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

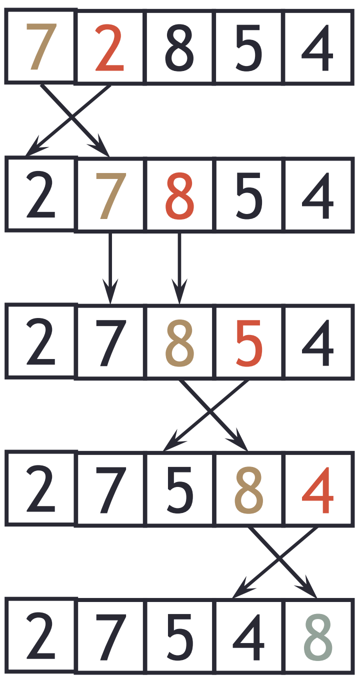
- Comparison-based and Linear Algorithms
  - Comparison-based Algorithms →Only uses pairwise key comparisons
  - Linear Algorithms → Uses additional properties of keys
- Comparison-based
  - Proven lower bound of O(n log(n))
  - Examples
    - $O(n^2)$ →Bubblesort, Selection sort, Insertion sort
    - O(nlog(n)) → Treesort, Heapsort, Quicksort, Mergesort
- Linear Algorithms
  - Counting sort
  - Bucket (bin) sort
  - Radix sort

Bubble Sort

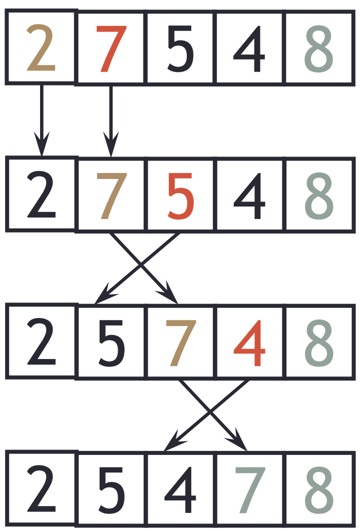
- Approach
  - Iteratively sweep through shrinking portions of list
  - Swap element x with its right neighbor if x is larger
- Performance
  - O(n^2) average / worst case

