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Searching, Sorting, Complexity Part 02

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Efficiency

- Efficiency
  - Producing desired results with little to no waste
  - Well organized and prevents wasteful use of a resource
- Resources
  - Time
  - Space
- How do we measure efficiency?
  - Algorithms do not require computers

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Complexity

- Complexity
  - Classifies Computational Problems based on inherent difficulty
  - Relates problems to each other
  - Time and Space
- Asymptotic Analysis
  - A way to describe a *limiting* behavior / function
  - Limits in math are a value that a function *approaches* as the input *approaches* some value
  - Time and Space Complexity

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Big O Notation

- Theoretical upper bound of an algorithm
- The "Worst Case" scenario
- Let f and g be functions defined on some subset of real numbers

$$f(n) = O(g(n))\ where\ n \in \mathbb{R}\ \text{as}\ n \to \infty$$

- Let M be a constant that's sufficiently large then we can say

$$|f(n)| \leq M|g(n)|\ \ for\ all\ n \geq n_0$$

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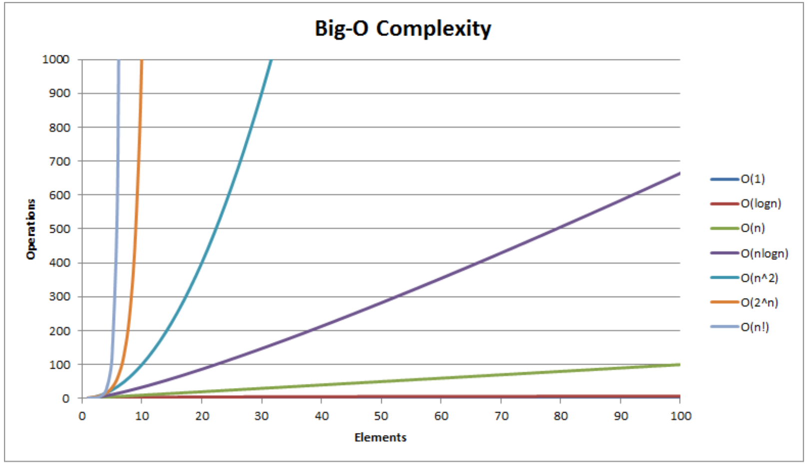
Big O Notation

- Common Big O Complexities
  - $O(1)$ – Constant
  - $O(\log(n))$ – Logarithmic
  - $O(n)$ – Linear
  - $O(n\log n)$ – Linearithmic
  - $O(n^2)$ – Quadratic
  - $O(2^n)$ – Exponential “Bad”
  - $O(n!)$ – Factorial “Really Bad”

Big O



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Example

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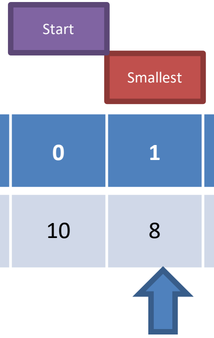

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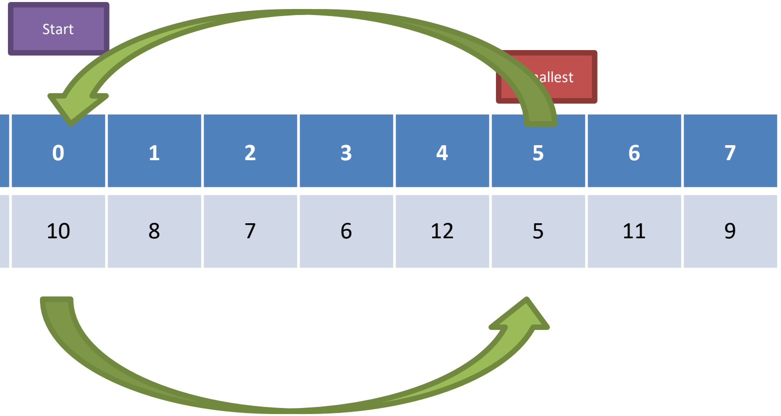

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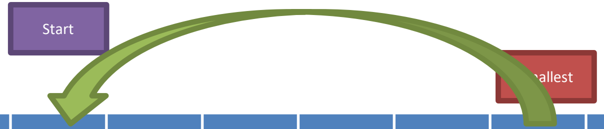

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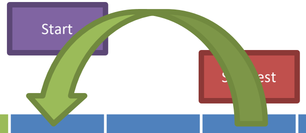

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A Few Swaps Later

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Selection Sort Complexity

- Worst Case
  - Sorted in Descending Order
- Operations
  - Search for smallest value = n
  - Search for the next smallest value = n – 1
  - Search for the next smallest value = n – 2
  - …
  - Search for the largest element = 1

<u>Complexity</u>

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$$O(n^2)$$

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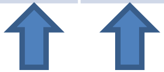

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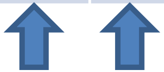

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  - Sorted in Descending Order
- Operations
  - Bubble Up Largest Value = n
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Complexity

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Can we do better?

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Sorting Algorithms

- Merge Sort
  1. Recursively split the array in half until single elements remain
  2. Merge two smaller arrays and return the sorted result
     1. Create an array of combined size
     2. Add elements from the two smaller arrays into the combined array in sorted order
  3. Repeat Step 2 until the final array is reached

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0	1	2	3	4	5	6	7
10	8	7	6	12	5	11	9

File Edit View Help

Sorting Algorithms

- Merge Sort
    1. Recursively split the array in half until single elements remain
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        2. Add elements from the two smaller arrays into the combined array in sorted order
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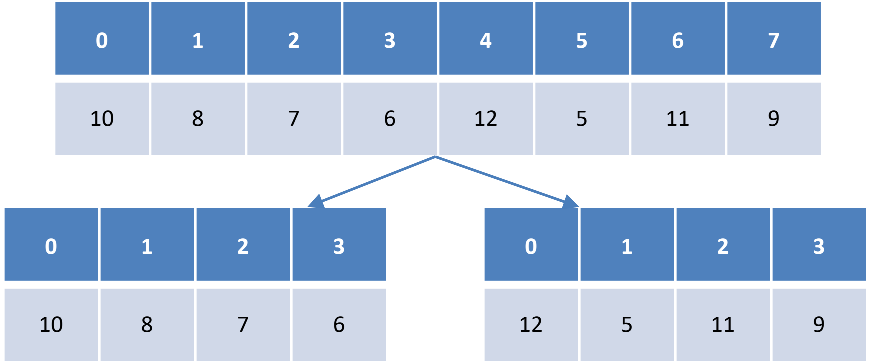

