CS1083 Week 4 : Polymorphism

Sorting, Merging

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Reducing disorder: Bubble Sort

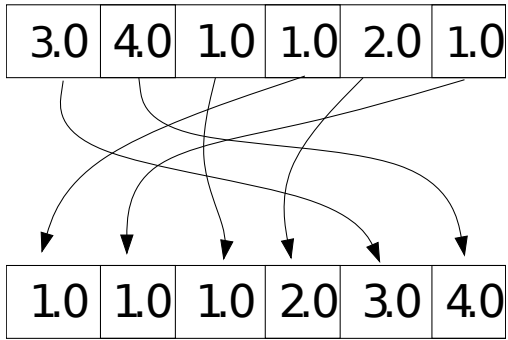
Increasing Order: Selection Sort

Merging

Sorting

Given An array A.

Return Array B, such that each element of B is an element of A (and vice-versa), and $B[i] \leq B[j]$ when $i < j$.



Reducing Disorder: Bubble Sort

Rough Idea

1. Initially $B = A$.
2. At each step, we reduce the number of *bad pairs*:
   - pairs (i, j) such that $i \prec j$ and $B[i] \succ B[j]$
3. When no bad pairs remain, we are done.

$$\begin{array}{ccccccc} 5 & [6 & 1] & 3 & 2 & 4 & 7 \\ 5 & [1 & 6] & 3 & 2 & 4 & 7 \end{array}$$

Reducing Disorder: Bubble Sort

Rough Idea

1. Initially $B = A$.
2. At each step, we reduce the number of *bad pairs*:
   - pairs (i, j) such that $i < j$ and $B[i] > B[j]$
3. When no bad pairs remain, we are done.

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3. When no bad pairs remain, we are done.

$$\begin{array}{cccccccc} 5 & [6 & 1] & 3 & 2 & 4 & 7 \\ 5 & [1 & 6] & 3 & 2 & 4 & 7 \end{array}$$

Checking all pairs is boring

- If $B[i] \leq B[i+1]$ for $0 \leq i < B.length$, then there are no bad pairs.

  Math Note: *This is because $\leq$ is transitive. And needs a proof by induction. See CS1303.*

- So we only need to check pairs $(i, i+1)$.
- Basic operation will be to adjacent elements.
- But notice this may introduce a new bad pair, so we start at the again.

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- So we only need to check pairs $(i, i+1)$.
- Basic operation will be to swap adjacent elements.
- But notice this may introduce a new bad pair, so we start at the beginning of the array again.

Bubbling in Action

pass 1

5	[6	1]	3	**2**	**4**	**7**
5	1	[	3]	2	4	7
5	1	3	[6	]	4	7
5	1		2	[6	4]	7
5	1	3	2	4	[6	7]

Bubbling in Action

pass 1

5	[6	1]	3	**2**	**4**	**7**
5	1	[6	3]	2	4	7
5	1	3	[6	]	4	7
5	1		2	[6	4]	7
5	1	3	2	4	[6	7]

pass 2

[5	1]	3	**2**	4	6	7
1	[5	3]	2	4	6	7
1	3	[5	2]	4	6	7
1	3	2	[	4]	6	7
1	3	2	4	[5	6]	7

pass 3

1	[3	2]	4	5	6	7
1	2	[3	4]	5	6	7

pass 4

1	2	3	4	5	6	7

Bubbling in Action

pass 1

5	[6	1]	3	**2**	**4**	**7**
5	1	[6	3]	2	4	7
5	1	3	[6	2]	4	7
5	1		2	[6	4]	7
5	1	3	2	4	[6	7]

pass 2

[5	1]	3	**2**	**4**	**6**	**7**
1	[5	3]	2	4	6	7
1	3	[5	2]	4	6	7
1	3	2	[	4]	6	7
1	3	2	4	[5	6]	7

pass 3

1	[3		]	4	5	6	7
1	2	[3	4]	5	6	7

pass 4

1 2 3 4 5 6 7

Bubbling in Action

pass 1

5	[6	1]	3	**2**	**4**	**7**
5	1	[6	3]	2	4	7
5	1	3	[6	2]	4	7
5	1	3	2	[6	4]	7
5	1	3	2	4	[6	7]

pass 2

[5	1]	3	**2**	**4**	**6**	**7**
1	[5	3]	2	4	6	7
1	3	[5	2]	4	6	7
1	3	2	[	4]	6	7
1	3	2	4	[5	6]	7

