Sorting Algorithms

Sorting: Arranging data in a specific order (ascending or descending)

Applications of Sorting Algorithms

- Arranging student records by marks or names
- Sorting products by price, rating, or popularity in e-commerce apps
- Organizing files and folders by name, size, or date modified
- Displaying leaderboard rankings in games

Example:
Imagine a baseball team is lined up on the field, as shown in Figure 3.1. You want to arrange the players in order of increasing height (with the shortest player on the left) for the team picture. How would you go about this sorting process?

FIGURE 3.1 The unordered baseball team.

FIGURE 3.2 The ordered baseball team.

Bubble Sort

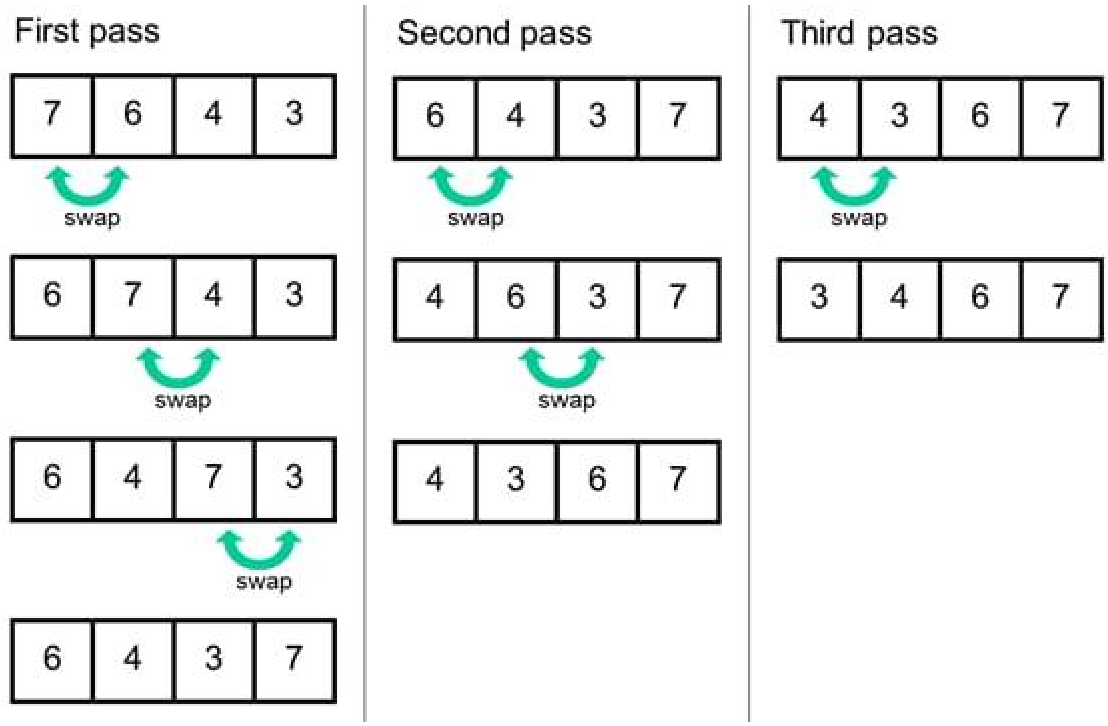
A simple comparison-based sorting algorithm

It repeatedly compares and swaps **adjacent elements** until the list is sorted.

How It Works:

- Start at the beginning of the array.
- Compare each pair of adjacent elements.
- Swap them if they are in the wrong order.
- After each pass, the largest element is placed at the end.
- Repeat until the array is sorted

Example: Here is an array `[7, 6, 4, 3]` being sorted using **Bubble Sort**.



Best Case *(Already Sorted)*: **O(n)**

Worst Case (*Reversed Order*): **O(n²)**

Pseudocode:

```
Algorithm: Sequential-Bubble-Sort (A)
for i ← 1 to length [A] do
for j ← length [A] down-to i +1 do
   if A[A] < A[j-1] then
      Exchange A[j] ↔ A[j-1]
```

Java Code for Bubble Sort

```
import java.io.*;
import java.util.*;
public class BubbleSort {
   public static void main(String args[]) {
      int n = 5;
      int[] arr = {67, 44, 82, 17, 20}; //initialize an array
      System.out.print("Array Before Sorting: ");
      for(int i = 0; i<n; i++)
         System.out.print(arr[i] + " ");
      System.out.println();
      for(int i = 0; i<n; i++) {
         int swaps = 0; //flag to detect any swap is there or
not
         for(int j = 0; j<n-i-1; j++) {
            if(arr[j] > arr[j+1]) { //when the current item is
bigger than next
               int temp;
               temp = arr[j];
               arr[j] = arr[j+1];
               arr[j+1] = temp;
               swaps = 1; //set swap flag
            }
         }
         if(swaps == 0)
            break;
      }
      System.out.print("Array After Sorting: ");
      for(int i = 0; i<n; i++)
```

```
            System.out.print(arr[i] + " ");
        System.out.println();
    }
}
```

Output:

```
Array Before Sorting: 67 44 82 17 20
Array After Sorting: 17 20 44 67 82
```

