# CMSC 132: Object-Oriented Programming II

## Sorting

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# Sorting

- Goal
  - Arrange elements in predetermined order
    - Based on key for each element
  - Derived from ability to compare two keys by size
- Properties
  - **Stable**  relative order of equal keys unchanged
    - Stable: 3, 1, 4, 3, 3, 2 → 1, 2, 3, 3, 3, 4
    - Unstable: 3, 1, 4, 3, 3, 2 → 1, 2, 3, 3, 3, 4
  - **In-place**  uses only constant additional space
  - **External**  can efficiently sort large # of keys
    - Most algorithms discussed in lecture are internal and based on arrays

# Type of Sorting Algorithms

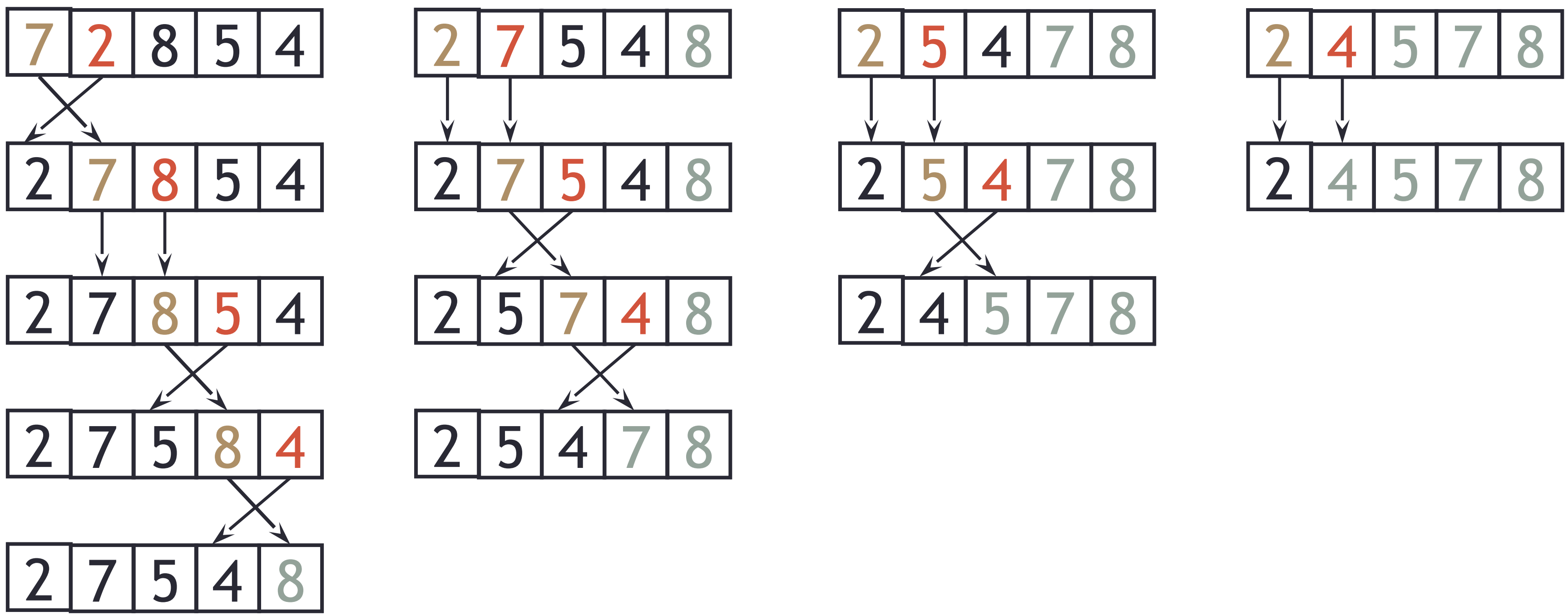
- Comparison-based and Linear Algorithms
  - Comparison-based Algorithms □Only uses pairwise key comparisons
    - Linear Algorithms □ Uses additional properties of keys
  - Comparison-based
  - Proven lower bound of O( n log(n) )
  - Examples
    - O(n2) □Bubblesort, Selection sort, Insertion sort
    - O(nlog(n)) □ Treesort, Heapsort, Quicksort, Mergesort
  - Linear Algorithms
    - Counting sort
    - Bucket (bin) sort
    - Radix sort

