Searching and Sorting

Algorithms Revisited

- An **algorithm** is a procedure for effecting some result.
- There can be many different algorithms for solving the same problem.
- How can we compare algorithms against one another?
- What's the best algorithm for solving a given problem?

Two Famous Problems

- **Searching**
  - Given an array of values, determine whether some value is contained in that array.
  - Very important: finding medical records, determining if a bookstore has a copy of a book, etc.
- **Sorting**
  - Given an array of values, rearrange those values to put them in sorted order.
  - Enormously important: shows up in iTunes, Google, Facebook, etc.

Searching

Can I get some volunteers?

Linear Search

Linear Search

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private int linearSearch(int[] arr, int key) {
    for (int i = 0; i < arr.length; i++) {
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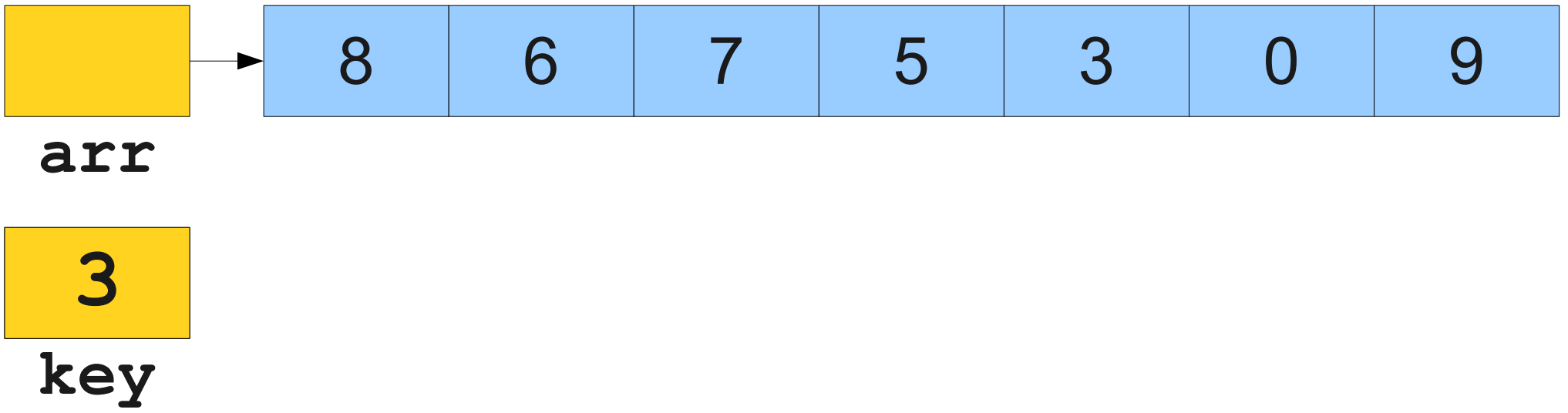

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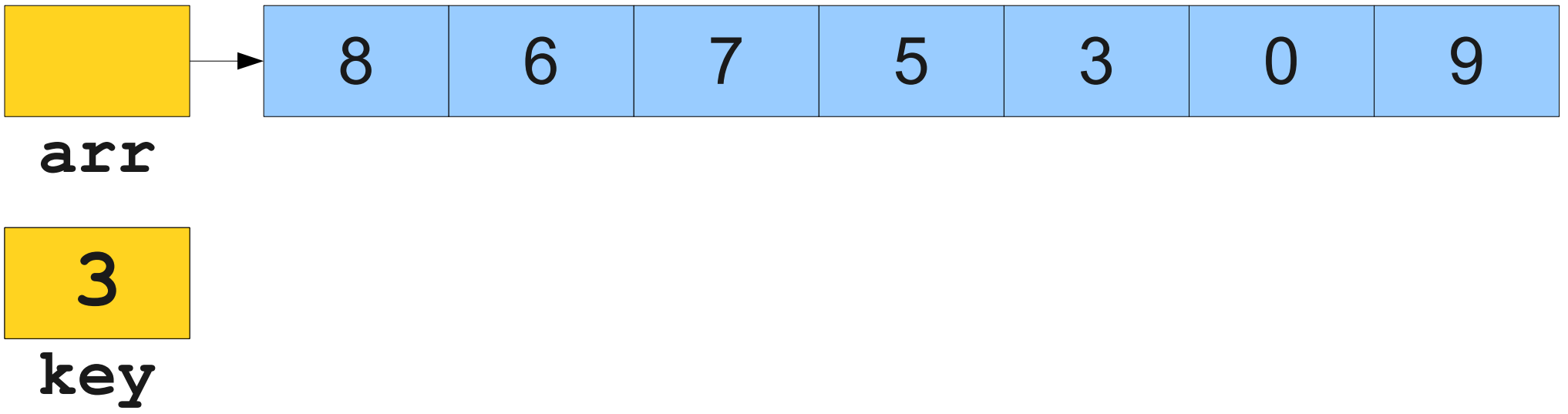

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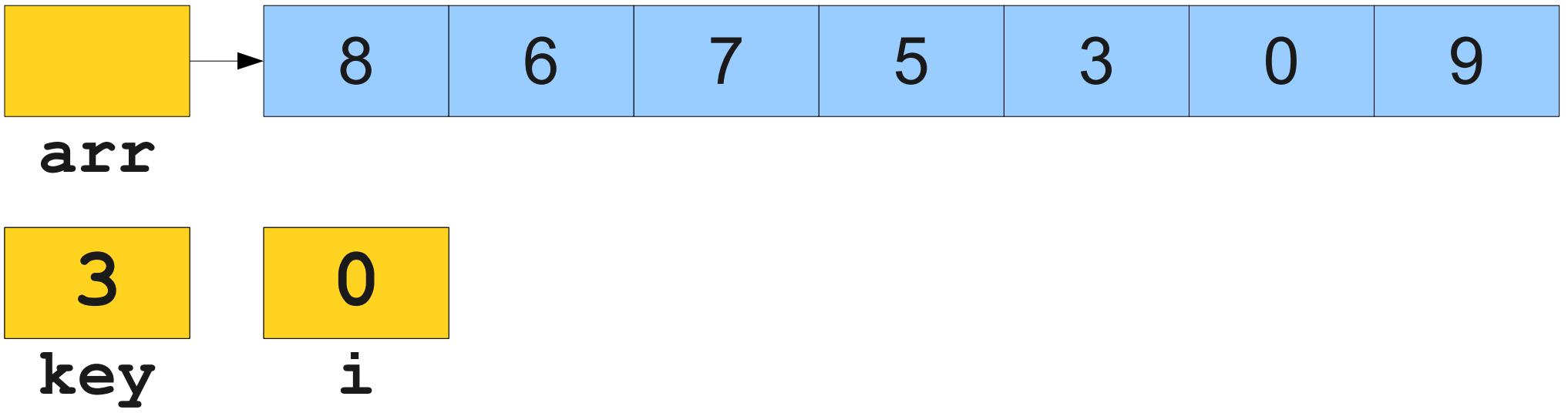

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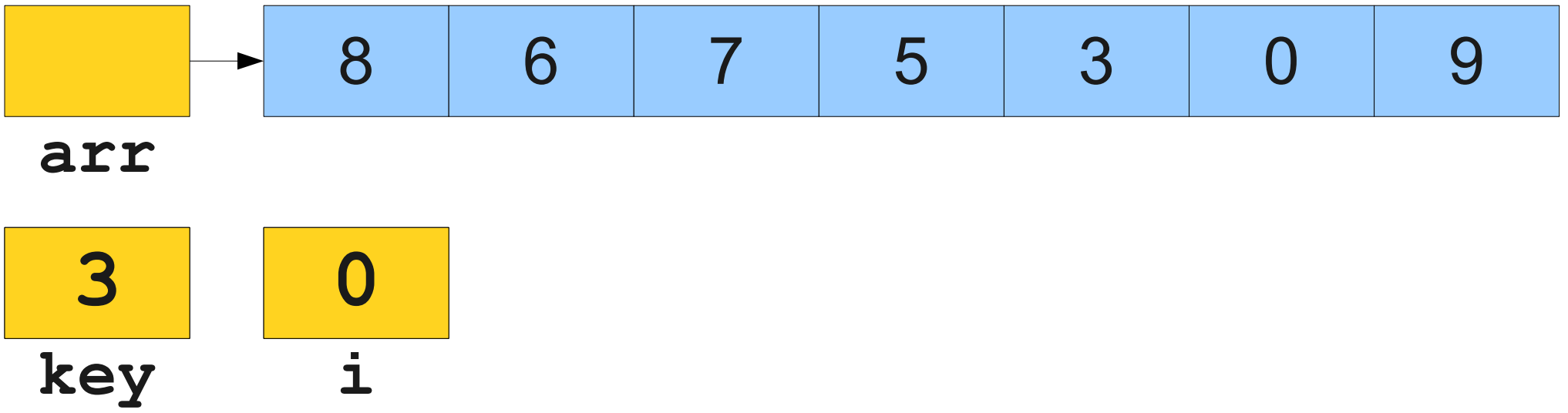

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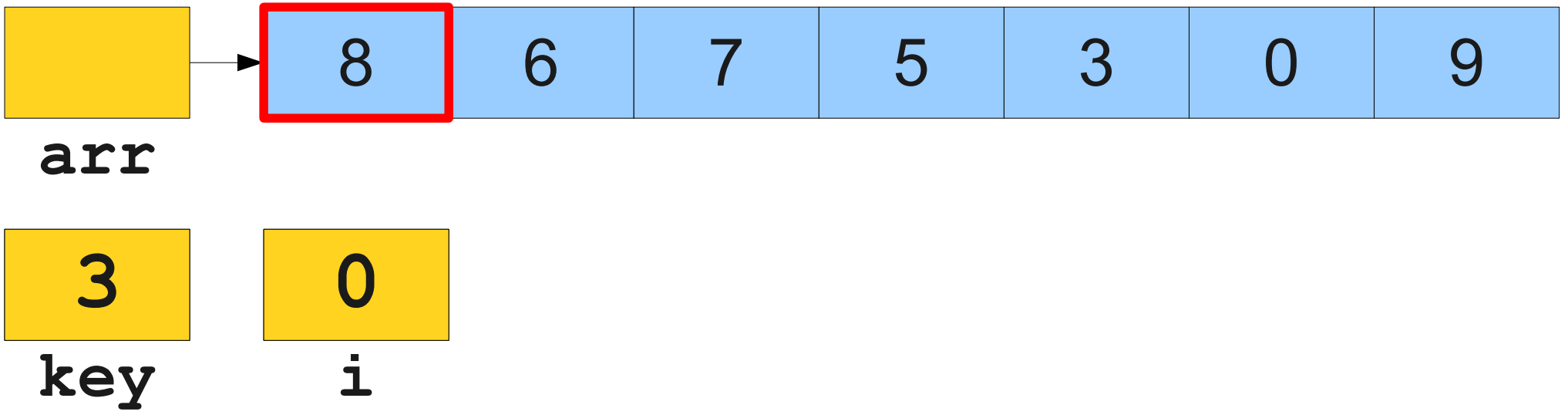

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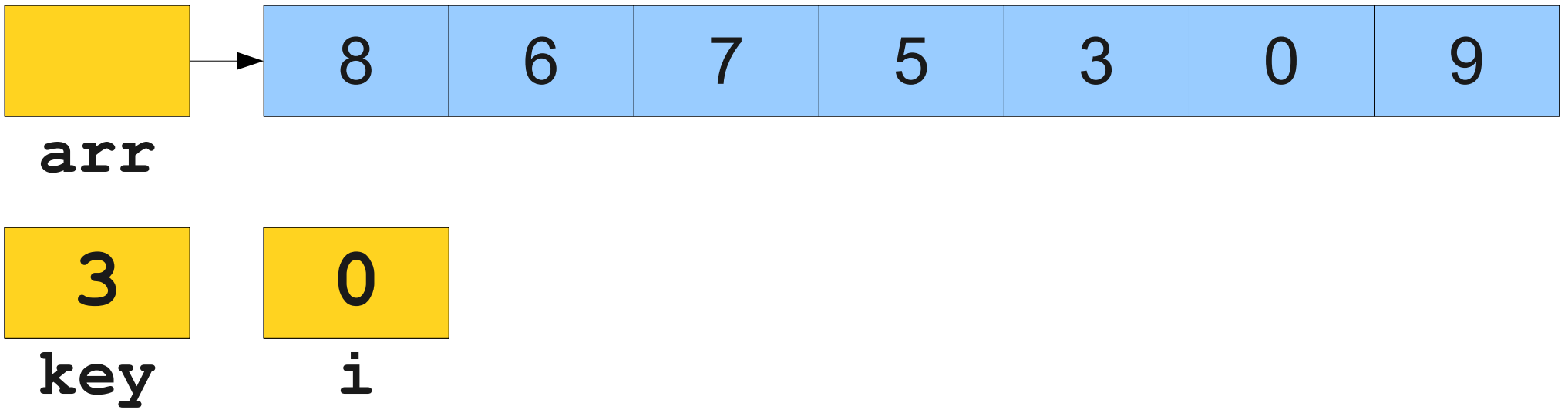

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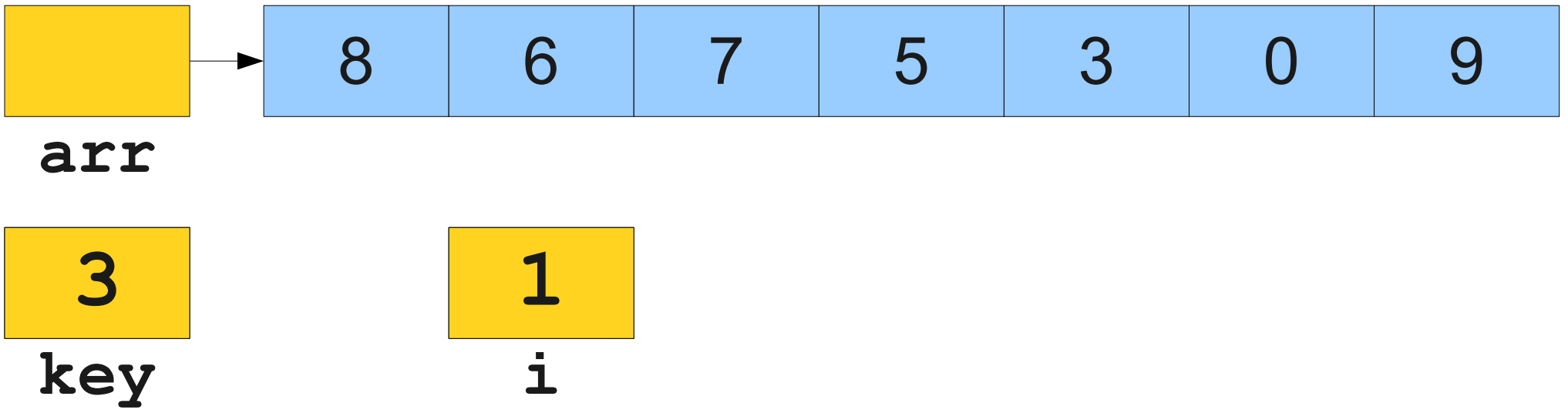

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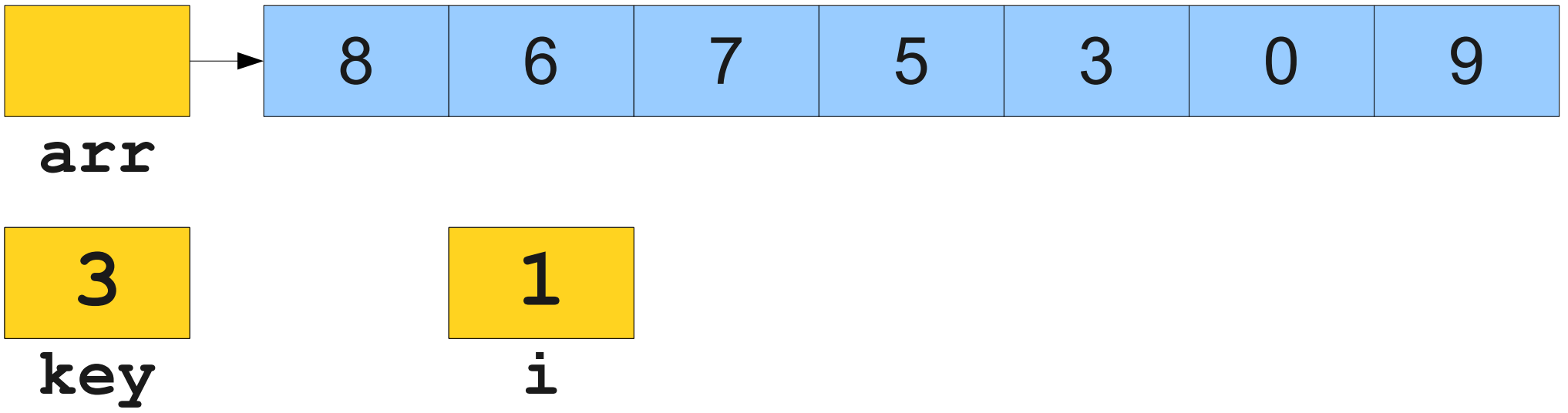

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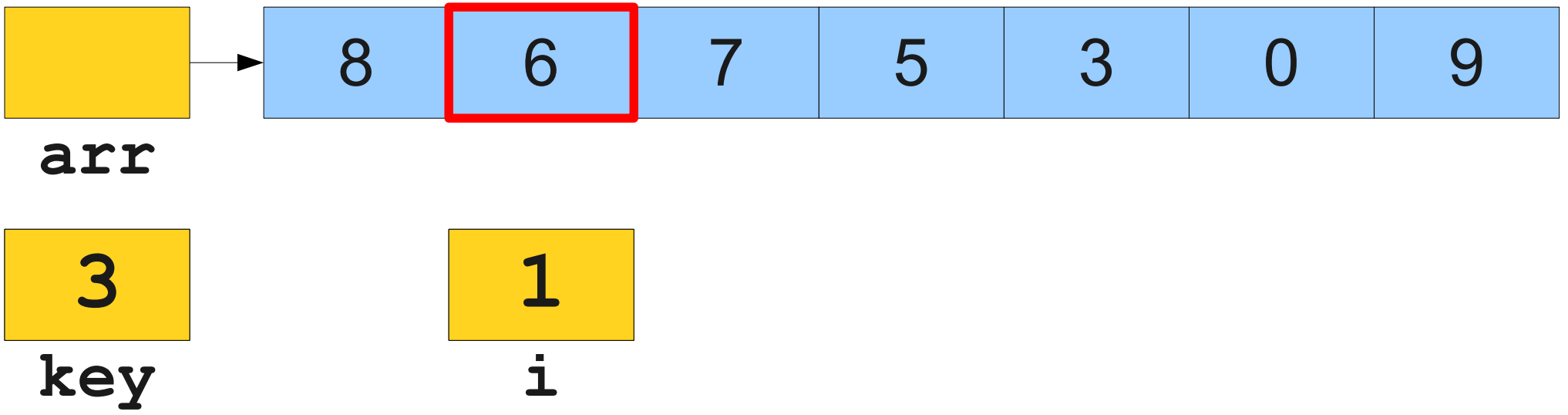

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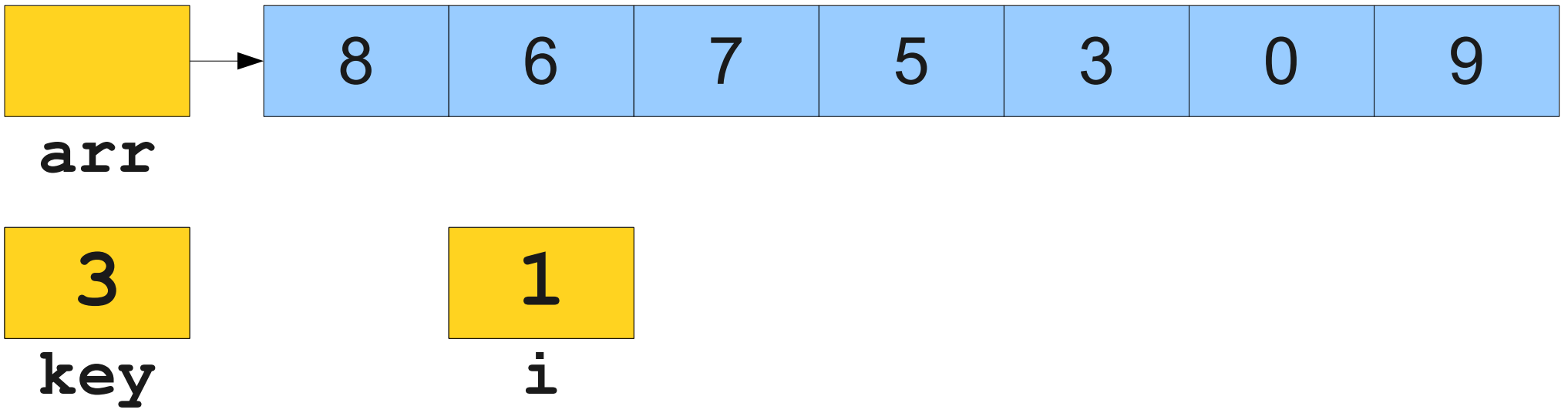

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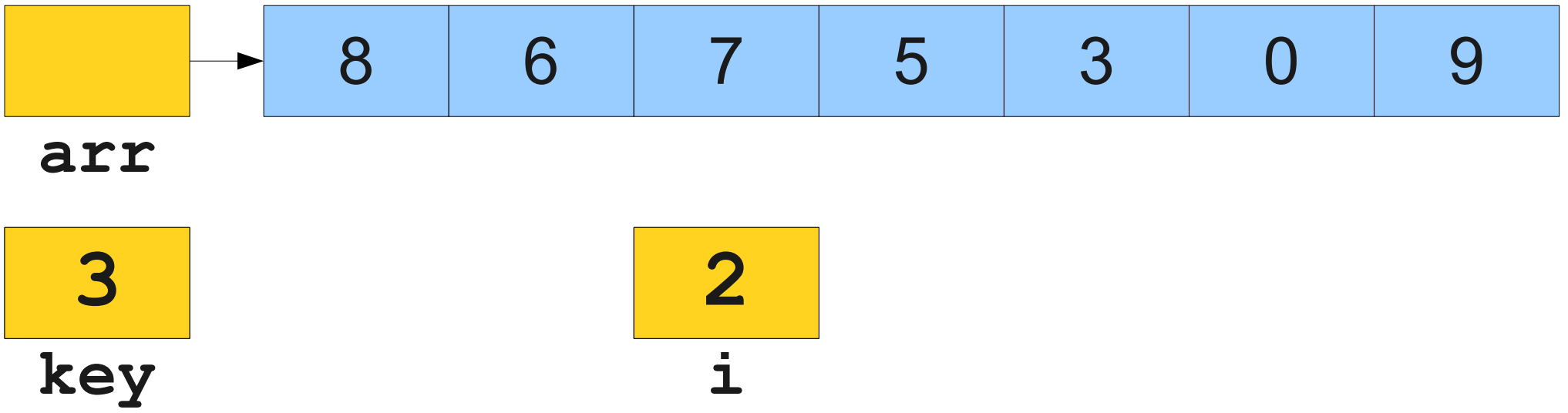

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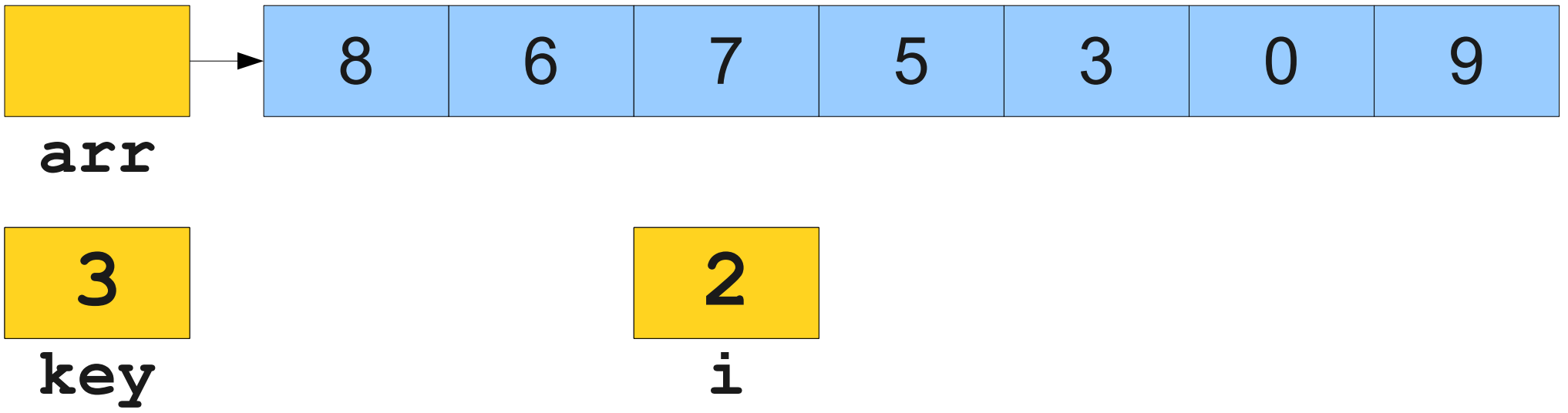

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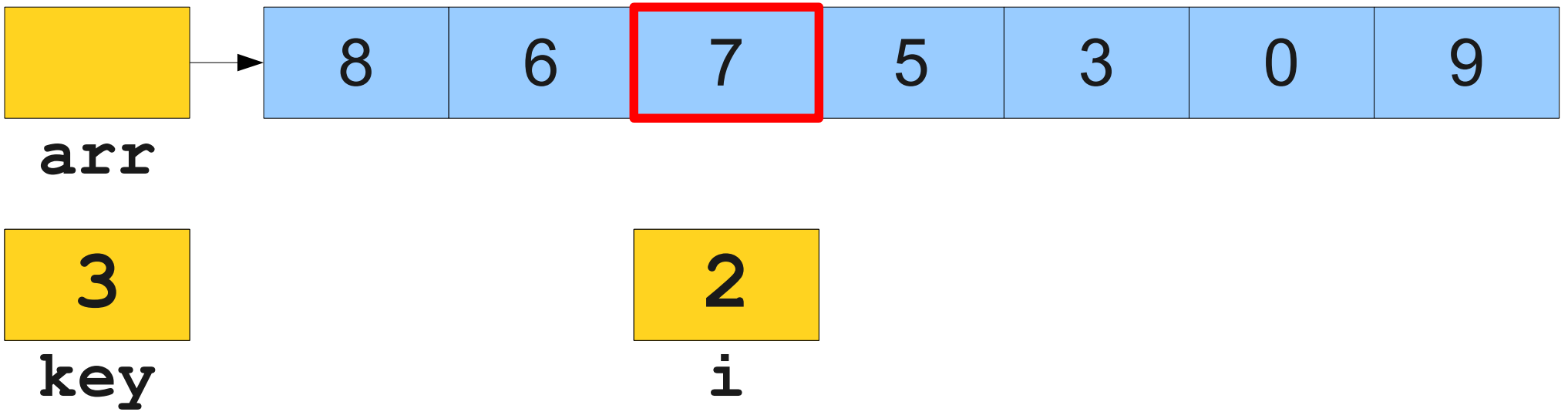

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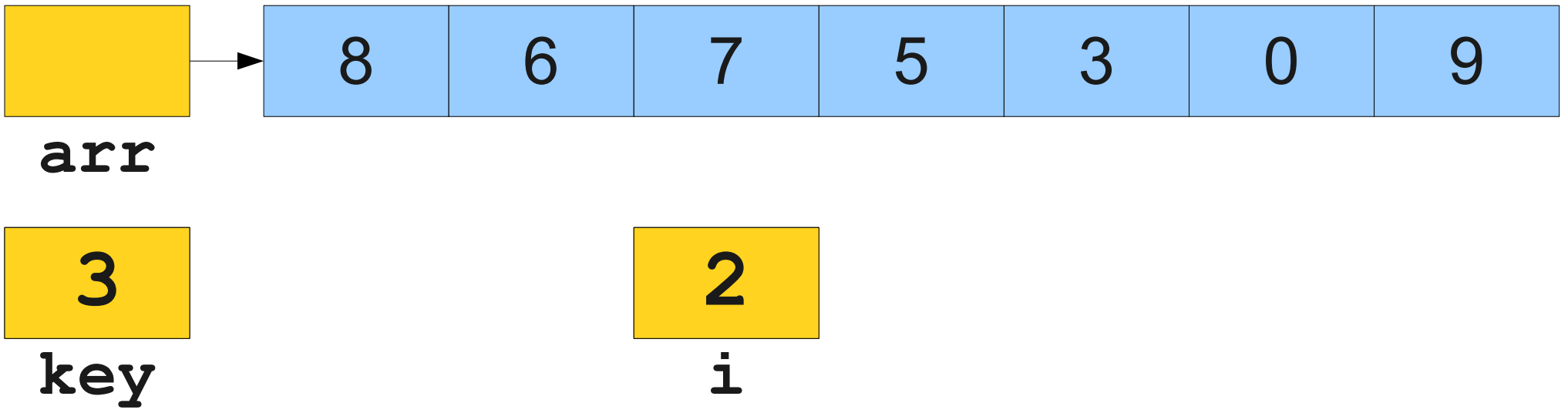

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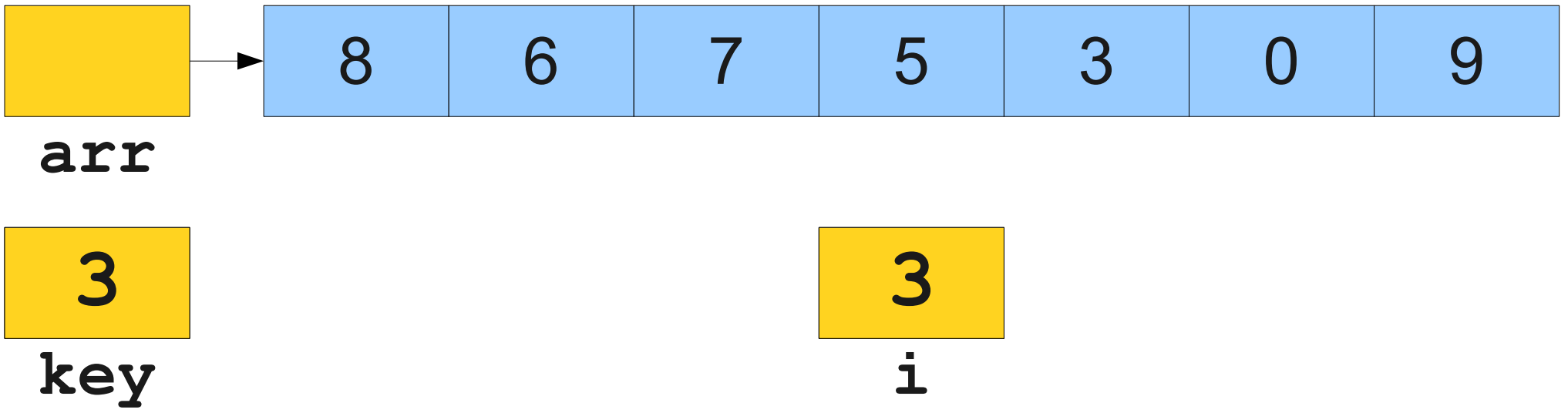

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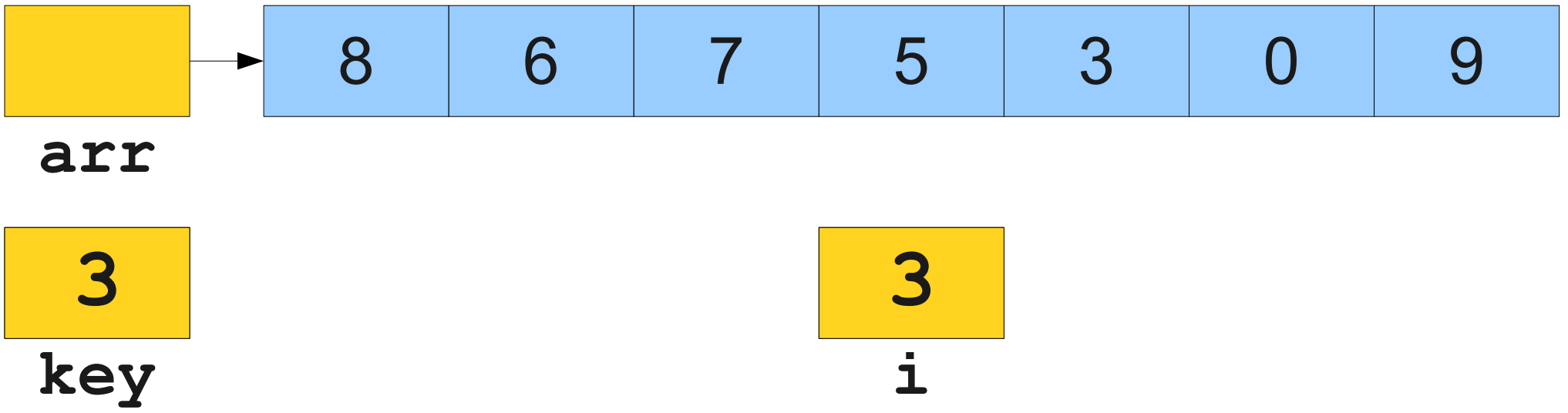

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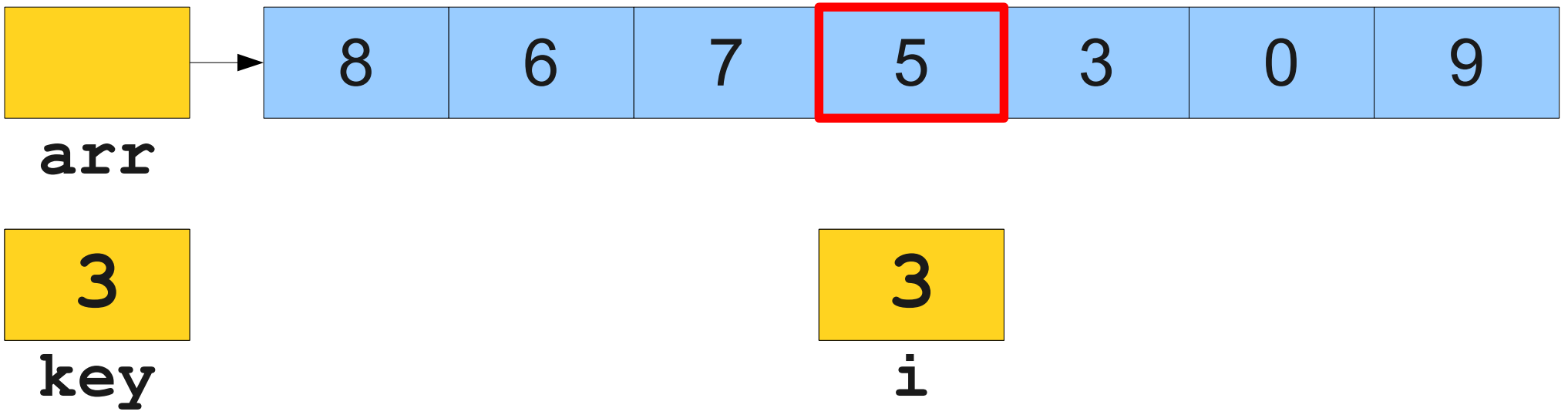

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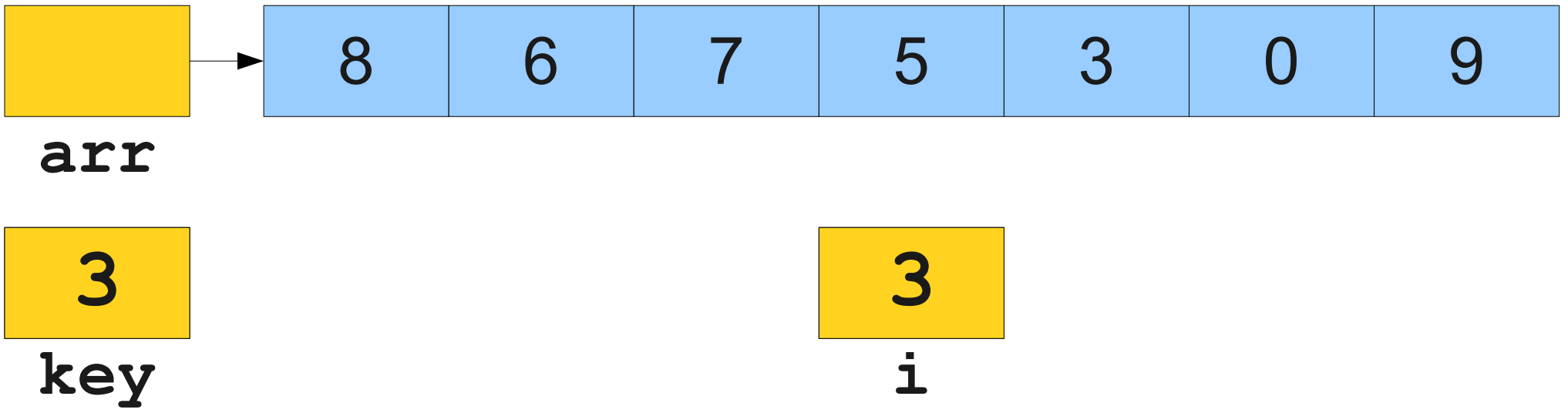

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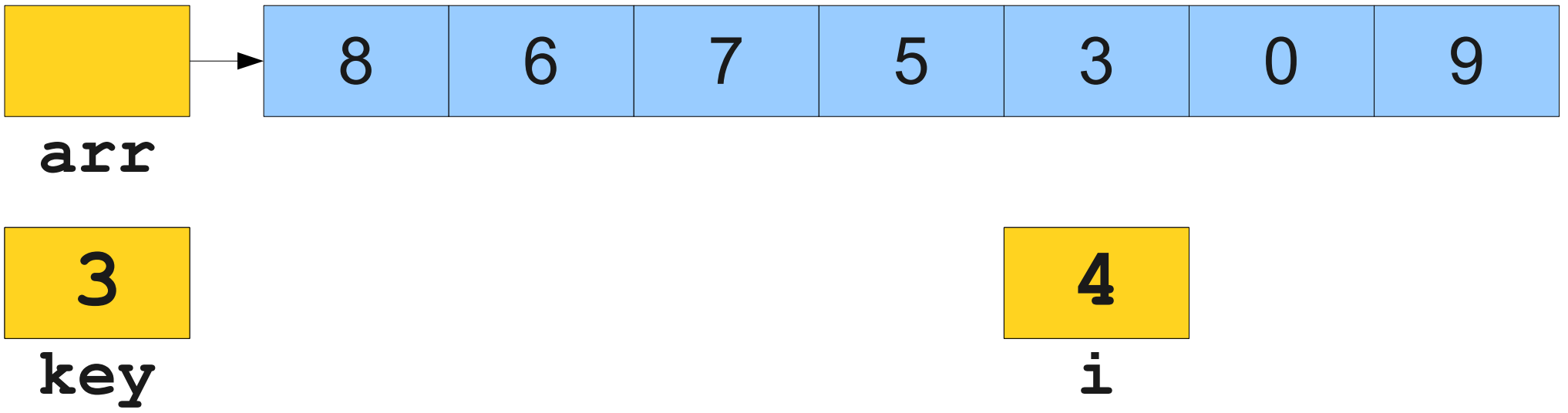

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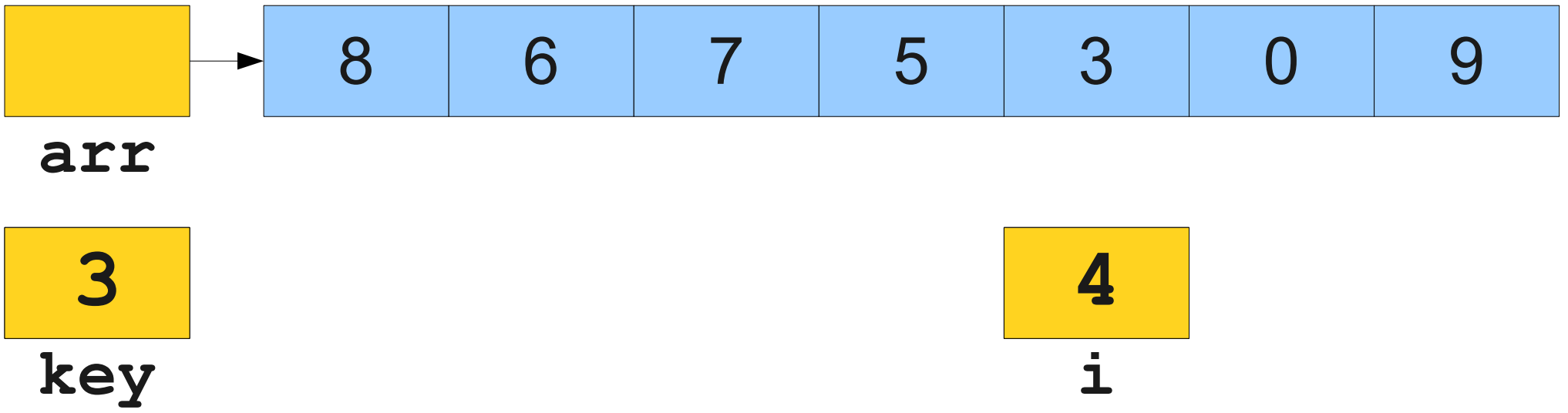

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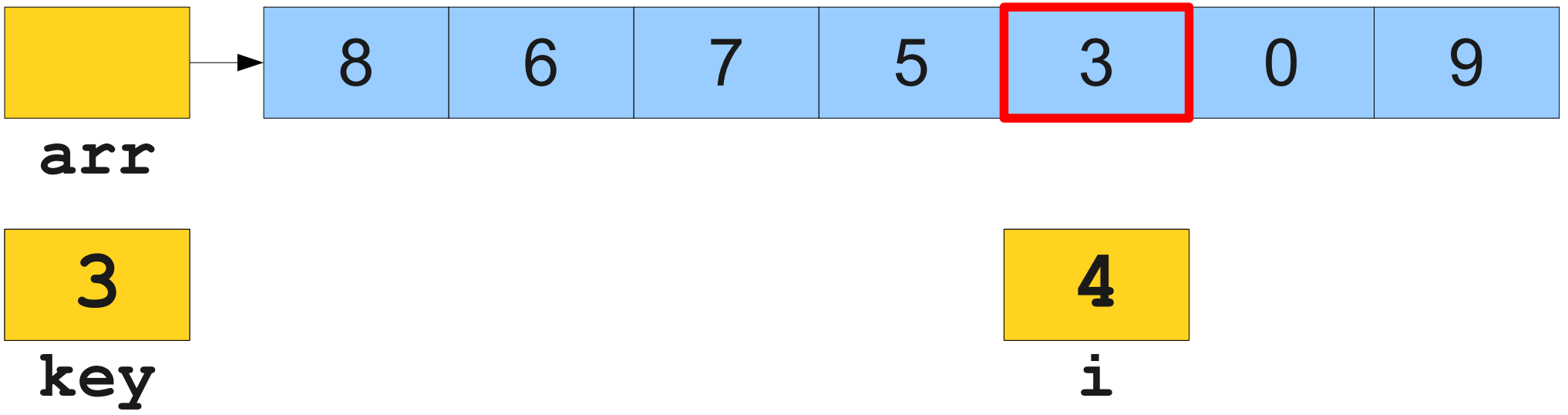

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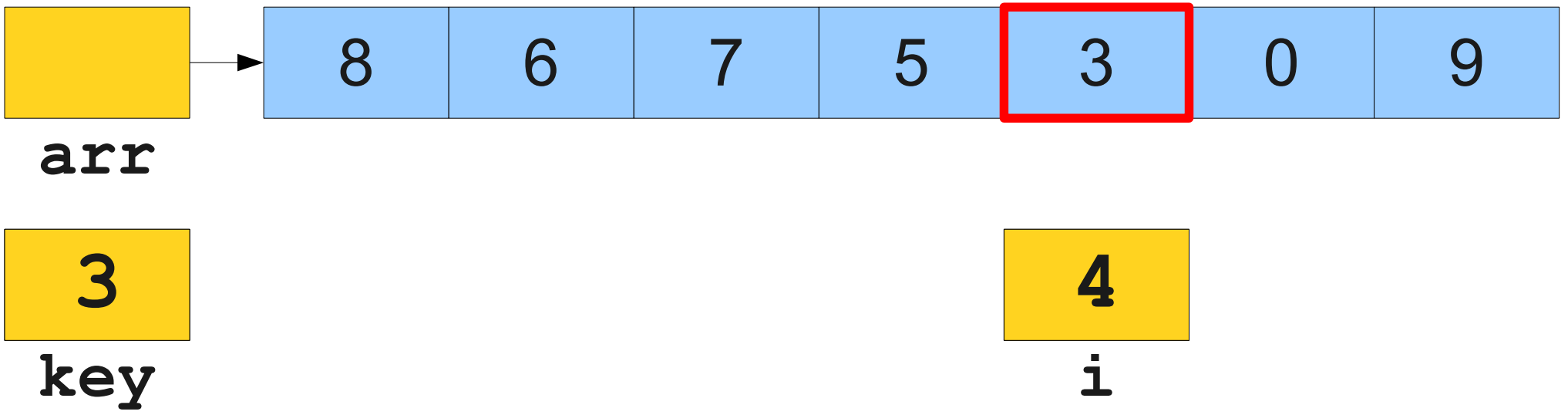

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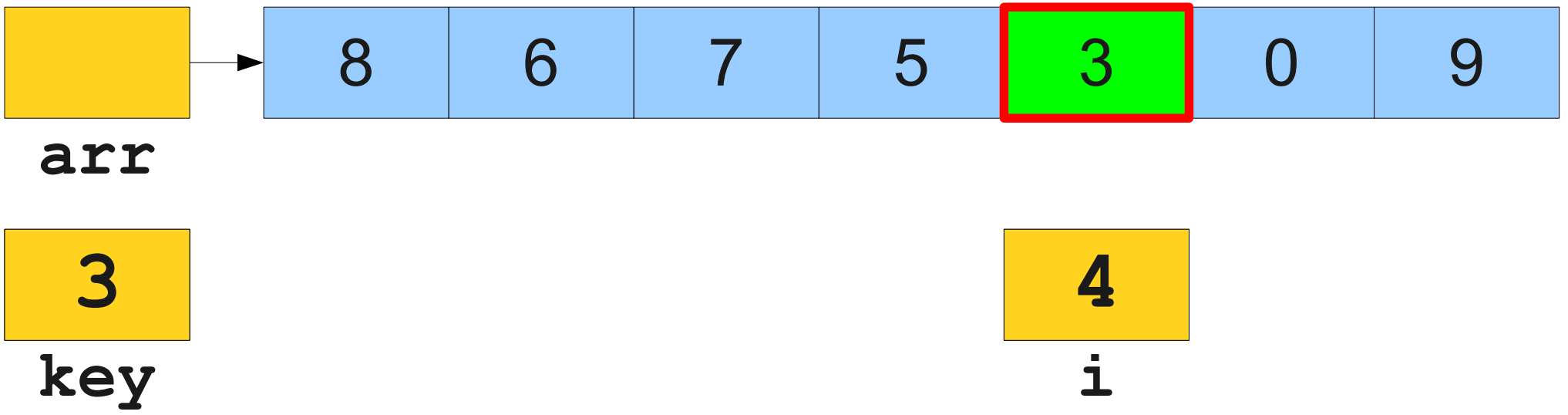

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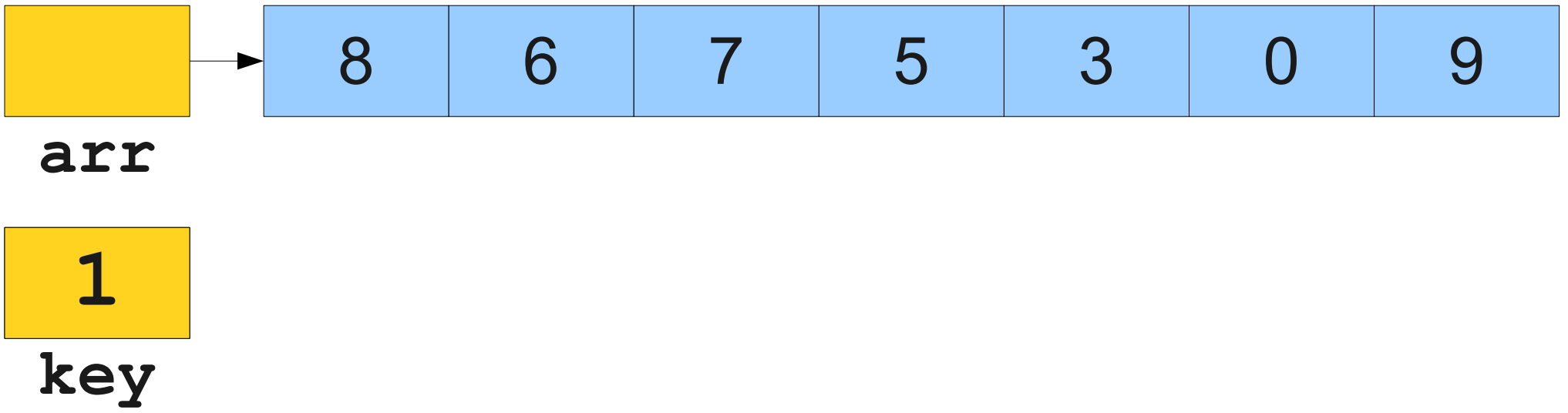

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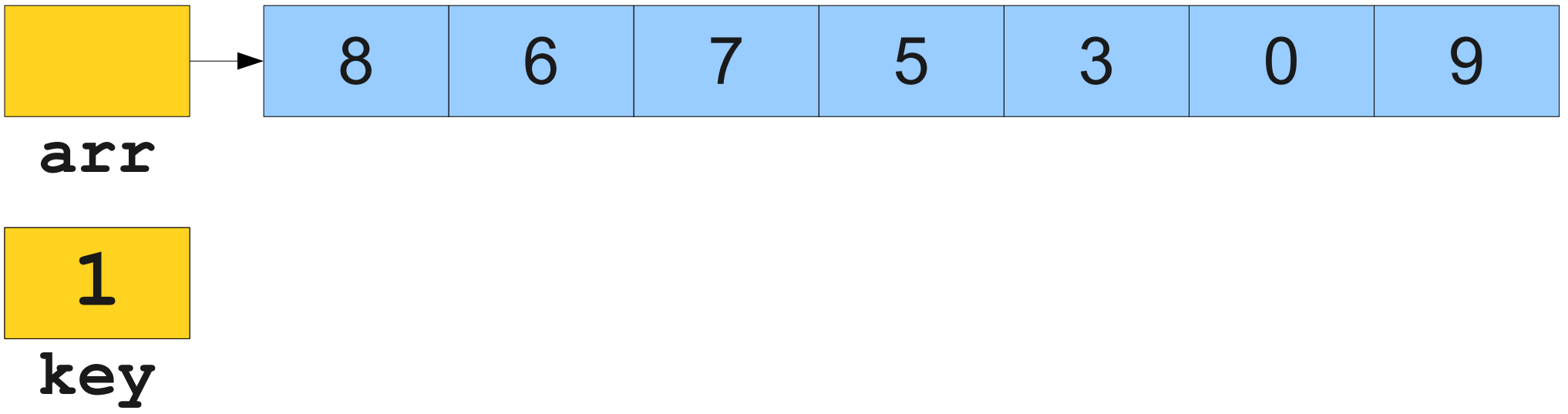

