The background of the slide features a large, semi-transparent watermark of the NPTEL logo. The logo consists of a circular emblem with a stylized flower or sunburst in the center, surrounded by a ring of colored segments. Below the emblem, the word "NPTEL" is written in large, bold, sans-serif capital letters.

NPTEL MOOC, JAN-FEB 2015  
Week 2, Module 7

# DESIGN AND ANALYSIS OF ALGORITHMS

## Quicksort

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# Merge Sort: Shortcomings

- \* Merging A and B creates a new array C
  - \* No obvious way to efficiently merge in place
- \* Extra storage can be costly
- \* Inherently recursive
  - \* Recursive call and return are expensive



# Alternative approach

- \* Extra space is required to merge
- \* Merging happens because elements in left half must move right and vice versa
- \* Can we divide so that everything to the left is smaller than everything to the right?
  - \* No need to merge!



# Divide and conquer without merging

- \* Suppose the median value in A is  $m$
- \* Move all values  $\leq m$  to left half of A
  - \* Right half has values  $> m$
  - \* This shifting can be done in place, in time  $O(n)$
- \* Recursively sort left and right halves
- \* A is now sorted! No need to merge
  - \*  $t(n) = 2t(n/2) + n = O(n \log n)$



# Divide and conquer without merging

- \* How do we find the median?
  - \* Sort and pick up middle element
  - \* But our aim is to sort!
- \* Instead, pick up some value in A — **pivot**
  - \* Split A with respect to this pivot element



