# DS:
# **Sorting**

Liwei

# What is sorting

- Definition: sorting refers to arranging data in a particular format: either ascending or descending.
- Example:
  - Before sorting
  - After sorting

# Sorting

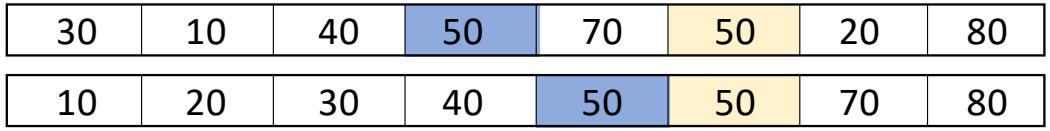
- On the basis of space used
  - In-Place
  - Out-of-place
- On the basis of Stability
  - Stable
  - Un-stable

# In-Place vs Out-Place Sorting

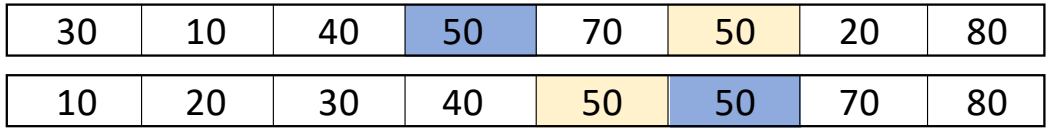
- In-Place sort:
  - Sorting algorithms which does not require any extra space for sorting
  - Example – Bubble sort
- Out-Place sort:
  - Sorting algorithms which requires extra space for sorting
  - Example – Merge sort

# Stable vs Un-Stable Sorting

- Stable sort:
  - If a sorting algorithms after sorting the contents does not change the sequence of similar content in which they appear, is called Stable sorting.
  - Example – Insertion sort




- Un-Stable sort:
  - If a sorting algorithms after sorting the contents, changes the sequence of similar content in which they appear, it is called unstable sorting.
  - Example – Quick Sort



# Why stable sort is important?

- Scenarios where sort key is not the entire identity of the item
- Consider a person object with a name and a age. Let's say we sorted based on their name. If we were to sort by age in a stable way. We'd guarantee that our original ordering would be perserved for people with the same age.

| UnSorted Data | |
|---|---|
| Name | Age |
| Reena | 1 |
| Nalini | 2 |
| Reshma | 2 |
| Preeti | 1 |
| Sita | 1 |

| **Sorted by Name** | |
|---|---|
| Name | Age |
| Nalini | 2 |
| Preeti | 1 |
| Reena | 1 |
| Reshma | 2 |
| Sita | 1 |

| **Sorted by Age** (Stable) | |
|---|---|
| Name | Age |
| Preeti | 1 |
| Reena | 1 |
| Sita | 1 |
| Nalini | 2 |
| Reshma | 2 |

| **Sorted by Age** (Unstable) | |
|---|---|
| Name | Age |
| Preeti | 1 |
| Sita | 1 |
| Reena | 1 |
| Nalini | 2 |
| Reshma | 2 |

# Bubble Sort

# What is bubble sort

- Bubble sort, sometimes is also referred as Sinking sort
- Repeatedly steps through the list to be sorted, compares each pair of adjacent items and swaps them if they are in the wrong order.

# Bubble sort algorithm

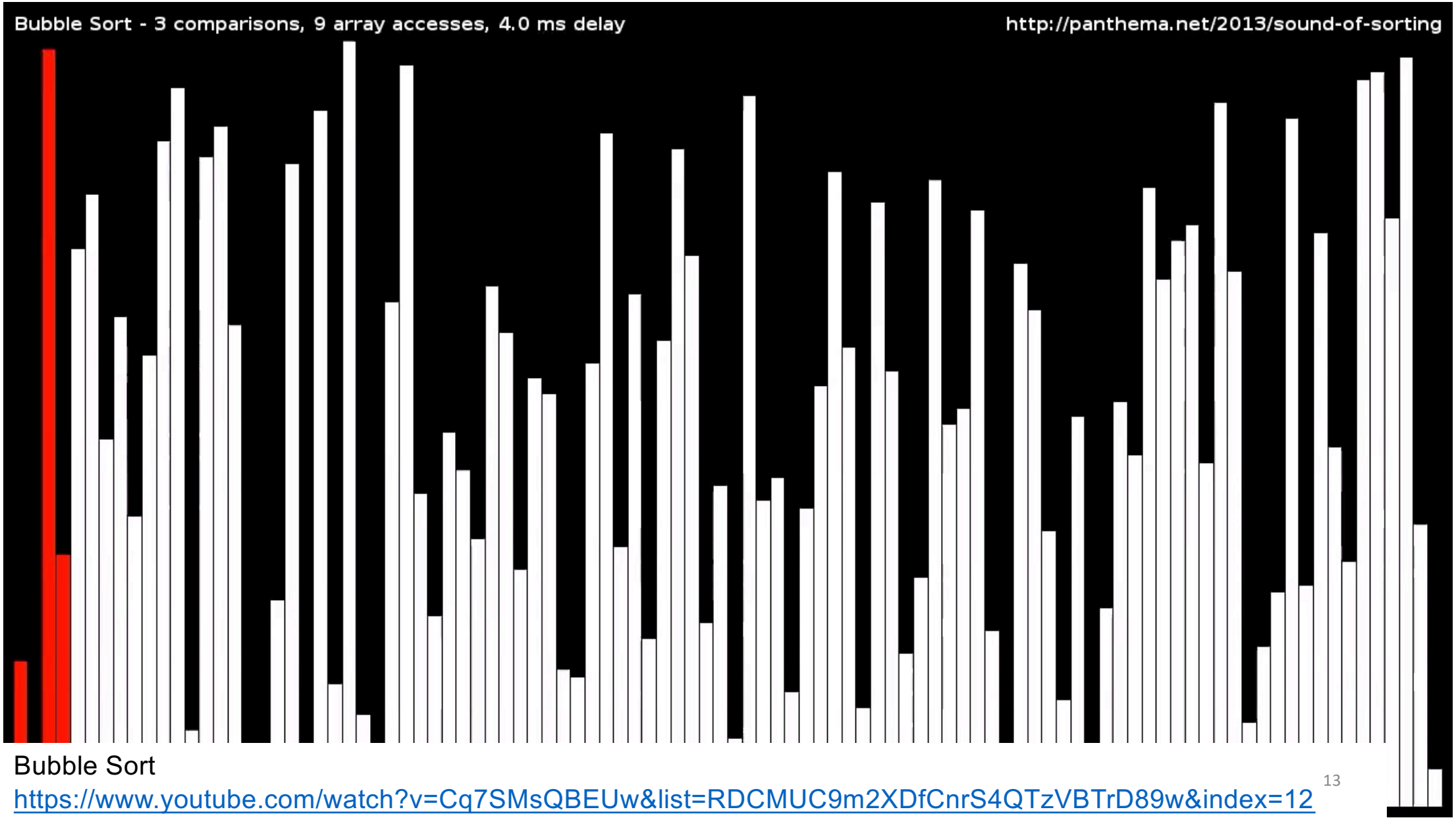
```
bubbleSort(int arr[])
        int n = arr.length
        loop i = 0 to n-1
                loop j = 0 to n-i-1
                        if(arr[j] > arr[j+1])
                                swap(arr[j], arr[j+1])
```

Time Complexity: $O(n^2)$

# When to use / avoid Bubble sort

- When to use
  - Space is a concern
  - Easy to implement

- When not to use
  - Average case time complexity is poor




Bubble Sort

https://www.youtube.com/watch?v=Cq7SMsQBEUw&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&index=12

# Selection Sort

# Selection sort

- Selection sort algorithm is based on the idea of finding the minimum or maximum element in an unsorted array and then putting it in its correct position in a sorted array.