Usage Limitations

- Inefficient for large datasets (Time complexity: **$O(n^2)$**)
- Involves many swap operations, increasing **memory write overhead**
- Not suitable for **real-time or performance-critical systems**

Real-World Applications

- Small clinics: Sorting 10–15 patient files by appointment time manually
- Freelancing: Organizing 8–12 invoices by payment amount in a spreadsheet
- Team stand-ups: Prioritizing 5–10 tasks on a whiteboard by estimated completion time
- IoT devices: Sorting 10–20 sensor readings on low-power embedded systems
- Classroom use: Arranging student presentation order manually based on duration

Common Mistakes

- ❌ Not using the `swapped` flag → leads to unnecessary passes on already sorted data
- ❌ Incorrect loop boundaries → may cause **ArrayIndexOutOfBoundsException**
- ❌ Using Bubble Sort in real systems where efficiency matter

Question:

You are given the following array:
`[29, 10, 14, 37, 14]`

1. Sort the array using **Bubble Sort**.
2. How many **swaps** are made in total?

Selection Sort

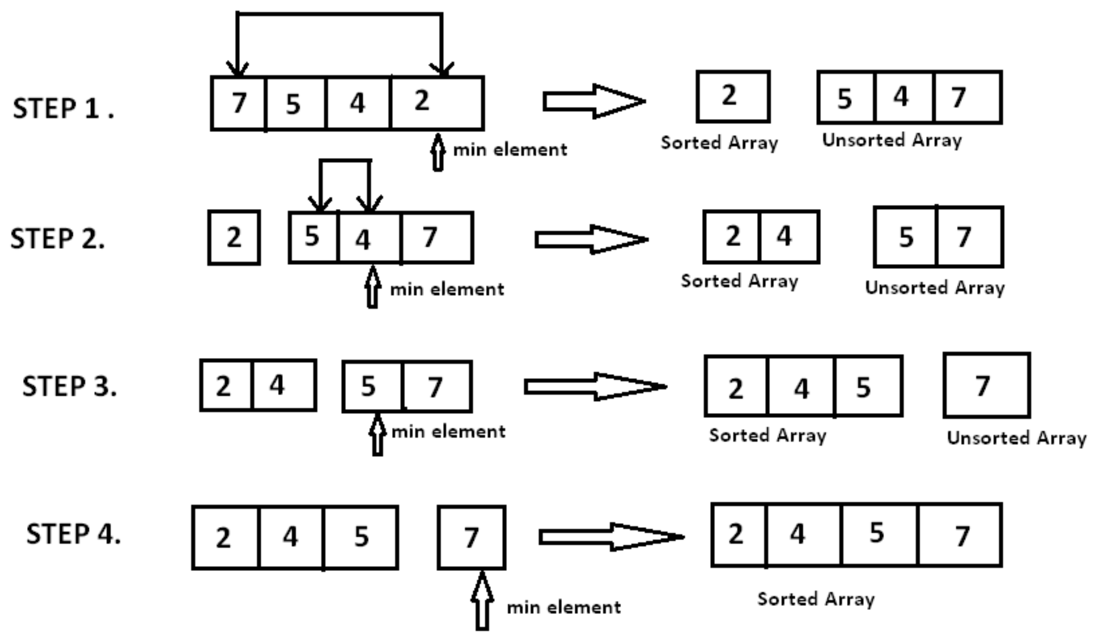
Selection Sort works by **repeatedly selecting the smallest (or largest)** element from the unsorted portion and moving it to the correct position.

It divides the list into a **sorted and an unsorted part**, growing the sorted portion one element at a time.

How It Works:

- Start with the first element as the minimum. Scan the unsorted part to find the actual minimum.
- Swap it with the first unsorted element.
- Move the boundary of the sorted portion forward by one.
- Repeat until the entire array is sorted.

Example: Here is an array `[7, 5, 4, 2]` being sorted using **Selection Sort**.



Best Case: **O(n²)**

Worst Case: **O(n²)**

Pseudocode:

```
Algorithm: Selection-Sort (A)
fori← 1 to n-1 do
   min j ←i;
   min x ← A[i]
   for j ←i + 1 to n do
      if A[j] < min x then
         min j ← j
         min x ← A[j]
   A[min j] ← A [i]
   A[i] ← min x
```

Java Code for Selection Sort

```java
import java.io.*;
public class SelectionSort {
   public static void main(String args[]) {
      int n = 5;
      int[] arr = {12, 19, 55, 2, 16}; //initialize an array
      System.out.print("Array Before Sorting: ");
      for(int i = 0; i<n; i++)
         System.out.print(arr[i] + " ");
      System.out.println();
      int imin;
      for(int i = 0; i<n-1; i++) {
         imin = i; //get index of minimum data
         for(int j = i+1; j<n; j++)
            if(arr[j] < arr[imin])
               imin = j;

         //placing in correct position
         int temp;
```

```
            temp = arr[i];
            arr[i] = arr[imin];
            arr[imin] = temp;
         }
         System.out.print("Array After Sorting: ");
         for(int i = 0; i<n; i++)
            System.out.print(arr[i] + " ");
         System.out.println();
      }
   }
```

