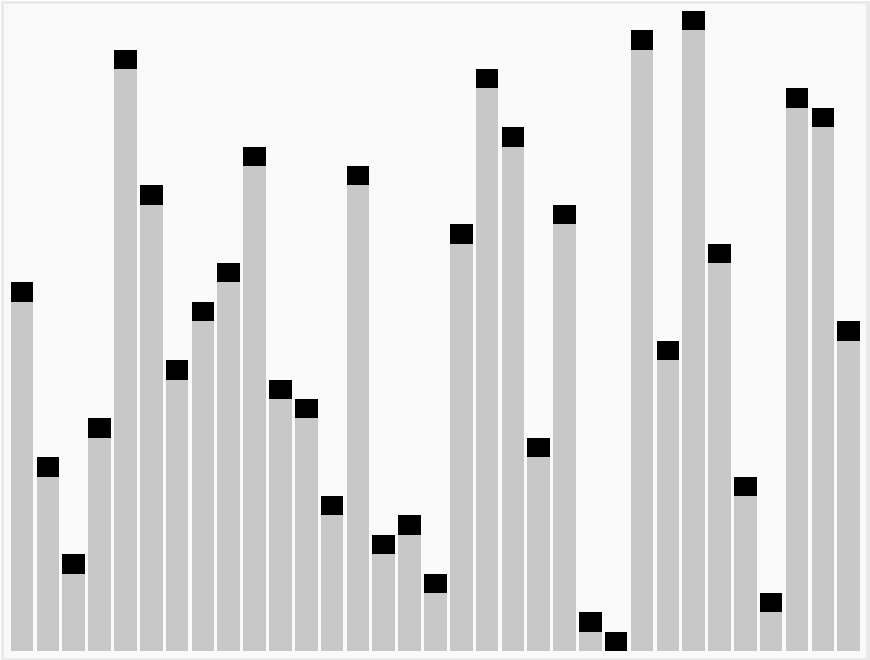


ECE244

*Wael Aboulsaadat*

# ***QuickSort***

Acknowledgment: these slides are partially based on slides by; Prof. Schmidt from Drexel U., Prof. Shewchuk from UC Berkely, Kruse & Ryba Data Structure and Program Design in C++, Prof. Savitch Problem Solving in C++ and others



# Example

We are given array of n integers to sort:

40	20	10	80	60	50	7	30	100
----	----	----	----	----	----	---	----	-----

# Pick Pivot Element

There are a number of ways to pick the pivot element. In this example, we will use the first element in the array:

40	20	10	80	60	50	7	30	100
----	----	----	----	----	----	---	----	-----

# Partitioning Array

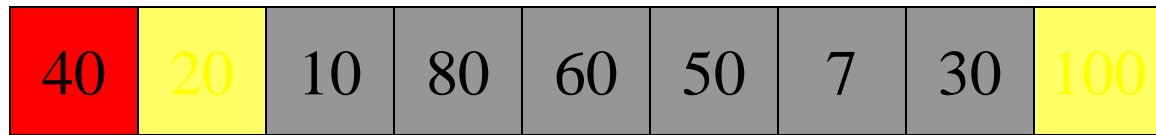
Given a pivot, partition the elements of the array such that the resulting array consists of:

1. One sub-array that contains elements  $\geq$  pivot
2. Another sub-array that contains elements  $<$  pivot

The sub-arrays are stored in the original data array.

Partitioning loops through, swapping elements below/above pivot.

pivot\_index = 0

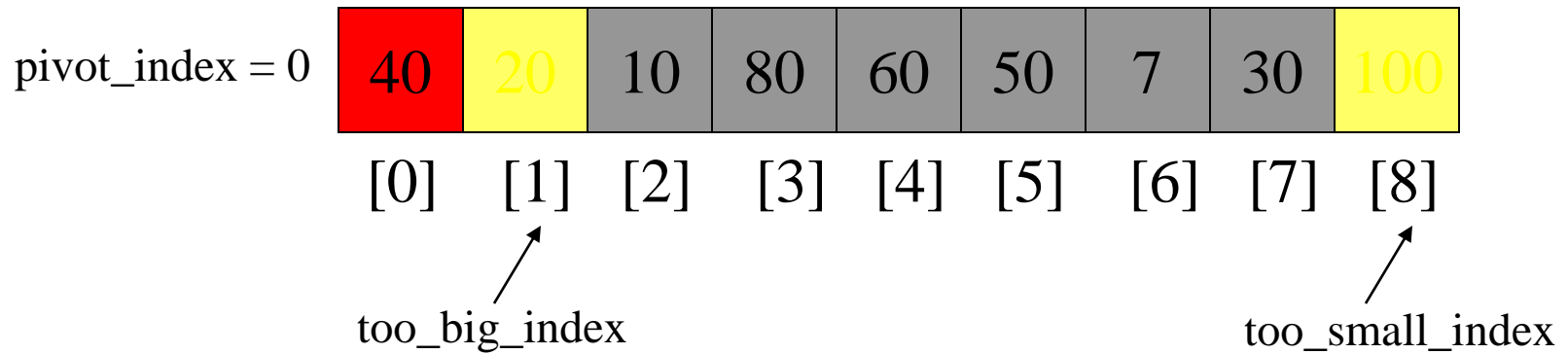


[0] [1] [2] [3] [4] [5] [6] [7] [8]