# Selection sort algorithm

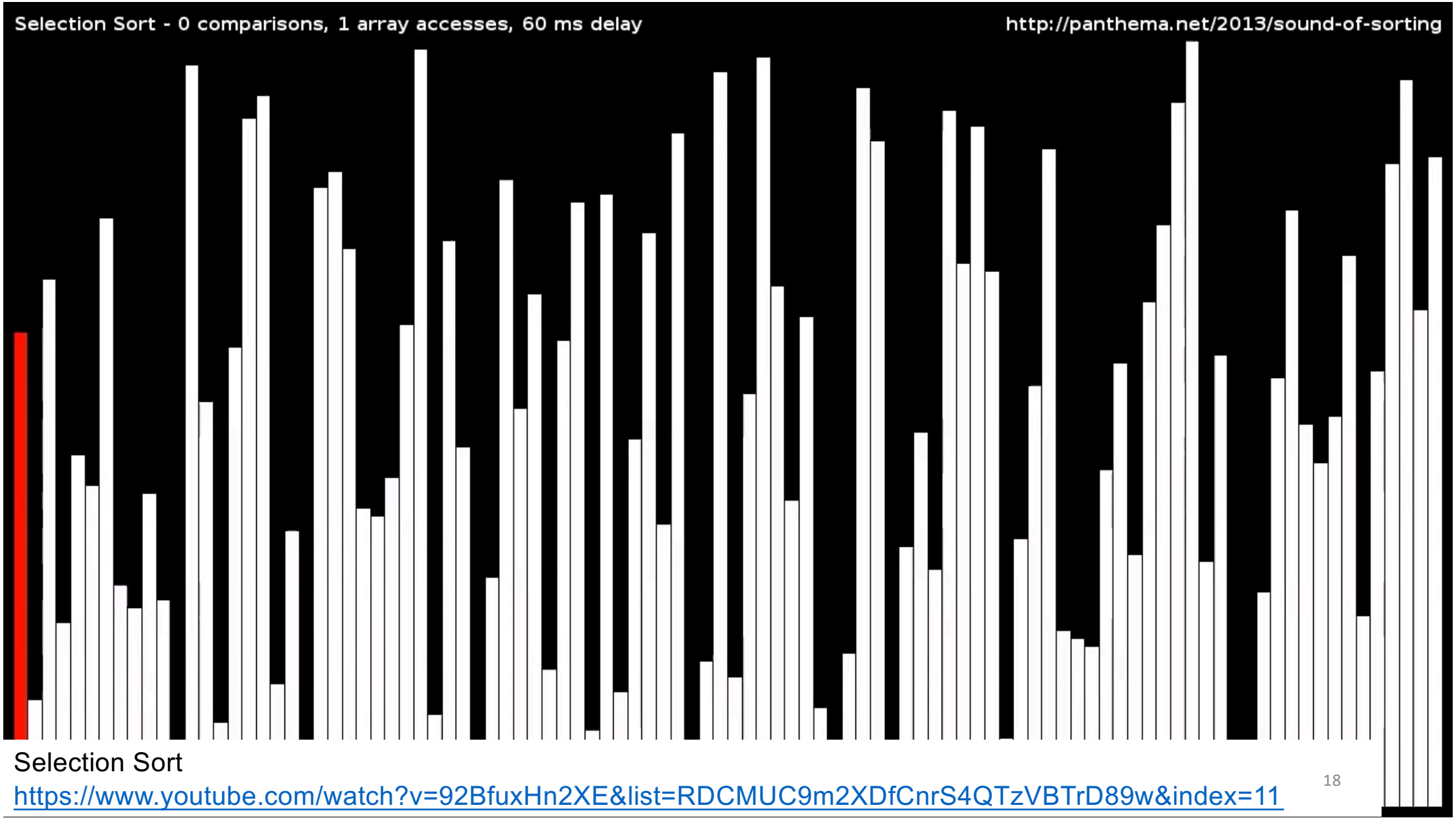
```
selectionSort(int arr[])
        loop j = 0 to n-1
                int iMin = j;
                loop i = j+1 to n-1
                        if(arr[i] < arr[iMin])
                                iMin = i;
                if (iMin != j)
                        swap(arr[j], arr[iMin])
```

Time Complexity: $O(n^2)$

# When to use / avoid Selection sort

- When to use
  - When we don’t have additional memory
  - Easy to implement

- When not to use
  - When time complexity is a concern




Selection Sort

https://www.youtube.com/watch?v=92BfuxHn2XE&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&index=11

# Insertion Sort

# Insertion sort

- In Insertion sort algorithm, we divide the given array into 2 parts. i.e., Sorted & Unsorted.
- Then from Unsorted we pick the first element and find its correct position in sorted array
- Repeat till Unsorted array is empty.

# Insertion sort algorithm

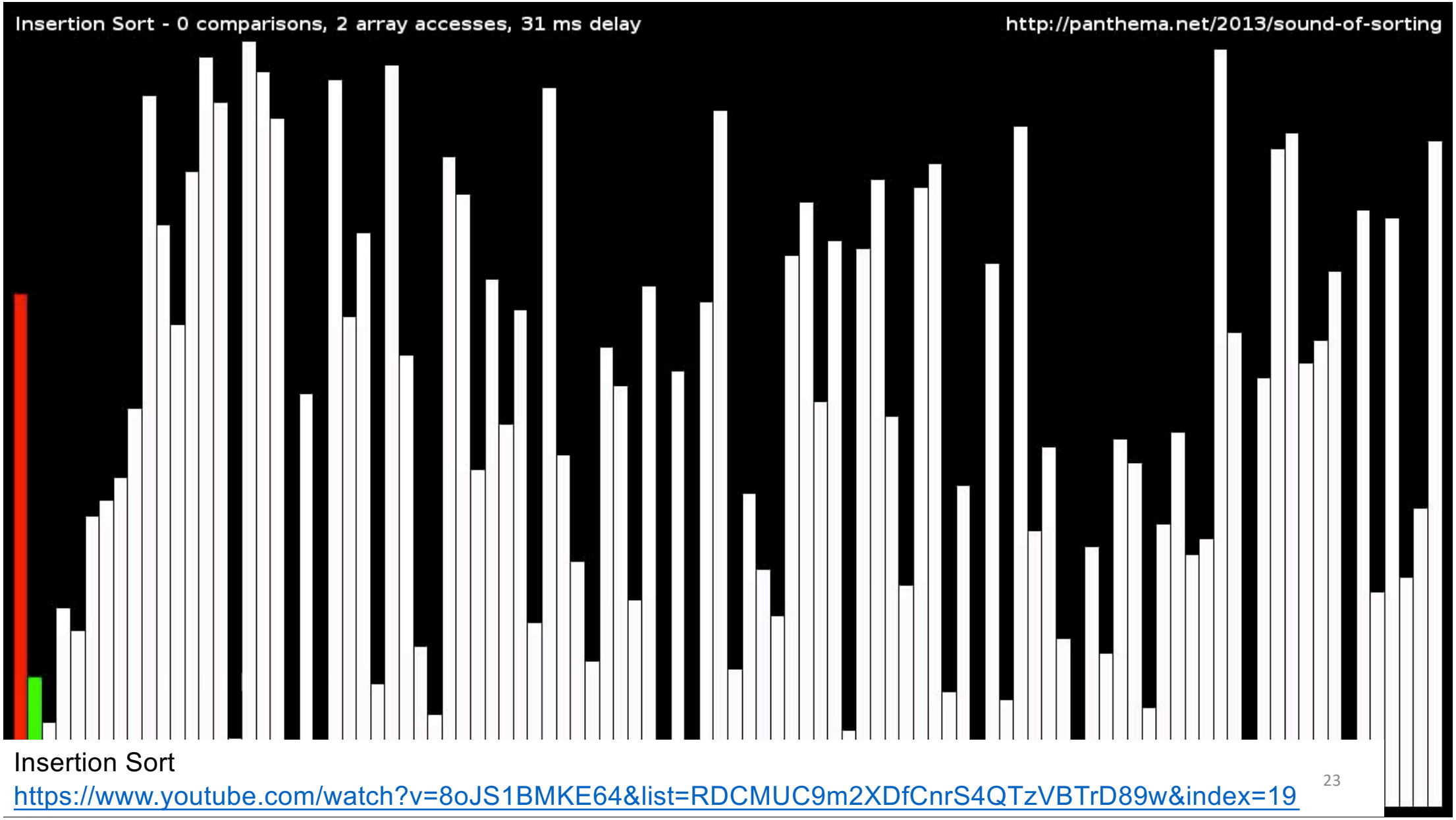
```
InsertionSort(A)
        loop i=1 to n
                currentNumber = A[i], j=i
                while (A[j-1] > currentNumber && j>0)
                        A[j] = A[j-1];
                        j--;
                A[j] = currentNumber;
```

