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Data Structures and Algorithms
★ Simple Sorting ★

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SCAN ME

Objectives

- Understand and know how to use basic sorting methods.
  - Bubble Sort
  - Selection Sort
  - Insertion Sort
- Compare their performance

Major Topics

- Introductory Remarks
- Bubble Sort
- Selection Sort
- Insertion Sort
- Sorting Objects
- Comparing Sorts

Introduction

- Why do we need to sort data?
  - To get the lowest price
  - To get the most crowded country
  - etc.
- So many lists are better dealt if ordered.
- Sorting data may be a preliminary step to searching

Introduction

- Sorting is time-consuming task
  - ➔ many sorting algorithms are developed
- Will look at simple sorting first.
  - Note: there are books written on many advanced sorting techniques. E.g. shell sort; quicksort; heapsort; etc.
- Will start with ‘simple’ sorts.
  - Relatively slow,
  - Easy to understand, and
  - Excellent performance under circumstances.
- All these are $O(N^2)$ sorts.

How would you do it?

ARRANGE PLAYER IN ORDER OF INCREASING HEIGHT

Basic idea of these simple sorts

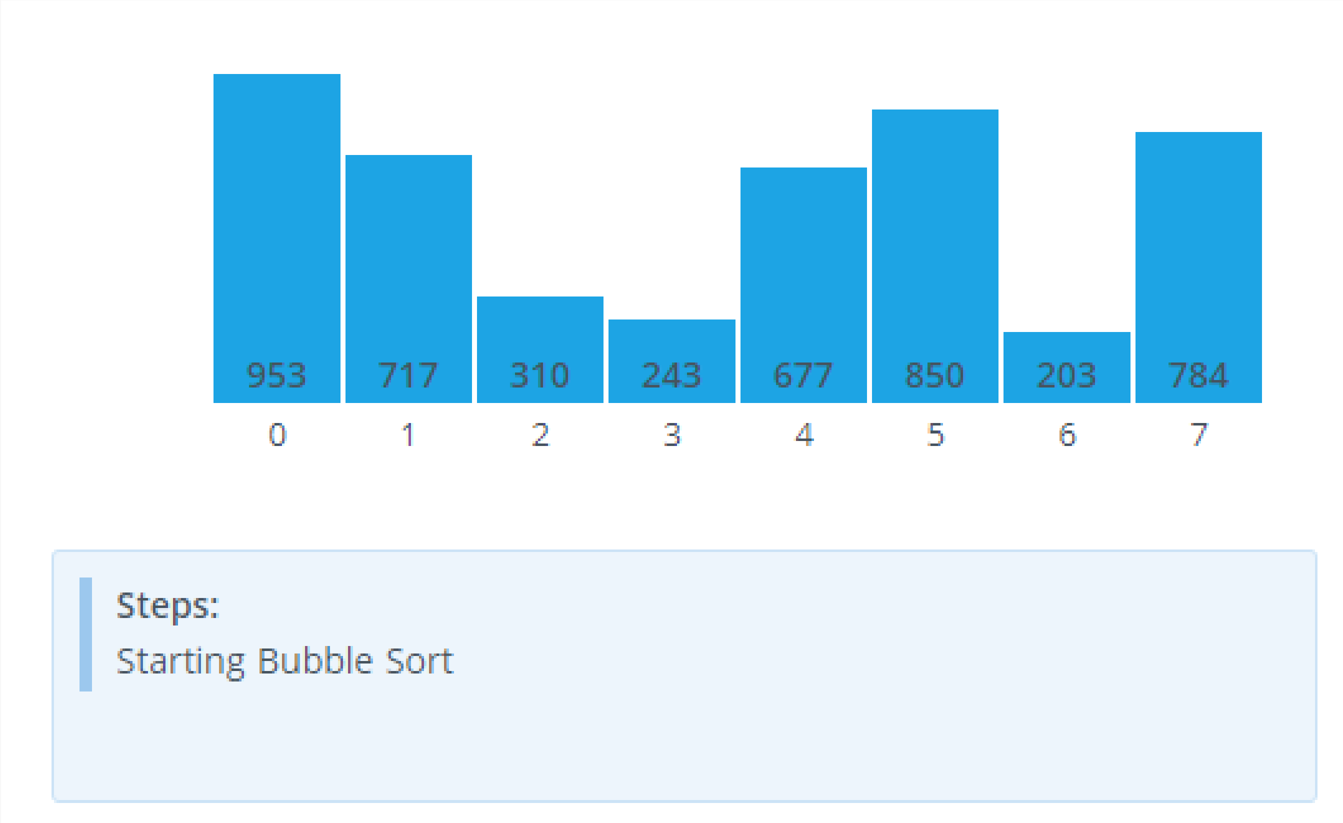
- Compare two items
- Swap or Copy over
- Depending on the specific algorithm…
- Don’t need additional space

