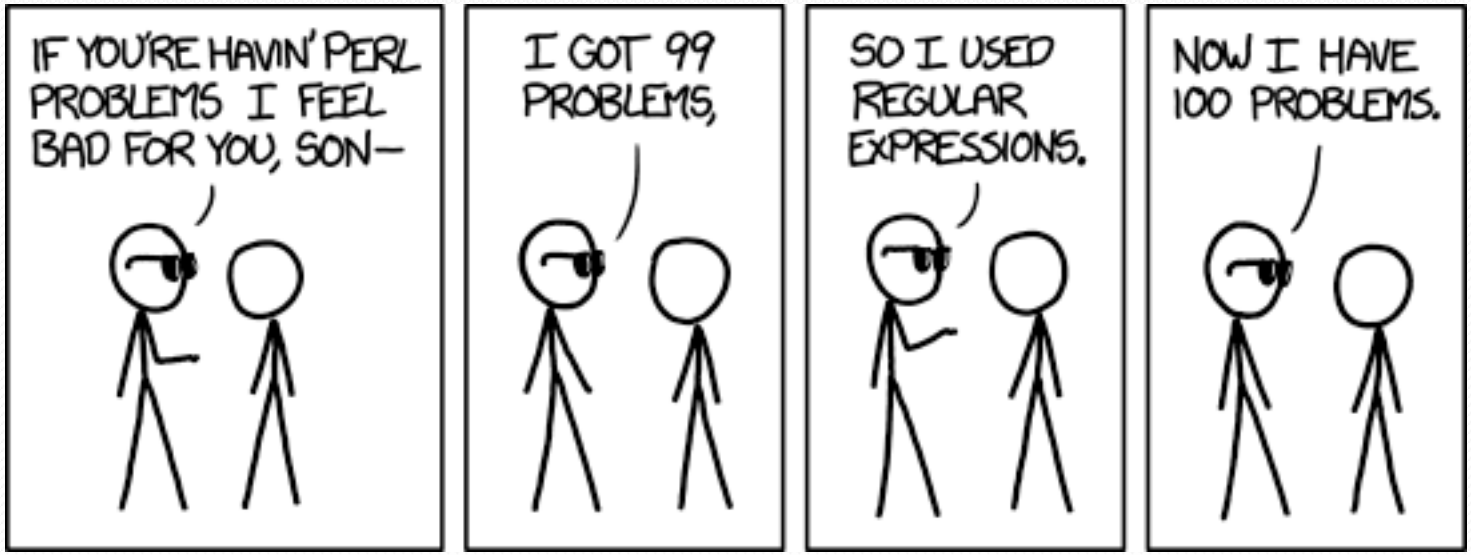
# Building Java Programs

Chapter 13
Sorting

**reading: 13.3, 13.4**




Perl is a scripting language generally used for text processing.

Matches valid dates in m/d/y format:

```
^(?:(?:(?:0?[13578]|1[02])(\/|-|\.)31)\1|(?:(?:0?[13-9]|
1[0-2])(\/|-|\.)(?:29|30)\2))(?:(?:1[6-9]|[2-9]\d)?\d{2})$|
^(?:0?2(\/|-|\.)29\3(?:(?:(?:1[6-9]|[2-9]\d)?(?:0[48]|[2468]
[048]|[13579][26])|(?:(?:16|[2468][048]|[3579][26])00))))$|
^(?:(?:0?[1-9])|(?:1[0-2]))(\/|-|\.)(?:0?[1-9]|1\d|2[0-8])
\4(?:(?:1[6-9]|[2-9]\d)?\d{2})$
```

Seriously.