Time Complexity: $O(n^2)$

# When to use / avoid Insertion sort

- When to use
  - No extra space
  - Easy to implement
  - Best when we have continuous inflow of numbers and we want to keep the list shorted

- When not to use
  - Average case is bad




Insertion Sort

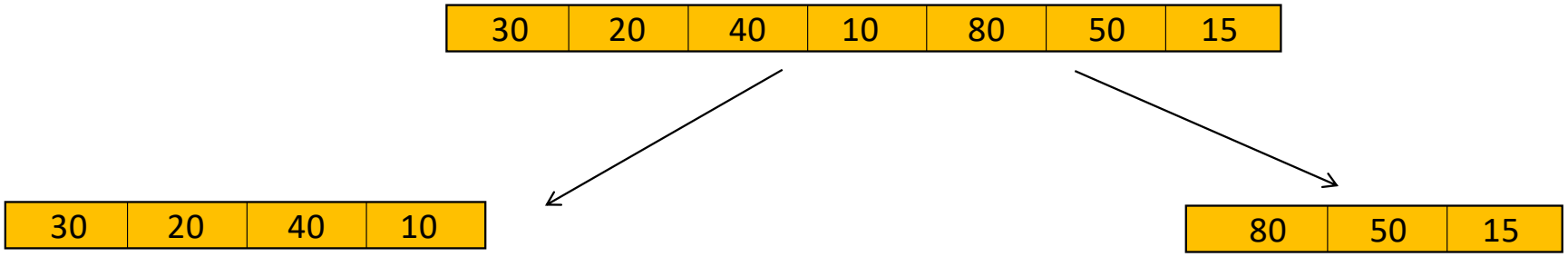
https://www.youtube.com/watch?v=8oJS1BMKE64&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&index=19