# Bubble Sort

- Approach
  - Iteratively sweep through shrinking portions of list
  - Swap element x with its right neighbor if x is larger
- Performance
  - O( n2 ) average / worst case

# Bubble Sort Example

**Sweep 1** **Sweep 2** **Sweep 3** **Sweep 4**



# Bubble Sort Code

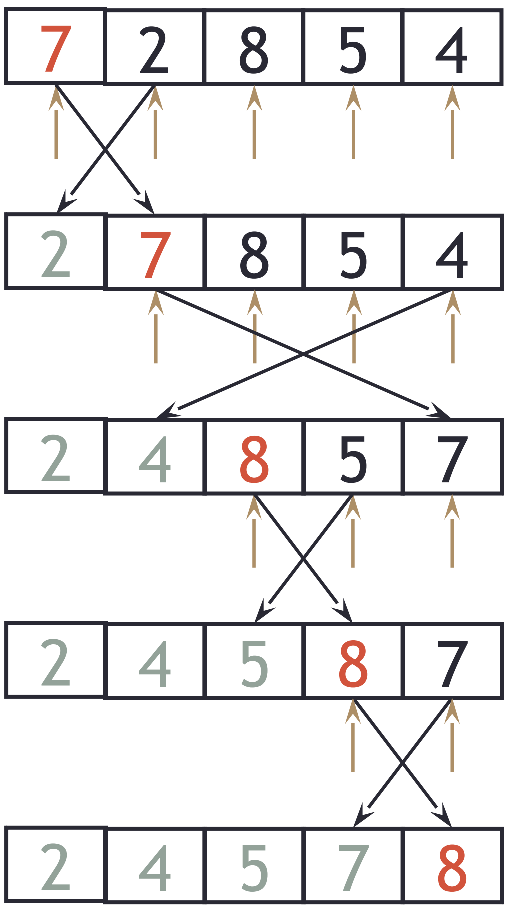
```
void bubbleSort(int[ ] a) {
  int outer, inner;
  for (outer = a.length - 1; outer > 0; outer--)
      for (inner = 0; inner < outer; inner++)
       if (a[inner] > a[inner + 1])
           swap(a, inner, inner+1);
}

void swap(int a[ ], int x, int y) {
  int temp = a[x];
  a[x] = a[y];
  a[y] = temp;
}
```

**Swap with right neighbor if larger**

How can we improve it?

# Selection Sort

- Approach
  - Iteratively sweep through shrinking portions of list
  - Select smallest element found in each sweep
  - Swap smallest element with front of current list




- Performance
  - O( n2 ) average / worst case

# Selection Sort Code

```
void selectionSort(int[] a) {
    int outer, inner, min;
    for (outer = 0; outer < a.length - 1; outer++) {
        min = outer;
        for (inner = outer + 1; inner < a.length; inner++) {
            if (a[inner] < a[min]) {
                min = inner;
            }
        }
        swap(a, outer, min);
    }
}
```

**Sweep through array**

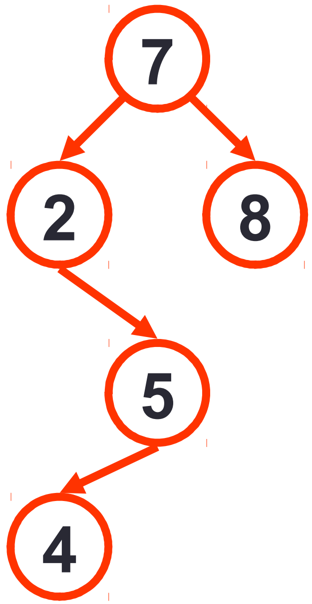
**Find smallest element**

**Swap with smallest element found**

# Tree Sort

- Approach
  - Insert elements in binary search tree
  - List elements using inorder traversal
- Performance
  - Binary search tree
    - O( n log(n) ) average case
    - O( n2 ) worst case
  - Balanced binary search tree
    - O( n log(n) ) average / worst case