Bubble Sort Example

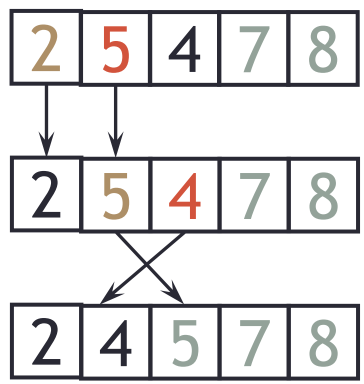
Sweep 1



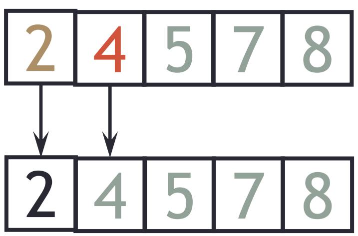
Sweep 2



Sweep 3



Sweep 4



Bubble Sort Code

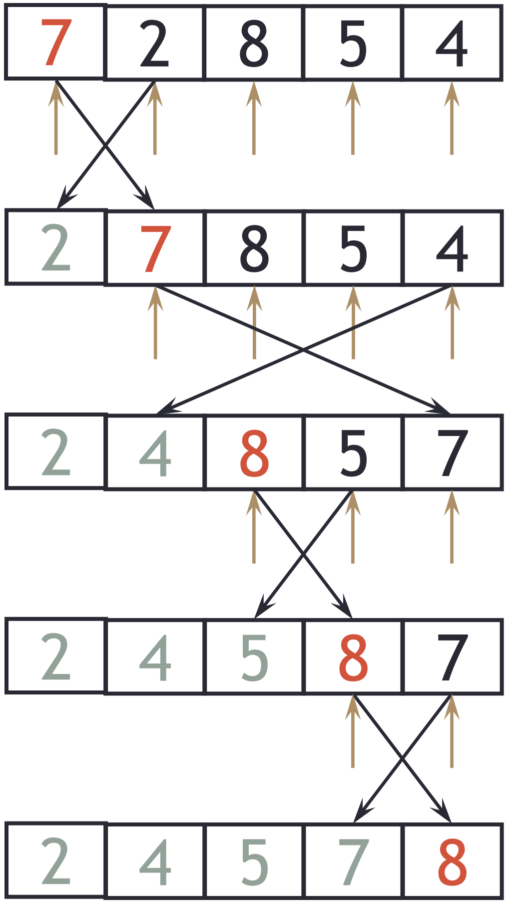
```
void bubbleSort(int[ ] a) {
  int outer, inner;
  for (outer = a.length - 1; outer > 0; outer--)
      for (inner = 0; inner < outer; inner++)
          if (a[inner] > a[inner + 1])
              swap(a, inner, inner+1);
}

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
    1. Iteratively sweep through shrinking portions of list
    2. Select smallest element found in each sweep
    3. Swap smallest element with front of current list



- Performance
    - O(n^2) 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

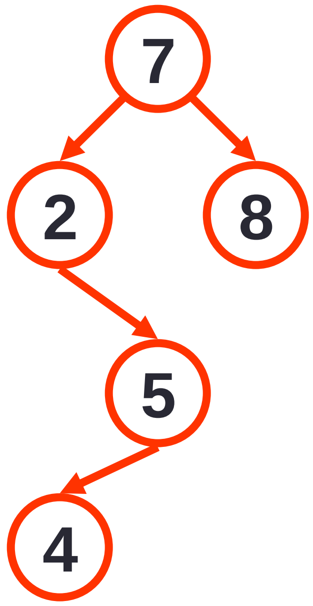
Find smallest element

