SORTING

CS062

DATA STRUCTURES AND ADVANCED PROGRAMMING

12: Sorting Fundamentals

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Lecture 12: Sorting Fundamentals

- Introduction
- Selection sort
- Insertion sort

Some slides adopted from Algorithms 4th Edition or COS226

Why study sorting?

- It's more common than you think: e.g., sorting flights by price, contacts by last name, files by size, emails by day sent, neighborhoods by zipcode, etc.
- Good example of how to compare the performance of different algorithms for the same problem.
- Some sorting algorithms relate to data structures.
- Sorting your data will often be a good starting point when solving other problems (keep that in mind for interviews).

Definitions

- Sorting: the process of arranging n items of a collection in non-decreasing order (e.g., numerically or alphabetically).
- Key: assuming that an item consists of multiple components, the key is the property based on which we sort items.
  - Examples: items could be books and potential keys are the title or the author which can be sorted alphabetically or the ISBN which can be sorted numerically.

Total order

- Sorting is well defined if and only if there is total order.
- Total order: a binary relation $\leq$ on a set C that satisfies the following statements for all v, w, and x in C:
  - Connexity: $v \leq w$ or $w \leq v$.
  - Transitivity: for all v, w, x, if $v \leq w$ and $w \leq x$ then $v \leq x$.
  - Antisymmetry: if both $v \leq w$ and $w \leq v$, then $v = w$.

How many different algorithms for sorting can there be?

- Adaptive heapsort
- Bitonic sorter
- Block sort
- Bubble sort
- Bucket sort
- Cascade mergesort
- Cocktail sort
- Comb sort
- Flashsort
- Gnome sort
- **Heapsort**
- **Insertion sort**
- Library sort
- **Mergesort**
- Odd-even sort
- Pancake sort
- **Quicksort**
- Radixsort
- **Selection sort**
- Shell sort
- Spaghetti sort
- Treesort
- ...

Rules of the game - Comparing

- We will be sorting arrays of n items, where each item contains a key. In Java, objects are responsible in telling us how to *naturally* compare their keys.
- Let's say we want to sort an array of objects of type T.
- Our class `T` should implement the `Comparable` interface (more on this in a few lectures). We will need to implement the `compareTo` method to satisfy a total order.

https://docs.oracle.com/javase/8/docs/api/java/lang/Comparable.html

Rules of the game - Comparing

- `public int compareTo(T that)`
- Implement it so that `v.compareTo(w)`:
  - Returns >0 if v is greater than w.
  - Returns <0 if v is smaller than w.
  - Returns 0 if v is equal to w.
- Java classes such as `Integer`, `Double`, `String`, `File` all implement `Comparable`.

https://docs.oracle.com/javase/8/docs/api/java/lang/Comparable.html

Two useful abstractions

- We will refer to data only through comparisons and exchanges.
- Less: Is v less than w?

```
private static boolean less(Comparable v, Comparable w) {
      return v.compareTo(w) < 0;
}
```

- Exchange: swap item in array a[] at index i with the one at index j.

```
private static void exch(Comparable[] a, int i, int j) {
        Comparable swap = a[i];
        a[i]=a[j];

        a[j]=swap;
}
```

Rules of the game - Cost model

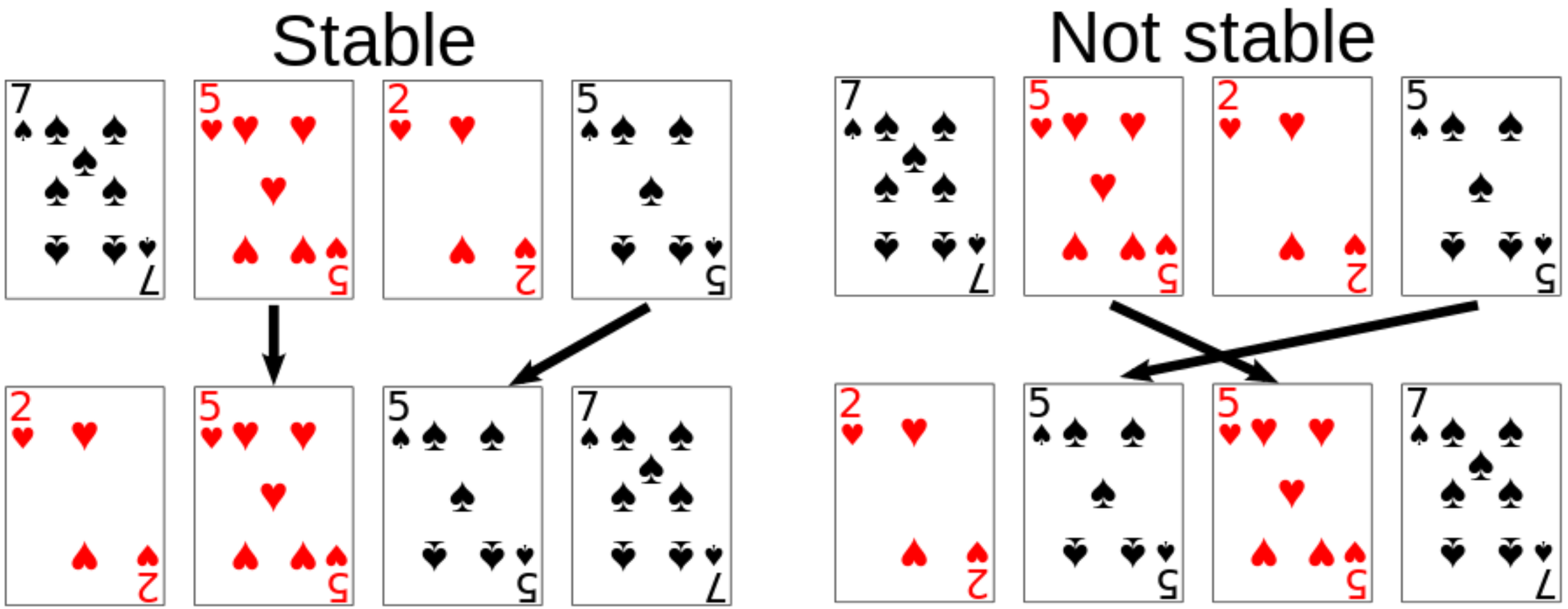
- Sorting cost model: we count compares and exchanges. If a sorting algorithm does not use exchanges, we count array accesses.
- There are other types of sorting algorithms where they are not based on comparisons (e.g., radixsort). We will not see these in CS62 but stay tuned for CS140.

Rules of the game - Memory usage

- Extra memory: often as important as running time. Sorting algorithms are divided into two categories:
  - In place: use constant or logarithmic extra memory, beyond the memory needed to store the items to be sorted.
  - Not in place: use linear auxiliary memory.

Rules of the game - Stability

- Stable: sorting algorithms that sort repeated elements in the same order that they appear in the input.



https://en.wikipedia.org/wiki/Sorting_algorithm#/media/File:Sorting_stability_playing_cards.svg

Lecture 12: Sorting Fundamentals

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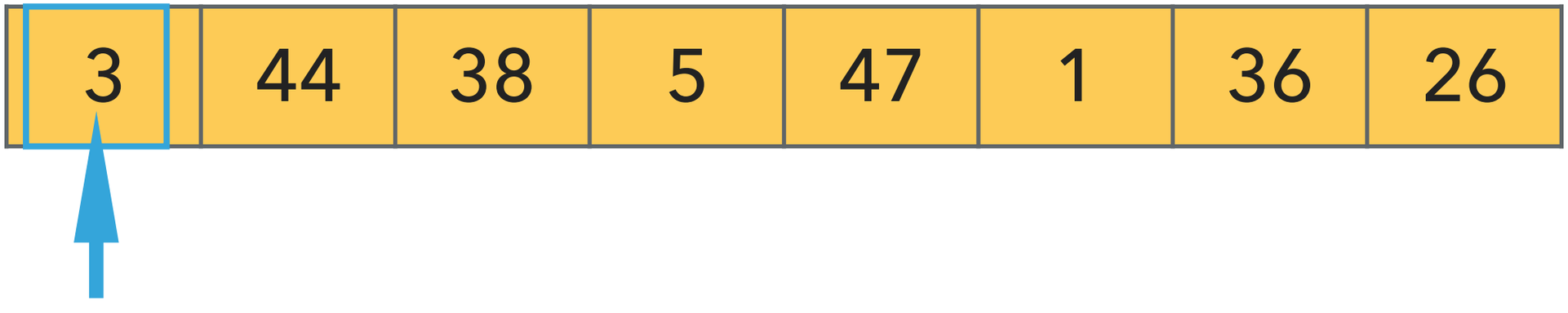
Selection sort

- Divide the array in two parts: a sorted subarray on the left and an unsorted on the right.
- Repeat:
  - Find the smallest element in the unsorted subarray.
  - Exchange it with the leftmost unsorted element.
  - Move subarray boundaries one element to the right.