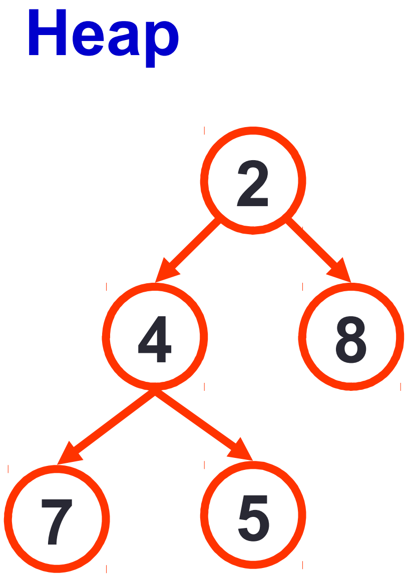
**Binary search tree**




**{ 7, 2, 8, 5, 4 }**

# Heap Sort

- Approach
  - Insert elements in heap
  - Remove smallest element in heap, repeat
  - List elements in order of removal from heap
- Performance
  - O( n log(n) ) average / worst case



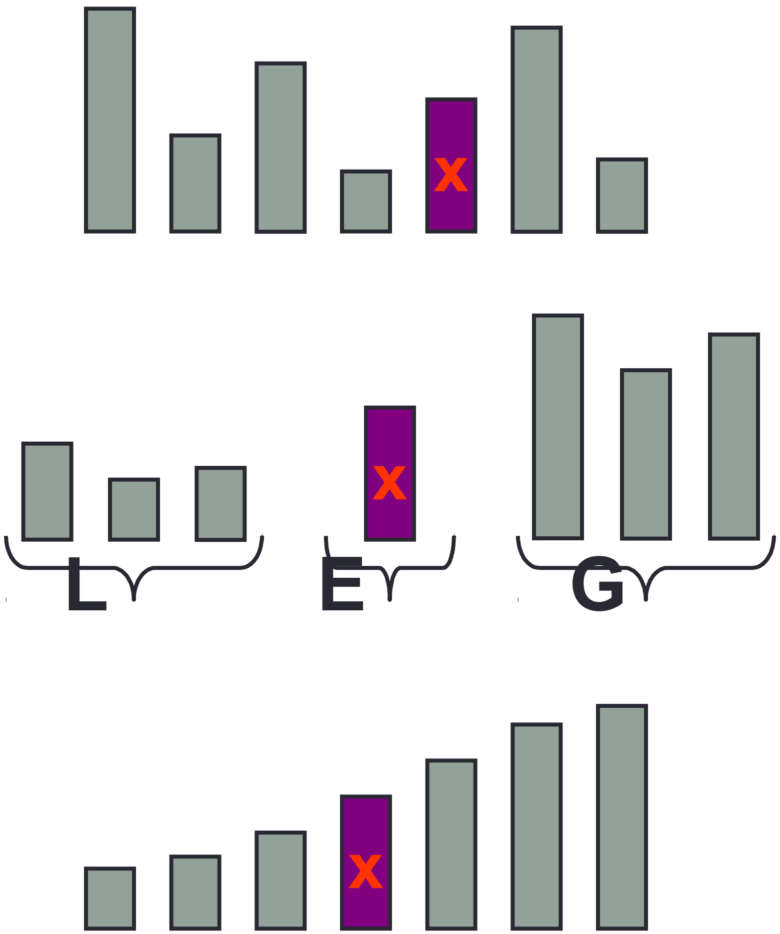

**{ 7, 2, 8, 5, 4 }**

# Quick Sort

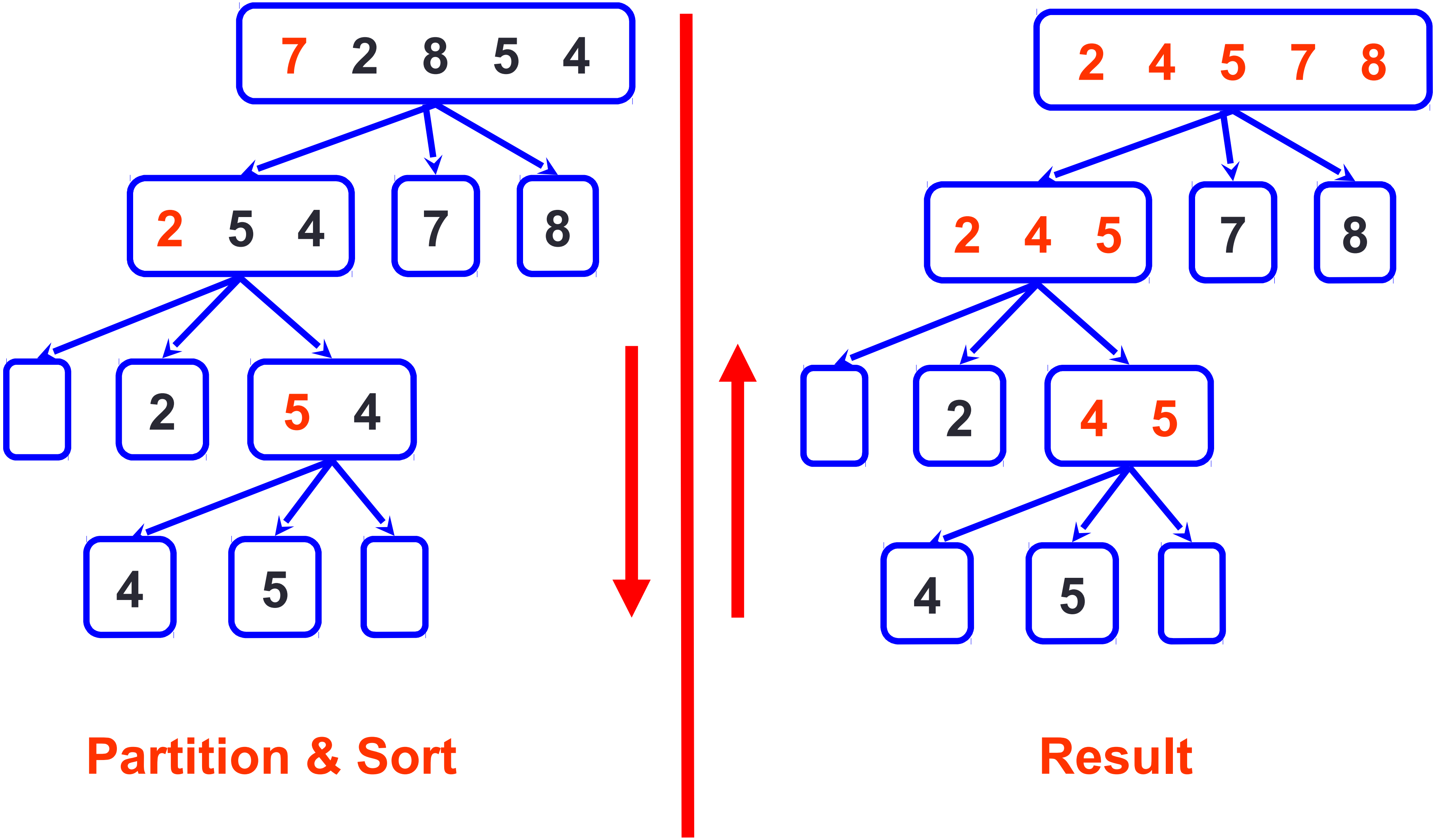
- Approach
  - Select pivot value (near median of list)
  - Partition elements (into 2 lists) using pivot value
  - Recursively sort both resulting lists
  - Concatenate resulting lists
  - For efficiency pivot needs to partition list evenly
- Performance
  - O( n log(n) ) average case
  - O( n2 ) worst case
- Used by Arrays.sort
- Runs faster than mergesort in most cases