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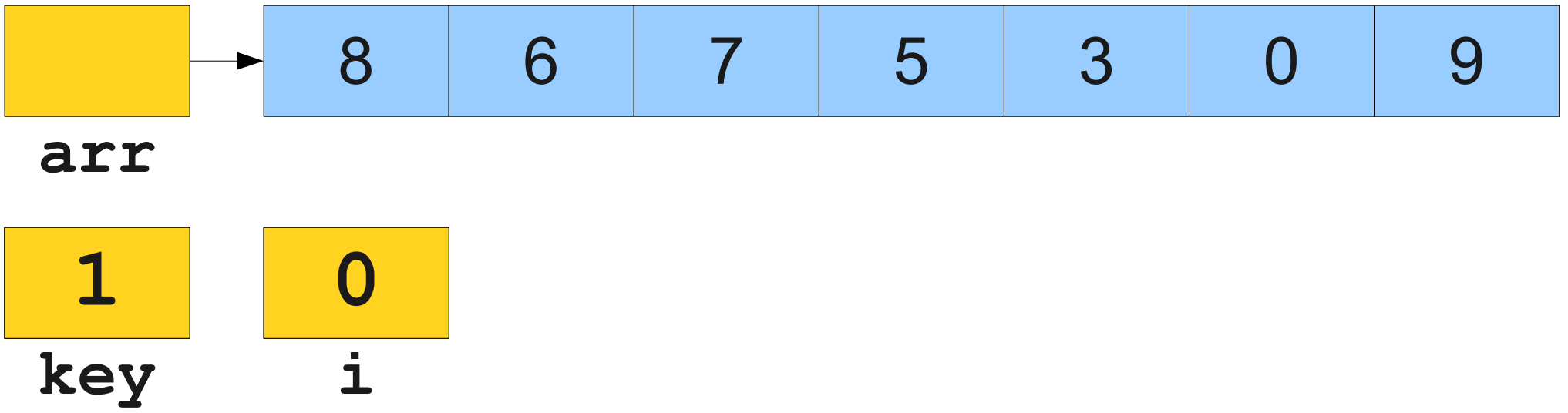

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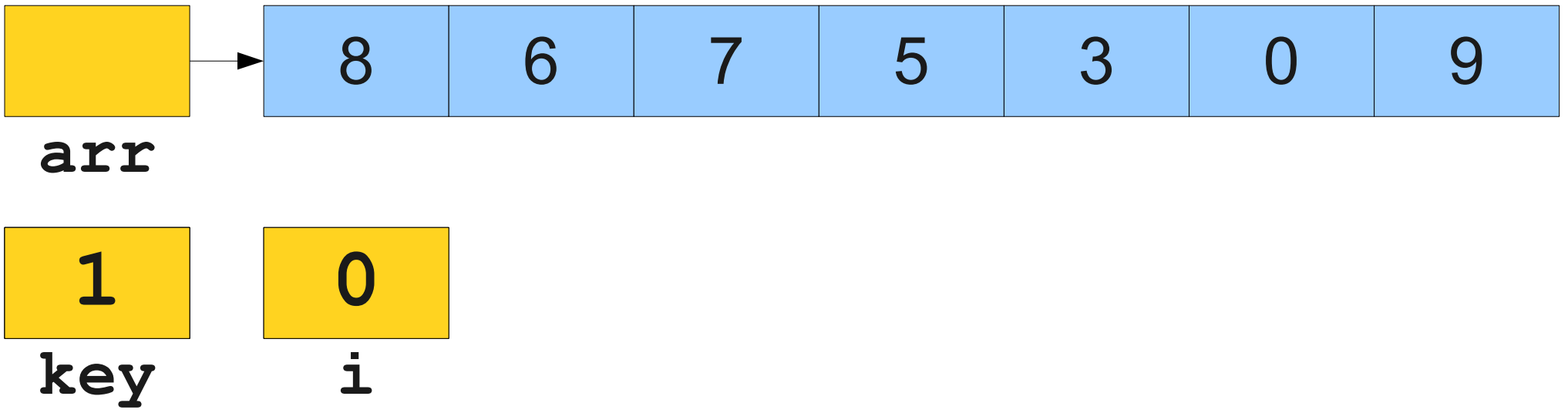

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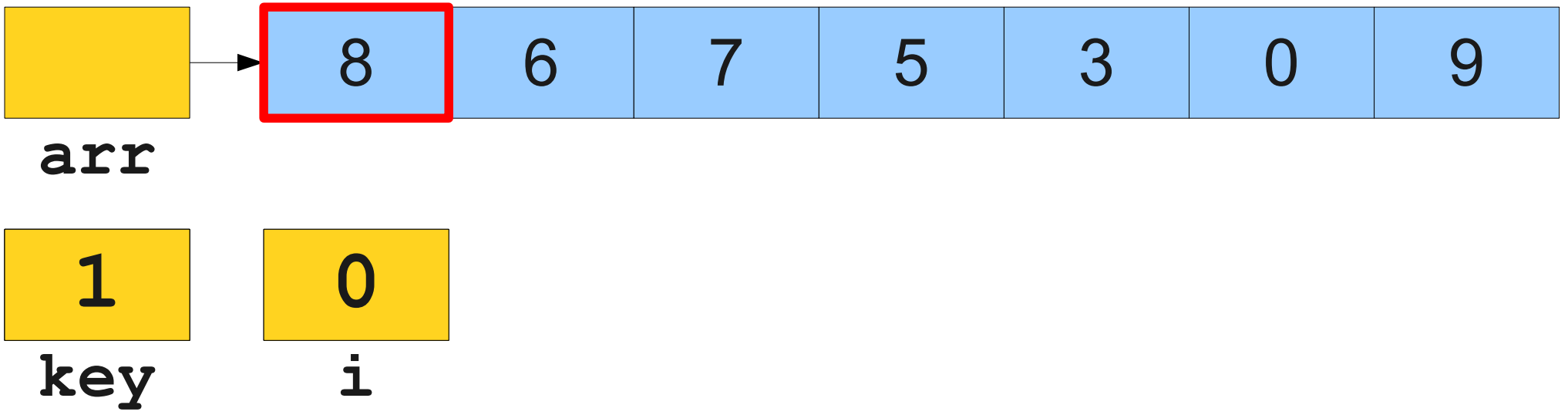

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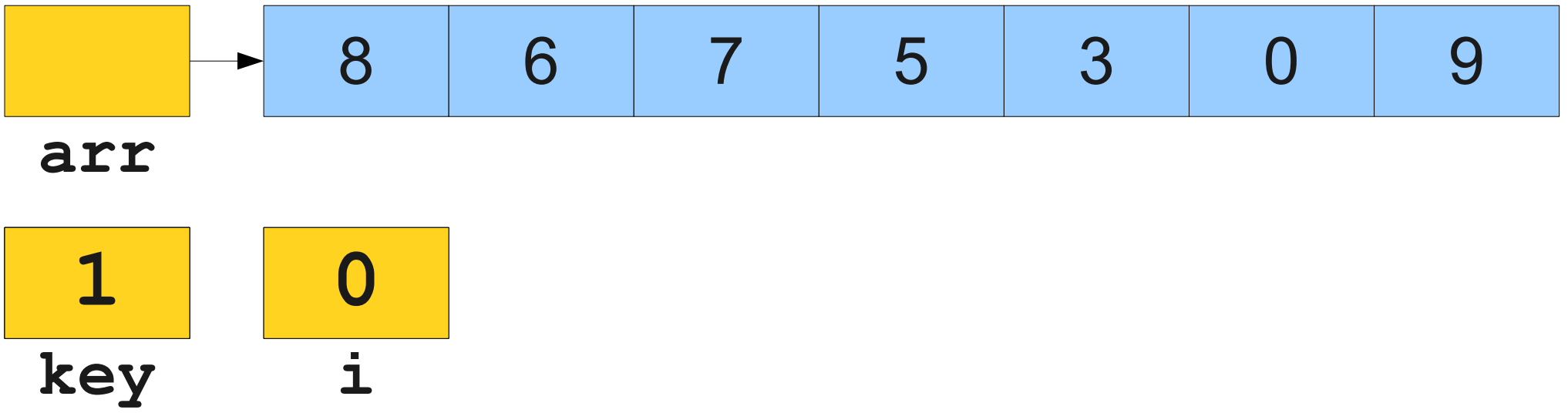

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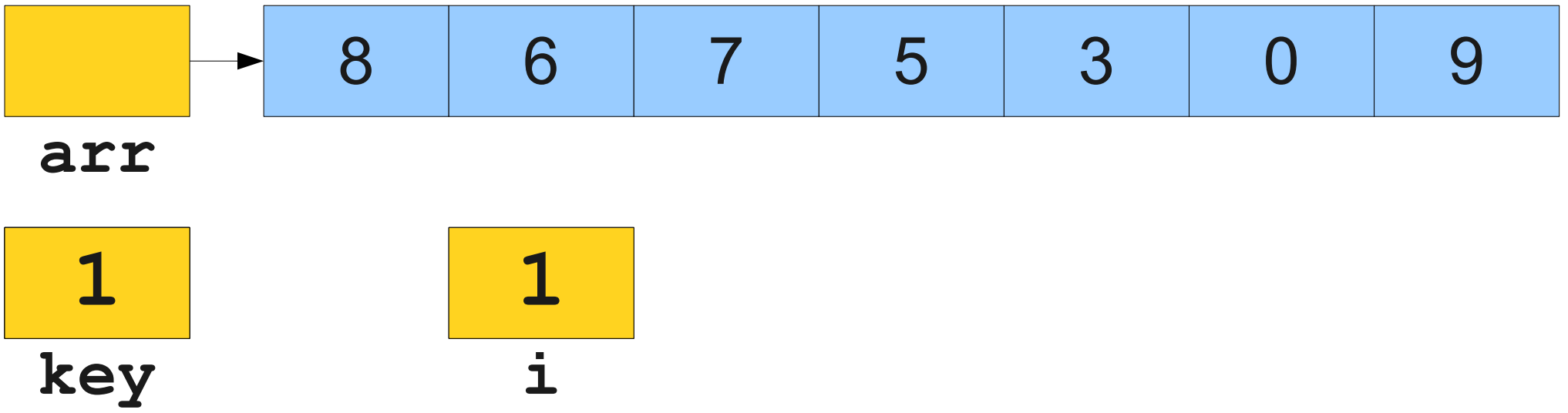

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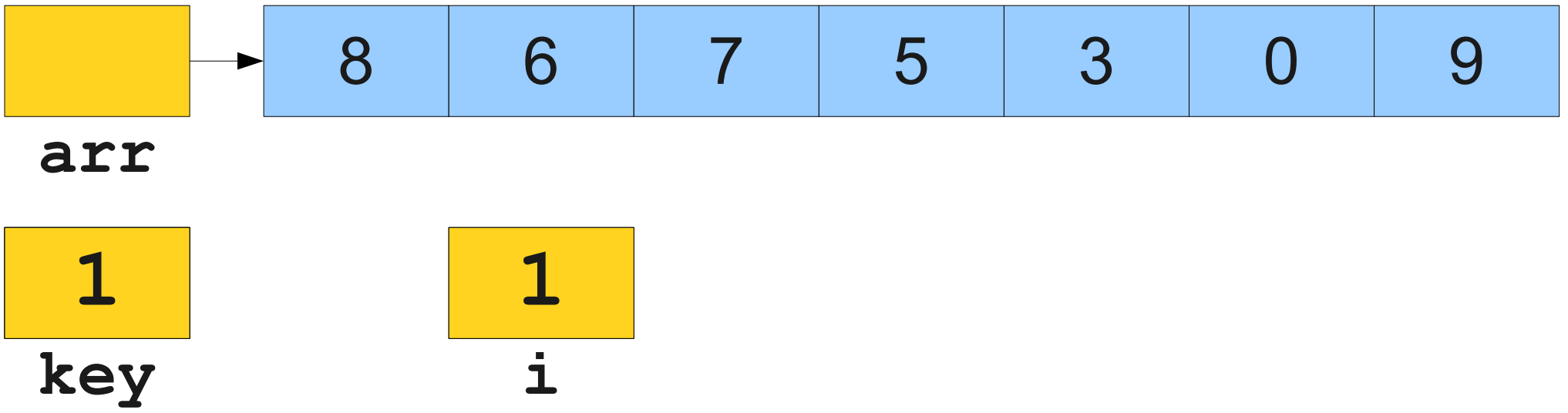

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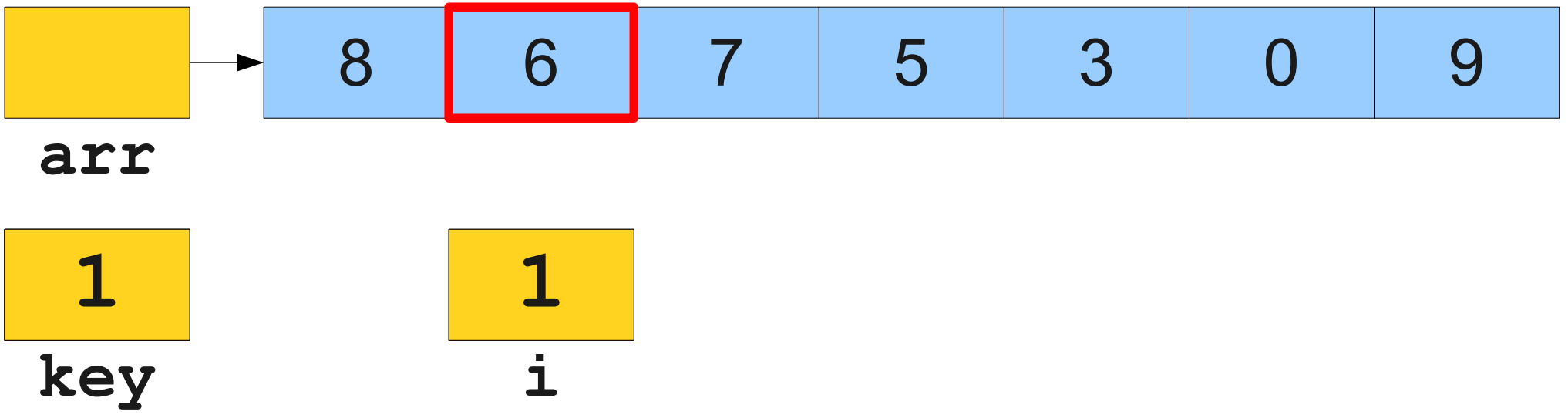

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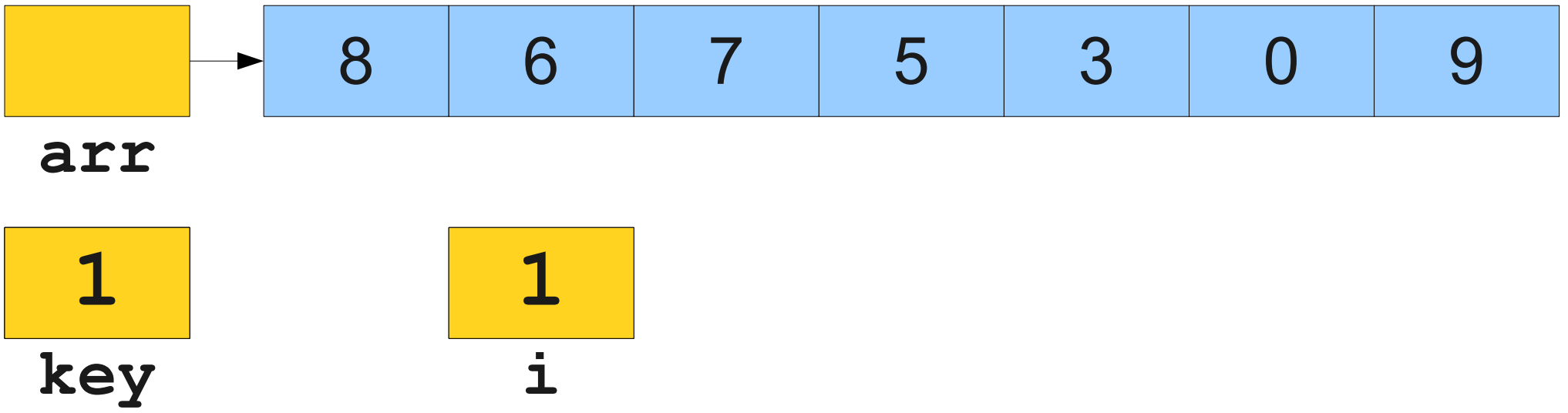

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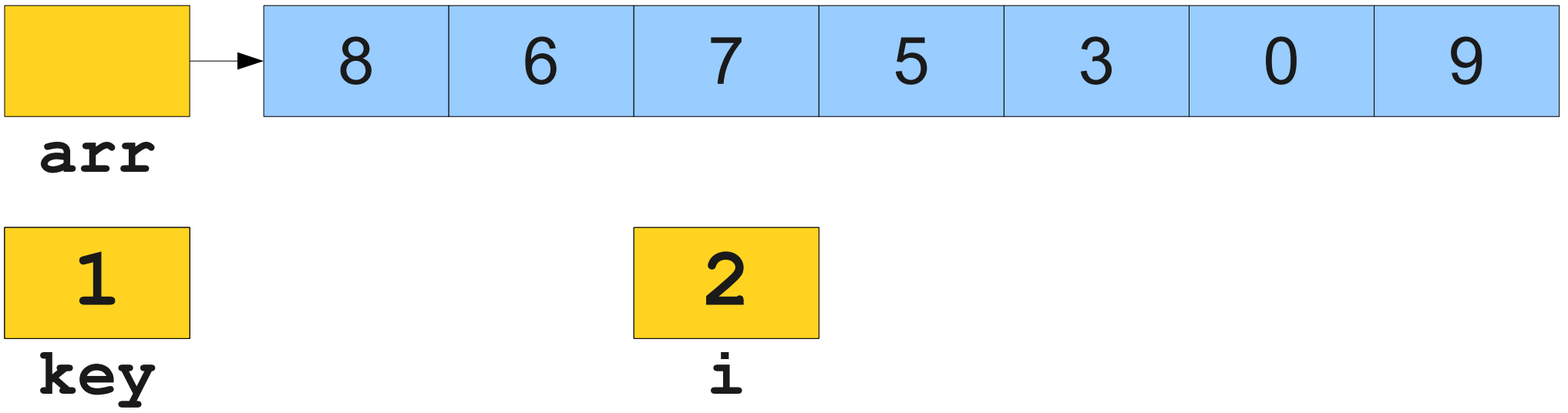

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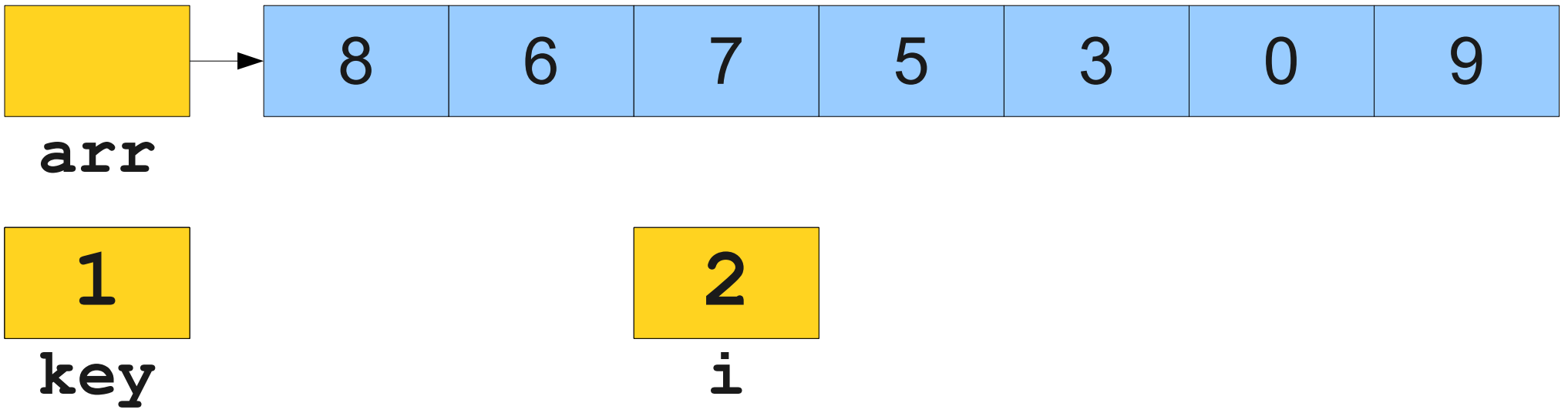

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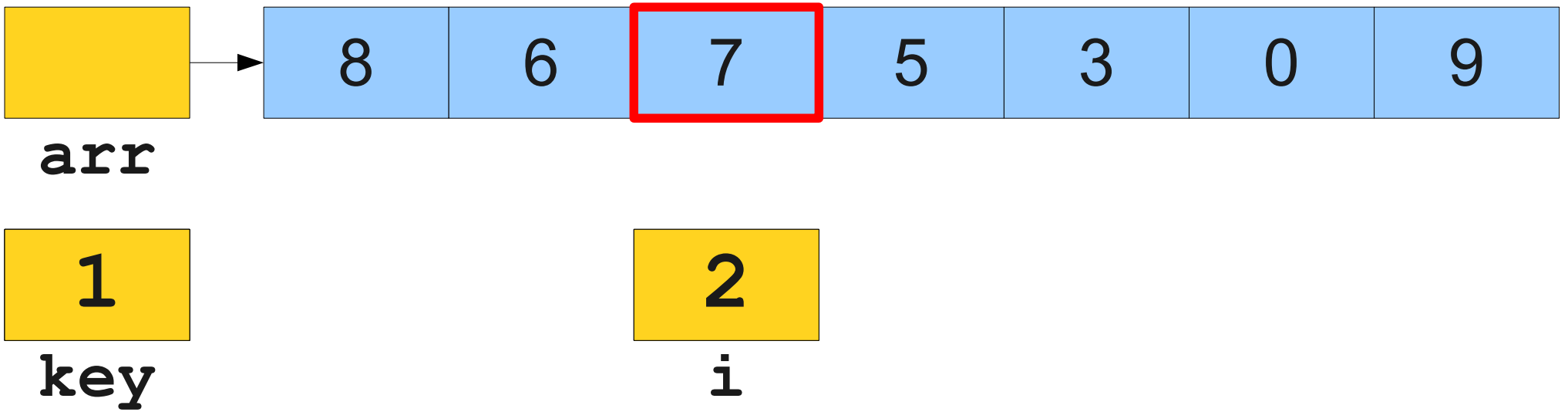

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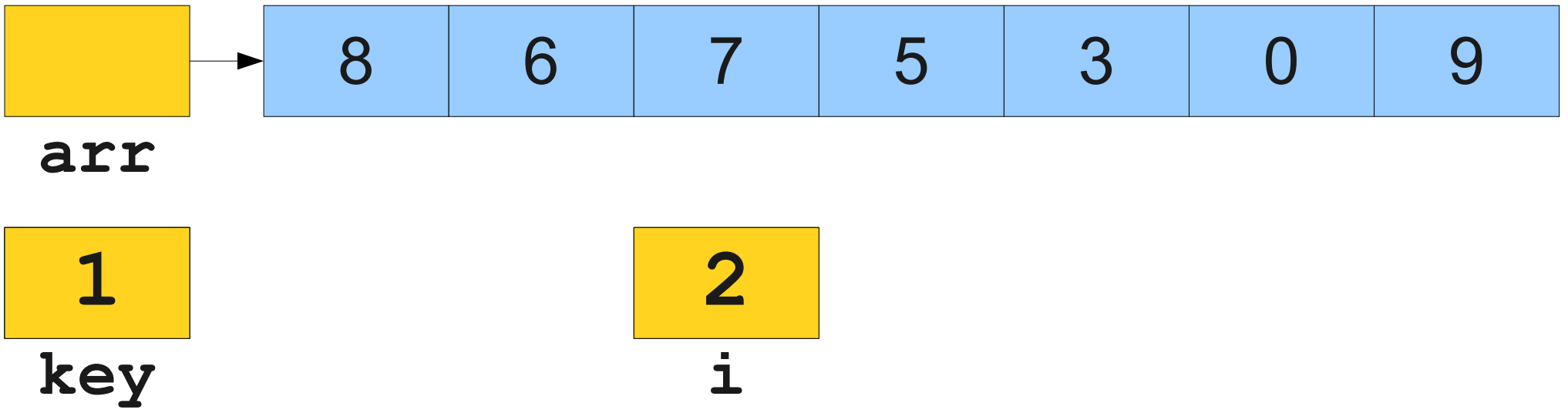

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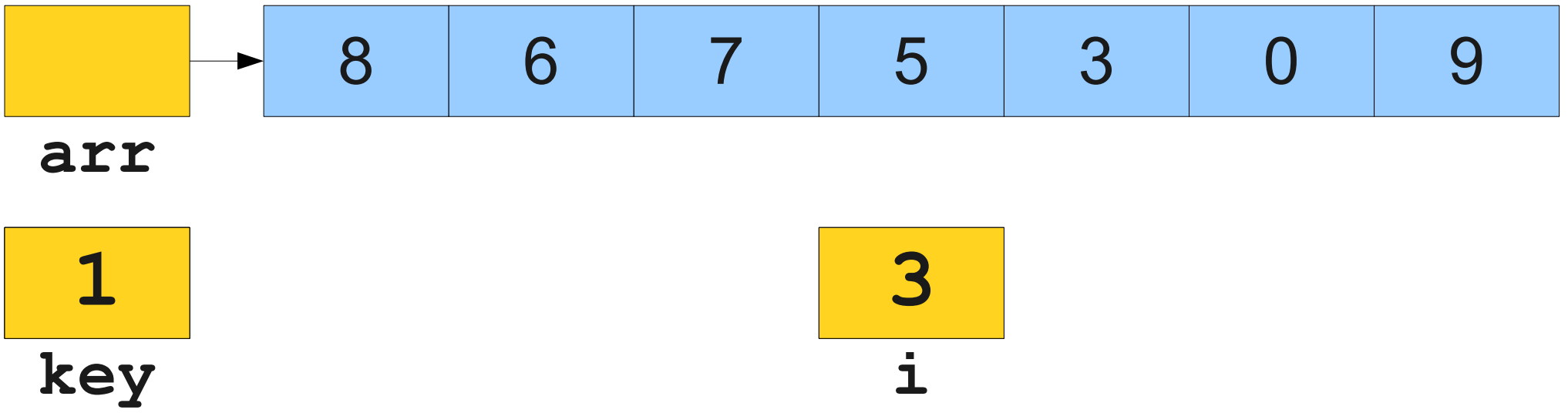

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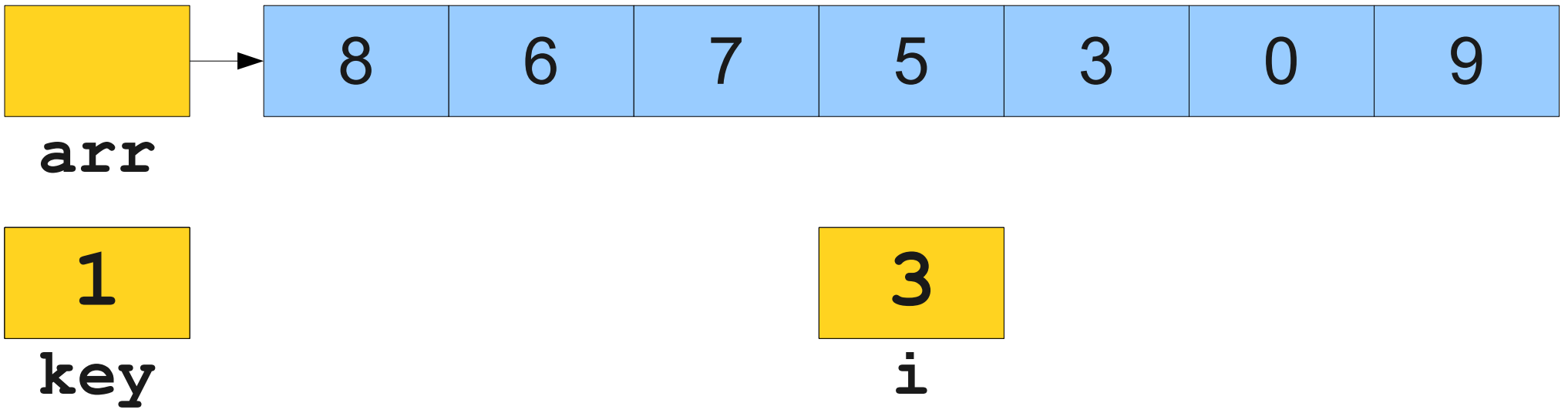

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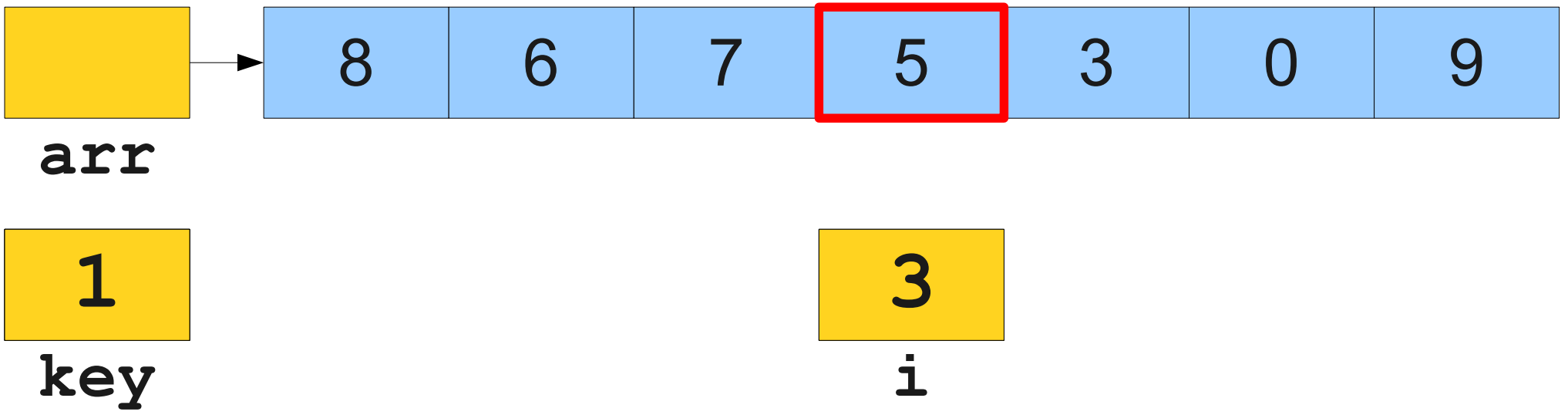

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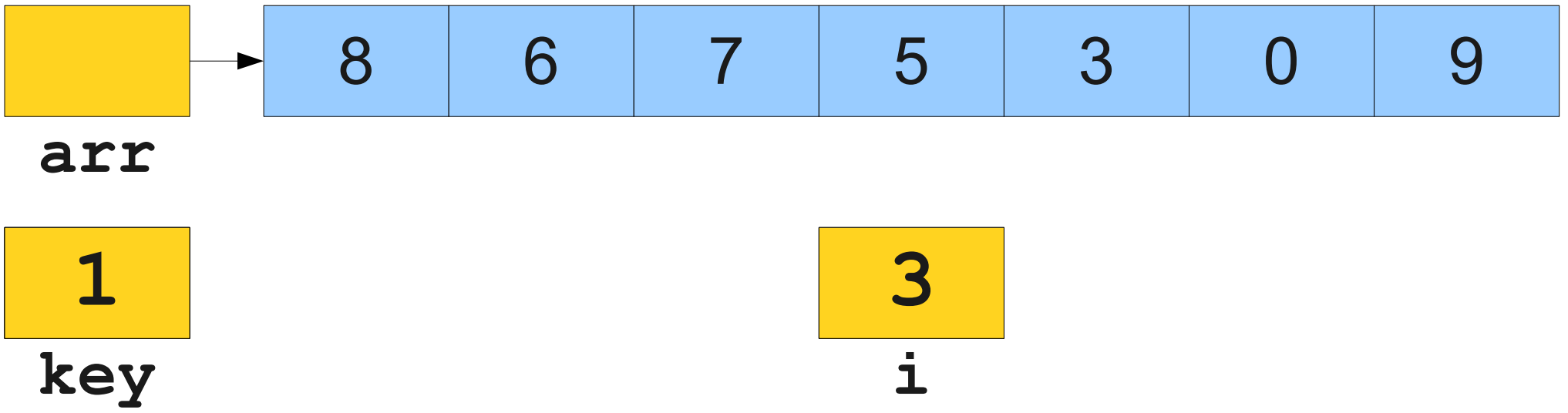

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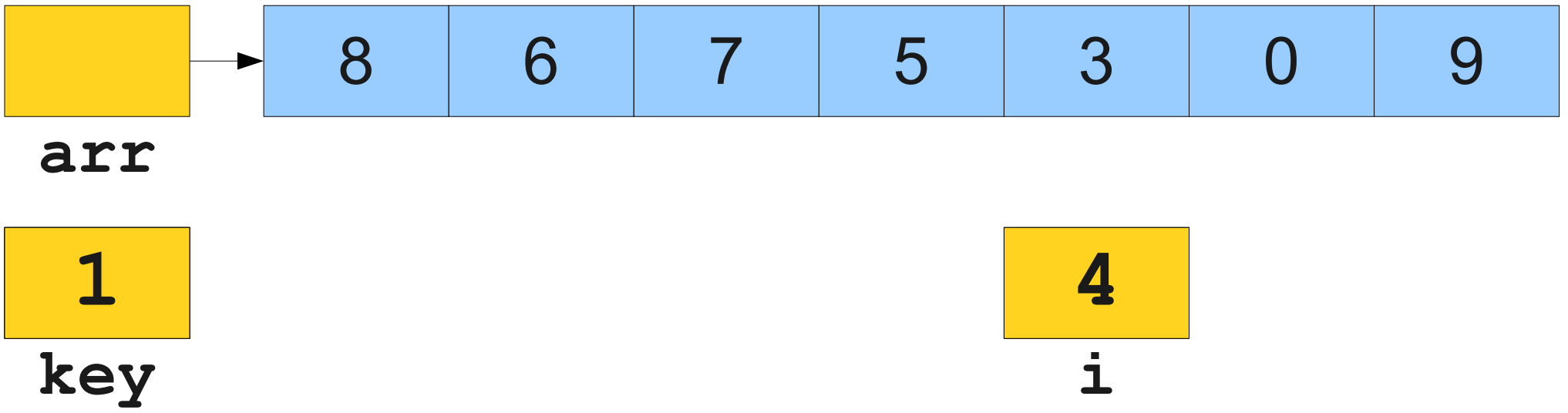

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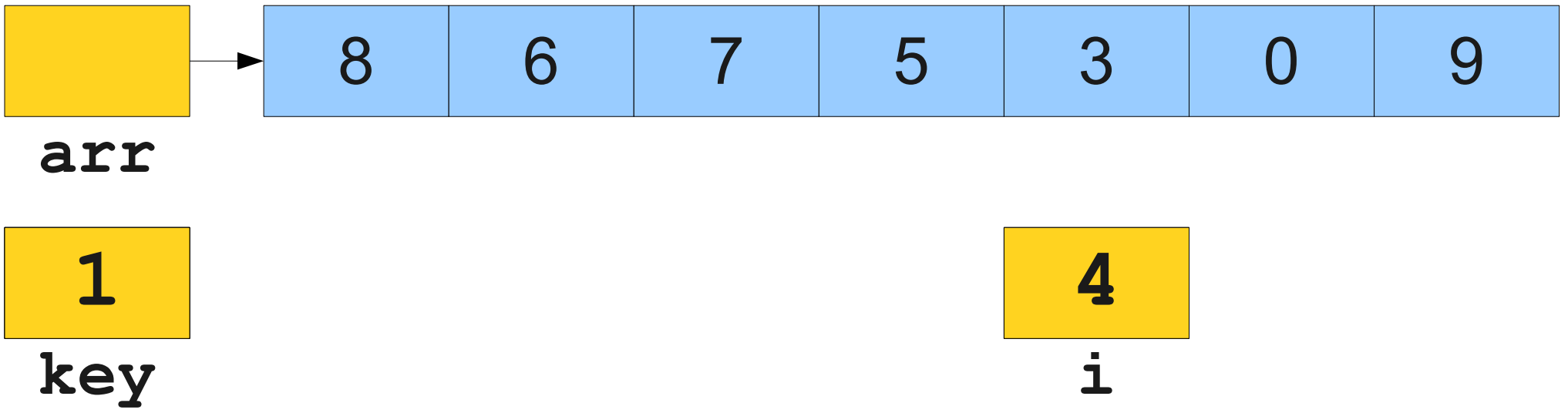

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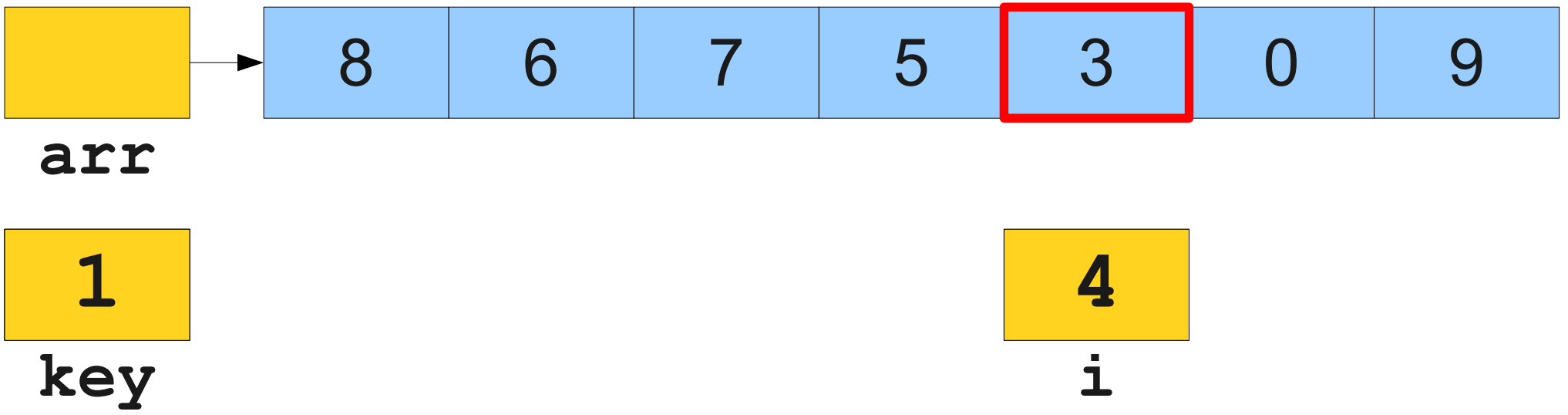

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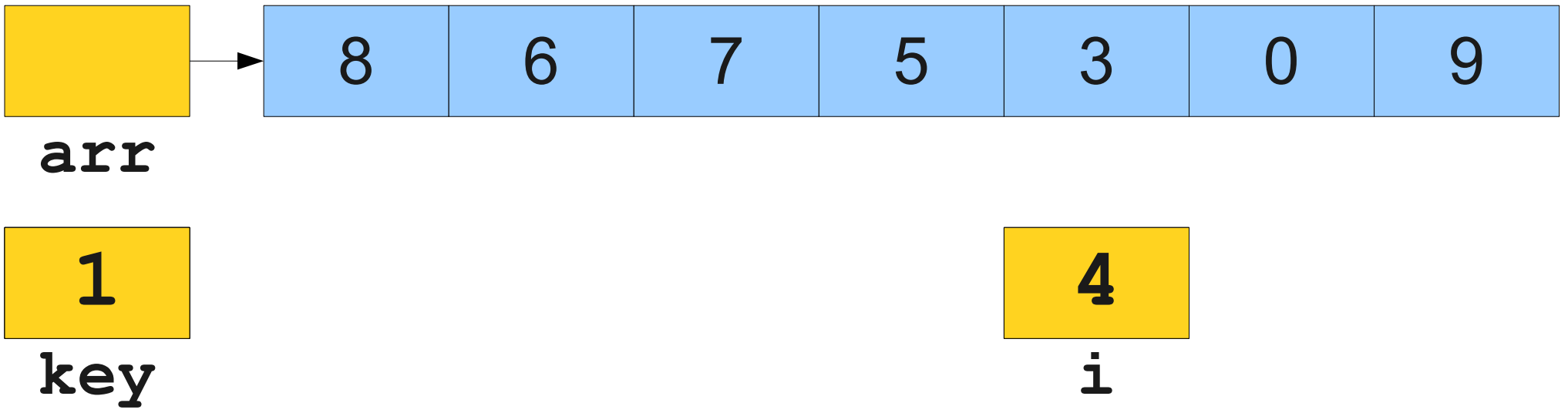

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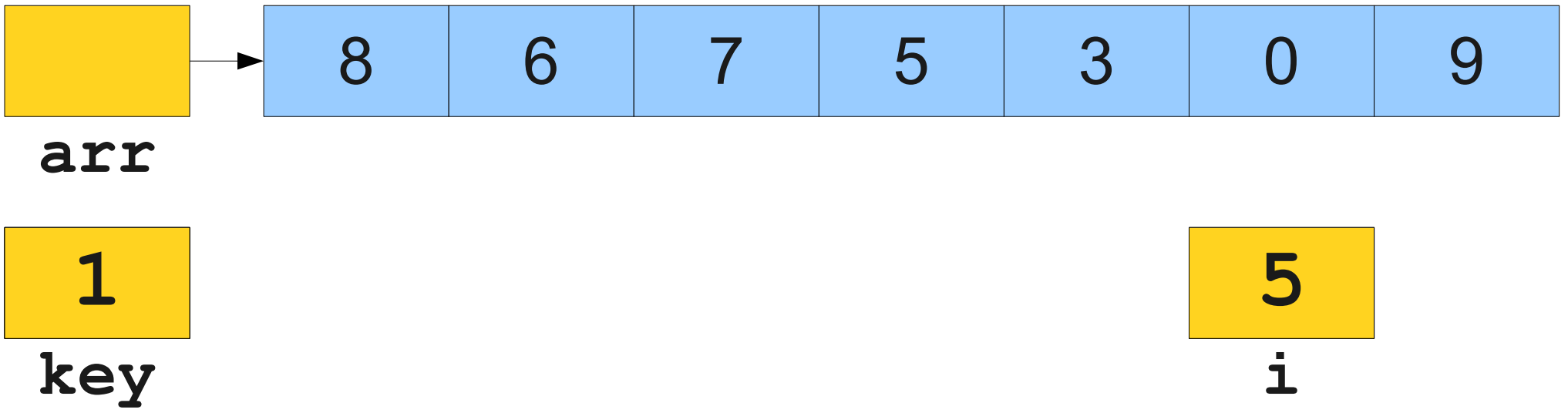

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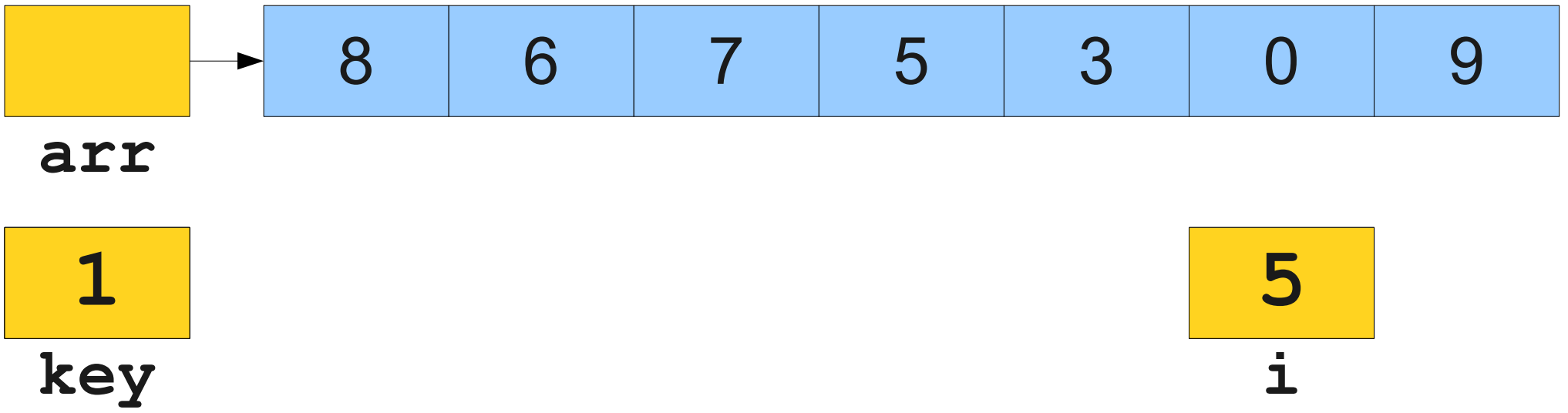

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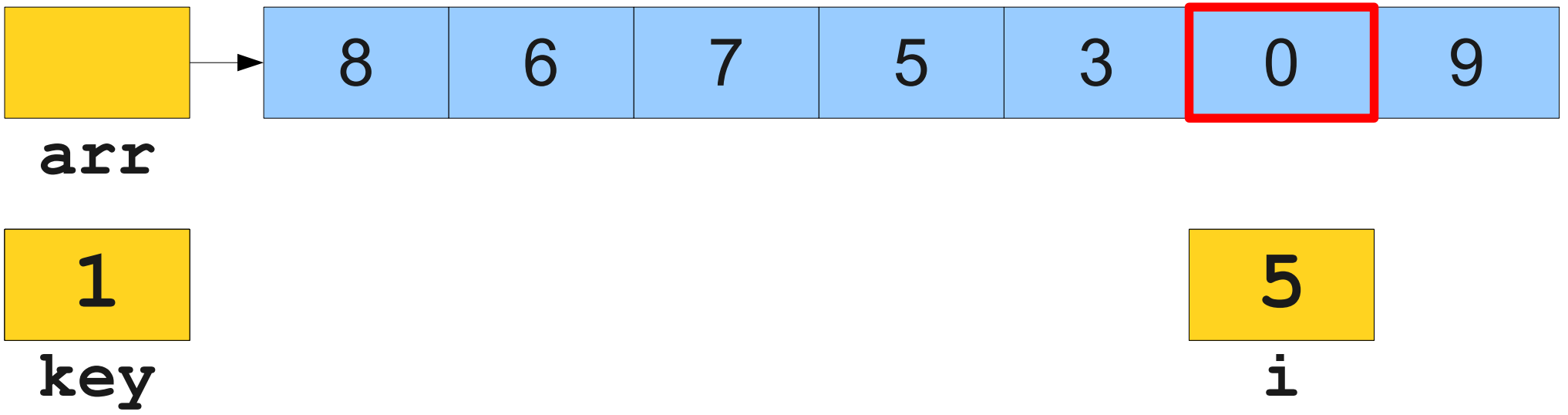

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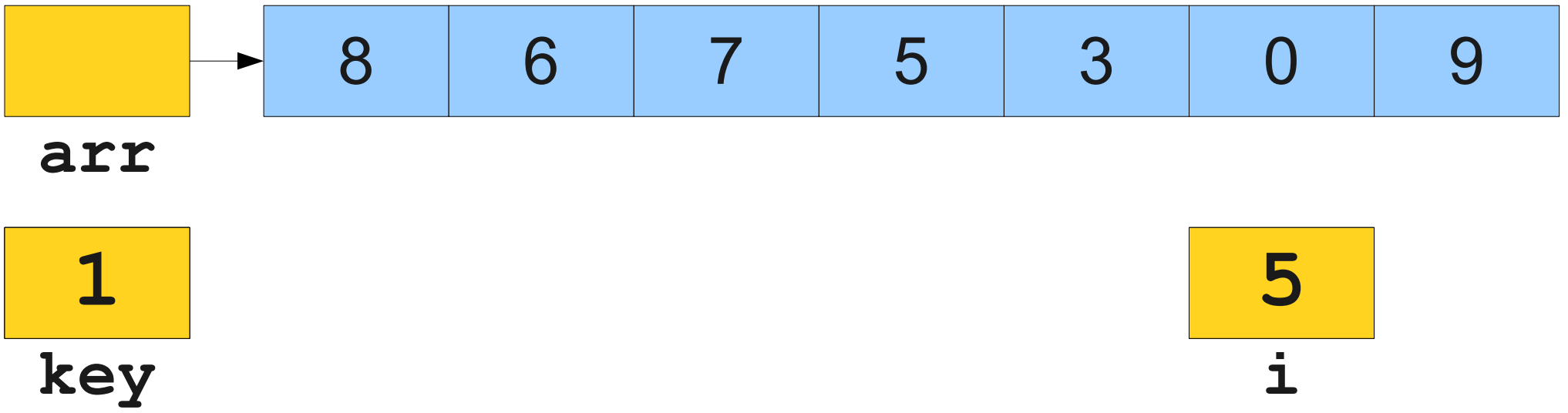

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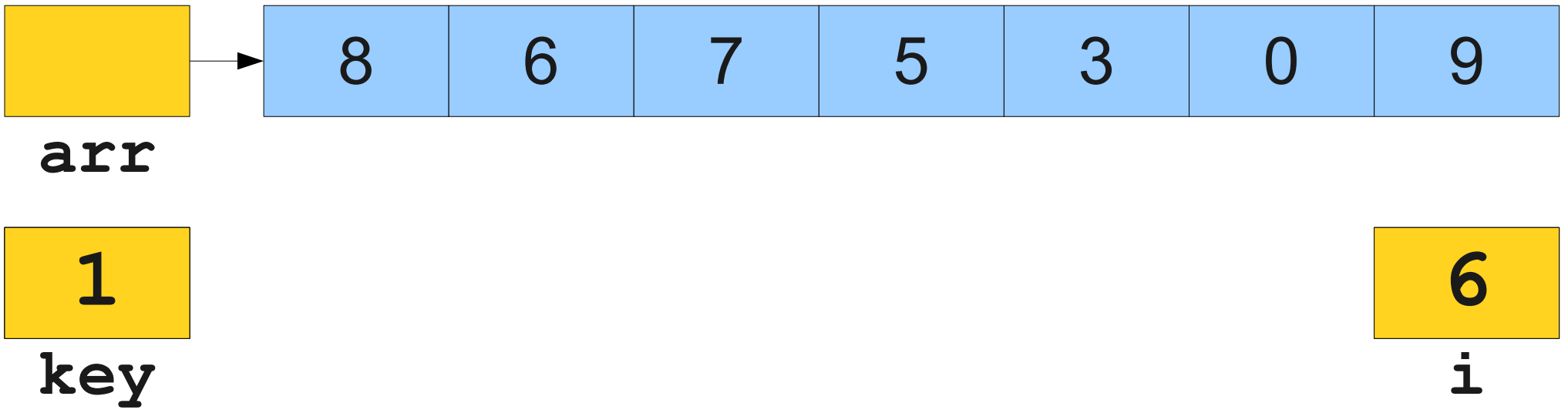

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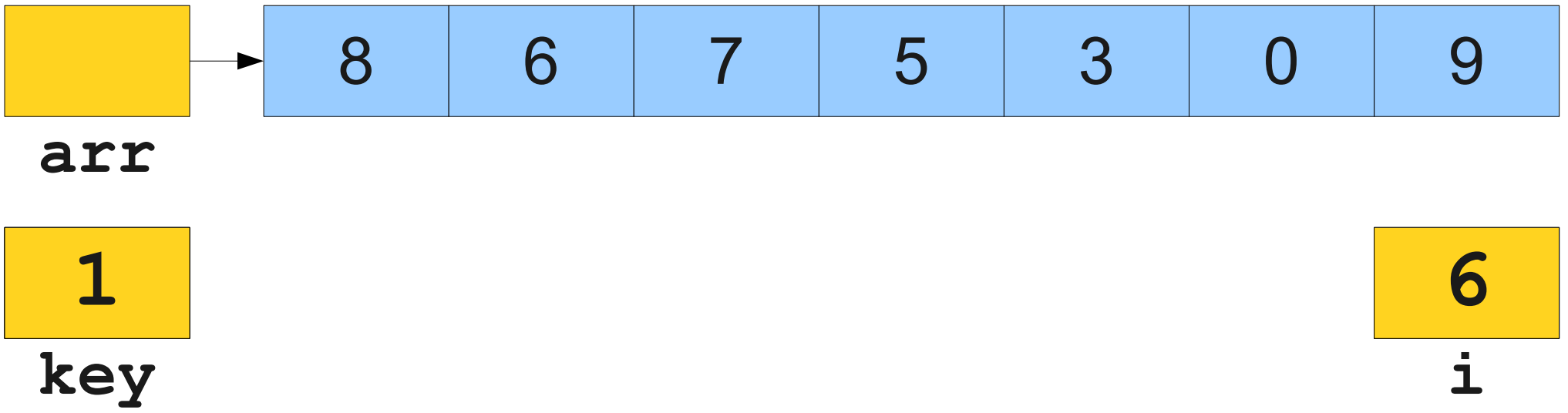