Bubble sort

Bubble Sort

- Very slow but simple
- Basic idea:
  - Compare the first item in the first two positions (e.g., the left most)
  - If the first one is larger, swap with the second
  - Move one position right.
- At end, the largest item is in the last position.
  - (e.g., the right most)
- That why is name Bubble sort

Simulation



https://www.hackerearth.com/practice/algorithms/sorting/bubble-sort/visualize/

https://visualgo.net/en/sorting

Bubble Sort process

- After first pass, we made
  - n -1 comparisons
  - 0 to n-1 swaps (depend on data)
- Continue this process.
- Next time we do not check the last entry (N-1), because we know it is in the right spot. We stop comparing at (N-2).
- See the simulation: https://www.hackerearth.com/practice/algorithms/sorting/bubble-sort/visualize/
- See Some code (p85-86).

Bubble Sort process

```
for(out=nElems-1; out>1; out--)   // outer loop (backward)
   for(in=0; in<out; in++)        // inner loop (forward)
      if( a[in] > a[in+1] )       // out of order?
         swap(in, in+1);          // swap them
```

Hand-on

+ Try with some examples

89	58	29	40	12	42	10	1
1	32	12	53	11	76	23	89

Efficiency of the Bubble Sort – **Comparisons**

- Can readily see that there are fewer comparisons each 'pass.'
- Thus, number of comparisons is computed as:
  $(n-1)+(n-2)+\ldots + 1 = n(n-1)/2$;
- For 10 elements, the number is $10*9/2 = 45$.
- So, the algorithm makes about $n^2/2$ comparisons
- (ignoring the -1 which is negligible especially if N is large)

Efficiency of the Bubble Sort - **Swaps**

- Fewer SWAPS than COMPARISONS
  - since every comparison does not result in a swap.
- In general, a swap will occur half the time.
  - For **$n^2/2$** comparisons,
    we have **$n^2/4$** swaps.
- Worst case, every compare results in a swap (which case?)

Overall – Bubble Sort

- Both swaps and compares are proportional to n^2.
  - Ignore the 2 and 4

➔ Complexity of Bubble Sort is $O(n^2)$

➔ Rather slow.

- Hint to determine Big-O:
  - 2 nested-loop ➔ $O(n^2)$
  - Outer loop executes n times and inner loop executes in n times PER execution of the outer n times: hence n^2

Question

- The bubble sort algorithm alternates between:
  - A) Comparing and swapping
  - B) Moving and copying
  - C) Moving and comparing
  - D) Copying and comparing
- What can be improved in Bubble Sort algorithm?

Selection sort

Selection Sort

- Fewer swaps, same comparisons.
  - Swaps $O(n^2) \rightarrow O(n)$
  - Comparisons $O(n^2)$