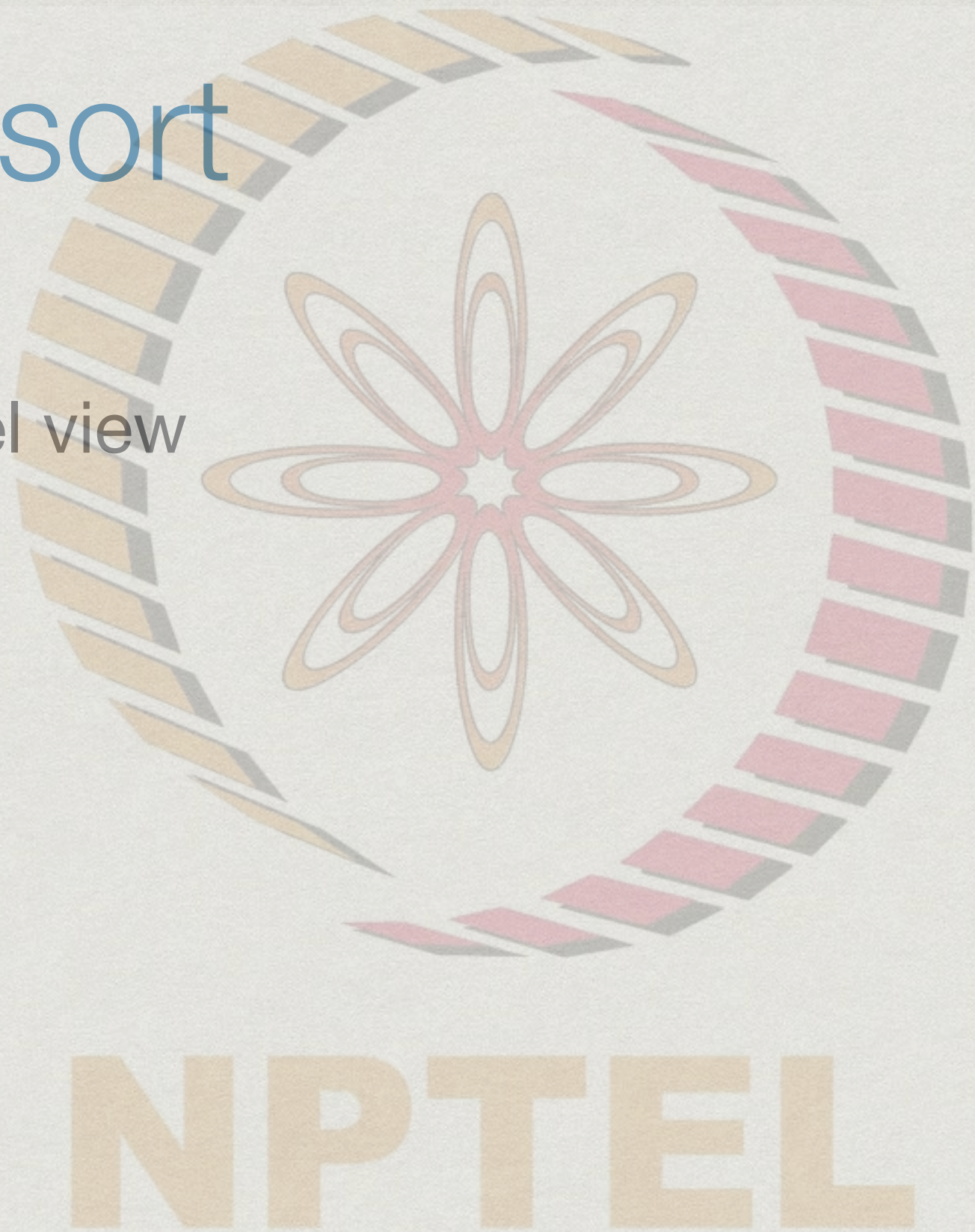
# Quicksort

- \* Choose a pivot element
  - \* Typically the first value in the array
- \* Partition A into lower and upper parts with respect to pivot
- \* Move pivot between lower and upper partition
- \* Recursively sort the two partitions



# Quicksort

- \* High level view





# Quicksort

- \* High level view

43	32	22	78	63	57	91	13
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# Quicksort

- \* High level view

<b>43</b>	32	22	78	63	57	91	13
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# Quicksort

- \* High level view

43	32	22	78	63	57	91	13
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# Quicksort

- \* High level view

13	32	22	43	63	57	91	78
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# Quicksort

- \* High level view

13	22	32	43	57	63	78	91
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# Quicksort: Partitioning





# Quicksort: Partitioning

<b>43</b>	32	22	78	63	57	91	13
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# Quicksort: Partitioning





# Quicksort: Partitioning



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# Quicksort: Partitioning

43	32	22	78	63	57	91	13
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# Quicksort: Partitioning

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# Quicksort: Partitioning

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# Quicksort: Partitioning

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# Quicksort: Partitioning



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# Quicksort: Partitioning



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# Quicksort: Implementation

```
Quicksort(A,l,r) // Sort A[l..r-1]

    if (r - l <= 1) return; // Base case

    // Partition with respect to pivot, a[l]
    yellow = l+1;
    for (green = l+1; green < r; green++)
        if (A[green] <= A[l])
            swap(A,yellow,green);
            yellow++;

    swap(A,l,yellow-1); // Move pivot into place

    Quicksort(A,l,yellow); // Recursive calls
    Quicksort(A,yellow+1,r);
```



# Quicksort: Another Partitioning Strategy





# Quicksort: Another Partitioning Strategy

<b>43</b>	32	22	78	63	57	91	13
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# Quicksort: Another Partitioning Strategy

<b>43</b>	32	22	78	63	57	91	13
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# Quicksort: Another Partitioning Strategy

43	32	22	78	63	57	91	13
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The diagram illustrates a partitioning strategy in the Quicksort algorithm. It shows an array of eight numbers: 43, 32, 22, 78, 63, 57, 91, and 13. The number 22 is highlighted with a yellow arrow pointing to it from below, and the number 13 is highlighted with a green arrow pointing to it from below. The background features a faint watermark of the NPTEL logo, which consists of a stylized flower-like shape with multiple petals, surrounded by a circular border with diagonal stripes, and the text 'NPTEL' at the bottom.



# Quicksort: Another Partitioning Strategy





# Quicksort: Another Partitioning Strategy

43	32	22	13	63	57	91	78
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A diagram illustrating a partitioning strategy in the Quicksort algorithm. It shows an array of eight numbers: 43, 32, 22, 13, 63, 57, 91, and 78. The numbers 43, 32, 22, and 13 are colored red, yellow, orange, and yellow respectively. The number 63 is grey, 57 is dark grey, 91 is dark grey, and 78 is green. Below the array, there are two vertical arrows: a yellow one pointing up to the number 63 and a green one pointing up to the number 91. The background features a large, faint watermark of the NPTEL logo, which consists of a stylized flower-like shape with multiple petals, surrounded by a circular border with diagonal lines.

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# Quicksort: Another Partitioning Strategy

43	32	22	13	63	57	91	78
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The diagram illustrates a partitioning step in the Quicksort algorithm. An array of eight numbers is shown: 43, 32, 22, 13, 63, 57, 91, and 78. The number 63 is highlighted in grey and has an orange arrow pointing to it from below, indicating it is the pivot. The number 57 is highlighted in dark purple and has a green arrow pointing to it from below, indicating it is the element being compared to the pivot. The other numbers are color-coded: 43 is red, 32 and 22 are yellow, 13 is orange, 91 is green, and 78 is dark green.

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# Quicksort: Another Partitioning Strategy

43	32	22	13	63	57	91	78
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# Quicksort: Another Partitioning Strategy

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# Quicksort: Another Partitioning Strategy