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(n^2) worst case
  - Balanced binary search tree
    - O(n log(n)) average / worst case

Binary search tree

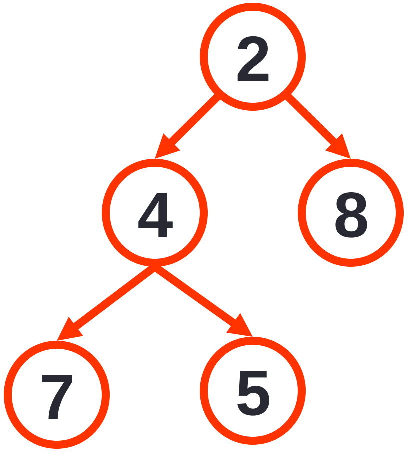


{ 7, 2, 8, 5, 4 }

Heap Sort

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

Heap



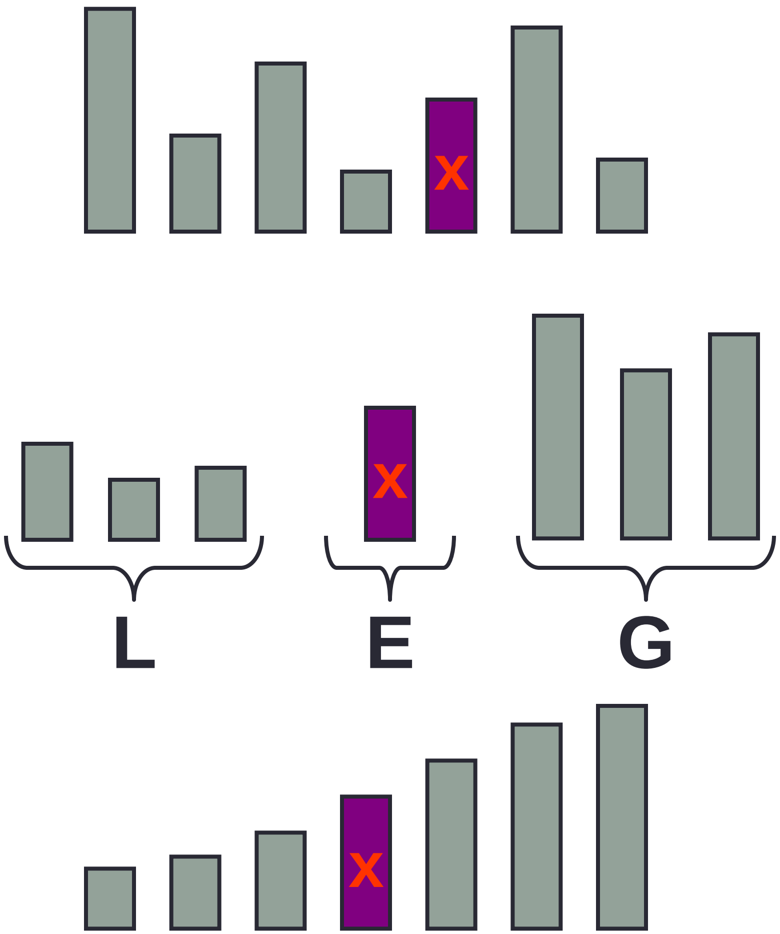
{ 7, 2, 8, 5, 4 }

Quick Sort

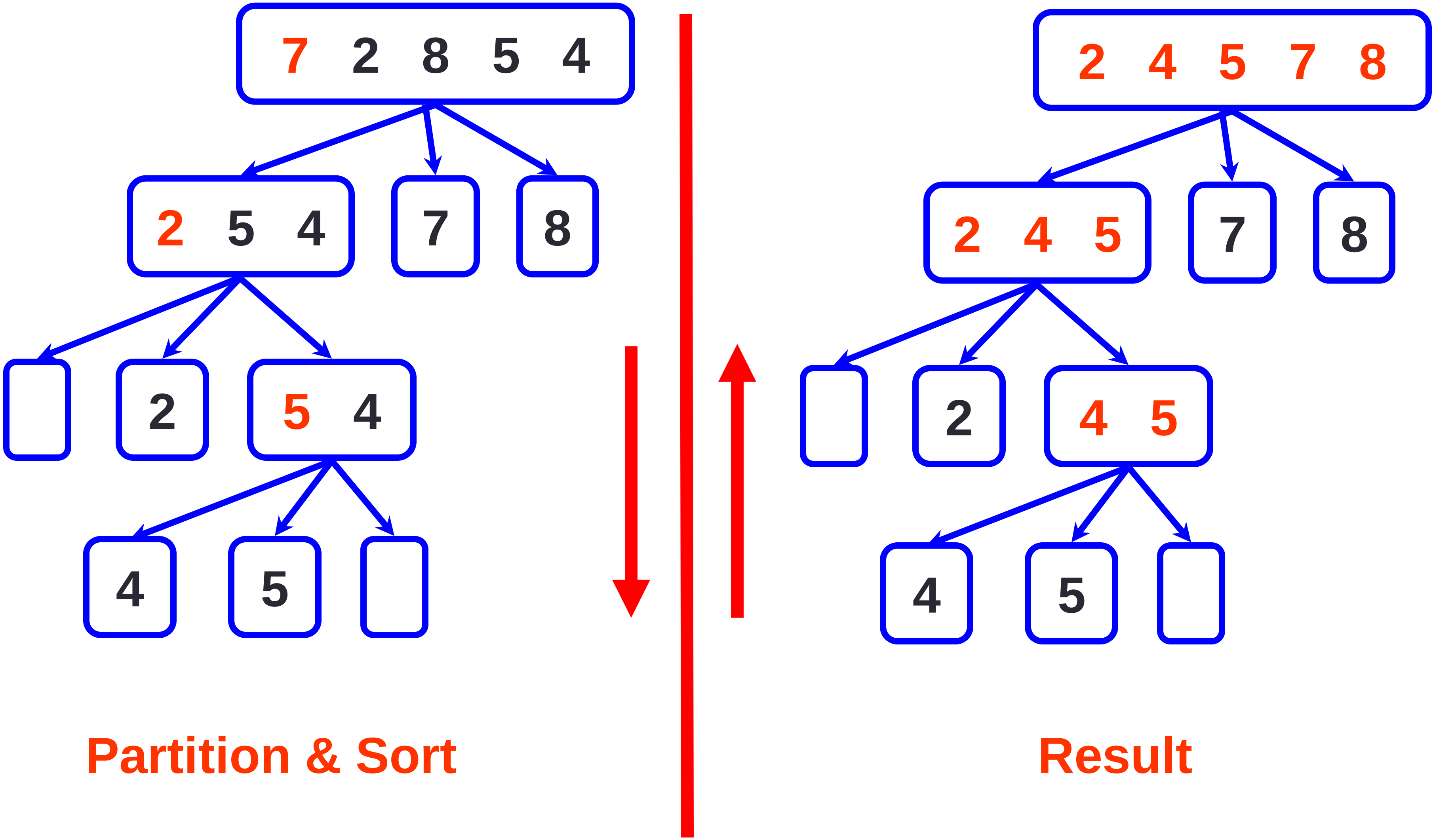
- Approach
  1. Select pivot value (near median of list)
  2. Partition elements (into 2 lists) using pivot value
  3. Recursively sort both resulting lists
  4. Concatenate resulting lists
  5. For efficiency pivot needs to partition list evenly
- Performance
  - O(n log(n)) average case
  - O(n^2) 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



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
}
```