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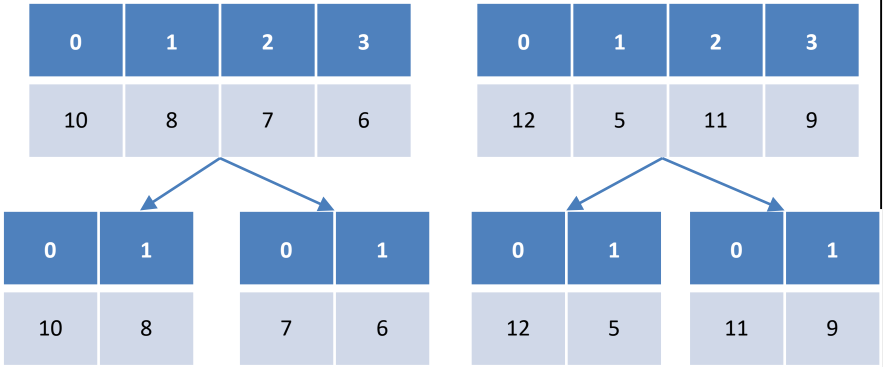

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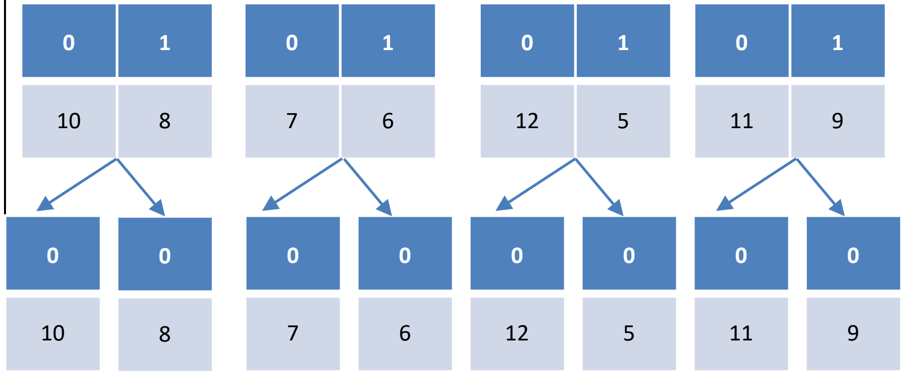

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Example

0	0	0	0	0	0	0	0
10	8	7	6	12	5	11	9

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Sorting Algorithms

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  1. Recursively split the array in half until single elements remain
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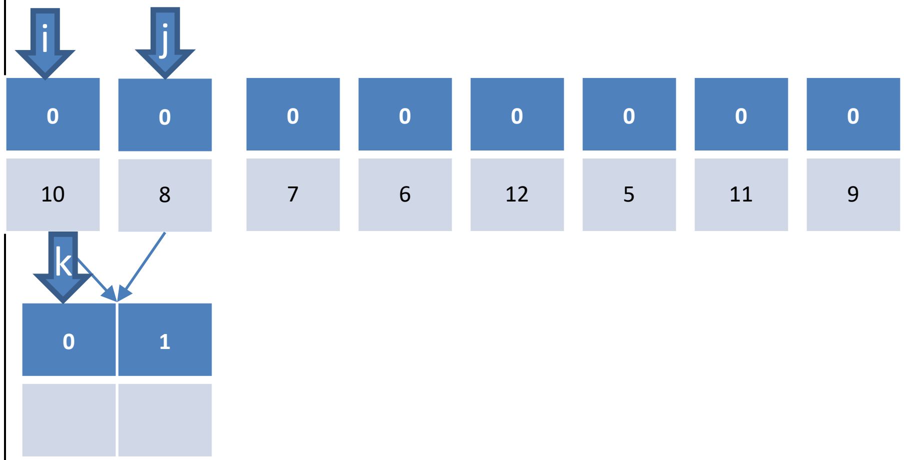

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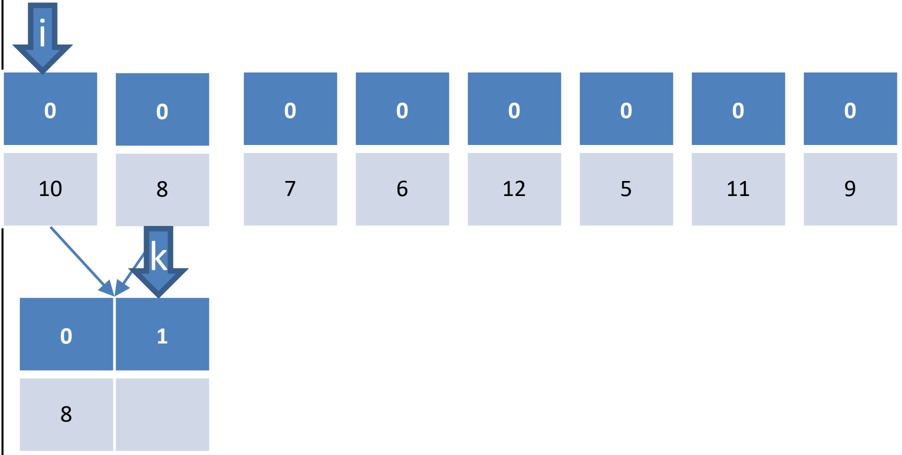

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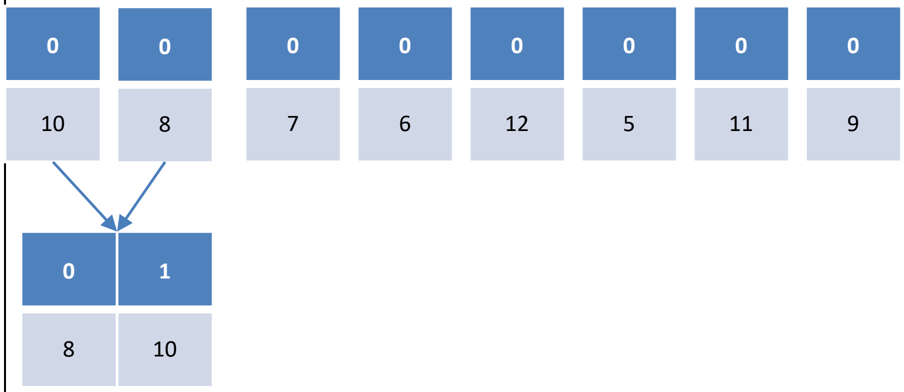