Output:

```
Array Before Sorting: 12 19 55 2 16
Array After Sorting: 2 12 16 19 55
```

Usage Limitations

- Always performs $O(n^2)$ comparisons, regardless of initial order
- Inefficient for large datasets despite fewer swaps
- Not stable by default (may change the order of equal elements)
- Less cache-friendly compared to divide-and-conquer sorts
- Not ideal for real-time, high-performance systems

Real-World Applications

- Sorting a list of assignments by deadline for planning
- Organizing a playlist by song length for quick selections
- Arranging books by height on a small shelf
- Ordering small batches of quiz scores in a classroom
- Sorting expiry dates in a small grocery inventory

Common Mistakes

- Forgetting to update the minimum (or maximum) index during the inner loop
- Setting wrong loop boundaries, causing skipped elements or errors
- Swapping an element with itself unnecessarily

Question:
Sort the array `[29, 20, 73, 34, 64]` using **Selection Sort**.

1. Show the array after each **selection and swap**.
2. How many **total comparisons and swaps** were made?

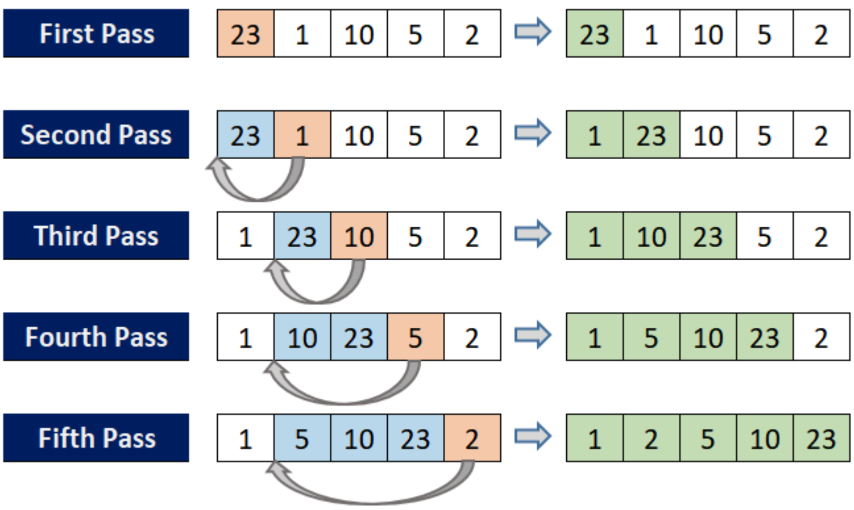
Insertion Sort

Insertion Sort works by building a sorted sequence one element at a time.
It starts with the **second element**, comparing it with the previous elements, and inserting it into its correct position.
This process repeats until the entire list is sorted.

How It Works:

- Consider the first element as sorted.
- Pick the next element and compare it with the sorted portion.
- Shift larger elements to the right to make space.
- Insert the element in its correct position.
- Repeat until all elements are sorted.

Example: Here is an array `[23, 1, 10, 5, 2]` being sorted using **Insertion Sort**.



Best Case (Already Sorted): **O(n)**

Worst Case (Reversed Order): **O(n^2)**

Pseudocode:

```
Algorithm: Insertion-Sort (A)
for j = 2 to A.length -1
   key = A[j]
   i = j - 1
   while i >=0 and A[i] > key
      A[i+1] = A[i]
      i = i - 1
   A[i + 1] = key
```

Java Code for Insertion Sort

```
import java.io.*;
public class InsertionSort {
   public static void main(String args[]) {
      int n = 5;
      int[] arr = {44, 80, 67, 155, 12}; //initialize an array
      System.out.print("Array Before Sorting: ");
      for(int i = 0; i<n; i++)
          System.out.print(arr[i] + " ");
      System.out.println();
      for(int i = 1; i<n; i++) {
           int key = arr[i]; //take value
           int j = i;
           while(j>0 && arr[j-1]>key){
               arr[j] = arr[j-1];
               j-- ;
          }
           arr[j] = key; //insert in right place
          }
          System.out.print("Array After Sorting: ");
```

```java
            for(int i = 0; i<n; i++)
                System.out.print(arr[i] + " ");
            System.out.println();
        }
}
```

Output:

```
Array Before Sorting: 44 80 67 155 12
Array After Sorting: 12 44 67 80 155
```

Usage Limitations

- Worst-case and average-case performance is $O(n^2)$ – not ideal for large datasets
- May require many shifts in totally unsorted data
- Not suitable for heavy, real-time data processing
- Less cache-efficient than certain divide-and-conquer algorithms
- Best used on small or nearly sorted arrays

Real-World Applications

- Maintaining a sorted music playlist as new songs are added
- Inserting patient arrival times into a pre-sorted appointment schedule
- Organizing library books as new ones arrive
- Keeping a small real-time log sorted in embedded systems
- Updating casual game leaderboards dynamically

Common Mistakes

- Starting from the wrong index (should start at index 1)
- Failing to store the current element (key) before shifting
- Using swaps instead of shifting elements

- Incorrect inner loop conditions leading to errors or infinite loops

Question:
Sort the array `[22, 11, 99, 88, 9, 7, 42]` using **Insertion Sort**.