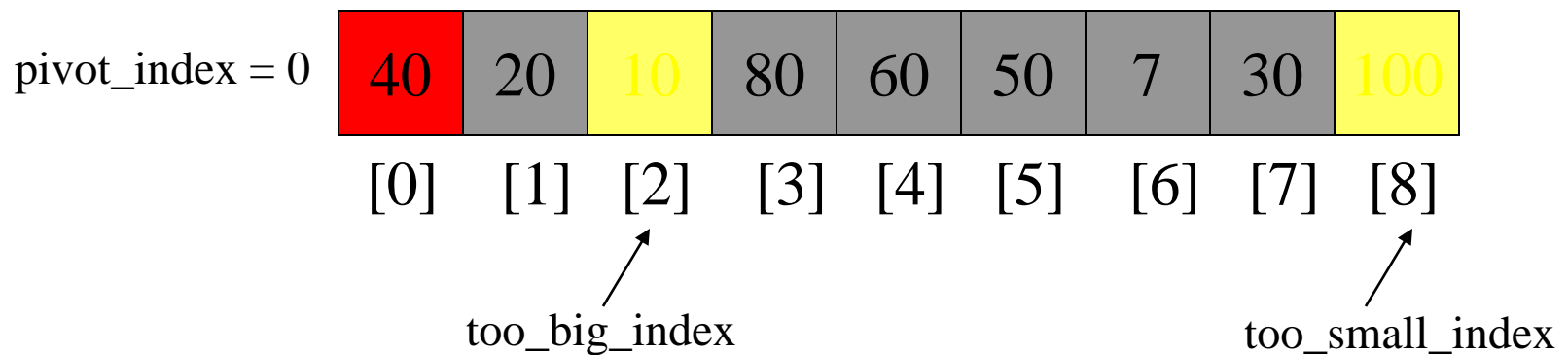
too\_big\_index

too\_small\_index

1. While `data[too_big_index] <= data[pivot]`  
    `++too_big_index`

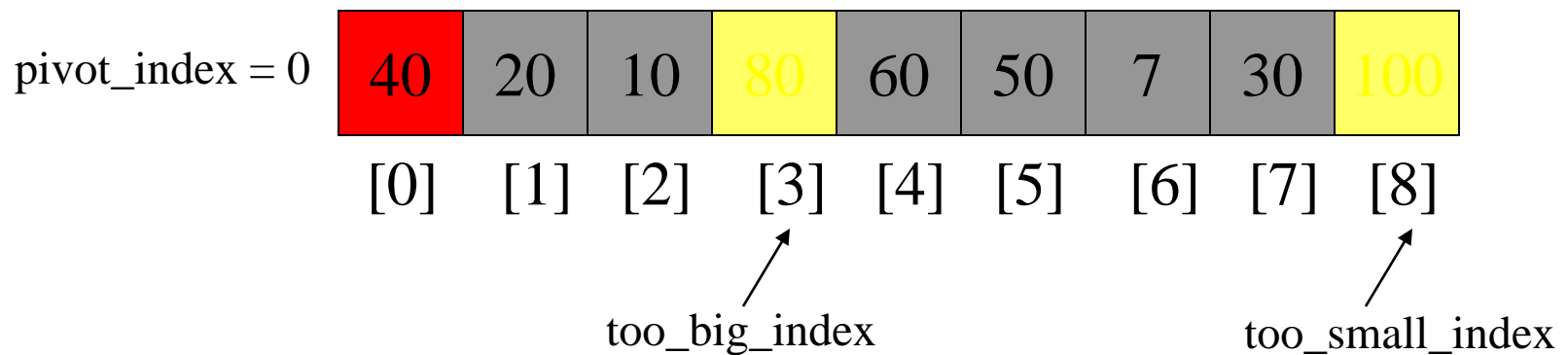


1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$

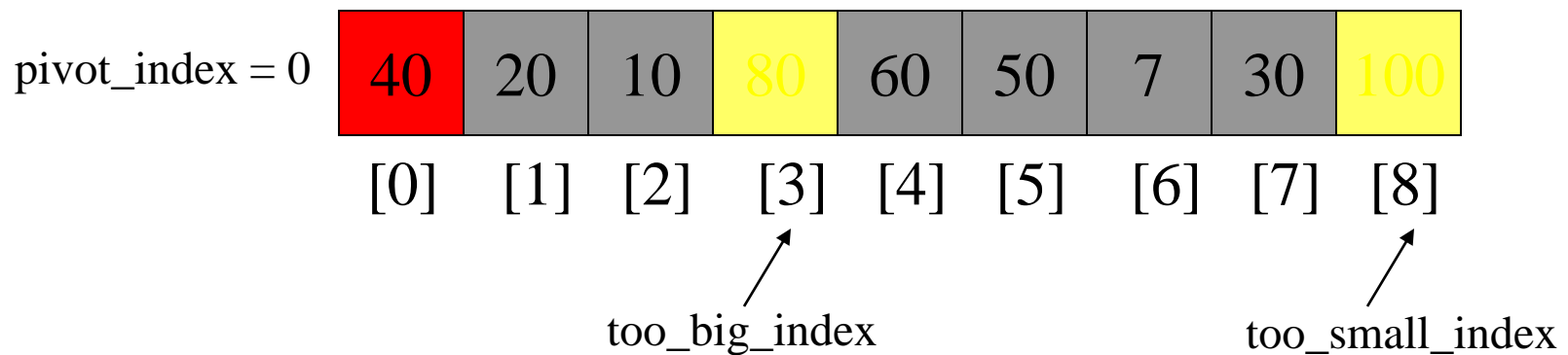




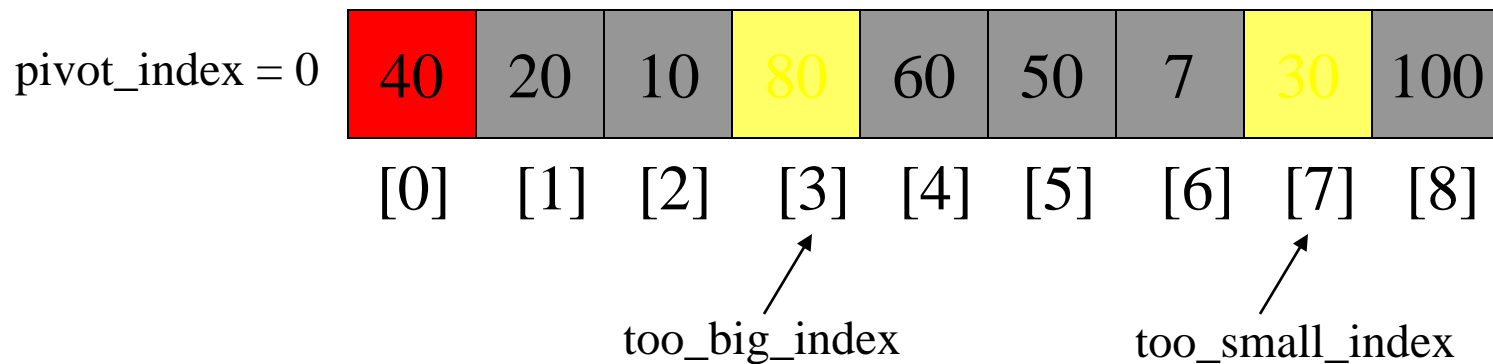
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$