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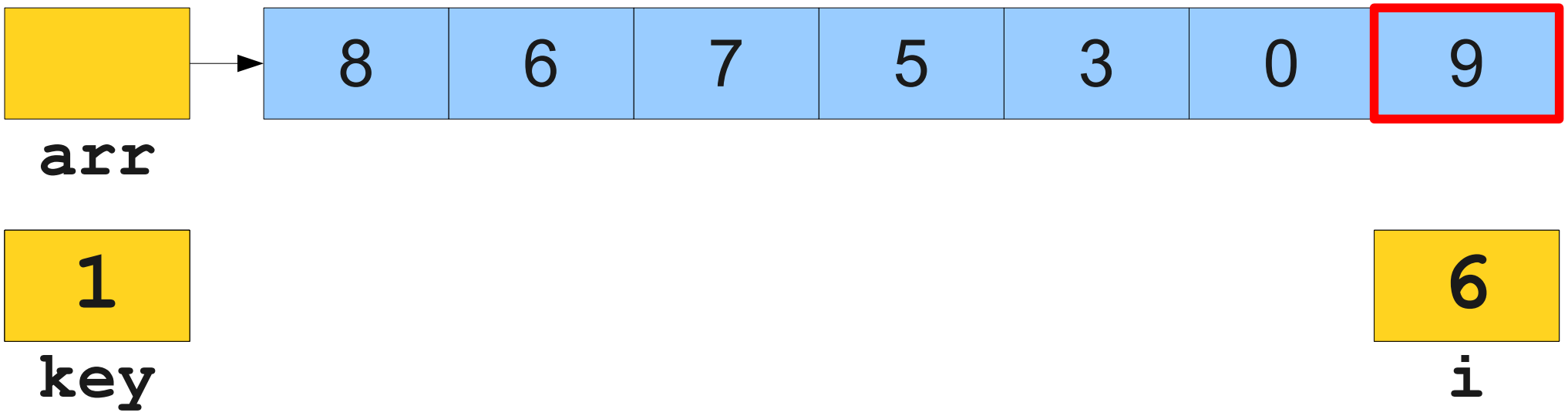

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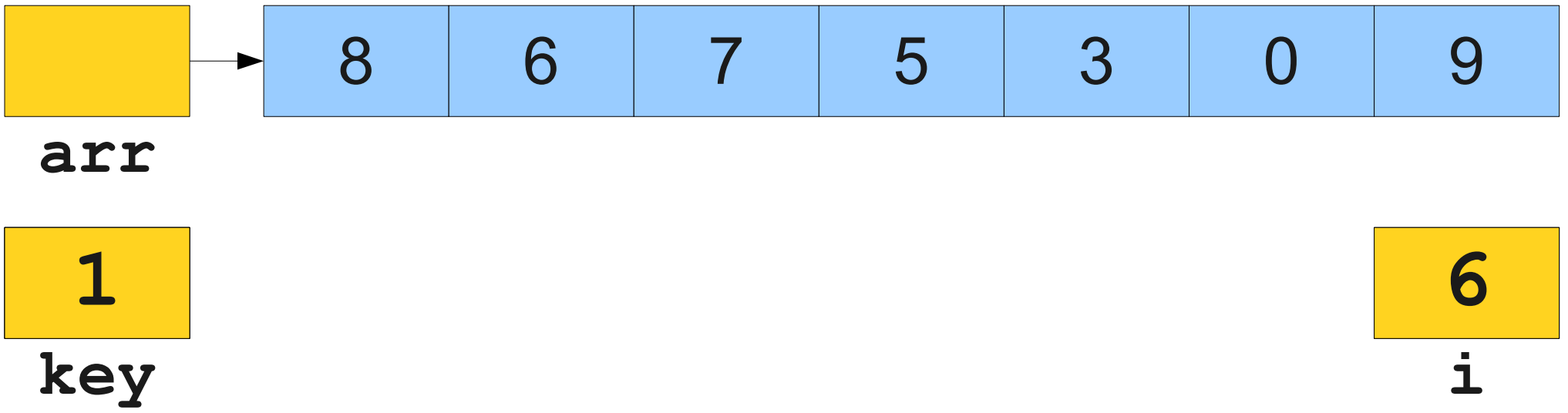

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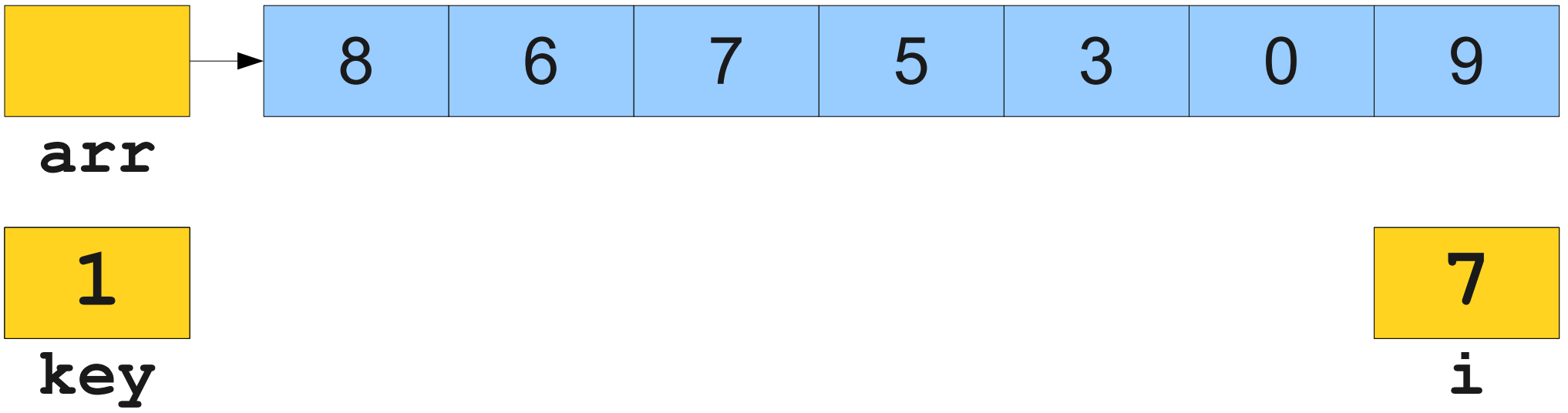

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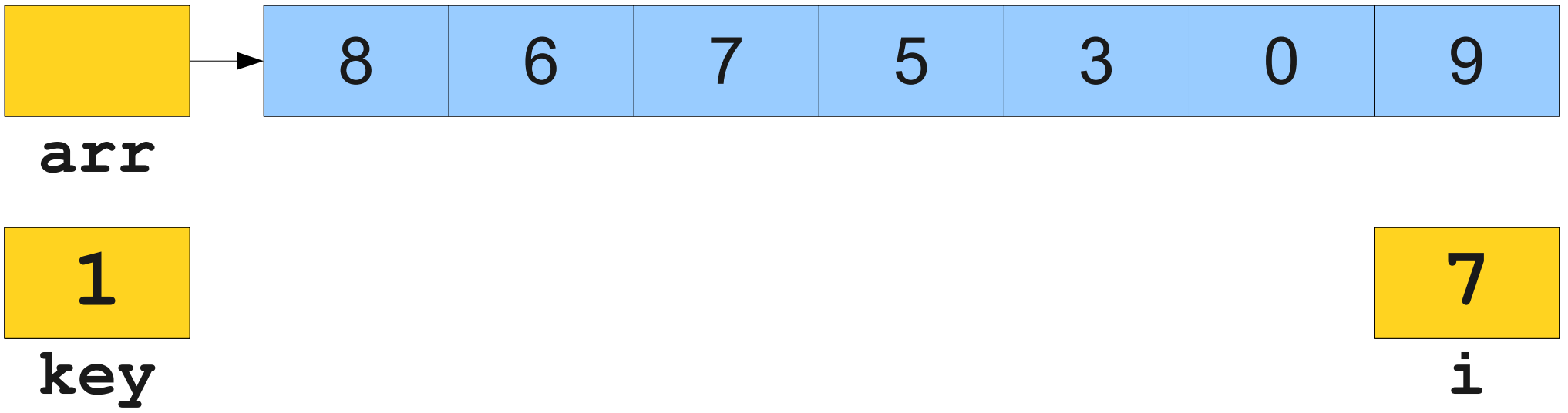

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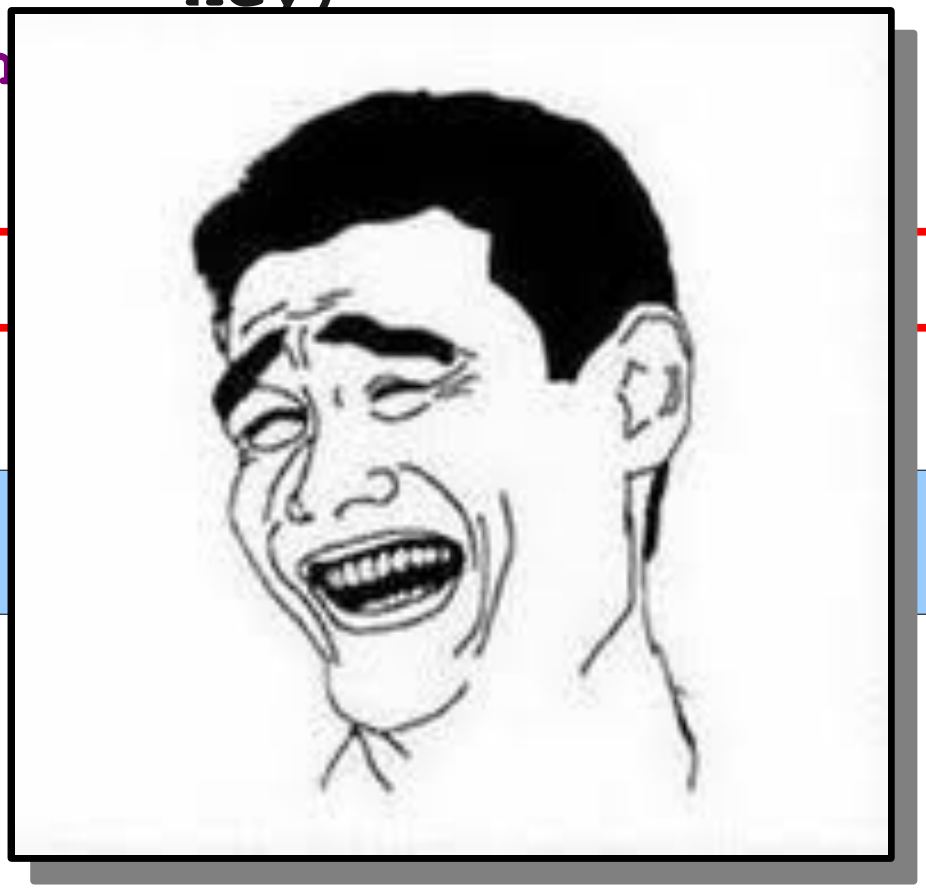

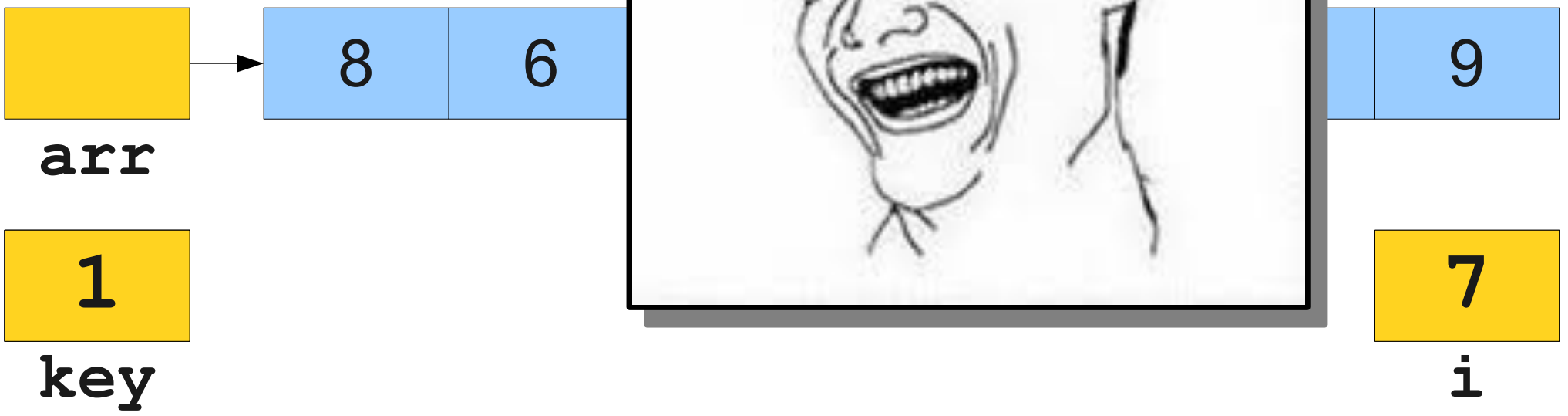

Searching II

Binary Search

2	3	5	7	11	13	17	19	23	29	31	37	41
43	47	53	59	61	67	71	73	79	83	89	97	101
103	107	109	113	127	131	137	139	149	151	157	163	167

Find 137 from the Sorted Array/List

Binary Search

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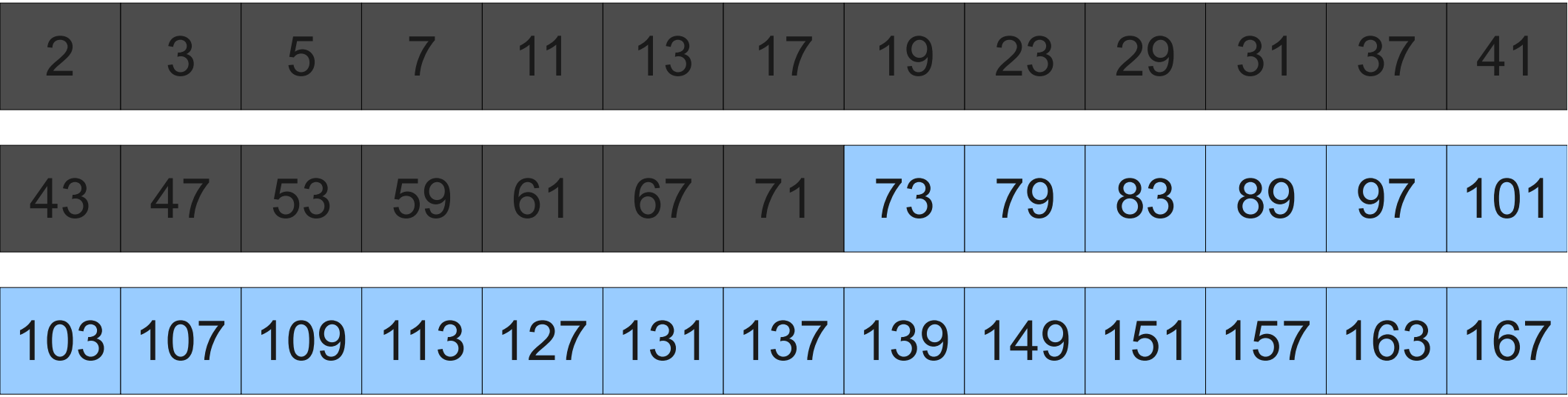

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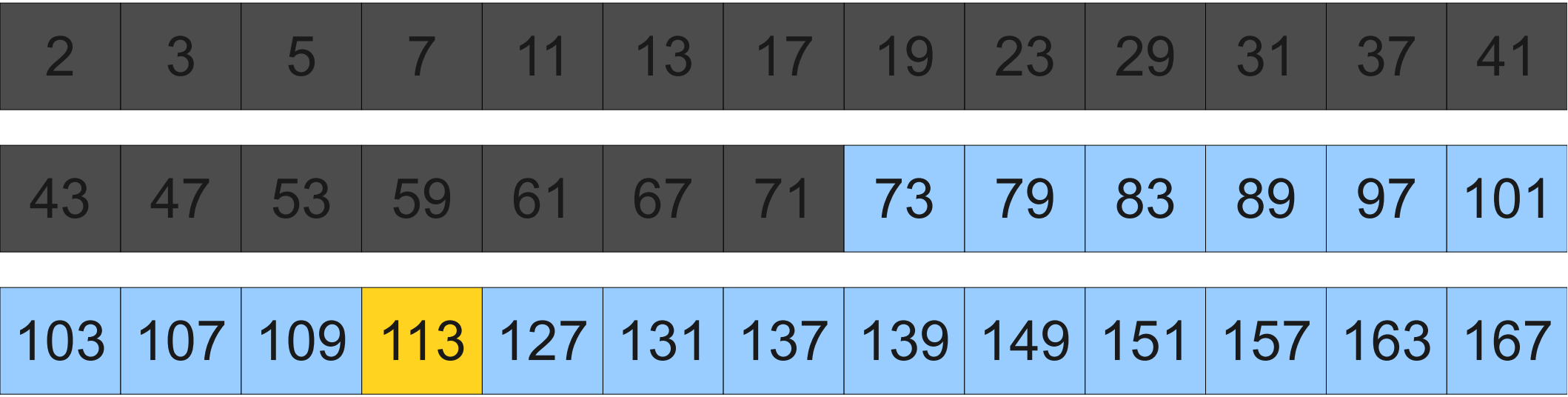

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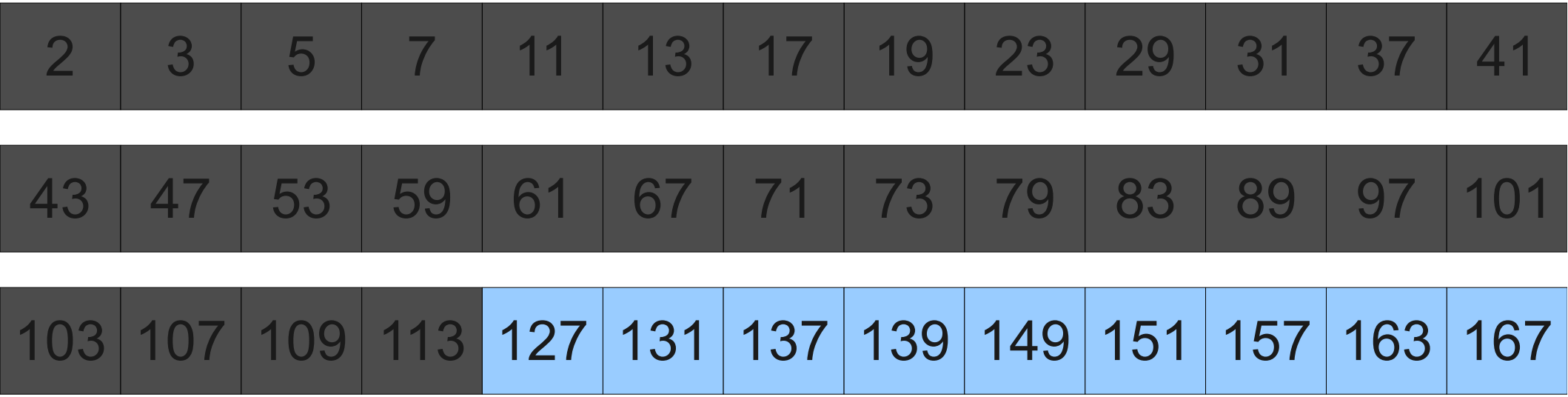

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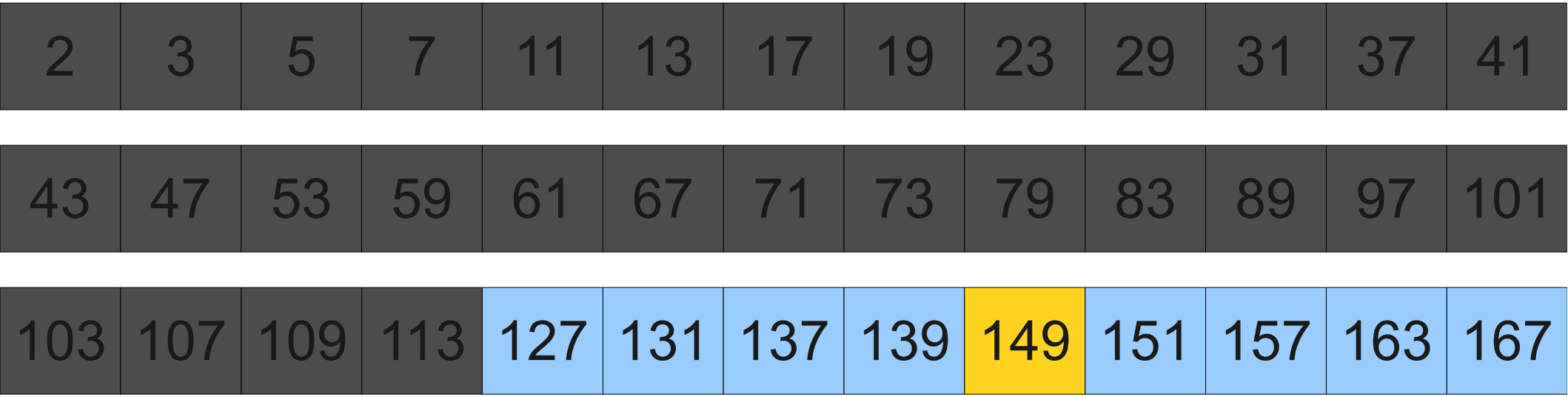

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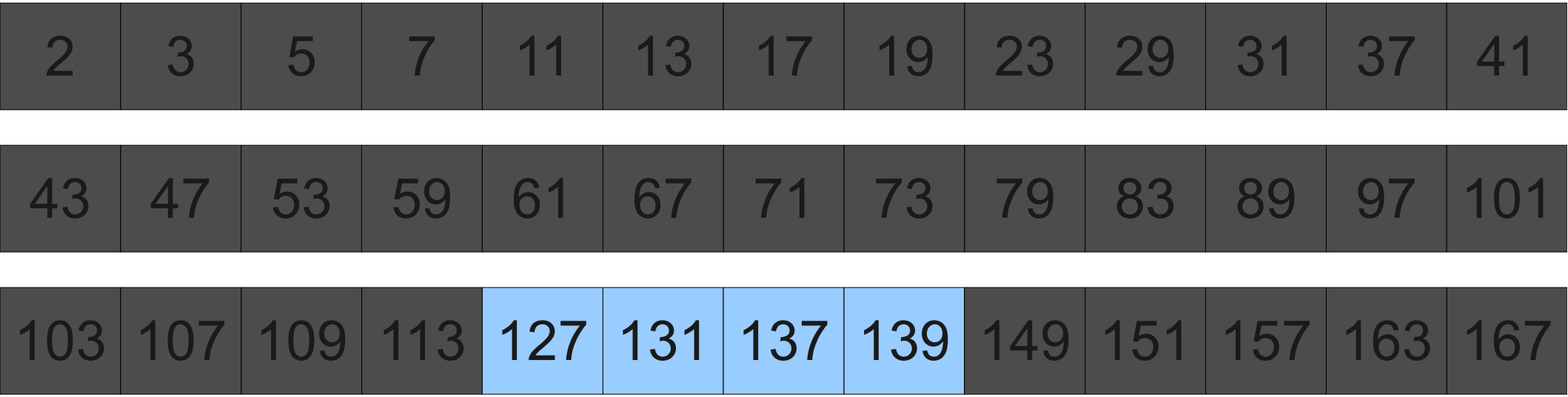

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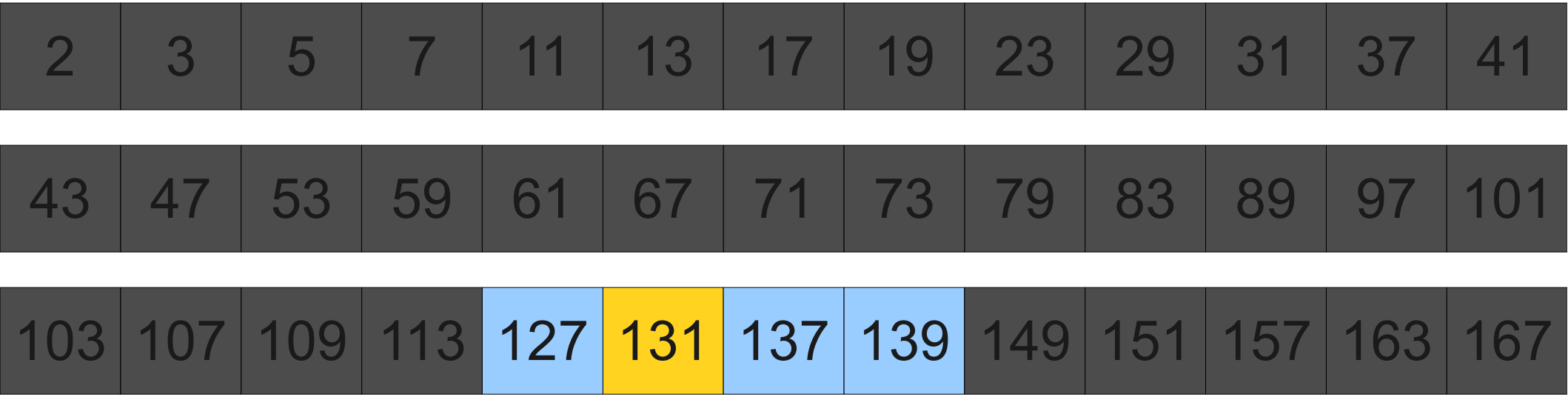

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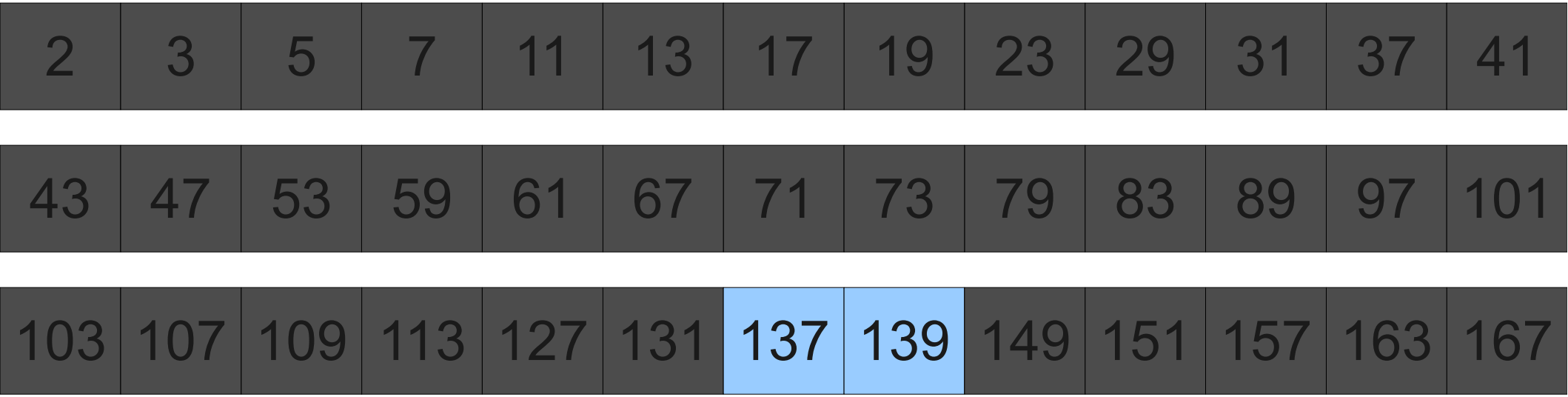

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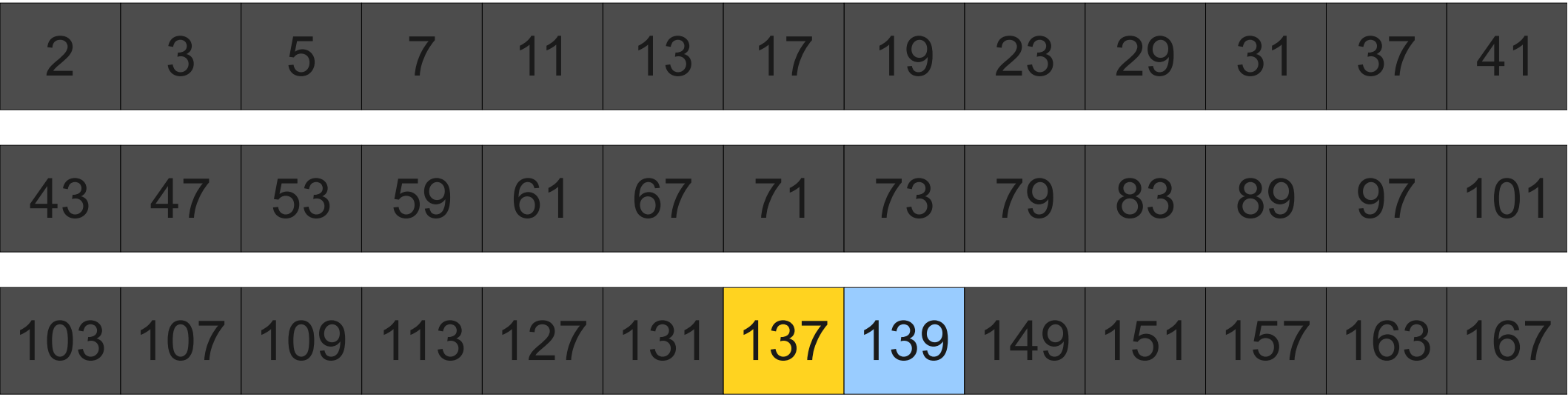

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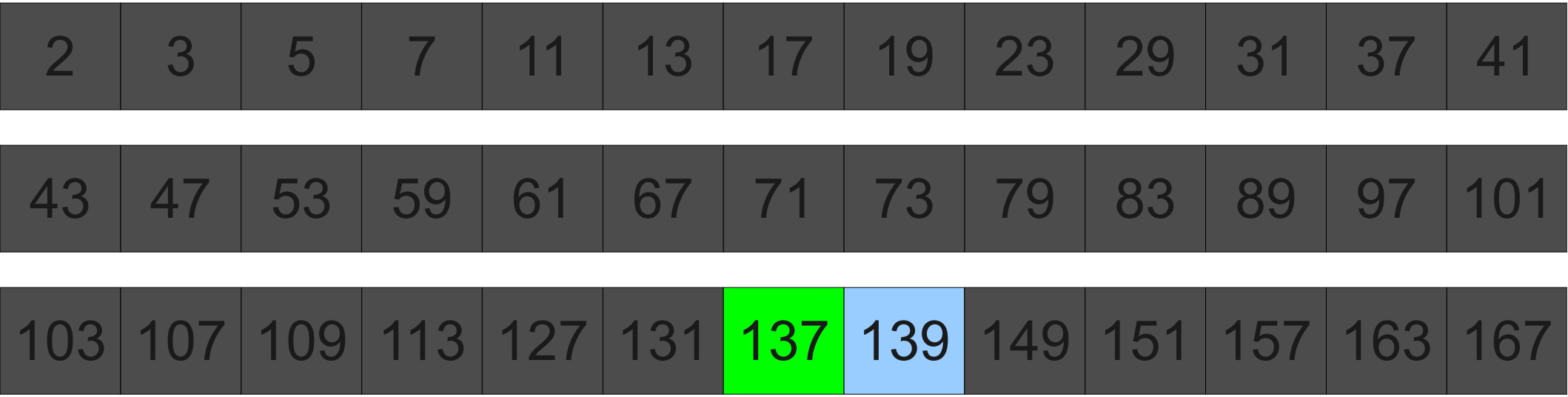

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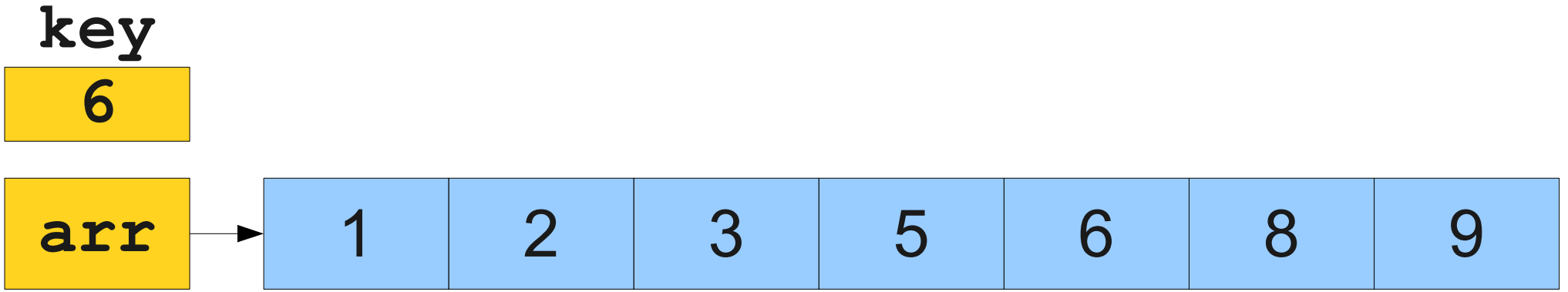

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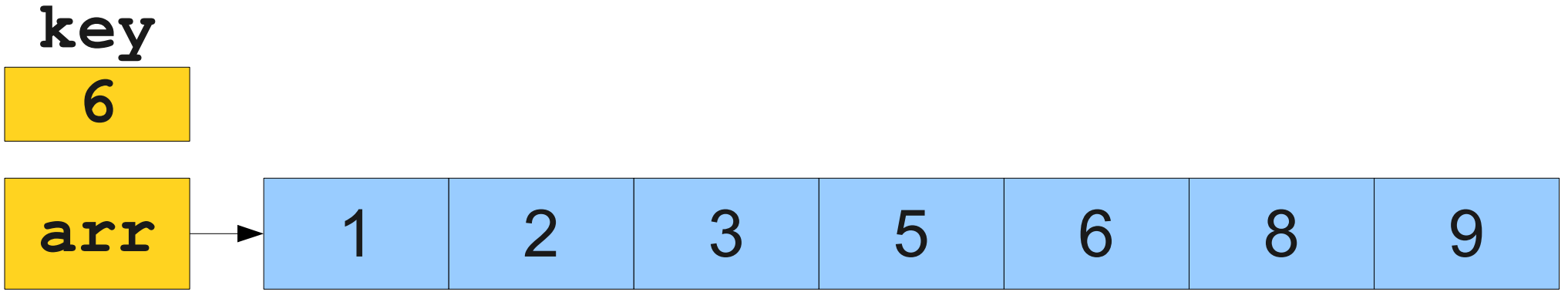

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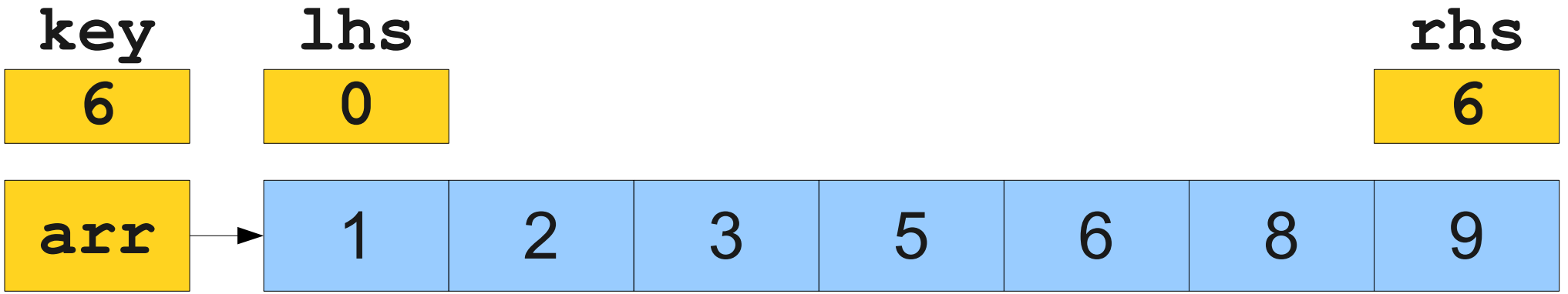

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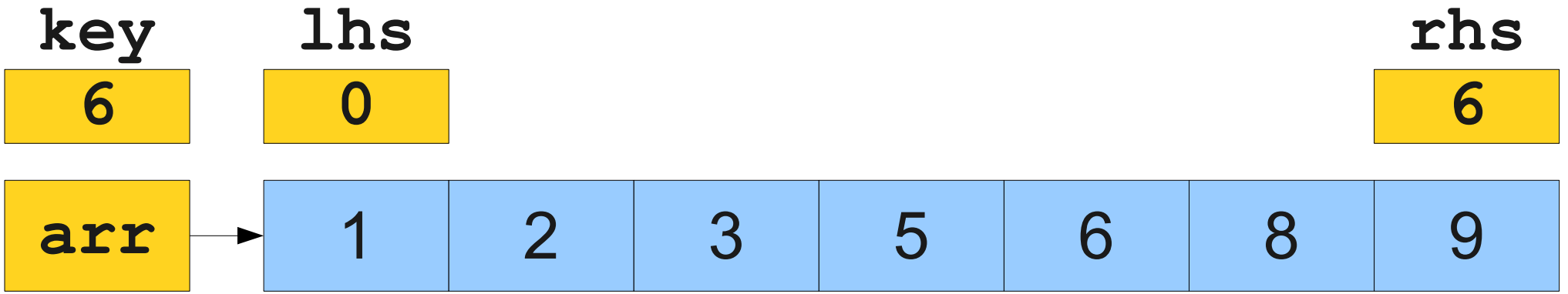

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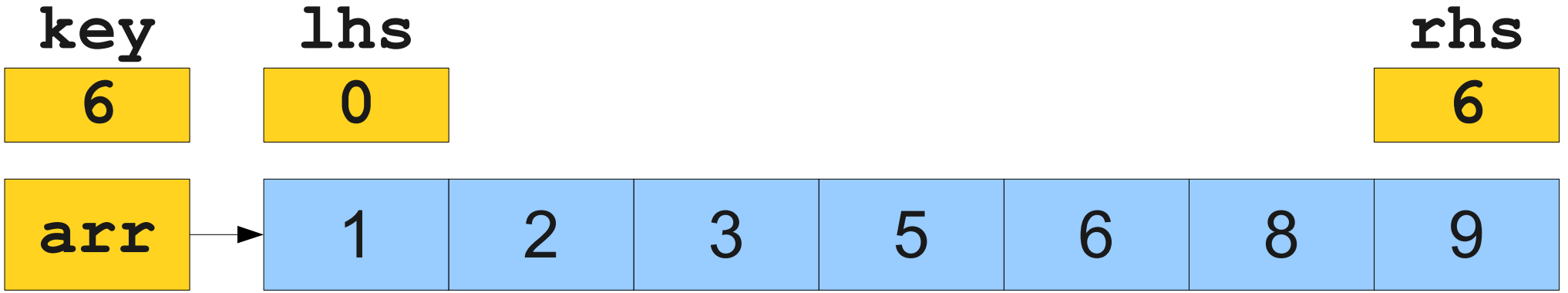

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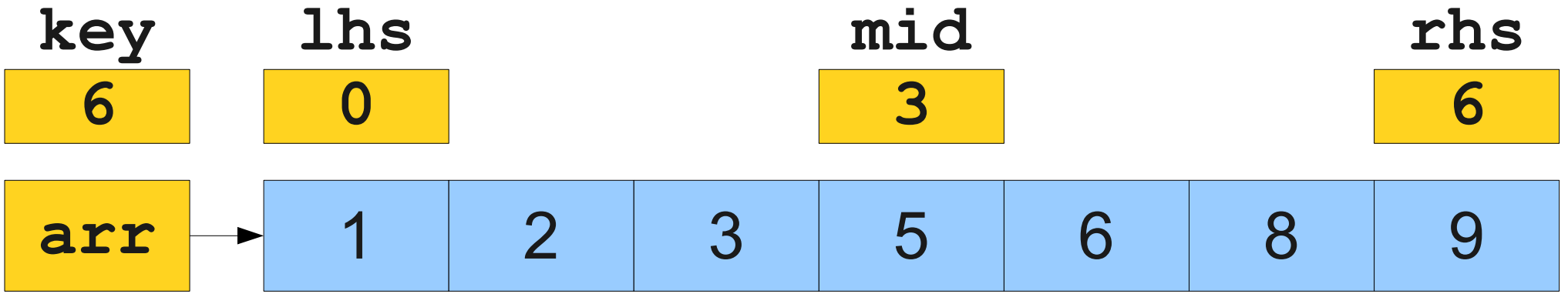

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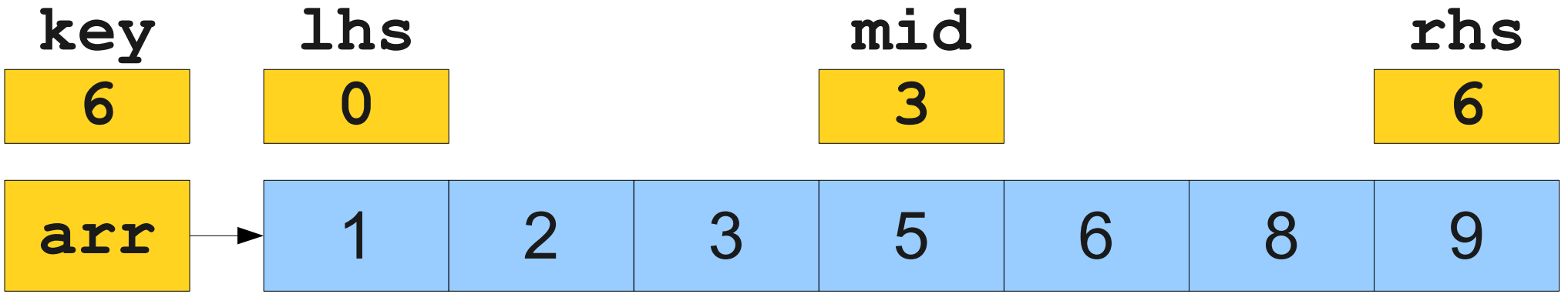

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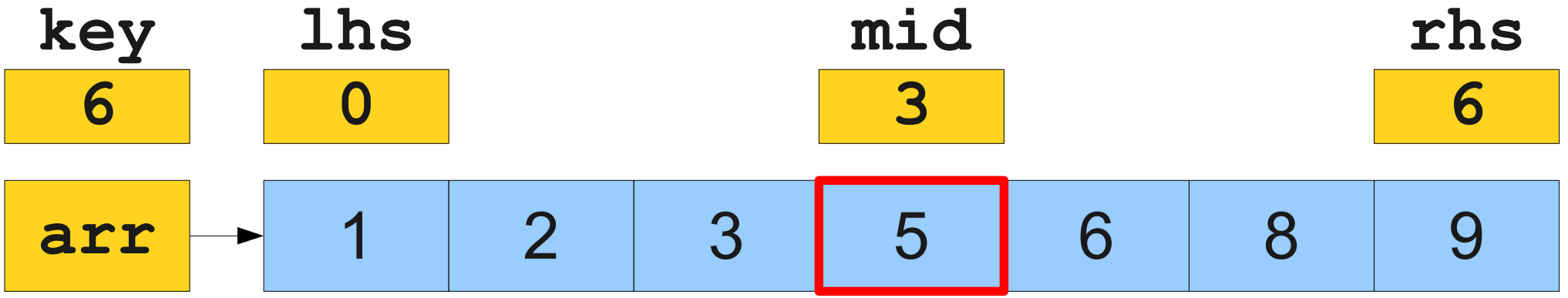

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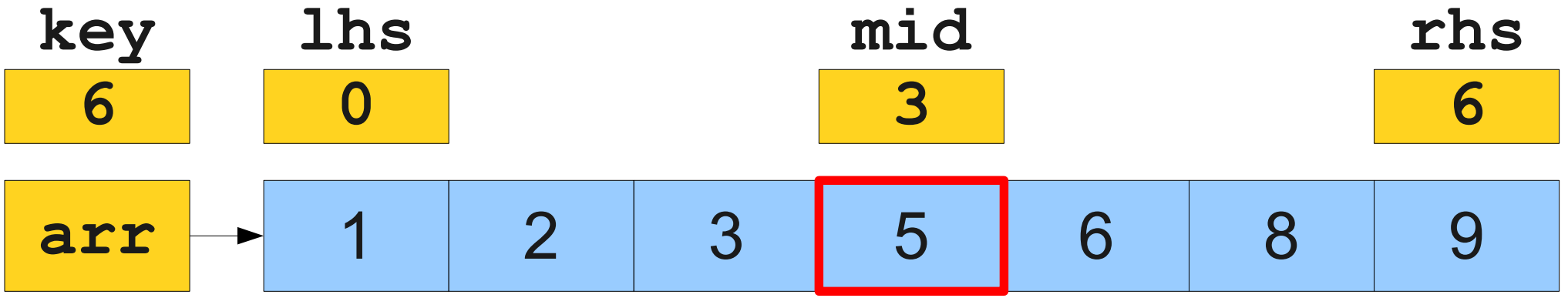

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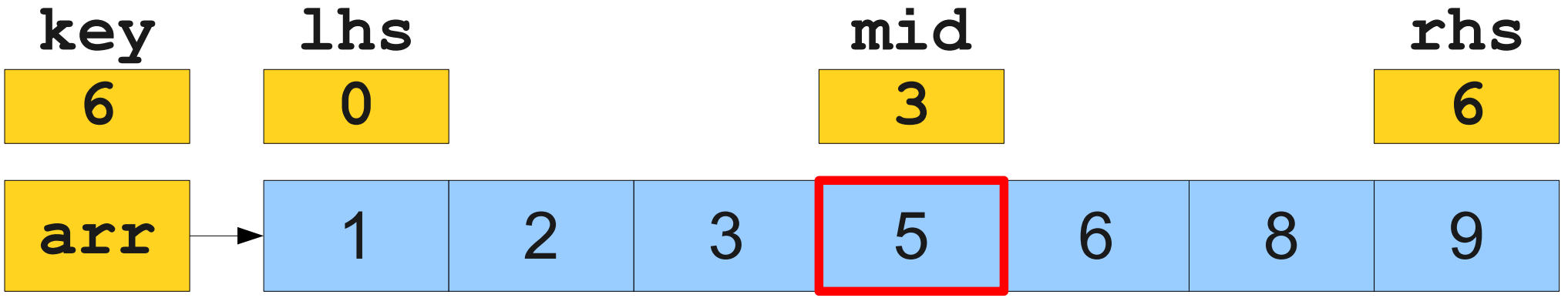

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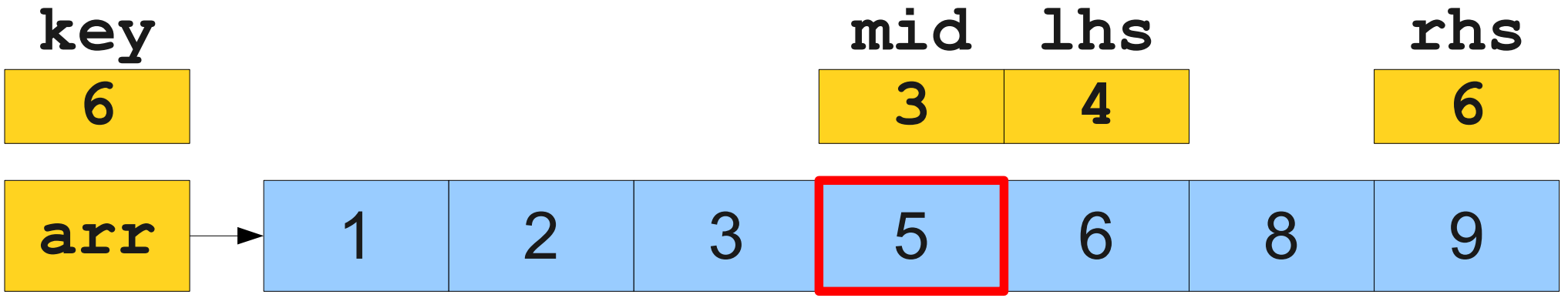

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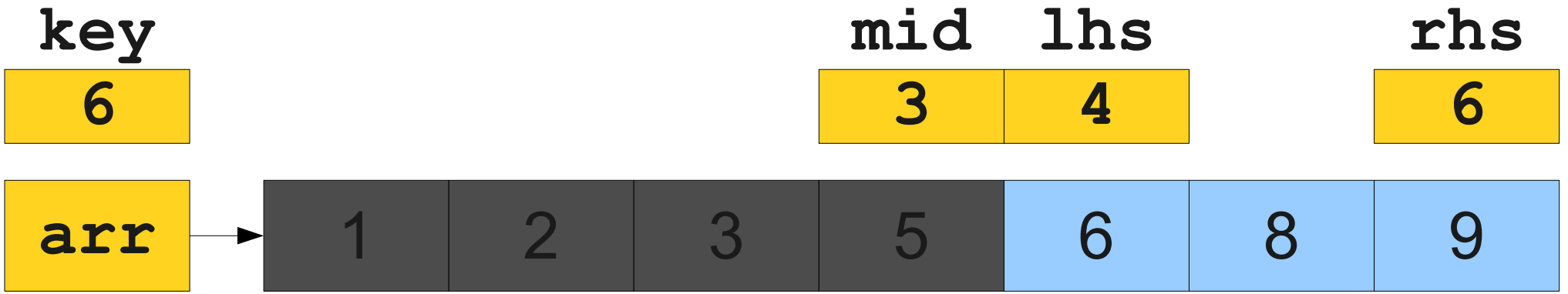

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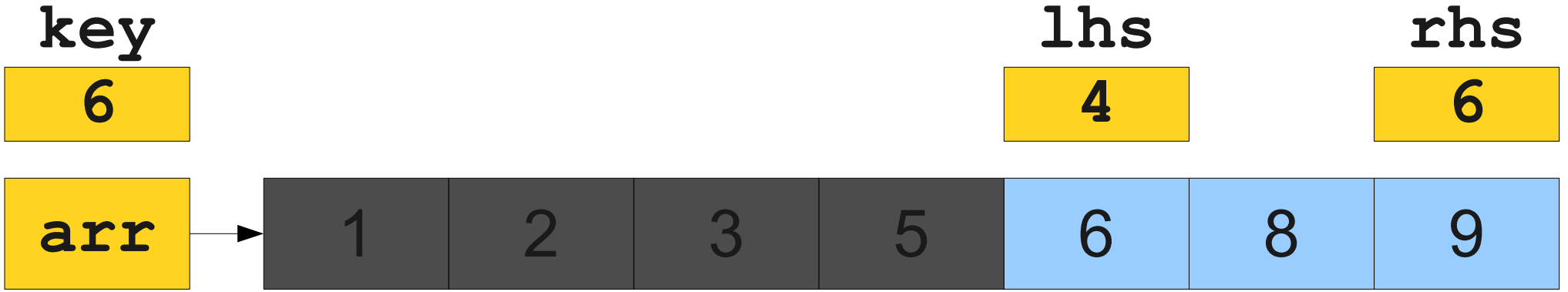

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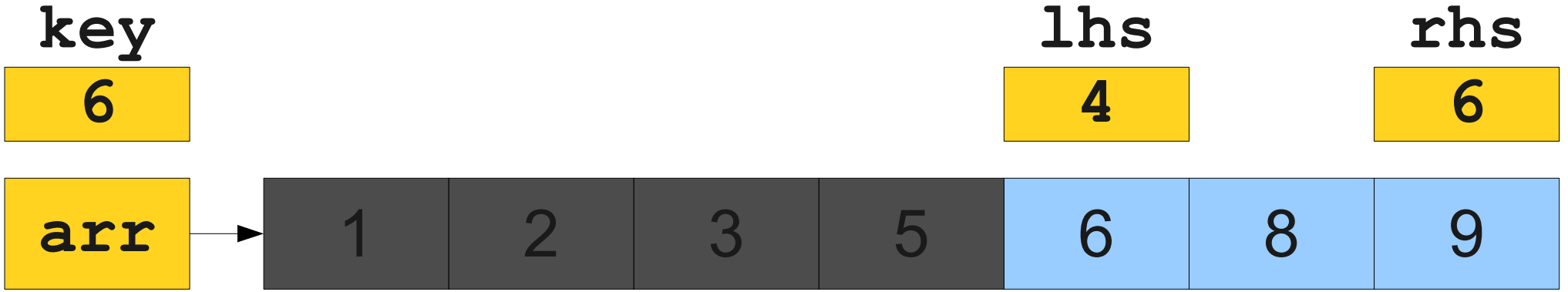

