sort the quick brown fox jumped over the lazy dog  
brown dog fox jumped lazy over quick the the
```

Plan.

```
public class Sort {  
    /** Sort and print WORDS lexicographically. */  
    public static void main(String[] words) {  
        sort(words, 0, words.length-1);  
        print(words);  
    }  
  
    /** Sort items A[L..U], with all others unchanged. */  
    static void sort(String[] A, int L, int U) { /* "TOMORROW" */ }  
  
    /** Print A on one line, separated by blanks. */  
    static void print(String[] A) { /* "TOMORROW" */ }  
}
```

How do We Know If It Works?

- *Unit testing* refers to the testing of individual units (methods) within a program, rather than the whole program.
- *Module testing* refers to testing of classes or other groupings of methods and data.
- *System testing* (or *acceptance testing*) refers to the testing of the functionality of an entire program.
- *Integration testing* is sort of intermediate between unit and system testing, and tests that modules work correctly together.
- *Regression testing* refers to testing with the specific goal of checking that fixes, enhancements, or other changes have not introduced faults (regressions).
- In this class, we mainly use the JUnit tool for unit testing.
- Example: `AGTestYear.java` in lab #1.
- Our system testing is somewhat more *ad hoc*, and customized to the program. At its simplest, one might just run specific input files through the program and compare with precomputed outputs.

Test-Driven Development

- Idea: write tests first.
- Implement unit at a time, run tests, fix and refactor until it works.
- We're only going to push it fairly lightly in this course, but it is useful and has quite a following.
- You'll see a lot more of it in CS169.

Testing sort

- This is pretty easy: just give a bunch of arrays to sort and then make sure they each get sorted properly.
- Have to make sure we cover the necessary cases:
 - *Corner cases*. E.g., empty array, one-element, all elements the same.
 - *Representative "middle" cases*. E.g., elements reversed, elements in order, one pair of elements reversed,

Simple JUnit

- The JUnit package provides some handy tools for unit testing.
- The Java annotation `@Test` on a method tells the JUnit machinery to call that method.
- (An *annotation* in Java provides information about a method, class, etc., that can be examined within Java itself.)
- A collection of methods with names beginning with `assert` then allow your test cases to check conditions and report failures.
- [See example in the [code](#) link for lecture 6.]

Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = /*( Index s.t. A[k] is largest in A[L], ..., A[U] )*/;
        /*{ swap A[k] with A[U] }*/;
        /*{ Sort items L to U-1 of A. }*/;
    }
}
```

And we're done! Well, OK, not quite.

Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = indexOfLargest(A, L, U);
        /*{ swap A[k] with A[U] }*/;
        /*{ Sort items L to U-1 of A. }*/;
    }
}
```

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    ...
}
```

Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = indexOfLargest(A, L, U);
        /*{ swap A[k] with A[U] }*/;
        sort(A, L, U-1);    // Sort items L to U-1 of A
    }
}
```

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    ...
}
```


Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = indexOfLargest(A, L, U);
        String tmp = A[k]; A[k] = A[U]; A[U] = tmp;
        sort(A, L, U-1);    // Sort items L to U-1 of A
    }
}
```

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    ...
}
```

Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = indexOfLargest(A, L, U);
        String tmp = A[k]; A[k] = A[U]; A[U] = tmp;
        sort(A, L, U-1);    // Sort items L to U-1 of A
    }
}
```

What would an iterative version look like?

```
while (?) {
    ?
}
```

Selection Sort

```
/** Sort items A[L..U], with all others unchanged. */
static void sort(String[] A, int L, int U) {
    if (L < U) {
        int k = indexOfLargest(A, L, U);
        String tmp = A[k]; A[k] = A[U]; A[U] = tmp;
        sort(A, L, U-1);      // Sort items L to U-1 of A
    }
}
```

Iterative version:

```
while (L < U) {
    int k = indexOfLargest(A, L, U);
    String tmp = A[k]; A[k] = A[U]; A[U] = tmp;
    U -= 1;
}
```

Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (?)
        return i1;
    else {

    }
}
```

Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {

    }
}
```

Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = /*( index of largest value in V[i0 + 1..i1] )*/;
        return /*( whichever of i0 and k has larger value )*/;
    }
}
```

Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return /*( whichever of i0 and k has larger value )*/;
    }
}
```

Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return (V[i0].compareTo(V[k]) > 0) ? i0 : k;
        // if (V[i0].compareTo(V[k]) > 0) return i0; else return k;
    }
}
```

- Turning this into an iterative version is tricky: not tail recursive.
- What are the arguments to `compareTo` the first time it's called?