pass 3

1	[3	]	4	5	6	7
1	2	[3	4]	5	6	7

pass 4

1	2	3	4	5	6	7

Bubbling in Action

pass 1

$$
\begin{array}{ccccccc}
5 & [6 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{7} \\
5 & 1 & [6 & 3] & 2 & 4 & 7 \\
5 & 1 & 3 & [6 & 2] & 4 & 7 \\
5 & 1 & 3 & 2 & [6 & 4] & 7 \\
5 & 1 & 3 & 2 & 4 & [6 & 7]
\end{array}
$$

pass 2

$$
\begin{array}{ccccccc}
[5 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{6} & \mathbf{7} \\
1 & [5 & 3] & 2 & 4 & 6 & 7 \\
1 & 3 & [5 & 2] & 4 & 6 & 7 \\
1 & 3 & 2 & [& 4] & 6 & 7 \\
1 & 3 & 2 & 4 & [5 & 6] & 7
\end{array}
$$

pass 3

$$
\begin{array}{ccccccc}
1 & [3 &] & 4 & \mathbf{5} & \mathbf{6} & \mathbf{7} \\
1 & 2 & [3 & 4] & 5 & 6 & 7
\end{array}
$$

pass 4

$$
1\ 2\ 3\ 4\ 5\ 6\ 7
$$

Bubbling in Action

pass 1

$$
\begin{array}{ccccccc}
5 & [6 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{7} \\
5 & 1 & [6 & 3] & 2 & 4 & 7 \\
5 & 1 & 3 & [6 & 2] & 4 & 7 \\
5 & 1 & 3 & 2 & [6 & 4] & 7 \\
5 & 1 & 3 & 2 & 4 & [6 & 7]
\end{array}
$$

pass 2

$$
\begin{array}{ccccccc}
[5 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{6} & \mathbf{7} \\
1 & [5 & 3] & 2 & 4 & 6 & 7 \\
1 & 3 & [5 & 2] & 4 & 6 & 7 \\
1 & 3 & 2 & [5 & 4] & 6 & 7 \\
1 & 3 & 2 & 4 & [5 & 6] & 7
\end{array}
$$

pass 3

$$
\begin{array}{ccccccc}
1 & [3 &] & 4 & \mathbf{5} & \mathbf{6} & \mathbf{7} \\
1 & 2 & [3 & 4] & 5 & 6 & 7
\end{array}
$$

pass 4

$$
1\ 2\ 3\ 4\ 5\ 6\ 7
$$

Bubbling in Action

pass 1

5	[6	1]	3	**2**	**4**	**7**
5	1	[6	3]	2	4	7
5	1	3	[6	2]	4	7
5	1	3	2	[6	4]	7
5	1	3	2	4	[6	7]

pass 2

[5	1]	3	**2**	**4**	**6**	**7**
1	[5	3]	2	4	6	7
1	3	[5	2]	4	6	7
1	3	2	[5	4]	6	7
1	3	2	4	[5	6]	7

pass 3

1	[3	]	**4**	**5**	**6**	**7**
1	2	[3	4]	5	6	7

pass 4

1	2	3	4	5	6	7

Bubbling in Action

pass 1

$5\ [6\ 1]\ 3\ \mathbf{2}\ \mathbf{4}\ \mathbf{7}$
$5\ 1\ [6\ 3]\ 2\ 4\ 7$
$5\ 1\ 3\ [6\ 2]\ 4\ 7$
$5\ 1\ 3\ 2\ [6\ 4]\ 7$
$5\ 1\ 3\ 2\ 4\ [6\ 7]$

pass 2

$[5\ 1]\ 3\ \mathbf{2}\ \mathbf{4}\ \mathbf{6}\ \mathbf{7}$
$1\ [5\ 3]\ 2\ 4\ 6\ 7$
$1\ 3\ [5\ 2]\ 4\ 6\ 7$
$1\ 3\ 2\ [5\ 4]\ 6\ 7$
$1\ 3\ 2\ 4\ [5\ 6]\ 7$

pass 3

$1\ [3\ \mathbf{2}]\ \mathbf{4}\ \mathbf{5}\ \mathbf{6}\ \mathbf{7}$
$1\ 2\ [3\ 4]\ 5\ 6\ 7$