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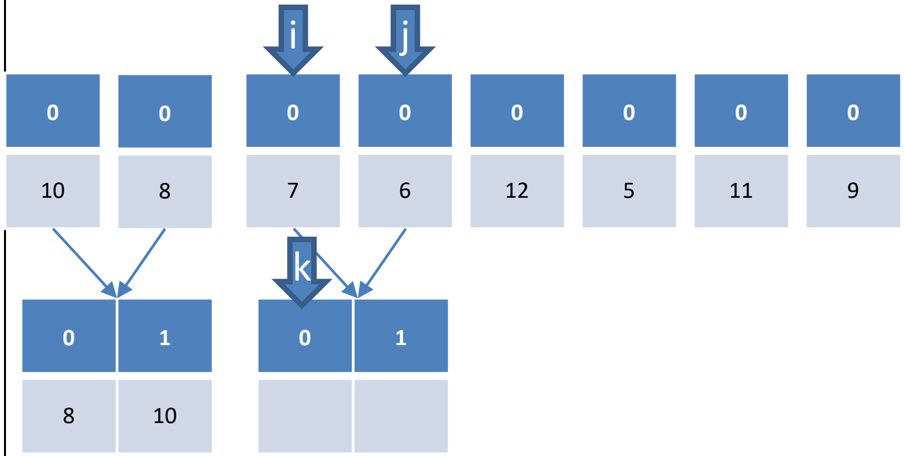

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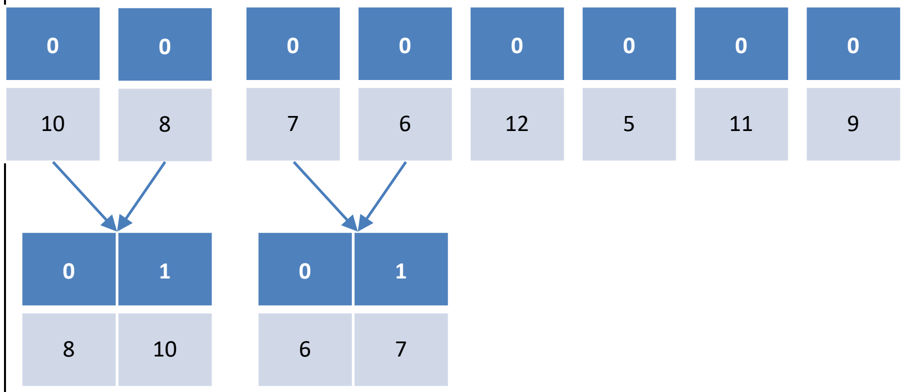

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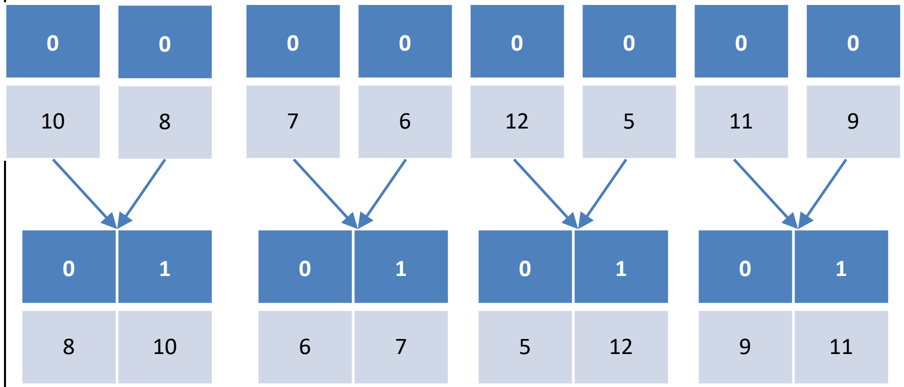

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Example

0	1
8	10

0	1
6	7

0	1
5	12

0	1
9	11

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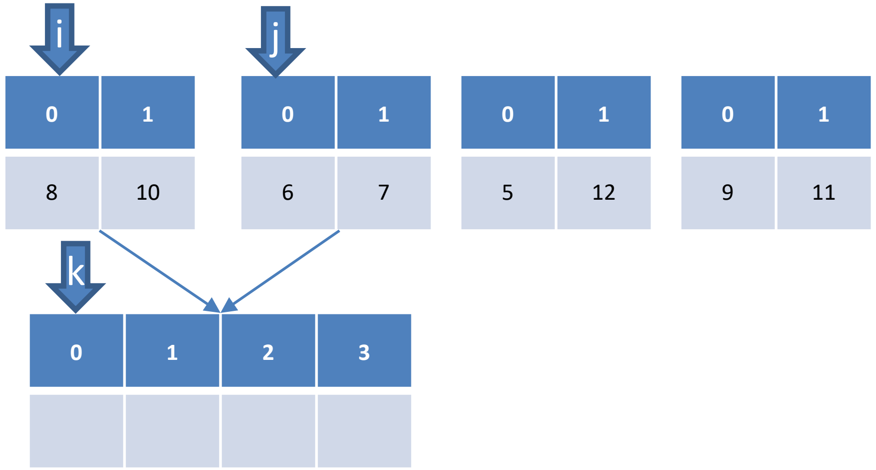