Iteratively Find Largest

```
/** Value k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return (V[i0].compareTo(V[k]) > 0) ? i0 : k;
        // if (V[i0].compareTo(V[k]) > 0) return i0; else return k;
    }
}
```

Iterative:

```
int i, k;
k = ?; // Deepest iteration
for (i = ?; ...?; i ...?)
    k = ?;
return k;
```

Iteratively Find Largest

```
/** Value k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return (V[i0].compareTo(V[k]) > 0) ? i0 : k;
        // if (V[i0].compareTo(V[k]) > 0) return i0; else return k;
    }
}
```

Iterative:

```
int i, k;
k = i1; // Deepest iteration
for (i = ?; ...?; i ...?)
    k = ?;
return k;
```

Iteratively Find Largest

```
/** Value k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return (V[i0].compareTo(V[k]) > 0) ? i0 : k;
        // if (V[i0].compareTo(V[k]) > 0) return i0; else return k;
    }
}
```

Iterative:

```
int i, k;
k = i1; // Deepest iteration
for (i = i1 - 1; i >= i0; i -= 1)
    k = ?;
return k;
```

Iteratively Find Largest

```
/** Value k, I0<=k<=I1, such that V[k] is largest element among
 * V[I0], ... V[I1]. Requires I0<=I1. */
static int indexOfLargest(String[] V, int i0, int i1) {
    if (i0 >= i1)
        return i1;
    else /* if (i0 < i1) */ {
        int k = indexOfLargest(V, i0 + 1, i1);
        return (V[i0].compareTo(V[k]) > 0) ? i0 : k;
        // if (V[i0].compareTo(V[k]) > 0) return i0; else return k;
    }
}
```

Iterative:

```
int i, k;
k = i1; // Deepest iteration
for (i = i1 - 1; i >= i0; i -= 1)
    k = (V[i].compareTo(V[k]) > 0) ? i : k;
return k;
```

Finally, Printing

```
/** Print A on one line, separated by blanks. */  
static void print(String[] A) {  
    for (int i = 0; i < A.length; i += 1)  
        System.out.print(A[i] + " ");  
    System.out.println();  
}
```

```
/* Java also provides a simple, specialized syntax for looping  
 * through an entire array: */  
for (String s : A)  
    System.out.print(s + " ");
```

Another Problem

Given an array of integers, A , of length $N > 0$, find the smallest index, k , such that all elements at indices $\geq k$ and $< N - 1$ are greater than $A[N - 1]$. Then rotate elements k to $N - 1$ right by one. For example, if A starts out as

{ 1, 9, 4, 3, 0, 12, 11, 9, 15, 22, 12 }

then it ends up as

{ 1, 9, 4, 3, 0, 12, 11, 9, 12, 15, 22 }

As another example,

{ 1, 9, 4, 3, 0, 12, 11, 9, 15, 22, -2 }

would become

{ -2, 1, 9, 4, 3, 0, 12, 11, 9, 15, 22 }

What if A starts like this?

{ 1, 9, 4, 3, 0, 12, 11, 9, 12, 15, 22 }

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Given an array of integers, A , of length $N > 0$, find the smallest index, k , such that all elements at indices $\geq k$ and $< N - 1$ are greater than $A[N - 1]$. Then rotate elements k to $N - 1$ right by one. For example, if A starts out as

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What if A starts like this?

{ 1, 9, 4, 3, 0, 12, 11, 9, 12, 15, 22 }

Answer: It's unchanged. (No, the spec is not ambiguous.)

Your turn

```
public class Shove {  
  
    /** Rotate elements A[k] to A[A.length-1] one element to the  
     * right, where k is the smallest index such that elements  
     * k through A.length-2 are all larger than A[A.length-1].  
     */  
    static void moveOver(int[] A) {  
        // FILL IN  
    }  
  
}
```