1. Show the array after each **insertion step**.
2. How many **shifts** were made in total?

Merge Sort

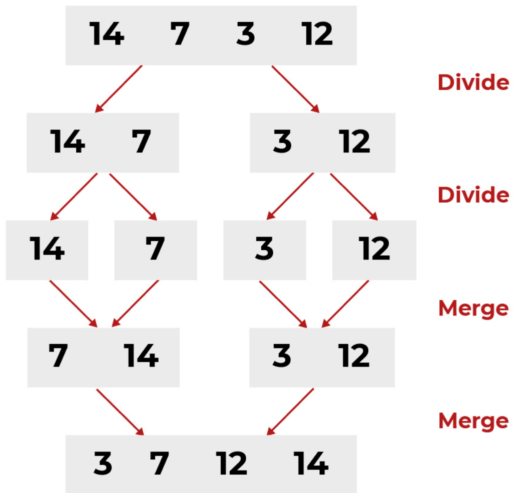
Merge Sort is a powerful **divide-and-conquer** sorting algorithm.

It works by **recursively dividing** the array into two halves.

How It Works:

- Divide the array into two halves.
- Recursively apply merge sort to each half.
- Once the halves are sorted, **merge them** by comparing and arranging elements.
- Repeat this process until the entire array is merged and sorted.

Example: Here is an array `[14, 7, 3, 12]` being sorted using **Merge Sort**.



Best Case: **O(n log n)**

Worst Case: **O(n log n)**

Pseudocode:

```
procedure mergesort( var a as array )
   if ( n == 1 ) return a
      var l1 as array = a[0] ... a[n/2]
      var l2 as array = a[n/2+1] ... a[n]
      l1 = mergesort( l1 )
      l2 = mergesort( l2 )
      return merge( l1, l2 )
end procedure
procedure merge( var a as array, var b as array )
   var c as array
   while ( a and b have elements )
      if ( a[0] > b[0] )
         add b[0] to the end of c
         remove b[0] from b
      else
         add a[0] to the end of c
         remove a[0] from a
      end if
   end while
   while ( a has elements )
      add a[0] to the end of c
      remove a[0] from a
   end while
   while ( b has elements )
      add b[0] to the end of c
      remove b[0] from b
   end while
   return c
end procedure
```

Java Code for Merge Sort

```java
public class Merge_Sort {
```

```
   static int a[] = { 5, 44, 32, 122, 0, 41, 73, 92, 99, 54,
12 };
   static int b[] = new int[a.length];
// Function to merge two sorted subarrays
   static void merging(int low, int mid, int high) {
      int l1, l2, i;
        // l1 = start of left subarray
       // l2 = start of right subarray
       // i = current index in merged array

      for(l1 = low, l2 = mid + 1, i = low; l1 <= mid && l2 <=
high; i++) {
         if(a[l1] <= a[l2])   // If left element is smaller, copy
it
            b[i] = a[l1++];
         Else                     // Else copy right element
            b[i] = a[l2++];
      }
      while(l1 <= mid)
         b[i++] = a[l1++];
      while(l2 <= high)
         b[i++] = a[l2++];
      for(i = low; i <= high; i++)
         a[i] = b[i];
   }

// Recursive Merge Sort function
   static void sort(int low, int high) {
      int mid;
      if(low < high) {
         mid = (low + high) / 2;   // Find the middle index
         sort(low, mid);           // Sort the left half
         sort(mid+1, high);        // Sort the right half
         merging(low, mid, high);  // Merge the two halves
      } else {
         return;          // Base case: only one element

      }
```

```
    }
    public static void main(String args[]) {
        int i;
        int n = a.length;
        System.out.println("Array Before sorting");
        for(i = 0; i < n; i++)
            System.out.print(a[i] + " ");
        sort(0, n-1);
        System.out.println("\nArray After sorting");
        for(i = 0; i < n; i++)
             System.out.print(a[i]+" ");
    }
}
```

Output:

```
Array Before Sorting: 5 44 32 122 0 41 73 92 99 54 12
Array After Sorting: 0 5 12 32 41 44 54 73 92 99 122
```

Usage Limitations

- Requires additional memory (not an in-place algorithm)
- Slower than Quick Sort in practice due to memory allocation
- Overhead of recursive calls may be costly for small arrays

Real-World Applications

- Sorting large datasets in databases or external files
- Merging sorted logs in system backups or version control
- Sorting linked lists (efficient due to pointer manipulation)
- Handling huge numeric arrays in scientific computations
- Used in standard libraries (e.g., Java, Python for stable sorts)

Common Mistakes

- Forgetting to allocate temporary arrays for merging
- Incorrect merge logic causing out-of-bounds or skipped elements
- Not handling base cases correctly in recursion

Question:
Sort the array `[38, 27, 43, 3, 9, 82, 10]` using **Merge Sort**.