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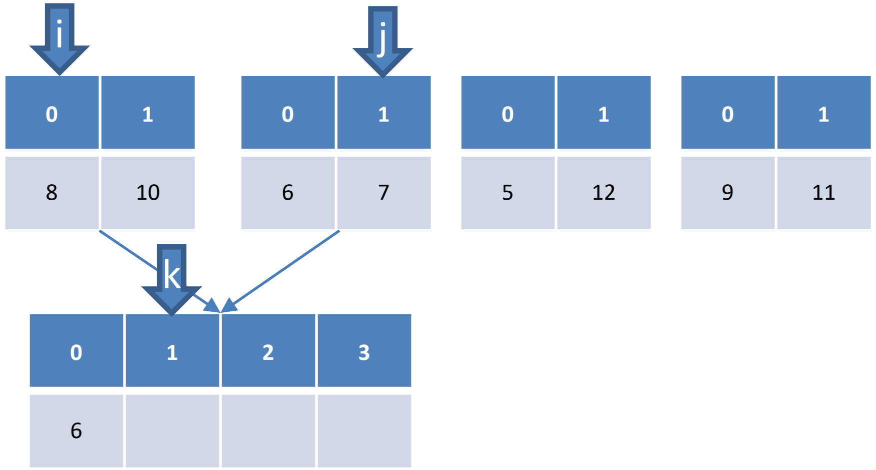

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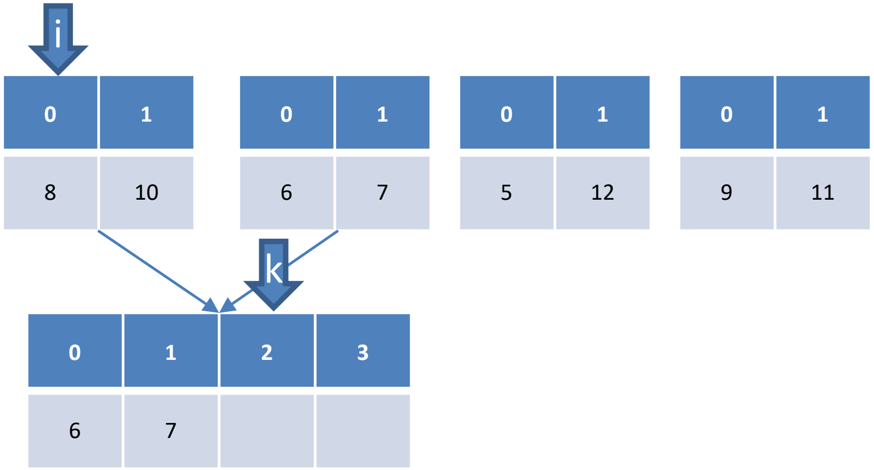

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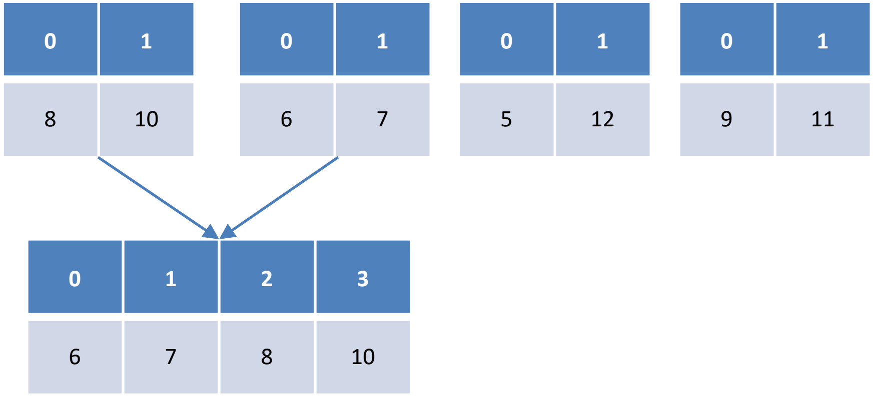

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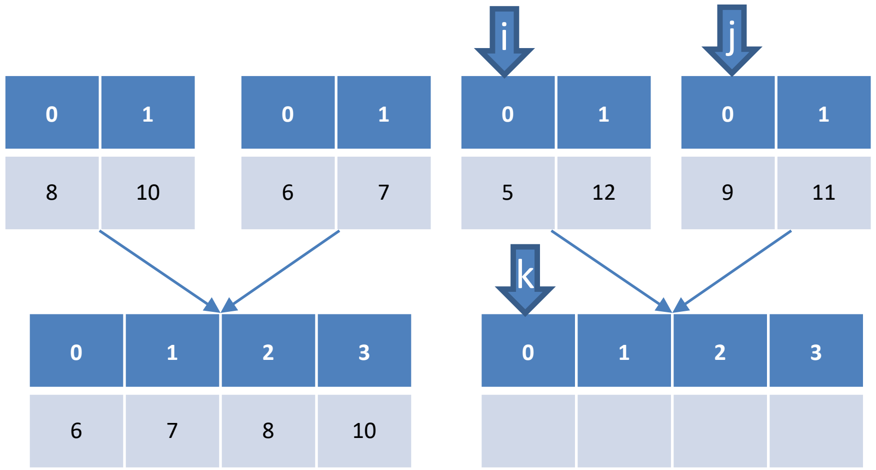

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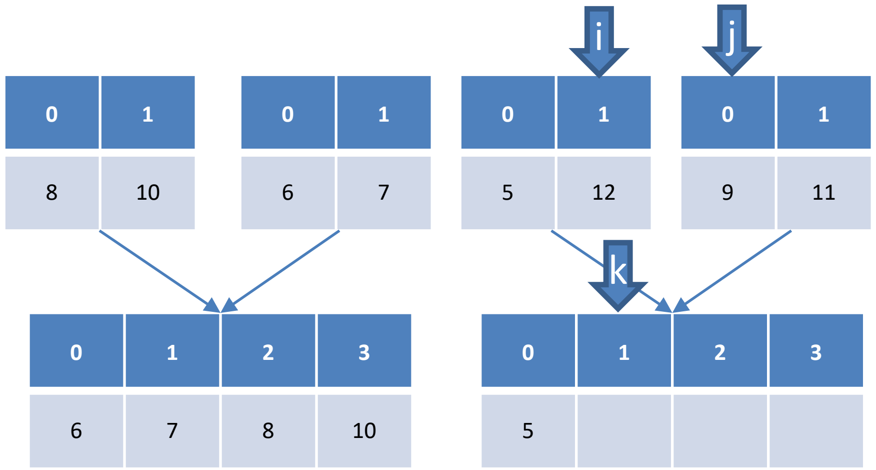