# `Collections` class

| Method name | Description |
|---|---|
| `binarySearch(`**list**`, `**value**`)` | returns the index of the given value in a sorted list (< 0 if not found) |
| `copy(`**listTo**`, `**listFrom**`)` | copies **listFrom**'s elements to **listTo** |
| `emptyList(), emptyMap(), emptySet()` | returns a read-only collection of the given type that has no elements |
| `fill(`**list**`, `**value**`)` | sets every element in the list to have the given value |
| `max(`**collection**`),` `min(`**collection**`)` | returns largest/smallest element |
| `replaceAll(`**list**`, `**old**`, `**new**`)` | replaces an element value with another |
| `reverse(`**list**`)` | reverses the order of a list's elements |
| `shuffle(`**list**`)` | arranges elements into a random order |
| `sort(`**list**`)` | arranges elements into ascending order |

# Binary search (13.1)

- **binary search**: Locates a target value in a *sorted* array/ list by successively eliminating half of the array from consideration.
  - How many elements will it need to examine? **O(log N)**
  - Can be implemented with a loop or recursively
  - Example: Searching the array below for the value **42**:

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | -4 | 2 | 7 | 10 | 15 | 20 | 22 | 25 | 30 | 36 | 42 | 50 | 56 | 68 | 85 | 92 | 103 |

min mid max

# Binary search code

```
// Returns the index of an occurrence of target in a,
// or a negative number if the target is not found.
// Precondition: elements of a are in sorted order
public static int binarySearch(int[] a, int target) {
    int min = 0;
    int max = a.length - 1;

    while (min <= max) {
        int mid = (min + max) / 2;
        if (a[mid] < target) {
            min = mid + 1;
        } else if (a[mid] > target) {
            max = mid - 1;
        } else {
            return mid;    // target found
        }
    }

    return -(min + 1);     // target not found
}
```

# Recursive binary search (13.3)

- Write a recursive `binarySearch` method.
  - If the target value is not found, return its negative insertion point.

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | -4 | 2 | 7 | 10 | 15 | 20 | 22 | 25 | 30 | 36 | 42 | 50 | 56 | 68 | 85 | 92 | 103 |

```
int index  = binarySearch(data, 42);  // 10
int index2 = binarySearch(data, 66);  // -14
```

# Exercise solution

```
// Returns the index of an occurrence of the given value in
// the given array, or a negative number if not found.
// Precondition: elements of a are in sorted order
public static int binarySearch(int[] a, int target) {
    return binarySearch(a, target, 0, a.length - 1);
}

// Recursive helper to implement search behavior.
private static int binarySearch(int[] a, int target,
                                int min, int max) {
    if (min > max) {
        return -1;          // target not found
    } else {
        int mid = (min + max) / 2;
        if (a[mid] < target) {          // too small; go
  right
            return binarySearch(a, target, mid + 1, max);
        } else if (a[mid] > target) {  // too large; go left
            return binarySearch(a, target, min, mid - 1);
        } else {
            return mid;    // target found; a[mid] == target
        }
    }
}
```

# Sorting

- **sorting**: Rearranging the values in an array or collection into a specific order (usually into their "natural ordering").
  - one of the fundamental problems in computer science
  - can be solved in many ways:
    - there are many sorting algorithms
    - some are faster/slower than others
    - some use more/less memory than others
    - some work better with specific kinds of data
    - some can utilize multiple computers / processors, ...
  - *comparison-based sorting* : determining order by comparing pairs of elements:
    - `<`, `>`, `compareTo`, ...

# Sorting methods in Java

- The `Arrays` and `Collections` classes in `java.util` have a static method `sort` that sorts the elements of an array/list

```
String[] words = {"foo", "bar", "baz", "ball"};
Arrays.sort(words);
System.out.println(Arrays.toString(words));
// [ball, bar, baz, foo]

List<String> words2 = new ArrayList<String>();
for (String word : words) {
    words2.add(word);
}
Collections.sort(words2);
System.out.println(words2);
// [ball, bar, baz, foo]
```

# Sorting algorithms

- **bogo sort**: shuffle and pray
- **bubble sort**: swap adjacent pairs that are out of order
- **selection sort**: look for the smallest element, move to front
- **insertion sort**: build an increasingly large sorted front portion
- **merge sort**: recursively divide the array in half and sort it
- **heap sort**: place the values into a sorted tree structure
- **quick sort**: recursively partition array based on a middle value

other specialized sorting algorithms:

- **bucket sort**: cluster elements into smaller groups, sort them
- **radix sort**: sort integers by last digit, then 2nd to last, then ...
- ...

# Bogo sort

- **bogo sort**: Orders a list of values by repetitively shuffling them and checking if they are sorted.
  - name comes from the word "bogus"

  The algorithm:
  - Scan the list, seeing if it is sorted.  If so, stop.
  - Else, shuffle the values in the list and repeat.

