

## CS61B Lecture #6: More Iteration: Sort an Array

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

```
% java sort the quick brown fox jumped over the lazy  
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 (method within a program, rather than the whole program).
- In this class, we mainly use the JUnit tool for unit testing.
- Example: `AGTestYear.java` in lab #1.
- *Integration testing* refers to the testing of entire (integration of modules—the whole program).
- In this course, we'll look at various ways to run the program with prepared inputs and checking the output.
- *Regression testing* refers to testing with the specific goal of ensuring that fixes, enhancements, or other changes have not introduced faults (regressions).

# Test-Driven Development

- Idea: write tests first.
- Implement unit at a time, run tests, fix and refactor until it passes.
- We're not really going to push it in this course, but it is used in the industry and has quite a following.

## Testing sort

- This is pretty easy: just give a bunch of arrays to sort and 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 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 runner to call that method.
- (An *annotation* in Java provides information about a method, etc., that can be examined within Java itself.)
- A collection of methods with names beginning with `assert` that you use in your test cases to check conditions and report failures.
- [See example.]

## 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
 *  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
 *  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
 *  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,  $I0 \leq k \leq I1$ , such that  $V[k]$  is largest element
 *   $V[I0], \dots, V[I1]$ . Requires  $I0 \leq I1$ . */
static int indexOfLargest(String[] V, int i0, int i1)
{
    if (i0 == i1)
        return i0;
    else {
        int k = i0;
        for (int j = i0 + 1; j <= i1; j++)
            if (V[j].compareTo(V[k]) > 0)
                k = j;
    }
}
```

## Find Largest

```
/** Index k, I0<=k<=I1, such that V[k] is largest element
 *  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
 *  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
 *  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
 *  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,  $I0 \leq k \leq I1$ , such that  $V[k]$  is largest element
 *   $V[I0], \dots, V[I1]$ . Requires  $I0 \leq I1$ . */
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,  $I0 \leq k \leq I1$ , such that  $V[k]$  is largest element  
 *  $V[I0], \dots, V[I1]$ . Requires  $I0 \leq I1$ . */  
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,  $I0 \leq k \leq I1$ , such that  $V[k]$  is largest element
 *   $V[I0], \dots, V[I1]$ . Requires  $I0 \leq I1$ . */
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,  $I0 \leq k \leq I1$ , such that  $V[k]$  is largest element
 *   $V[I0], \dots, V[I1]$ . Requires  $I0 \leq I1$ . */
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
 * 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  $k$ , 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?

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

## Another Problem

Given an array of integers,  $A$ , of length  $N > 0$ , find the smallest  $k$ , 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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$\{ -2, 1, 9, 4, 3, 0, 12, 11, 9, 15, 22 \}$

What if  $A$  starts like this?

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

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