Selection sort



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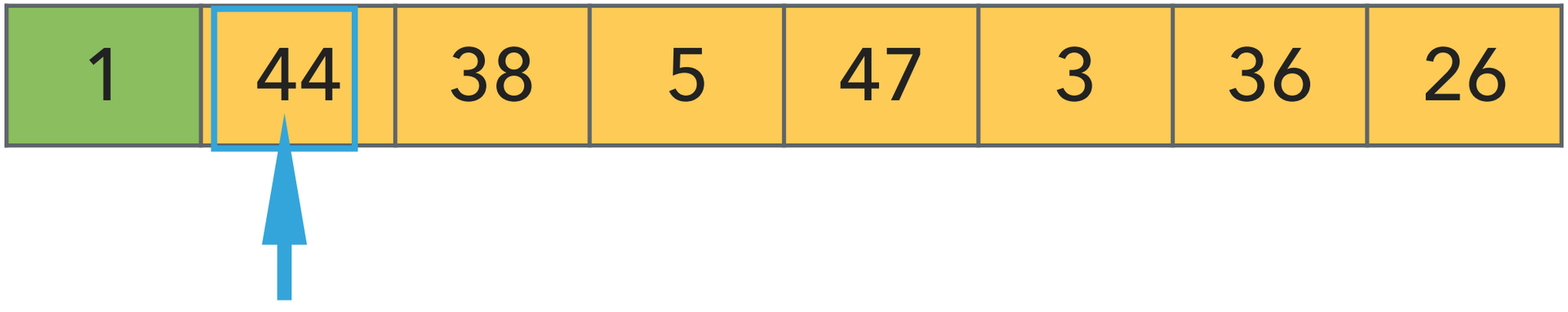

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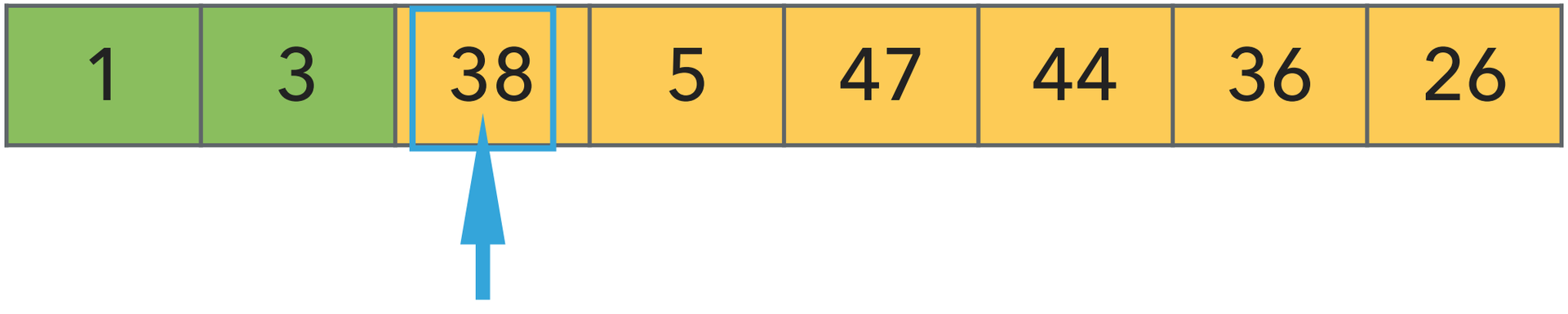

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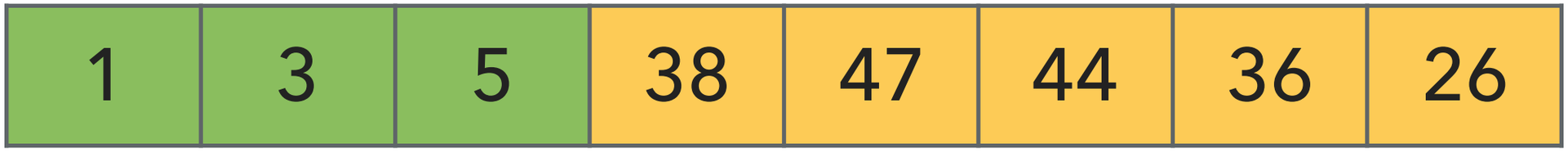

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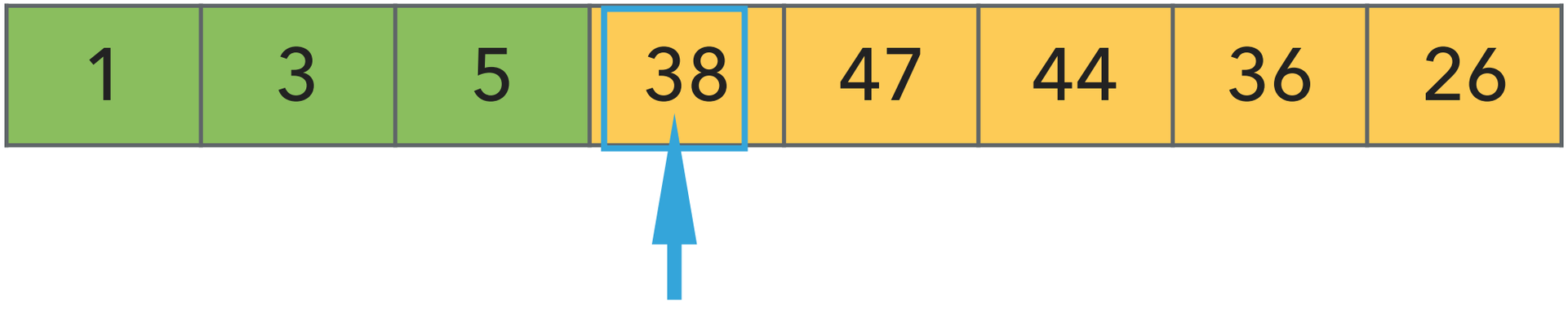

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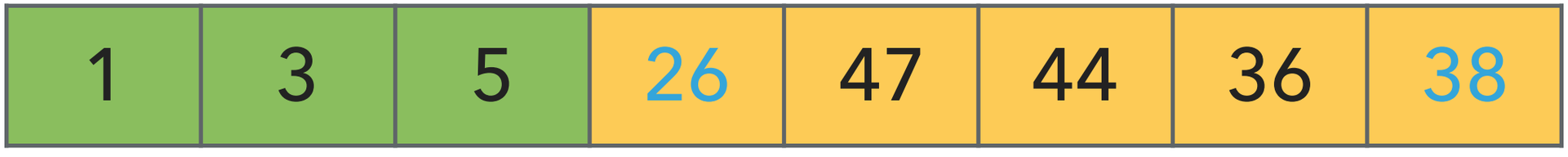

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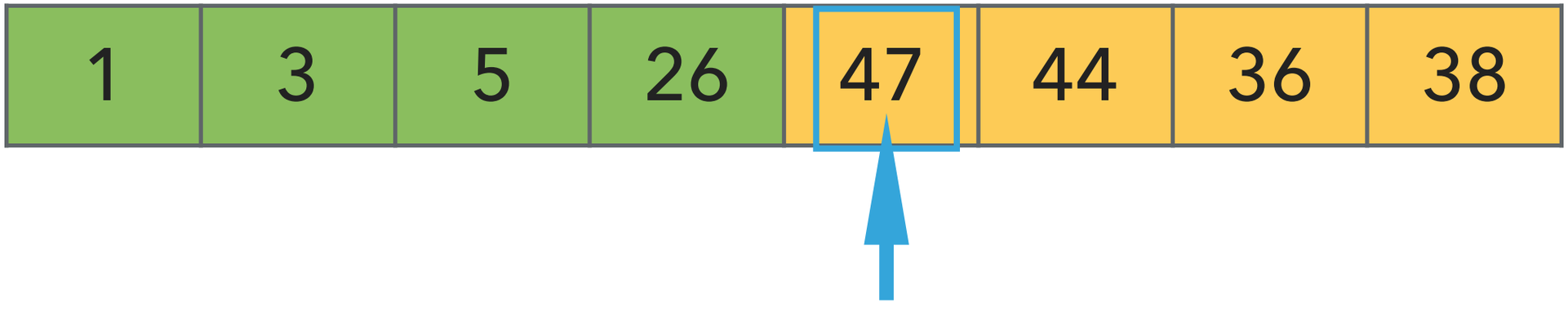