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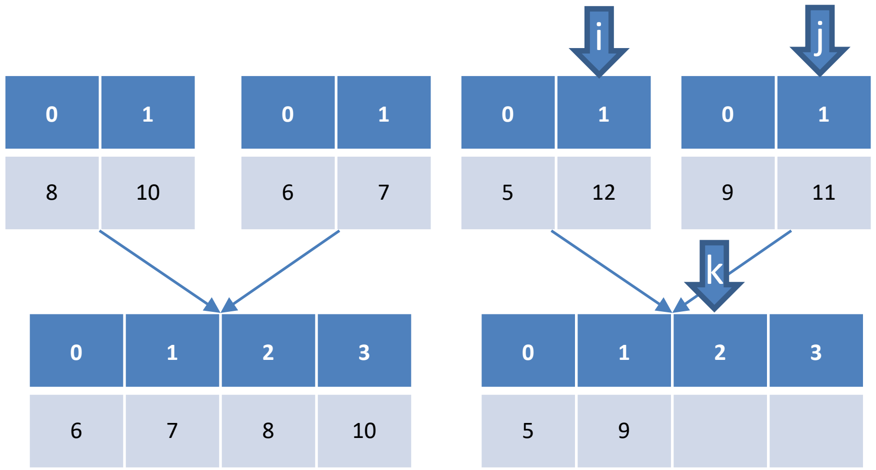

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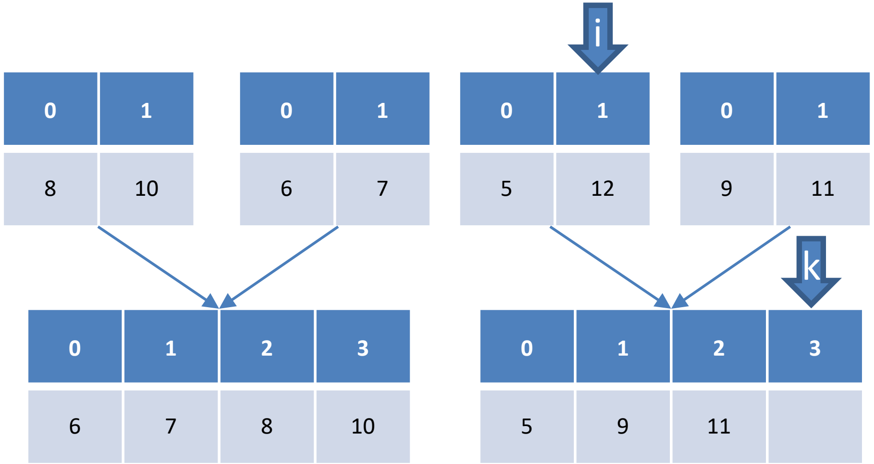

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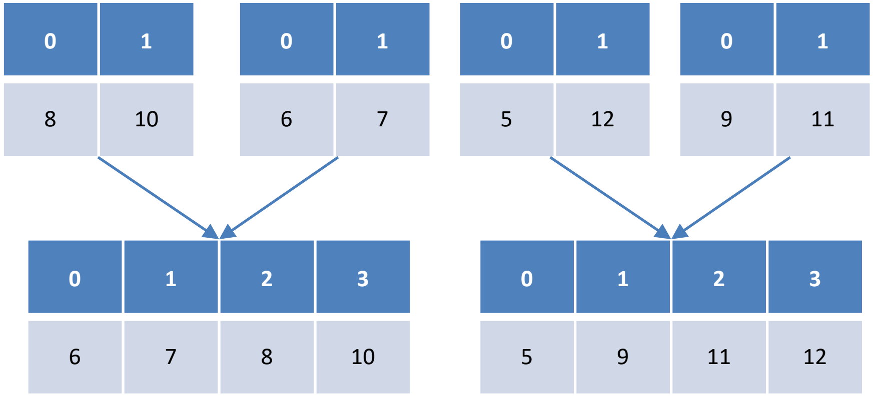

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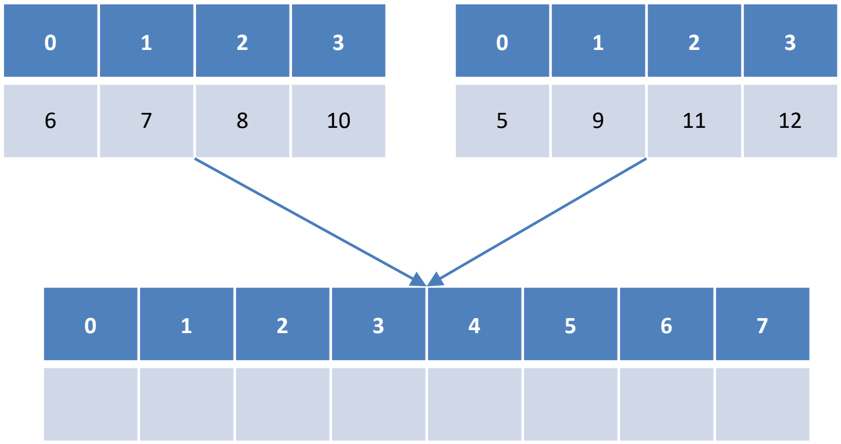

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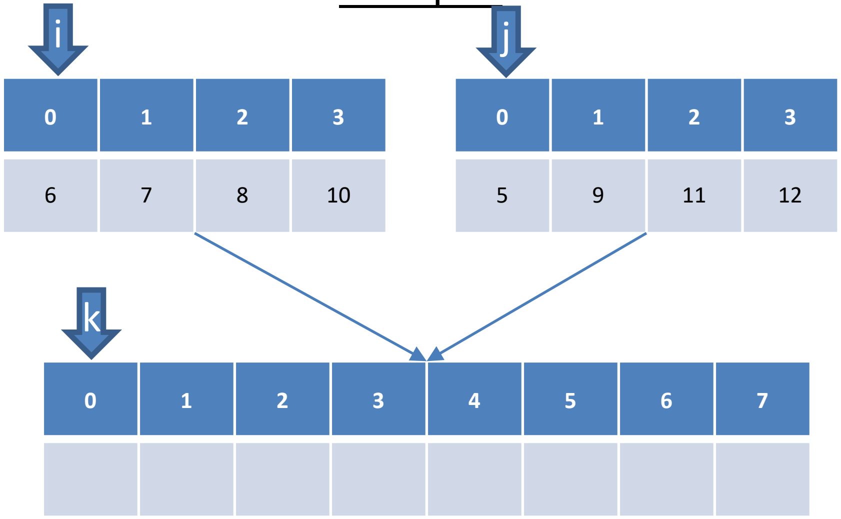