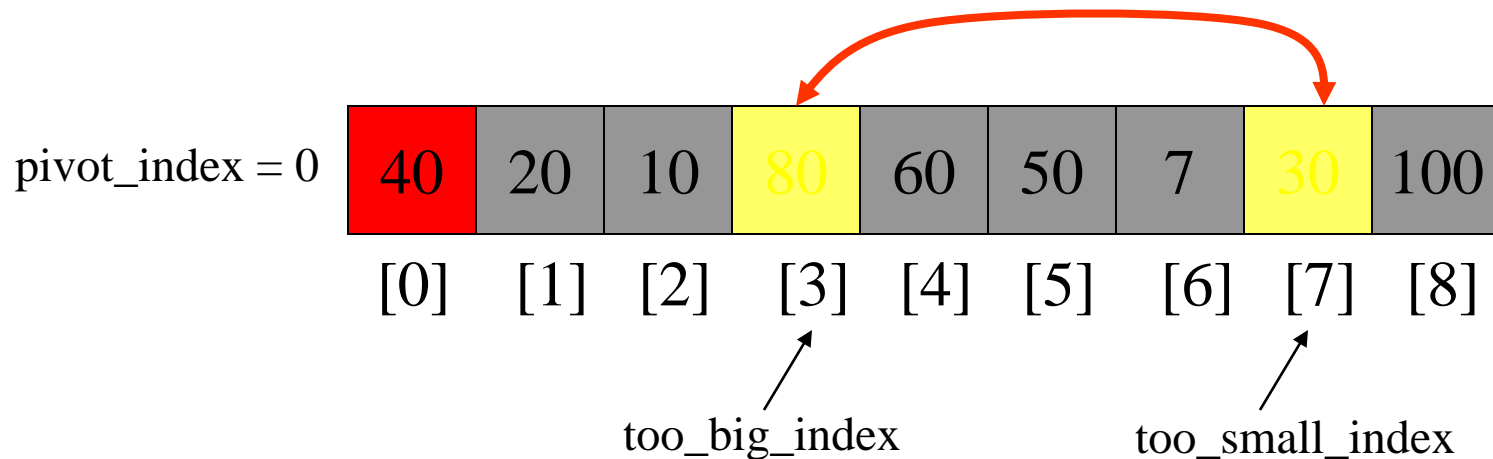
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$



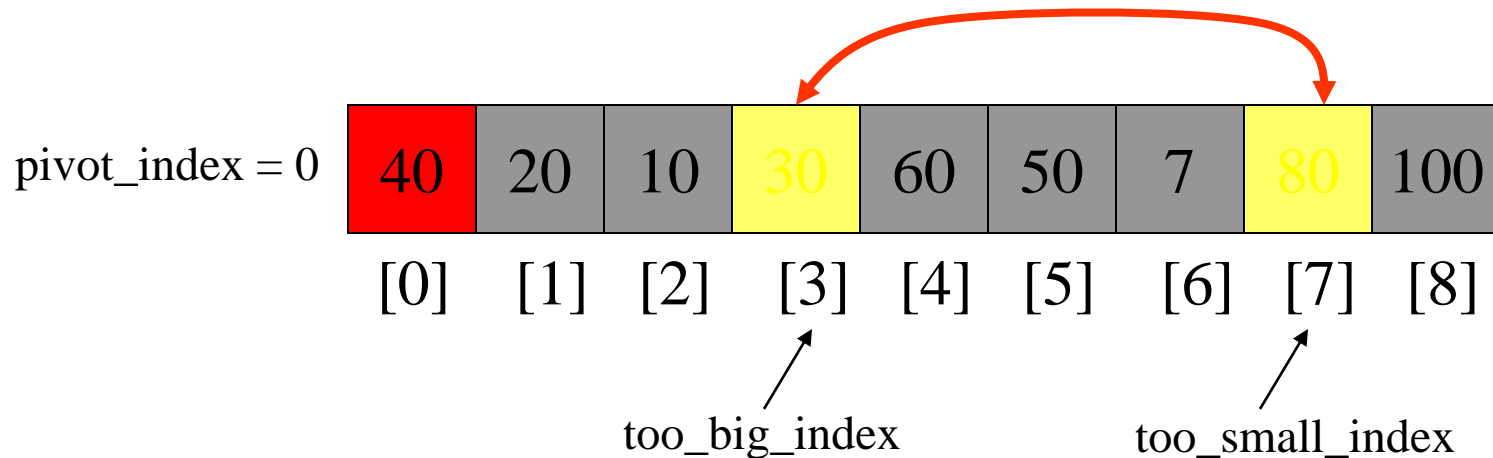
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$



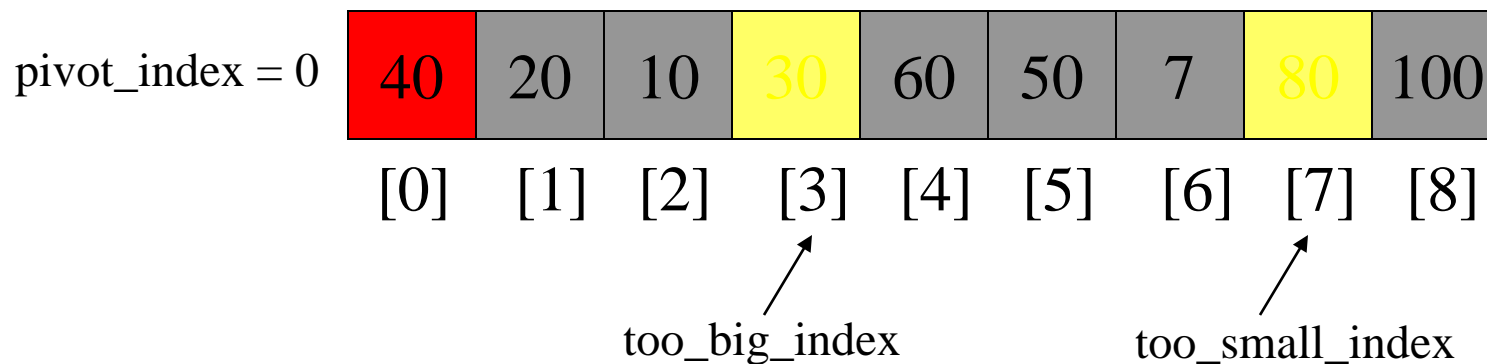
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$