pass 4

$1\ 2\ 3\ 4\ 5\ 6\ 7$

Bubbling in Action

pass 1

$$
\begin{array}{ccccccc}
5 & [6 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{7} \\
5 & 1 & [6 & 3] & 2 & 4 & 7 \\
5 & 1 & 3 & [6 & 2] & 4 & 7 \\
5 & 1 & 3 & 2 & [6 & 4] & 7 \\
5 & 1 & 3 & 2 & 4 & [6 & 7]
\end{array}
$$

pass 2

$$
\begin{array}{ccccccc}
[5 & 1] & 3 & \mathbf{2} & \mathbf{4} & \mathbf{6} & \mathbf{7} \\
1 & [5 & 3] & 2 & 4 & 6 & 7 \\
1 & 3 & [5 & 2] & 4 & 6 & 7 \\
1 & 3 & 2 & [5 & 4] & 6 & 7 \\
1 & 3 & 2 & 4 & [5 & 6] & 7
\end{array}
$$

pass 3

$$
\begin{array}{ccccccc}
1 & [3 & \mathbf{2}] & \mathbf{4} & \mathbf{5} & \mathbf{6} & \mathbf{7} \\
1 & 2 & [3 & 4] & 5 & 6 & 7
\end{array}
$$

pass 4

$$
\mathbf{1}\ \mathbf{2}\ \mathbf{3}\ \mathbf{4}\ \mathbf{5}\ \mathbf{6}\ \mathbf{7}
$$

Are we making progress or just bubbles?

There are two ways of looking at bubble-sort's progress.

1. After each pass, one element is bubbled into its correct place.
2. After each pass, the sorted sequence at the *end* of the array gets one longer.

$$
\begin{array}{ccccccc}
5 & [6 & 1] & 3 & 2 & 4 & 7 \\
5 & 1 & [& 3] & 2 & 4 & 7 \\
5 & 1 & 3 & [6 & 2] & 4 & 7 \\
5 & 1 & 3 & 2 & [6 & 4] & 7 \\
5 & 1 & 3 & 2 & 4 & [6 & 7]
\end{array}
$$

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5 & 1 & 3 & [6 & \mathbf{2}] & 4 & \mathbf{7} \\
5 & 1 & 3 & \mathbf{2} & [6 & 4] & \mathbf{7} \\
5 & 1 & 3 & \mathbf{2} & 4 & [6 & \mathbf{7}]
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5 & 1 & 3 & \mathbf{2} & [6 & 4] & \mathbf{7} \\
5 & 1 & 3 & \mathbf{2} & 4 & [\mathbf{6} & \mathbf{7}]
\end{array}
$$

Swapping elements

```
public void swap(T[] a,
                 int i, int j){
    T temp = a[i];


}
```

BubbleSort

Swapping elements

```
public void swap(T[] a,
                 int i, int j){
    T temp = a[i];
    a[i] = a[j];
    a[j] = temp;
}
```

Implementing Bubble Sort

BubbleSort

```
public void sort(T[] a){
    boolean finished=false;
    while(!finished){
        finished=true; // assume last pass









    }
}
```

Implementing Bubble Sort

BubbleSort

```
public void sort(T[] a){
    boolean finished=false;
    while(!finished){
        finished=true; // assume last pass
        for (int i=0; i<a.length-1; i++){




        }
    }
}
```

Implementing Bubble Sort

BubbleSort

```
public void sort(T[] a){
    boolean finished=false;
    while(!finished){
        finished=true; // assume last pass
        for (int i=0; i<a.length-1; i++){
            if (a[i].compareTo(a[i+1]) > 0){
                swap(a,i,i+1);
                finished=false;
            }
        }
    }
}
```

Analyzing Bubblesort

- What is the minimum number of passes?
- When does this make a difference?
- How many “steps” (comparisons) in each pass?

Using Bubble Sort for Strings

```
String[] names = {"Harry", "Tom",
                  "Moe", "Curly"};

BubbleSort<String> stringSorter=
    new BubbleSort<String>();

stringSorter.sort(names);

for (String name : names) {
    System.out.println(name);
}
```

BubbleSort

Using Bubble Sort for Integers

```
BubbleSort<Integer> integerSorter=
    new BubbleSort<Integer>();

Integer [] numbers = { 8, 4, 5, 2, 9, 1,
                       -3, 0, 1, 2, 3 };

integerSorter.sort(numbers);

for (Integer number : numbers) {
    System.out.println(number);
}
```

BubbleSort

Reducing disorder: Bubble Sort

Increasing Order: Selection Sort

Merging

Selection Sort

Idea

- Divide the array into two parts
- Left part is sorted
- Each pass extends the sorted part by one.

