COMP 204

Algorithm design: Selection and Insertion Sort

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based on material from Mathieu Blanchette, Christopher J.F. Cameron and Carlos G. Oliver

Sorting algorithms

A **sorting algorithm** is an algorithm that takes

- a list/array as input
- performs specified operations on the list/array
- outputs a sorted list/array

For example:

- $[a, c, d, b]$ could be sorted alphabetically to $[a, b, c, d]$
- $[1, 3, 2, 0]$ could be sorted:
    - increasing order: $[0, 1, 2, 3]$
    - or decreasing order: $[3, 2, 1, 0]$

Why is it useful to sort data?

Sorted data searching can be optimized to a very high level

- also used to represent data in more readable formats

Contacts

- your mobile phone stores the telephone numbers of contacts by names
- names can easily be searched to find a desired number

Dictionary

- dictionaries store words in alphabetical order to allow for easy searching of any word

Remember **binary search**?

Adding more algorithms to your toolbox

In the last lecture, we covered searching algorithms, specifically:

- linear search
- binary search

Today, we will cover the following sorting algorithms:

- selection sort
- insertion sort

Images for selection sort are taken from an online tutorial: `https://www.tutorialspoint.com/data_structures_algorithms/`

Selection sort

Conceptually the most simple of all the sorting algorithms

Start be selecting the smallest (or largest) item in a list

- then place this item at the start of the list
- repeat for the remaining items in the list
    - move next smallest/largest item to the second position
    - then the next
    - and so on and so on...
    - until the list is sorted

Let's consider the following unsorted list:

14	33	27	10	35	19	42	44

Selection sort #2

For the first position in the resulting sorted list

- the whole list is scanned sequentially
- the first position is where 14 is currently stored

We search the whole list

- to find that 10 is the lowest value in the list

14	33	27	10	35	19	42	44

Selection sort #3

We then replace 14 with 10

10	33	27	14	35	19	42	44

After one iteration

- 10, which happens to be the minimum value in the list
- appears in the first position of the sorted list

For the second position

- where 33 is residing
- we start scanning the rest of the list in a linear manner

10	33	27	14	35	19	42	44

Selection sort #4

14 is found to be the second lowest value in the list

- and should appear at the second place
- we swap these values.

10	33	27	14	35	19	42	44

After two iterations

- the two items with the least values
- are positioned at the beginning in a sorted manner

10	14	27	33	35	19	42	44

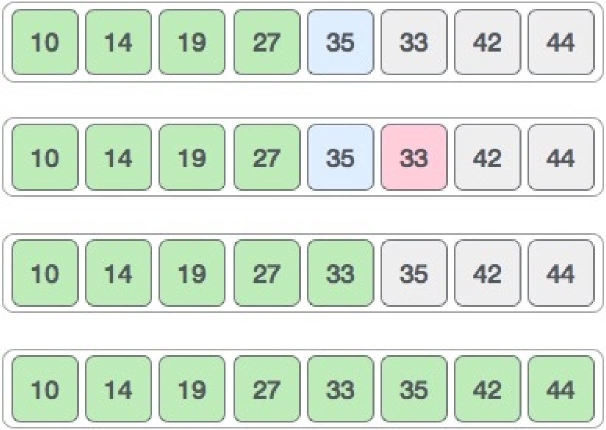
Selection sort #5

The same process is applied to the rest of the items in the list

10	14	27	33	35	19	42	44
10	14	27	33	35	19	42	44
10	14	19	33	35	27	42	44
10	14	19	33	35	27	42	44
10	14	19	27	35	33	42	44

Selection sort #6

Until the list is sorted



10	14	19	27	35	33	42	44
10	14	19	27	35	33	42	44
10	14	19	27	33	35	42	44
10	14	19	27	33	35	42	44

Selection sort algorithm

Selection sort (*sequence*)

Step 1 - find the item with the smallest value in *sequence*

Step 2 - swap it with the first item in *sequence*

Step 3 - find the item with the second smallest value in *sequence*

Step 4 - swap it with the second item in *sequence*

Step 5 - find the item with the third smallest value in *sequence*

Step 6 - swap it with the third item in *sequence*

Step 7 - repeat finding the item with the next smallest value

Step 8 - then swap it with the correct item until *sequence* is sorted

Selection sort: pseudocode

Algorithm 1 Selection sort

```
procedure SELECTION_SORT($sequence$)
    $N \leftarrow$ length of $sequence$
    for $i \leftarrow 0$ to $N-1$ do
        $min\_index \leftarrow i$
        for $j \leftarrow i+1$ to $N-1$ do
            if $sequence[j] \leq sequence[min\_index]$ then
                $min\_index \leftarrow j$
            end if
        end for
        SWAP($sequence[i]$,$sequence[min\_index]$)
    end for
end procedure
```

Selection sort: Python implementation

```python
def selection_sort(sequence):
    N = len(sequence)
    for i in range(0,N):
        min_index = i
        for j in range(i+1,N):
            if sequence[j] <= sequence[min_index]:
                min_index = j
        sequence[i],sequence[min_index] = \
            sequence[min_index],sequence[i]
    return sequence
```