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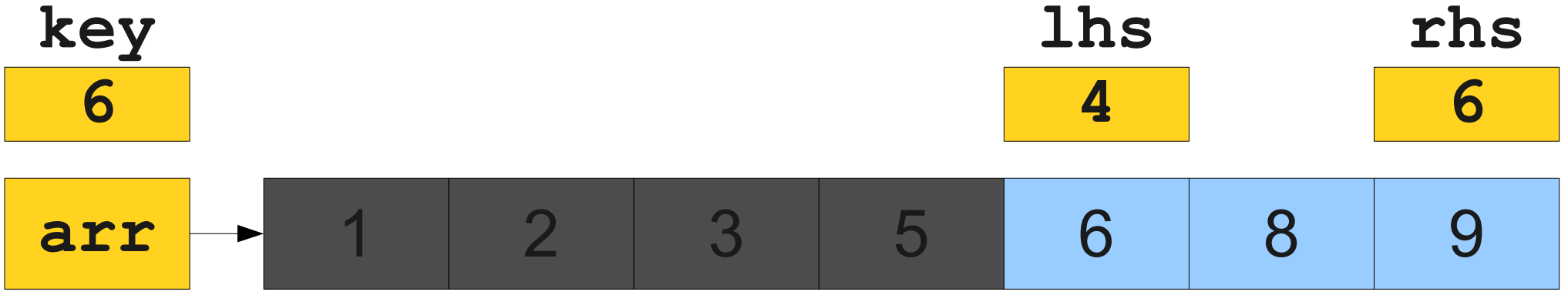

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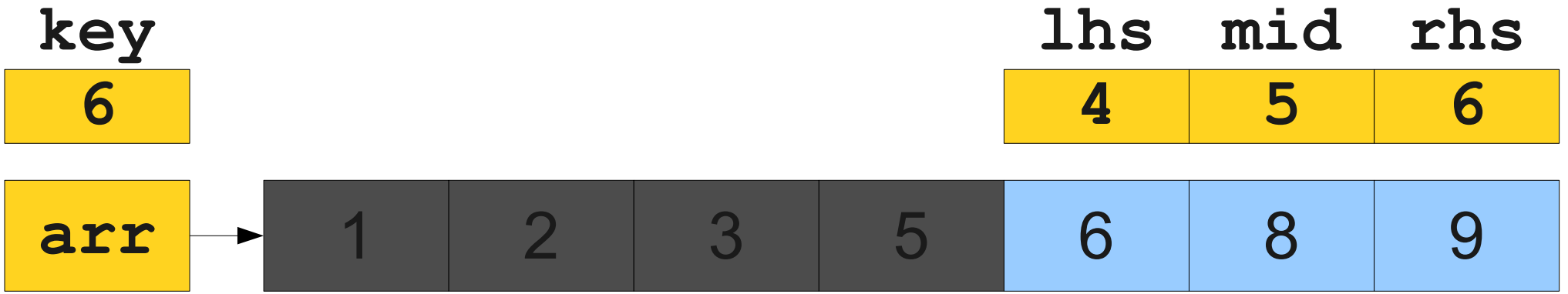

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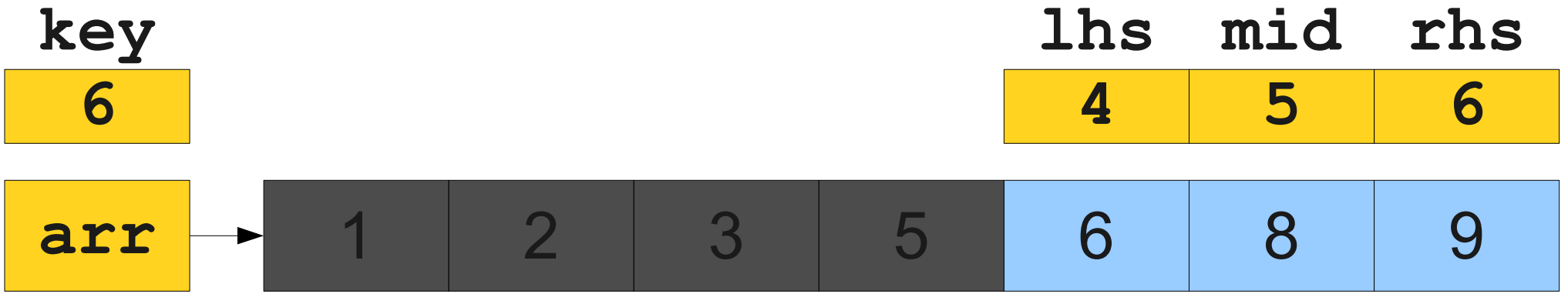

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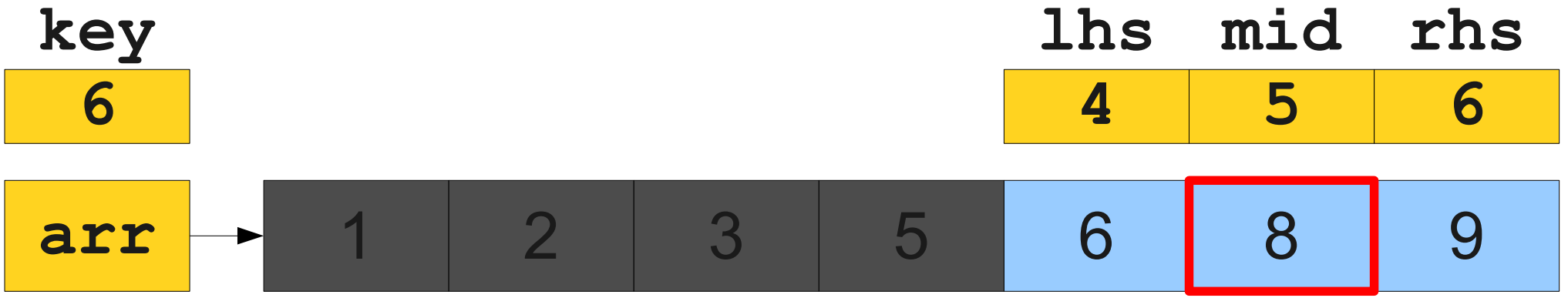

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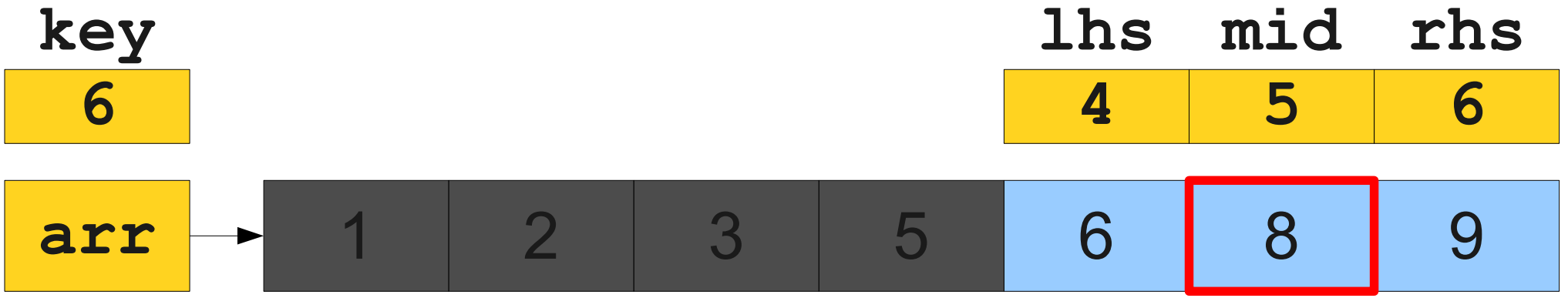

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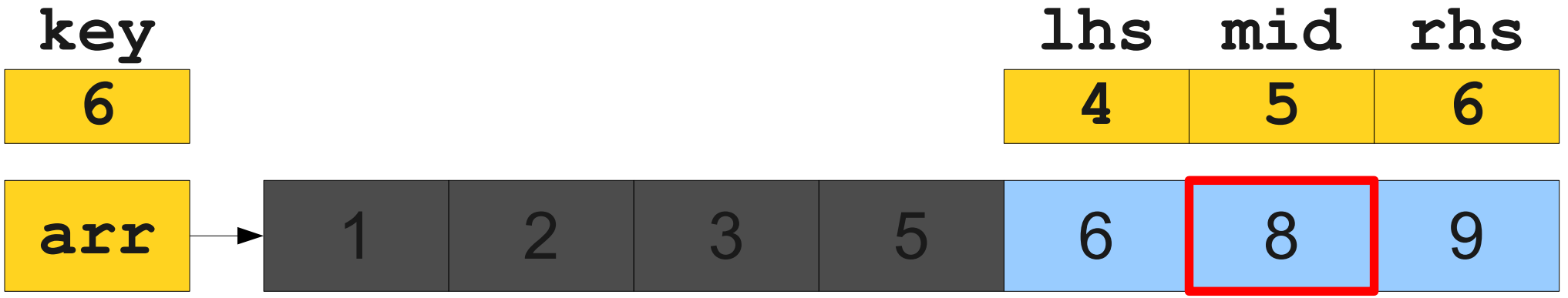

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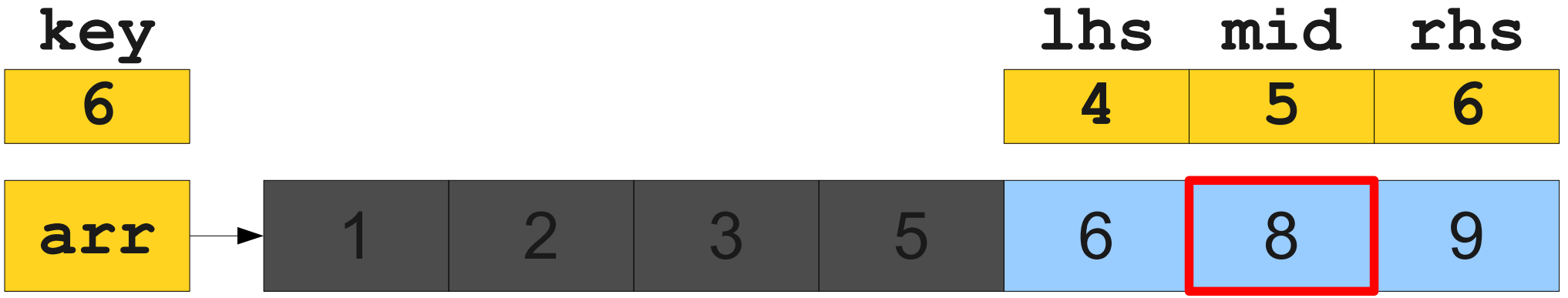

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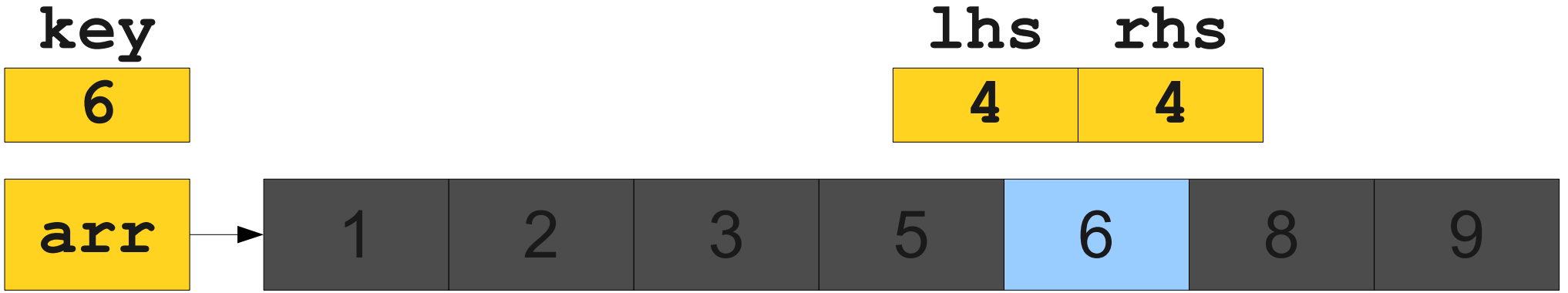

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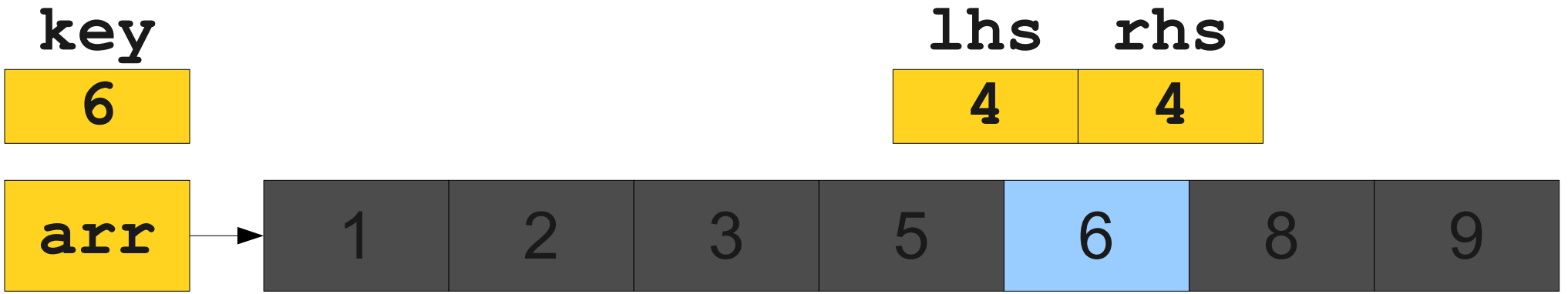

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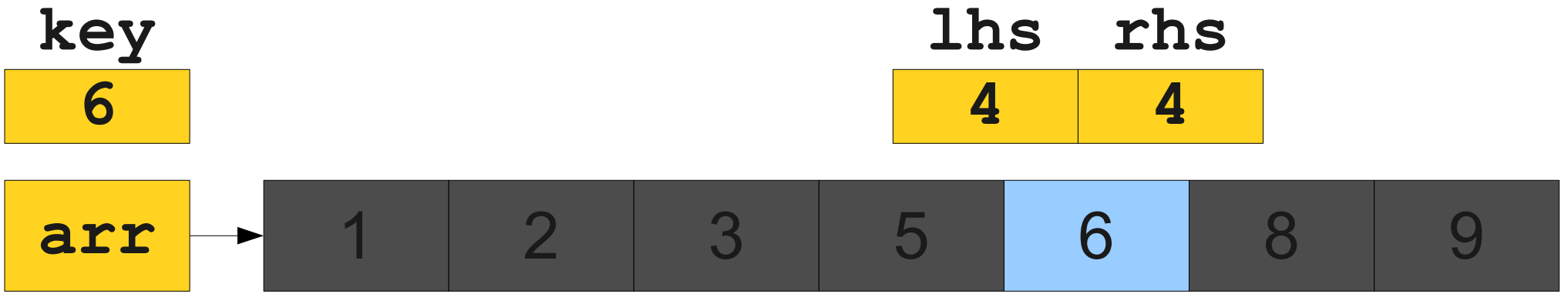

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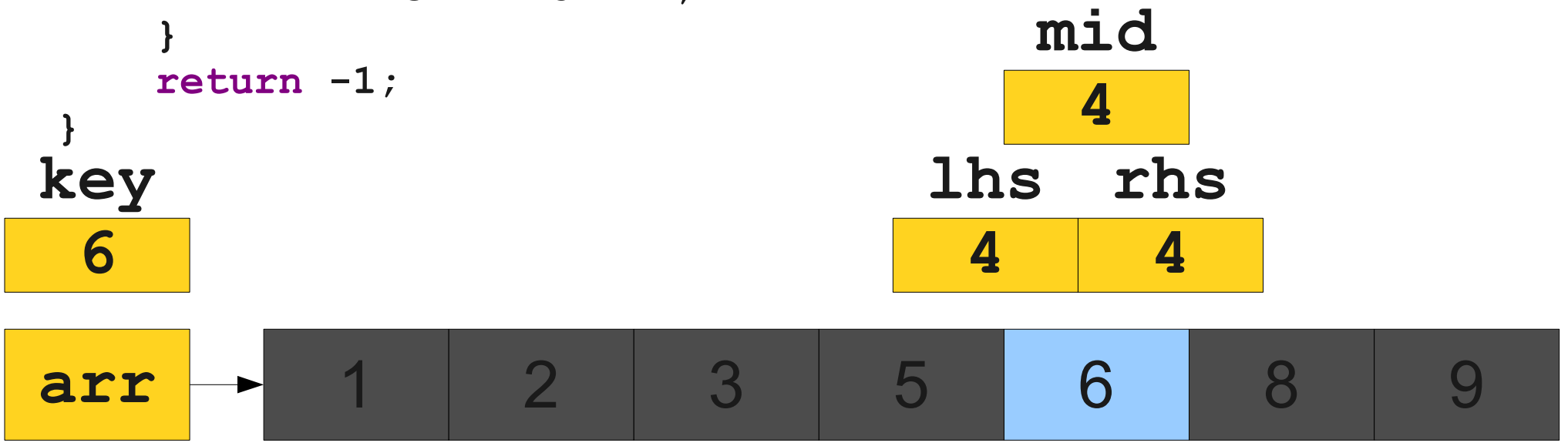

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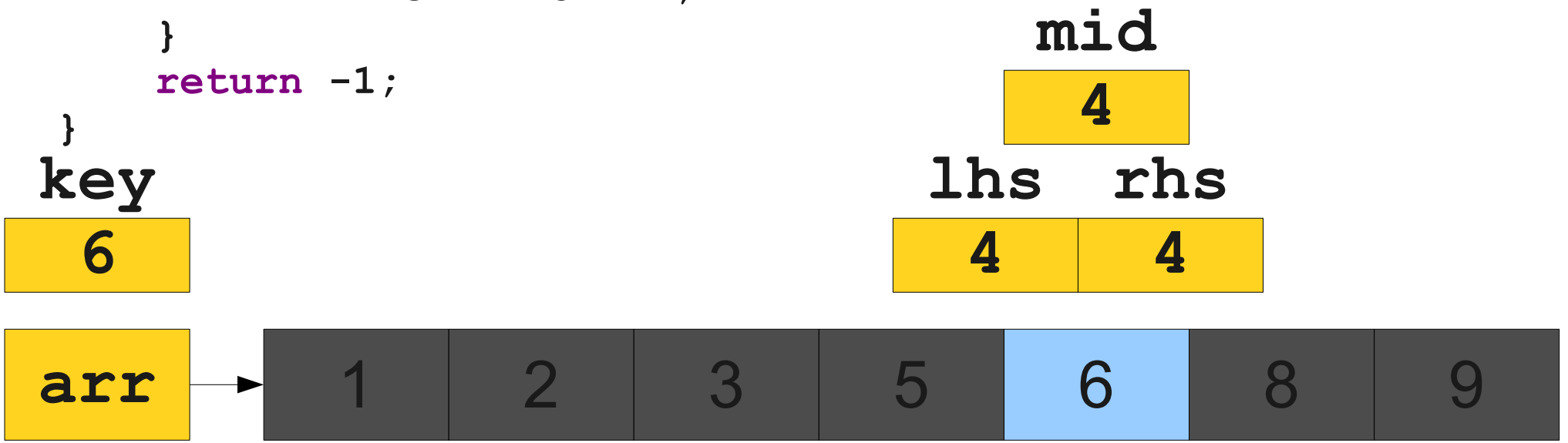

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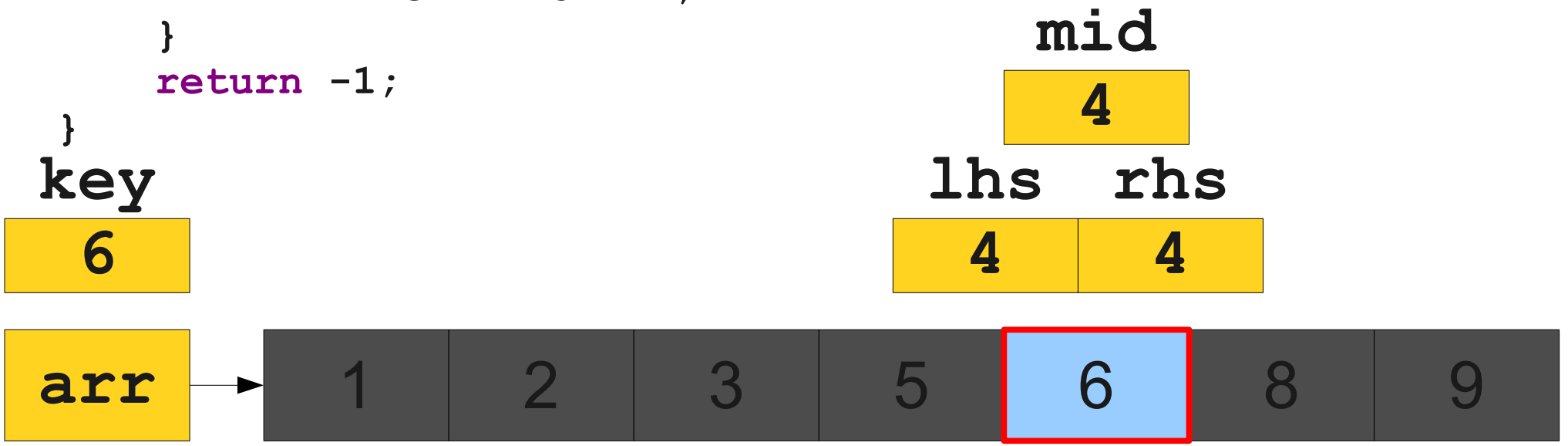

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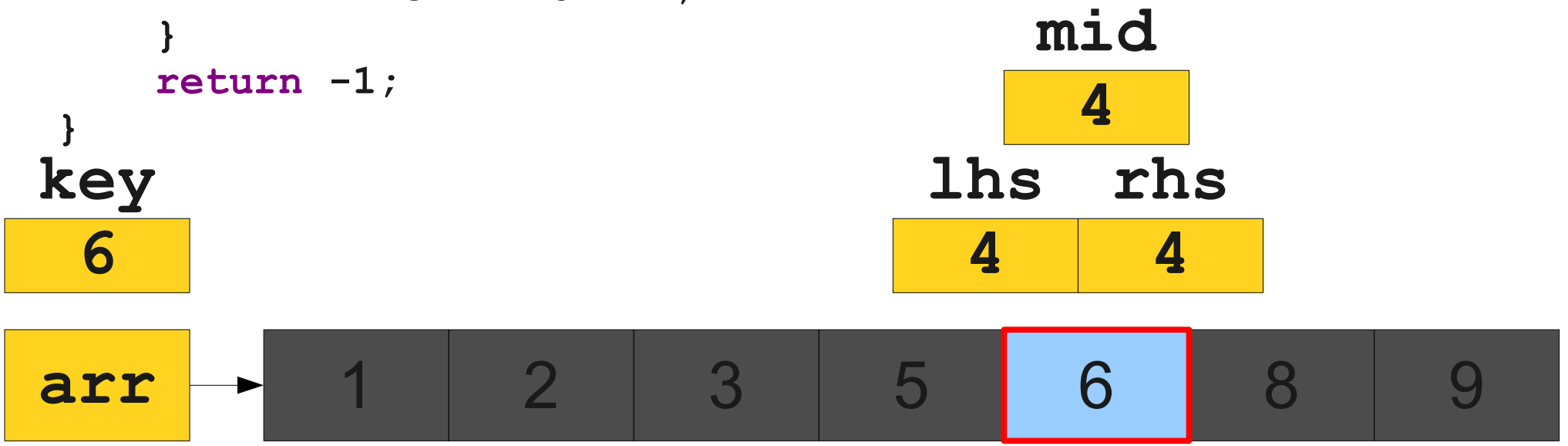

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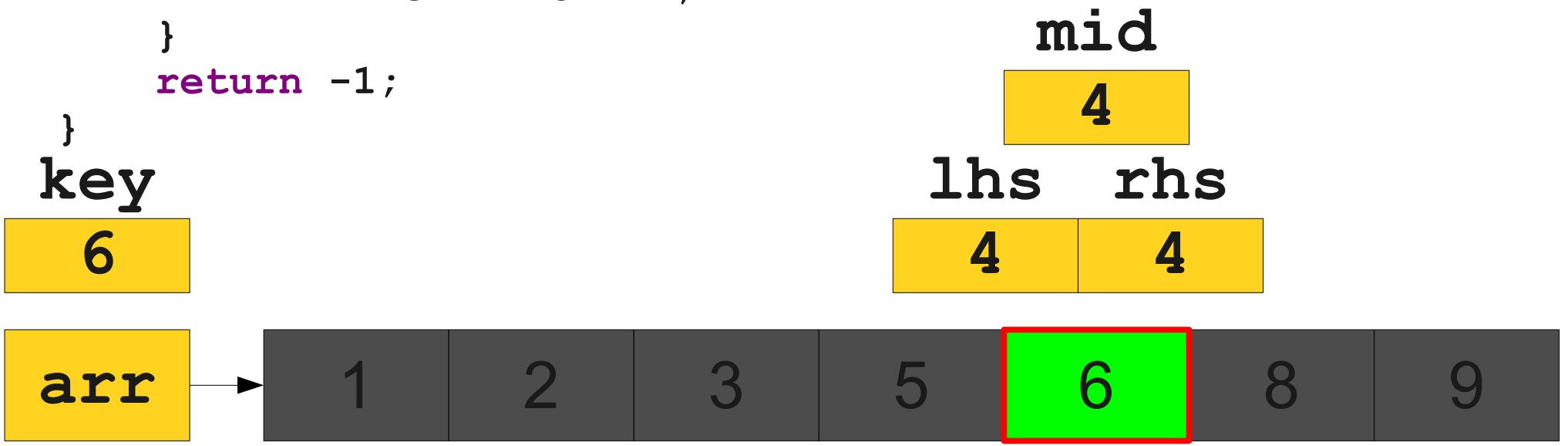

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```
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```

mid

4

key

6

lhs rhs

4 4

arr

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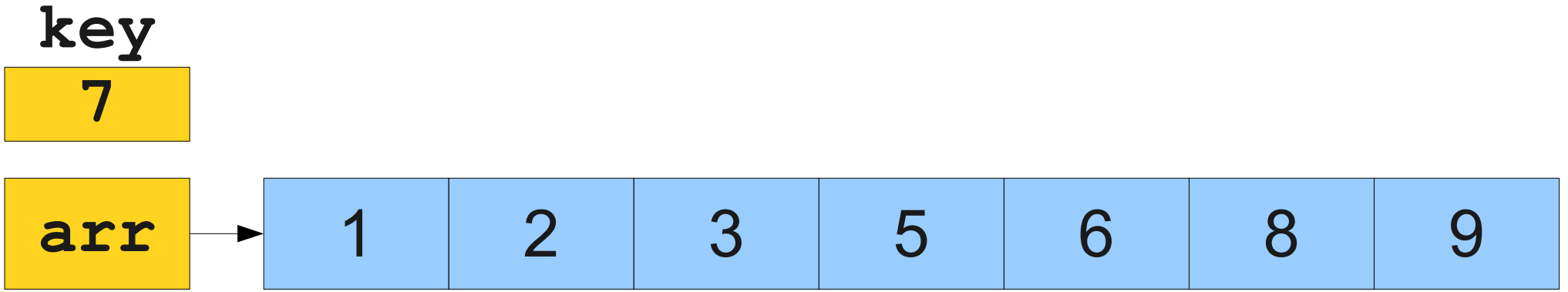

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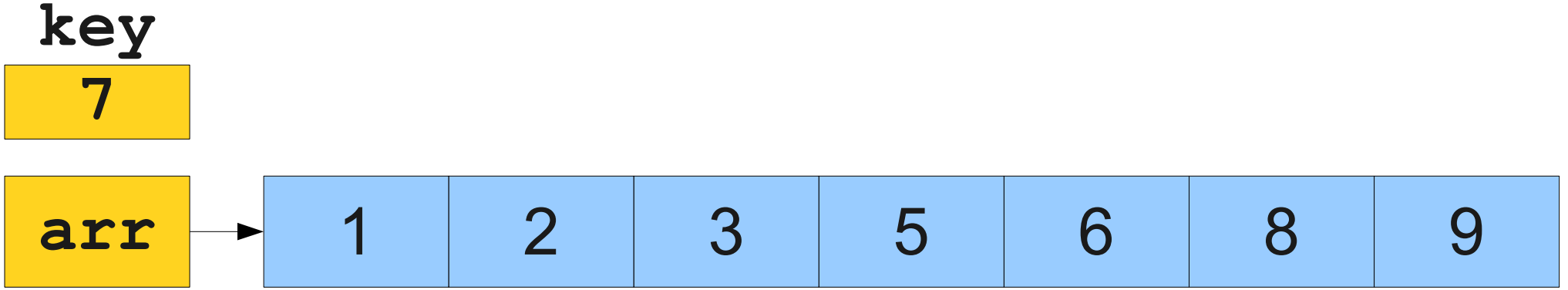

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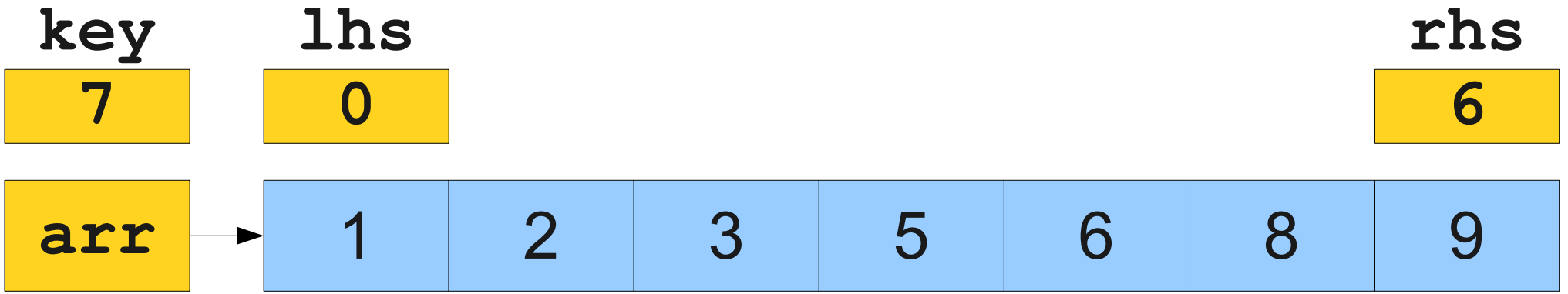

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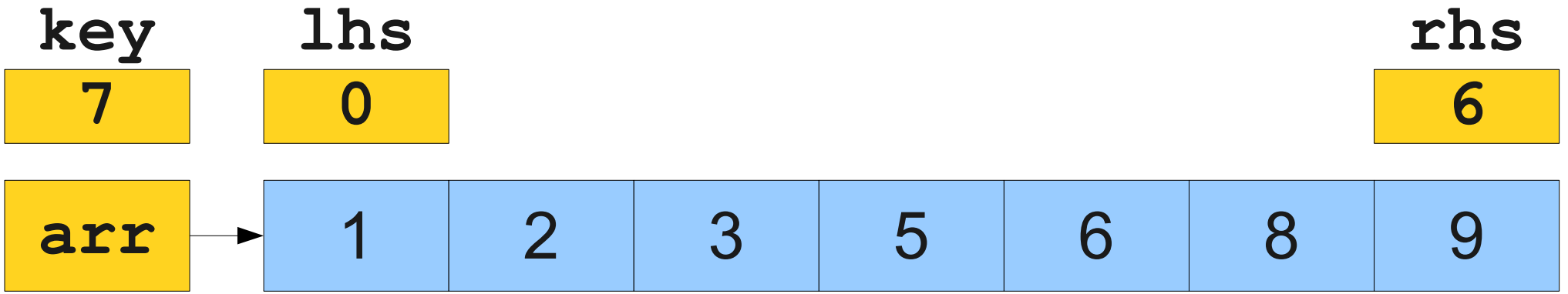

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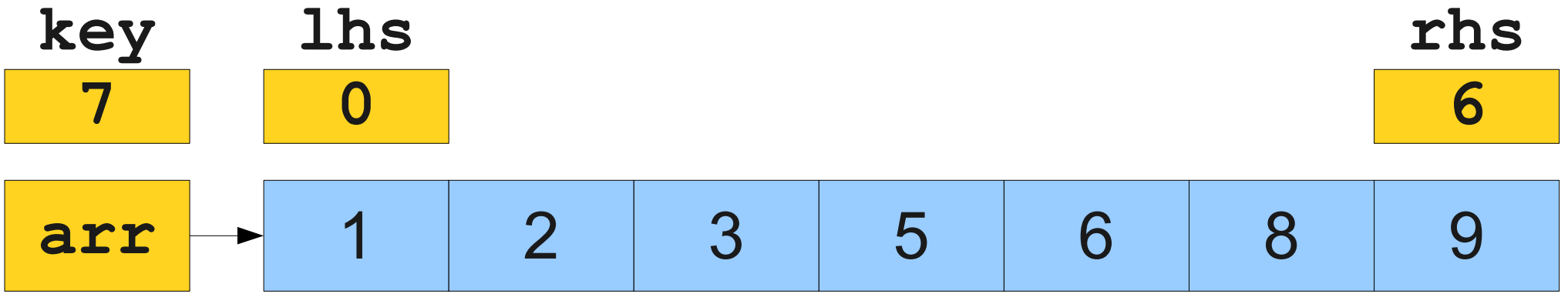

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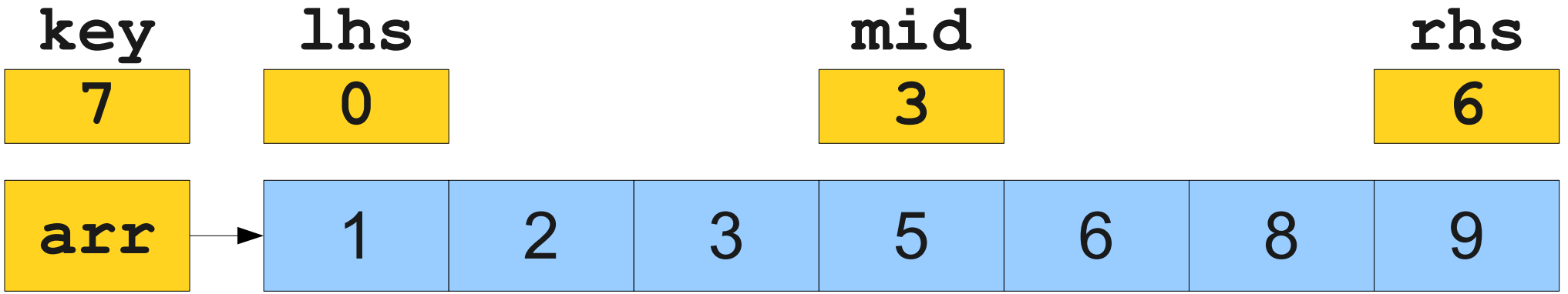

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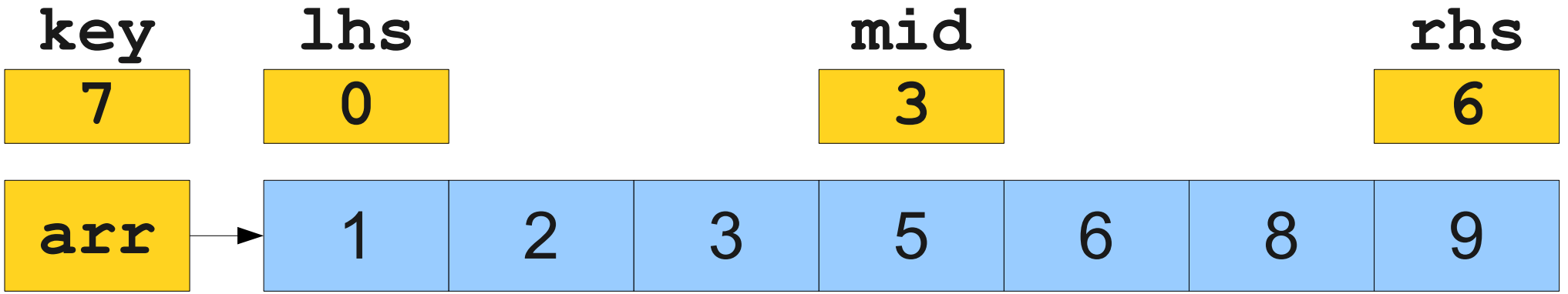

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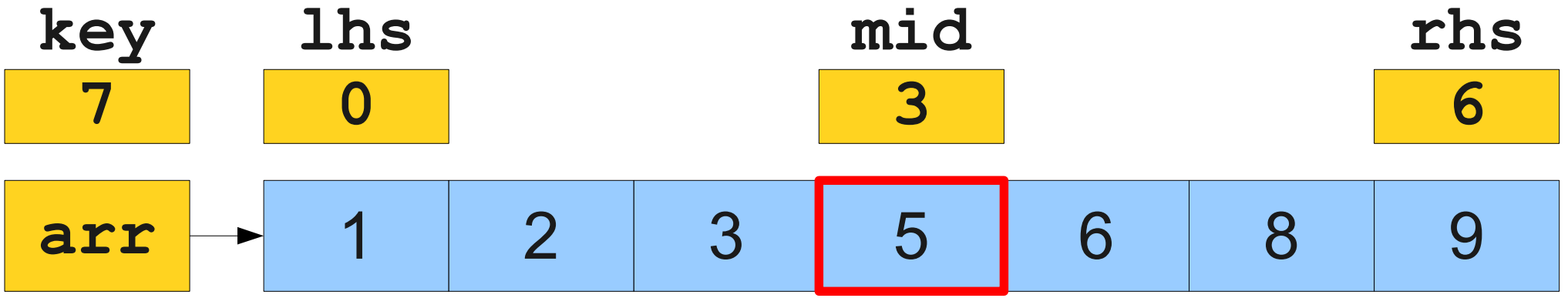

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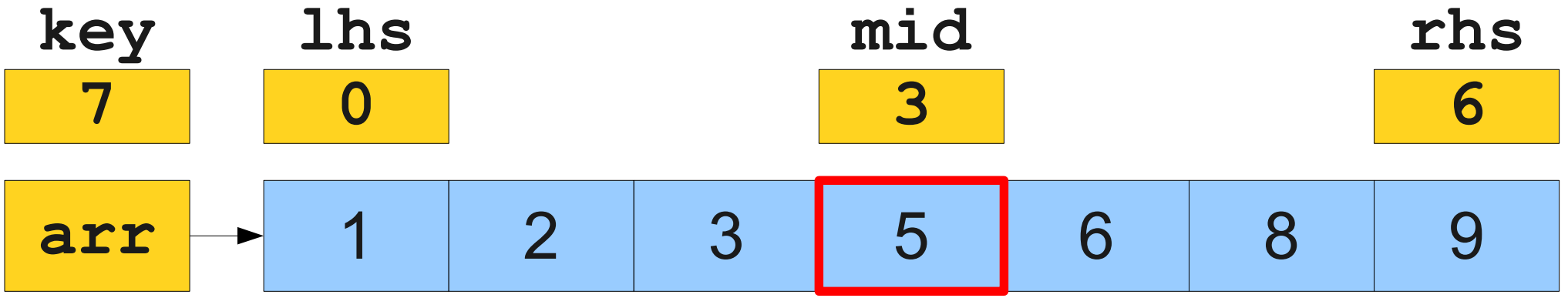

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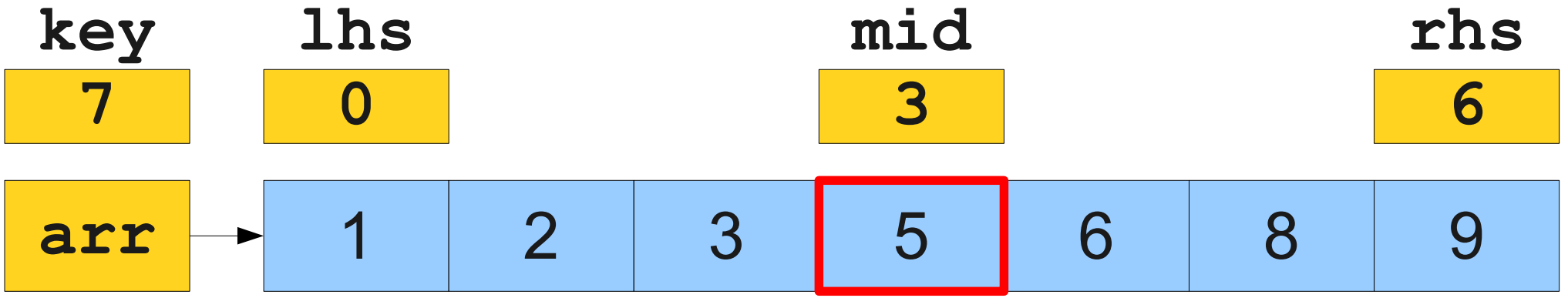

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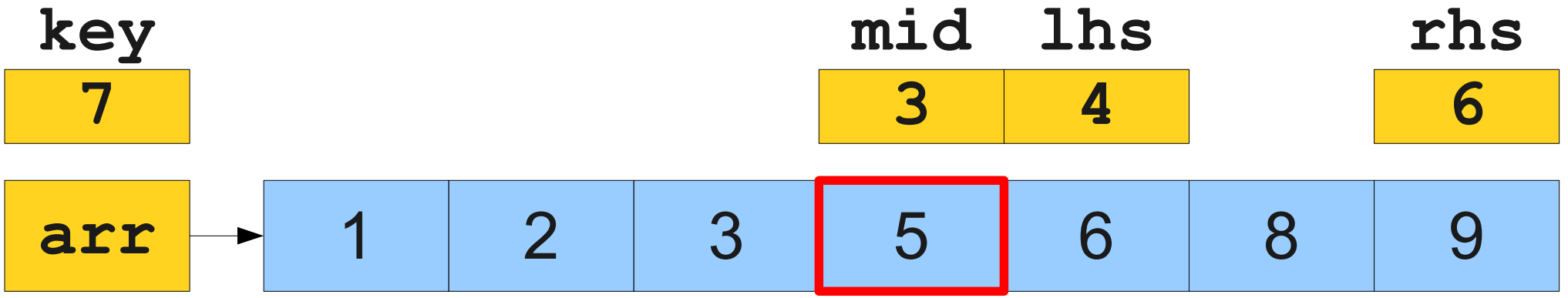

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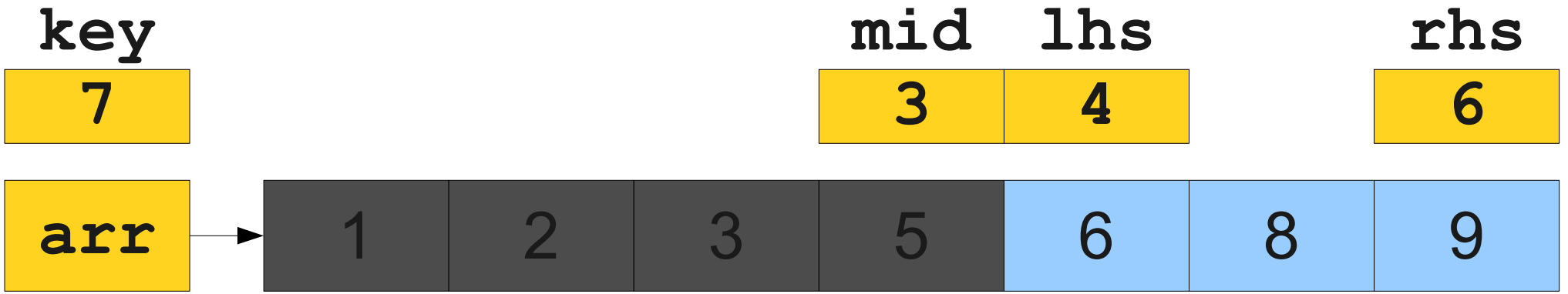

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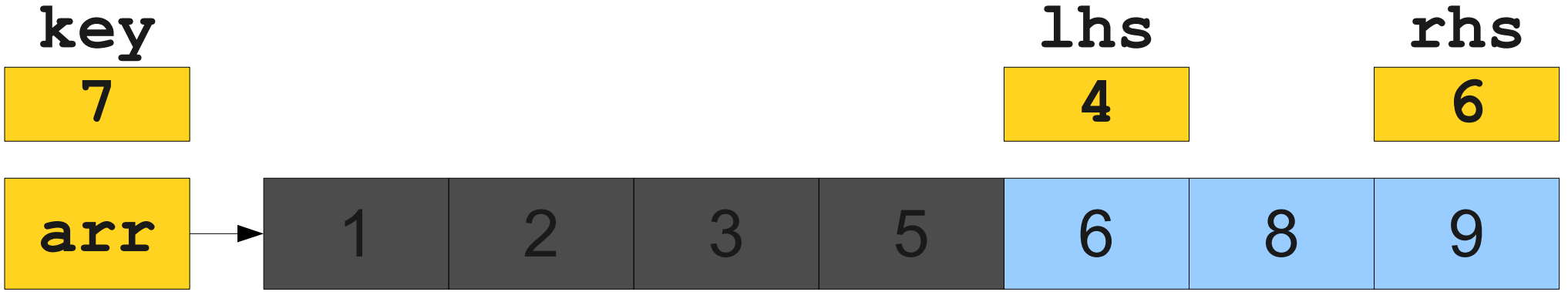

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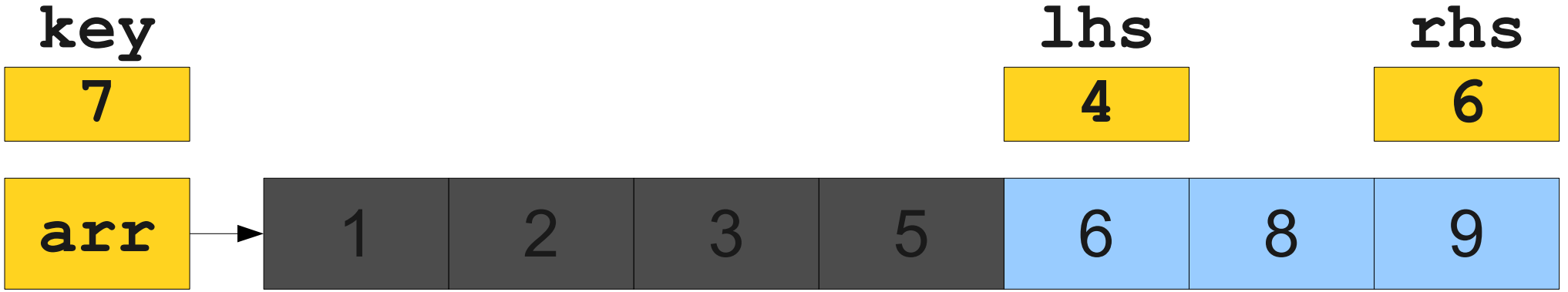

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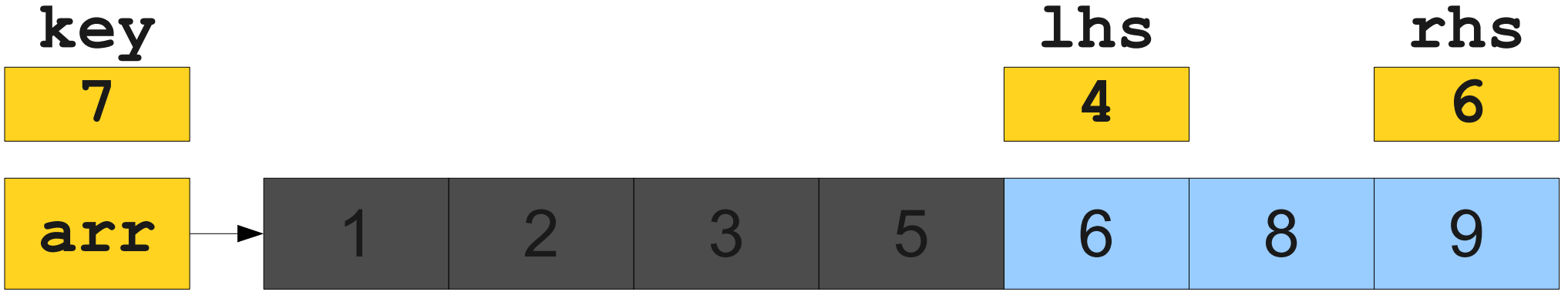

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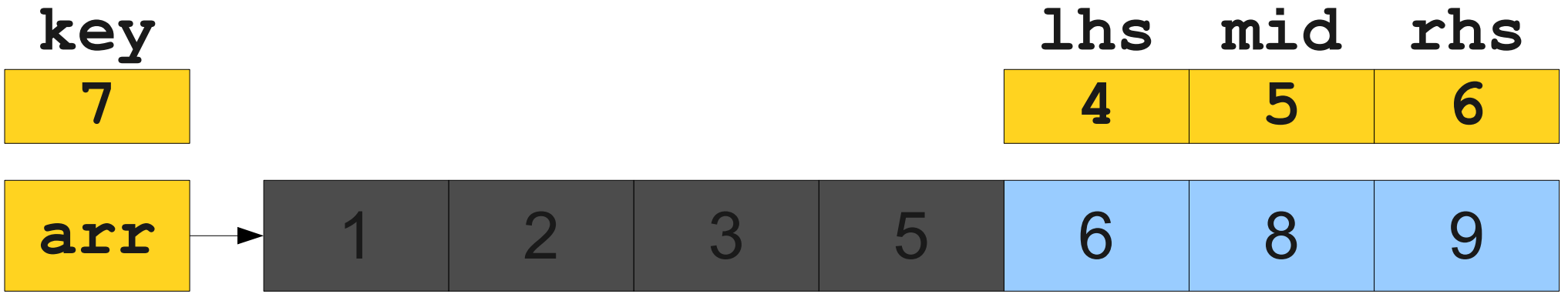

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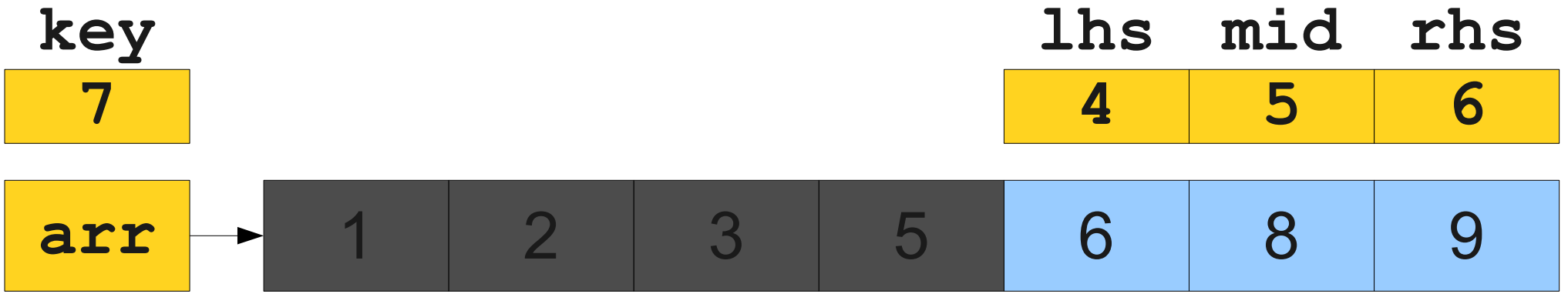