Improvement

Partition everything in the left part is smaller than everything in the unsorted part.

Selection each pass consists of *swapping* the smallest element in the unsorted part to the end of the sorted part.

Selection Sort in Action

$\|5$	7	9	1	4	8	6	2	10	3
1	$\|7$	9		4	8	6	2	10	3
1	2	$\|9$	5	4	8	6		10	3
1	2	3	$\|5$	4	8	6	7	10	
1	2	3		$\|5$	8	6	7	10	9
1	2	3	4		$\|8$	6	7	10	9
1	2	3	4	5	6	$\|$	7	10	9
1	2	3	4	5	6	7	$\|8$	10	9
1	2	3	4	5	6	7	8	$\|10$	9
1	2	3	4	5	6	7	8	9	10

- How many passes?
- How many comparisons in each pass? Minimum? Maximum?

Selection Sort in Action

$\|5$	7	9	1	4	8	6	2	10	3
1	$\|7$	9	5	4	8	6	2	10	3
1	2	$\|9$	5	4	8	6		10	3
1	2	3	$\|5$	4	8	6	7	10	
1	2	3		$\|5$	8	6	7	10	9
1	2	3	4		$\|8$	6	7	10	9
1	2	3	4	5	6	$\|$	7	10	9
1	2	3	4	5	6	7	$\|8$	10	9
1	2	3	4	5	6	7	8	$\|10$	9
1	2	3	4	5	6	7	8	9	10

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1	2	3	$\|5$	4	8	6	7	10	
1	2	3		$\|5$	8	6	7	10	9
1	2	3	4		$\|8$	6	7	10	9
1	2	3	4	5	6	$\|$	7	10	9
1	2	3	4	5	6	7	$\|8$	10	9
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Selection Sort in Action

$\|5$	7	9	1	4	8	6	2	10	3
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1	2	3		$\|5$	8	6	7	10	9
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- How many passes?
- How many comparisons in each pass? Minimum? Maximum?

Selection Sort in Action

‖5	7	9	1	4	8	6	2	10	3
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1	2	‖9	5	4	8	6	7	10	3
1	2	3	‖5	4	8	6	7	10	9
1	2	3	4	‖5	8	6	7	10	9
1	2	3	4		‖8	6	7	10	9
1	2	3	4	5	6	‖	7	10	9
1	2	3	4	5	6	7	‖8	10	9
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Selection Sort in Action

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1	2	3	4	5	$\|8$	6	7	10	9
1	2	3	4	5	6	$\|$	7	10	9
1	2	3	4	5	6	7	$\|8$	10	9
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Selection Sort in Action

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1	2	3	4	$\|5$	8	6	7	10	9
1	2	3	4	5	$\|8$	6	7	10	9
1	2	3	4	5	6	$\|8$	7	10	9
1	2	3	4	5	6	7	$\|8$	10	9
1	2	3	4	5	6	7	8	$\|10$	9
1	2	3	4	5	6	7	8	9	10

- How many passes?
- How many comparisons in each pass? Minimum? Maximum?

Finding minimum position

SelectionSort

```
public int minimumPosition(T [] a,
                           int from)  {
    int minPos = from;




    return minPos;
}
```

How many steps to find smallest element after position `from`?

Finding minimum position

SelectionSort

```
public int minimumPosition(T [] a,
                           int from)  {
    int minPos = from;
    for (int i = from + 1; i < a.length; i++){


    }
    return minPos;
}
```

How many steps to find smallest element after position `from`?

Finding minimum position

SelectionSort

```
public int minimumPosition(T [] a,
                           int from)  {
    int minPos = from;
    for (int i = from + 1; i < a.length; i++){
        if (a[i].compareTo(a[minPos]) <0)
            minPos = i;
    }
    return minPos;
}
```

How many steps to find smallest element after position `from`?