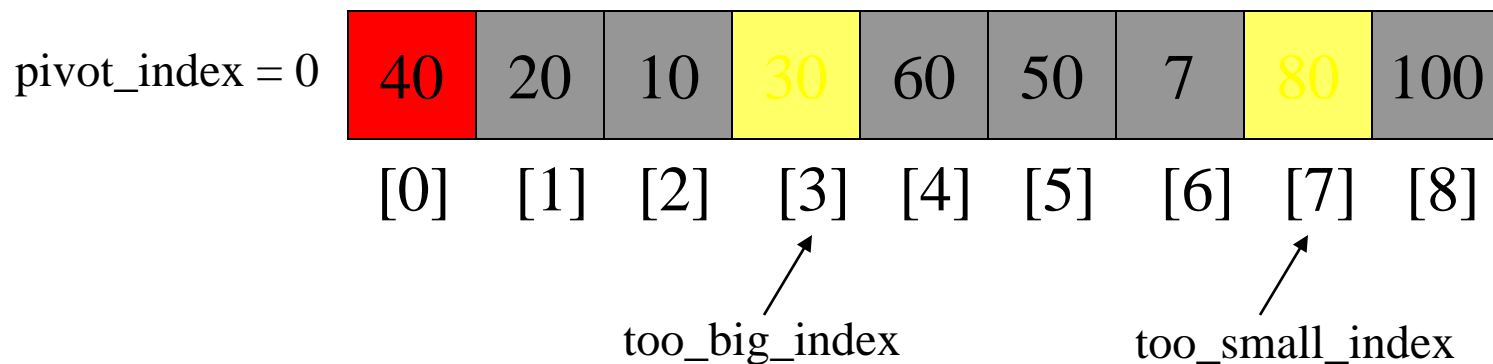
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$



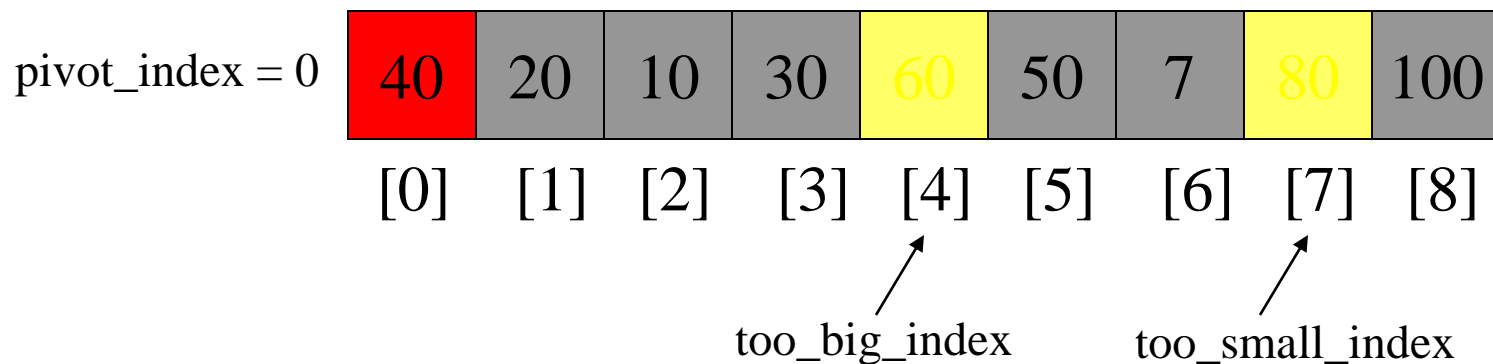
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



- 1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.

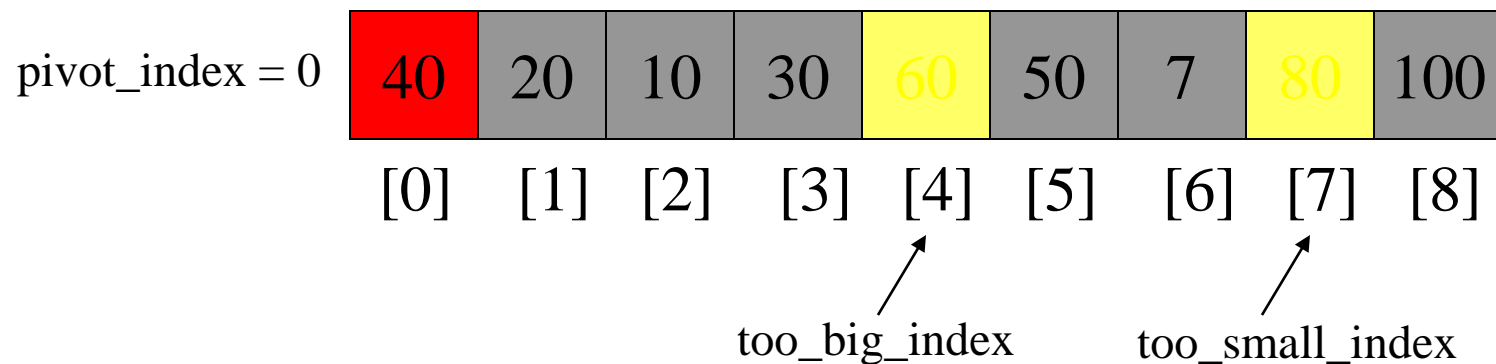


- 1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
- 3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
- 4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.