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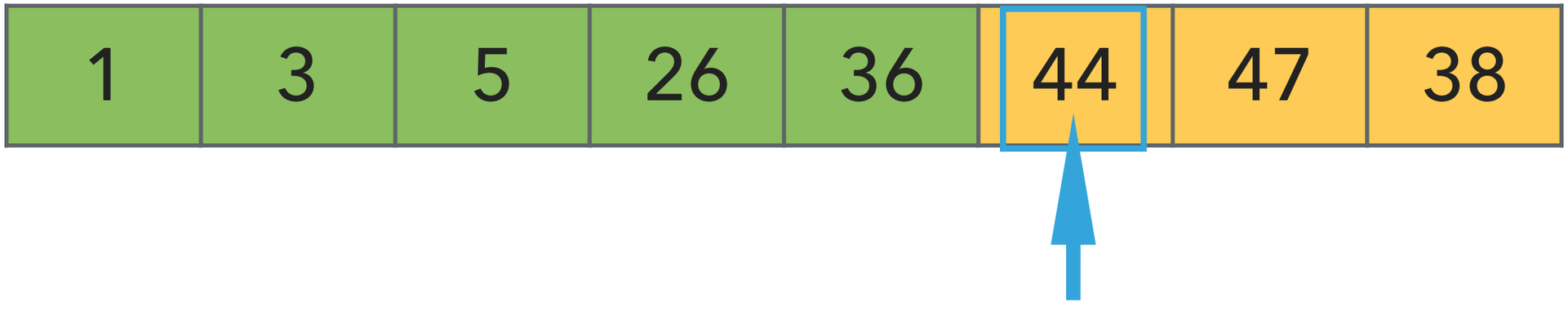

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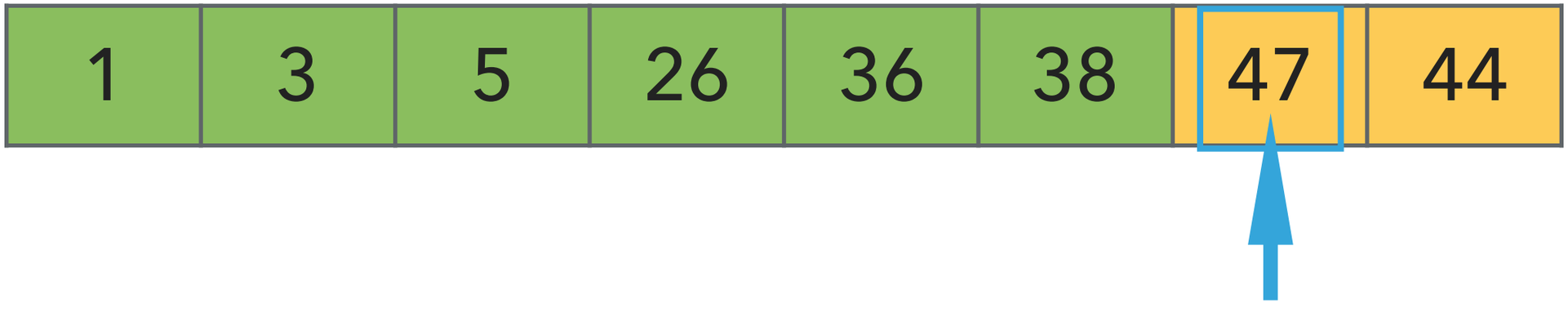

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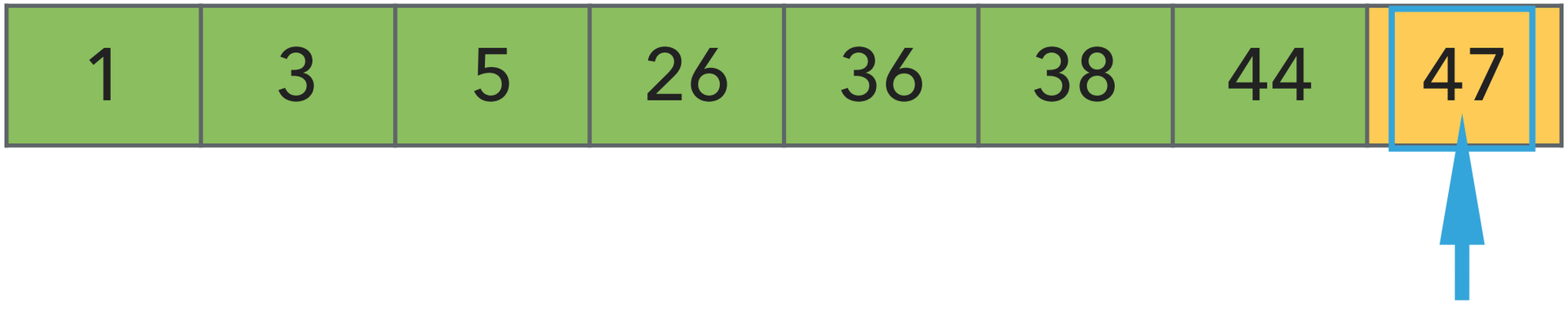

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Selection sort

```
public static void sort(Comparable[] a) {



}
```

Selection sort

```
public static void sort(Comparable[] a) {
        int n = a.length;
        for (int i = 0; i < n; i++) {
            int min = i;
            for (int j = i+1; j < n; j++) {
                if (less(a[j], a[min]))
                    min = j;
            }
            exch(a, i, min);
        }
    }
```

← In iteration i

← Find the index min of the smallest remaining array

← swap a[i] and a[min]

- Invariants: At the end of each iteration i:
  - the array a is sorted in ascending order for the first i+1 elements a[0…i]
  - no entry in a[i+1…n-1] is smaller than any entry in a[0…i]

Selection sort: mathematical analysis for worst-case

```
public static void sort(Comparable[] a) {
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            for (int j = i+1; j < n; j++) {
                if (less(a[j], a[min]))
                    min = j;
                }
            exch(a, i, min);
        }
    }
```

- Comparisons: $1 + 2 + \ldots + (n - 2) + (n - 1) \sim n^2/2$, that is $O(n^2)$.
- Exchanges: n or $O(n)$, making it useful when exchanges are expensive.
- Running time is quadratic, even if input is sorted.
- In-place, requires almost no additional memory.
- Not stable, think of the array [5_a, 3, 5_b, 1] which will end up as [1, 3, 5_b, 5_a].

Practice Time

- Using selection sort, sort the array with elements [12,10,16,11,9,7].
- Visualize your work for every iteration of the algorithm.

SELECTION SORT

Answer

https://subscription.packtpub.com/book/application_development/9781785888731/13/ch13lvl1sec89/selection-sort

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Insertion sort

- Keep a *partially* sorted subarray on the left and an unsorted subarray on the right
- Repeat:
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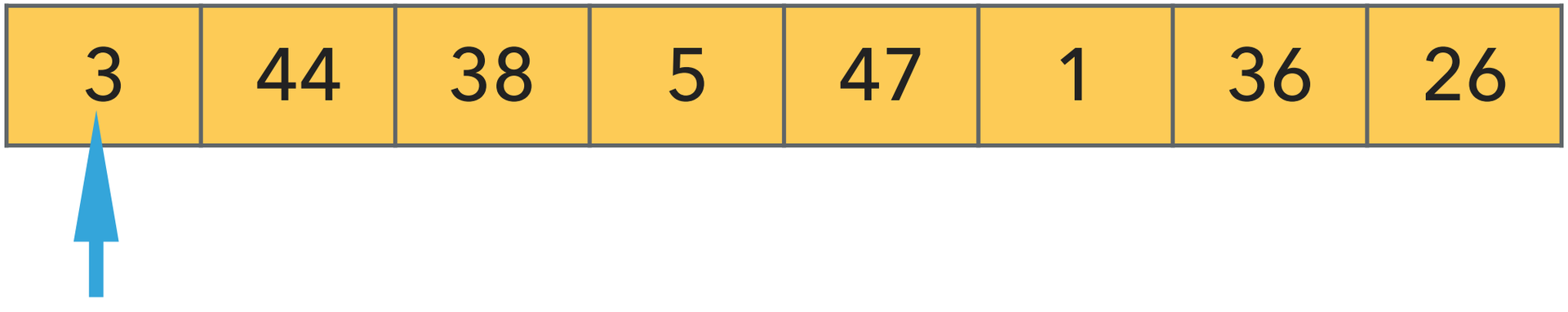