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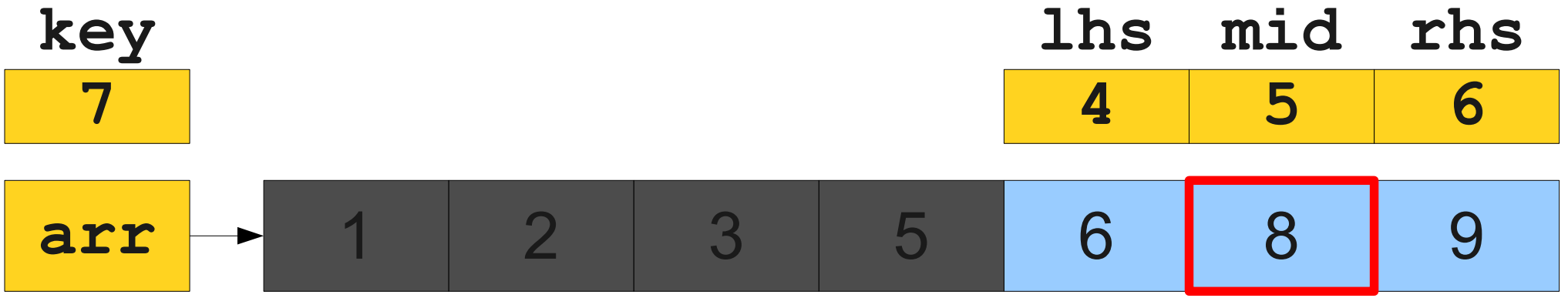

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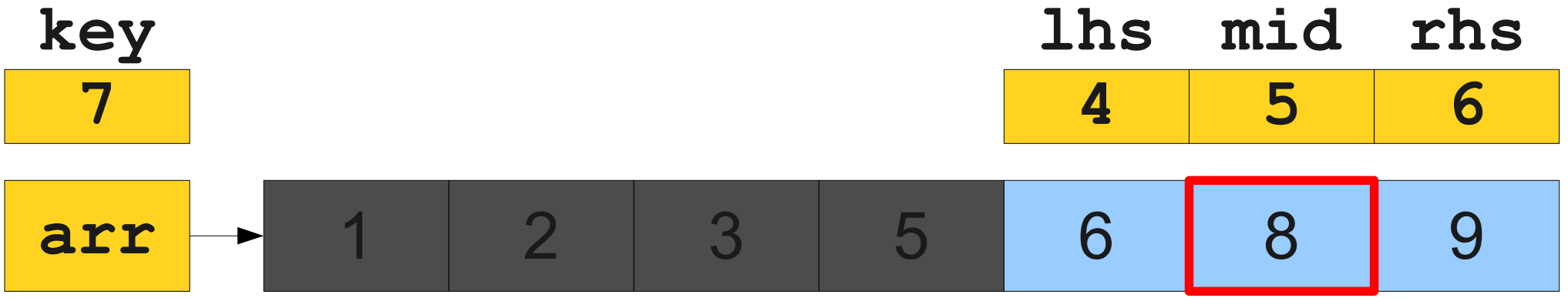

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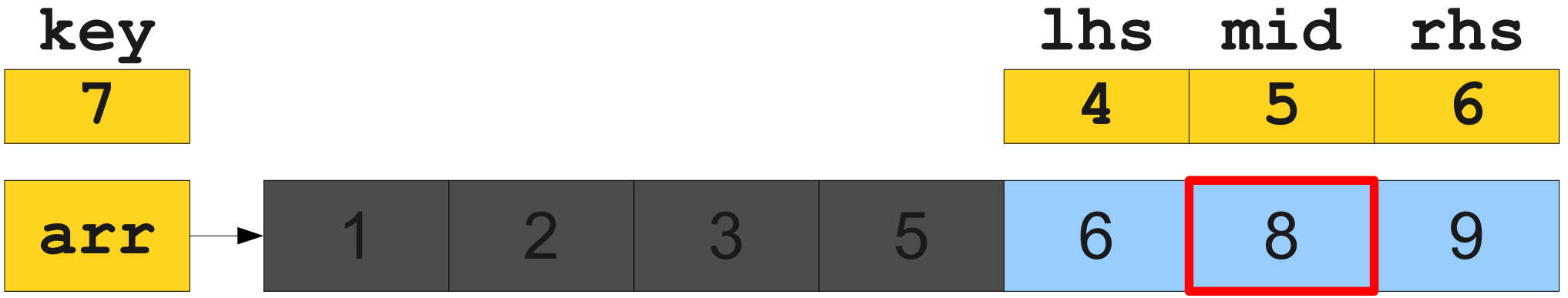

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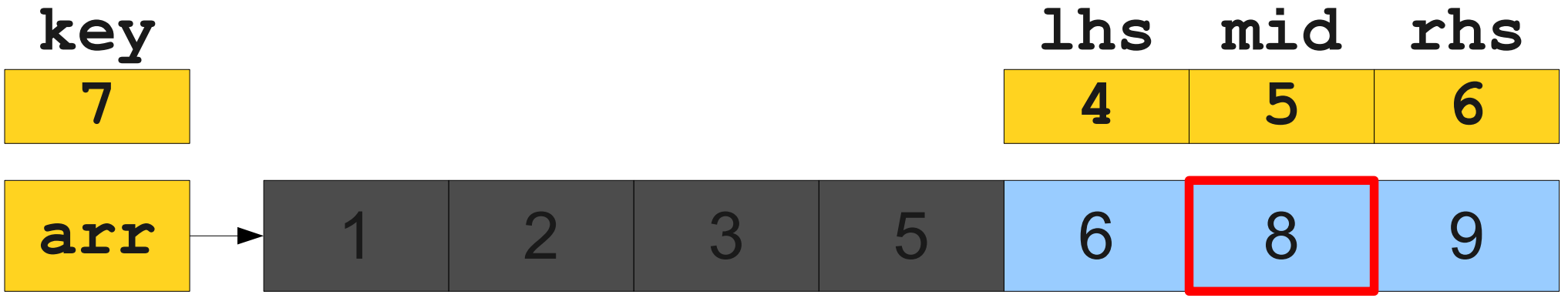

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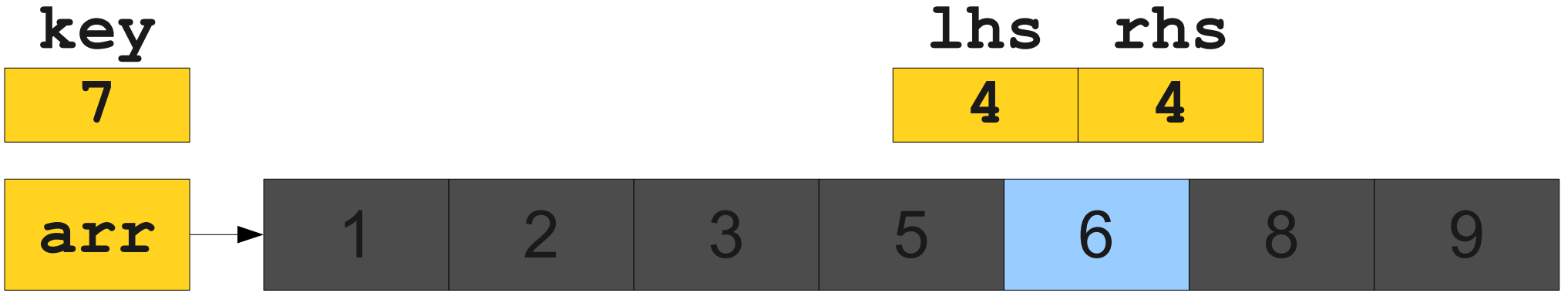

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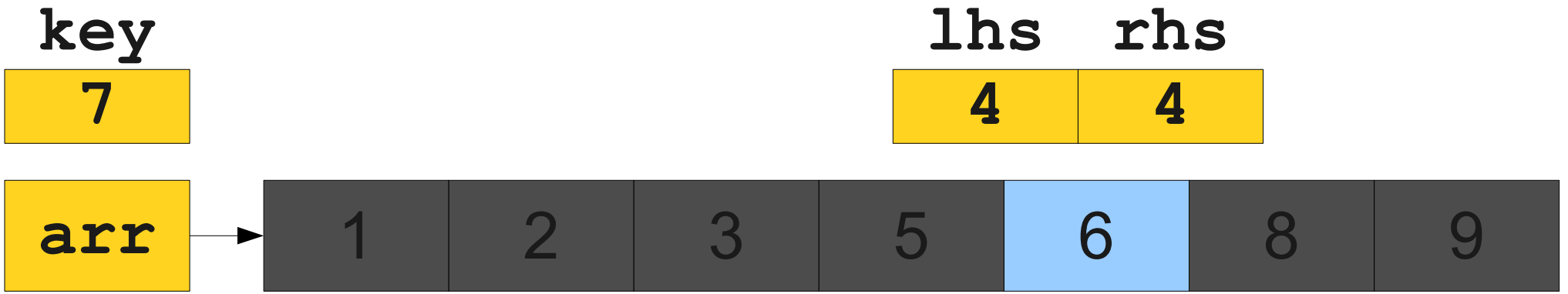

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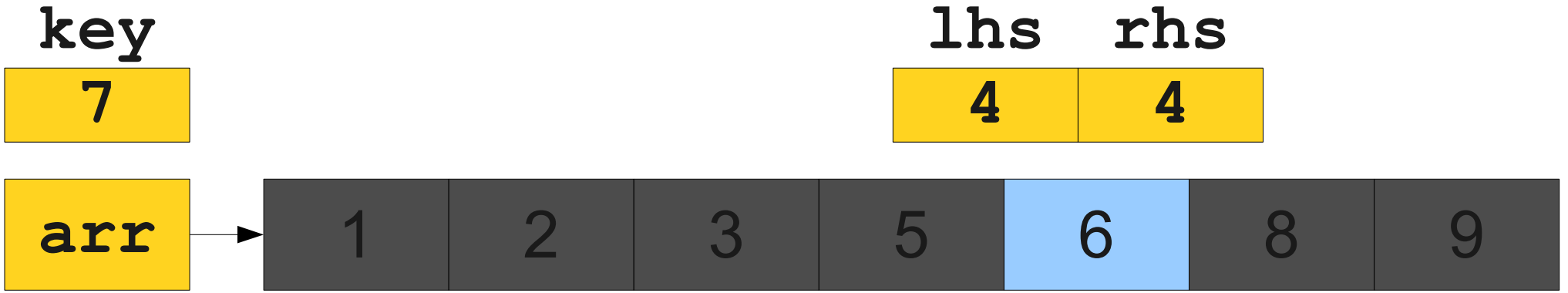

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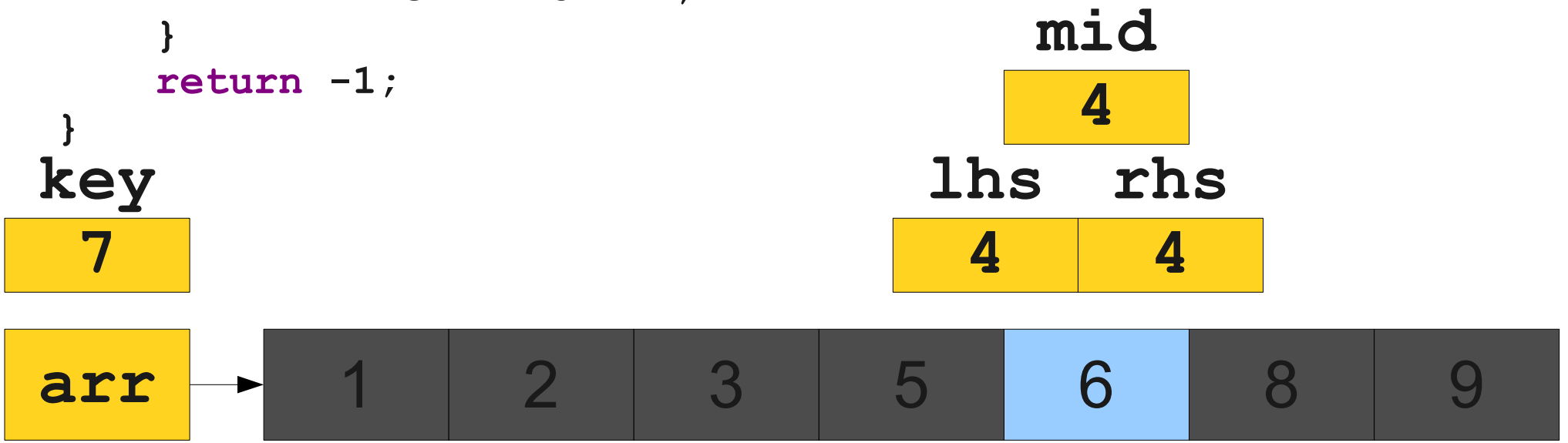

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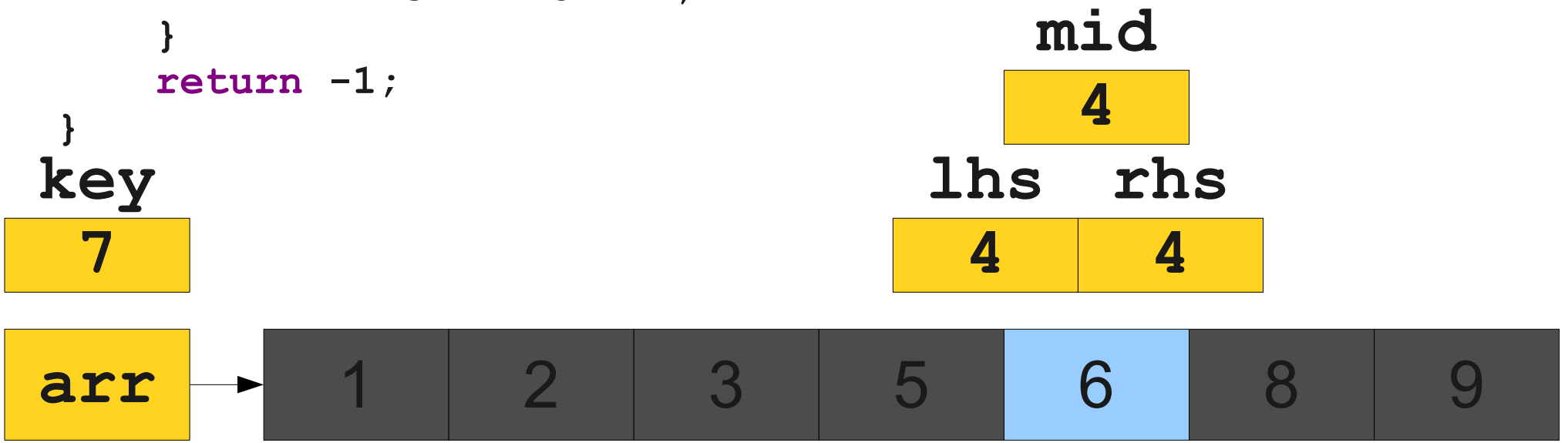

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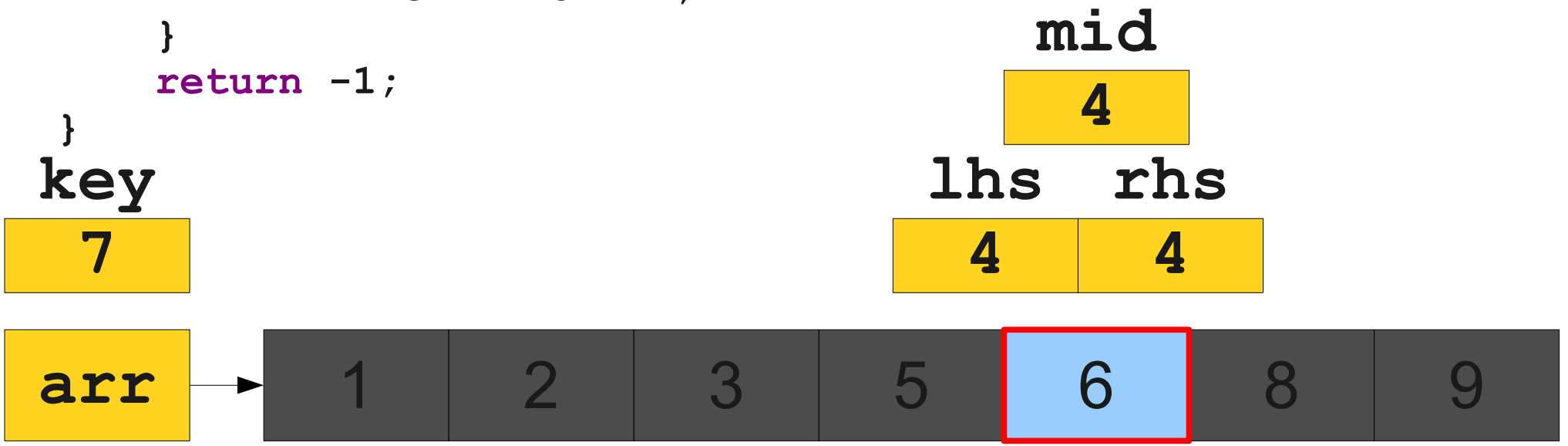

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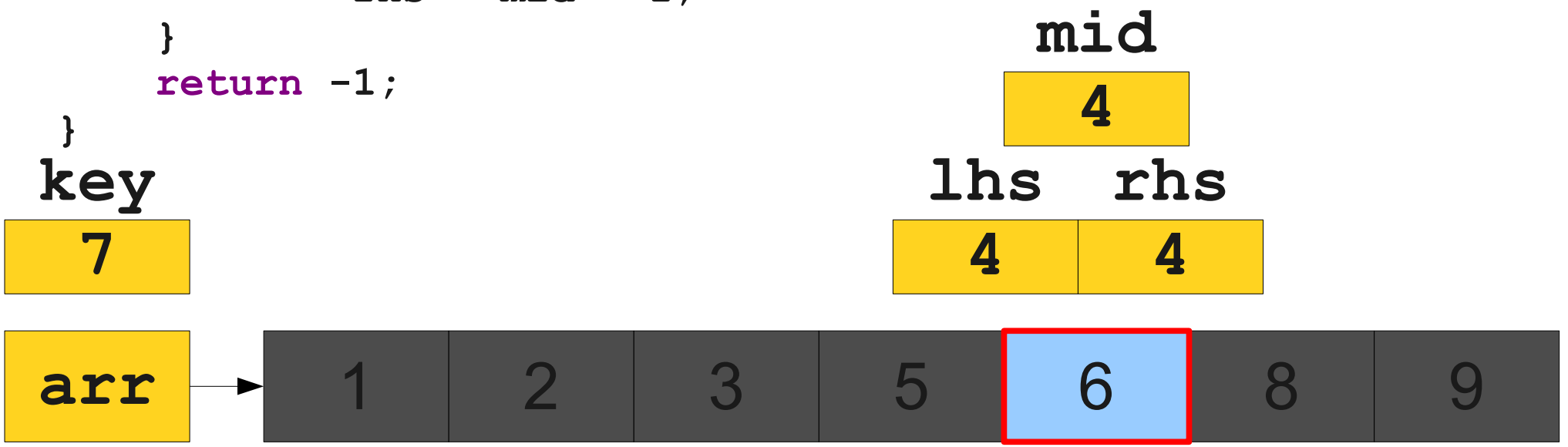

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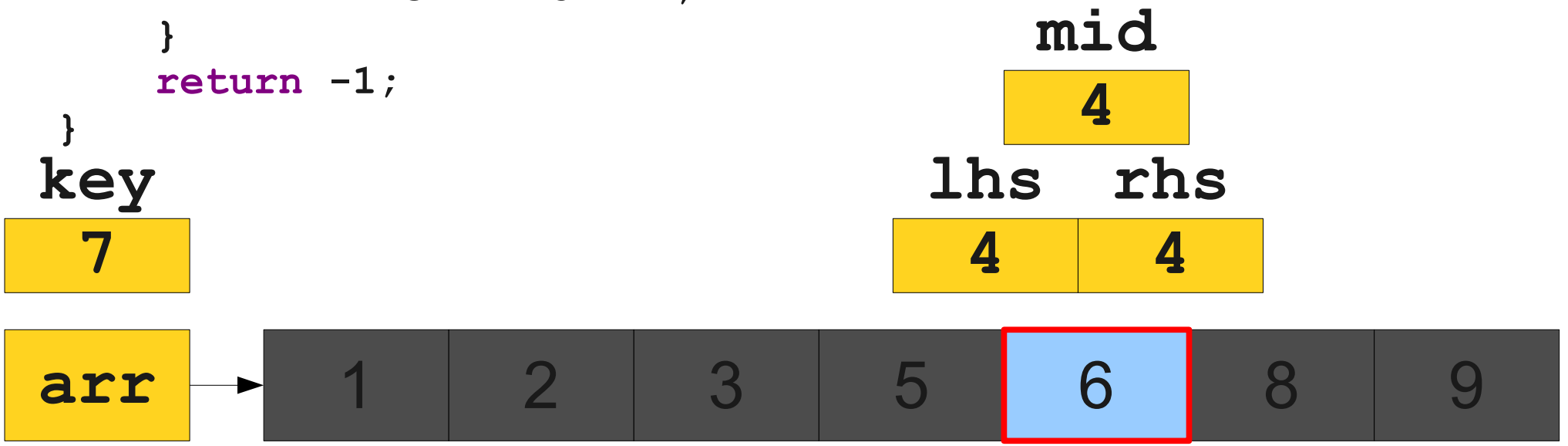

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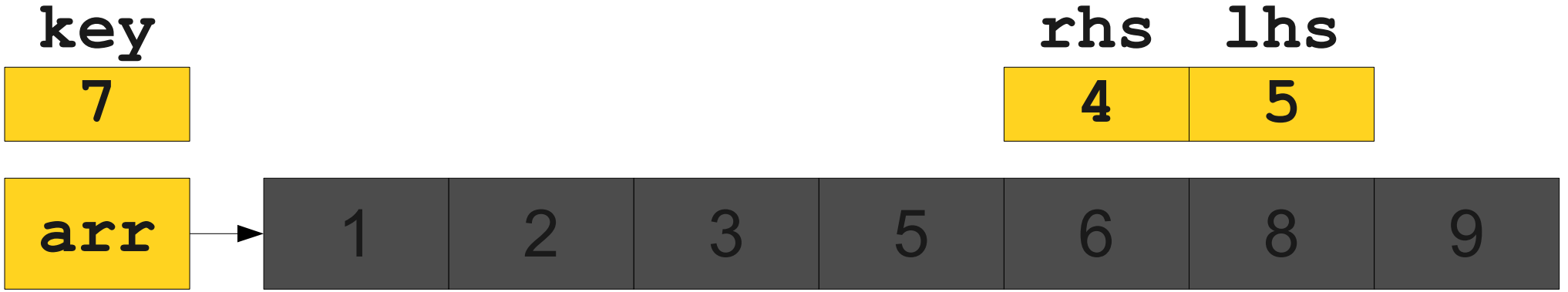

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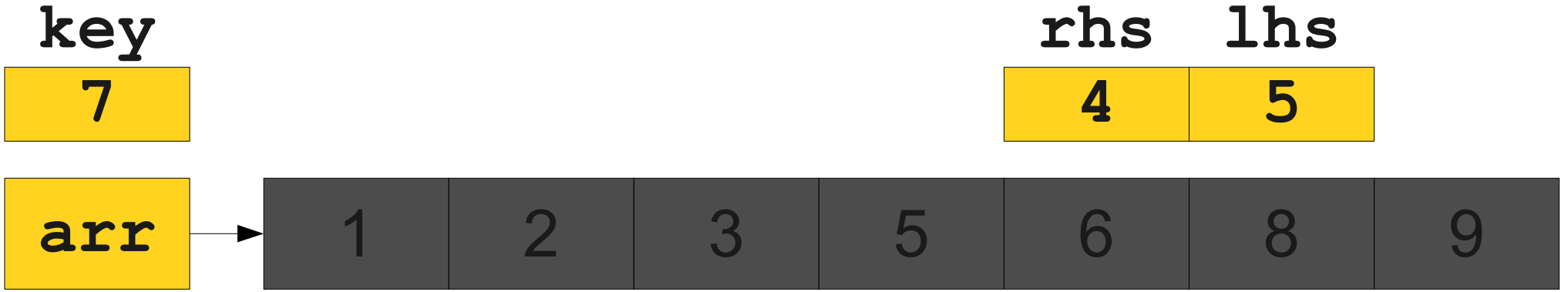

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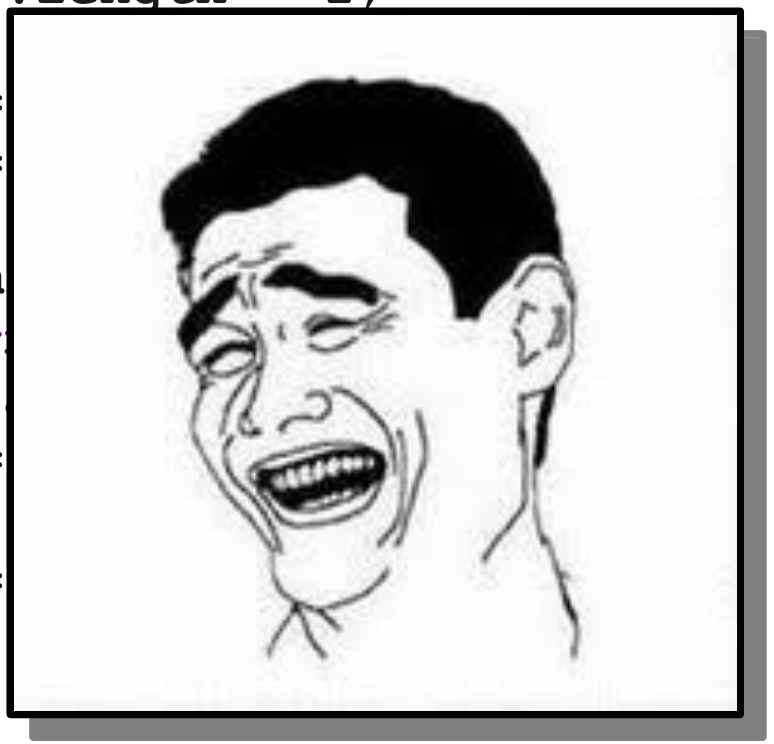

key

7

rhs lhs

4 5

arr → 1 2 3 5 6 8 9

Analyzing the Algorithms

For Comparison

```
private int linearSearch(int[] arr,
                         int key) {
    for (int i = 0; i < arr.length; i++) {
        if (arr[i] == key)
            return i;
    }

    return -1;
}
```

```
private int binarySearch(int[] arr,
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            rhs = mid - 1;
    }
    return -1;
}
```

Analyzing Linear Search

- How many elements of the array do we have to look at to do a linear search?
- Let's suppose that there are N elements in the array.
- We may have to look at each of them once.
- Number of lookups: N.

Analyzing Binary Search

- How many elements of the array do we have to look at to do a binary search?
- Let's suppose that there are N elements in the array.
- Each lookup cuts the size of the array in half.
- How many times can we cut the array in half before we run out of elements?

Slicing and Dicing

- After zero lookups: N
- After one lookup: $N / 2$
- After two lookups: $N / 4$
- After three lookups: $N / 8$

...

- After k lookups: $N / 2^k$

Cutting in Half

- After doing k lookups, there are N / 2^k elements left.
- The algorithm stops when there is just one element left.
- Solving for the number of iterations:

$$N / 2^k = 1$$

$$N = 2^k$$

$$\log_2 N = k$$

- So binary search stops after $\mathbf{\log_2 N}$ lookups.

For Comparison

N	$\log_2 N$
10	3
100	7
1000	10
1,000,000	20
1,000,000,000	30

Binary search can check whether a value exists in an array of **one billion elements** in just 30 array accesses!

A Feel for $\log_2 N$

- It is conjectured that the number of atoms in the universe is 10^{100}.
- $\log_2 10^{100}$ is roughly 300.
- If you (somehow) listed all the atoms in the universe in sorted order, you would need to look at 300 before you found the one you were looking for.

Sorting

Bubble Sort

- Until the array is sorted:
  - Look at each adjacent pair of elements.
  - If they are out of order, swap them.

Selection Sort

- Find the smallest number and swap it to the front of the array.
- Find the second-smallest number and swap it to the second position.
- Find the third-smallest number and swap it to the third position.
- ...

```
private void selectionSort(int[] array) {
    for (int index = 0; index < array.length; index++) {
        int smallestIndex = findSmallest(array, index);
        swap(array, index, smallestIndex);
    }
}

private int findSmallest(int[] array, int startPoint) {
    int smallestIndex = startPoint;
    for (int i = startPoint + 1; i < array.length; i++) {
        if (array[i] < array[smallestIndex])
            smallestIndex = i;
    }
    return smallestIndex;
}

private void swap(int[] array, int i, int j) {
    int temp = array[i];
    array[i] = array[j];
    array[j] = temp;
}
```