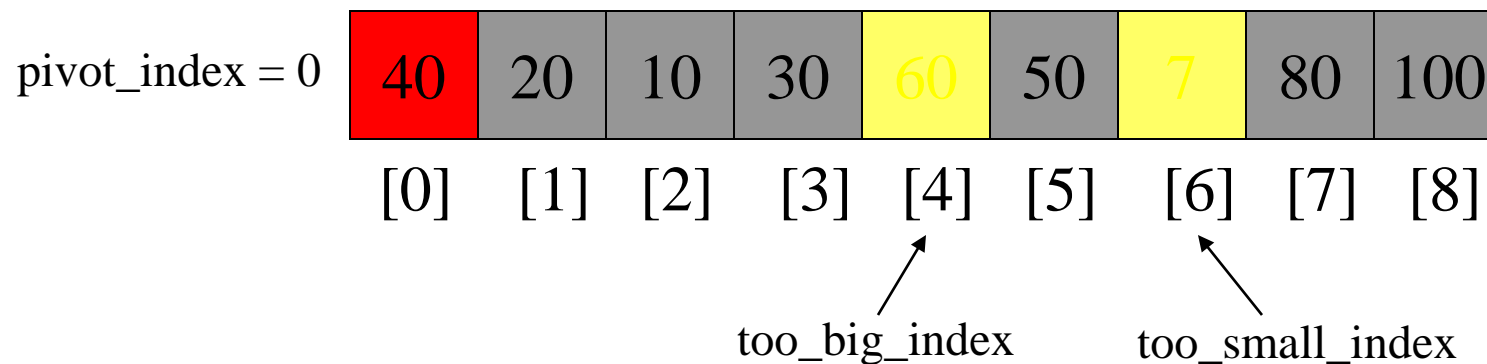




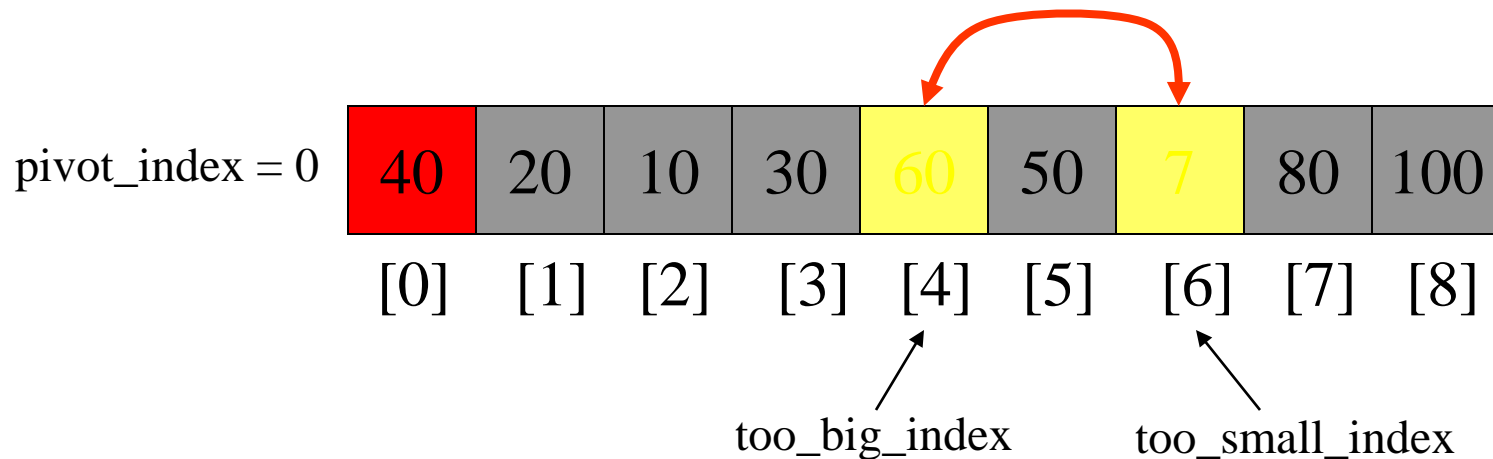
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



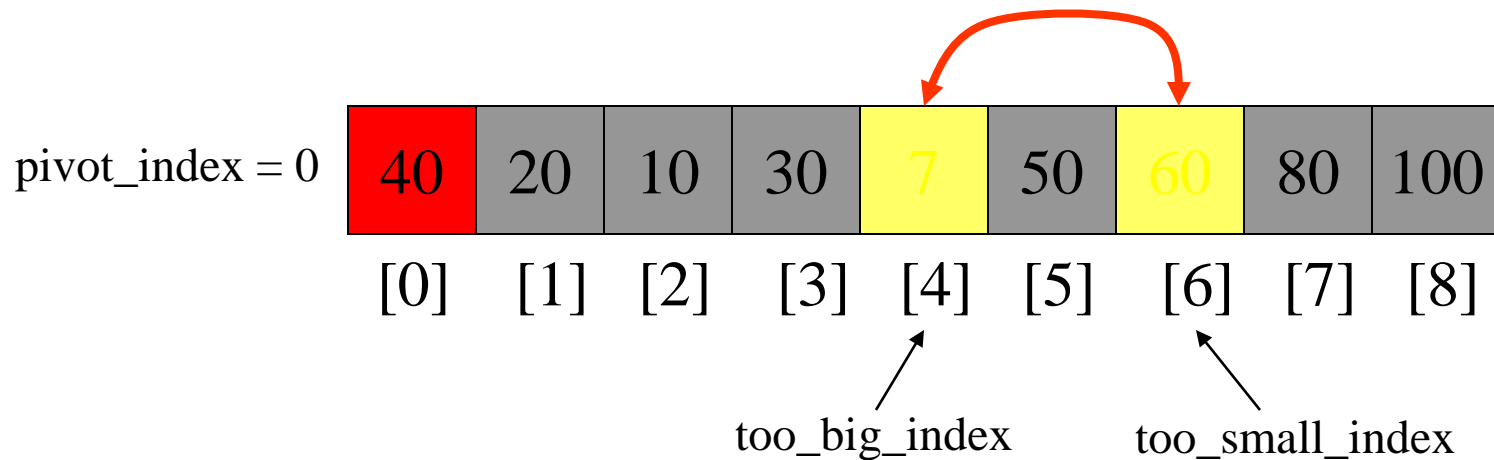
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



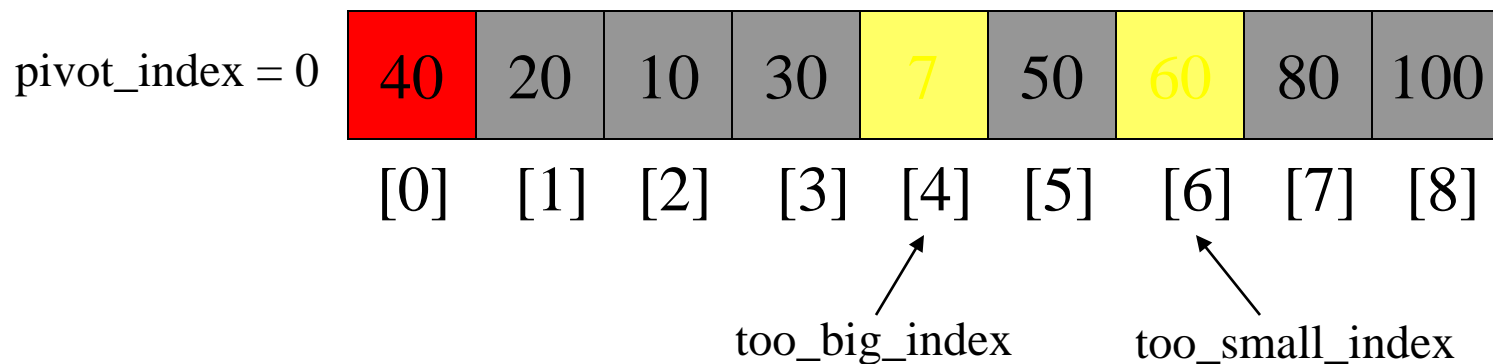
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
- 3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