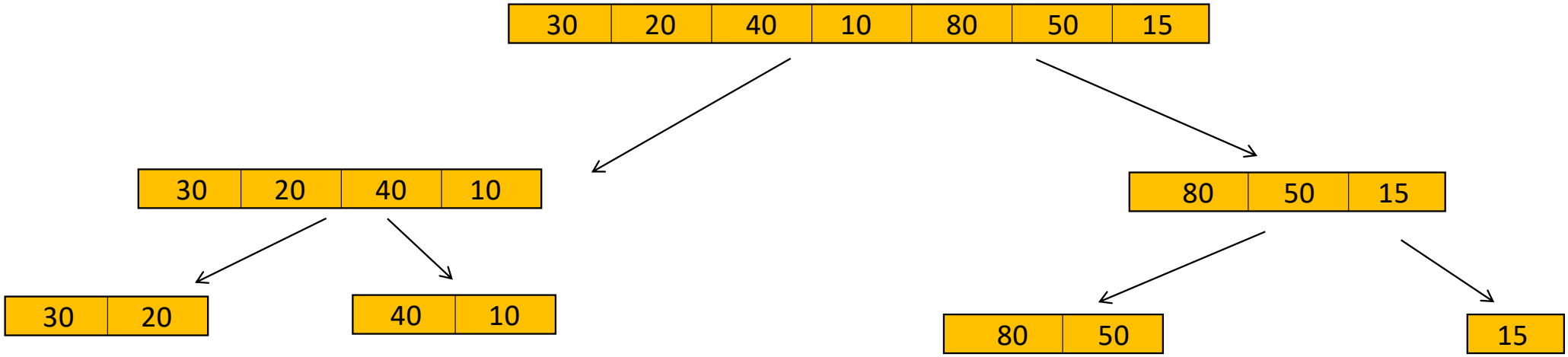
# Merge Sort

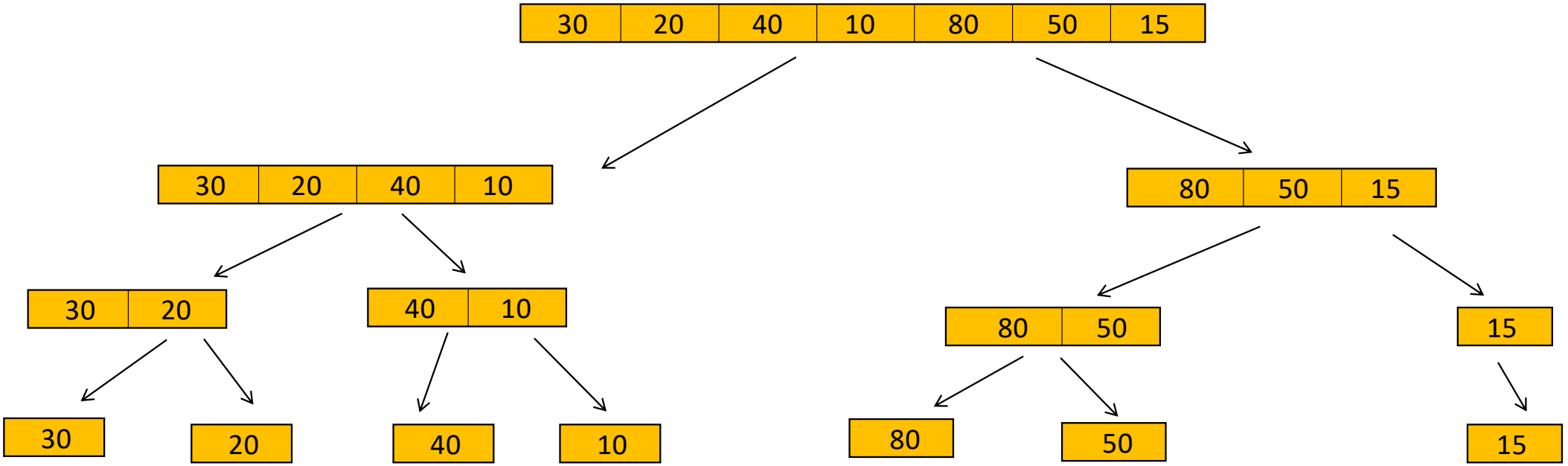
# Merge sort

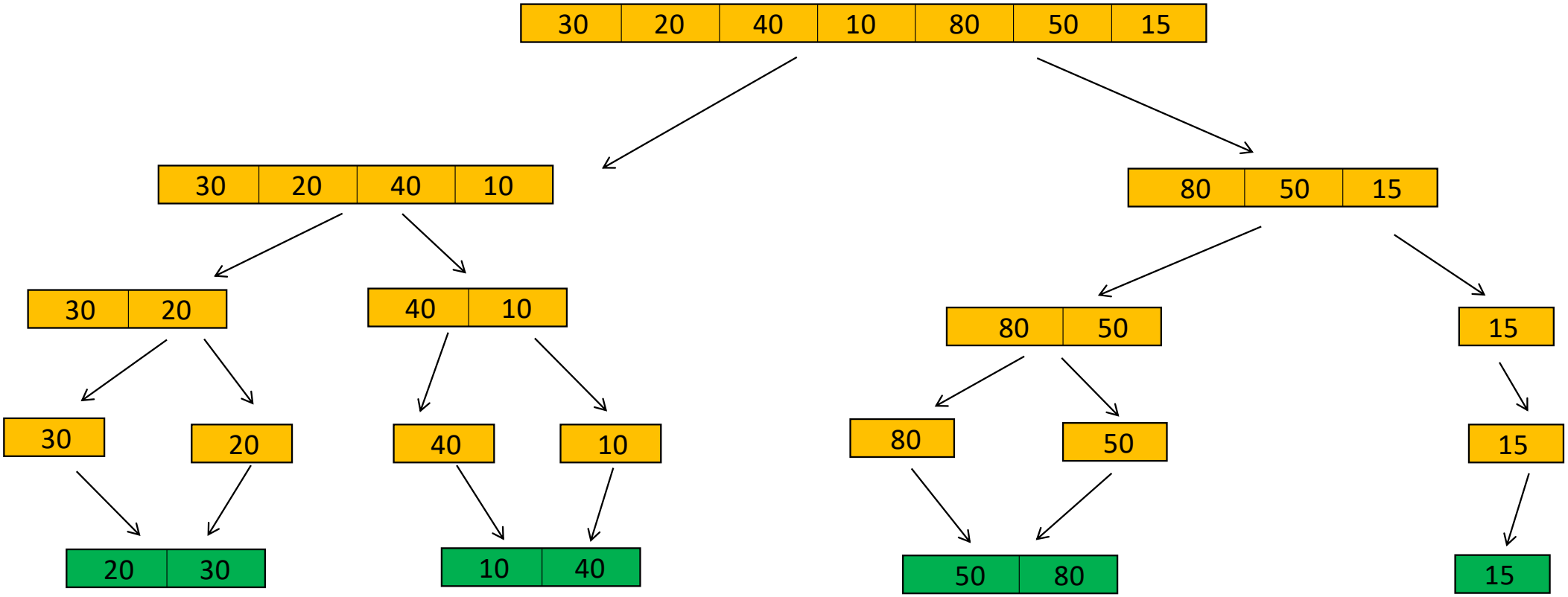
- Merge Sort is a Divide and Conquer algorithm
- It divides input array into two halves, keeps breaking those 2 halves recursively until they become too small to be broken further.
- Then each of the broken pieces are merged together to inch towards final answer

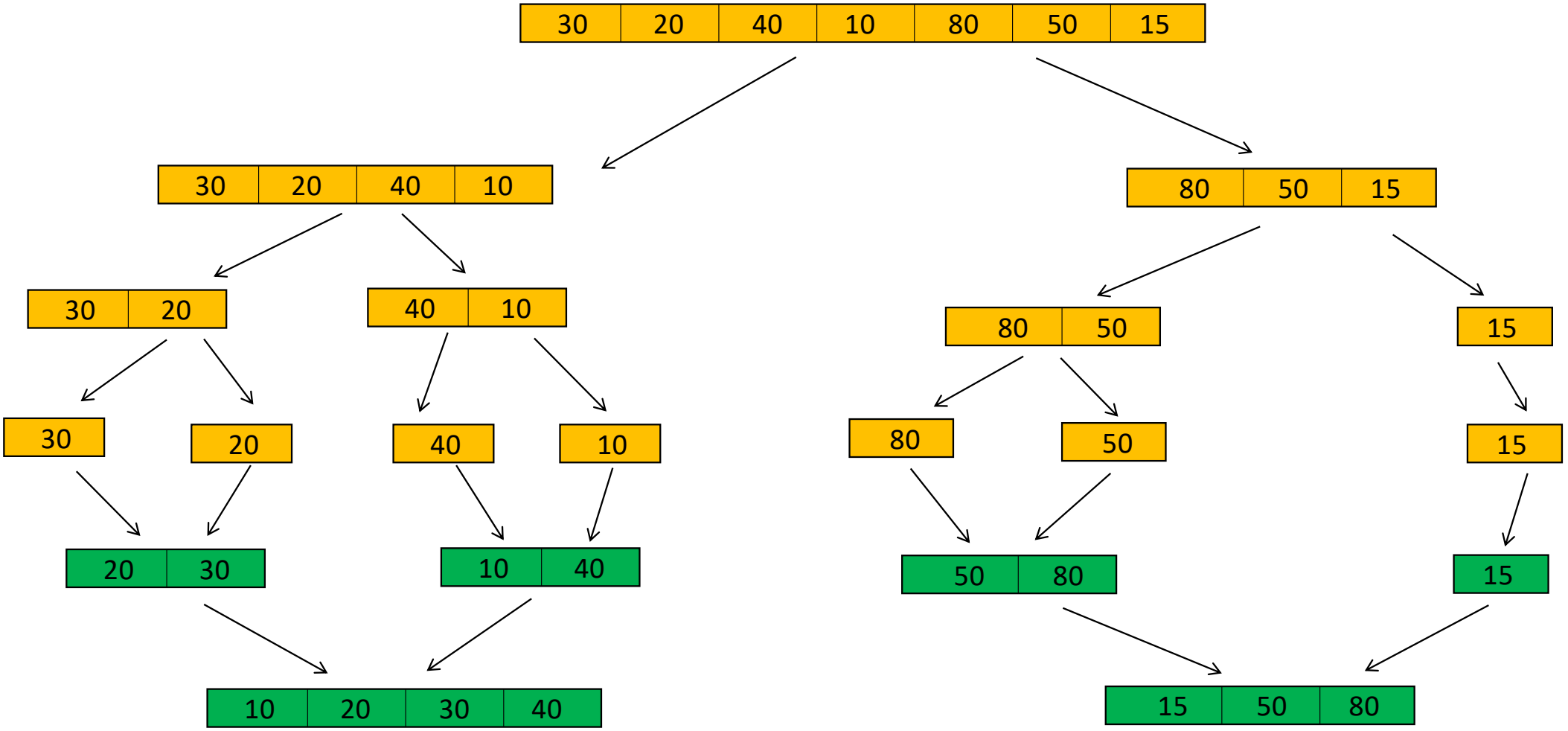
| 30 | 20 | 40 | 10 | 80 | 50 | 15 |
|---|---|---|---|---|---|---|