Selection Sort in Action

```
private void selectionSort(int[] array) {
    for (int index = 0; index < array.length; index++) {
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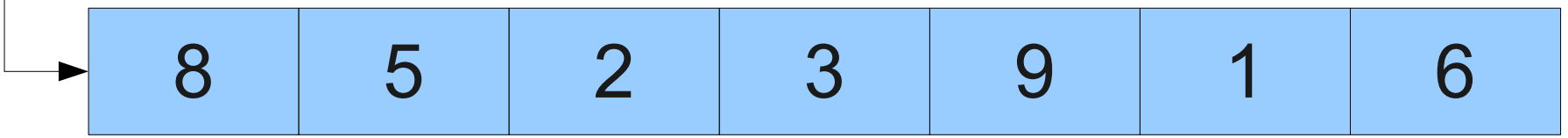
array



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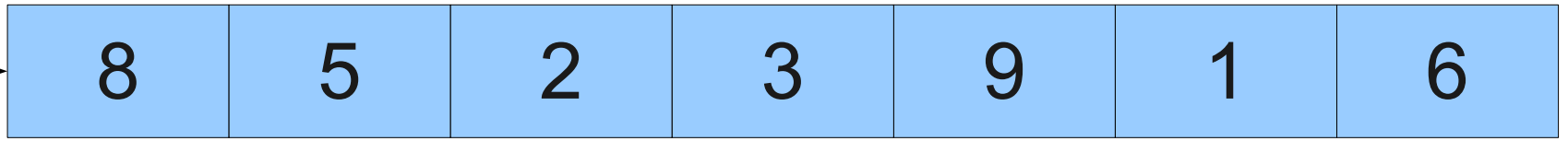

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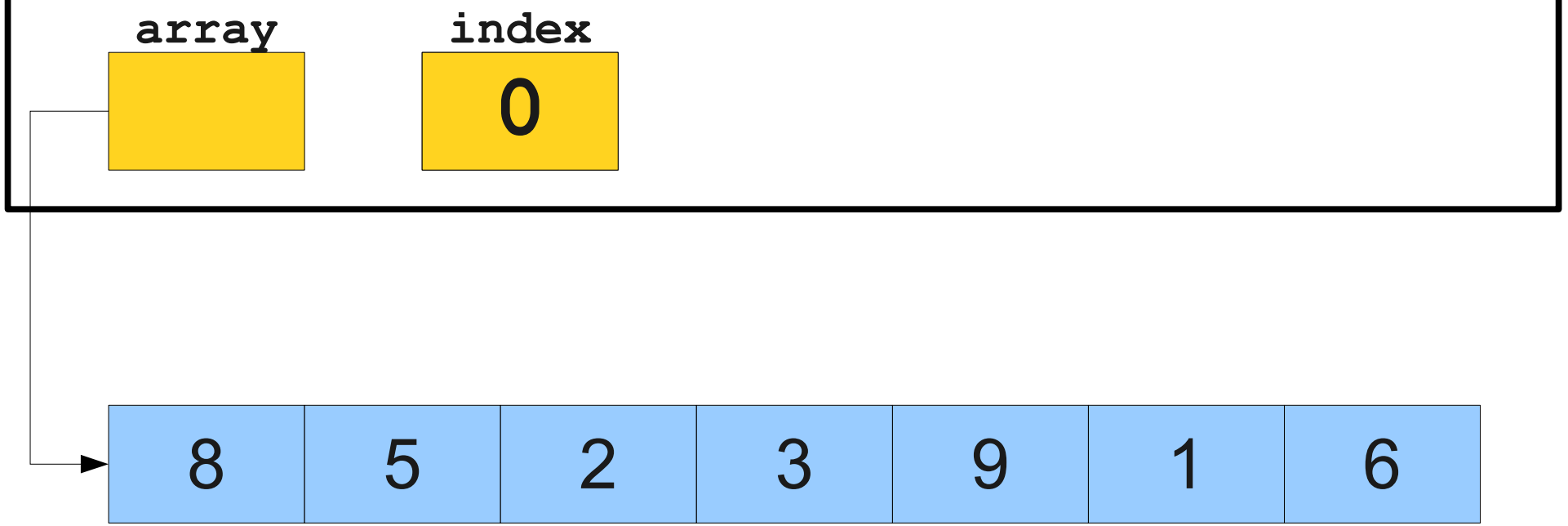

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index

0

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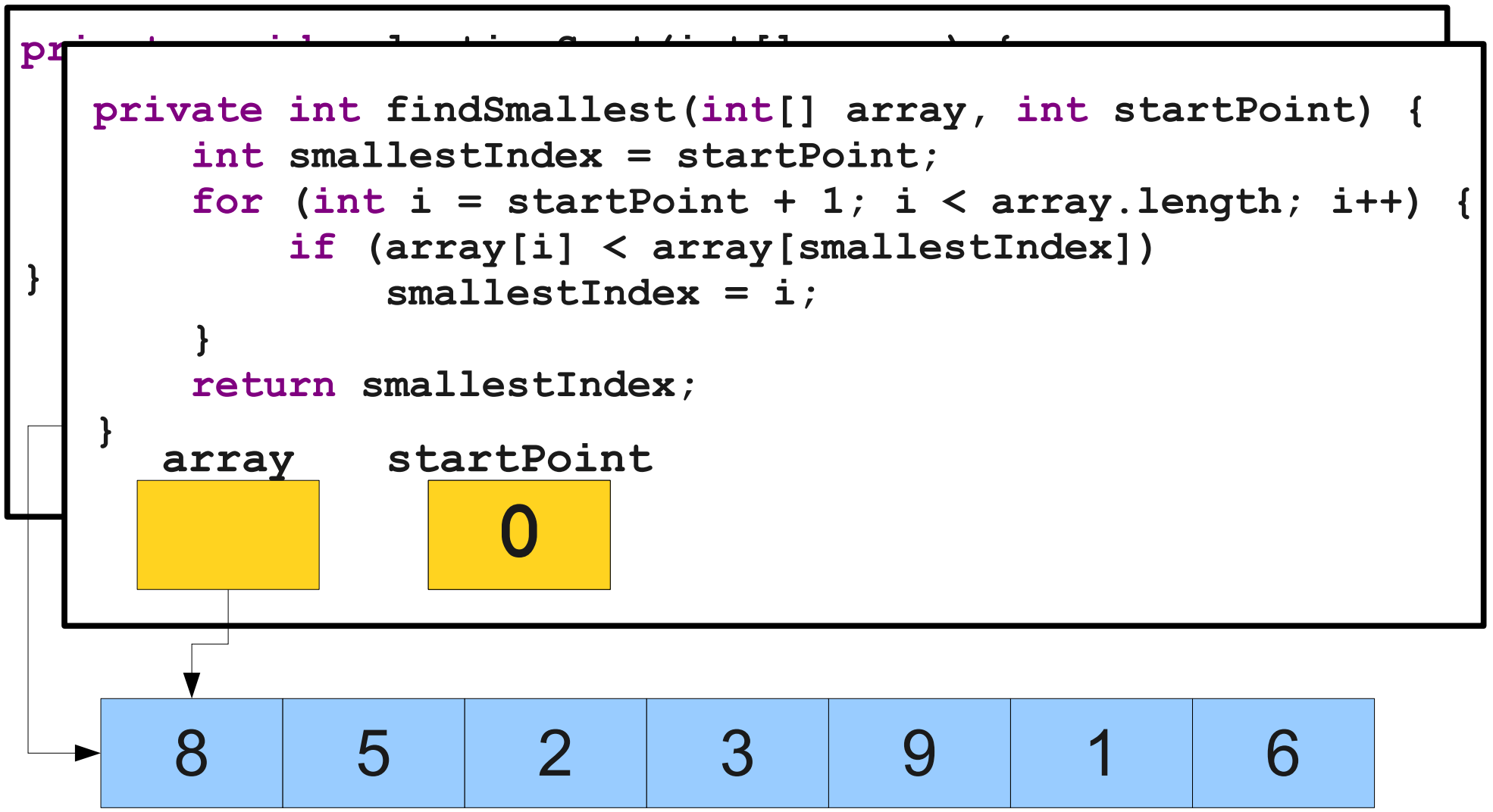

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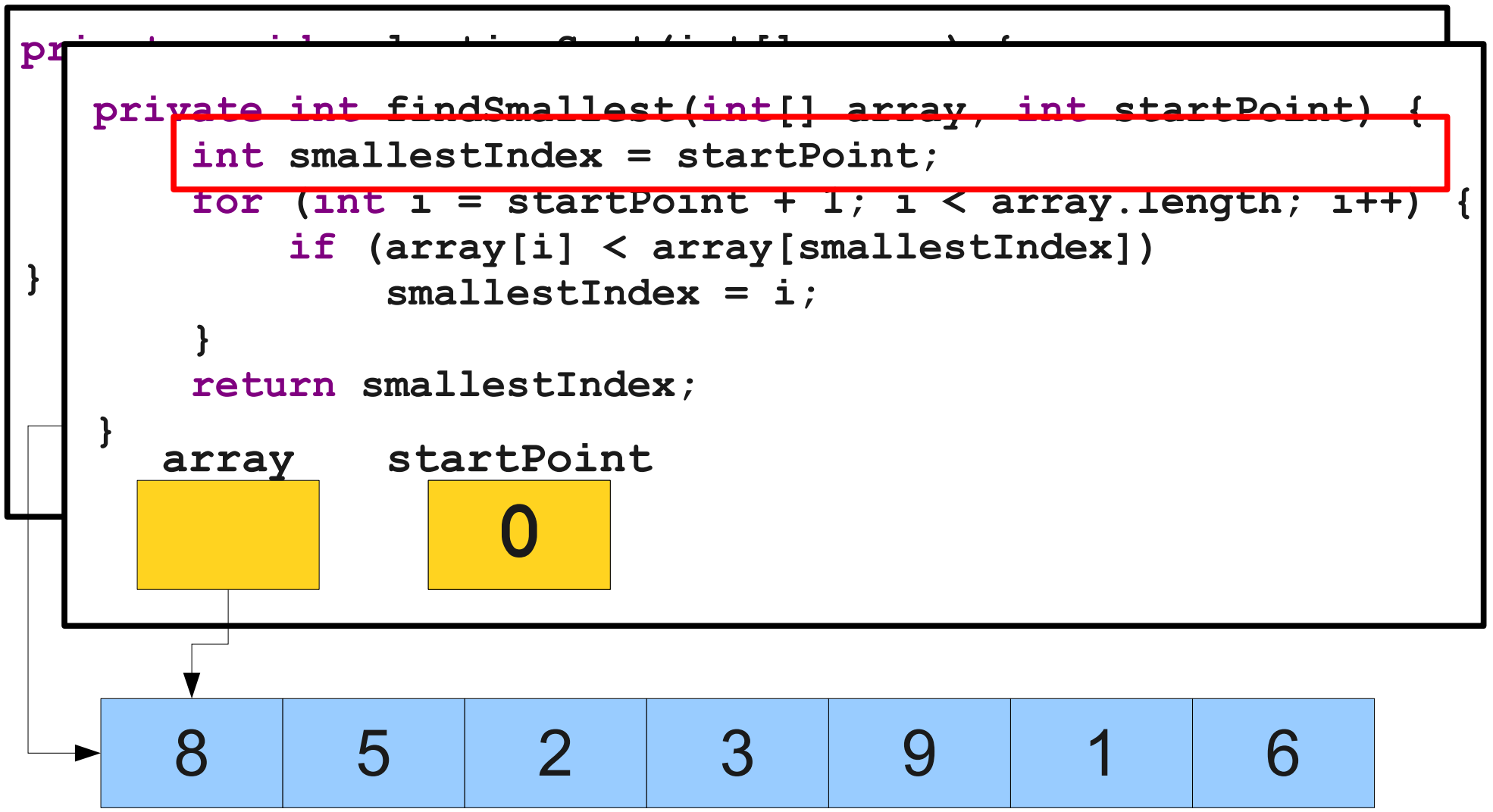

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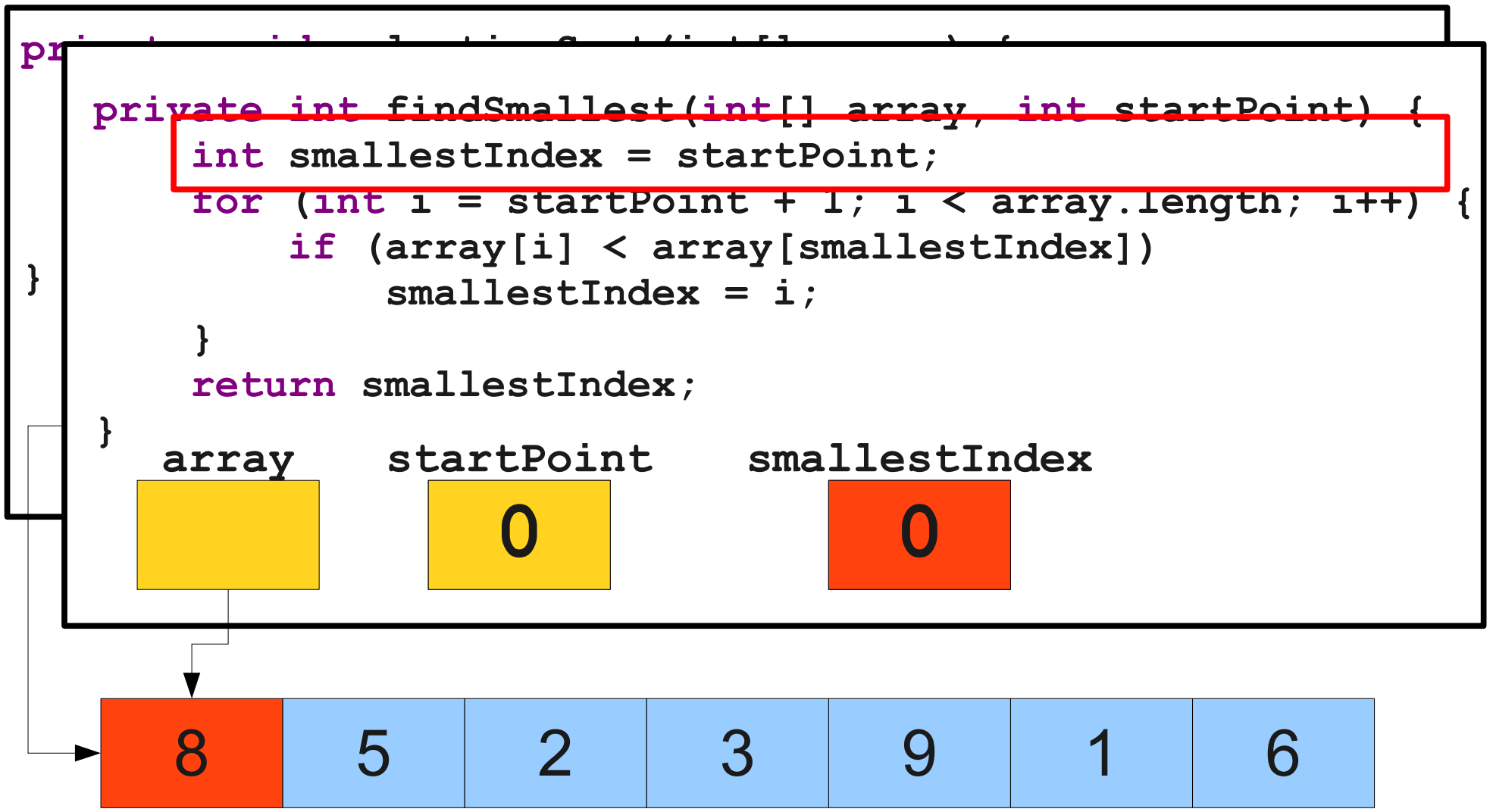

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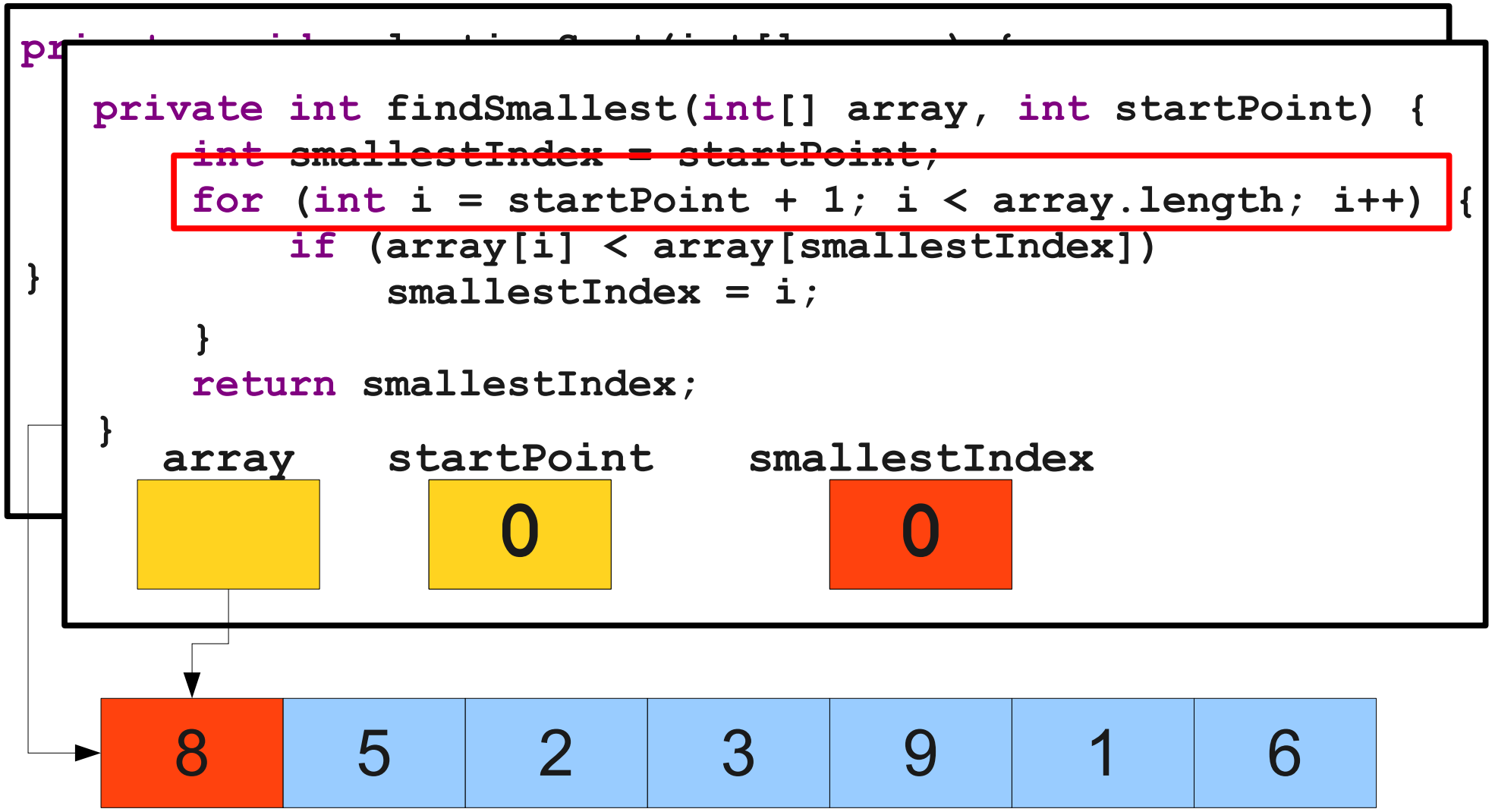
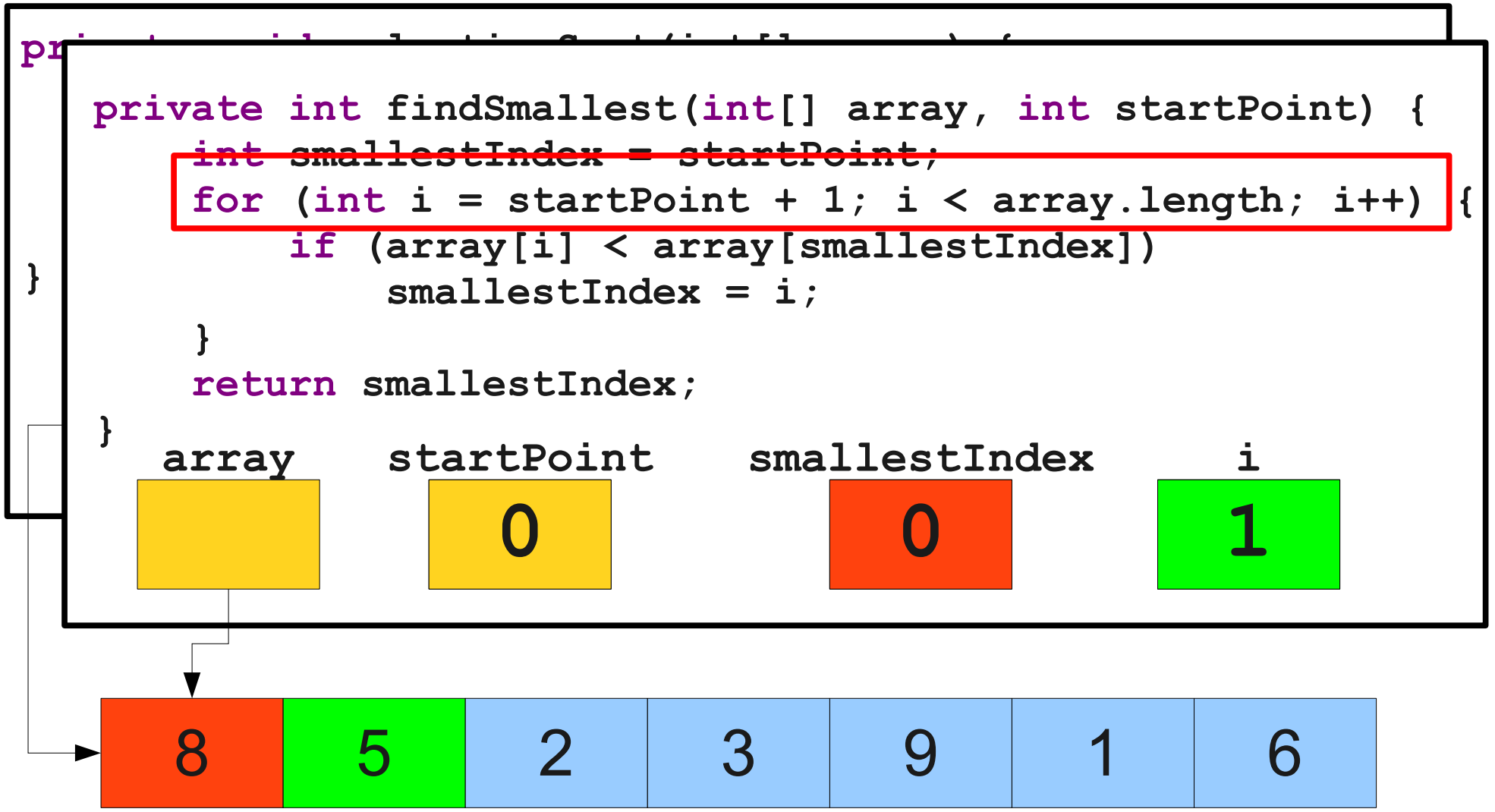
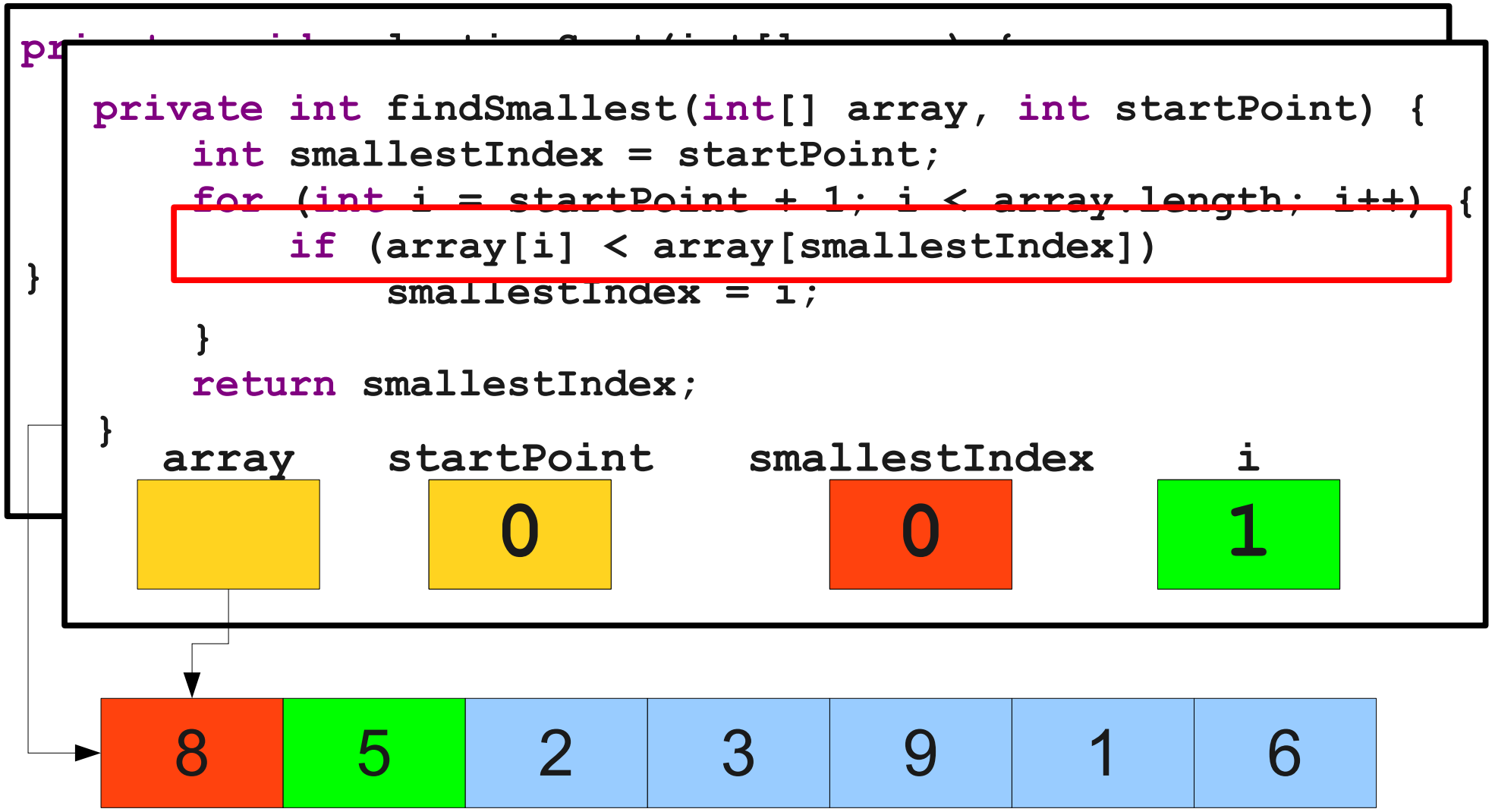


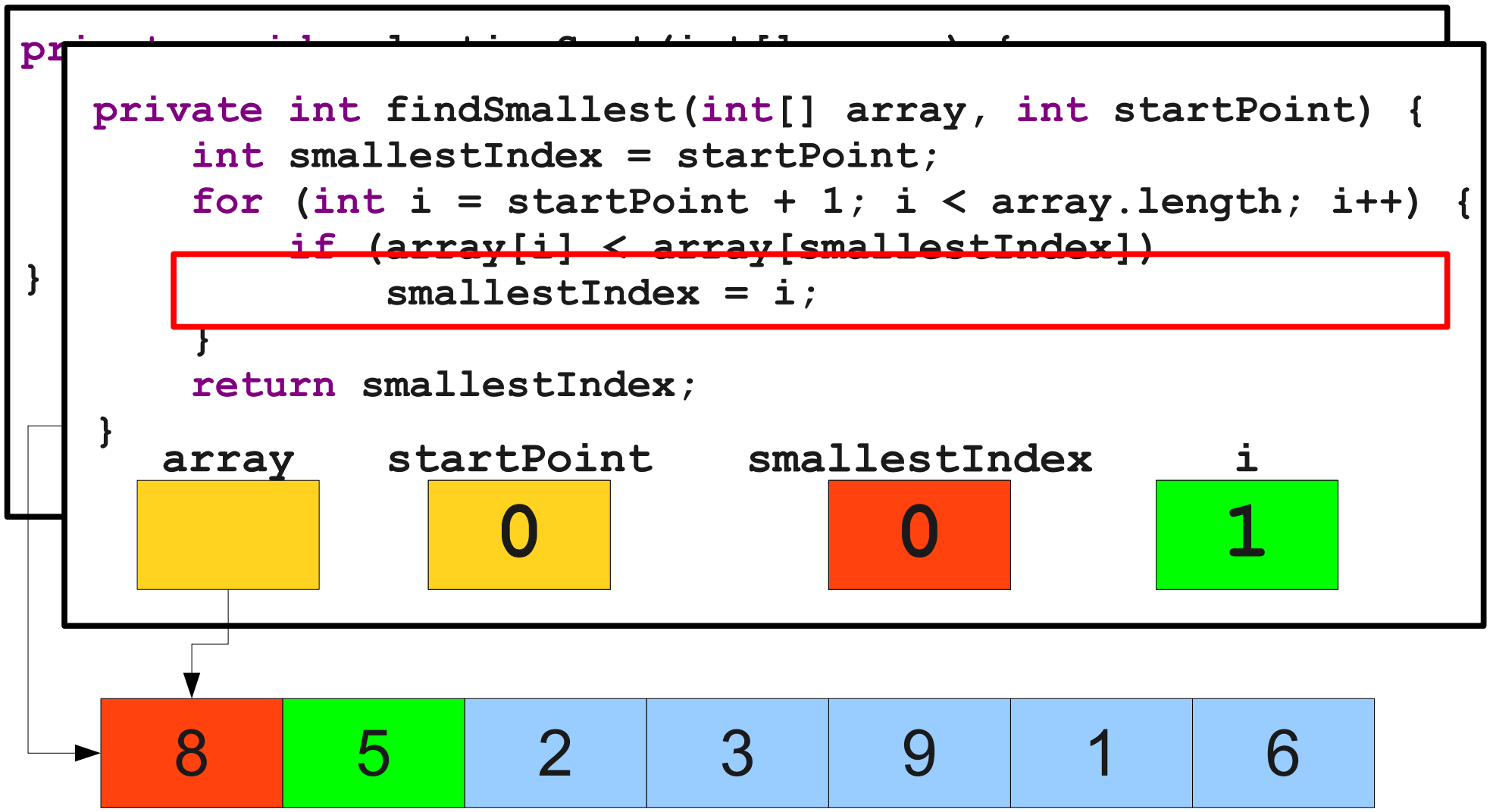
Selection Sort in Action



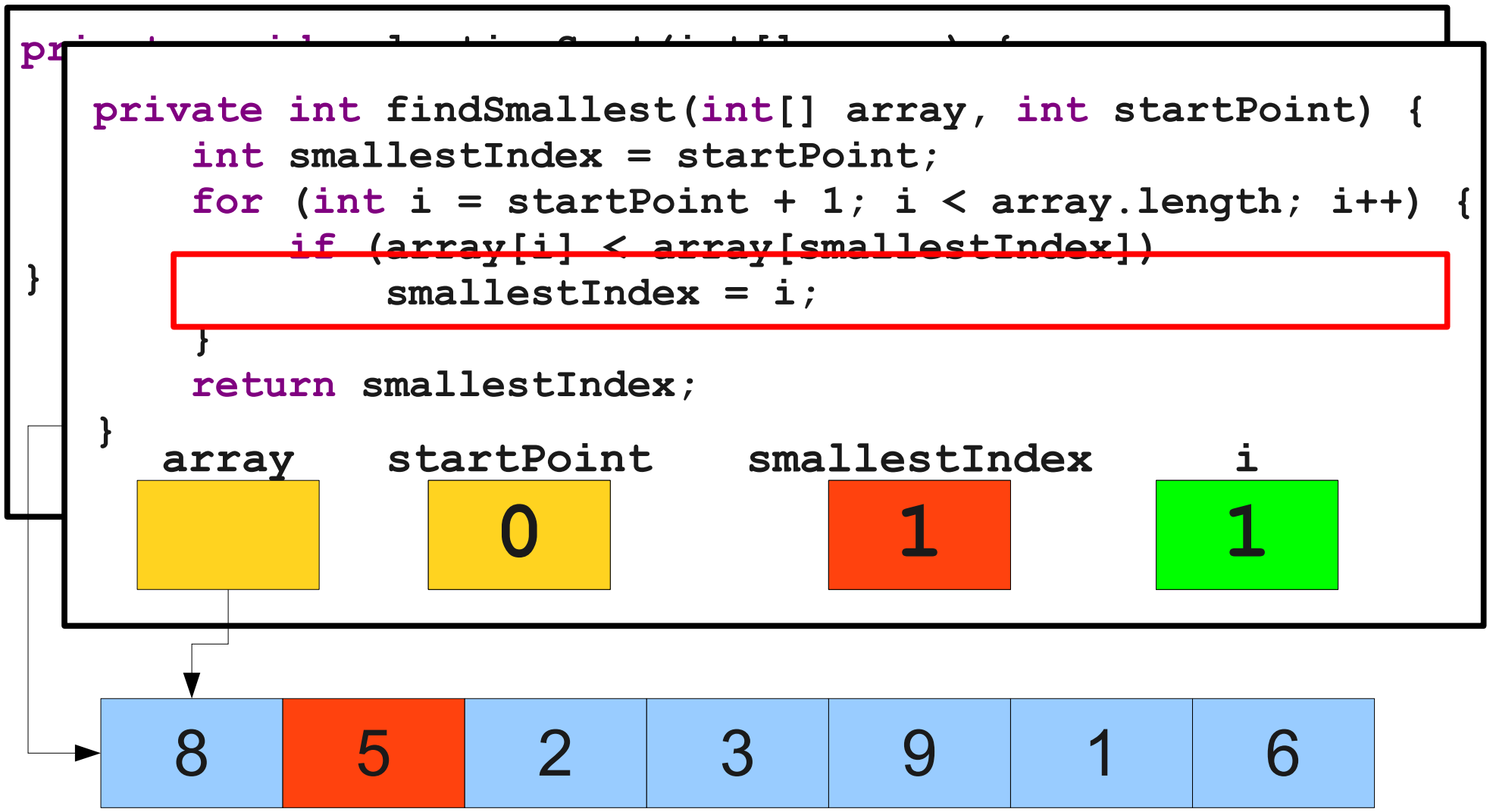
Selection Sort in Action



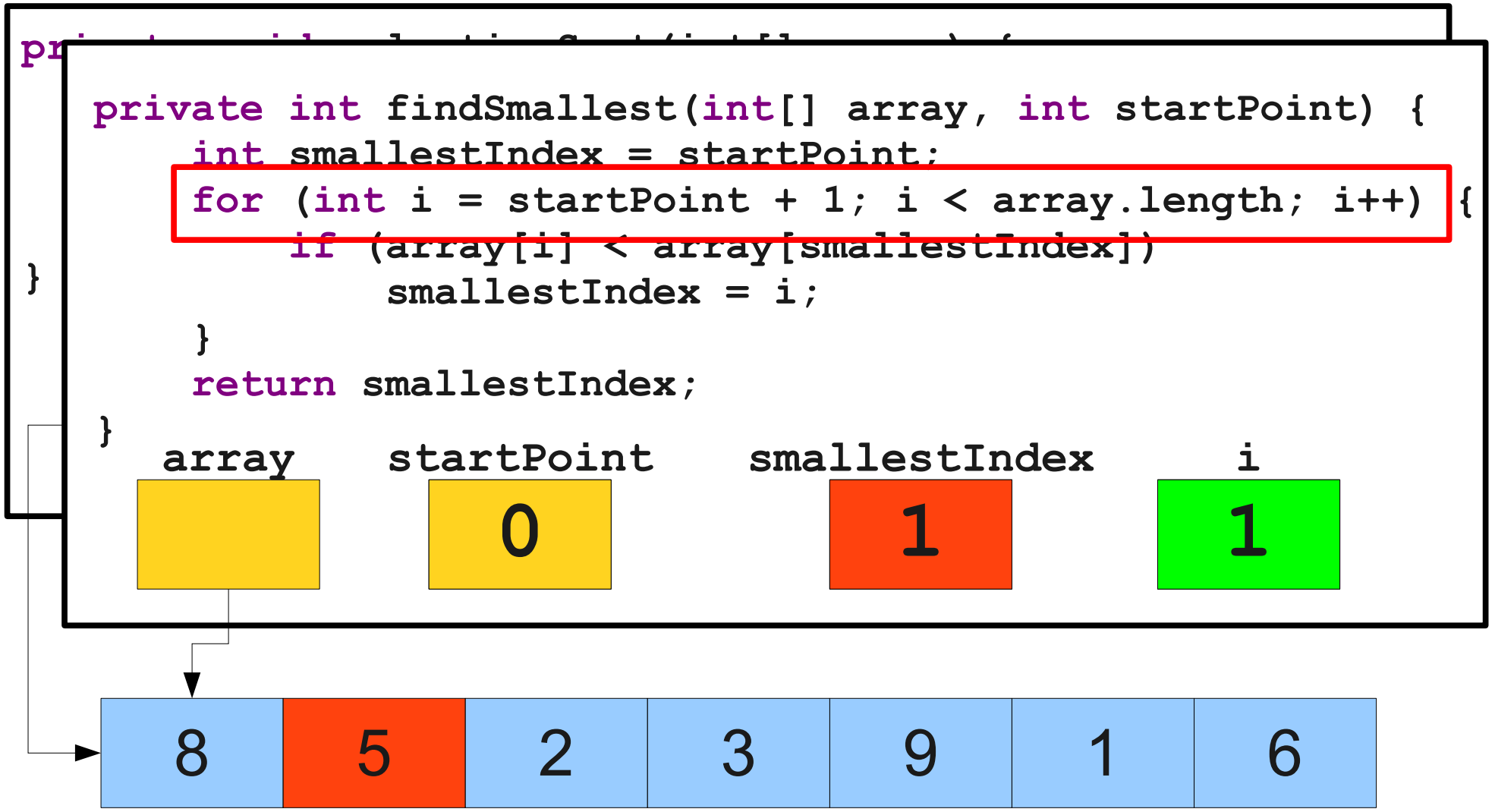
Selection Sort in Action



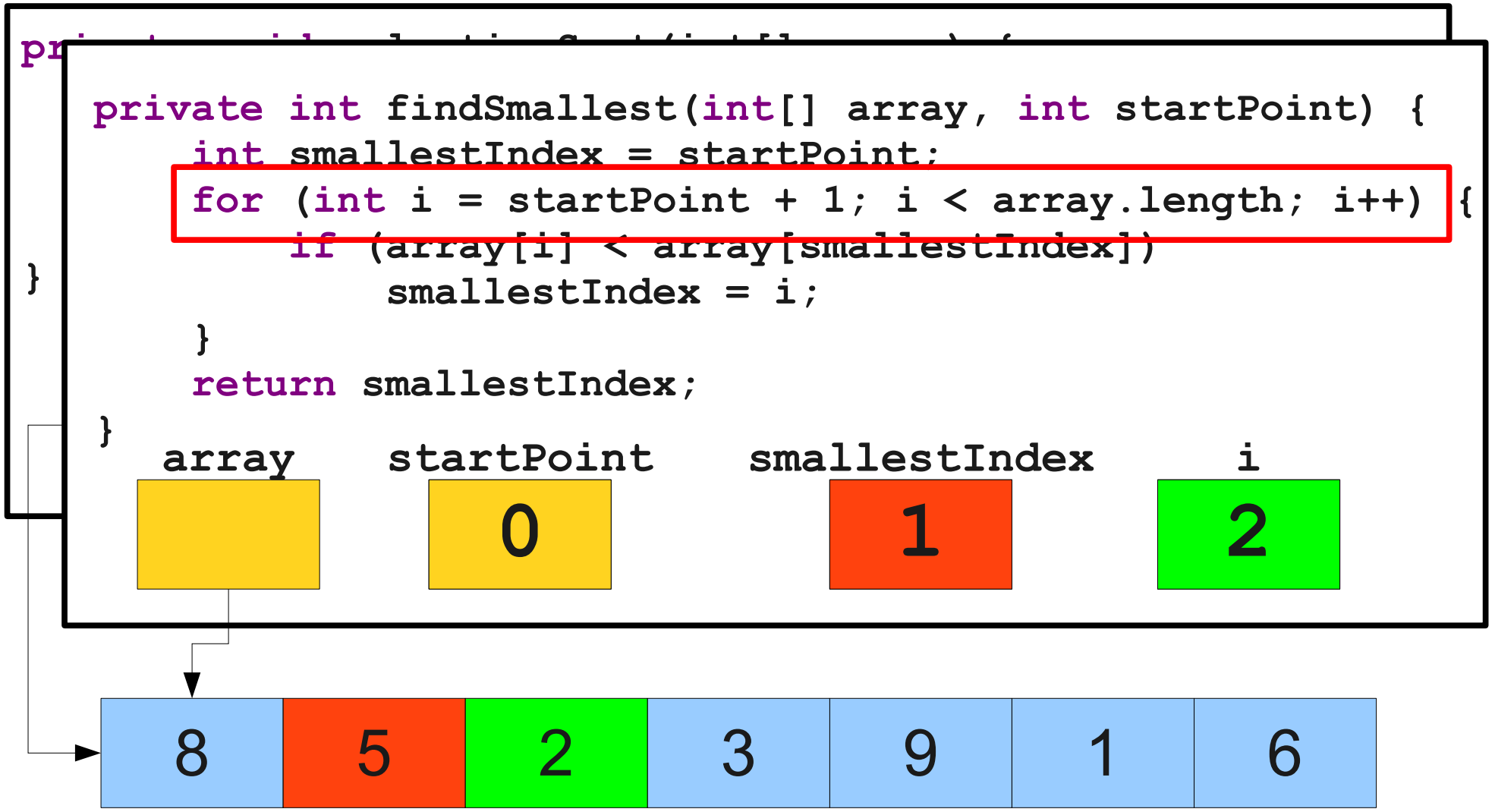
Selection Sort in Action



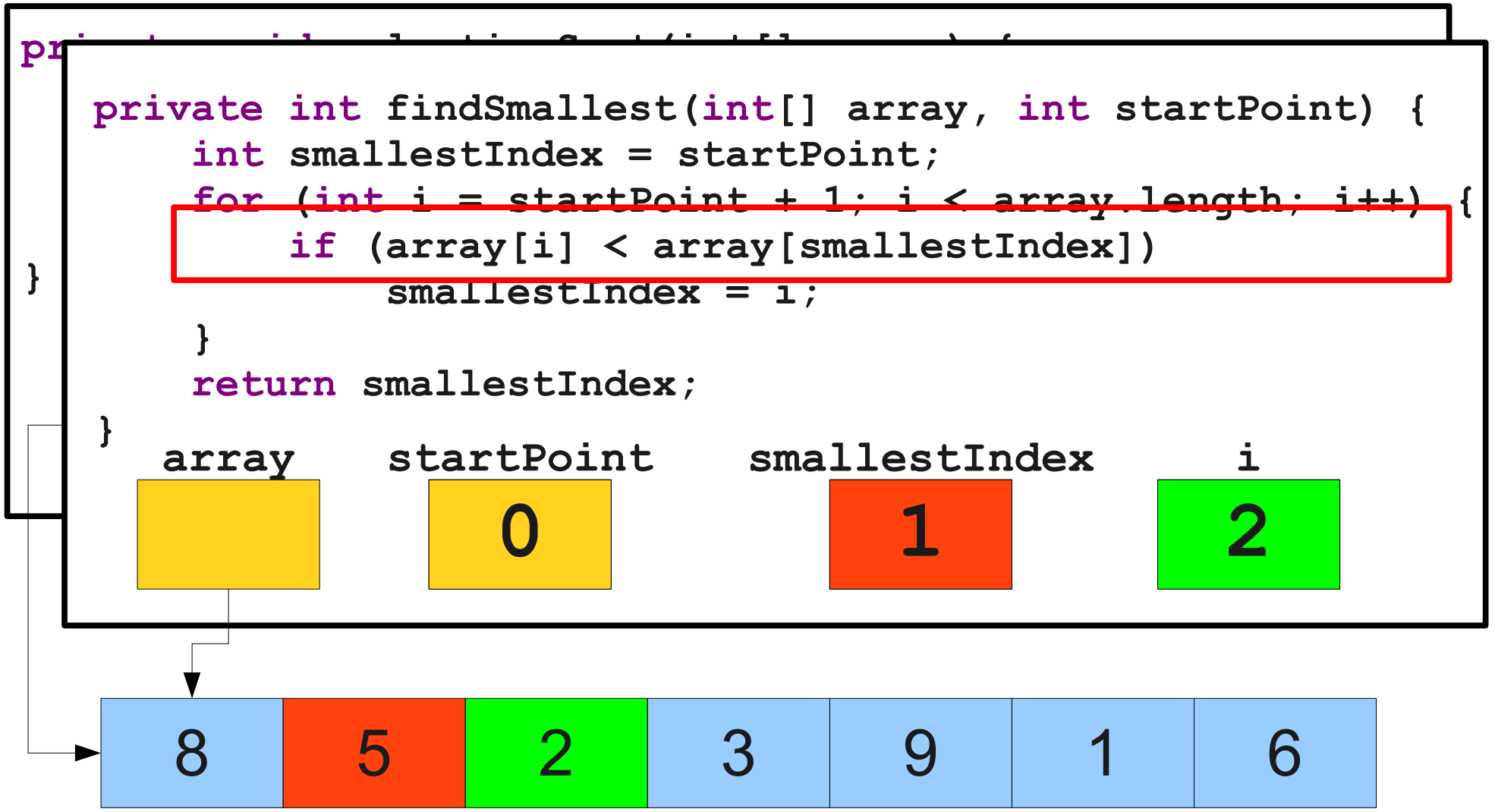
Selection Sort in Action



Selection Sort in Action



Selection Sort in Action



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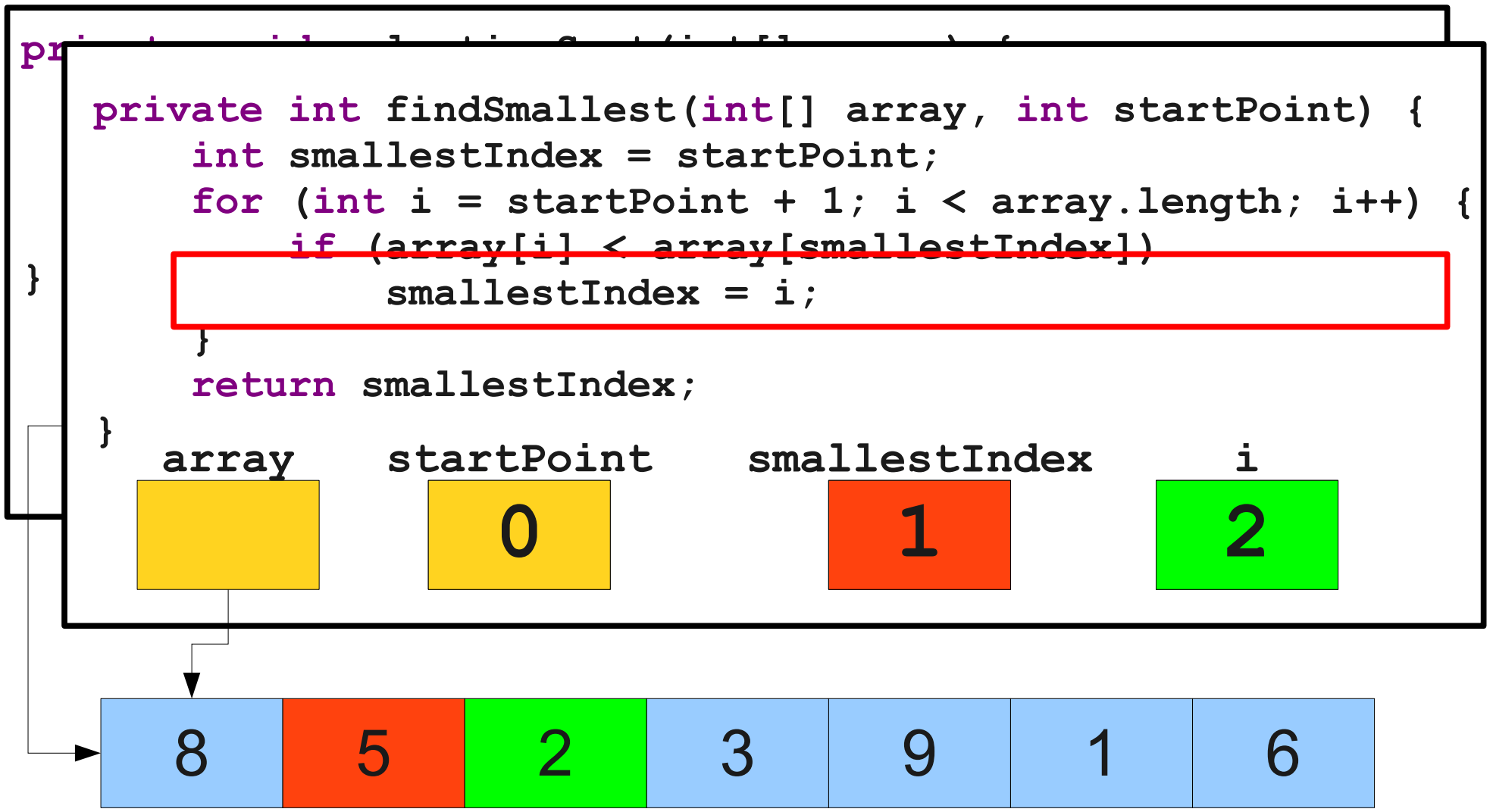

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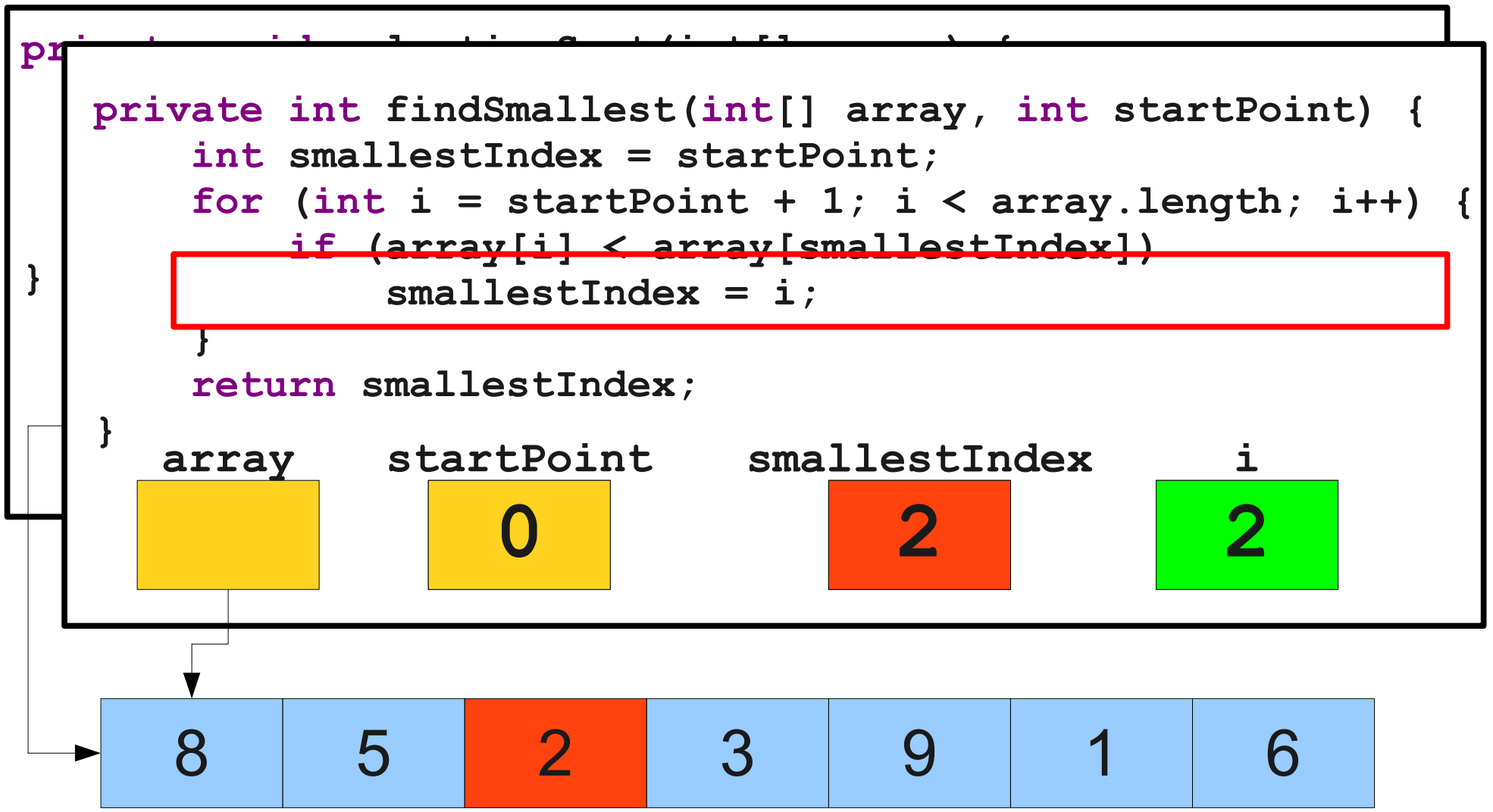

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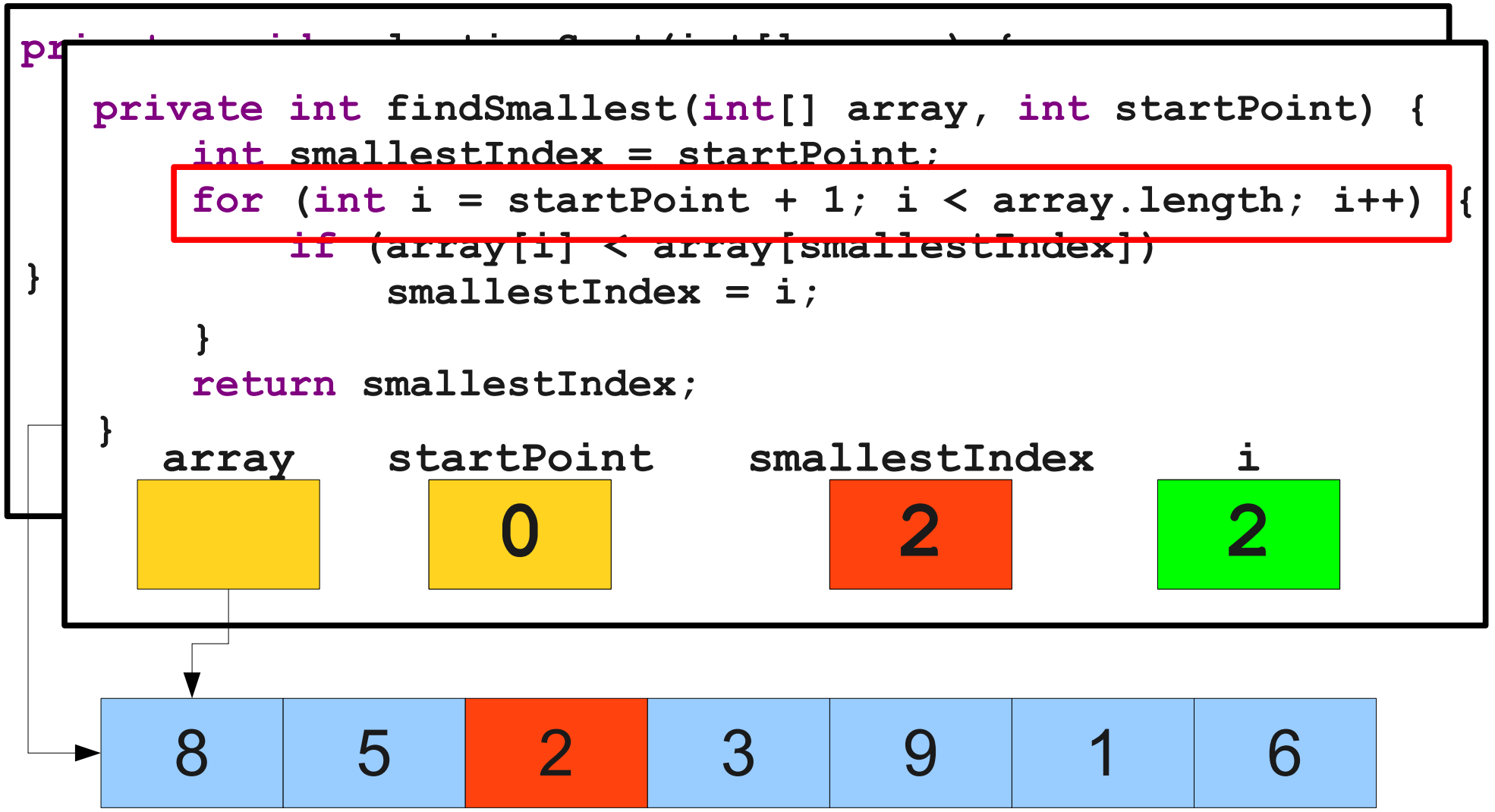

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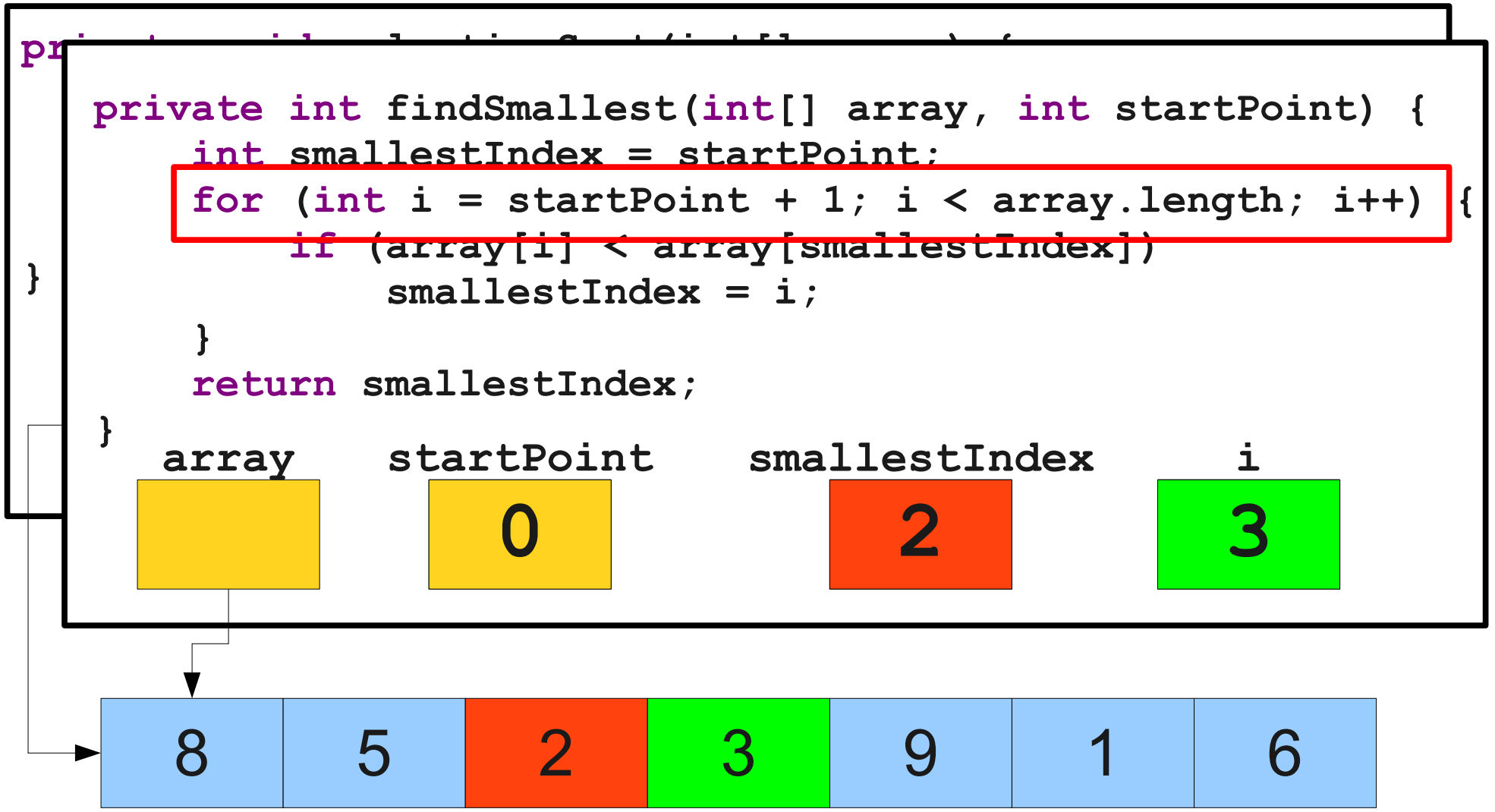

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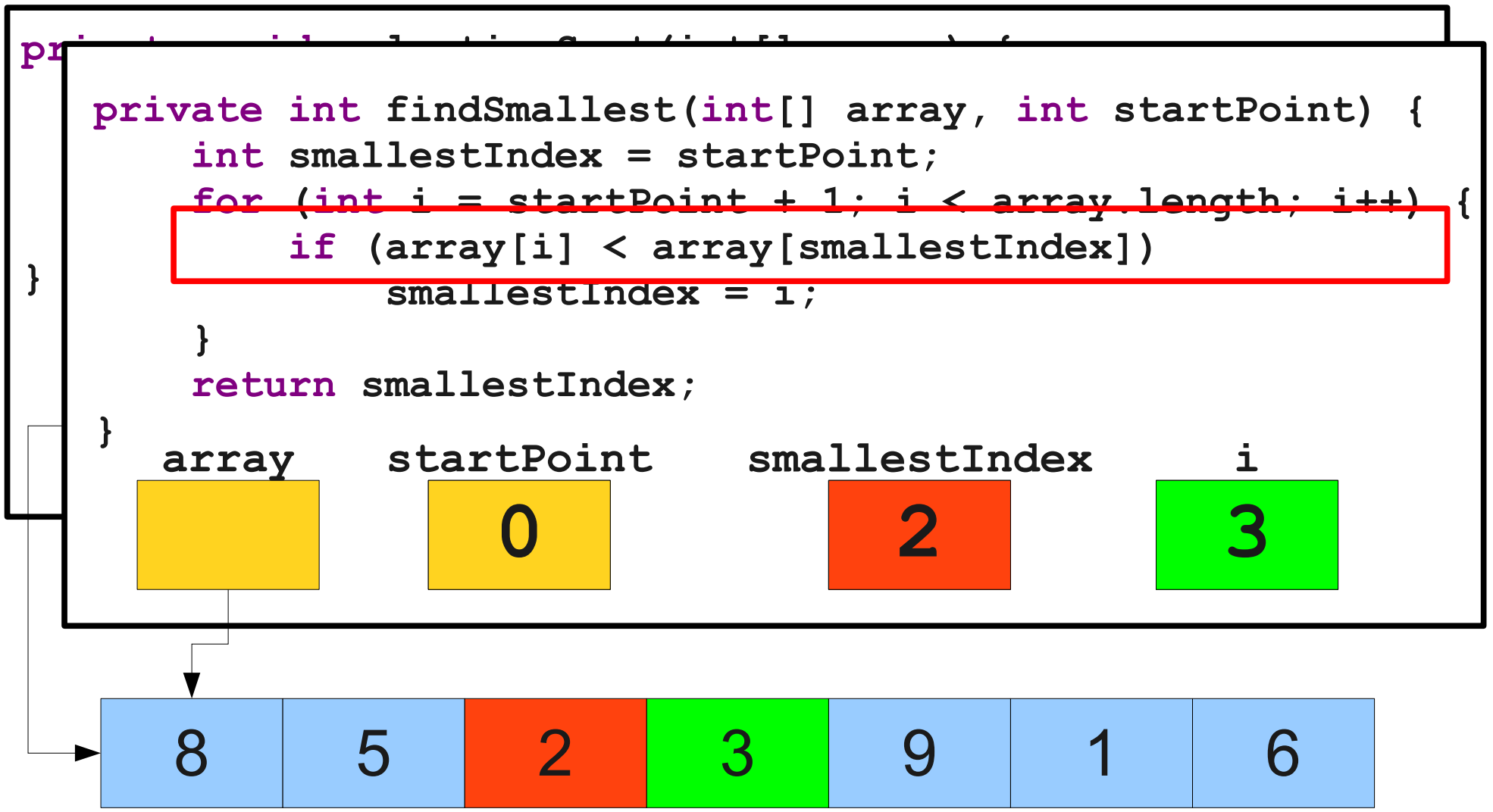

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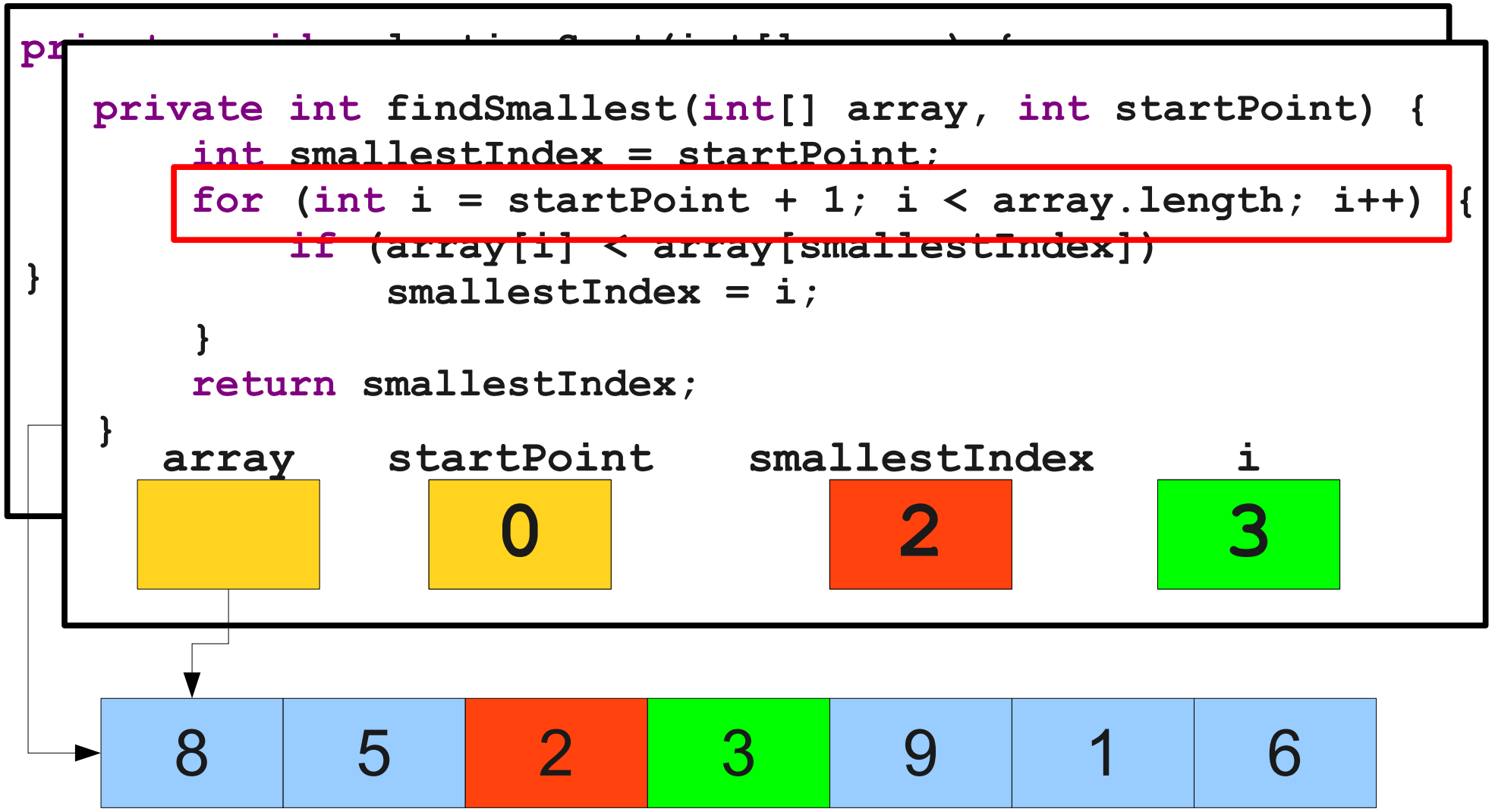

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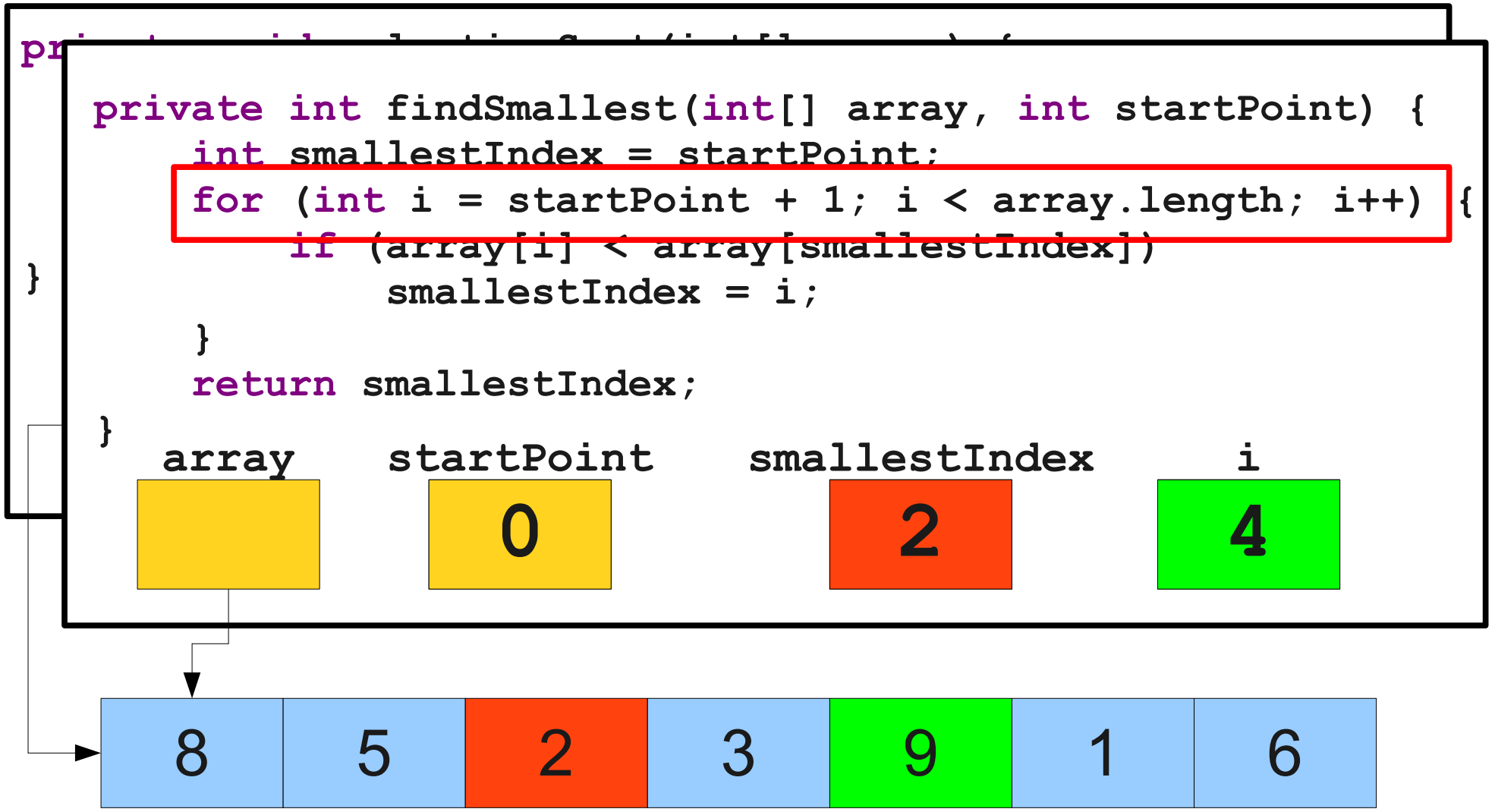

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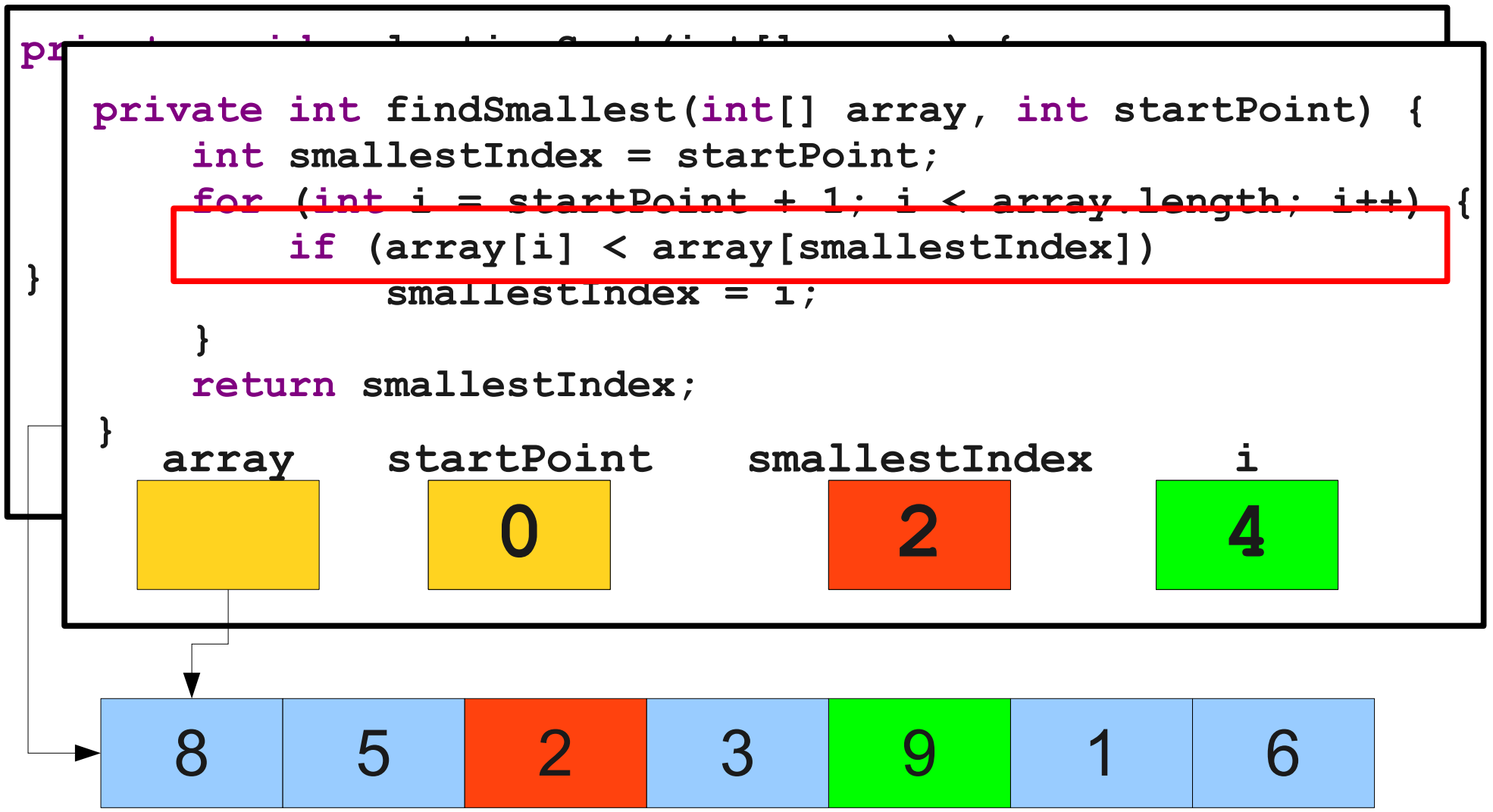

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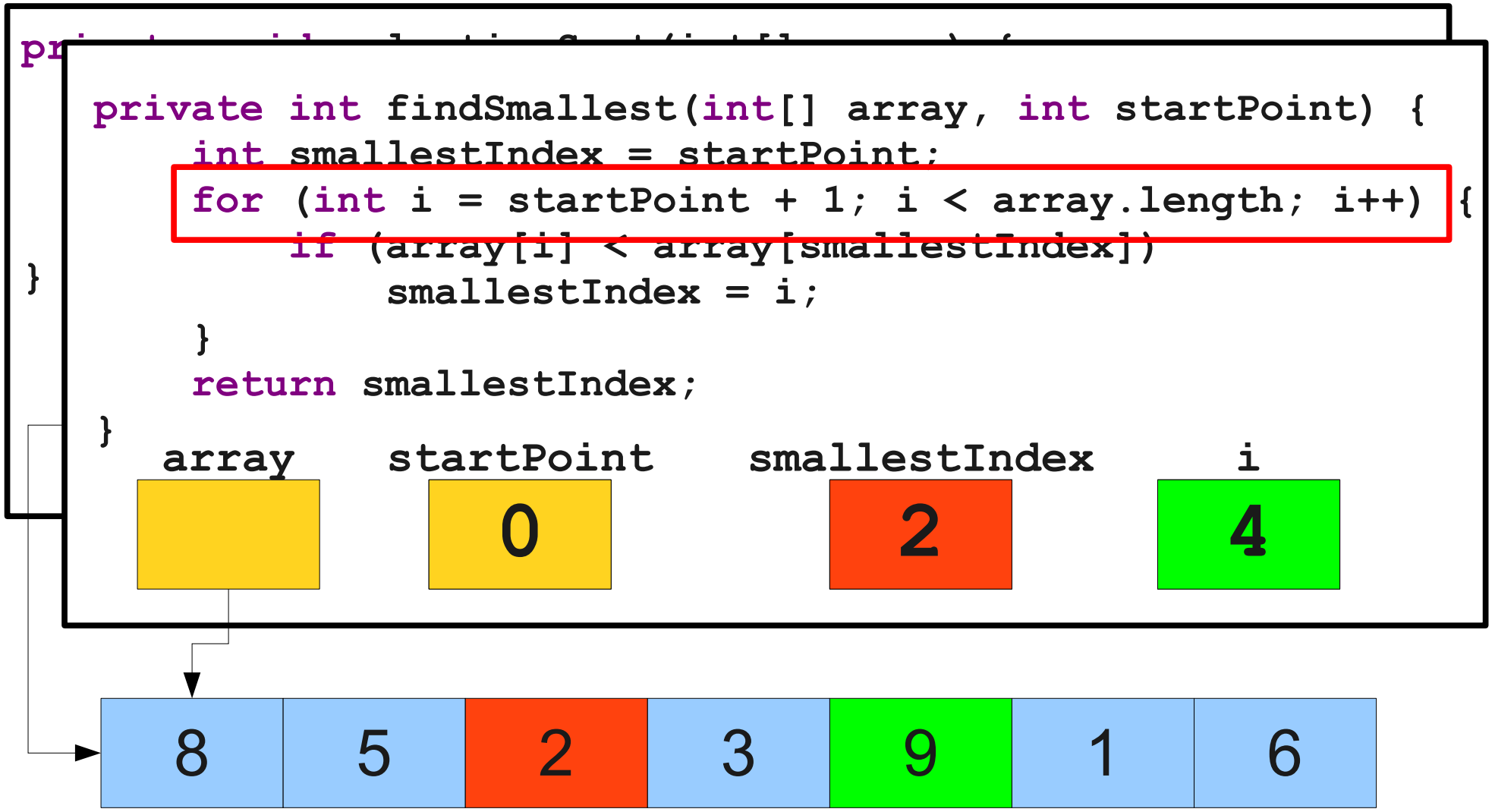
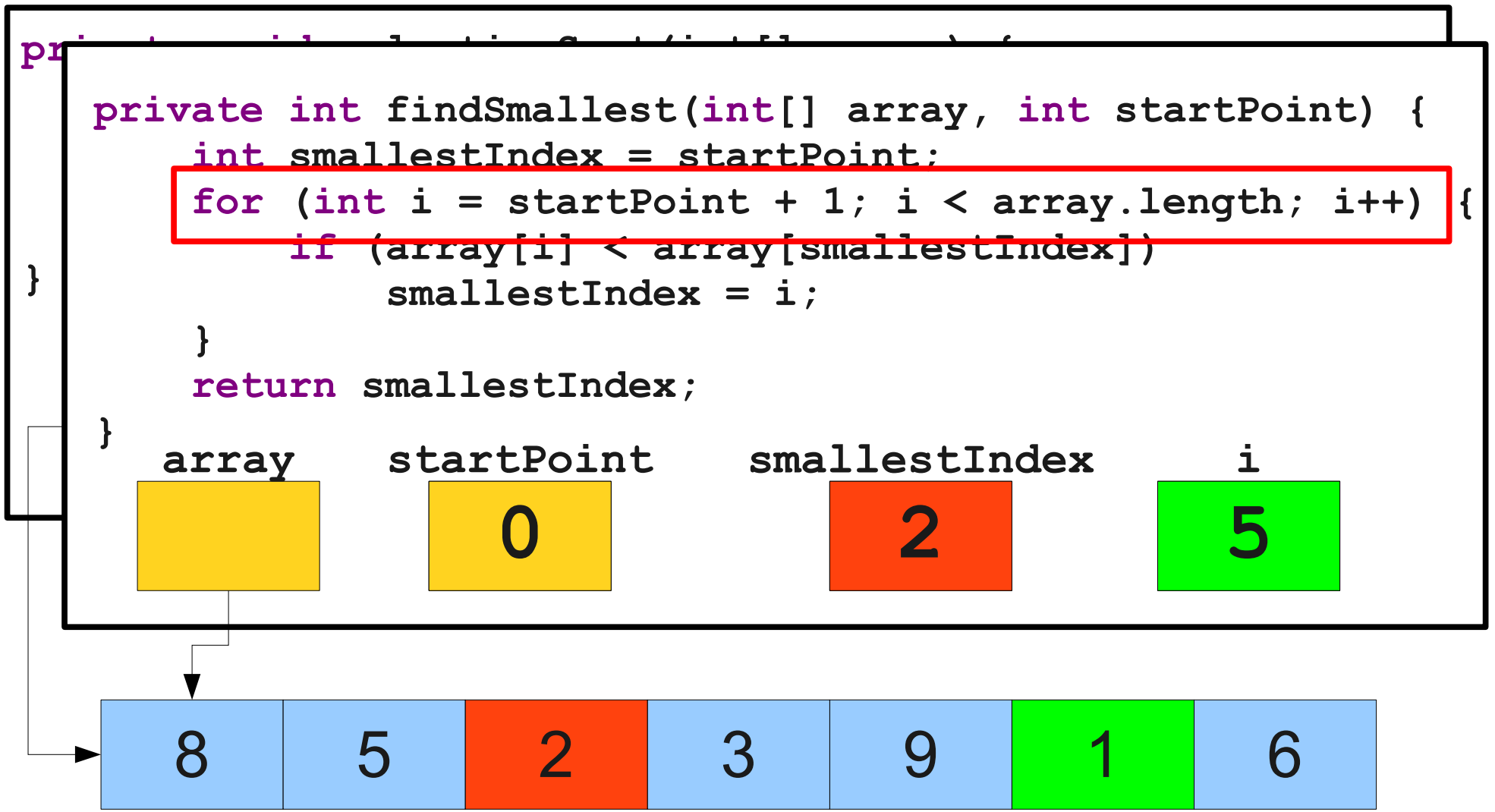


Selection Sort in Action