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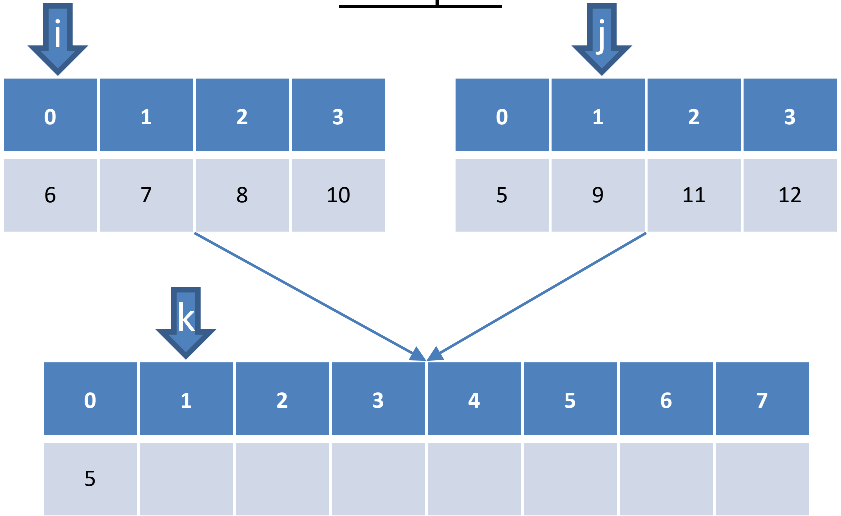

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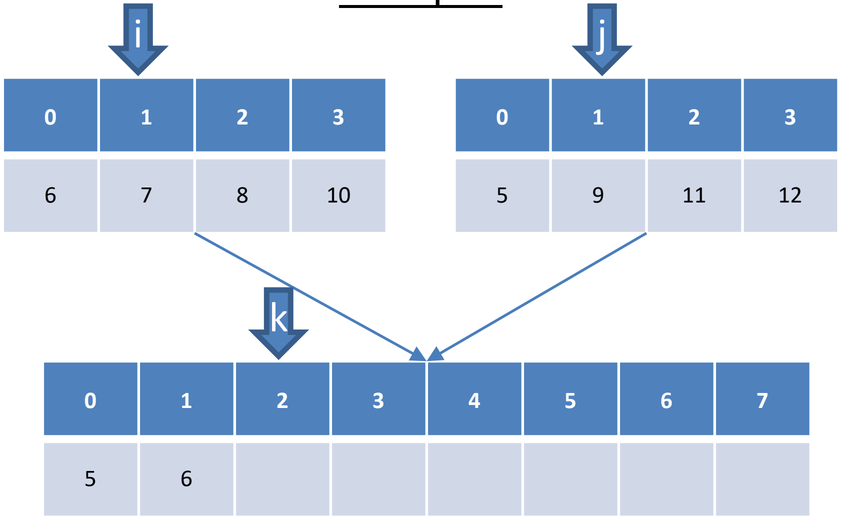

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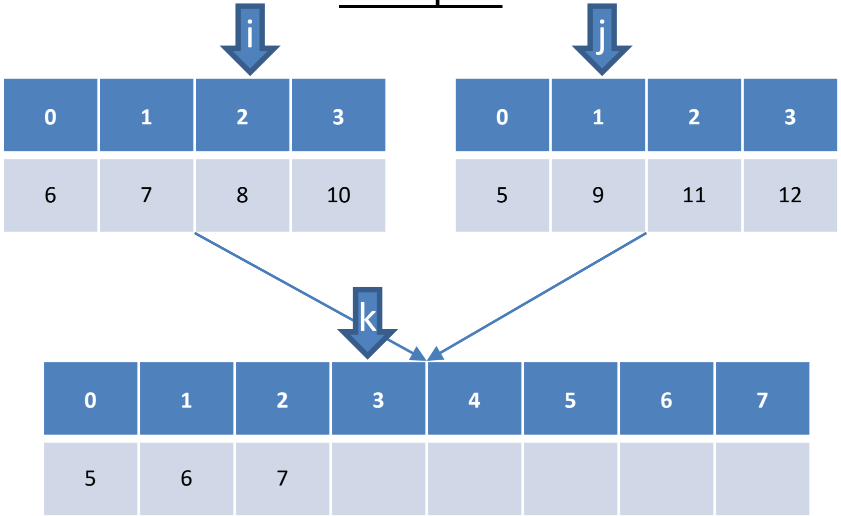

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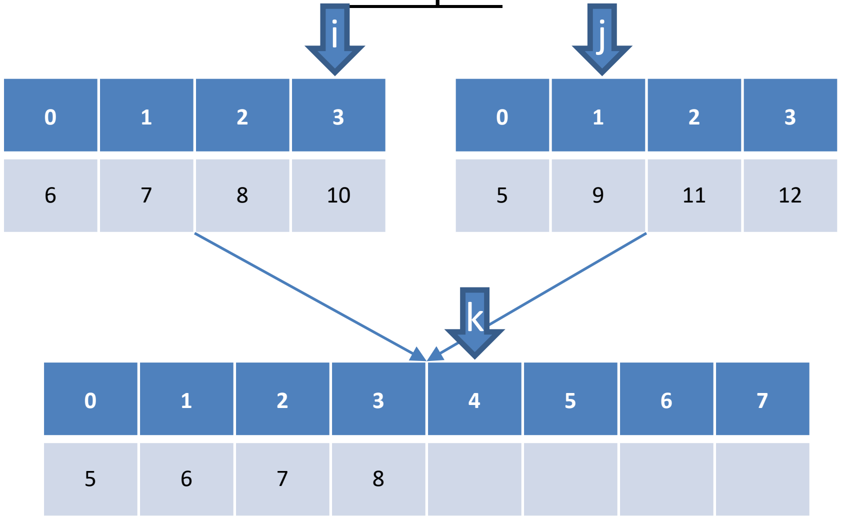