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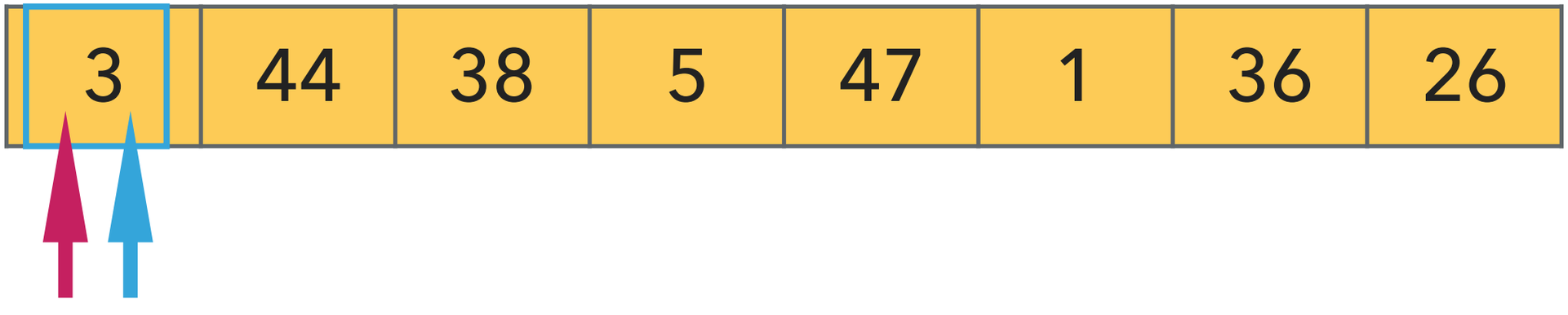

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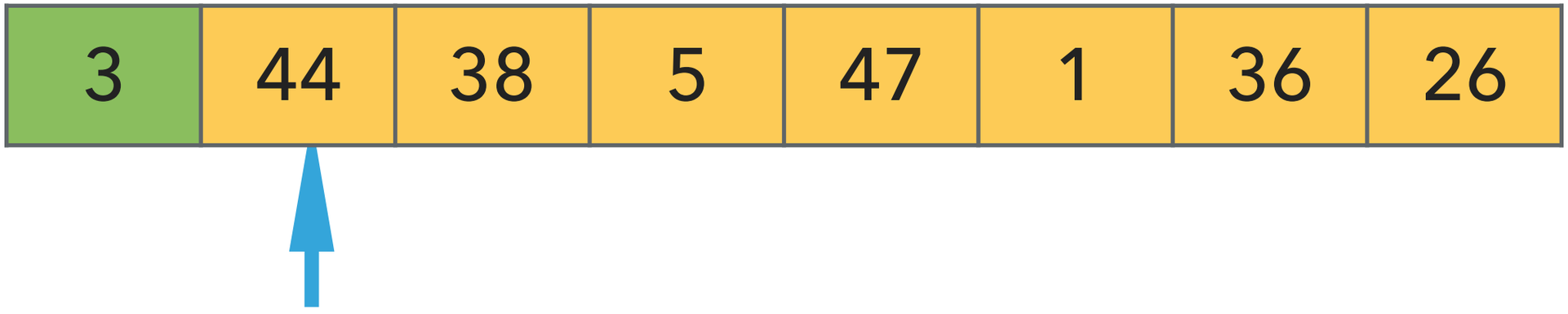

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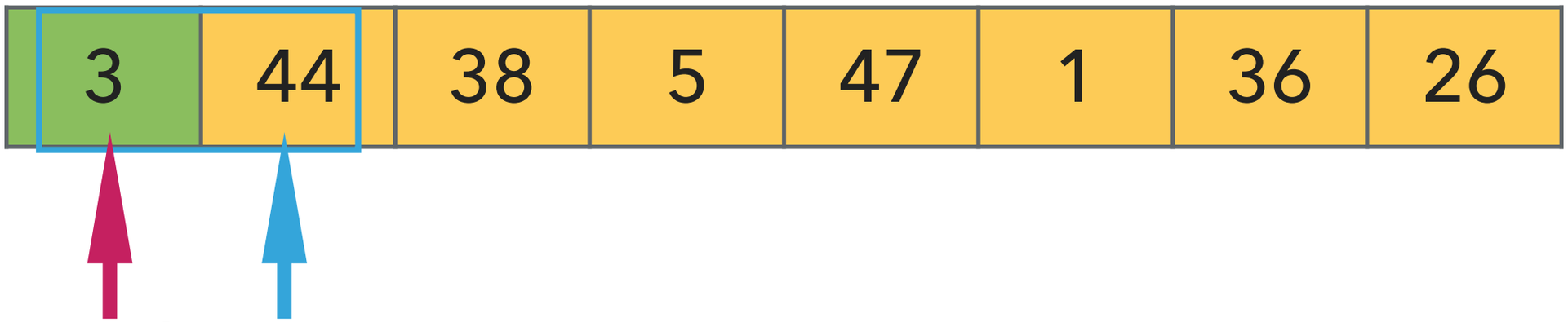

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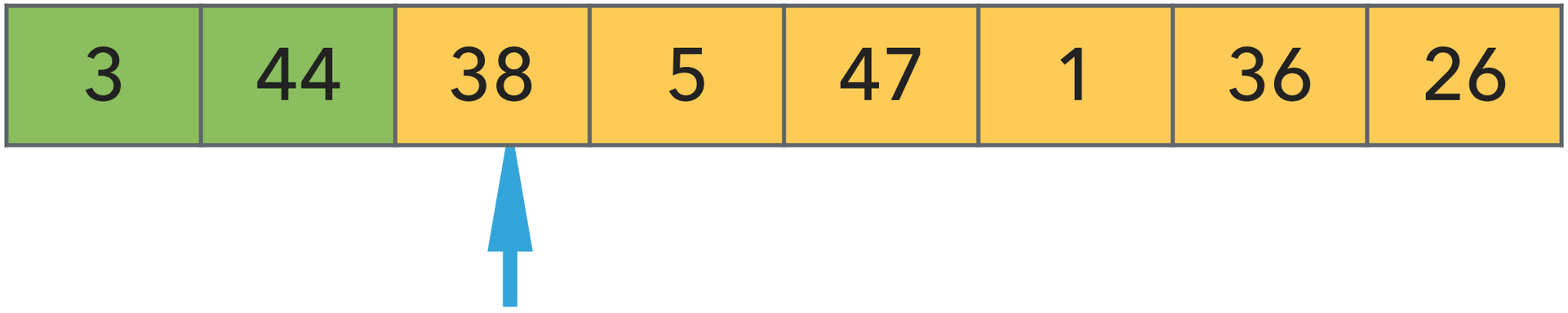

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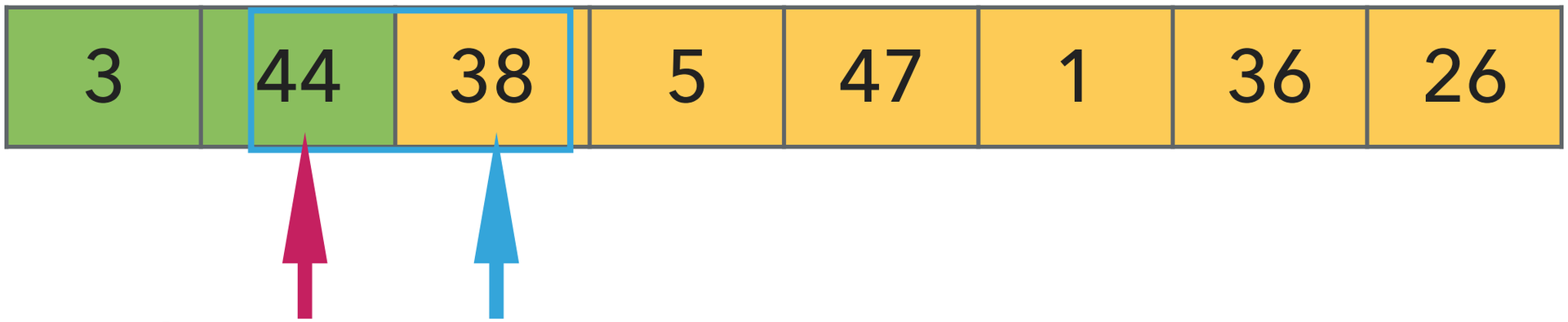