- This sorting algorithm (obviously) has terrible performance!
  - What is its runtime?

# Bogo sort code

```
// Places the elements of a into sorted order.
public static void bogoSort(int[] a) {
    while (!isSorted(a)) {
        shuffle(a);
    }
}

// Returns true if a's elements are in sorted order.
public static boolean isSorted(int[] a) {
    for (int i = 0; i < a.length - 1; i++) {
        if (a[i] > a[i + 1]) {
            return false;
        }
    }
    return true;
}
```

# Bogo sort code, cont'd.

```
// Shuffles an array of ints by randomly swapping each
// element with an element ahead of it in the array.
public static void shuffle(int[] a) {
    for (int i = 0; i < a.length - 1; i++) {
        // pick a random index in [i+1, a.length-1]
        int range = a.length - 1 - (i + 1) + 1;
        int j = (int) (Math.random() * range + (i + 1));
        swap(a, i, j);
    }
}

// Swaps a[i] with a[j].
public static void swap(int[] a, int i, int j) {
    if (i != j) {
        int temp = a[i];
        a[i] = a[j];
        a[j] = temp;
    }
}
```

# Selection sort

- **selection sort**: Orders a list of values by repeatedly putting the smallest or largest unplaced value into its final position.

  The algorithm:
  - Look through the list to find the smallest value.
  - Swap it so that it is at index 0.
  - Look through the list to find the second-smallest value.
  - Swap it so that it is at index 1.

    ...

  - Repeat until all values are in their proper places.

# Selection sort example

- Initial array:

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | 22 | 18 | 12 | -4 | 27 | 30 | 36 | 50 | 7 | 68 | 91 | 56 | 2 | 85 | 42 | 98 | 25 |

- After 1st, 2nd, and 3rd passes:

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | **-4** | 18 | 12 | **22** | 27 | 30 | 36 | 50 | 7 | 68 | 91 | 56 | 2 | 85 | 42 | 98 | 25 |

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | -4 | **2** | 12 | 22 | 27 | 30 | 36 | 50 | 7 | 68 | 91 | 56 | **18** | 85 | 42 | 98 | 25 |

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | -4 | 2 | **7** | 22 | 27 | 30 | 36 | 50 | **12** | 68 | 91 | 56 | 18 | 85 | 42 | 98 | 25 |

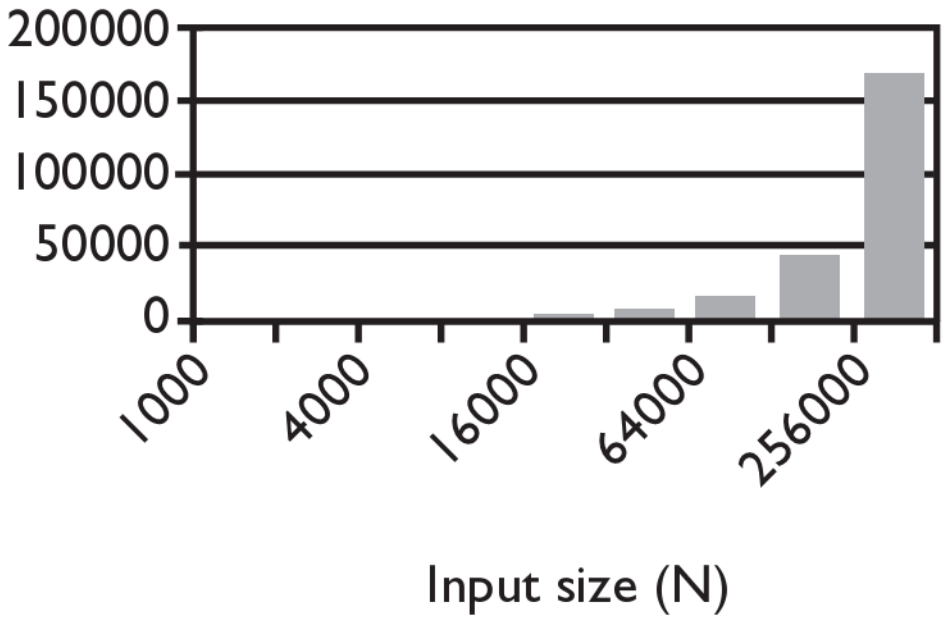
# Selection sort code

```
// Rearranges the elements of a into sorted order using
// the selection sort algorithm.
public static void selectionSort(int[] a) {
    for (int i = 0; i < a.length - 1; i++) {
        // find index of smallest remaining value
        int min = i;
        for (int j = i + 1; j < a.length; j++) {
            if (a[j] < a[min]) {
                min = j;
            }
        }
        // swap smallest value its proper place, a[i]
        swap(a, i, min);
    }
}
```