# Quick Sort Algorithm

1. If list below size K
   - Sort w/ other algorithm (e.g. insertion sort)
2. Else pick pivot x and partition S into
   - L elements < x
   - E elements = x
   - G elements > x
3. Quicksort L & G
4. Concatenate L, E & G
   - If not sorting in place



# Quick Sort Example




**Partition & Sort**

**Result**

# Quick Sort Code

```
void quickSort(int[] a, int x, int y) {
     int pivotIndex;
     if ((y – x) > 0) {
          pivotIndex = partitionList(a, x, y);
       quickSort(a, x, pivotIndex – 1);
       quickSort(a, pivotIndex+1, y);
     }
}

int partitionList(int[] a, int first, int last) {
      … // partitions list and returns index of pivot
}
```

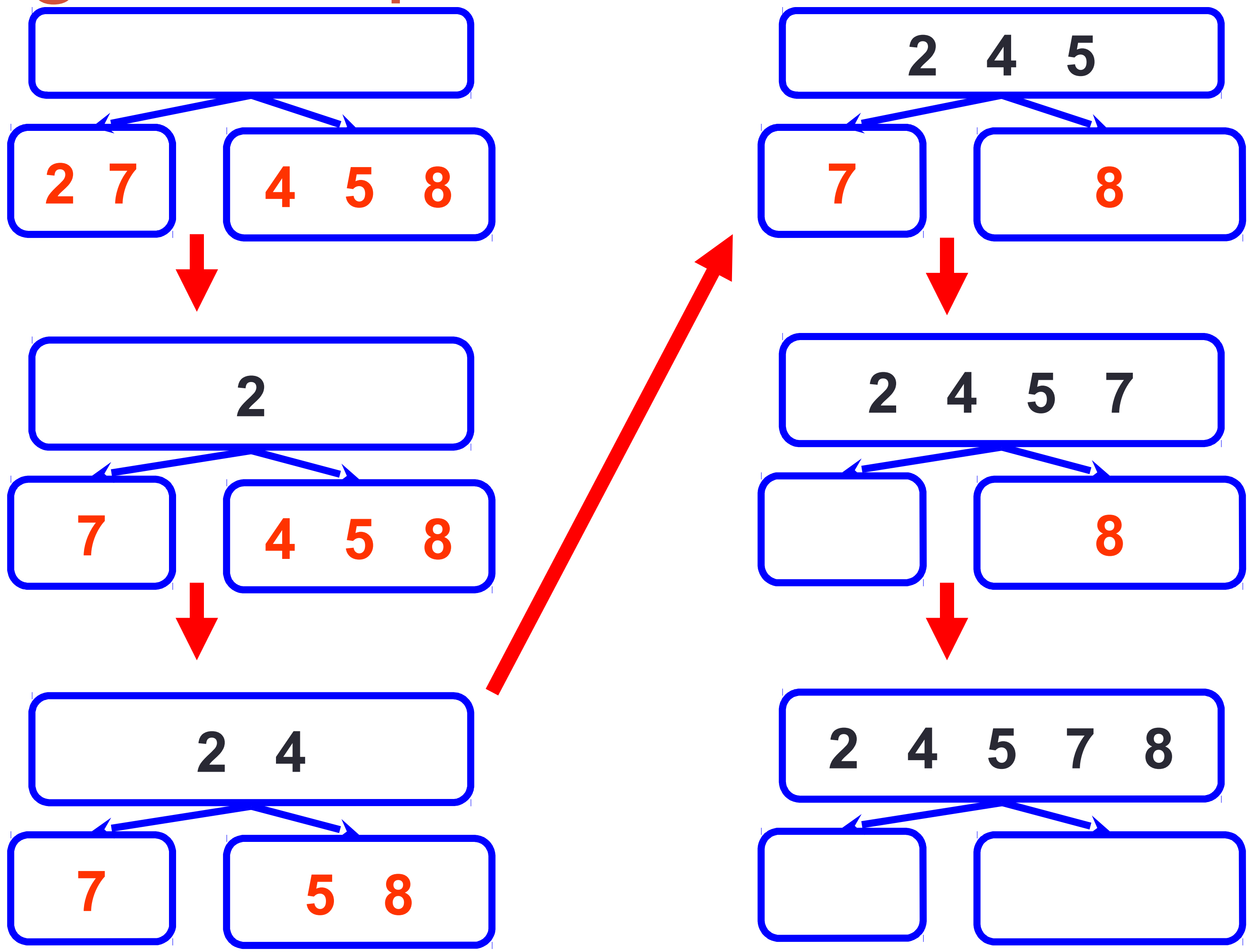
# Quick Sort Code

```
int partitionList(int a[], int first, int last) {
    int i, pivot, border;

    pivot = a[first];
    border = first;
    for (i = first + 1; i <= last; i++) {
        if (a[i] <= pivot) {
            border++;
     swap(a, border, i);
        }
    }
    swap(a, first, border);
    return border;
}
```