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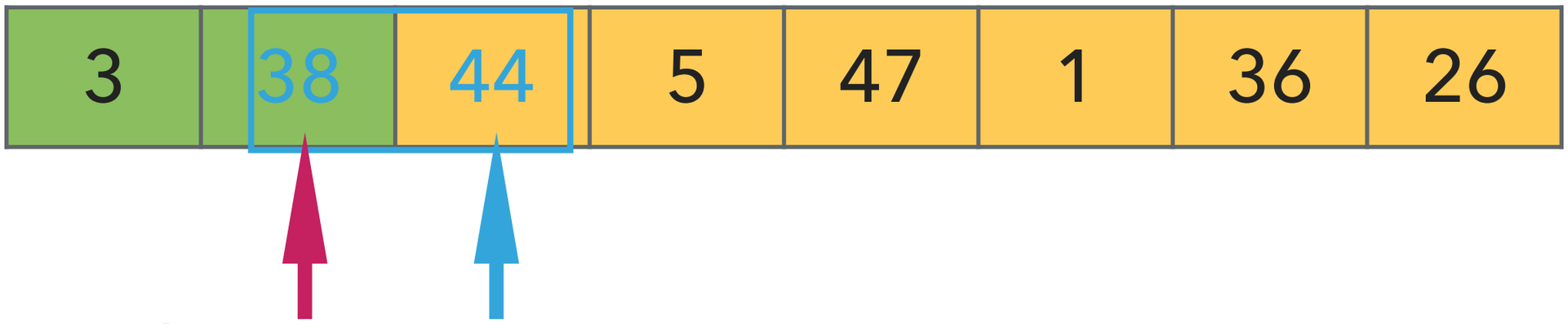

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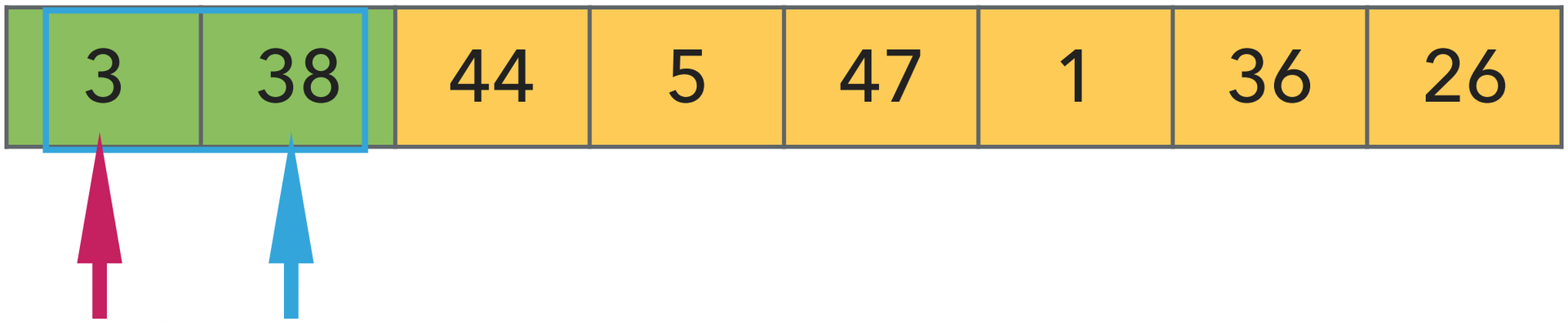

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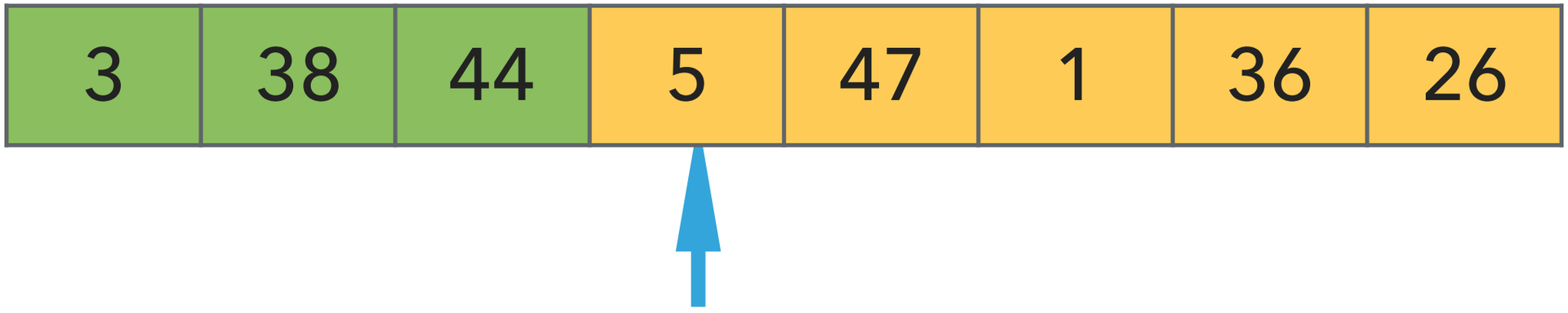

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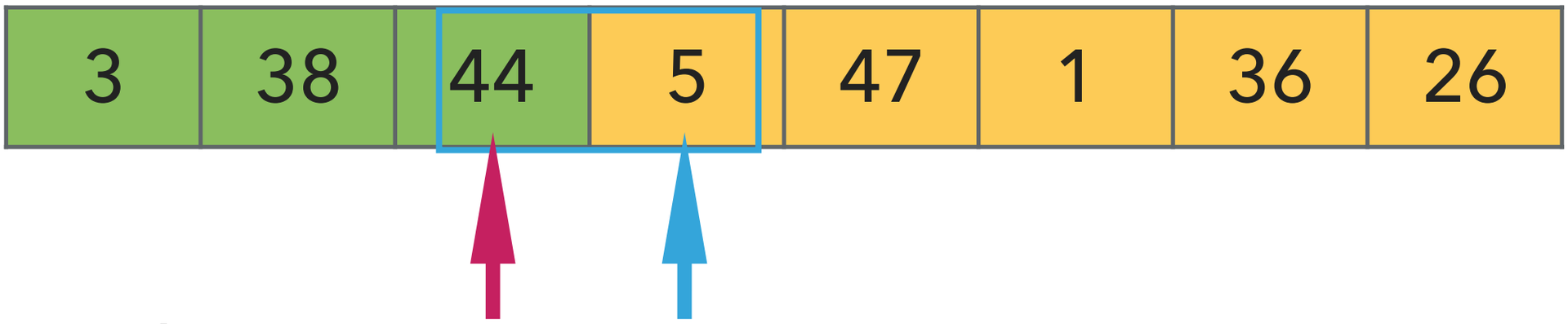

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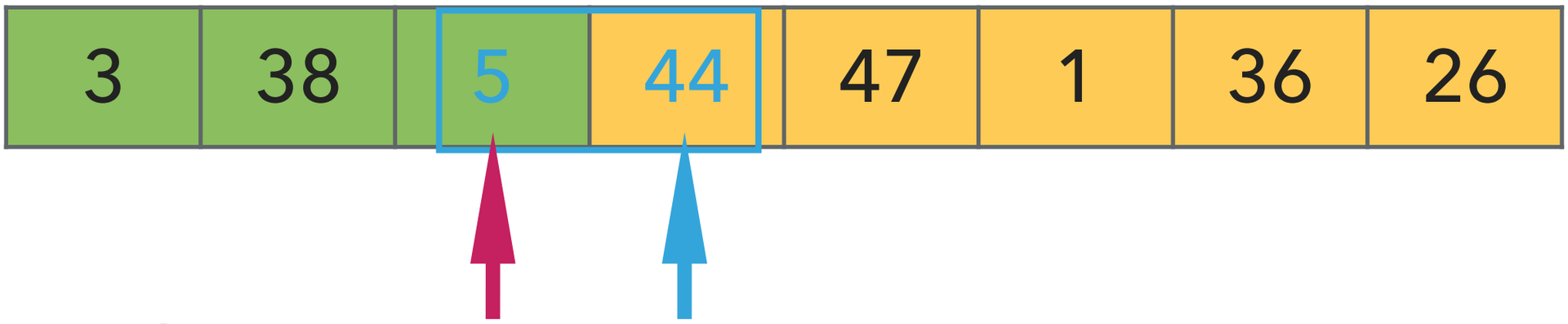