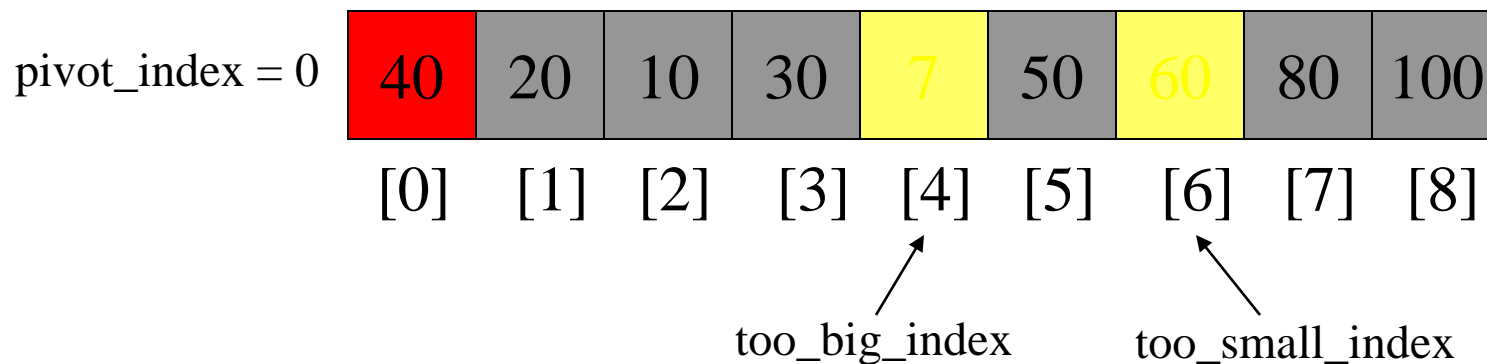
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
- 3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



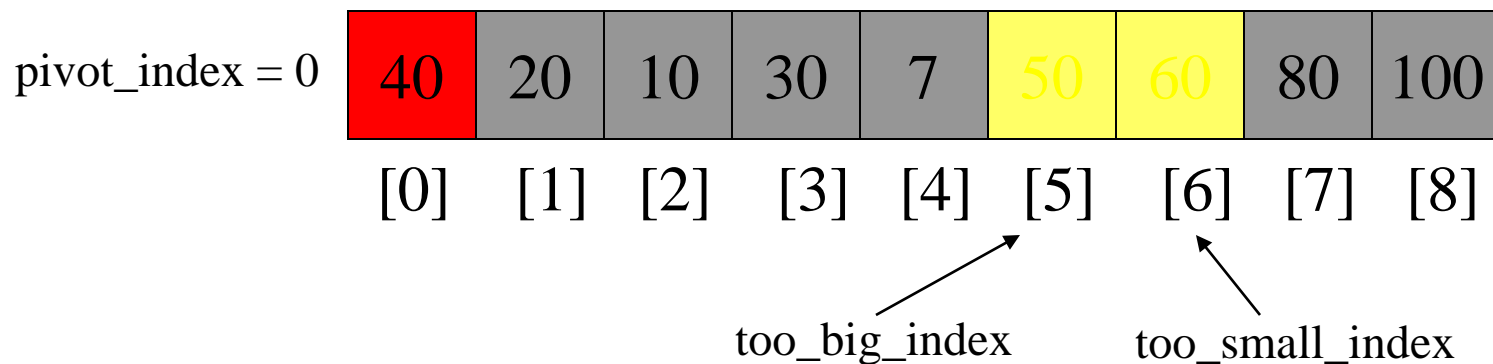
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
- 4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



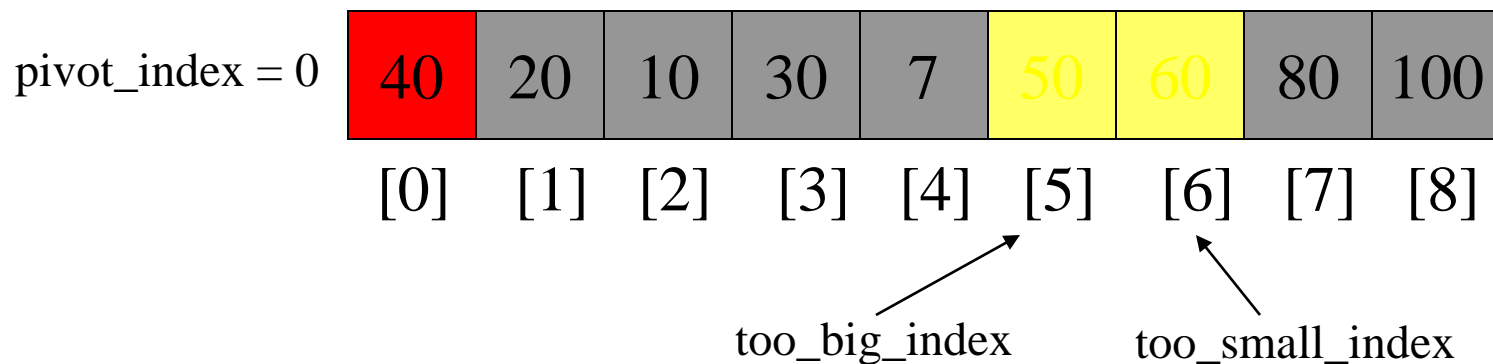
- 1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



- 1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.