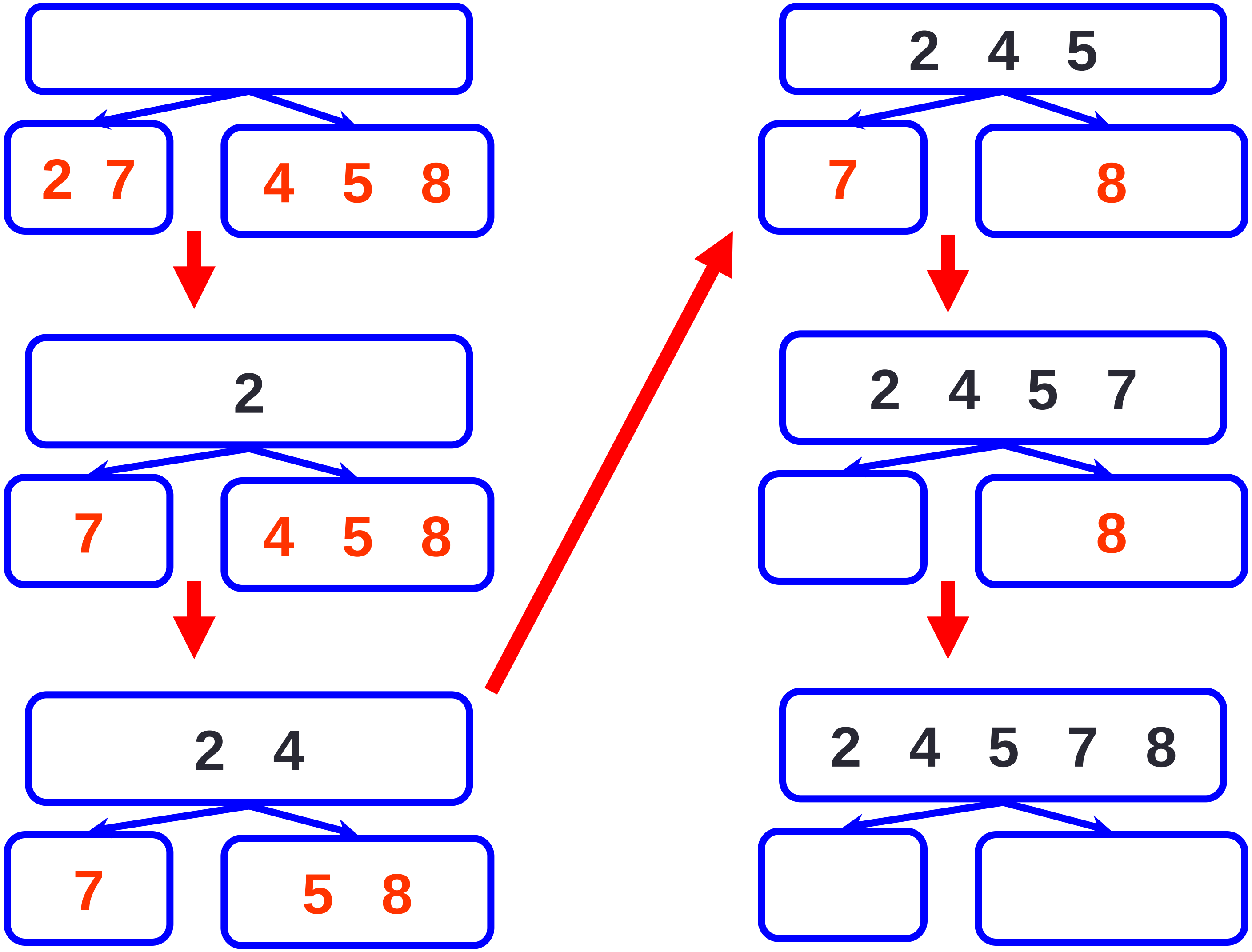
Quick Sort Code

```
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;
}
```