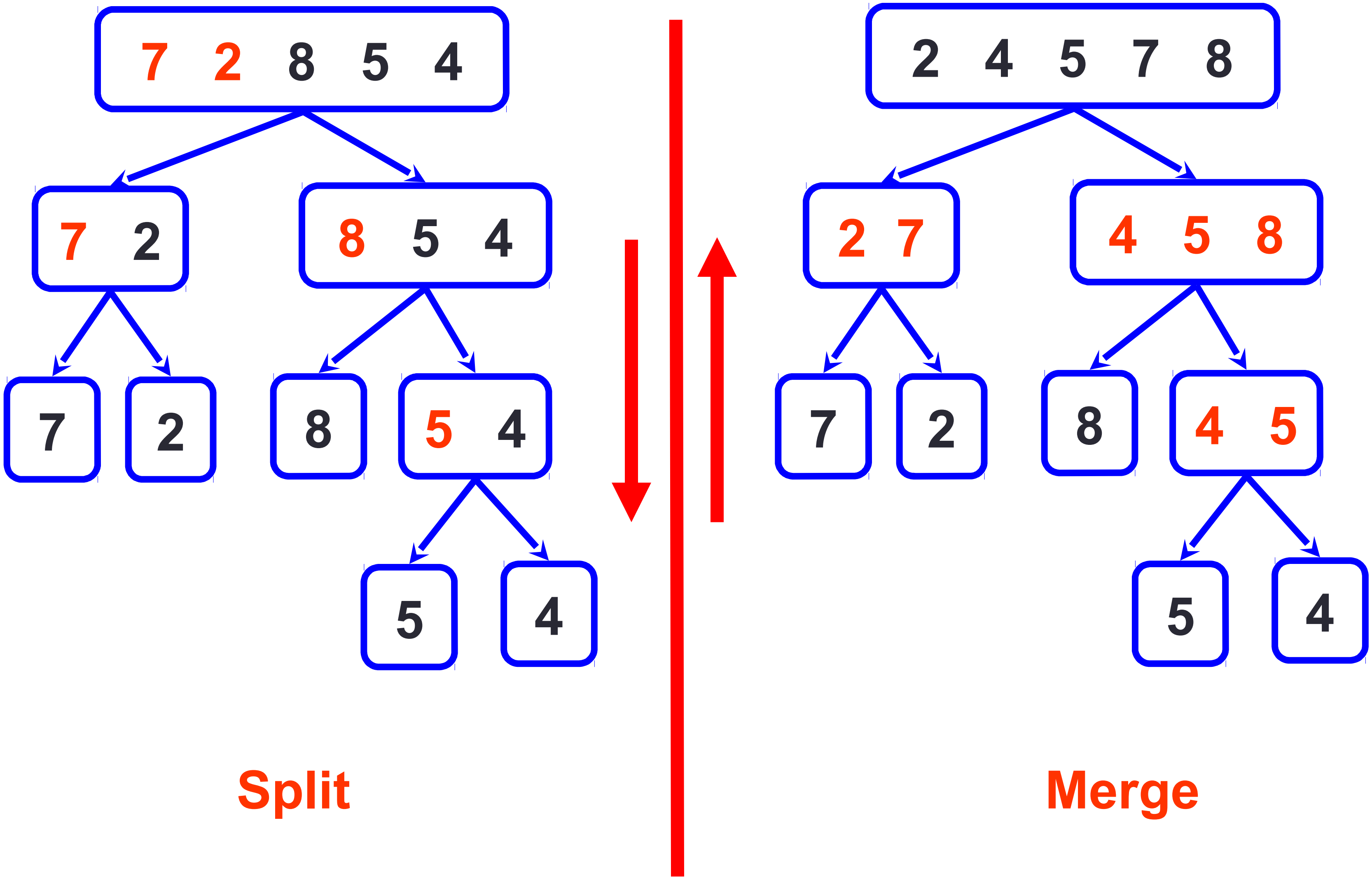
# Merge Sort

- Approach
  - Partition list of elements into 2 lists
  - Recursively sort both lists
  - Given 2 sorted lists, merge into 1 sorted list
    - Examine head of both lists
    - Move smaller to end of new list
- Performance
  - O( n log(n) ) average / worst case
- Used by Collections.sort

# Merge Example



# Merge Sort Example



# Merge Sort Code

```
void mergeSort(int[] a, int x, int y) {
    int mid = (x + y) / 2;
    if (x != y) {
      mergeSort(a, x, mid);
      mergeSort(a, mid + 1, y);
      merge(a, x, y, mid);
    }
}
void merge(int[] a, int x, int y, int mid) {
      ... // merges 2 adjacent sorted lists in array
}
```

**Lower end of array region to be sorted**

**Upper end of array region to be sorted**

# Merge Sort Code

```
void merge(int[] a, int x, int y, int mid) {
  int j, size = y - x + 1, left = x, right = mid + 1;
  int[] tmp = new int[a.length];

  for (j = 0; j < size; j++)
    if (left > mid)
      tmp[j] = a[right++];
    else