Implimenting Selection Sort

SelectionSort

```
public void sort(T [] a)
{
    for (int n = 0; n < a.length - 1; n++) {




    }
}
```

Implimenting Selection Sort

SelectionSort

```
public void sort(T [] a)
{
    for (int n = 0; n < a.length - 1; n++) {
        int minPos = minimumPosition(a, n);
        if (minPos != n){
            // swap



        }
    }
}
```

Implimenting Selection Sort

SelectionSort

```
public void sort(T [] a)
{
    for (int n = 0; n < a.length - 1; n++) {
        int minPos = minimumPosition(a, n);
        if (minPos != n){
            // swap
            T temp=a[n];
            a[n]=a[minPos];
            a[minPos]=temp;
        }
    }
}
```

Implimenting Selection Sort

SelectionSort

```
public void sort(T [] a)
{
    for (int n = 0; n < a.length - 1; n++) {
        int minPos = minimumPosition(a, n);
        if (minPos != n){
            // swap
            T temp=a[n];
            a[n]=a[minPos];
            a[minPos]=temp;
        }
    }
}
```

Implimenting Selection Sort

SelectionSort

```
public void sort(T [] a)
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    for (int n = 0; n < a.length - 1; n++) {
        int minPos = minimumPosition(a, n);
        if (minPos != n){
            // swap
            T temp=a[n];
            a[n]=a[minPos];
            a[minPos]=temp;
        }
    }
}
```

Using Selection Sort for Strings

```
String[] names = {"Harry", "Tom",
                  "Moe", "Curly"};

SelectionSort<String> stringSorter=
    new SelectionSort<String>();

stringSorter.sort(names);

for (String name : names) {
    System.out.println(name);
}
```

SelectionSort

Using Selection Sort for Integers

```
SelectionSort<Integer> integerSorter=
    new SelectionSort<Integer>();

Integer [] numbers = { 8, 4, 5, 2, 9, 1,
                       -3, 0, 1, 2, 3 };

integerSorter.sort(numbers);

for (Integer number : numbers) {
    System.out.println(number);
}
```

SelectionSort

Sorting Custom Comparables

```
SelectionSort<IntPair> pairSorter=
    new SelectionSort<IntPair>();
IntPair [] pairs = { new IntPair(8, 4), new IntPair(5, 2),
                     new IntPair(9, 1), new IntPair(-3, 0),
                     new IntPair(1, 2) };
pairSorter.sort(pairs);
for (IntPair pair : pairs) {
    System.out.println(pair);
}
```

SelectionSort

Reducing disorder: Bubble Sort

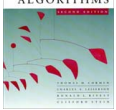
Increasing Order: Selection Sort

Merging

Merging two sorted arrays

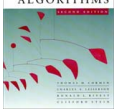
```
public void merge(T [] a, T[] b, T[] c) {
    int i=0, j=0;
    while (i + j < a.length + b.length) {
        T next;
        if (i >= a.length)
            next=b[j++];
        else if (j >= b.length)
            next=a[i++];
        else
            if (a[i].compareTo(b[j]) <= 0)
                next=a[i++];
            else
                next=b[j++];
        c[i+j-1]=next;
    }
}
```

ArrayMerger



Merging two sorted arrays

20	12
13	11
7	9
2	1



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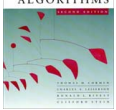
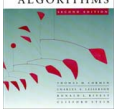
1



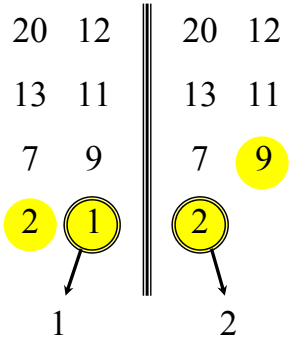
Merging two sorted arrays

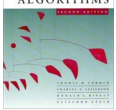
20	12		20	12
13	11		13	11
7	9		7	9
2	1		2	