```
private int findSmallest(int[] array, int startPoint) {
    int smallestIndex = startPoint;
    for (int i = startPoint + 1; i < array.length; i++) {
        if (array[i] < array[smallestIndex])
            smallestIndex = i;
    }
    return smallestIndex;
}
```



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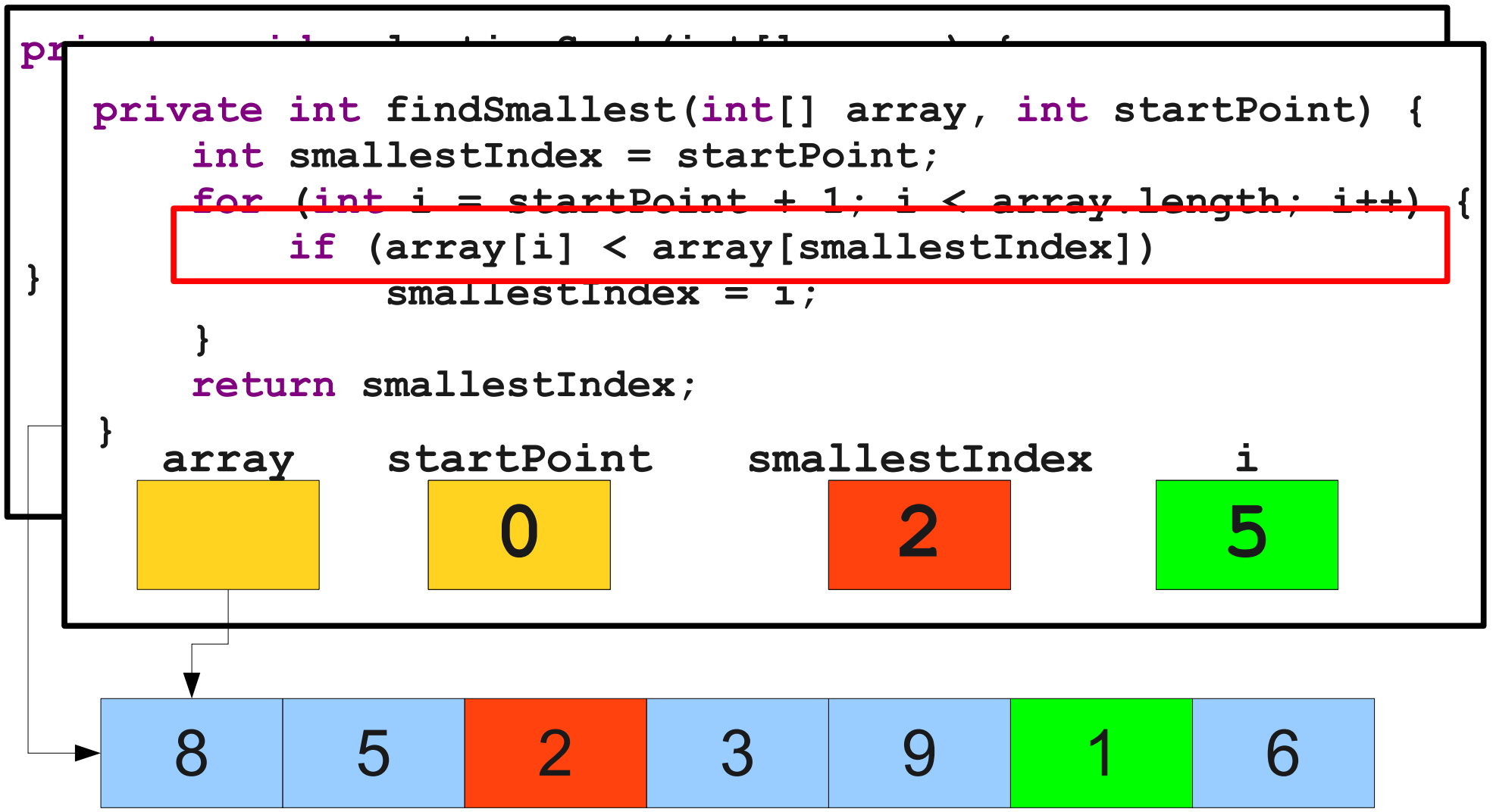

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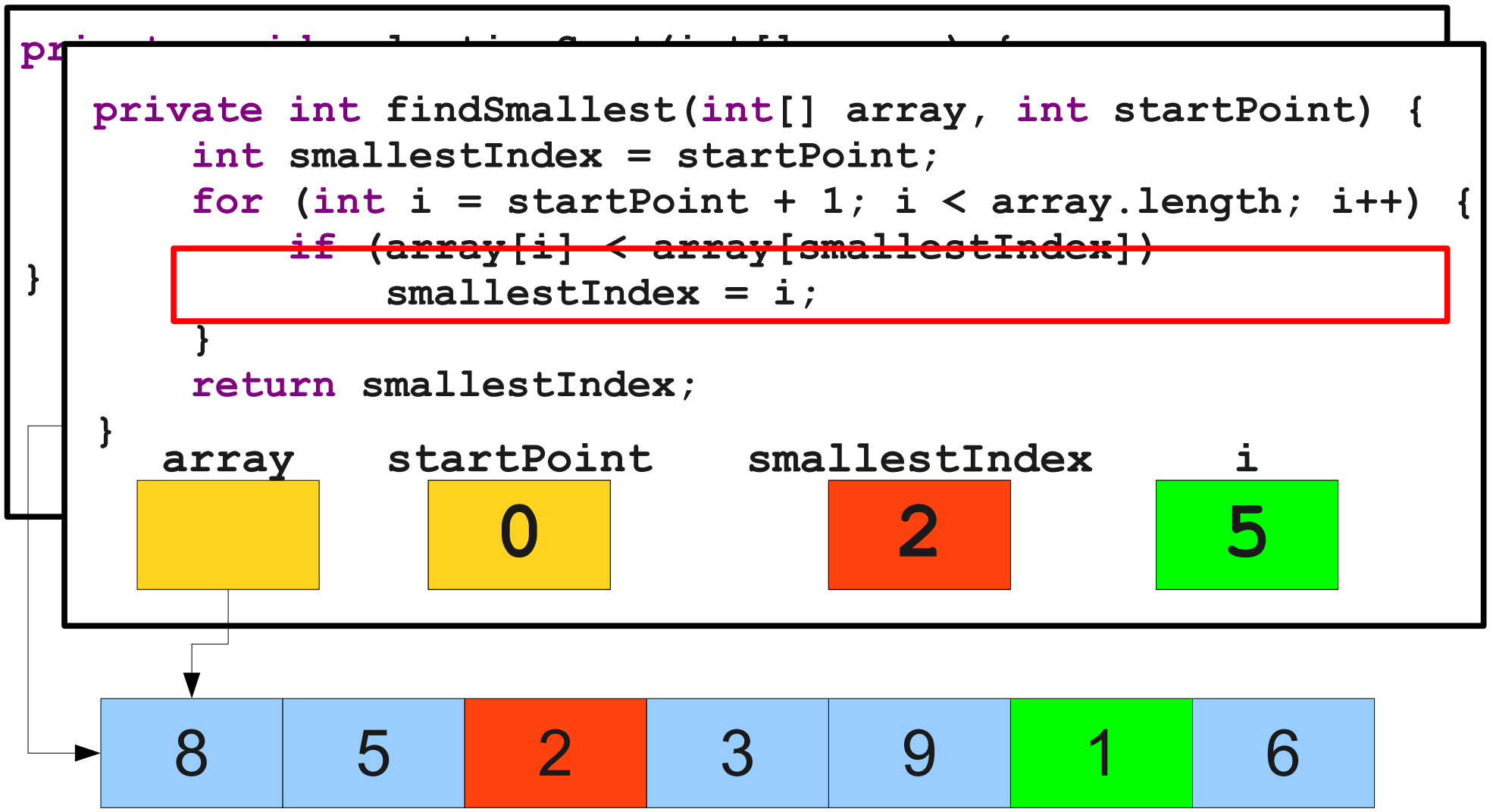
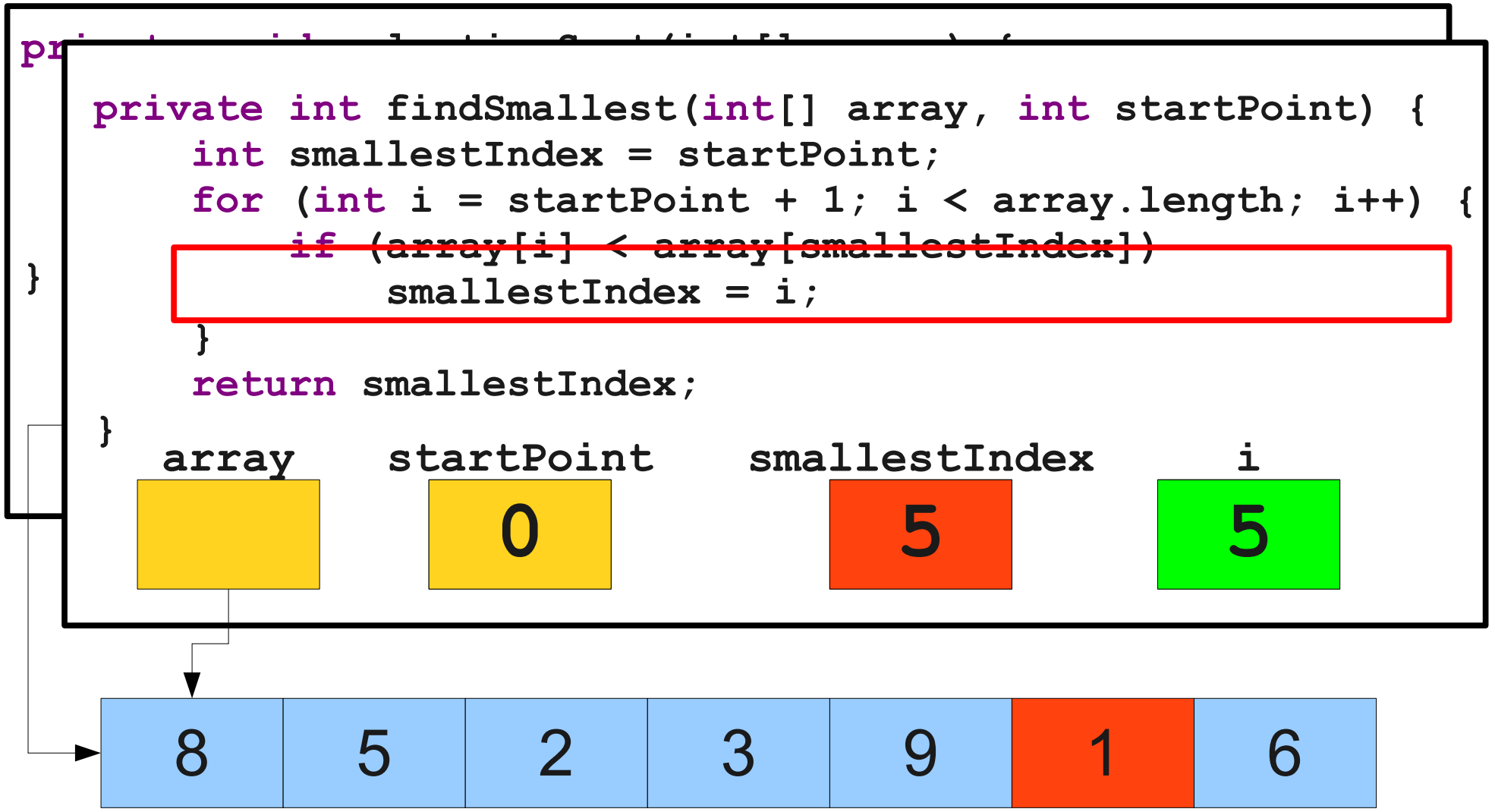
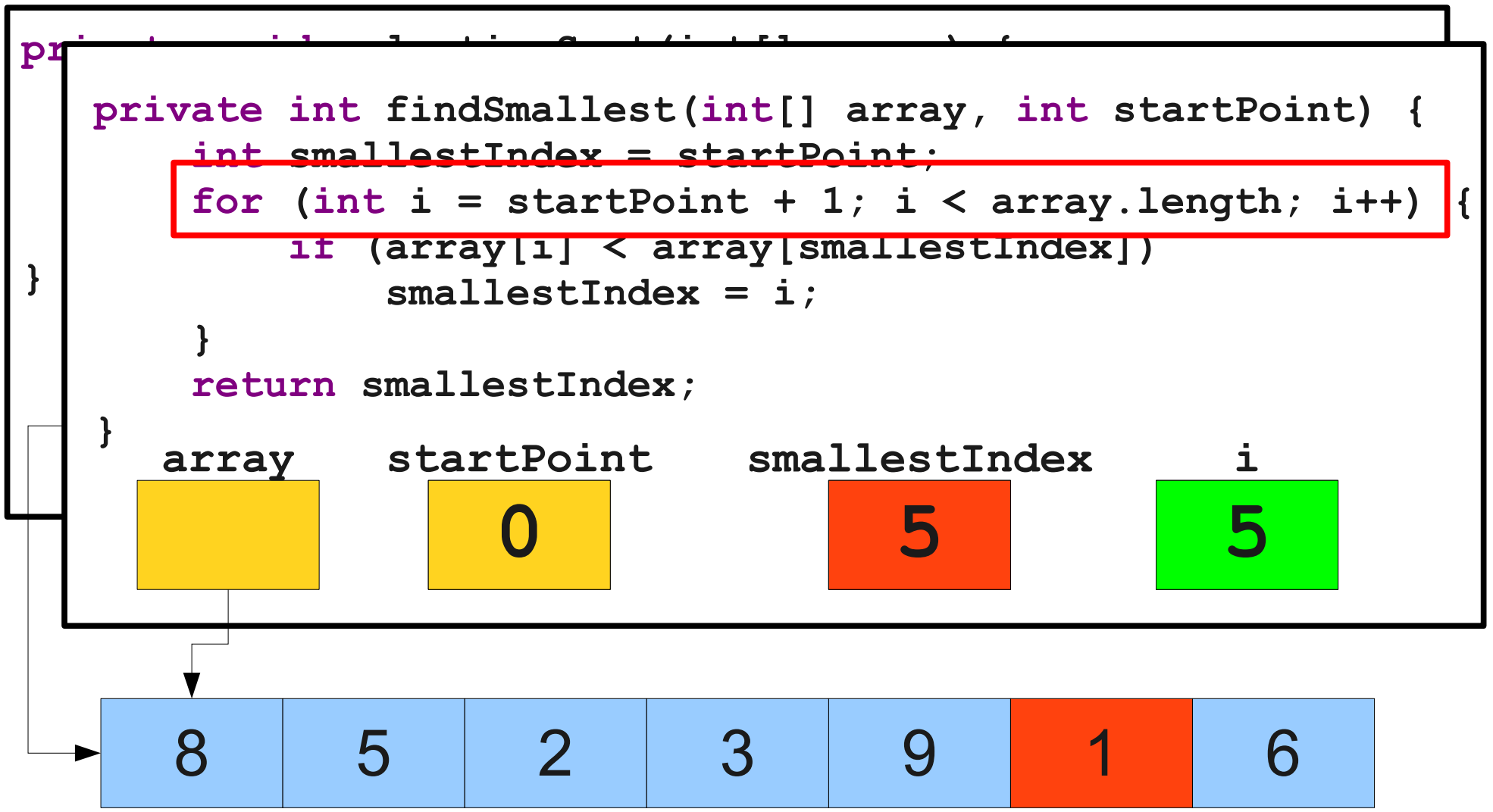


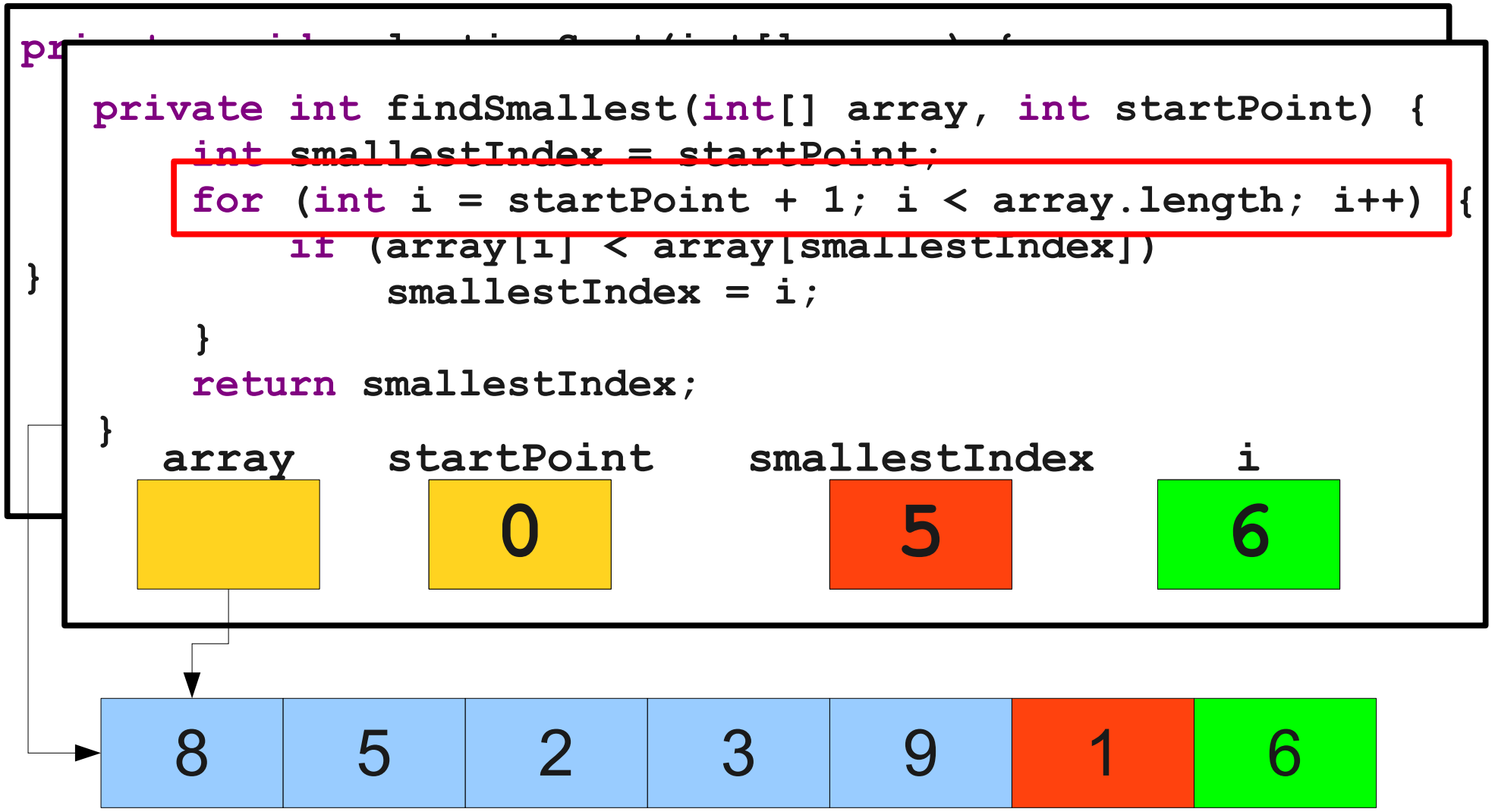
Selection Sort in Action



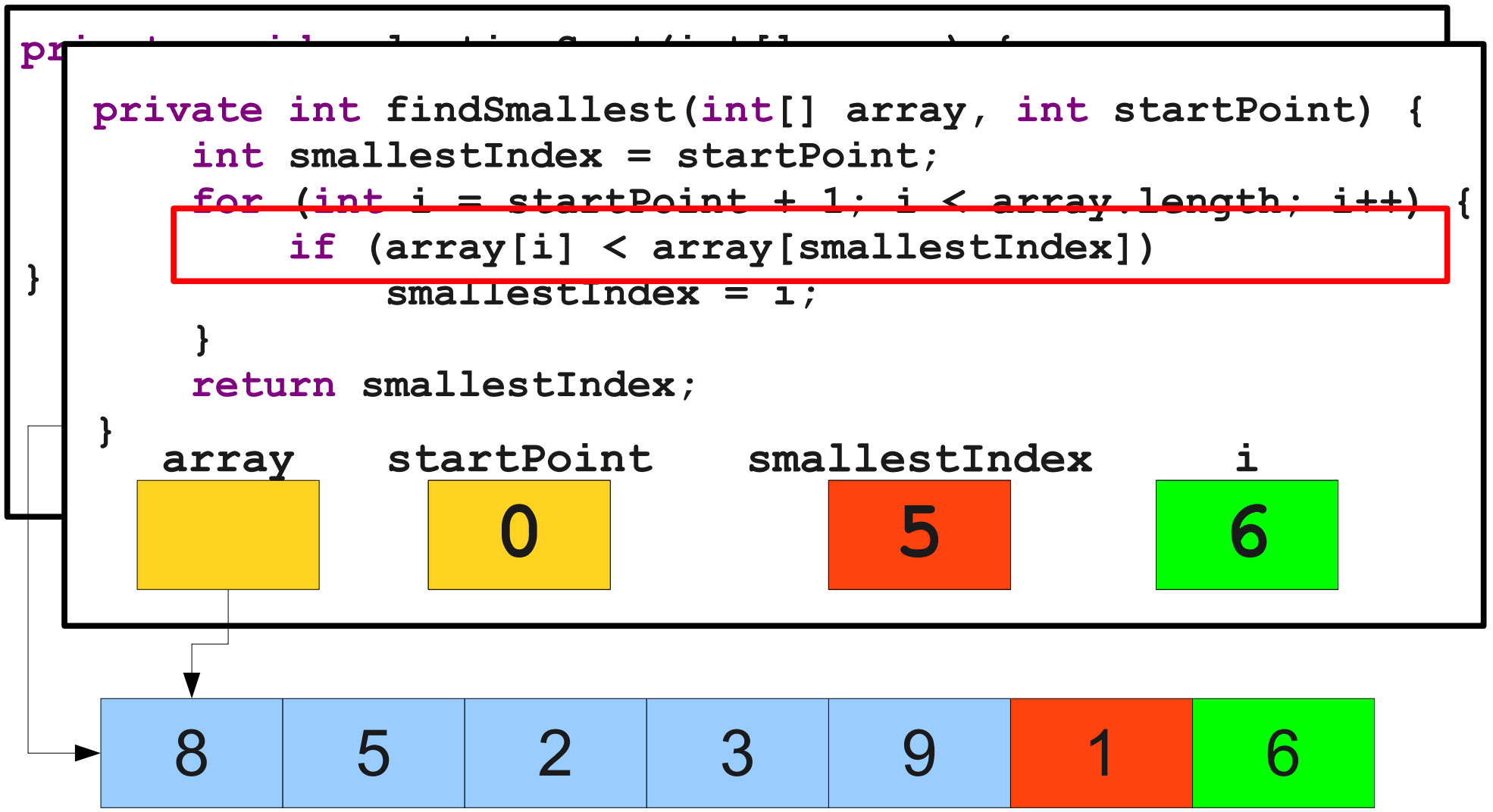
Selection Sort in Action



Selection Sort in Action



Selection Sort in Action



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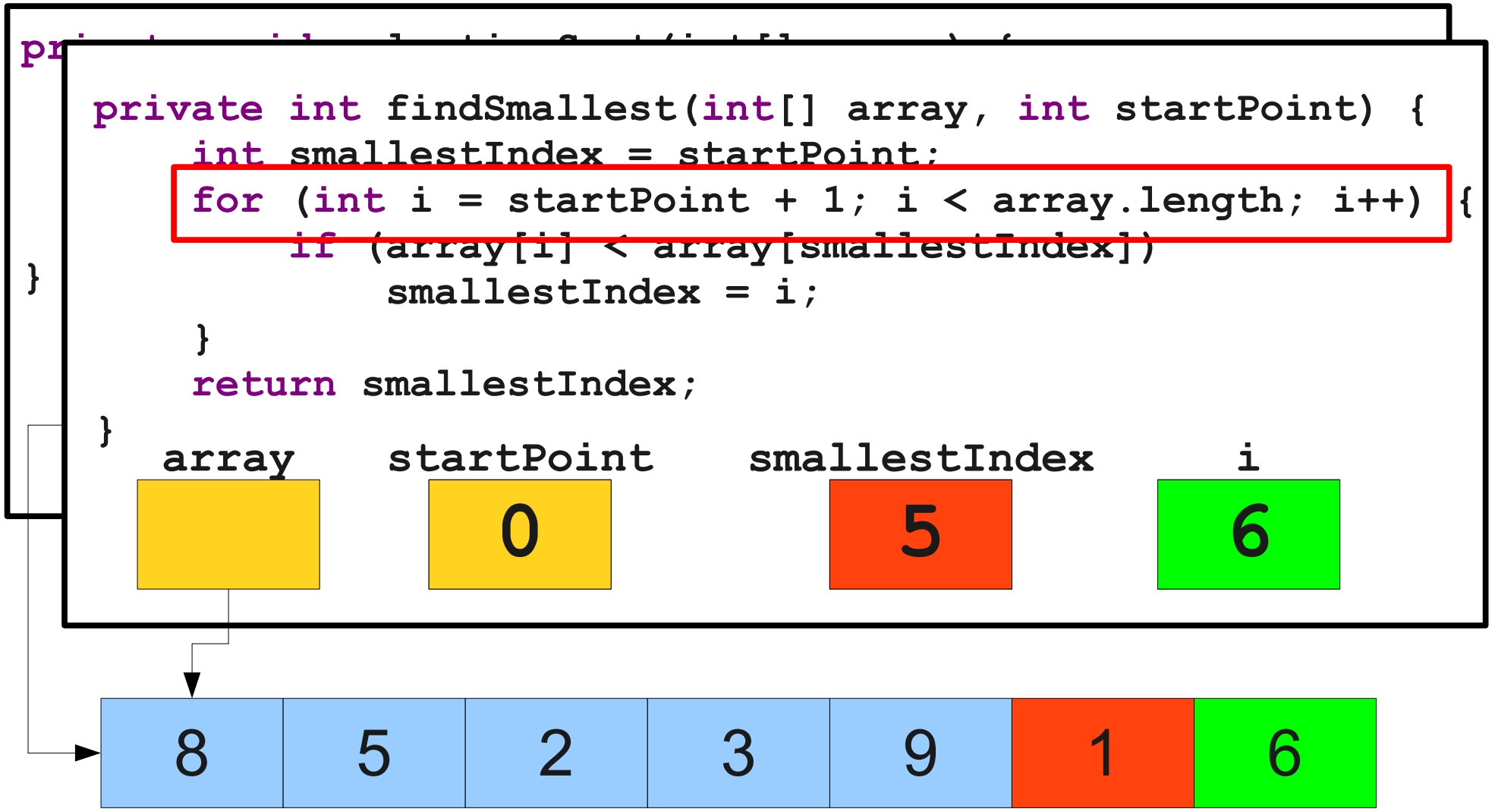

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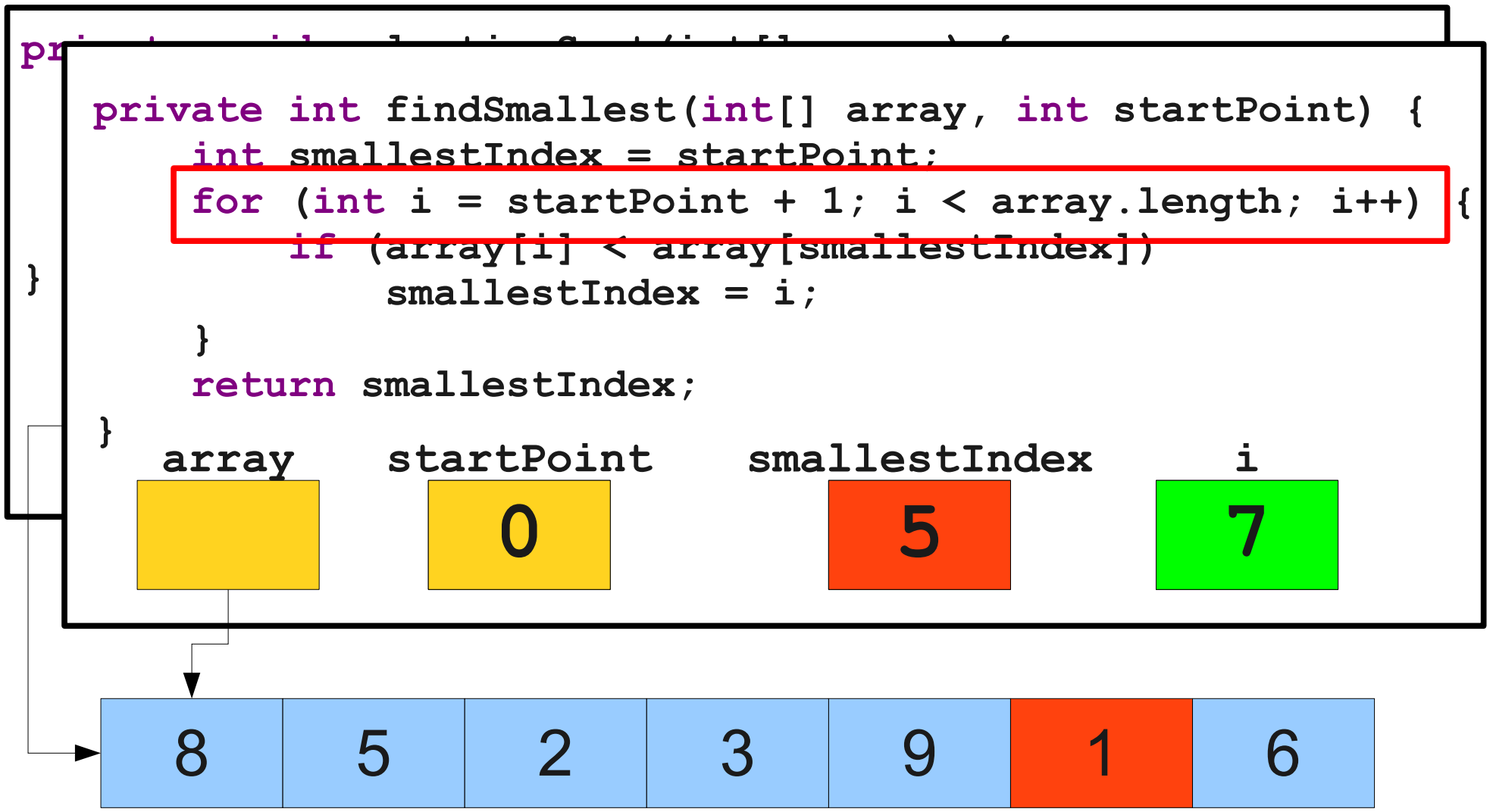

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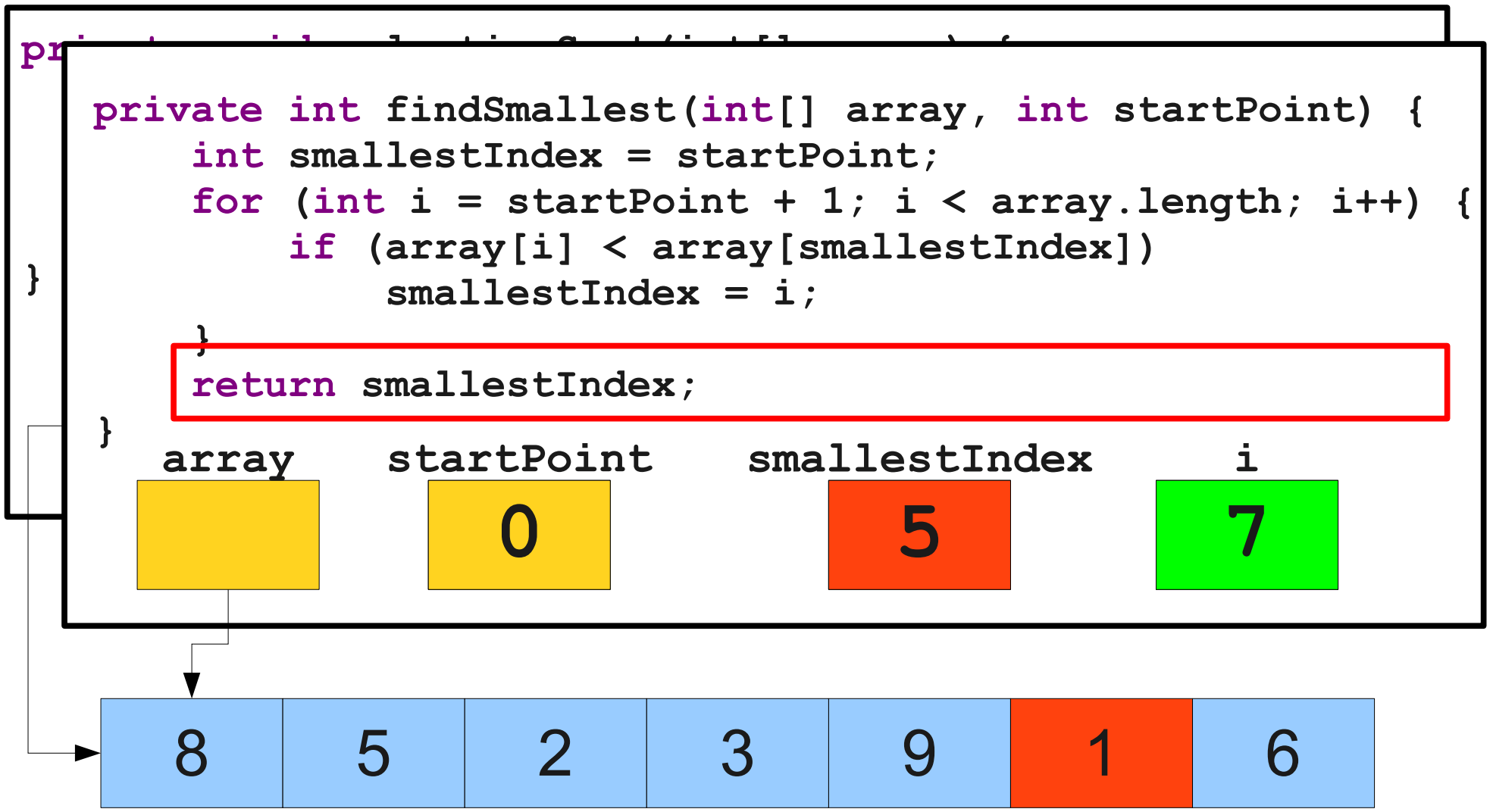

Selection Sort in Action

```
private void selectionSort(int[] array) {
    for (int index = 0; index < array.length; index++) {
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        swap(array, index, smallestIndex);
    }
}
```

array index smallestIndex

0 5

Selection Sort in Action

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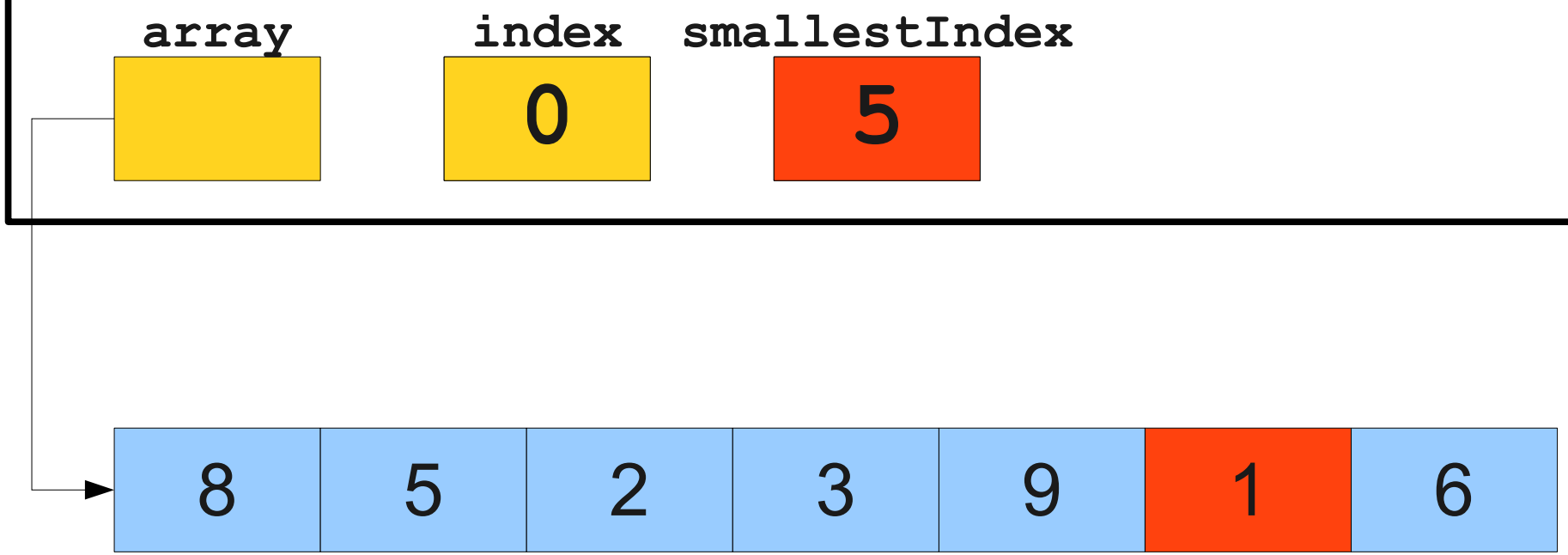

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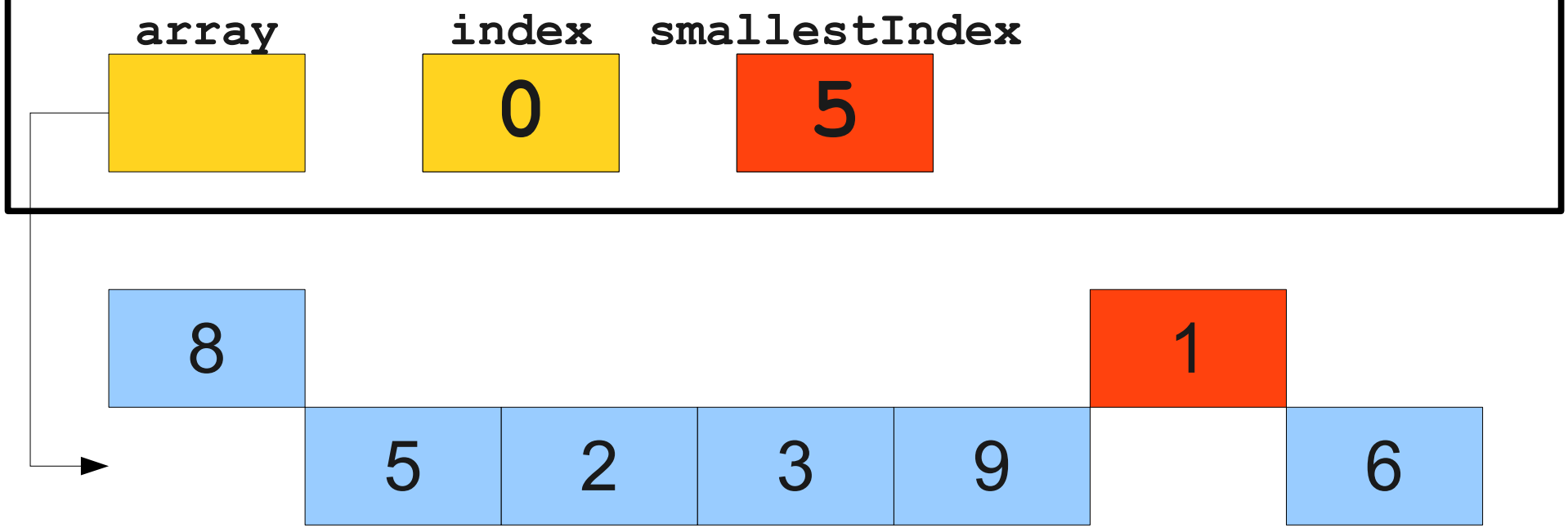

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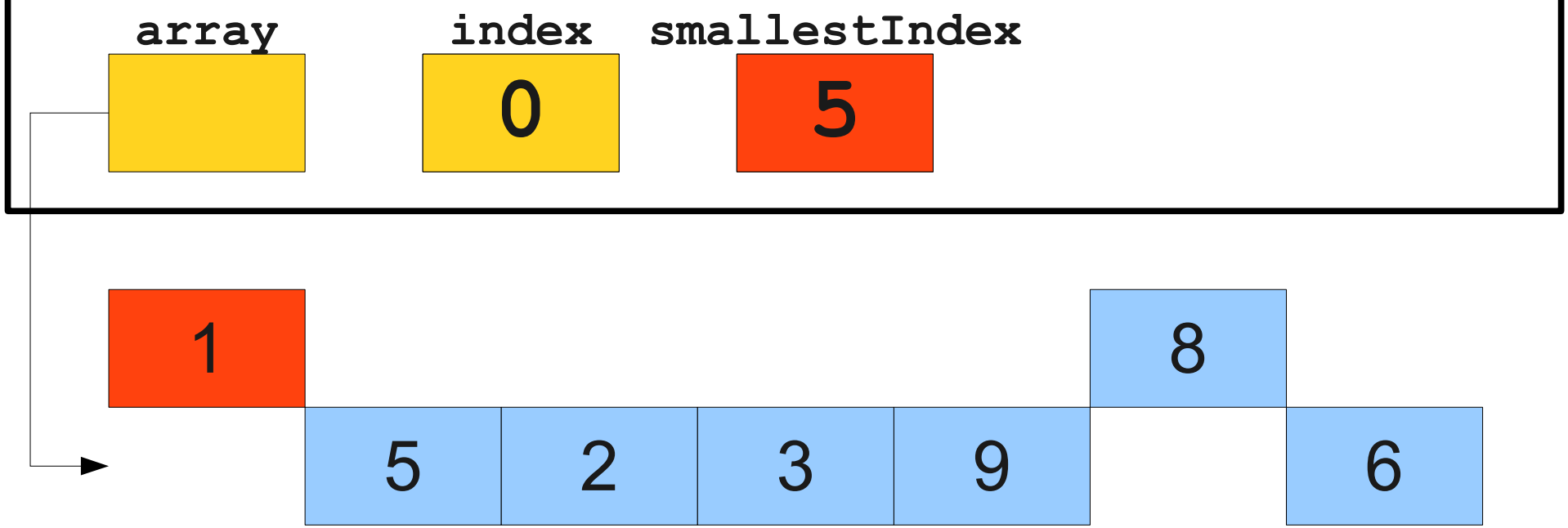

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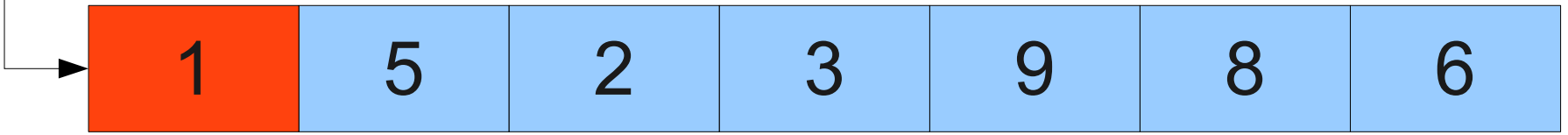
array index smallestIndex

0 5



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array

index

0

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array

index

1

Selection Sort in Action

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```

array

index

1

Selection Sort in Action

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array

index

1

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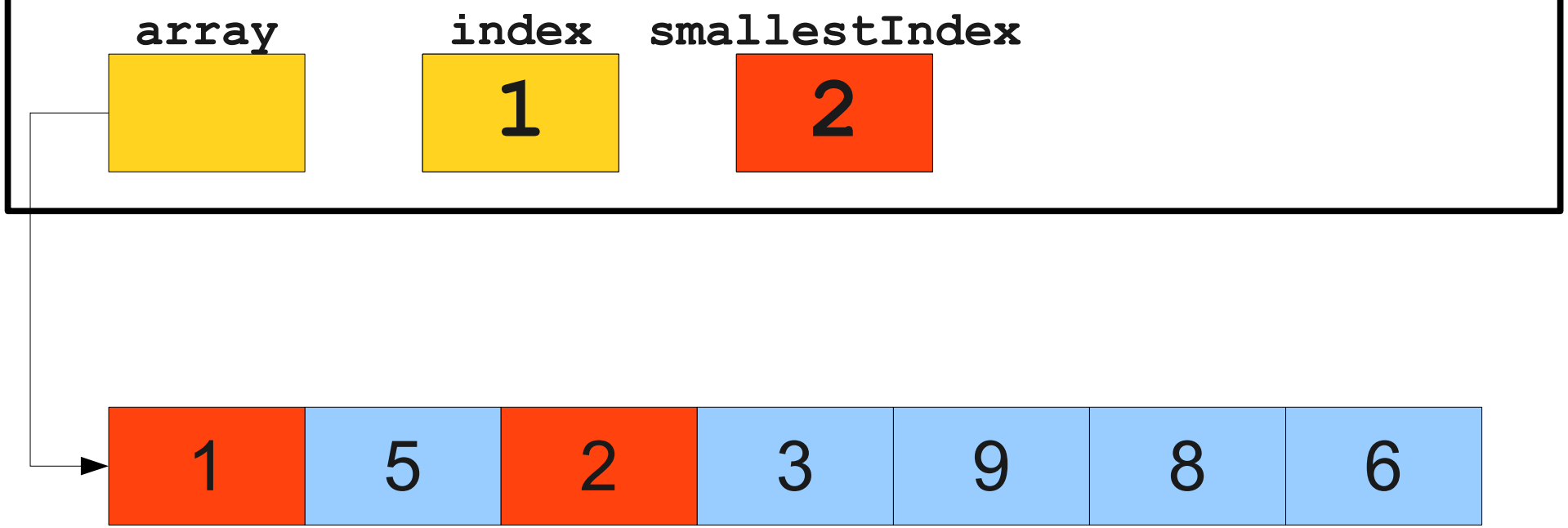

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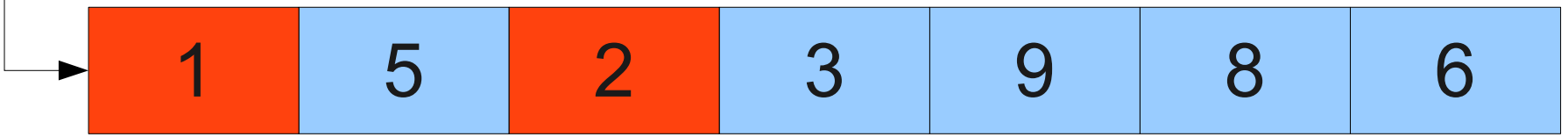

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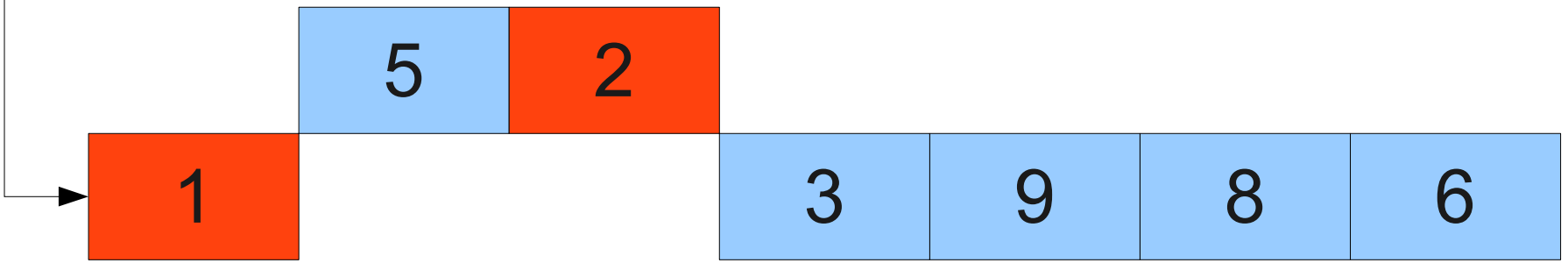

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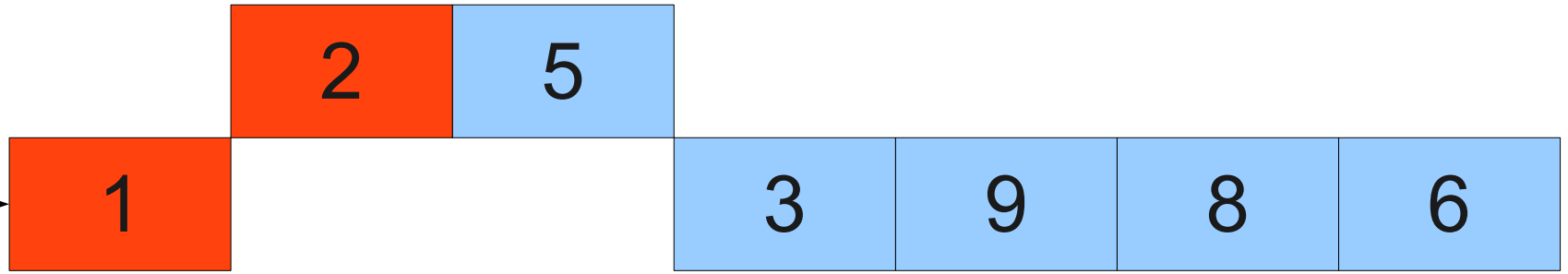

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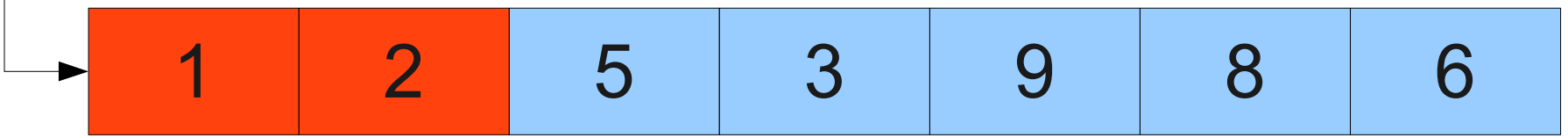
array index smallestIndex

1 2



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array

index

1

Selection Sort in Action

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}
```