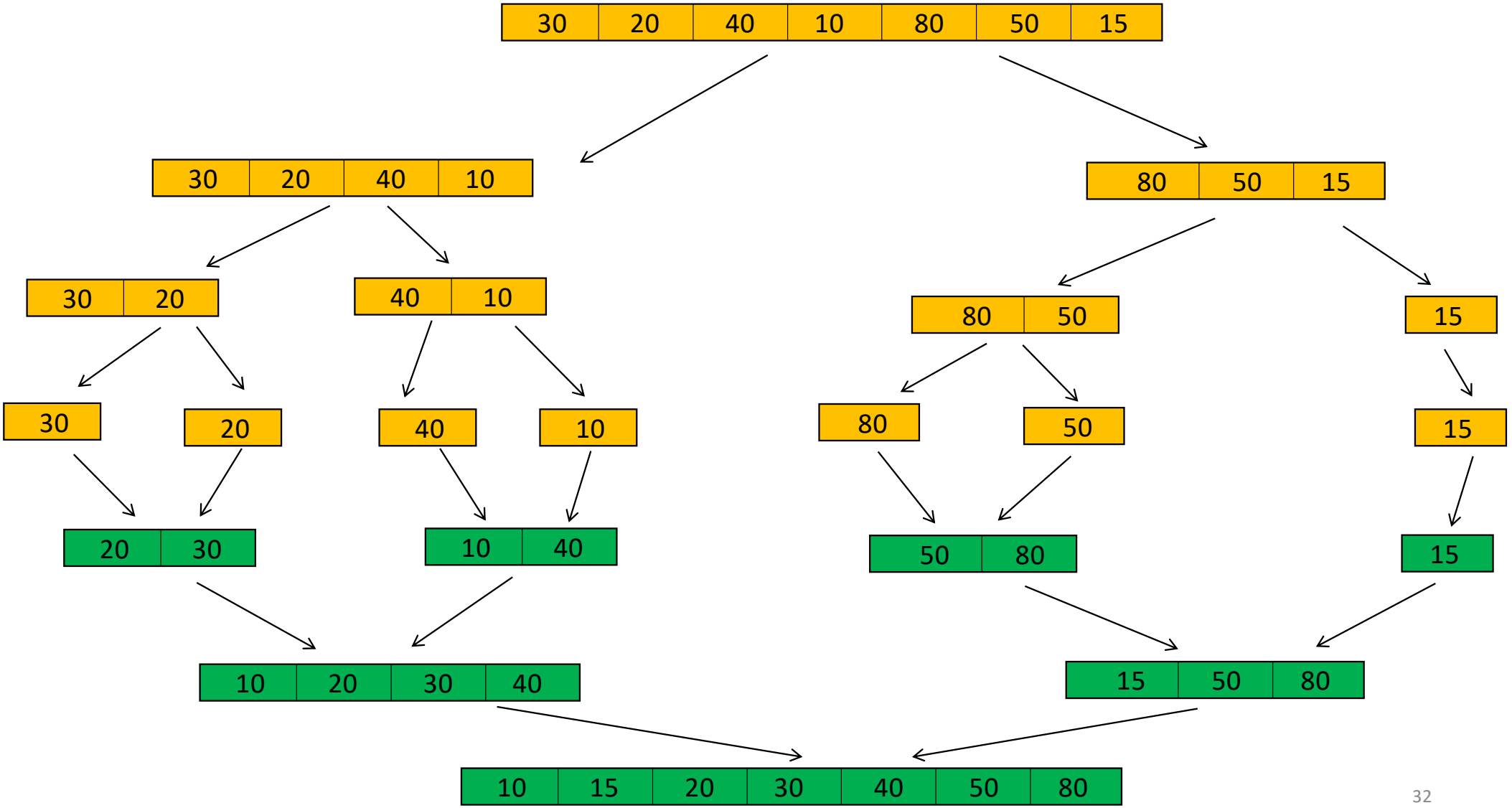

30 20 40 10 80 50 15
30 20 40 10
80 50 15


30 20 40 10 80 50 15
30 20 40 10
80 50 15
30 20
40 10
80 50
15


30 20 40 10 80 50 15
30 20 40 10
80 50 15
30 20
40 10
80 50
15
30
20
40
10
80
50
15


30 20 40 10 80 50 15
30 20 40 10
80 50 15
30 20
40 10
80 50
15
30
20
40
10
80
50
15
20 30
10 40
50 80
15


30 20 40 10 80 50 15
30 20 40 10
80 50 15
30 20
40 10
80 50
15
30
20
40
10
80
50
15
20 30
10 40
50 80
15
10 20 30 40
15 50 80


30 20 40 10 80 50 15
30 20 40 10
80 50 15
30 20
40 10
80 50
15
30
20
40
10
80
50
15
20 30
10 40
50 80
15
10 20 30 40
15 50 80
10 15 20 30 40 50 80

# merge sort algorithm

```
mergeSort(A,l,r)
        if r > l
                middle m = (l+r)/2
                mergeSort(A,l,m)
                mergeSort(A,m+1,r)
                merge(A,l,m,r)
```

```
merge(A,l,m,r)
        create tmp array L & R
        copy A,l,m into L & A m+1,r into R
        i=j=0
        loop k = l to r
                if L[i] < R[j]
                        A[k] = L[i++];
                else
                        A[k] = R[j++];
```

Time complexity: O(n logn)

Time Complexity: O(nlogn)

# Time Complexity

$T(n) = O(1) + O(1) + T(n/2) + T(n/2) + O(n)$

$= 2T(n/2) + O(n)$

$= 2(2T(n/4) + O(n/2)) + O(n)$

$= 4(T(n/4)) + 2*O(n) + O(n)$ // O(n/2) can be represented as O(n)