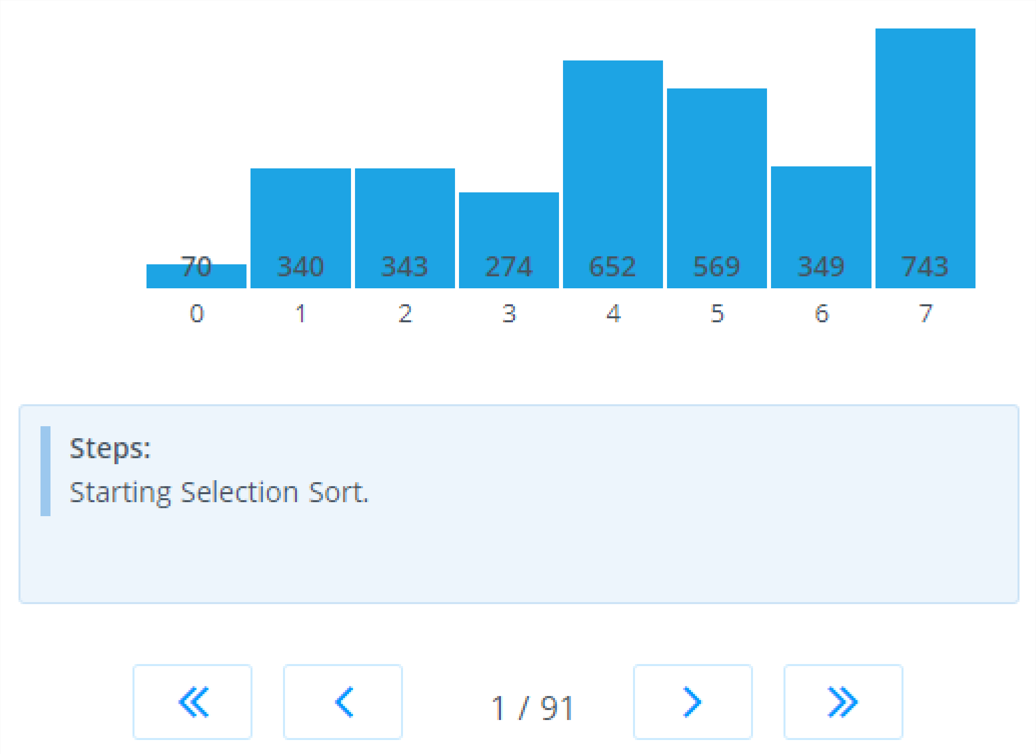
➔Important while dealing with large records

➔Reduction in swap time is more important than one in comparison time

How does the Selection Sort work?

- Start from the first element (e.g., the left end)
- Scan all elements to selecting the smallest (largest) item.
- Swap with the first element
- Next pass, move one position right
- Repeat until all are sorted.

Animation



https://www.hackerearth.com/practice/algorithms/sorting/selection-sort/visualize/

https://visualgo.net/en/sorting

Selection Sort – in more detail

- So, in one pass, you have made n comparisons but possibly ONLY ONE Swap!
- With each succeeding pass,
  - one more item is sorted and in place;
  - one fewer item needs to be considered.
- Java code for the Selection Sort (p93-94).

Selection Sort

```
for(out=0; out<nElems-1; out++)   // outer loop
   {
   min = out;                     // minimum
   for(in=out+1; in<nElems; in++) // inner loop
      if(a[in] < a[min] )         // if min greater,
          min = in;               // we have a new min
   swap(out, min);                  // swap them
   }  // end for(out)
}  // end selectionSort()
```

Hand-on

+ Try with some examples

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Selection Sort itself - more

+ Algorithm implies it is an $O(n^2)$ sort (and it is).
  + How did we see this?
+ In comparison with Bubble Sort
  + Same number of comparisons **$n^2/2$**
  + Fewer swap **n**

→ Faster than Bubble Sort

Insertion sort

Insertion Sort

- In many cases, this sort is considered the best of these elementary sorts.
- Still an $O(n^2)$ but:
  - about twice as fast as bubble sort and
  - somewhat faster than selection sort in most situations.
- Easy, but a bit more complex than the others
- Sometimes used as **final stage** of some more sophisticated sorts, such as a **QuickSort** (coming).