# Selection sort runtime (Fig. 13.6)

- What is the complexity class (Big-Oh) of selection sort?

| N | Runtime (ms) |
|---|---|
| 1000 | 0 |
| 2000 | 16 |
| 4000 | 47 |
| 8000 | 234 |
| 16000 | 657 |
| 32000 | 2562 |
| 64000 | 10265 |
| 128000 | 41141 |
| 256000 | 164985 |



# Similar algorithms

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | 22 | 18 | 12 | -4 | 27 | 30 | 36 | 50 | 7 | 68 | 91 | 56 | 2 | 85 | 42 | 98 | 25 |

- **bubble sort**: Make repeated passes, swapping adjacent values
  - slower than selection sort (has to do more swaps)

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | 18 | 12 | -4 | 22 | 27 | 30 | 36 | 7 | 50 | 68 | 56 | 2 | 85 | 42 | 91 | 25 | 98 |

22 → 50 → 91 → 98 →

- **insertion sort**: Shift each element into a sorted sub-array
  - faster than selection sort (examines fewer values)

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | -4 | 12 | 18 | 22 | 27 | 30 | 36 | 50 | 7 | 68 | 91 | 56 | 2 | 85 | 42 | 98 | 25 |

sorted sub-array (indexes 0-7)

← 7

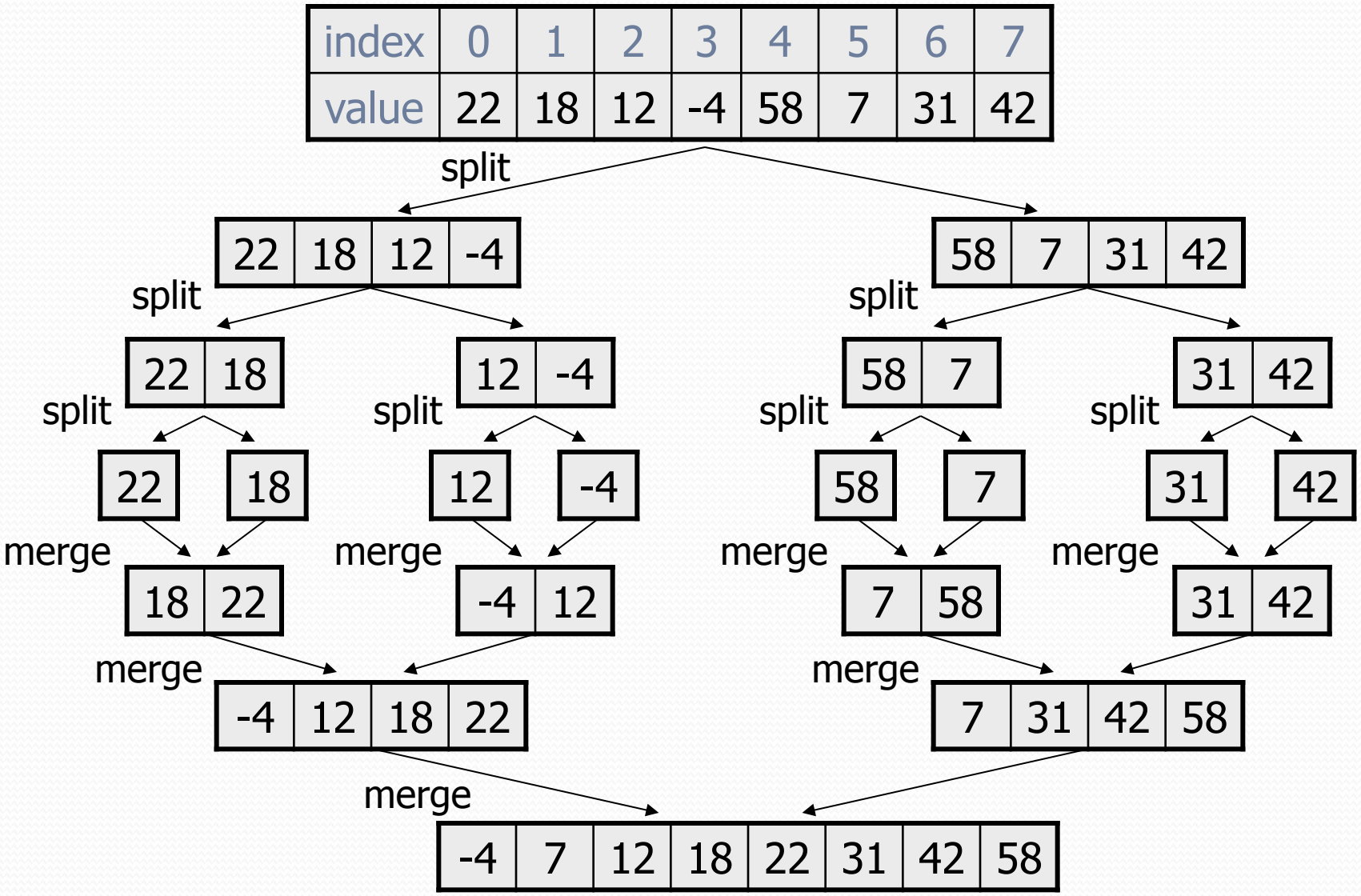
# Merge sort

- **merge sort**: Repeatedly divides the data in half, sorts each half, and combines the sorted halves into a sorted whole.

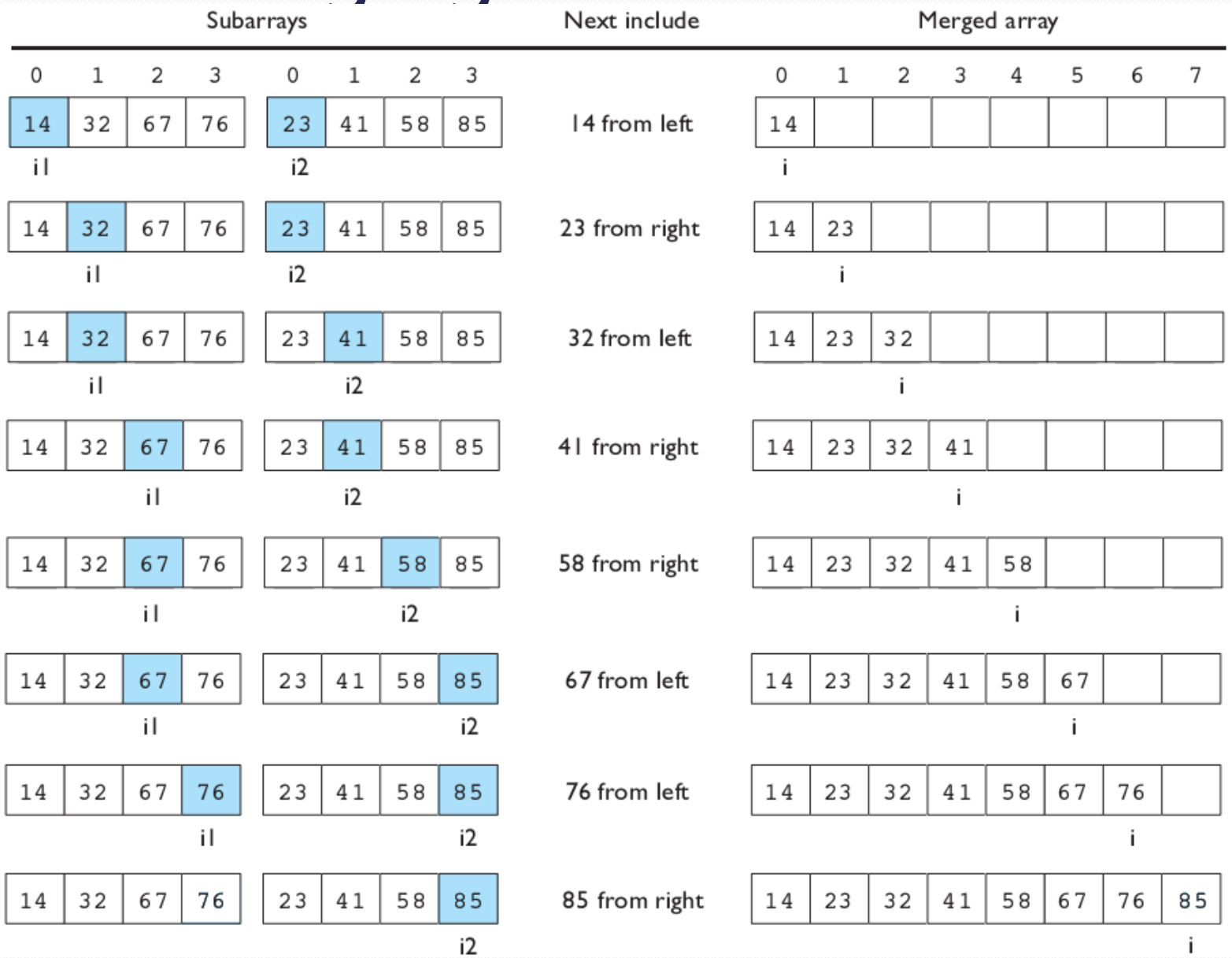
  The algorithm:
  - Divide the list into two roughly equal halves.
  - Sort the left half.
  - Sort the right half.
  - Merge the two sorted halves into one sorted list.