      if (right > y || a[left] < a[right])
        tmp[j] = a[left++];
      else
        tmp[j] = a[right++];

  for (j = 0; j < size; j++)
    a[x + j] = tmp[j];
}
```

# Sorting Properties

| Name | Compari-son Sort | Avg Case Complexity | Worst Case Complexity | In Place | Can be Stable |
|---|---|---|---|---|---|
| Bubble | √ | O(n2) | O(n2) | √ | √ |
| Selection | √ | O(n2) | O(n2) | √ | √ |
| Tree | √ | O(n log(n)) | O(n2) | | |
| Heap | √ | O(n log(n)) | O(n log(n)) | | |
| Quick | √ | O(n log(n)) | O(n2) | √ | |
| Merge | √ | O(n log(n)) | O(n log(n)) | | √ |

# Links

- President and Sorting
  - http://www.youtube.com/watch?v=k4RRi_ntQc8
- Sorting Algorithms Comparison
  - http://www.cs.ubc.ca/~harrison/Java/sorting-demo.html
- Ineffective Sorts
  - http://xkcd.com/1185/
- Selection vs. Quicksort
  - http://jtf.acm.org/demos/classroom/SortDemo.html
- What different sorting algorithms sound like
  - http://www.youtube.com/watch?v=t8g-iYGHpEA
- Sorting Algorithms
  - http://maven.smith.edu/~thiebaut/java/sort/demo.html