1

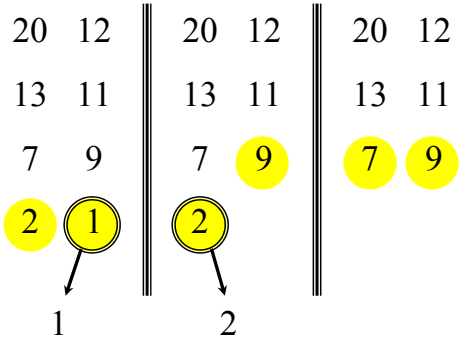


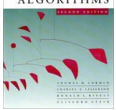
Merging two sorted arrays



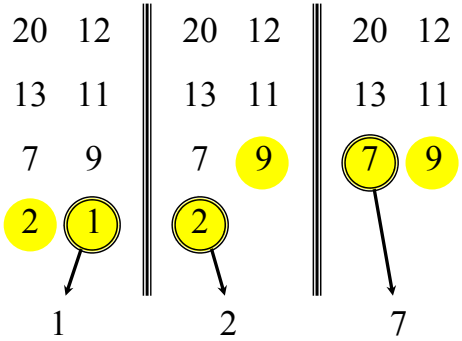


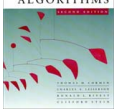
Merging two sorted arrays



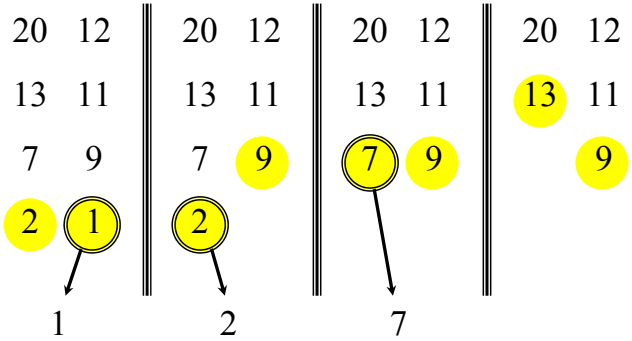


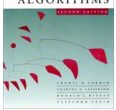
Merging two sorted arrays



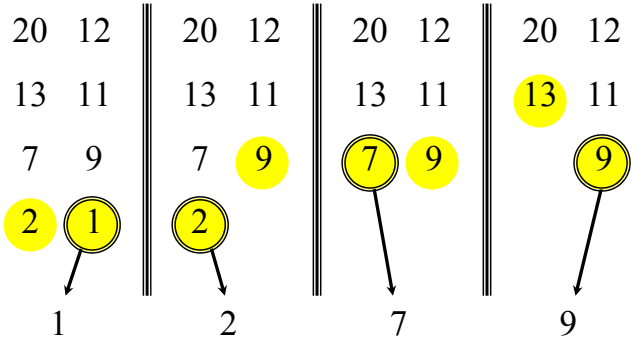


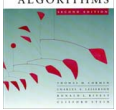
Merging two sorted arrays



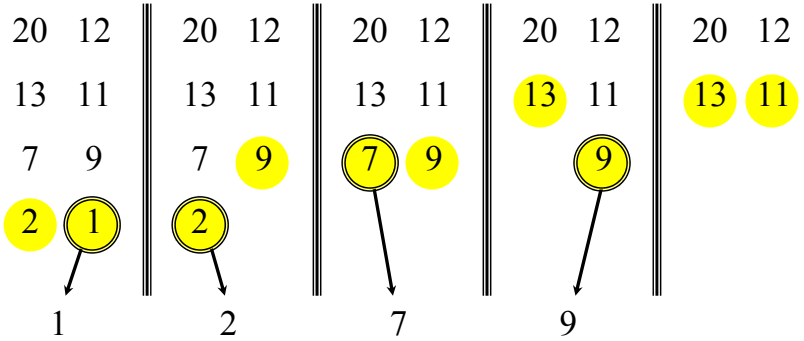


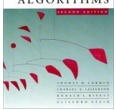
Merging two sorted arrays



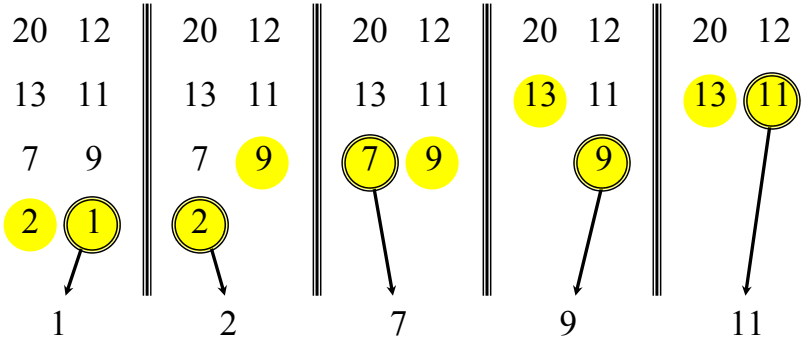


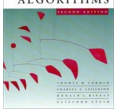
Merging two sorted arrays





Merging two sorted arrays





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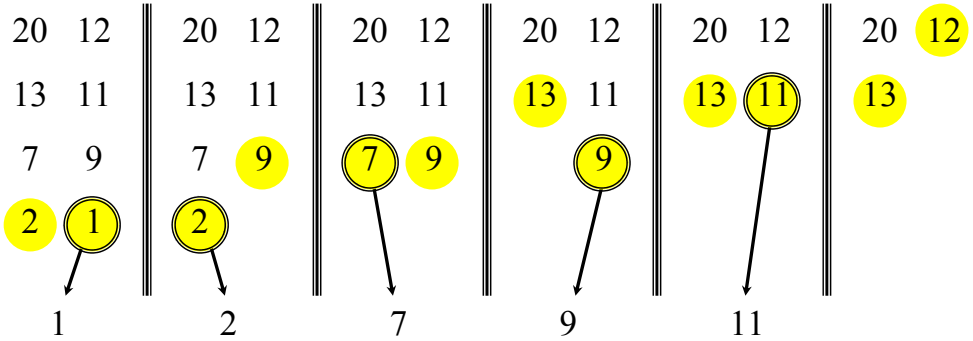
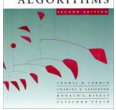
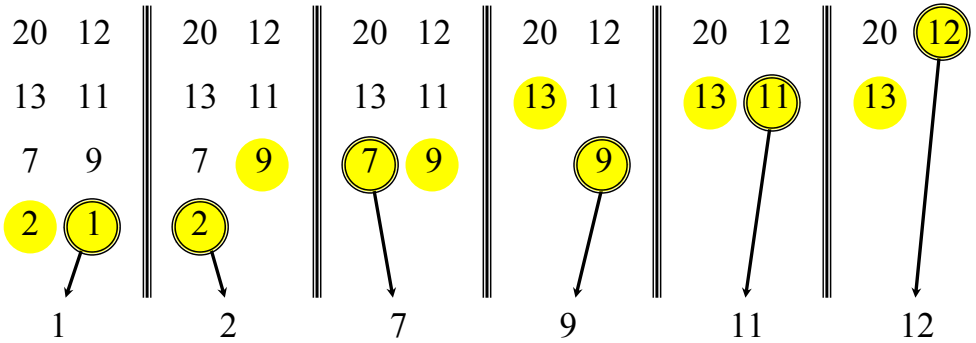