Insertion Sort – The idea

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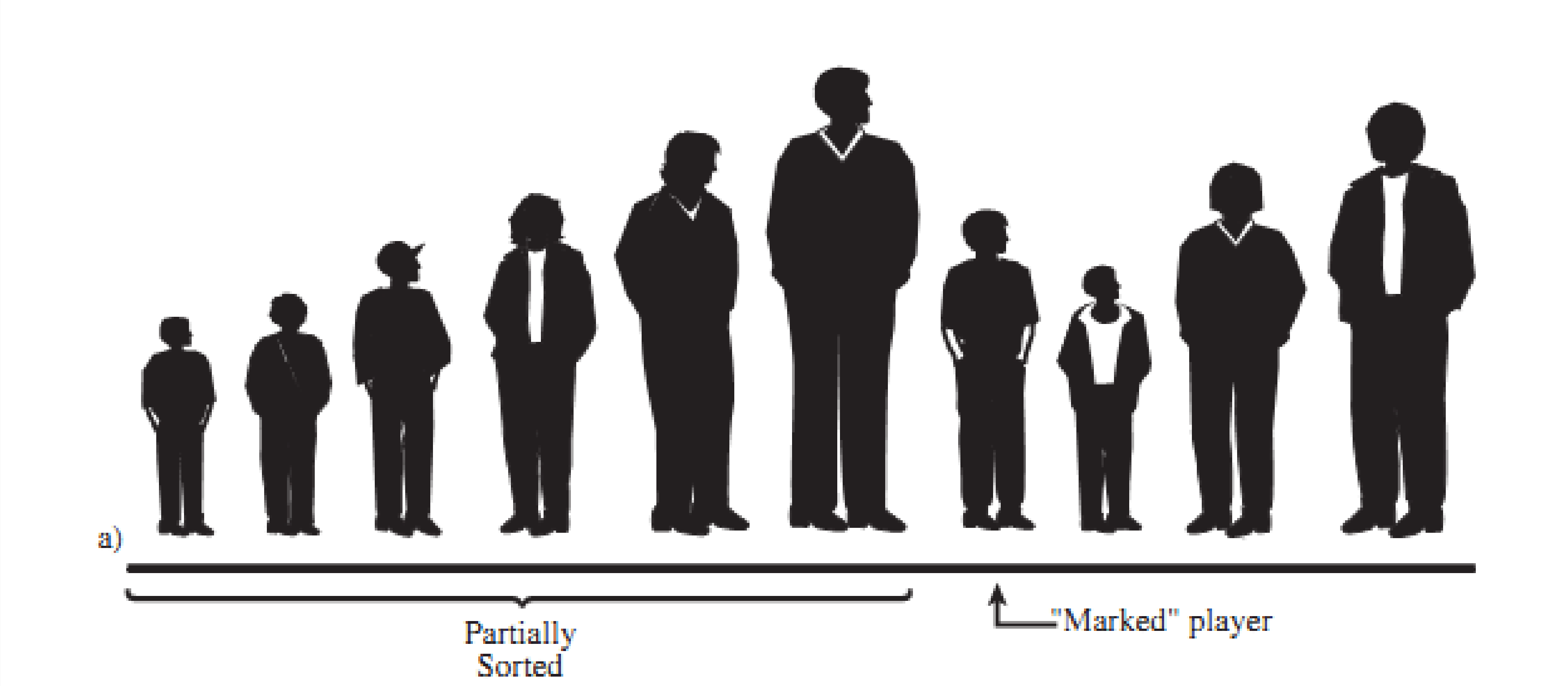