1. Show the array as it is **divided** step by step.
2. Show the **merge steps** and how sorted subarrays are formed.

Quick Sort

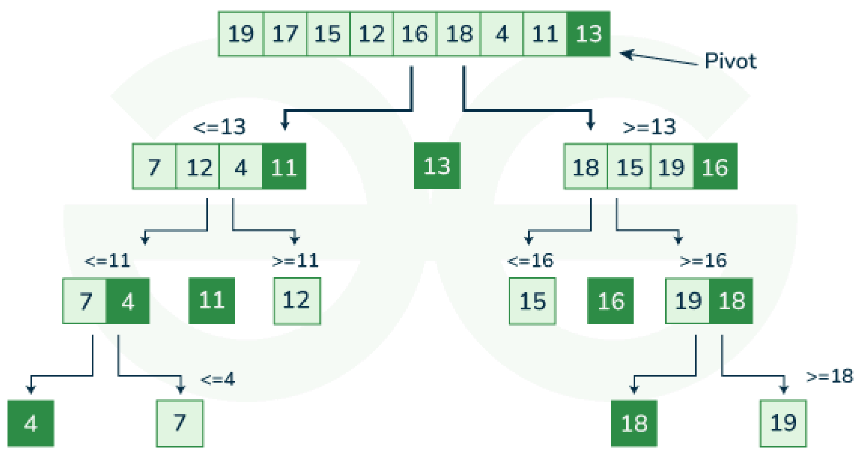
Quick Sort is a highly efficient **divide-and-conquer** algorithm.

It works by selecting a **pivot** element.

How It Works:

- Choose a **pivot** element
- **Partition** the array: place smaller elements on the left, larger on the right.
- Recursively apply quick sort to the left and right subarrays.
- Combine the results – the array becomes fully sorted.

Example: Here is an array `[19, 17, 15, 12, 16, 18, 4, 11, 13]` being sorted using **Quick Sort**.



Best Case: **O(n log n)**

Worst Case: **O(n²)**

Pseudocode:

```
procedure quickSort(A, left, right)
    if left >= right then
        return
    else
        pivot ← A[right]
        partitionIndex ← partition(A, left, right, pivot)
        quickSort(A, left, partitionIndex - 1)
        quickSort(A, partitionIndex + 1, right)
    end if
end procedure
```

Java Code for Quick Sort

```
import java.util.Arrays;

public class QuickSort {

    int[] intArray = {4, 6, 3, 2, 1, 9, 7};

    // Swap function to exchange two elements in the array
    void swap(int num1, int num2) {
        int temp = intArray[num1];
        intArray[num1] = intArray[num2];
        intArray[num2] = temp;
    }

    // Partition function to rearrange elements around the pivot
    int partition(int left, int right, int pivot) {
        int leftPointer = left;         // Start from left
        int rightPointer = right - 1;   // Start just before the
pivot

        while (true) {
            // Move leftPointer to the right until an element >=
pivot is found
```

```
            while (leftPointer <= rightPointer &&
intArray[leftPointer] < pivot)
                leftPointer++;

            // Move rightPointer to the left until an element <=
pivot is found
            while (rightPointer >= leftPointer &&
intArray[rightPointer] > pivot)
                rightPointer--;

           // If pointers cross, partitioning is done
            if (leftPointer >= rightPointer)
                break;
            else
                swap(leftPointer, rightPointer); // Swap
elements to correct sides
        }

       // Swap pivot element to its correct position
        swap(leftPointer, right);
        return leftPointer;
    }

    // Recursive Quick Sort function
    void quickSort(int left, int right) {
        // Base case: if the section is 1 or 0 elements, it's
already sorted
        if (left >= right) return;

        // Choose the last element as pivot
        int pivot = intArray[right];

        // Partition the array and get the pivot's final index
        int partitionPoint = partition(left, right, pivot);

        quickSort(left, partitionPoint - 1);     // Sort left
side
        quickSort(partitionPoint + 1, right);    // Sort right
side
    }

    public static void main(String[] args) {
        QuickSort sort = new QuickSort();
        System.out.println("Contents of the array:");
```

```
        System.out.println(Arrays.toString(sort.intArray));

        sort.quickSort(0, sort.intArray.length - 1);

        System.out.println("Contents of the array after
sorting:");
        System.out.println(Arrays.toString(sort.intArray));
    }
}
```

```
Output:
Contents of the array: [4, 6, 3, 2, 1, 9, 7]
Contents of the array after sorting: [1, 2, 3, 4, 6, 7, 9]
```

Usage Limitations

- Worst-case time complexity is $O(n^2)$ (e.g., already sorted input with poor pivot)
- Recursive calls can lead to stack overflow for large arrays
- Performance depends heavily on pivot selection

Real-World Applications

- General-purpose in-memory sorting (used in many libraries)
- Sorting datasets in web servers or applications for fast response
- Efficient sorting in competitive programming and embedded systems
- Often used in C/C++ standard sort implementations (e.g., `qsort()`)

Common Mistakes

- Choosing a poor pivot (e.g., always first/last element) causing worst-case performance

- Not partitioning correctly → elements can end up in the wrong segment
- Forgetting to reduce the recursive range (infinite recursion)

Question:
Sort the array `[45, 23, 78, 10, 89, 34]` using **Quick Sort**.