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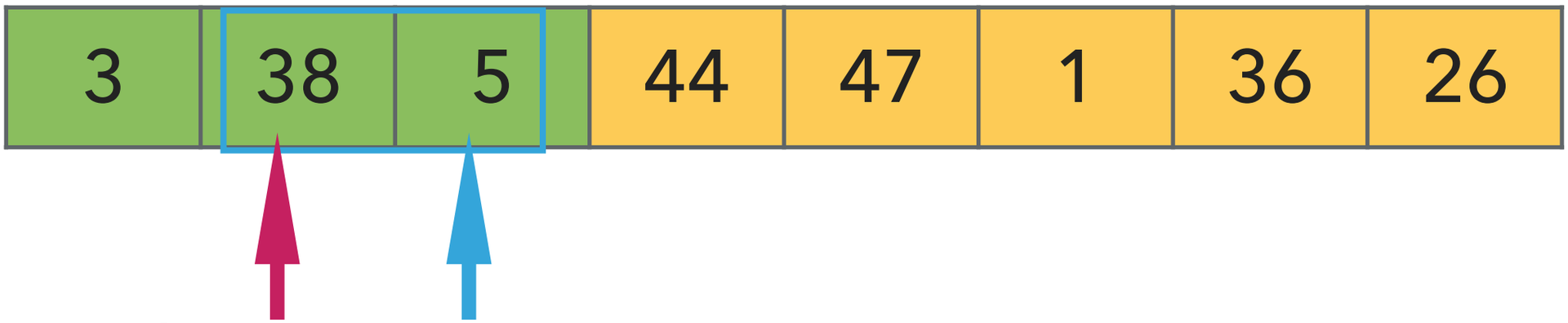

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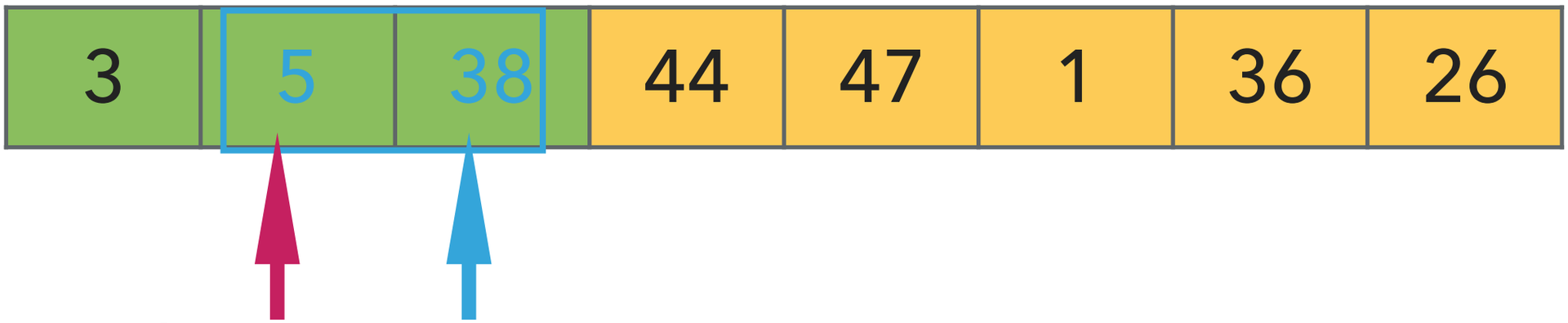

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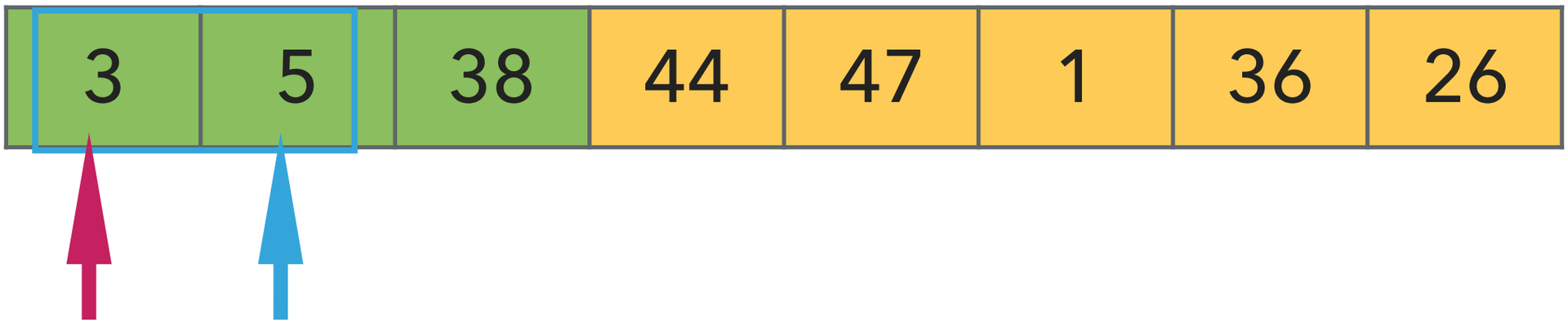

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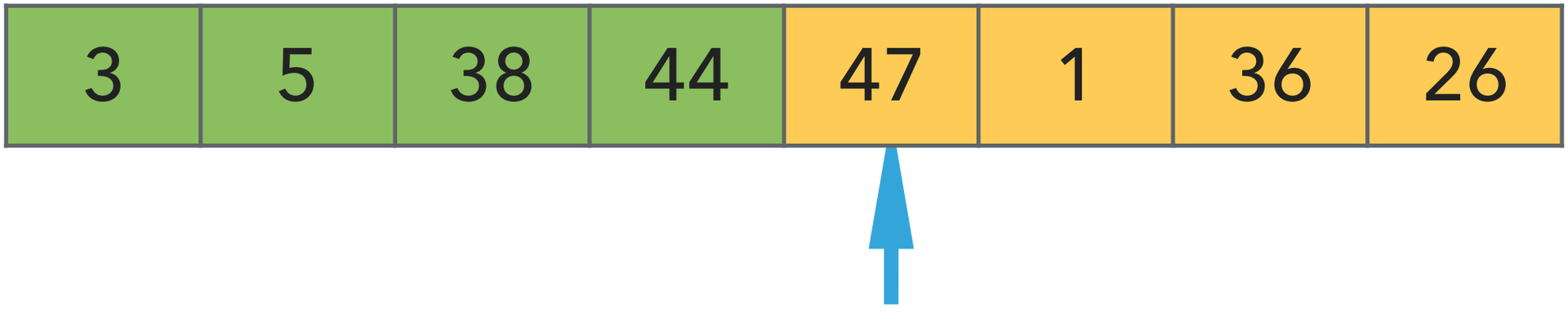

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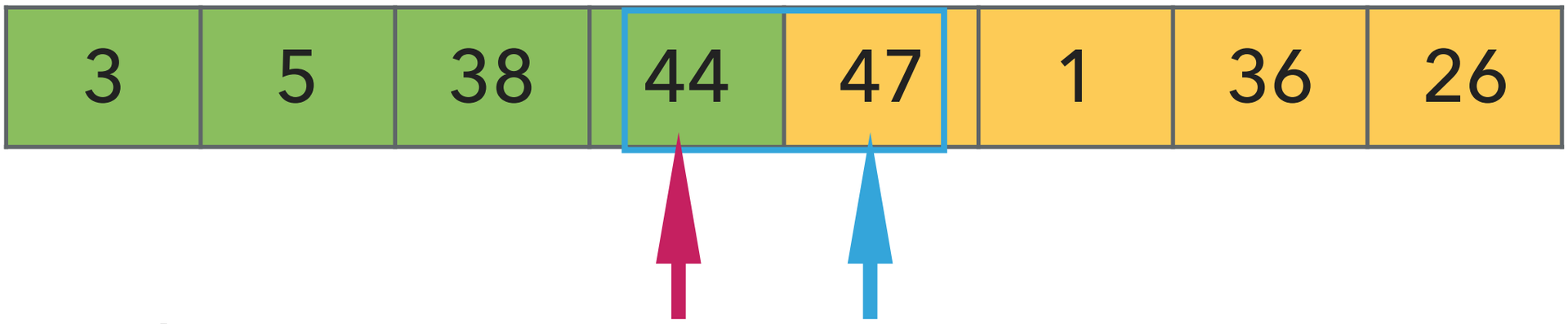

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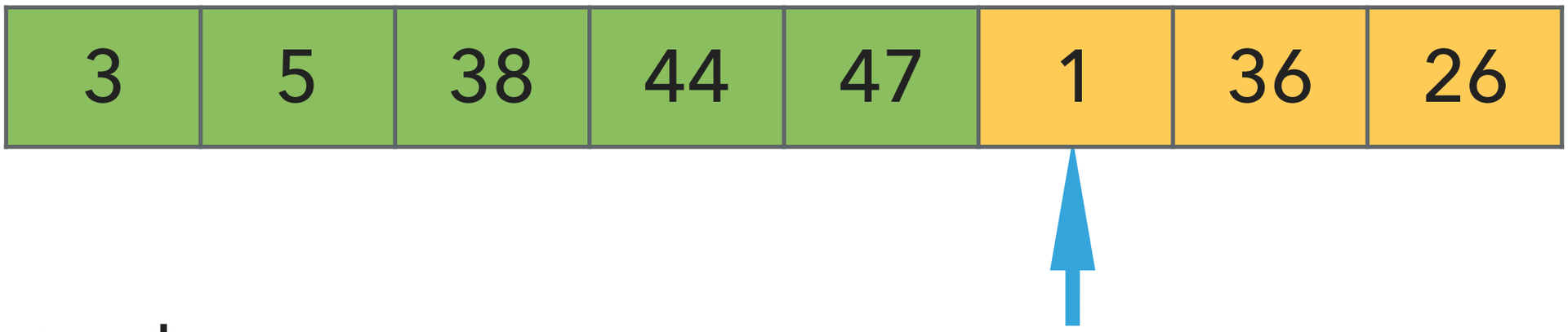