Insertion sort

Insertion sort does what you might expect

- inserts each item of the list into its proper position
- resulting in progressively larger sequences of a sorted list

Start with a sorted list of 1 element on the left and N-1 unsorted items on the right

- take the first unsorted item
- insert it into the sorted list, moving elements as necessary
- now have a sorted list of size 2, and N -2 unsorted elements
- repeat for all items

Insertion sort #2

Let's reuse our unsorted list from before and sort it in ascending order:

14	33	27	10	35	19	42	44

Start by finding out where to insert **33**:

33

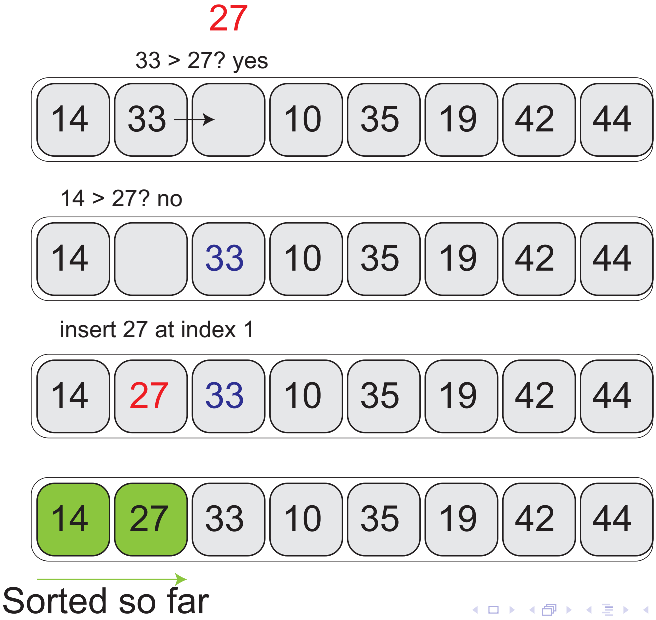
14 > 33? no

14		27	10	35	19	42	44

14	33	27	10	35	19	42	44

put 33 back

Insertion sort #3



27

33 > 27? yes

14	33 →		10	35	19	42	44

14 > 27? no

14		33	10	35	19	42	44

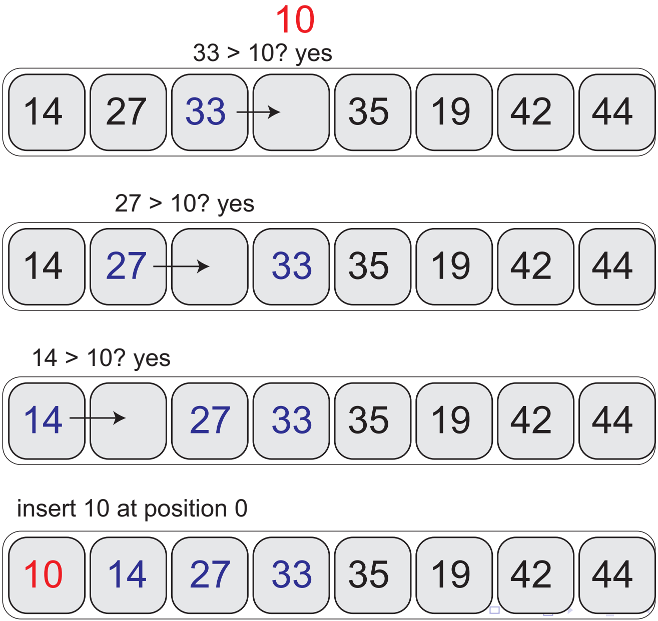
insert 27 at index 1

14	27	33	10	35	19	42	44

14	27	33	10	35	19	42	44

Sorted so far

Insertion sort #4



10

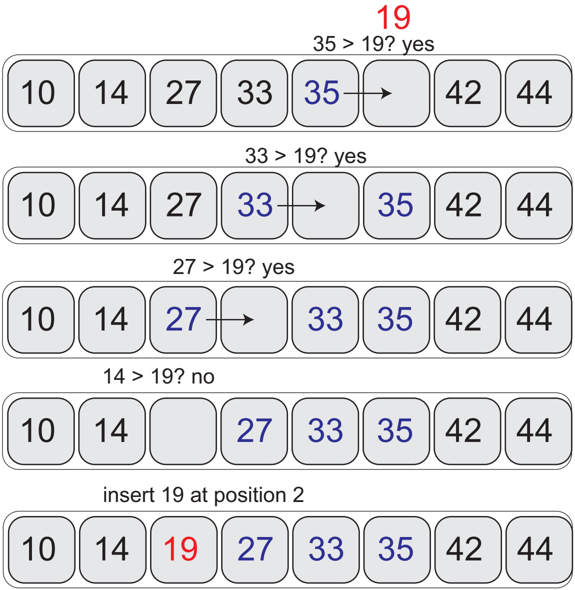
33 > 10? yes

27 > 10? yes

14 > 10? yes

insert 10 at position 0

Insertion sort #5



19

35 > 19? yes

10 14 27 33 35 → 42 44

33 > 19? yes

10 14 27 33 → 35 42 44

27 > 19? yes

10 14 27 → 33 35 42 44

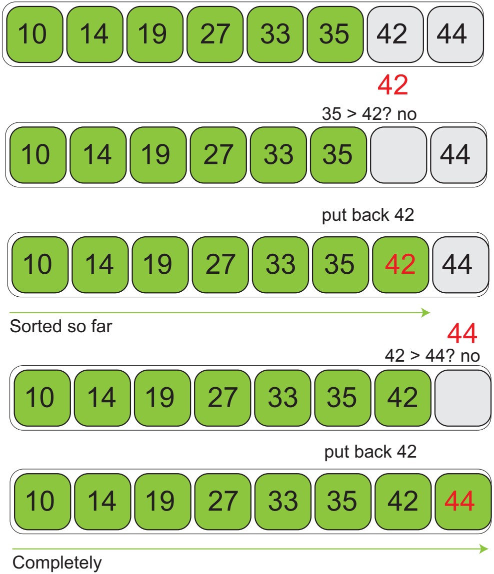
14 > 19? no

10 14 27 33 35 42 44

insert 19 at position 2

10 14 19 27 33 35 42 44

Insertion sort #5



10	14	19	27	33	35	42	44

42

35 > 42? no

10	14	19	27	33	35		44

put back 42

10	14	19	27	33	35	42	44

Sorted so far

44

42 > 44? no

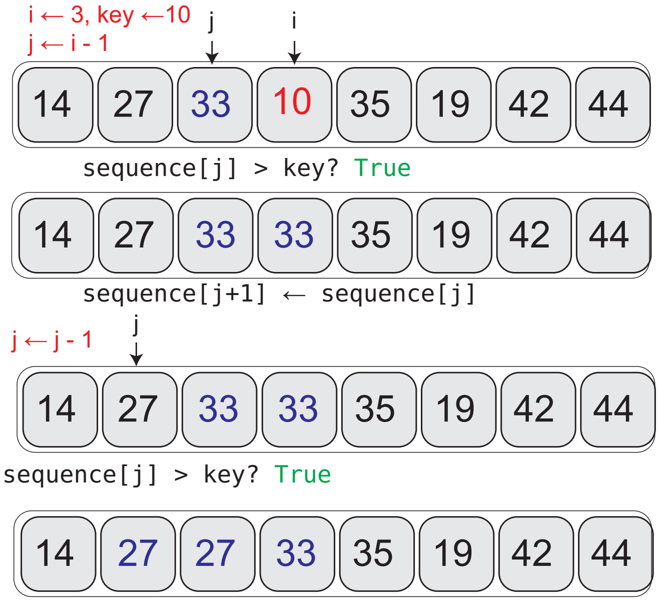
10	14	19	27	33	35	42	

put back 42

10	14	19	27	33	35	42	44

Completely

Insertion sort algorithm



i ← 3, key ←10

j ← i - 1

14	27	33	10	35	19	42	44

`sequence[j] > key? True`

14	27	33	33	35	19	42	44

`sequence[j+1] ← sequence[j]`

j ← j - 1

14	27	33	33	35	19	42	44

`sequence[j] > key? True`

14	27	27	33	35	19	42	44