$= 2^kT(n/2^k) + k*O(n)$ // now replace k with logn to meet the base condition

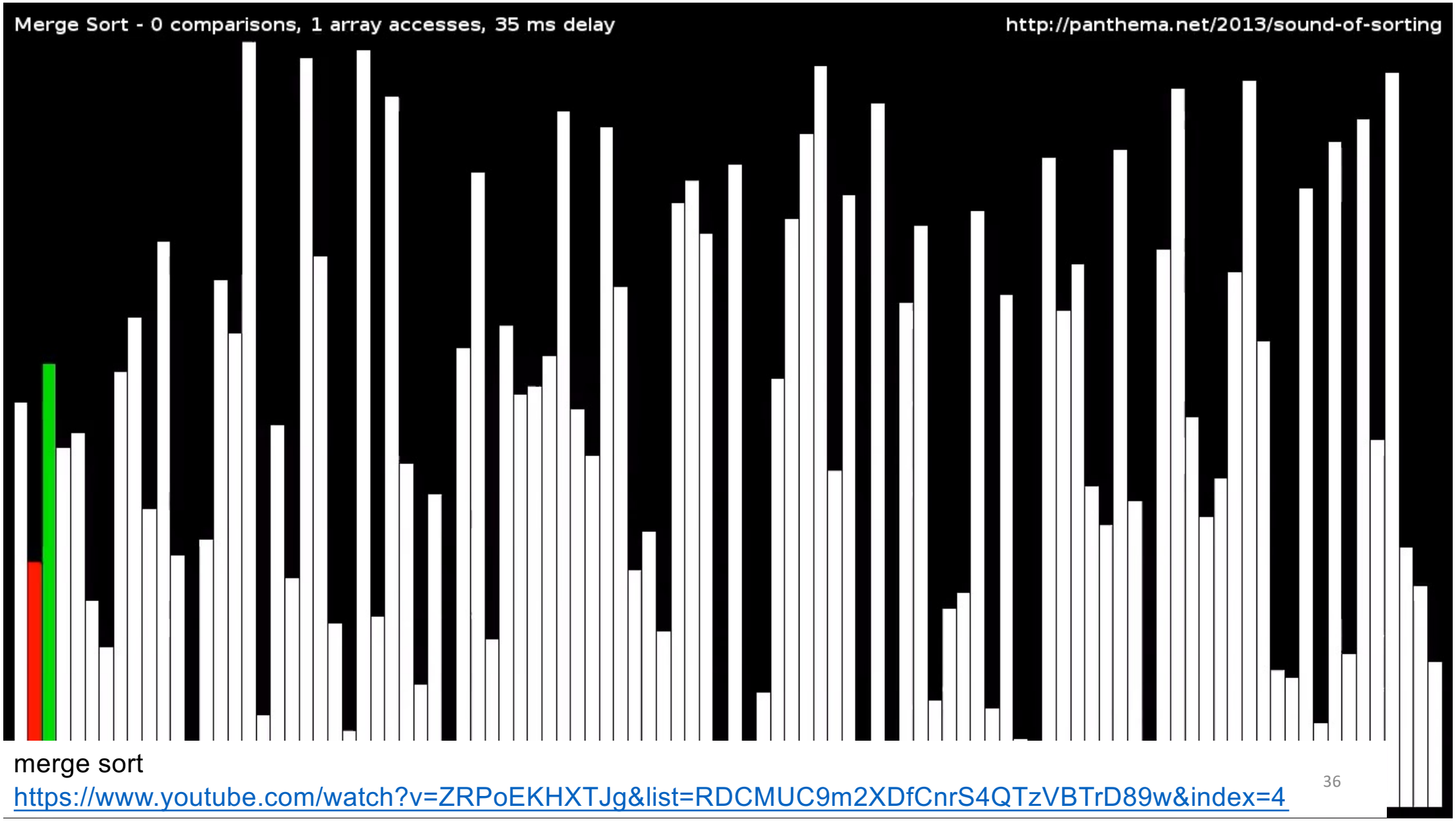
$= 2^{logn}*1+logn*O(n)$

$=O(nlogn)$

# When to use / avoid Merge sort

- When to use
  - When you need a stable sort
  - When average expected time is O(nlogn)

- When not to use
  - When space is a concern like embedded systems
  - Ps. Java 6 and earlier versions use merge sort as the sorting algorithms



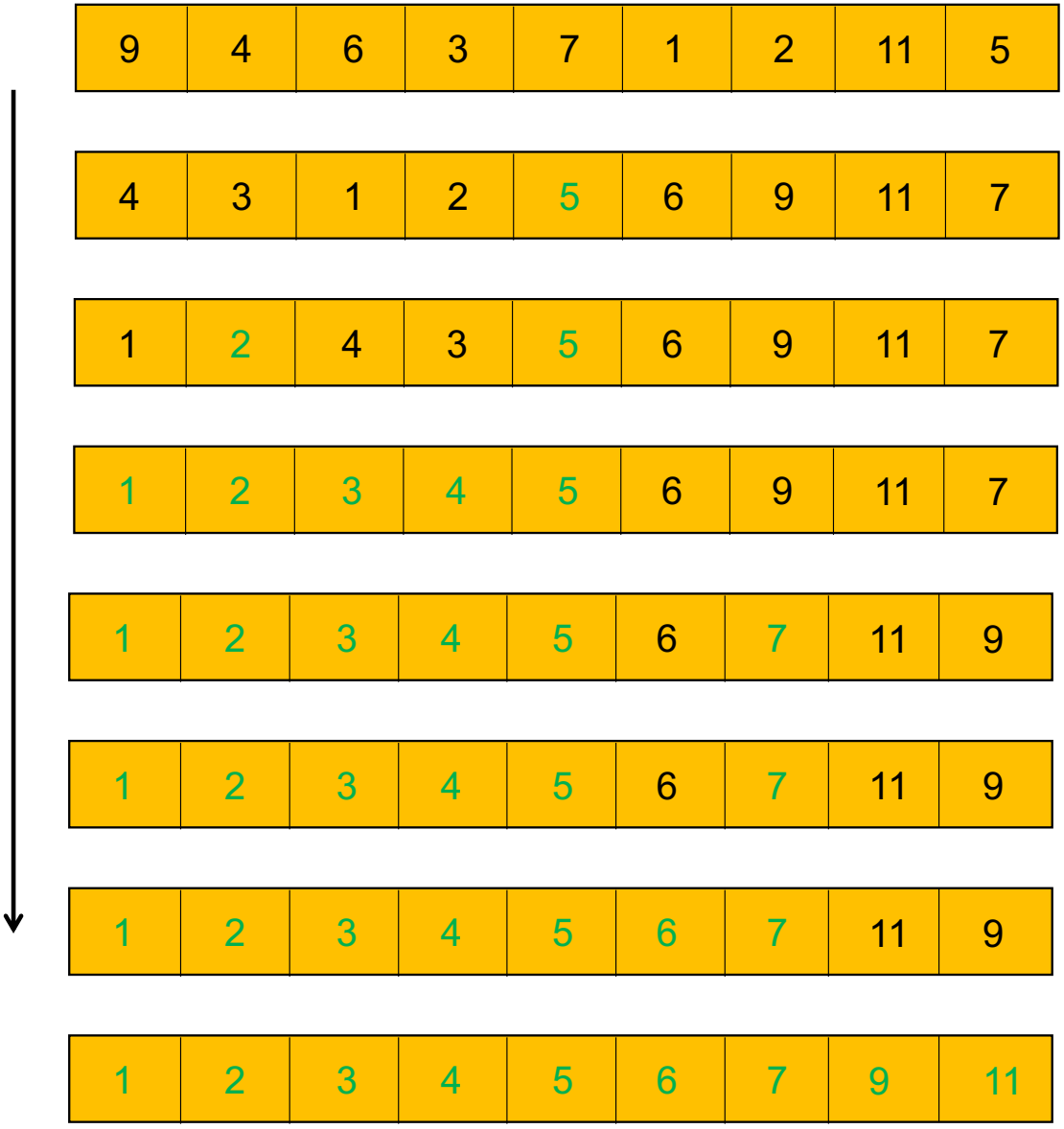

merge sort

https://www.youtube.com/watch?v=ZRPoEKHXTJg&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&index=4

# Quick Sort

# Quick sort

- Quick Sort is a Divide and Conquer algorithm
- At each step it finds “Pivot” and then makes sure that all the smaller elements are left of “Pivot” and all bigger elements are Right of “Pivot”.
- It does this recursively until the entire array is sorted
- Unlike Merge Sort it does not requires any external space


9 4 6 3 7 1 2 11 5
4 3 1 2 5 6 9 11 7
1 2 4 3 5 6 9 11 7
1 2 3 4 5 6 9 11 7
1 2 3 4 5 6 7 11 9
1 2 3 4 5 6 7 11 9
1 2 3 4 5 6 7 11 9
1 2 3 4 5 6 7 9 11

# quick sort algorithm

```
quickSort(A,p,q)
        if p < q
                r = partition (A,p,q)
                quickSort(A,p,r-1)
                quickSort(A,r+1,q)
```

```
Partition(A,p,q)
        pivot = q
        i =p-1
        loop j = p to q
                if A[j] <= A[pivot]
                        i++
                        swap (A[i], A[j])
```

Time Complexity: O(nlogn)

# Time Complexity

$T(n) = O(1) + O(1) + T(n/2) + T(n/2) + O(n)$

$= 2T(n/2) + O(n)$

$= 2(2T(n/4) + O(n/2)) + O(n)$

$= 4(T(n/4)) + 2*O(n) + O(n)$ // O(n/2) can be represented as O(n)