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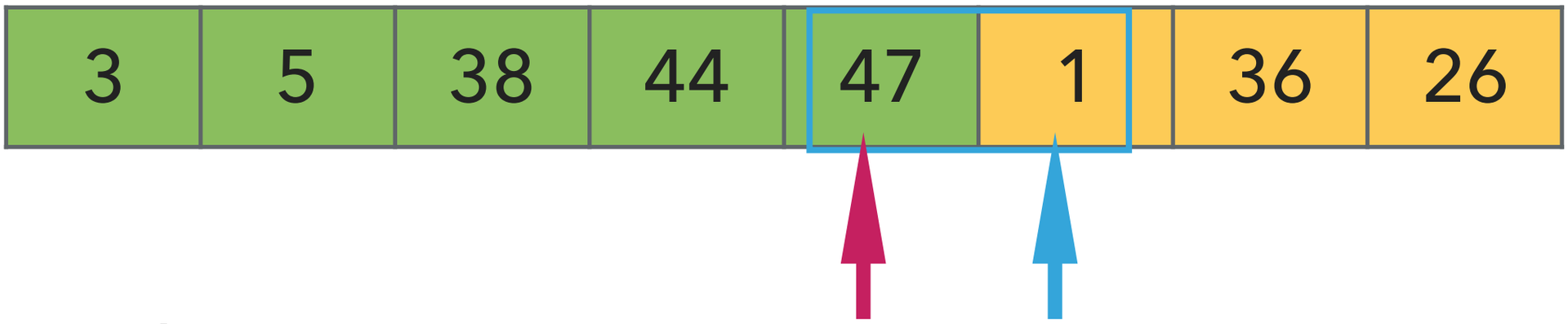
Insertion sort



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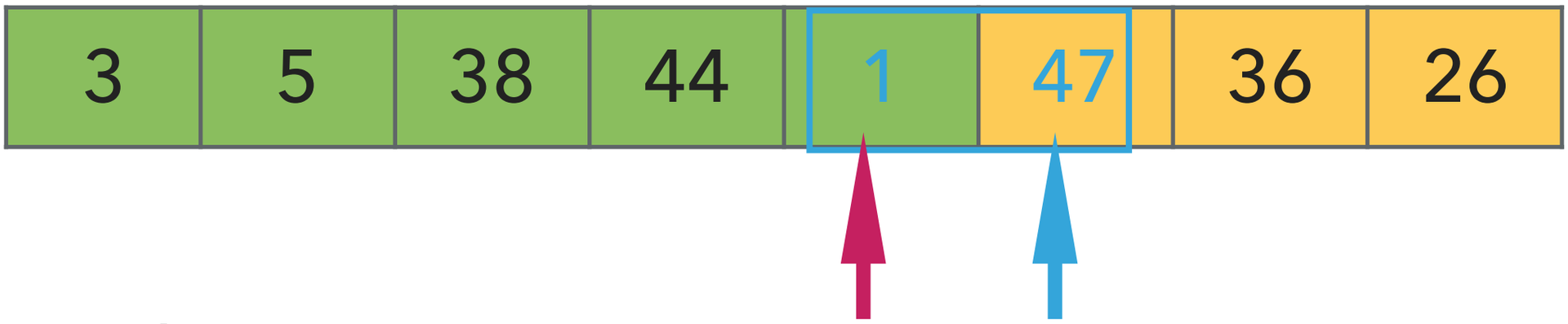

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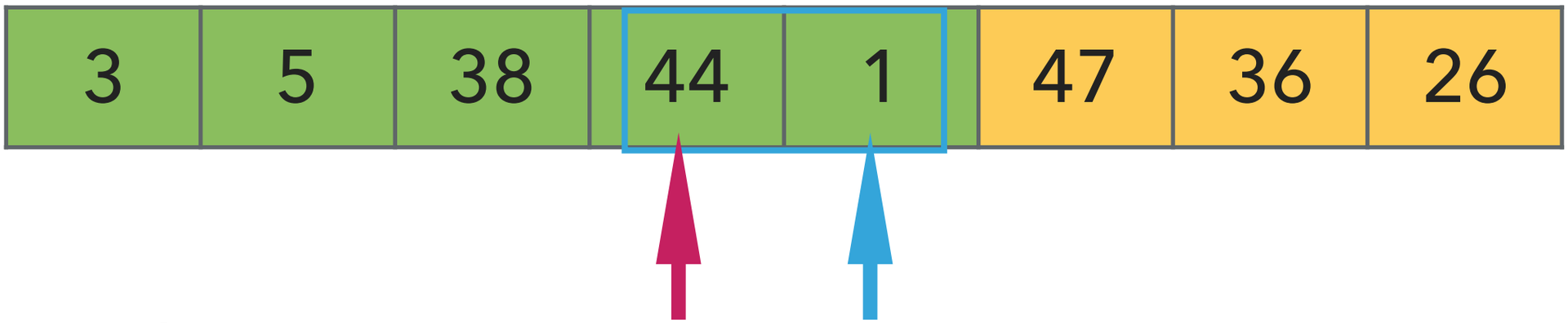

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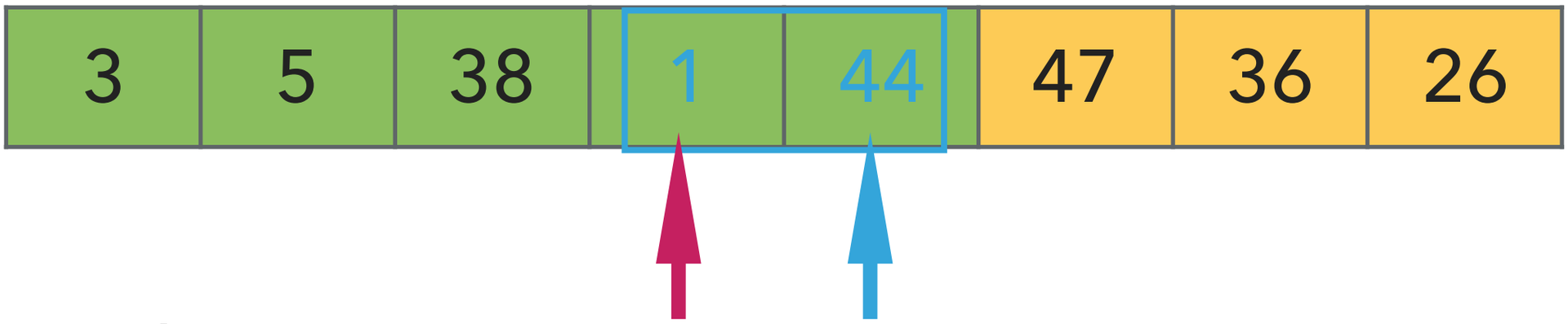

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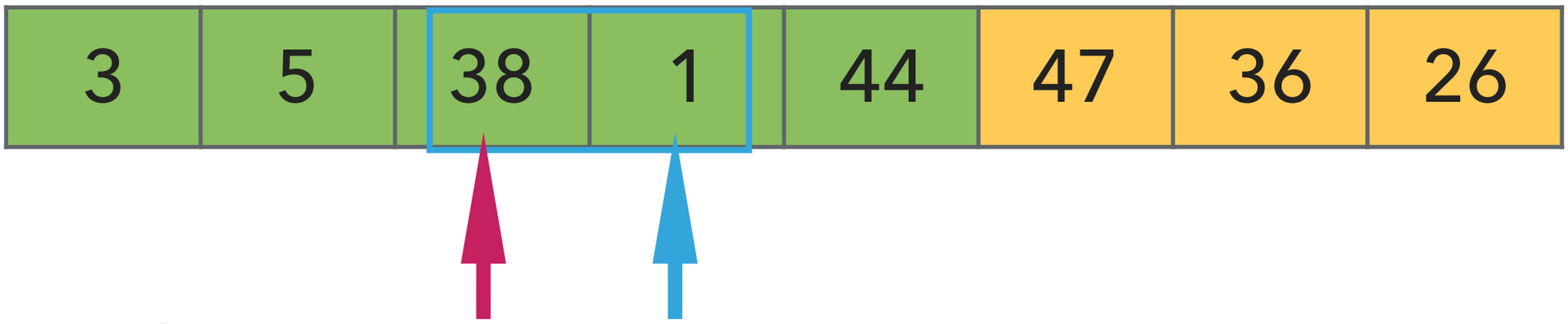