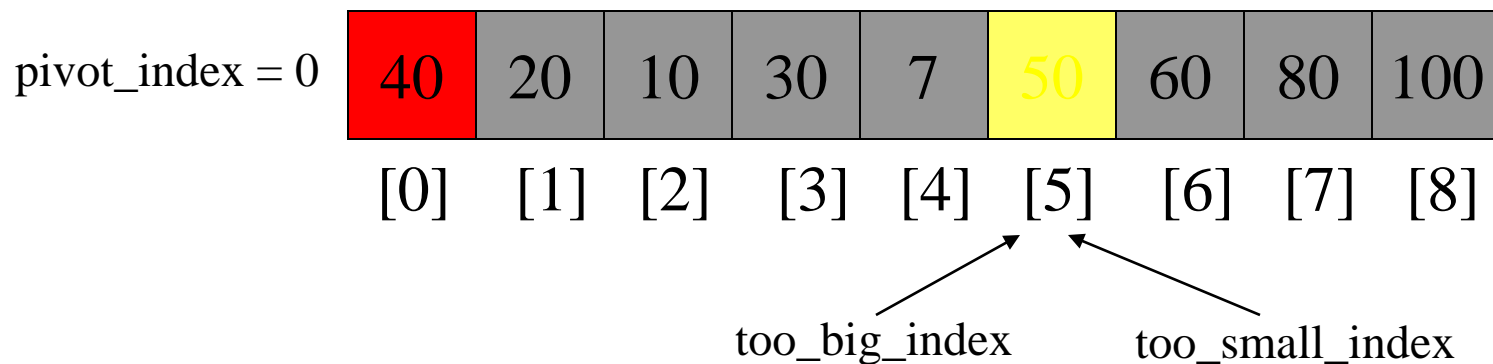


1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.

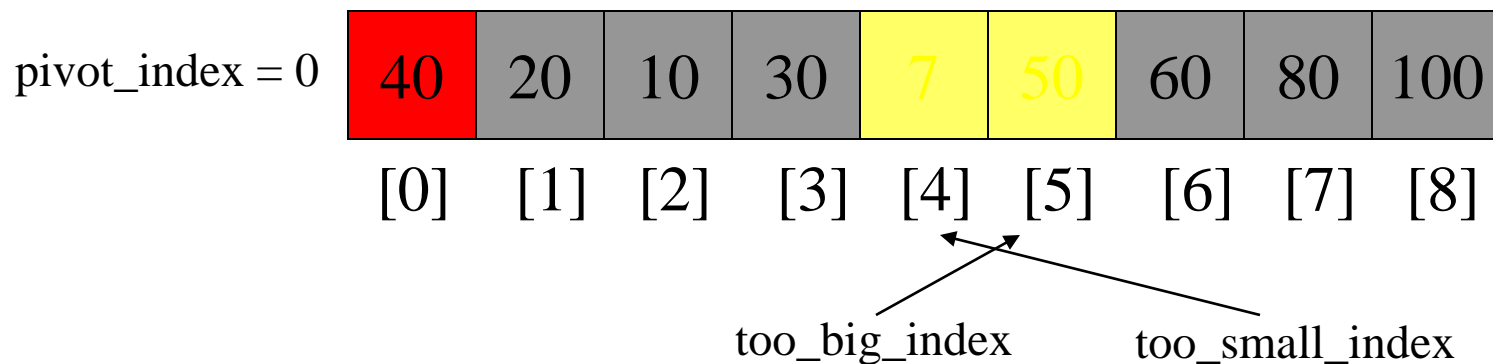




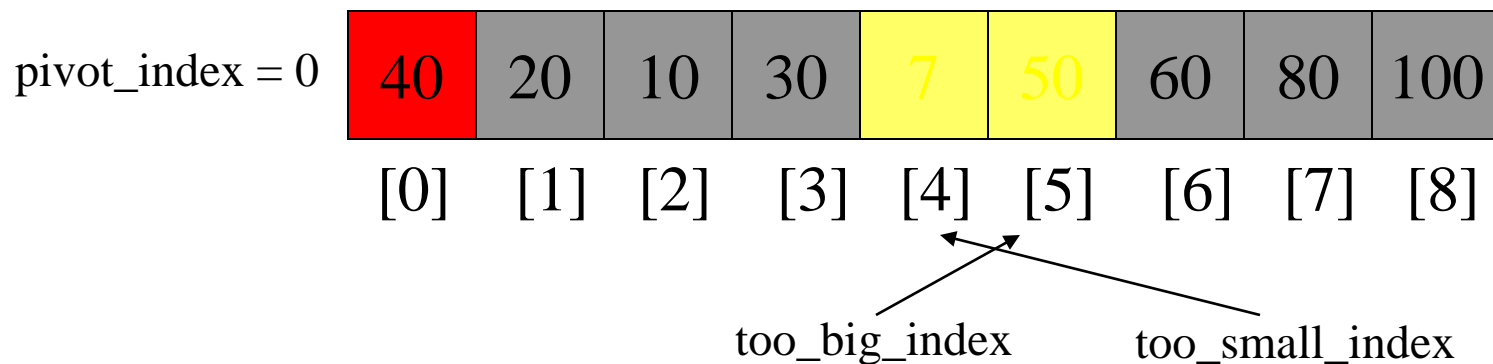
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



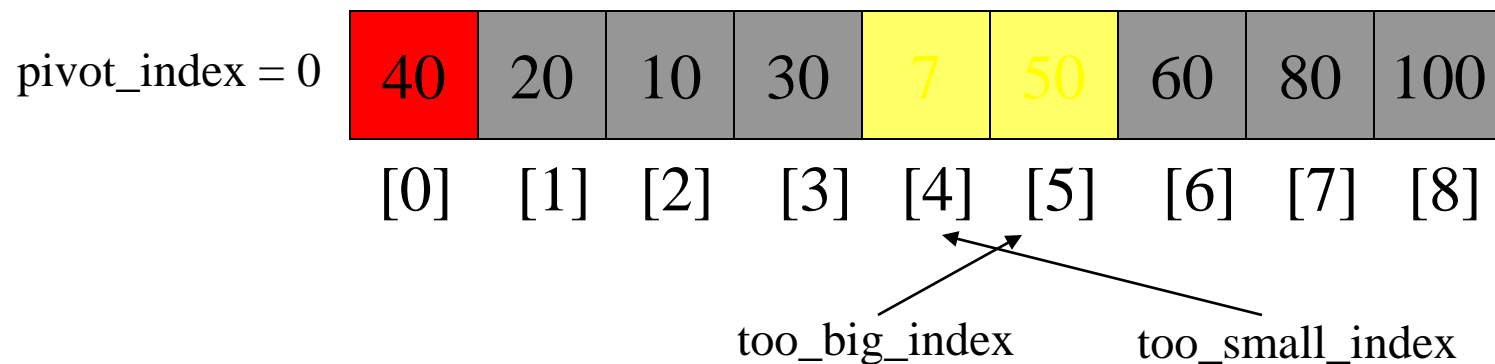
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
- 2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