1. Use the **last element as pivot**.
2. Show the **partitioning steps** and pivot placement after each round.

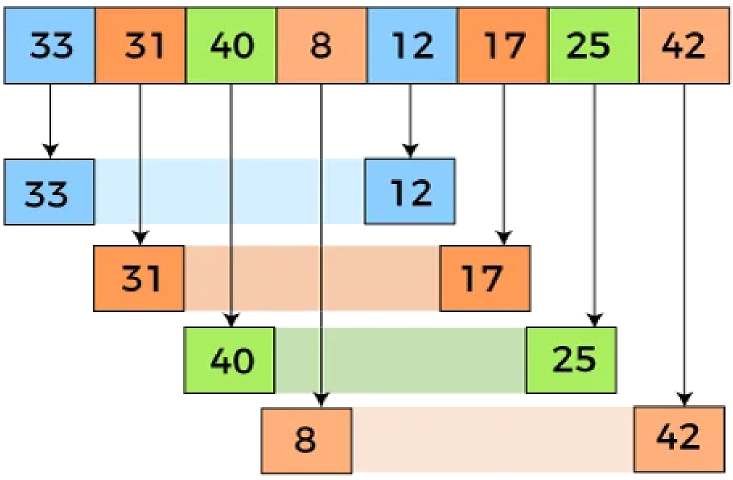
Shell Sort

Shell Sort is an optimized version of Insertion Sort
It works by sorting elements that are a certain **gap** distance apart and then gradually reducing the gap.

How It Works:

- Start with a large **gap** between elements (e.g., n/2).
- Sort elements at that gap distance using Insertion Sort.
- Reduce the gap and repeat the process.
- Continue until the gap is 1 — final pass is like regular Insertion Sort.

Example: Here is an array `[33, 31, 40, 8, 12, 17, 25, 42]` being sorted using **Shell Sort**.



Best Case: **O(n log n)** (depends on gap sequence)

Worst Case: **O(n²)** (for some gap sequences)

Pseudocode:

```
procedure shellSort(A)
    n ← length of A
    interval ← 1

    // Calculate initial interval
 interval = interval * 3 + 1
    while interval < n / 3 do
        interval ← interval * 3 + 1
    end while

    // Start with the largest interval and reduce it each iteration
    while interval > 0 do
        for outer ← interval to n - 1 do
            valueToInsert ← A[outer]
            inner ← outer

            // Shift elements to the right until correct position
is found
            while inner ≥ interval and A[inner - interval] >
valueToInsert do
                A[inner] ← A[inner - interval]
                inner ← inner - interval
            end while

            // Insert the value at its correct position
            A[inner] ← valueToInsert
        end for

        // Reduce interval
        interval ← (interval - 1) / 3
    end while
end procedure
```

Java Code for Shell Sort

```java
import java.io.*;
```

```java
import java.util.*;
public class ShellSort {
   public static void main(String args[]) {
      int n = 5;
      int[] arr = {33, 45, 62, 12, 98}; //initialize an array
      System.out.print("Array Before Sorting: ");
      for(int i = 0; i<n; i++)
         System.out.print(arr[i] + " ");
      System.out.println();
      int gap;
      for(gap = n/2; gap > 0; gap = gap / 2) { //initially gap =
n/2, decreasing by gap /2
         for(int j = gap; j<n; j++) {
            for(int k = j-gap; k>=0; k -= gap) {
               if(arr[k+gap] >= arr[k])
                  break;
               else {
                  int temp;
                  temp = arr[k+gap];
                  arr[k+gap] = arr[k];
                  arr[k] = temp;
               }
            }
         }
      }
      System.out.print("Array After Sorting: ");
      for(int i = 0; i<n; i++)
         System.out.print(arr[i] + " ");
      System.out.println();
   }
}
```

Output:

```
Array Before Sorting: 33 45 62 12 98
Array After Sorting:  12 33 45 62 98
```

Usage Limitations

- Gap sequence selection greatly affects performance
- Not stable (can change the order of equal elements)
- Harder to understand/teach compared to simpler sorts
- Less commonly used in modern libraries due to unpredictability

Real-World Applications

- Sorting **medium-sized arrays** with better performance than Bubble/Insertion
- Used in **embedded systems** where recursion (like in Merge/Quick Sort) isn't preferred
- Effective in **real-time systems** when good gap sequences are chosen
- Suitable for **in-place sorting** where memory is limited
- Sometimes used in **hardware sorting implementations**

Common Mistakes

- ❌ Using poor or fixed gap sequences (like halving) without analysis
- ❌ Misunderstanding inner loop logic—needs to sort elements at gap distance
- ❌ Forgetting to update the gap correctly → leads to infinite loops
- ❌ Assuming stability without verifying implementation

Question:
Sort the array `[64, 34, 25, 12, 22, 11, 90]` using **Shell Sort**.

1. Use **gap sequence: n/2, n/4, ..., 1**.
2. Show the array after each gap-based pass.
3. How is this more efficient than regular Insertion Sort for this input?