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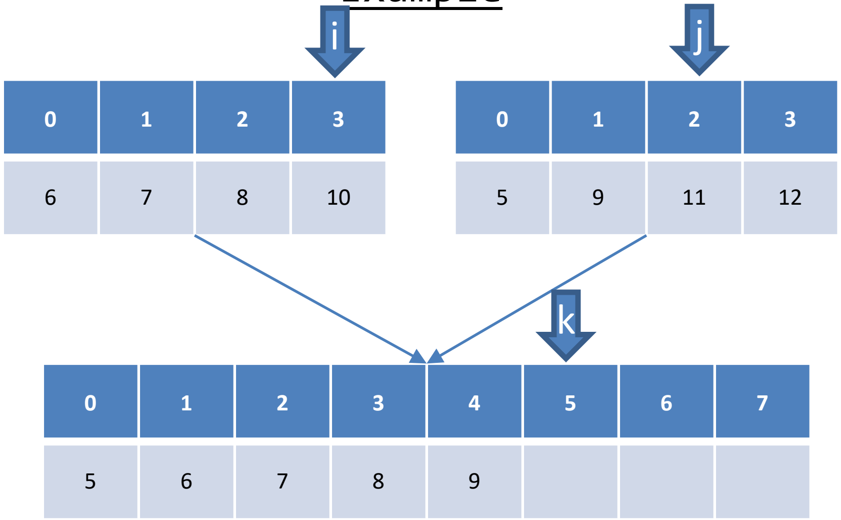

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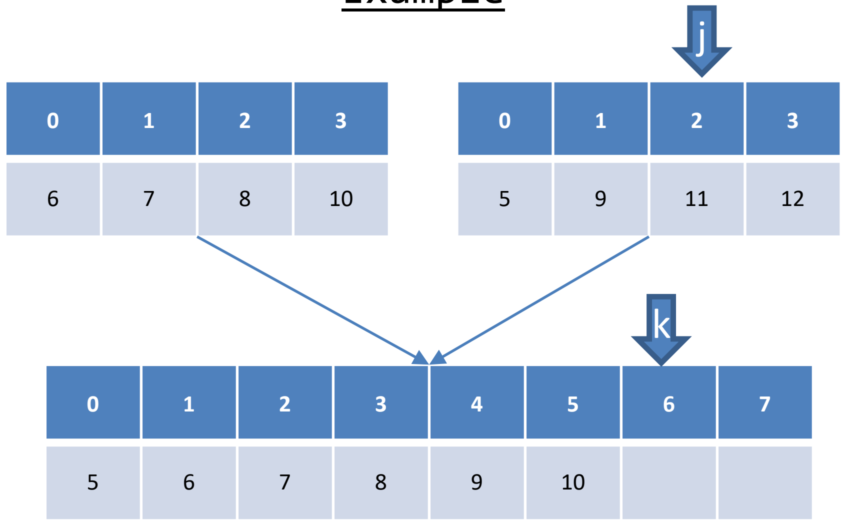

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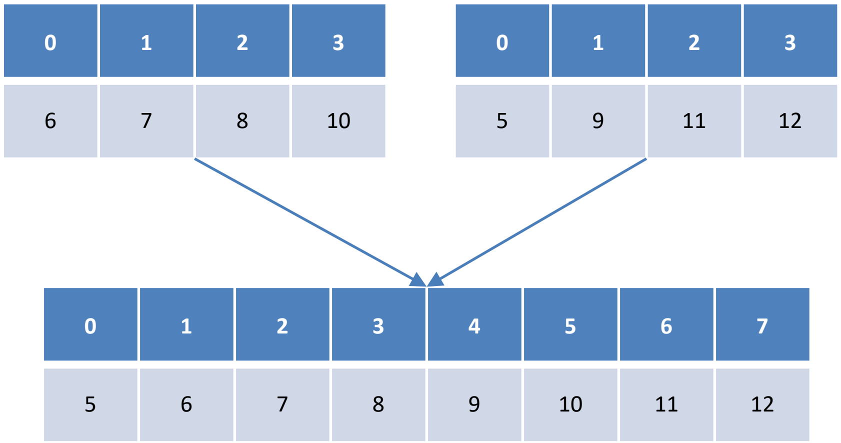

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Example

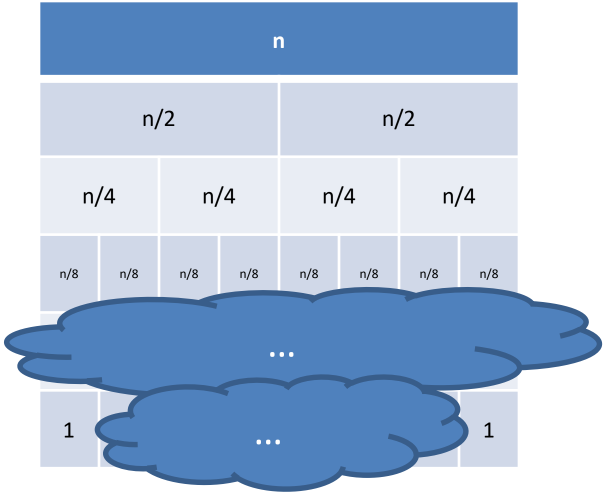
0	1	2	3	4	5	6	7
5	6	7	8	9	10	11	12

File Edit View Help

Merge Sort Complexity

- Worst Case
  - Sorted in Descending Order
- Operations
  - Split
  - Merge

Complexity Visual



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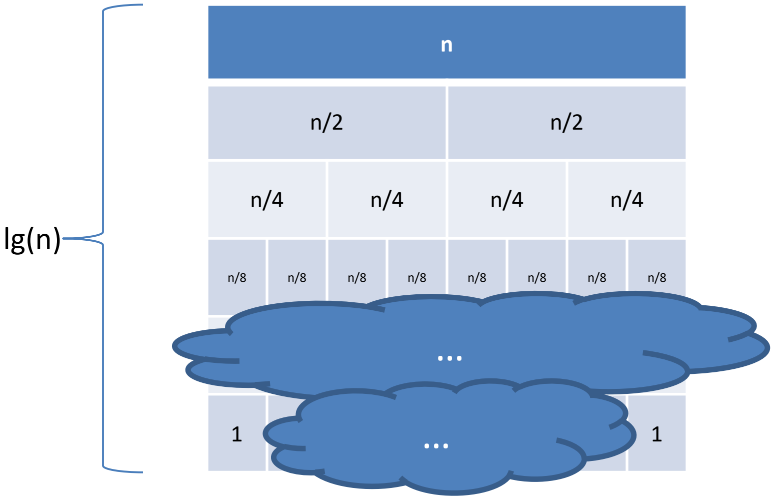