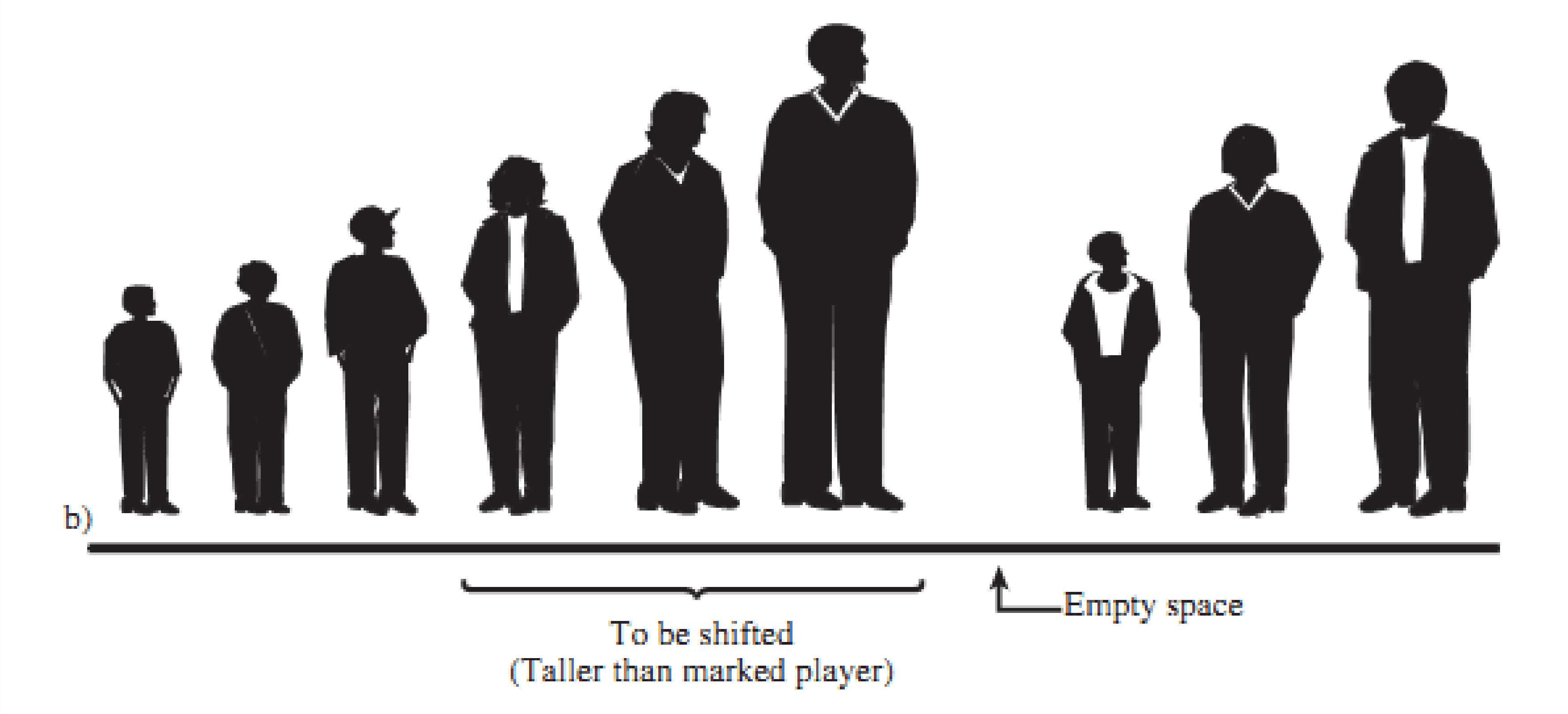
+ Thinking that 'half' of the list of items to be sorted. (*Partially sorted* , *Marked*, *Unsorted* items)