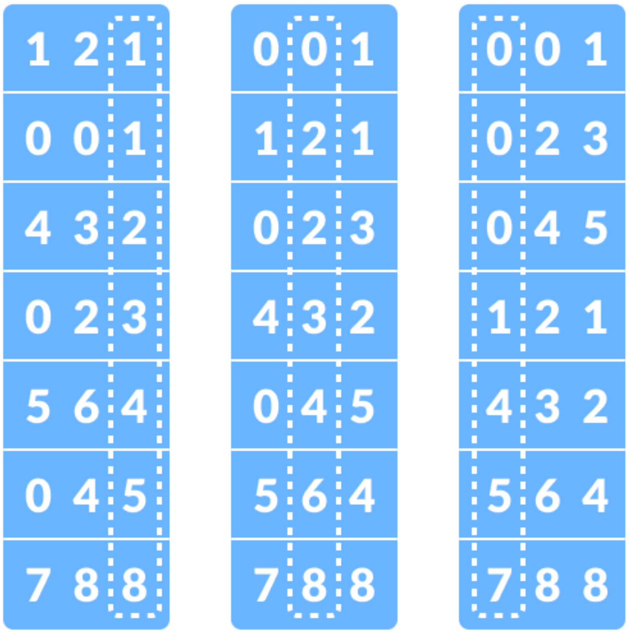
Radix Sort

Radix Sort is a **non-comparison-based** sorting algorithm
It works by sorting numbers digit by digit, starting from the **least significant digit (LSD)** to the **most significant digit (MSD)**.

How It Works:

- Find the maximum number to determine the number of digits.
- Sort the numbers **based on each digit**, starting from the least significant.
- Use a **stable sort** (like Counting Sort) at each digit level.
- Repeat the process for each digit place until the entire list is sorted.

Example:



Best Case: **O(nk)**

Worst Case: **O(nk)**
(n = number of elements, k = number of digits in the largest number)

Pseudocode:

```
Algorithm: RadixSort(a[], n)

    // Step 1: Find the maximum number to know the number of digits
```

```
max = a[0]
for i = 1 to n-1 do
   if a[i] > max then
      max = a[i]

// Step 2: Apply counting sort for every digit place
pos = 1
while max / pos > 0 do
   countSort(a, n, pos)
   pos = pos * 10
```

Java Code for Radix Sort

```java
import java.io.*;
public class Main {
   static void countsort(int a[], int n, int pos) {
      int output[] = new int[n + 1];
      int max = (a[0] / pos) % 10;
      for (int i = 1; i < n; i++) {
         if (((a[i] / pos) % 10) > max)
            max = a[i];
      }
      int count[] = new int[max + 1];
      for (int i = 0; i < max; ++i)
         count[i] = 0;
      for (int i = 0; i < n; i++)
         count[(a[i] / pos) % 10]++;
      for (int i = 1; i < 10; i++)
         count[i] += count[i - 1];
      for (int i = n - 1; i >= 0; i--) {
         output[count[(a[i] / pos) % 10] - 1] = a[i];
         count[(a[i] / pos) % 10]--;
      }
      for (int i = 0; i < n; i++)
         a[i] = output[i];
   }
   static void radixsort(int a[], int n) {
      int max = a[0];
      for (int i = 1; i < n; i++)
```

```
            if (a[i] > max)
                max = a[i];
        for (int pos = 1; max / pos > 0; pos *= 10)
            countsort(a, n, pos);
    }
    public static void main(String args[]) {
        int a[] = {236, 15, 333, 27, 9, 108, 76, 498};
        int n = a.length;
        System.out.println("Before sorting array elements are: ");
        for (int i = 0; i < n; ++i)
            System.out.print(a[i] + " ");
        radixsort(a, n);
        System.out.println("\nAfter sorting array elements are: ");
        for (int i = 0; i < n; ++i)
            System.out.print(a[i] + " ");
    }
}
```

Output:

```
Before sorting array elements are: 236 15 333 27 9 108 76 498
After sorting array elements are:  9 15 27 76 108 236 333 498
```

Question:

Sort the array `[170, 45, 75, 90, 802, 24, 2, 66]` using **Radix Sort**.

1. Show how the array is sorted **digit by digit** (LSD first).
2. What stable sort would you use for each digit position?
3. How many **passes** are required for this array?