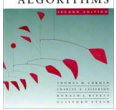


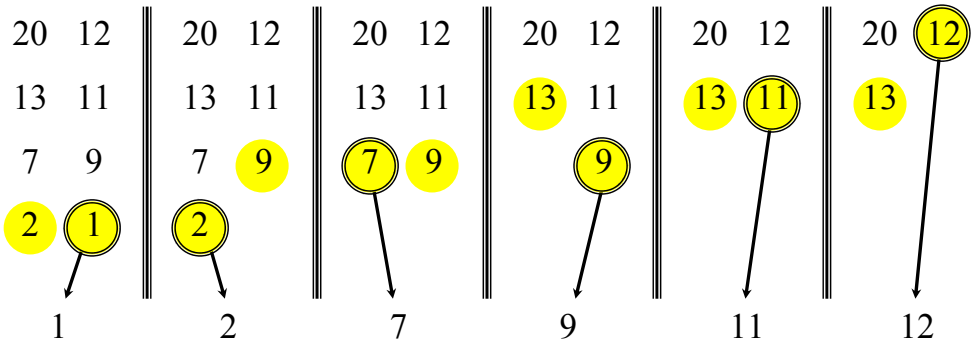


Merging two sorted arrays





Merging two sorted arrays



Time = $\Theta(n)$ to merge a total of n elements (linear time).

ArrayMerger Class

```
public class ArrayMerger<T extends Comparable<T>> {

    public void merge(T [] a, T[] b, T[] c) {

        int i=0, j=0;

        while (i + j < a.length + b.length) {
        ⋮
        }
    }

    ⋮
}
```

ArrayMerger

Using Array Merger

```
String[] names1 = {"Harry", "Tom", "Moe", "Curly"};
String[] names2 = {"Bob", "Alice", "Mallory"};

SelectionSort<String> sorter=new SelectionSort<String>();
sorter.sort(names1);
sorter.sort(names2);

String[] names3 = new String[names1.length+names2.length];
ArrayMerger<String> merger = new ArrayMerger<String>();

merger.merge(names1,names2, names3);

for (String name : names3) {
    System.out.println(name);
}
```

ArrayMerger