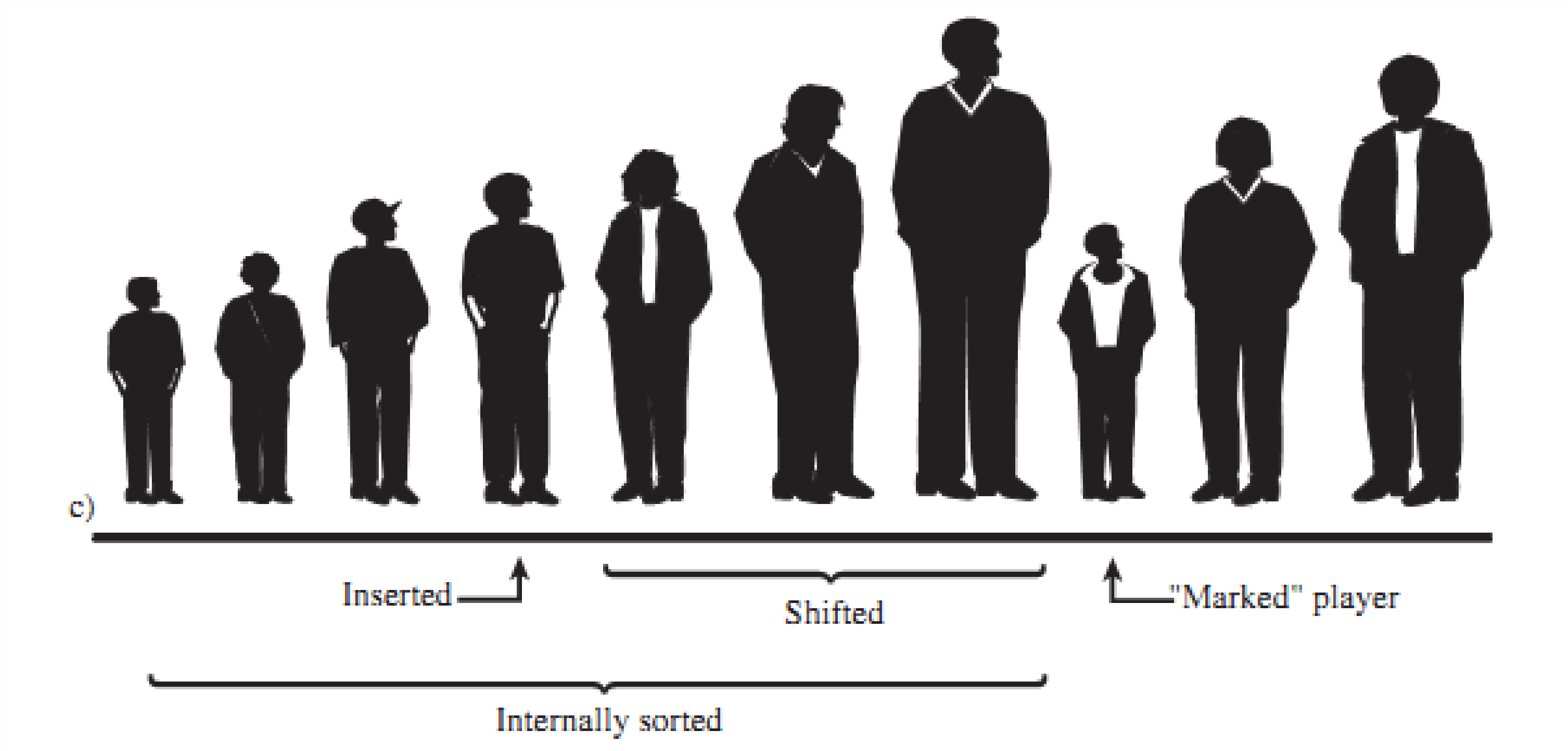


Insert *marked* item to *partially sorted* list

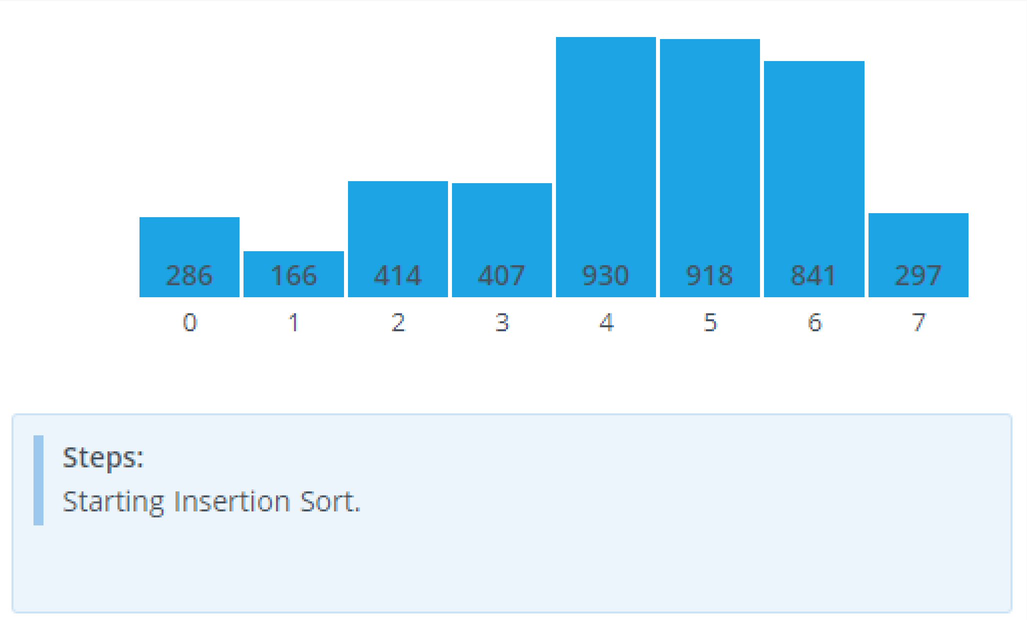
+ Take out of line → Shift right until appropriate place → Insert