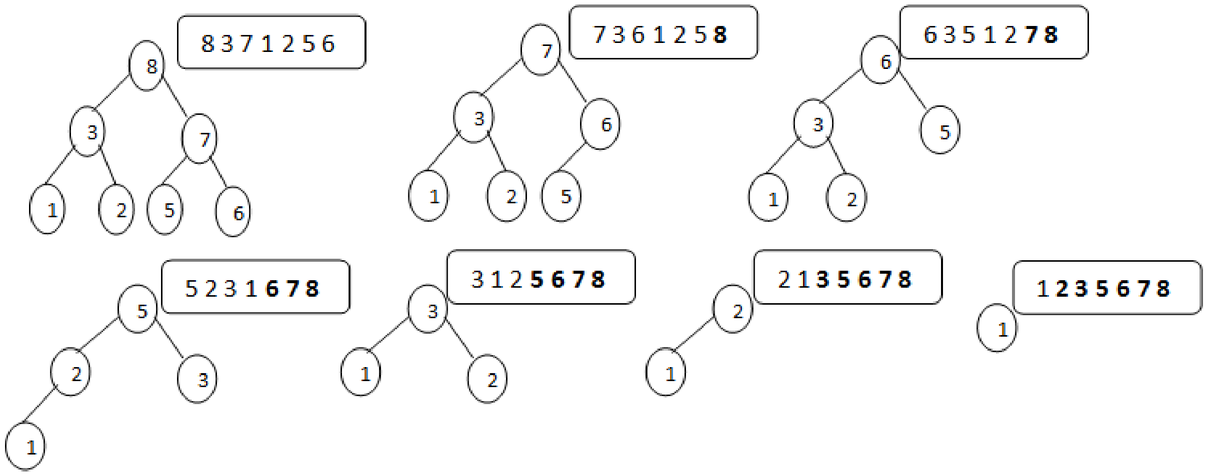
Heap Sort

Heap Sort is a **comparison-based** sorting algorithm that uses a **binary heap** data structure. It first builds a **max-heap** from the input data and then repeatedly removes the largest element (root of the heap), placing it at the end of the array.

How It Works:

- Convert the input array into a **max-heap**.
- Swap the **first (largest)** element with the last.
  Reduce the heap size and **heapify** the root.
- Repeat until all elements are sorted.

Example: Here is an array `[8, 3, 7, 1, 2, 5, 6]` being sorted using **Heap Sort**.



Best Case: **O(n log n)**

Worst Case: **O(n log n)**

Pseudocode:

```
Algorithm: HEAPSORT(A)
   BUILD-MAX-HEAP(A)
   for i = A.length downto 2 do
       exchange A[1] with A[i]
       A.heap-size = A.heap-size - 1
      MAX-HEAPIFY(A, 1)
```

Java Code for Heap Sort

```java
import java.io.*;

public class HeapSort {
    // Build Max Heap
```

```java
static void build_maxheap(int heap[], int n) {
    for (int i = 1; i < n; i++) {
        int c = i;
        do {
            int r = (c - 1) / 2;
            if (heap[r] < heap[c]) {
                int t = heap[r];
                heap[r] = heap[c];
                heap[c] = t;
            }
            c = r;
        } while (c != 0);
    }

    System.out.println("Heap array: ");
    for (int i = 0; i < n; i++) {
        System.out.print(heap[i] + " ");
    }

    sortHeap(heap, n);
}

// Sort the heap using Heap Sort logic
static void sortHeap(int heap[], int n) {
    for (int j = n - 1; j >= 0; j--) {
        int temp = heap[0];
        heap[0] = heap[j]; // swap max with last
        heap[j] = temp;

        int root = 0, c;
        do {
            c = 2 * root + 1;
            if (c + 1 < j && heap[c] < heap[c + 1]) {
                c++;
            }
            if (c < j && heap[root] < heap[c]) {
                temp = heap[root];
                heap[root] = heap[c];
```

```java
                    heap[c] = temp;
                }
                root = c;
            } while (c < j);
        }

        System.out.println("\nThe sorted array is: ");
        for (int i = 0; i < n; i++) {
            System.out.print(heap[i] + " ");
        }
    }

    public static void main(String args[]) {
        int heap[] = new int[10];
        heap[0] = 4;
        heap[1] = 3;
        heap[2] = 1;
        heap[3] = 0;
        heap[4] = 2;
        int n = 5;
        build_maxheap(heap, n);
    }
}
```

Output:

```
Heap array: 4 3 1 0 2
The sorted array is:  0 1 2 3 4
```

Usage Limitations

- Only works for integers or strings—not suitable for floating-point or complex data types
- Performance depends on the number of digits and the range of values
- Requires extra space for stable counting sort in each pass

Real-World Applications

- Sorting **postal codes** or **phone numbers**
- Arranging **large lists of student roll numbers**
- Organizing **fixed-length strings** like dates or IDs

Common Mistakes

❌ Not using a **stable sort** (like Counting Sort) → breaks sorting order

❌ Applying to data types not suited for digit-wise sorting

❌ Forgetting to handle **leading zeros** or digit lengths

❌ Miscalculating the **digit position** during iterations

Question:
Sort the array `[12, 11, 13, 5, 6, 7]` using **Heap Sort**.

1. Show how the array is converted into a **max heap**.
2. Show the array after each **extraction and heapify** step.
3. What is the **heap property**, and how does it help sorting?

Complexity Comparison Table

Algorithm	Best Case	Average Case	Worst Case
Bubble Sort	$O(n)$	$O(n^2)$	$O(n^2)$
Selection Sort	$O(n^2)$	$O(n^2)$	$O(n^2)$
Insertion Sort	$O(n)$	$O(n^2)$	$O(n^2)$
Merge Sort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$
Quick Sort	$O(n \log n)$	$O(n \log n)$	$O(n^2)$
Shell Sort	$O(n \log n)$	$O(n (\log n)^2)$	$O(n^2)$
Radix Sort	$O(nk)$	$O(nk)$	$O(nk)$
Heap Sort	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$