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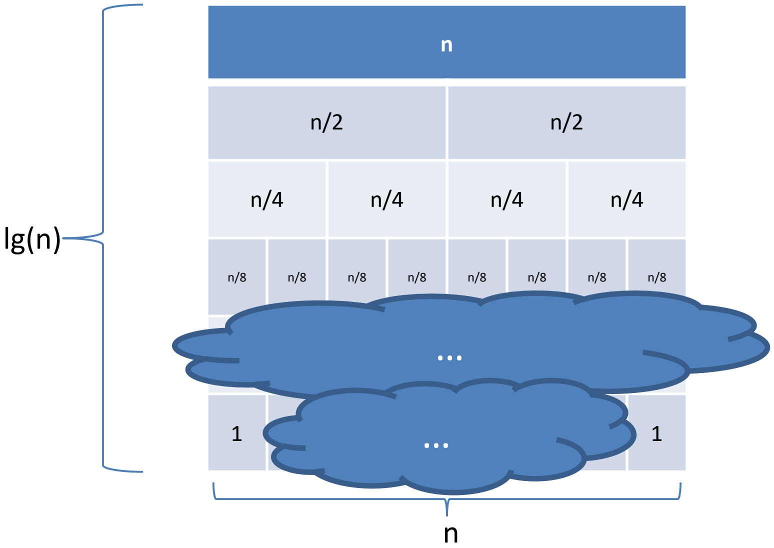

File Edit View Help

Merge Sort Complexity

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Complexity

$$O(n\lg(n))$$

File Edit View Help

Sorting Algorithms

- Quick Sort
  1. Pick an arbitrary value called a "pivot" from the array
  2. Using the pivot value "partition" the array
     1. Reorder the array where smaller values are to the left of the pivot, and large / equal values are to the right
     2. Once it has been partitioned the pivot value is where it should be
  3. Recursively continue now with the array to the left, and the array to the right of the pivot

Example

Index	0	1	2	3	4	5	6	7
Value	10	8	7	6	12	5	11	9

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Index	0	1	2	3	4	5	6	7
Value	10	8	7	6	12	5	11	9 pivot

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Example

Index	0	1	2	3	4	5	6	7
Value	10	8	7	6	12	5	11	9 pivot

If value at j is smaller than the pivot then swap values at i and j and increase i by 1

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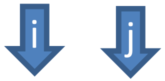

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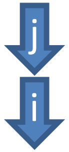

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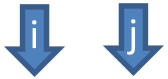

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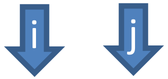

Index	0	1	2	3	4	5	6	7
Value	8	7	10	6	12	5	11	9 pivot

If value at j is smaller than the pivot then swap values at i and j and increase i by 1

File Edit View Help

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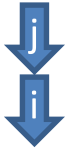

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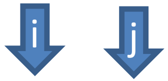

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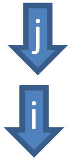

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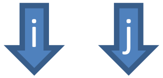

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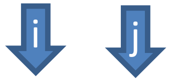

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					i			j
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Example

i

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Recursively do the same for the values to the left of the partition and to the right of the partition

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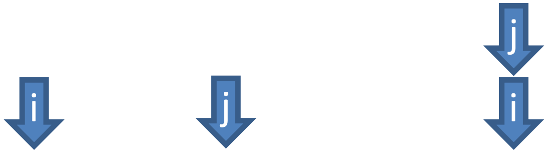

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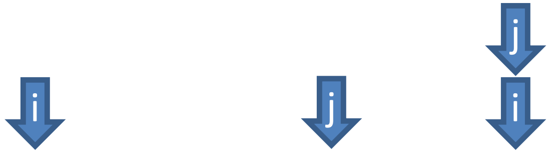

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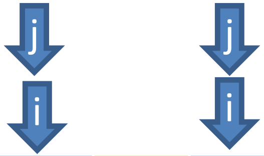

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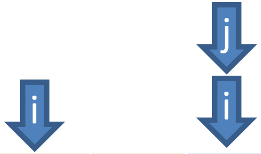

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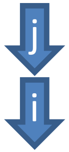

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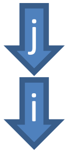

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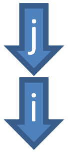

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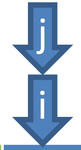

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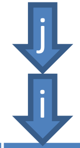

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     1. Reorder the array where smaller values are to the left of the pivot, and large / equal values are to the right
     2. Once it has been partitioned the pivot value is where it should be
  3. Recursively continue now with the array to the left, and the array to the right of the pivot

Example

i

Index	0	1	2	3	4	5	6	7
Value	5	6	7	8	9	10	11	12

Recursively do the same for the values to the left of the partition and to the right of the partition

File Edit View Help

Sorting Algorithms

- Quick Sort
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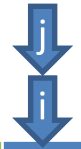
Example



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Quick Sort Complexity

- Worst Case
  - Sorted in Ascending Order
  - Assuming pivot is always picked from the last index
- Operations
  - The first index moves n spaces
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Complexity Example

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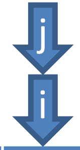

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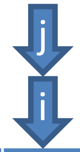

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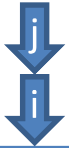

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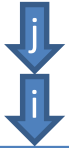

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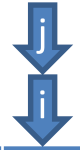

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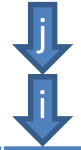

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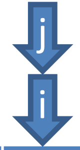

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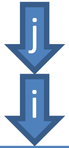

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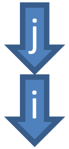

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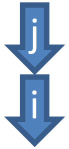

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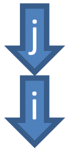

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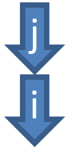

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Complexity

$$O(n^2)$$

File Edit View Help

Quick Sort Merge Sort Compared

Merge Sort

- Worst Time Complexity = $O(n\lg(n))$
- Average Time Complexity = $\Theta(n\lg(n))$
- Worst Space Complexity = $O(n)$ additional

Quick Sort

- Worst Time Complexity = $O(n^2)$
- Average Time Complexity = $\Theta(n\lg(n))$
- Worst Space Complexity = $O(\lg(n))$ additional