$= 2^kT(n/2^k) + k*O(n)$ // now replace k with logn to meet the base condition

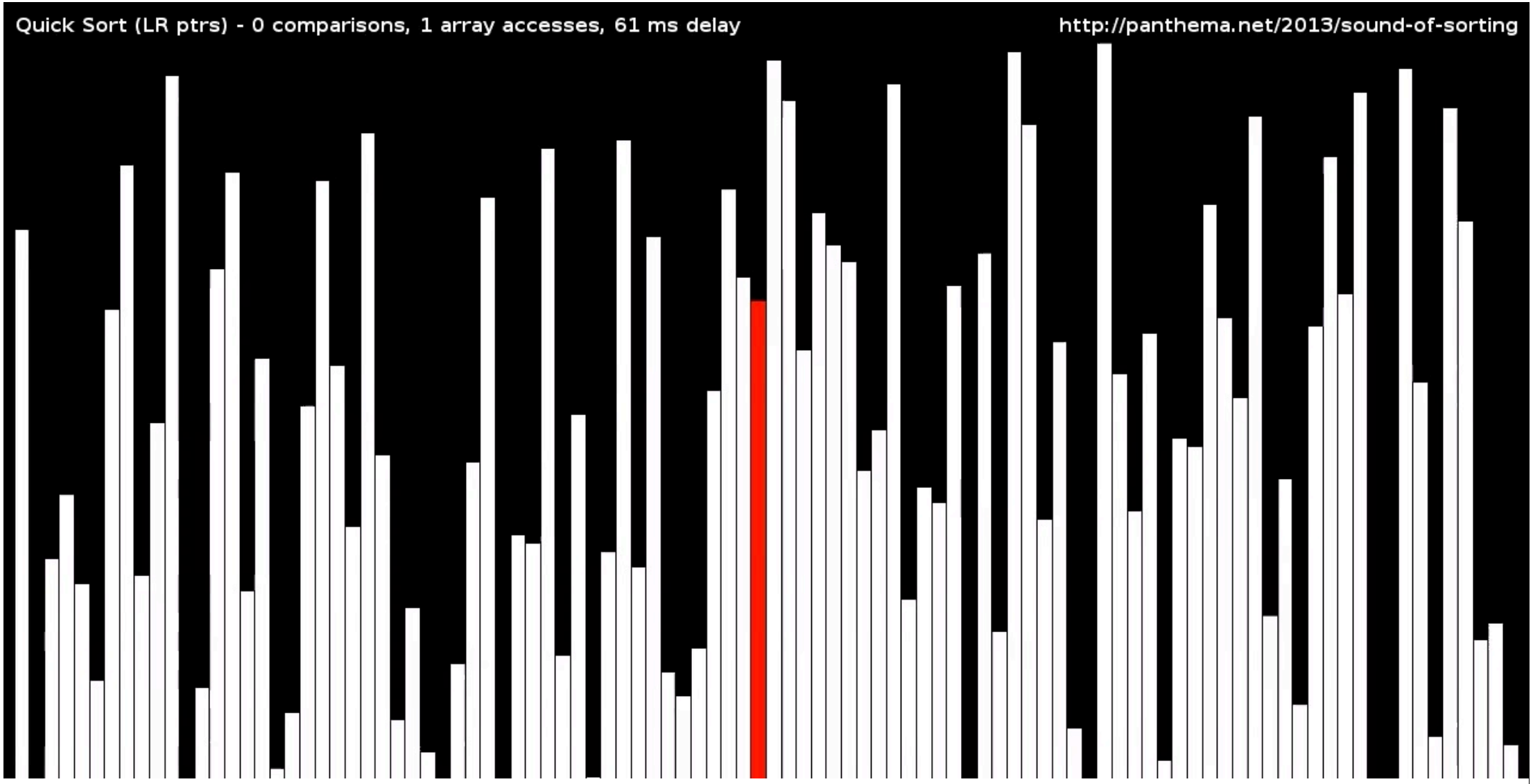
$= 2^{logn}*1+logn*O(n)$

$=O(nlogn)$

# When to use / avoid Quick sort

- When to use
  - When average is desired to be O(nlogn)

- When not to use
  - When space is a concern
  - When stable sort is required




Quick Sort

https://www.youtube.com/watch?v=8hEyhs3OV1w&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&start_radio=1&t=14

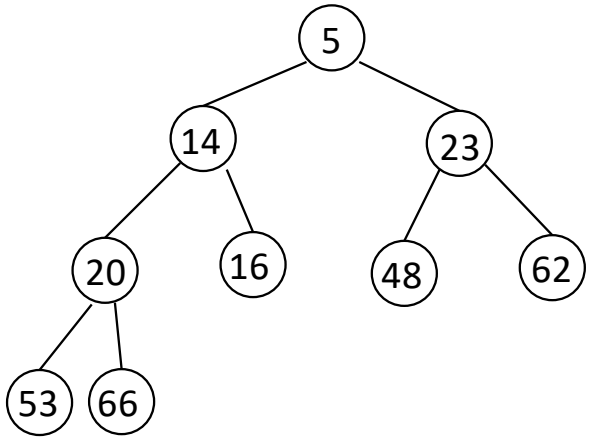
# Heap Sort

# Heap sort

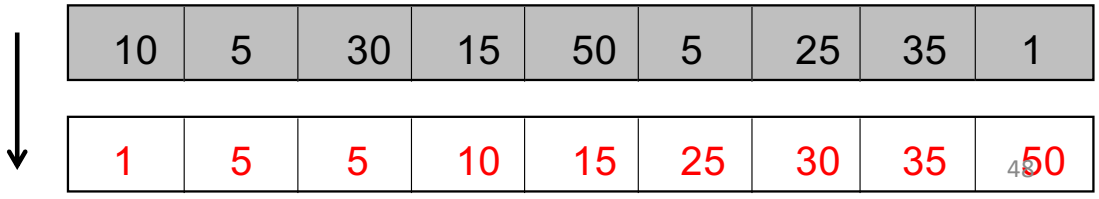
- Heap Sort works by first organizing the data to be sorted into a special type of binary tree called a heap
- It then removes the topmost item (the largest/smallest) and inserts it in current array. It keeps doing until binary heap is empty.
- It best suited with array. Does not works best with LinkedList

# What is binary Heap

- Definition: Binary Heap is a Binary tree with some special properties:
- Heap Properties:
  - Value of any given node must be <= value of its children (Min-Heap)
  - Value of any given node must be >= value of its children (Max-Heap)