`sequence[j+1] ← sequence[j]`

Insertion sort: pseudocode

Algorithm 2 Insertion sort

```
procedure INSERTION_SORT(sequence)
    for $i \leftarrow 1$ to $N$ do
        $key \leftarrow sequence[i]$
        // inset key into the sorted sub-list
        $j \leftarrow i - 1$
        while $j >= 0$ and $sequence[j] > key$ do
            $sequence[j+1] \leftarrow sequence[j]$
            $j \leftarrow j - 1$
        end while
        $sequence[j+1] \leftarrow key$
    end for
end procedure
```

Insertion sort: Python implementation

```python
def insertion_sort(sequence):
    N = len(sequence)
    for i in range(1,N):
        j = i-1
        key = sequence[i]
        while(j >= 0 and sequence[j] > key):
            sequence[j+1] = sequence[j]
            j -= 1
        sequence[j+1] = key
    return sequence
```

Which sorting algorithm is faster?

```python
def selection_sort(sequence):
    N = len(sequence)
    for i in range(0,N):
        min_index = i
        for j in range(i+1,N):
            if sequence[j] <= sequence[min_index]:
                min_index = j
        sequence[i],sequence[min_index] = \
            sequence[min_index],sequence[i]
    return sequence
```

```python
def insertion_sort(sequence):
    N = len(sequence)
    for i in range(1,N):
        j = i-1
        key = sequence[i]
        while(j >= 0 and sequence[j] > key):
            sequence[j+1] = sequence[j]
            j -= 1
        sequence[j+1] = key
    return sequence
```

Summary

Why learn both selection and insertion sort?

- insertion sort is expected to be faster in practice
- selection sort makes n passes to scan each element
    - insertion sort only scans each element (being sorted) *once*
- insertion sort does more swapping (i.e., memory usage) than selection sort at the worse case
- there are faster sorting algorithms: e.g., mergesort, quicksort (beyond the scope of this class)