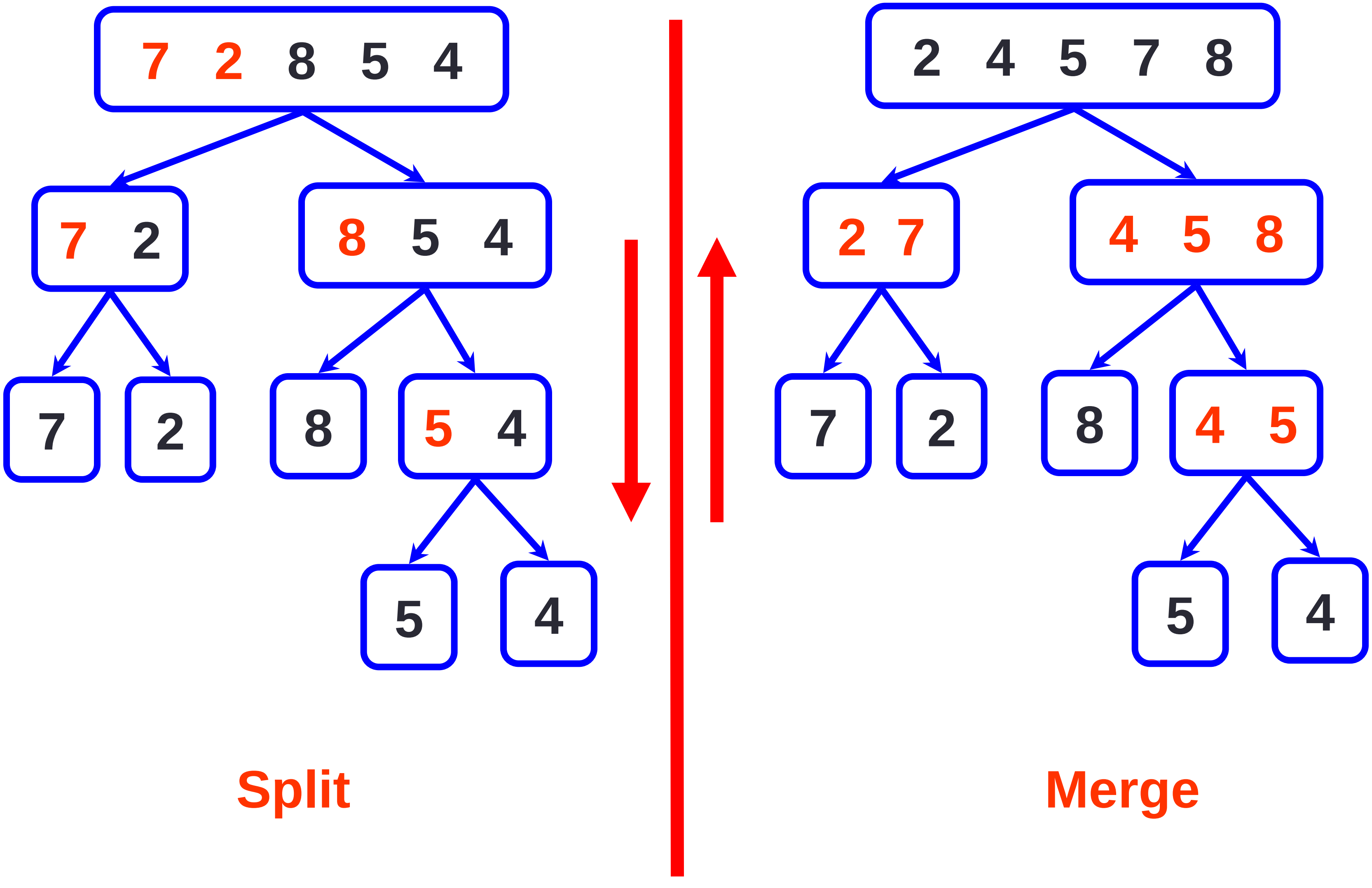
Merge Sort

- Approach
  1. Partition list of elements into 2 lists
  2. Recursively sort both lists
  3. 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	√	$O(n^2)$	$O(n^2)$	√	√
Selection	√	$O(n^2)$	$O(n^2)$	√	√
Tree	√	$O(n \log(n))$	$O(n^2)$		
Heap	√	$O(n \log(n))$	$O(n \log(n))$		
Quick	√	$O(n \log(n))$	$O(n^2)$	√	
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/
- 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