STEP 1: CREATE
STEP 2: EXTRACT



# heap sort algorithm

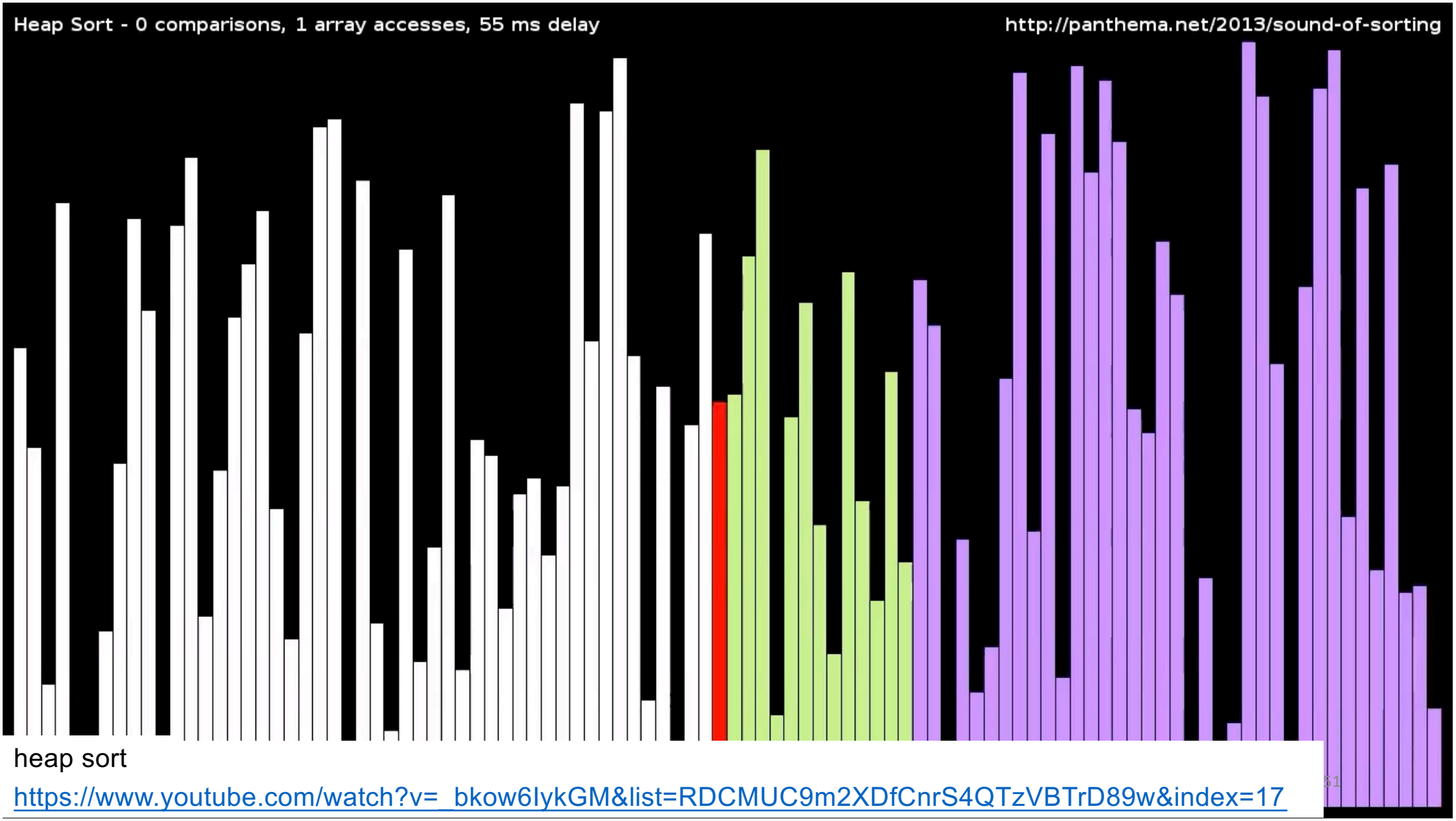
```
heapSort(A)
        for i=0 to A.length-1                   O(n)
                insertInHeap(A[i])              O(nlogn)
        for i=0 to A.length-1                   O(n)
                extractFromHeap[A[i]]           O(nlogn)
```

Time Complexity: O(nlogn)

# When to use / avoid Heap sort

- When to use
  - When space is a concern

- When not to use
  - When stable sort is required




heap sort

https://www.youtube.com/watch?v=_bkow6IykGM&list=RDCMUC9m2XDfCnrS4QTzVBTrD89w&index=17

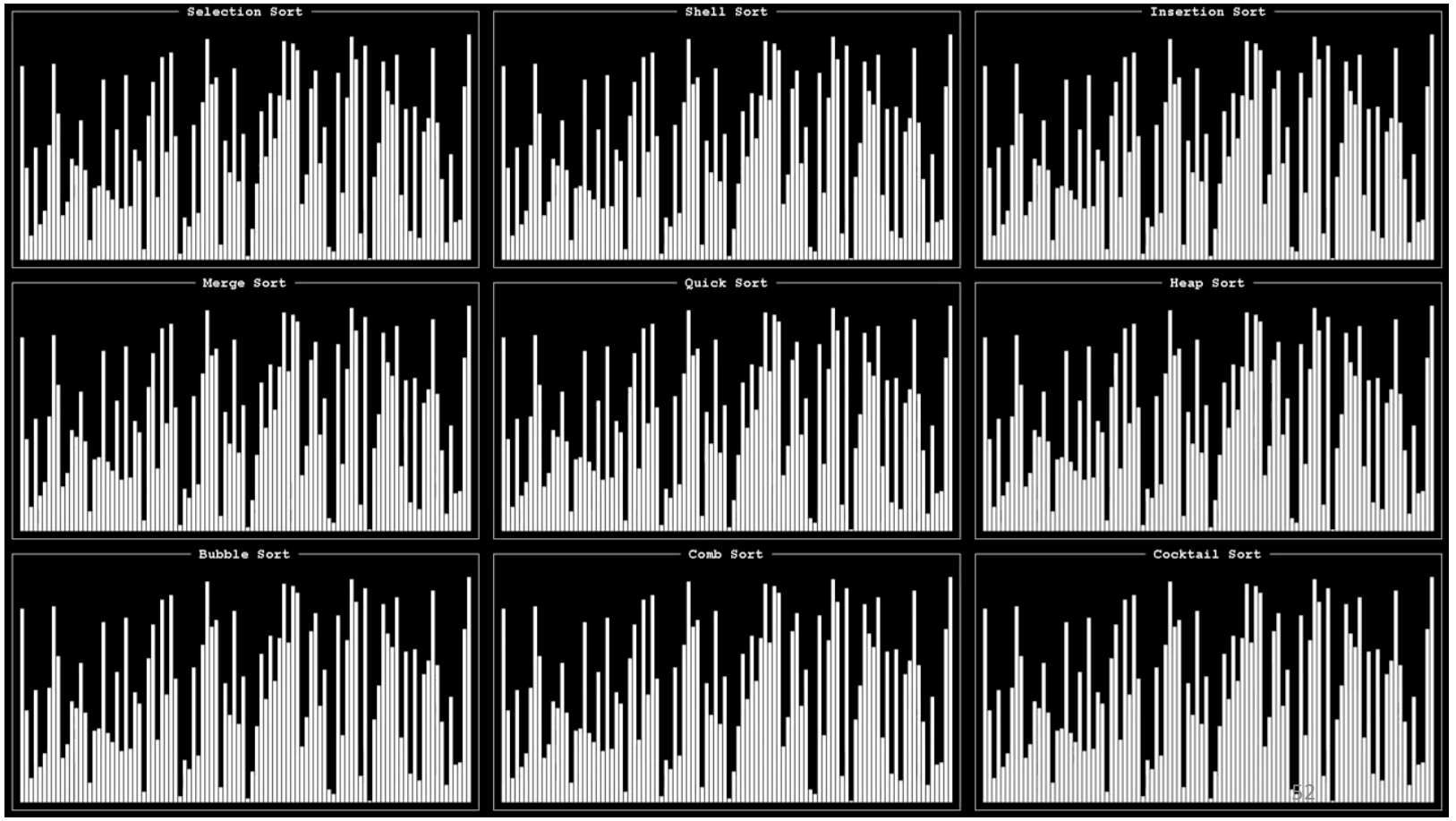
Visualization and comparison of 9 different sorting algorithms:

- selection sort
- shell sort
- insertion sort
- merge sort
- quick sort
- heap sort
- bubble sort
- comb sort
- cocktail sort

https://www.youtube.com/watch?v=ZZuD6iUe3Pc

With 4 types of input data:

- random 0:01
- few unique 1:07
- reversed 2:08
- almost sorted 3:38



# Sorting Algorithms compared

| Particulars | Time Complexity | Stable |
|---|---|---|
| Bubble Sort | $O(n^2)$ | Yes |
| Selection Sort | $O(n^2)$ | No |
| Insertion Sort | $O(n^2)$ | Yes |
| Bucket Sort | O(nlogn) | Yes* |
| Merge Sort | O(nlogn) | Yes |
| Quick Sort | O(nlogn) | No |
| Heap Sort | O(nlogn) | No |