  - Often implemented recursively.
  - An example of a "divide and conquer" algorithm.
    - Invented by John von Neumann in 1945

# Merge sort example



# Merging sorted halves



# Merge halves code

```
// Merges the left/right elements into a sorted result.
// Precondition: left/right are sorted
public static void merge(int[] result, int[] left,
                                       int[] right) {
    int i1 = 0;   // index into left array
    int i2 = 0;   // index into right array

    for (int i = 0; i < result.length; i++) {
        if (i2 >= right.length ||
            (i1 < left.length && left[i1] <= right[i2])) {
            result[i] = left[i1];    // take from left
            i1++;
        } else {
            result[i] = right[i2];   // take from right
            i2++;
        }
    }
}
```

# Merge sort code

```
// Rearranges the elements of a into sorted order using
// the merge sort algorithm.
public static void mergeSort(int[] a) {
    // split array into two halves
    int[] left  = Arrays.copyOfRange(a, 0, a.length/2);
    int[] right = Arrays.copyOfRange(a, a.length/2,
  a.length);

    // sort the two halves
    ...

    // merge the sorted halves into a sorted whole
    merge(a, left, right);
}
```

# Merge sort code 2

```
// Rearranges the elements of a into sorted order using
// the merge sort algorithm (recursive).
public static void mergeSort(int[] a) {
    if (a.length >= 2) {
        // split array into two halves
        int[] left  = Arrays.copyOfRange(a, 0, a.length/2);
        int[] right = Arrays.copyOfRange(a, a.length/2, a.length);

        // sort the two halves
        mergeSort(left);
        mergeSort(right);

        // merge the sorted halves into a sorted whole
        merge(a, left, right);
    }
}
```

# Merge sort runtime

- What is the complexity class (Big-Oh) of merge sort?

| N | Runtime (ms) |
|---|---|
| 1000 | 0 |
| 2000 | 0 |
| 4000 | 0 |
| 8000 | 0 |
| 16000 | 0 |
| 32000 | 15 |
| 64000 | 16 |
| 128000 | 47 |
| 256000 | 125 |
| 512000 | 250 |
| 1e6 | 532 |
| 2e6 | 1078 |
| 4e6 | 2265 |
| 8e6 | 4781 |
| 1.6e7 | 9828 |
| 3.3e7 | 20422 |
| 6.5e7 | 42406 |
| 1.3e8 | 88344 |