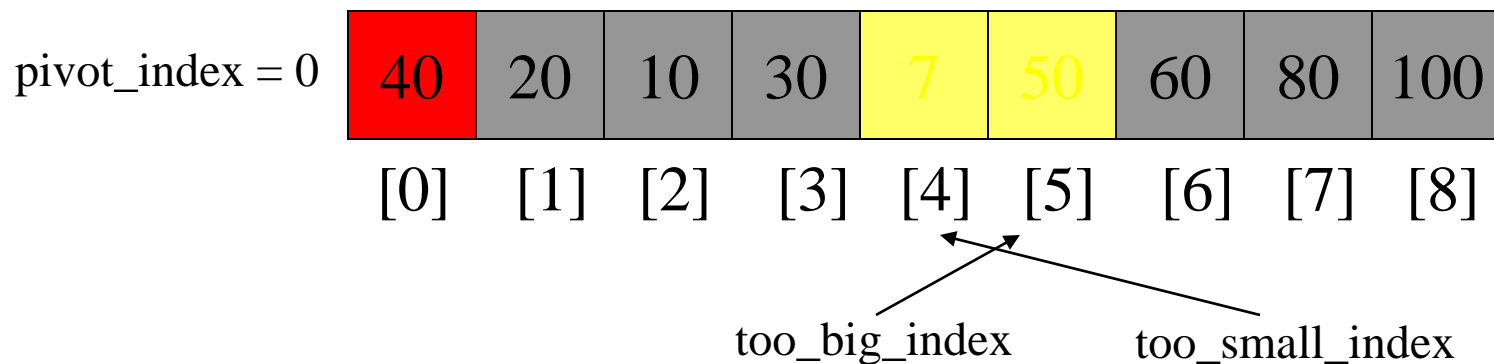
1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
- 3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.



1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
- 4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.

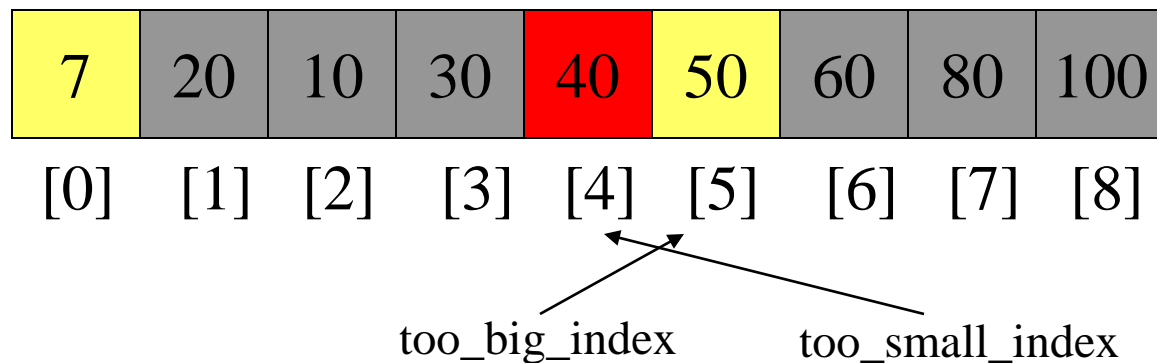


1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.
- 5. Swap  $\text{data}[\text{too\_small\_index}]$  and  $\text{data}[\text{pivot\_index}]$

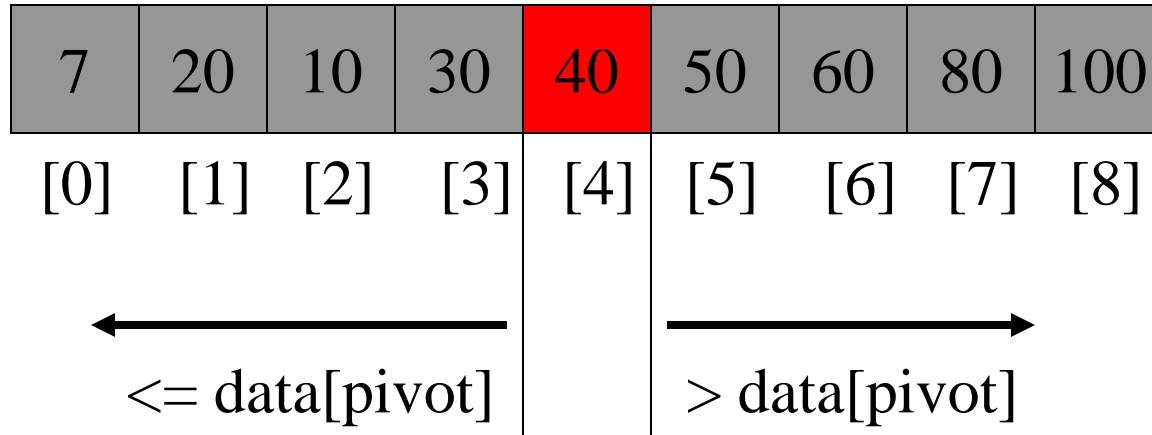


1. While  $\text{data}[\text{too\_big\_index}] \leq \text{data}[\text{pivot}]$   
     $++\text{too\_big\_index}$
2. While  $\text{data}[\text{too\_small\_index}] > \text{data}[\text{pivot}]$   
     $--\text{too\_small\_index}$
3. If  $\text{too\_big\_index} < \text{too\_small\_index}$   
    swap  $\text{data}[\text{too\_big\_index}]$  and  $\text{data}[\text{too\_small\_index}]$
4. While  $\text{too\_small\_index} > \text{too\_big\_index}$ , go to 1.
- 5. Swap  $\text{data}[\text{too\_small\_index}]$  and  $\text{data}[\text{pivot\_index}]$

**pivot\_index = 4**



# Partition Result



# Recursion: Quicksort Sub-arrays