array

index

2

Selection Sort in Action

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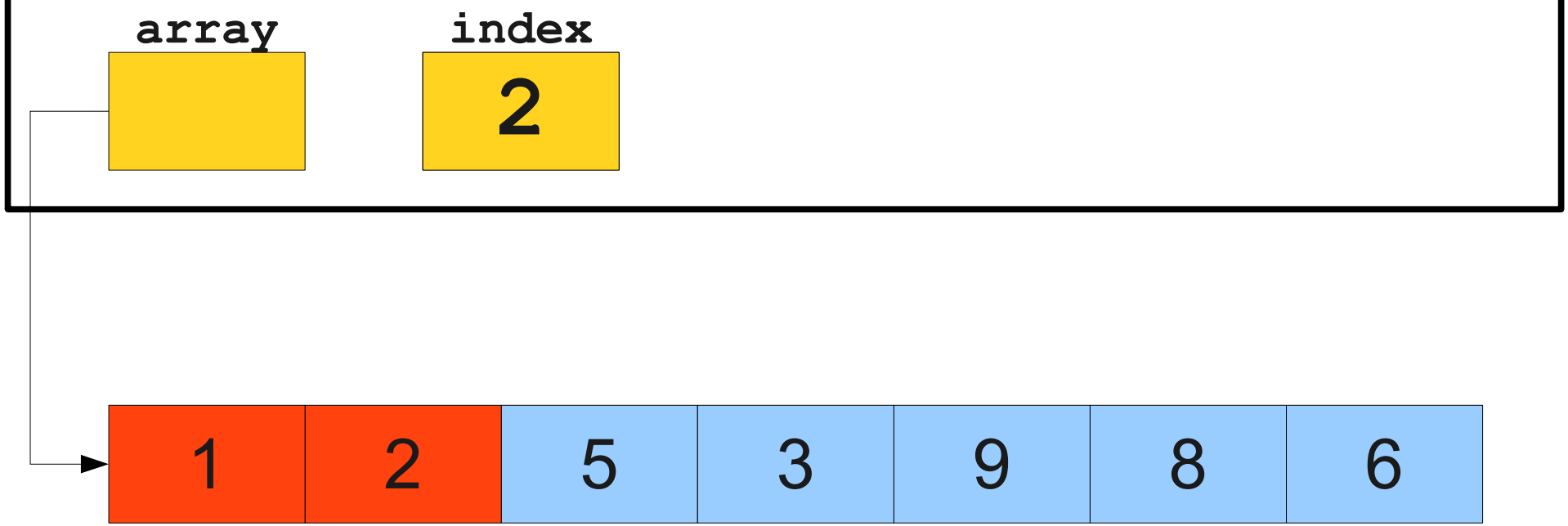

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```
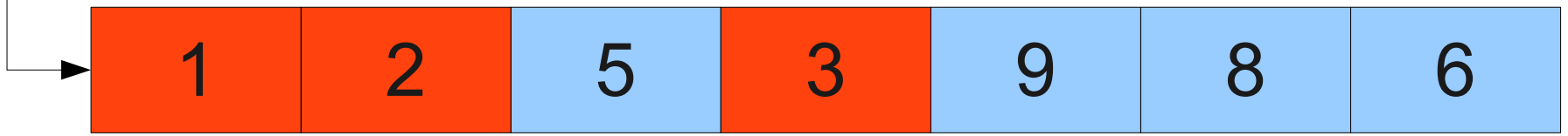

array

index

2



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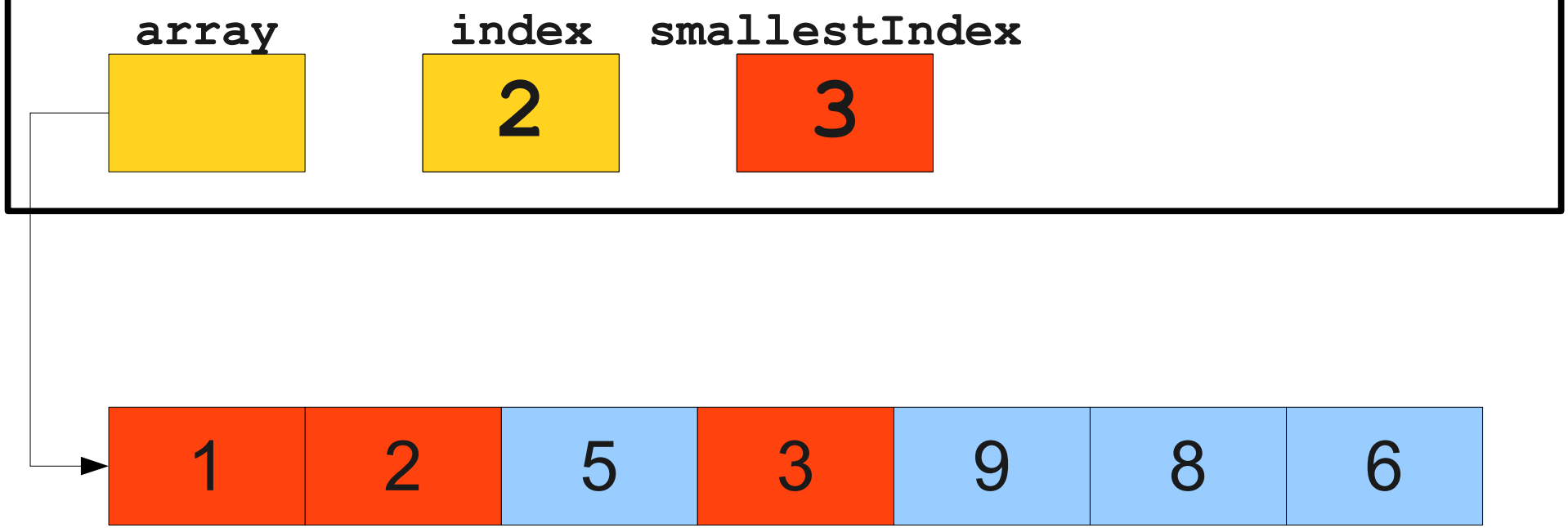

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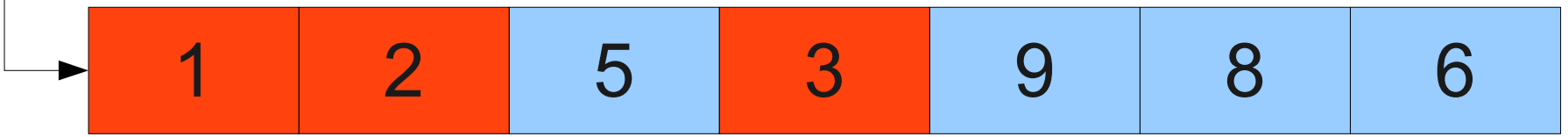

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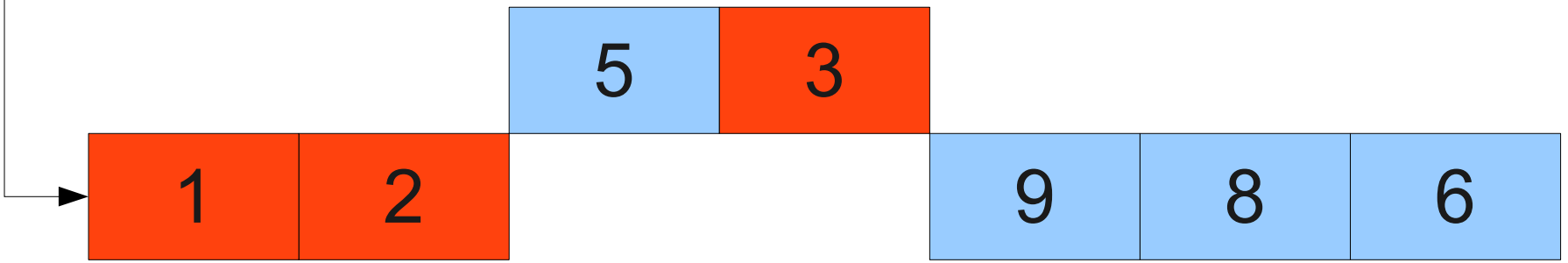

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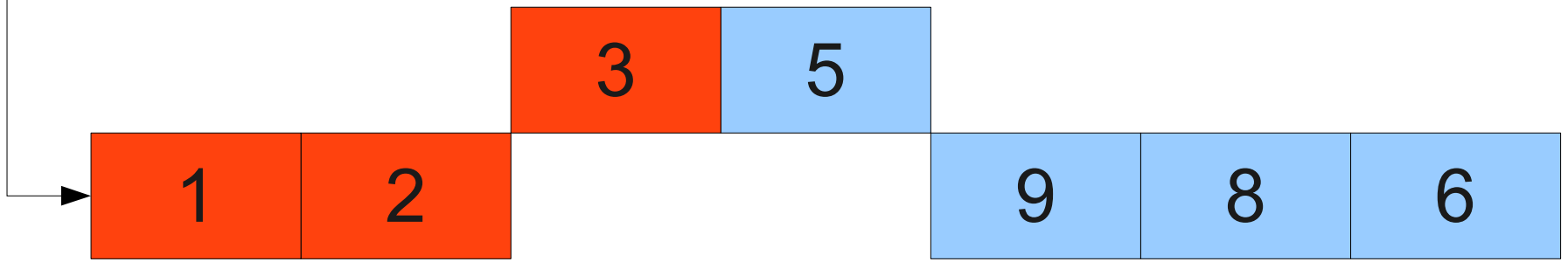

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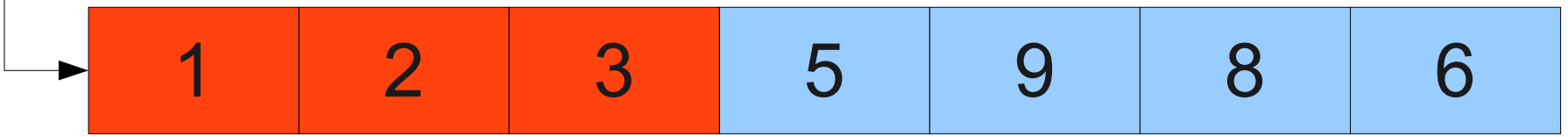

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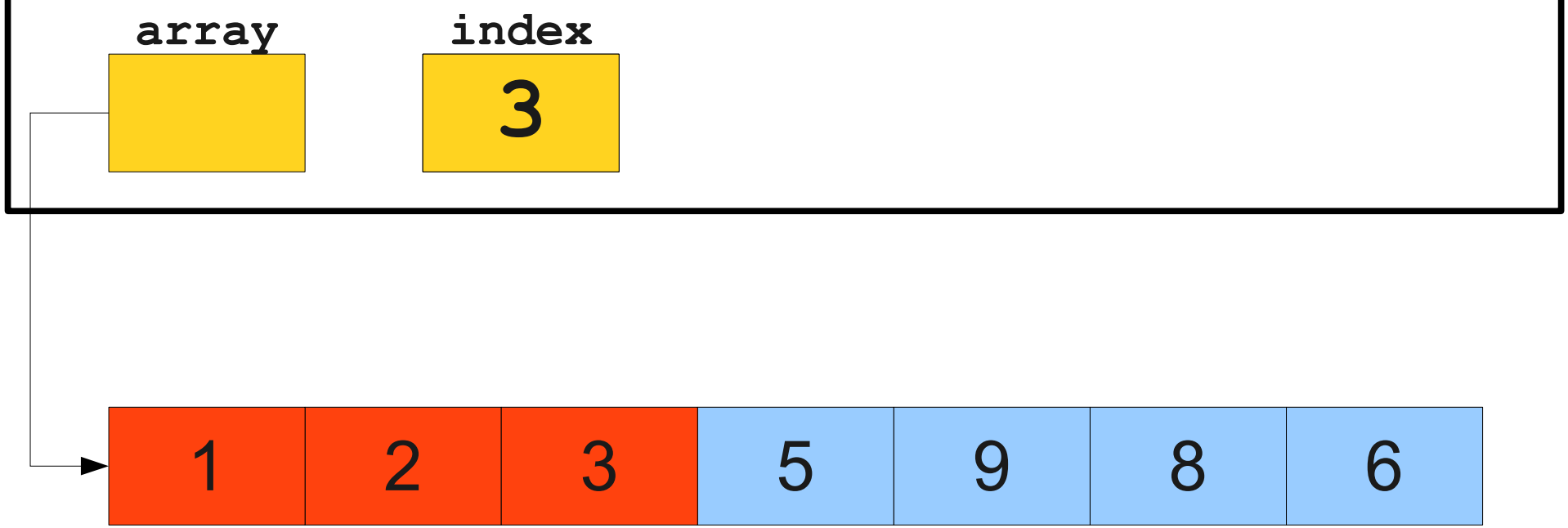

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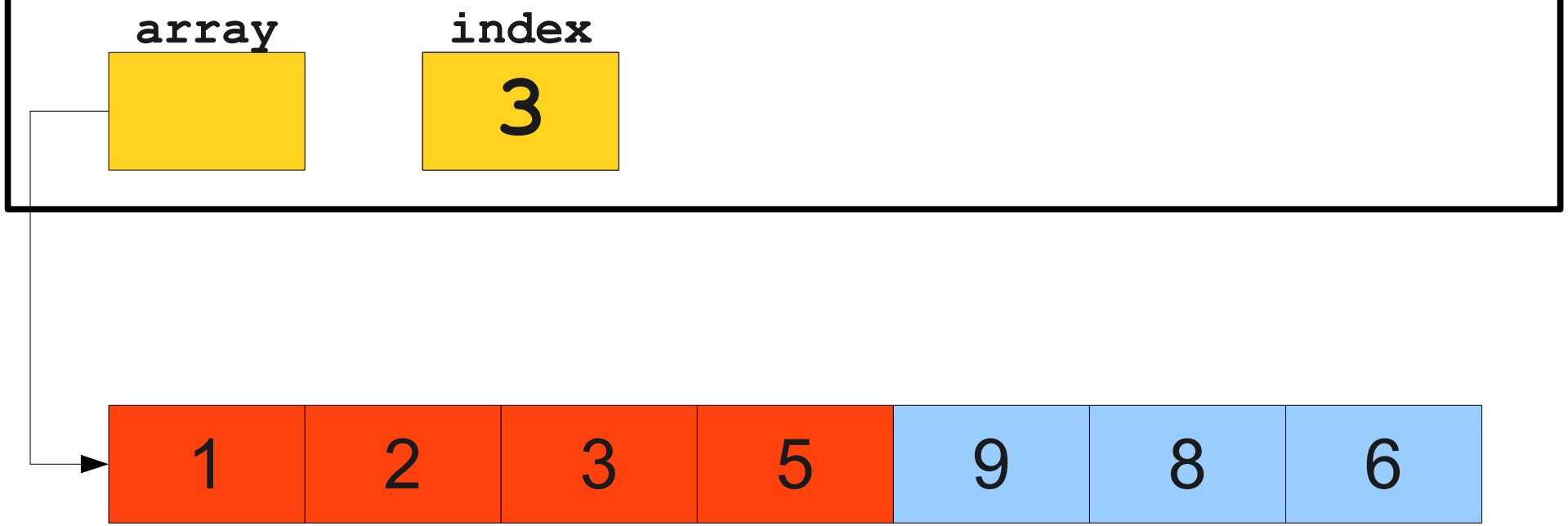

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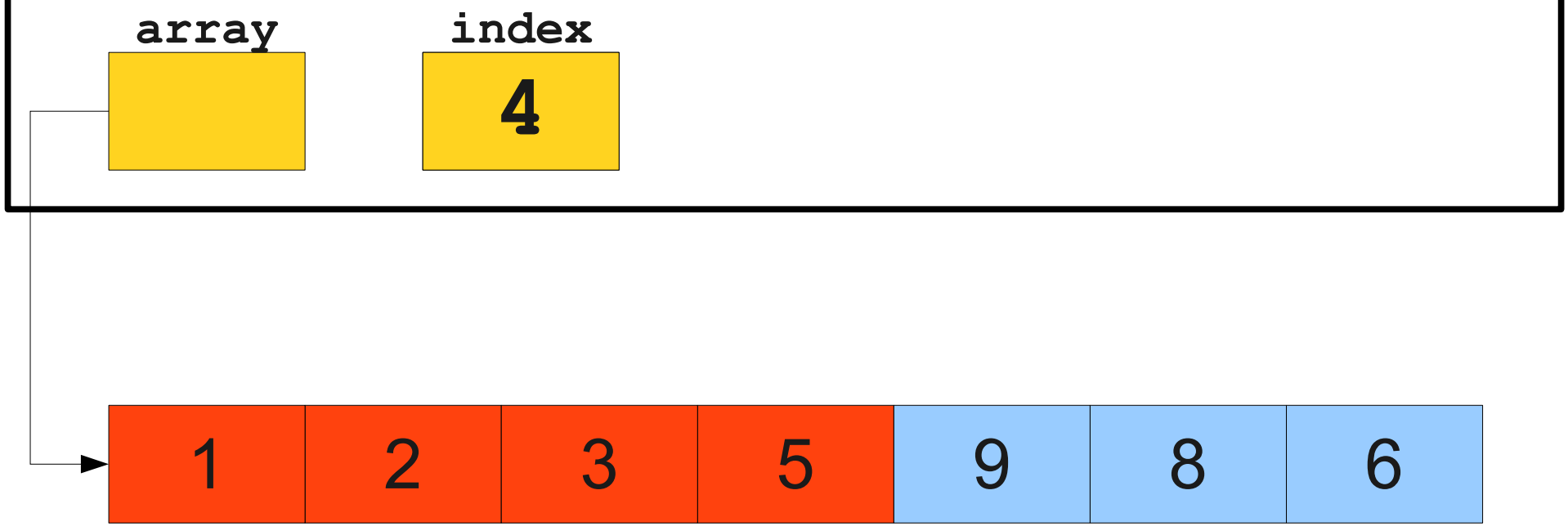

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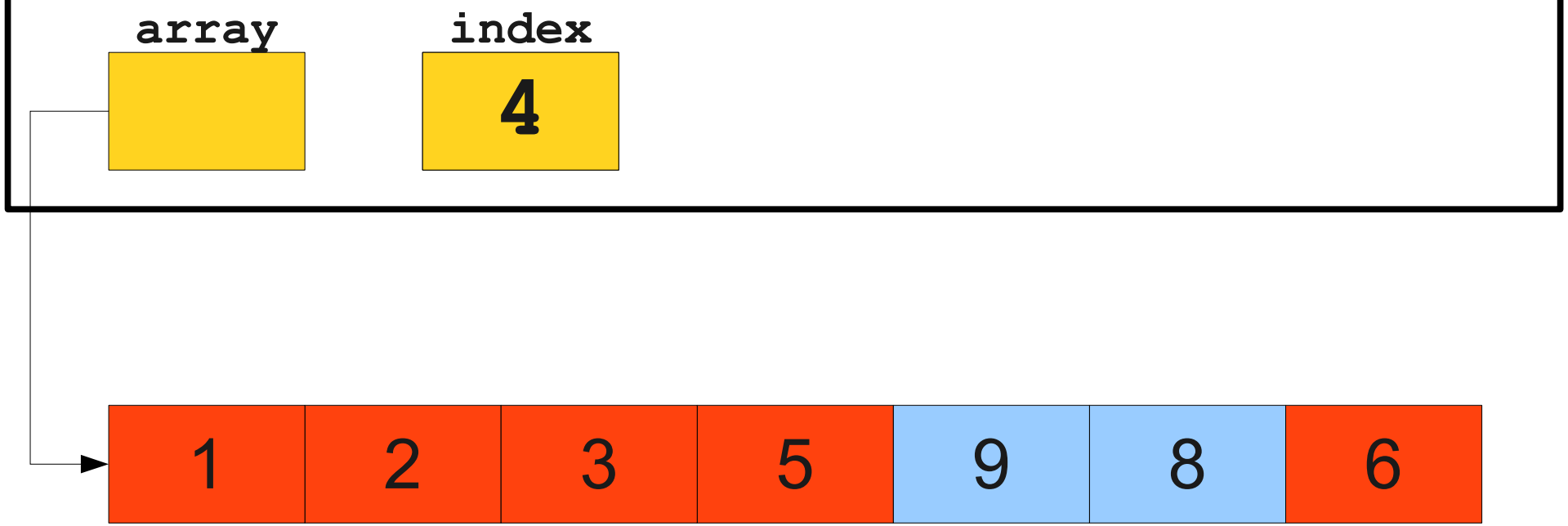

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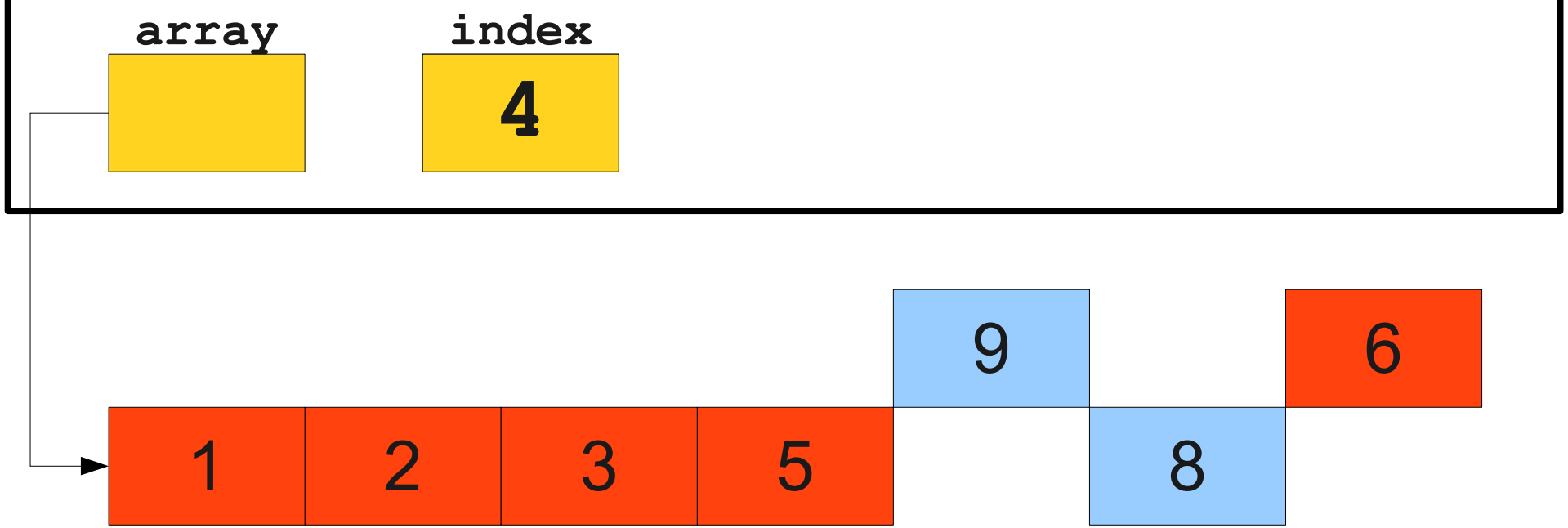

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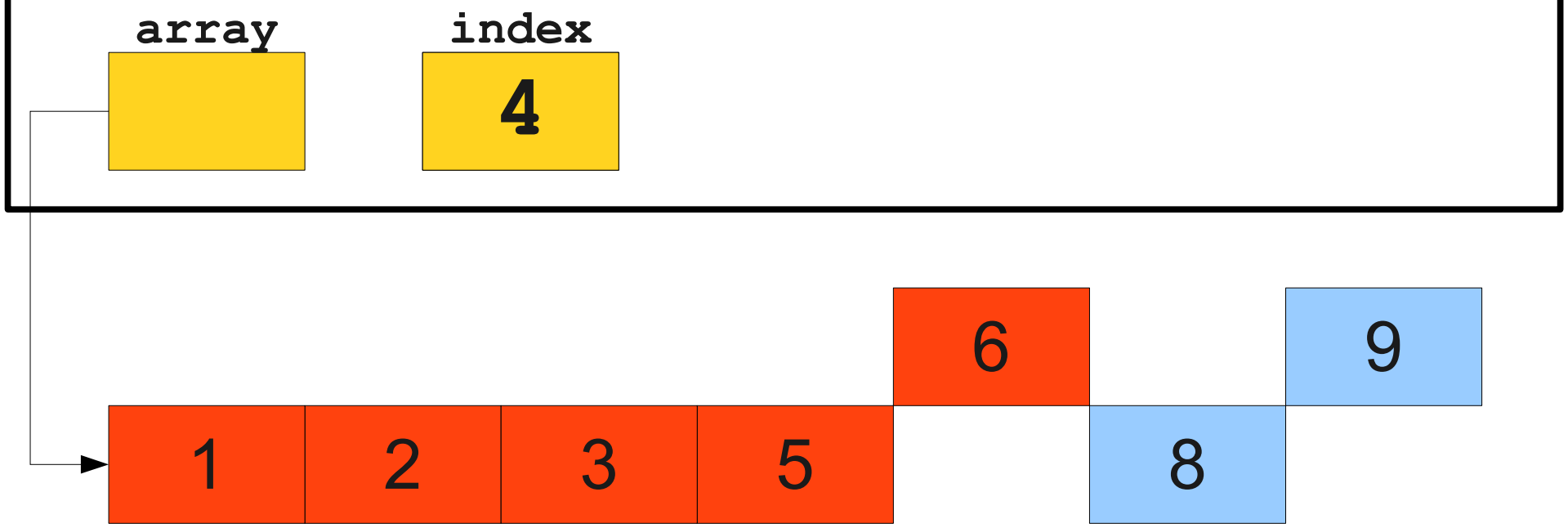

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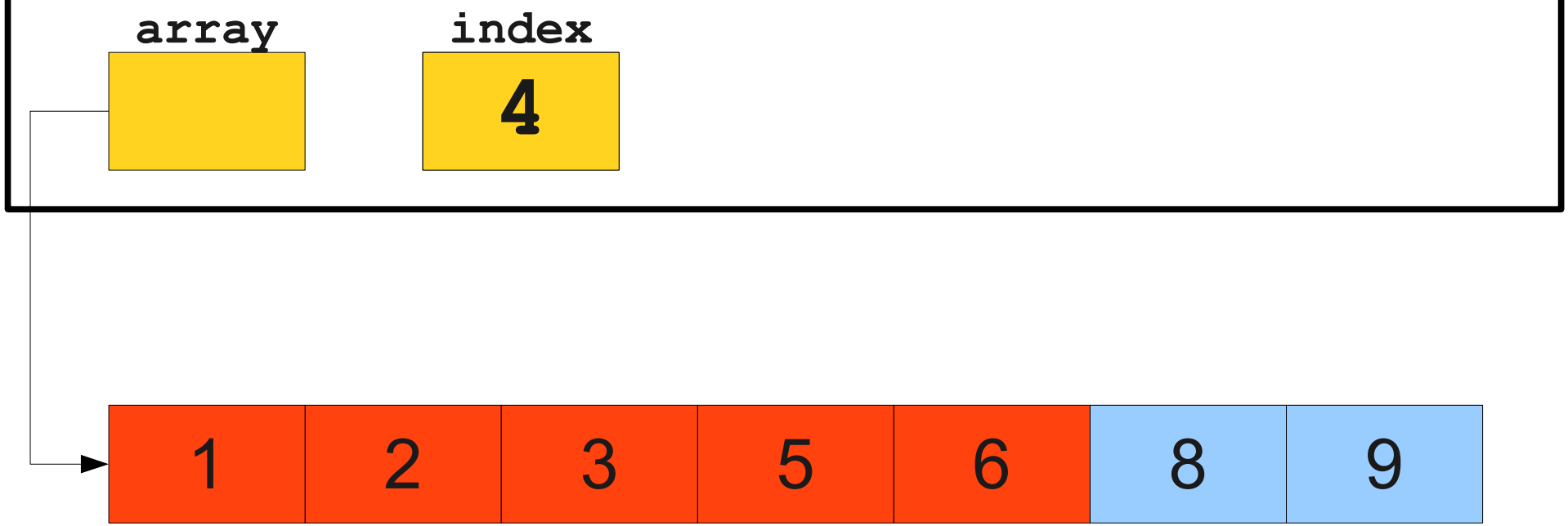

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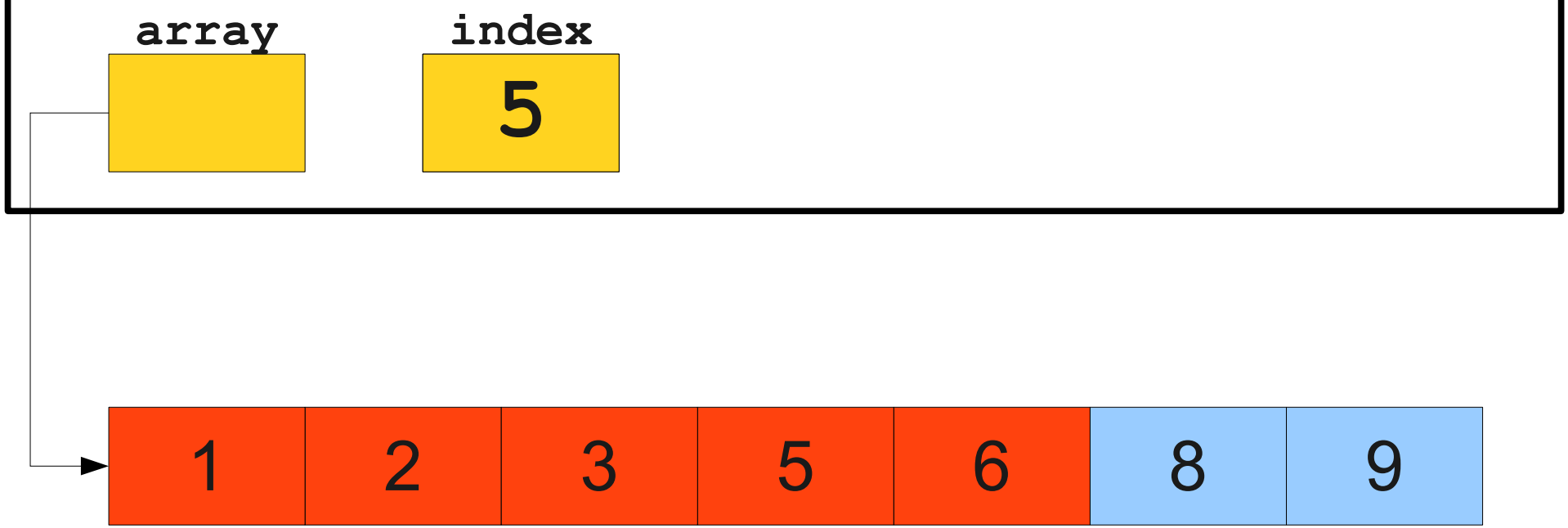

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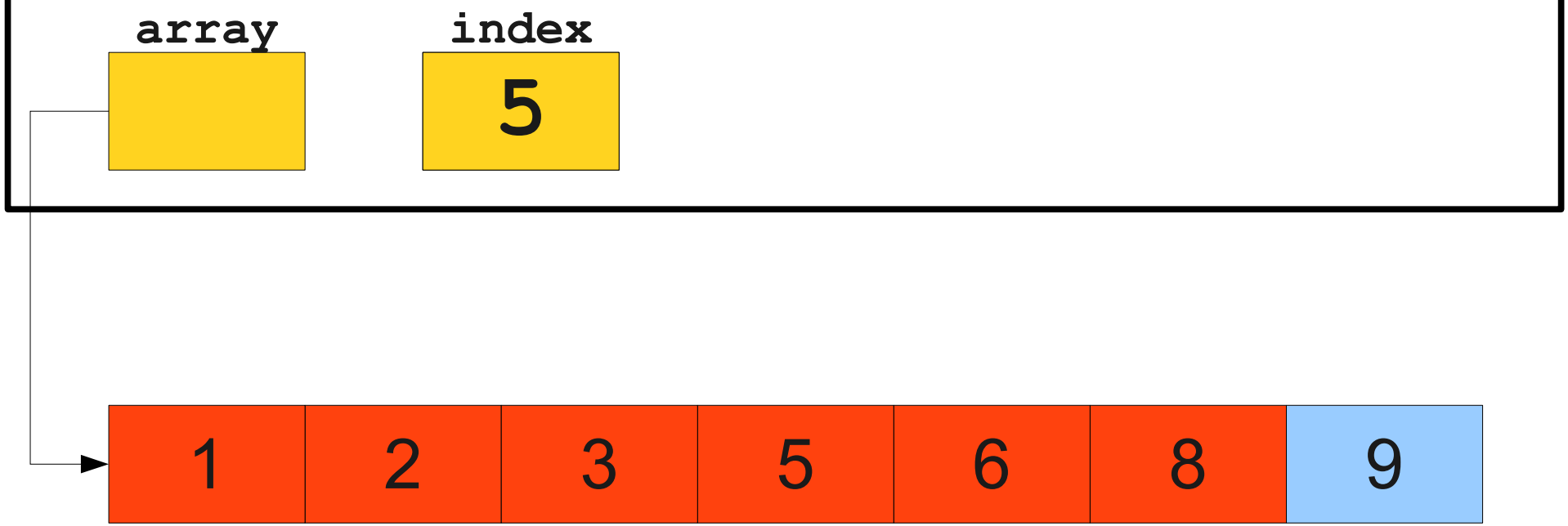

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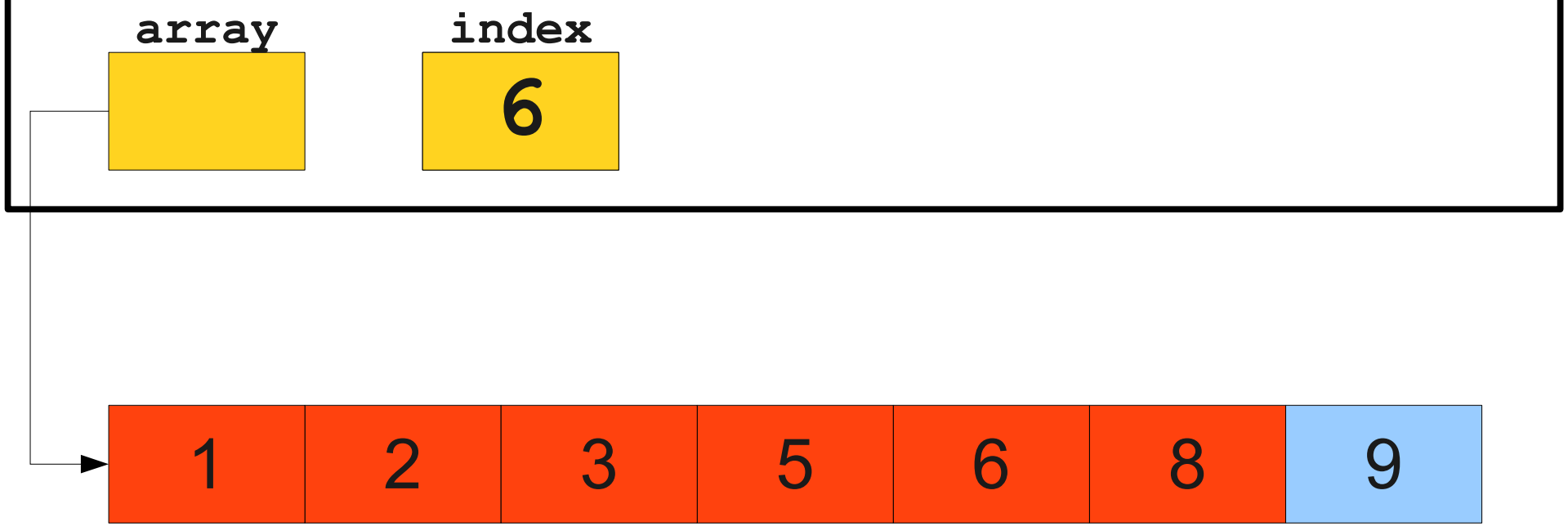

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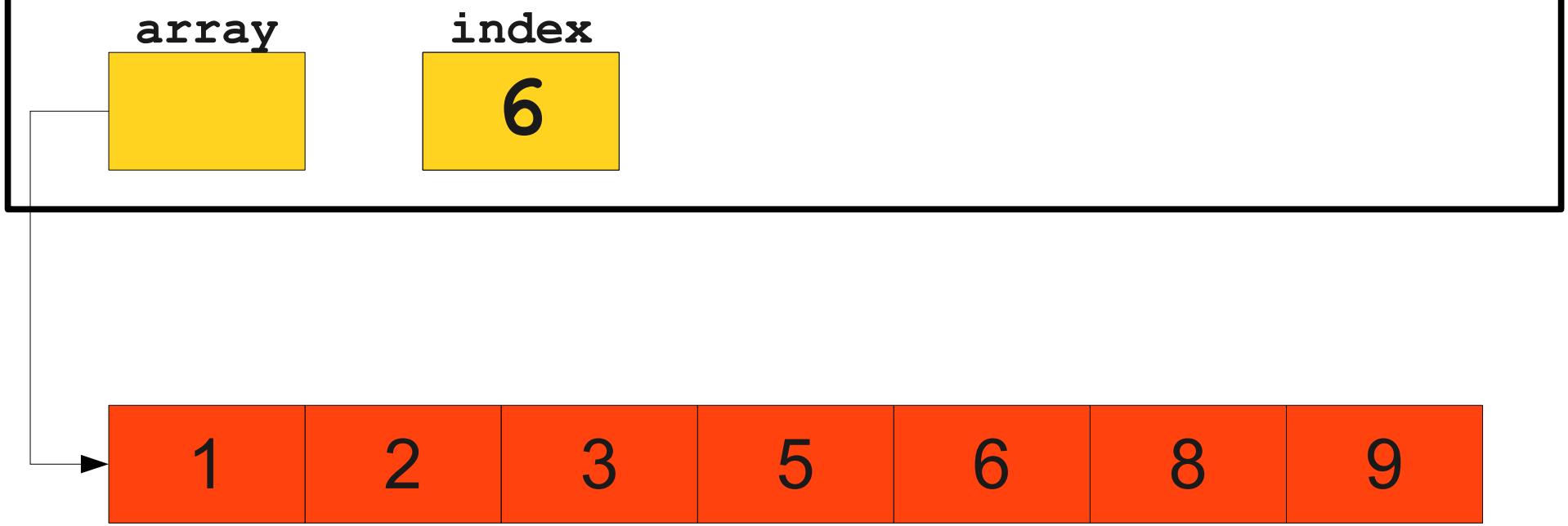

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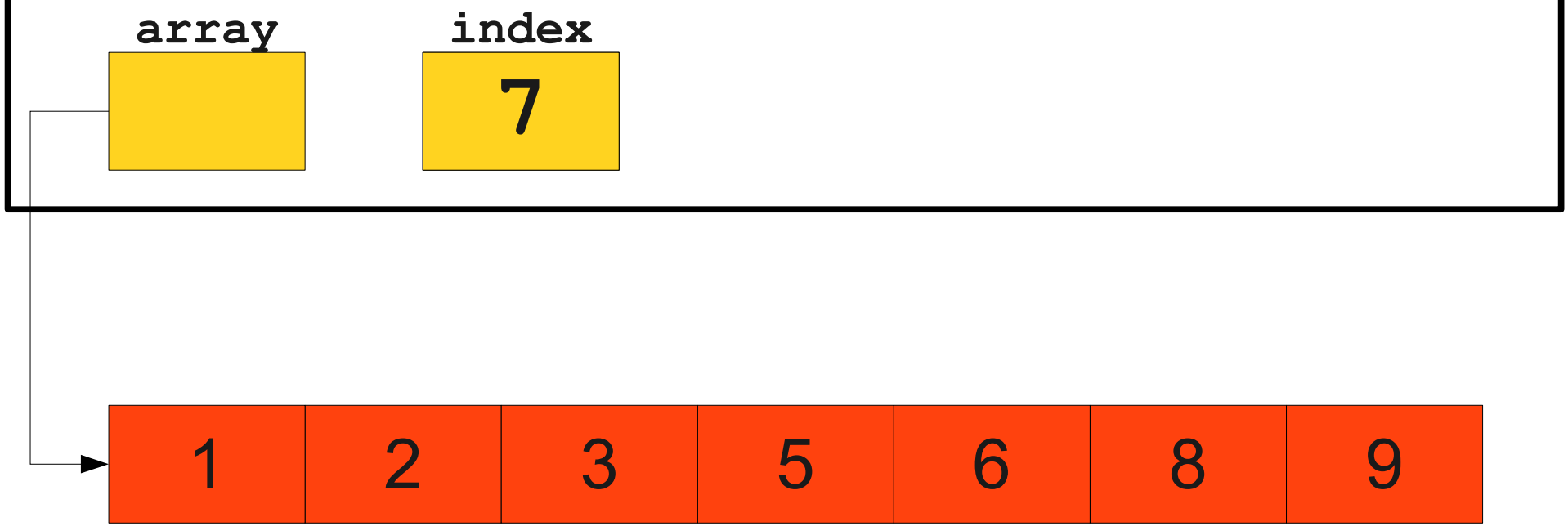
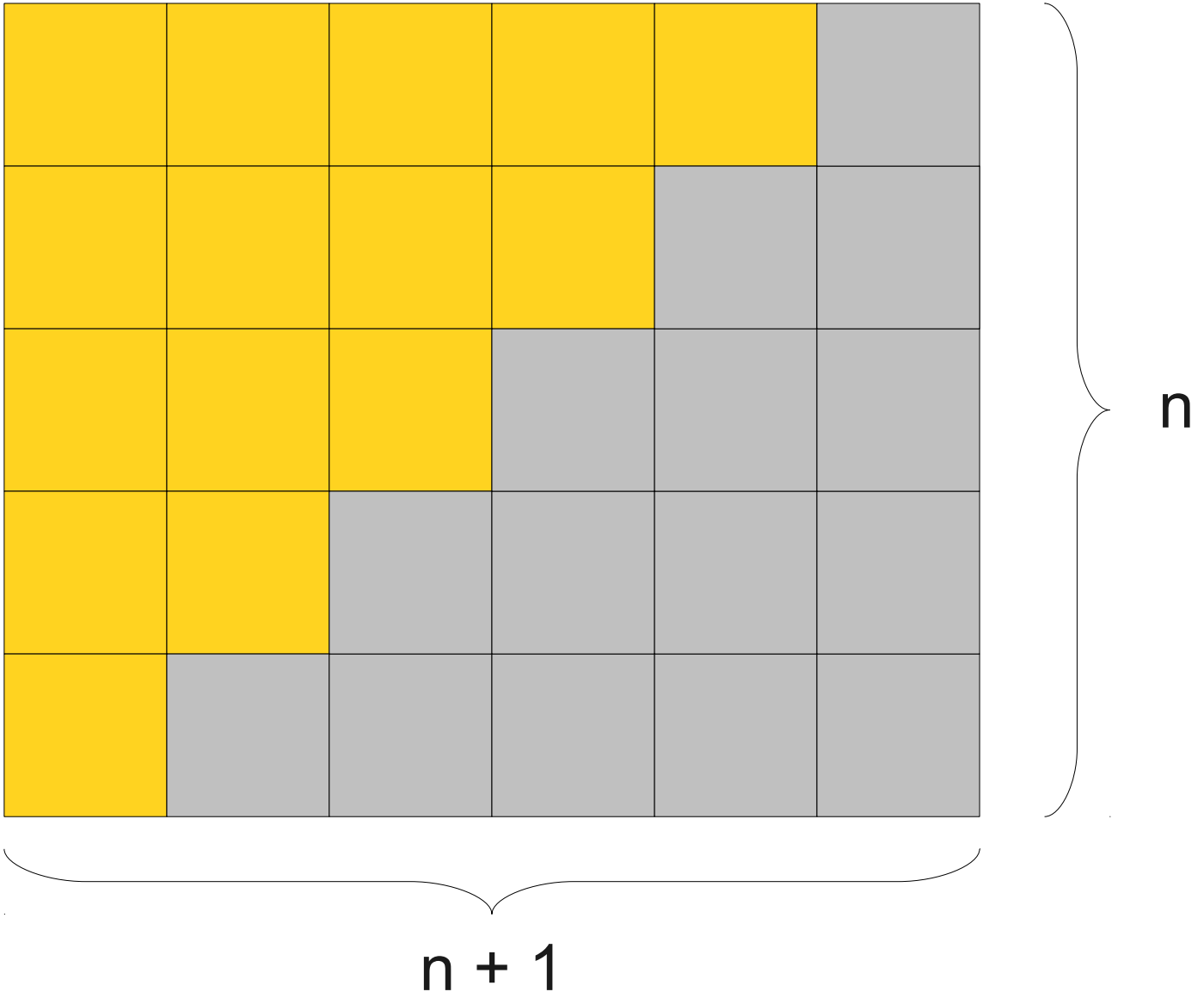


Selection Sort in Action

Analyzing Selection Sort

- How much work do we do for selection sort?
- To find the smallest value, we need to look at all N array elements.
- To find the second-smallest value, we need to look at N – 1 array elements.
- To find the third-smallest value, we need to look at N – 2 array elements.
- Work is $N + (N - 1) + (N - 2) + \ldots + 1$.

$$1 + 2 + \ldots + (n - 1) + n = n(n+1) / 2$$



An Interesting Observation

- Selection sort does roughly $N^2 / 2$ array lookups.
- Suppose we double the number of elements in the array we want to sort.
- How much longer will it take to sort the new array?

$$\begin{aligned} & \textit{newTime} / \textit{oldTime} \\ &= ((2N)^2 / 2) / (N^2 / 2) \\ &= (2N)^2 / N^2 \\ &= 4N^2 / N^2 \\ &= 4 \end{aligned}$$

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- So we should expect it to take about four times longer.

Analyzing Selection Sort

- Work done is roughly $N^2 / 2$.

N	$N^2 / 2$
10	50
100	5,000
1000	500,000
1,000,000	500,000,000,000
1,000,000,000	500,000,000,000,000,000

Analyzing Selection Sort

- Work do

N	
10	
10	
100	
1,000	,000
1,000,000,000	500,000,000,000,000,000

A Few Other Sorting Algorithms