Insertion sort – Intermediate result



Animation



https://www.hackerearth.com/practice/algorithms/sorting/insertion-sort/visualize/

https://visualgo.net/en/sorting

Insertion Sort

- Result after each round:
  - Partially-ordered list is now one item larger and
  - The unsorted list is now one item smaller.
  - Marked item moves one slot to the right, so once more it is again in front of the leftmost unsorted item.
- Continue process until all unsorted items have been inserted.
- Hence the name ‘insertion sort.’
- Code page 99 - 100

Insertion sort

```
for(out=1; out<nElems; out++)     // out is dividing line
   {
   long temp = a[out];        // remove marked item
   in = out;                           // start shifts at out
   while(in>0 && a[in-1] >= temp) // until one is smaller,
      {
      a[in] = a[in-1];              // shift item right,
      --in;                        // go left one position
      }
    a[in] = temp;                  // insert marked item
    }  // end for
 }  // end insertionSort()
```

Discussion– How it really implemented!!

- Start with out = 1, which means there is only a single element to its ‘left.’
  - We infer that this item to its left is sorted unto itself.
  - Hard to argue this is not true. (This is out = 0)
- a[out] is the marked item, and it is moved into temp.
  - a[out] is the leftmost unsorted item.

Hand-on

+ Try with some examples

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Efficiency of the Insertion Sort

- Comparisons:
- On pass one, max of one;

  pass two, max of two, etc.

  Up to a max of n-1 comparisons.

→ 1+2+3+…+n-1 = n*(n-1)/2 comparisons.

- But, on average

n*(n-1)/4.

Efficiency of the Insertion Sort (2 of 3)

- Copy:
  - Have lots of ‘copies’
  - (same as number of comparisons – about)
  - ➔ But a copy is not nearly as time-consuming as a **swap**. **Think about this!!**
- For random data,
  - twice as fast as the bubble sort
  - faster than the selection sort.
- Still runs on $O(n^2)$ time for random data.

Efficiency of the Insertion Sort (3 of 3)

- If data is *nearly sorted* ➔ quite well.
  - Condition in while loop is never true, so it almost runs in O(n) time; much better than $O(n^2)$ time!
- If data is in *very unsorted* order (nearly backward)
  - ➔ No faster than the bubble sort
  - as every possible comparison and shift is carried out.

Sorting Objects

Sorting Objects

- Very important to be able to sort objects.
- Must be careful, especially in noting that
  - An array are **objects**, and
  - The sort is based on **values of String attributes** inside of the object.
- Use inherited String method, *compareTo*.

Sorting Objects

```
while(in>0 &&                          // until smaller one found,
      a[in-1].getLast().compareTo(temp.getLast())>0)
   {
   a[in] = a[in-1];                    // shift item to the right
   --in;                               // go left one position
   }
```

TABLE 3.1 Operation of the `compareTo()` Method

`s2.compareTo(s1)`	**Return Value**
s1 < s2	< 0
s1 equals s2	0
s1 > s2	> 0

Secondary Sort Fields?

- Equal Keys Problems ? E.g., Last name
- Solutions
  - Using Secondary Key? e.g., ZIP code
  - Using 'Stable' Sort? What does this mean?
    - Only sort what needs to be sorted
    - Leave everything else in its original order
- All of the algorithms so far are stable
- Think Windows:
  - Arrange by Type; then by date modified…

Comparing the Simple Sorts

- Bubble Sort, Selection Sort, and Insertion Sort all have a worst-case time complexity of O(n^2).
- Bubble Sort, Selection Sort, and Insertion Sort all have a space complexity of O(1) as they are in-place sorting algorithms.

Comparing the Simple Sorts

- Bubble Sort – simplest.
  - Use only if you don't have other algorithms available and 'n' is small.
- Selection Sort
  - Minimizes number of swaps, but number of comparisons still high.
  - Useful when amount of data is small, and swapping is very time consuming – like when sorting records in tables – internal sorts.
- Insertion Sort
  - The most versatile, and is usually best bet in most situations, if amount of data is small or data is almost sorted.
- For large n, other sorts are better. We will cover advanced sorts later…

Comparing the Simple Sorts

- All require very little space, and they sort in place.
- Can't see the real efficiencies / differences unless you apply the different sources to large amounts of data.

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THANK YOU

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