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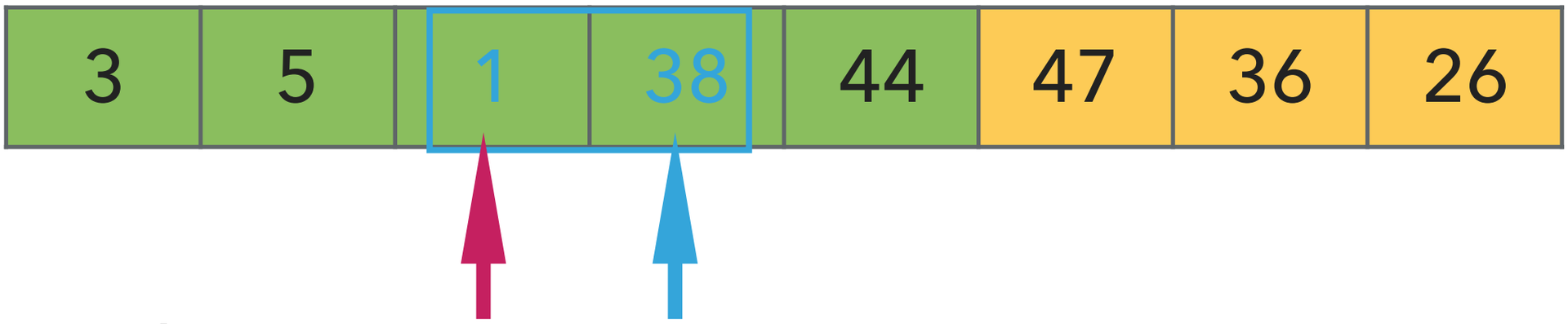

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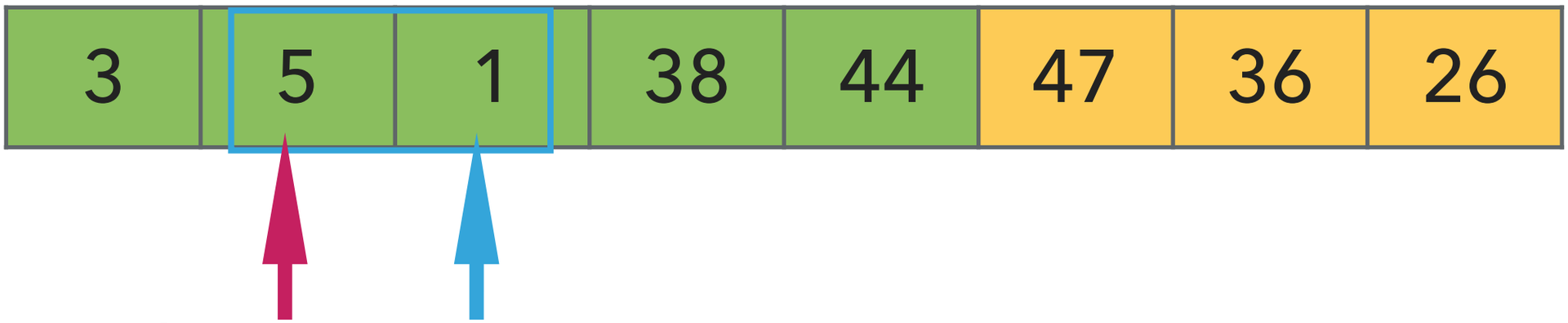

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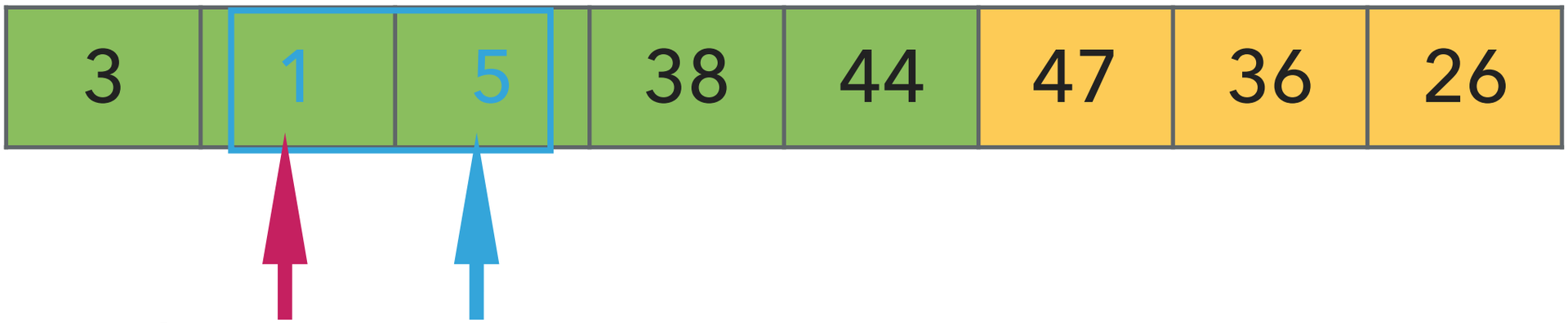

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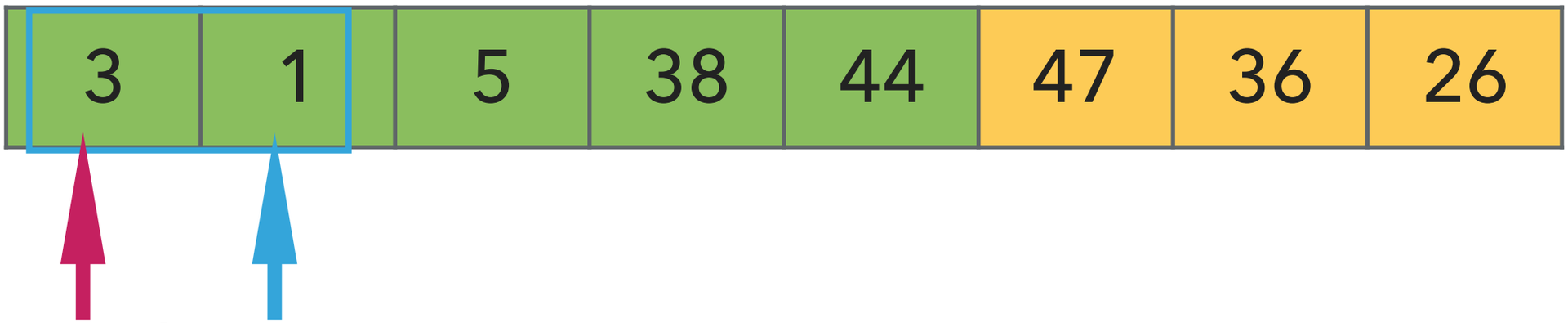

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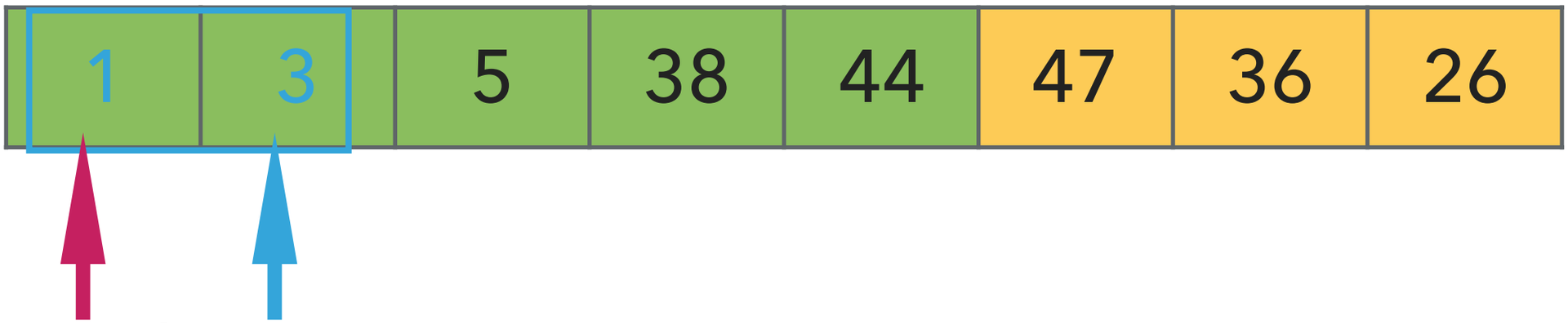

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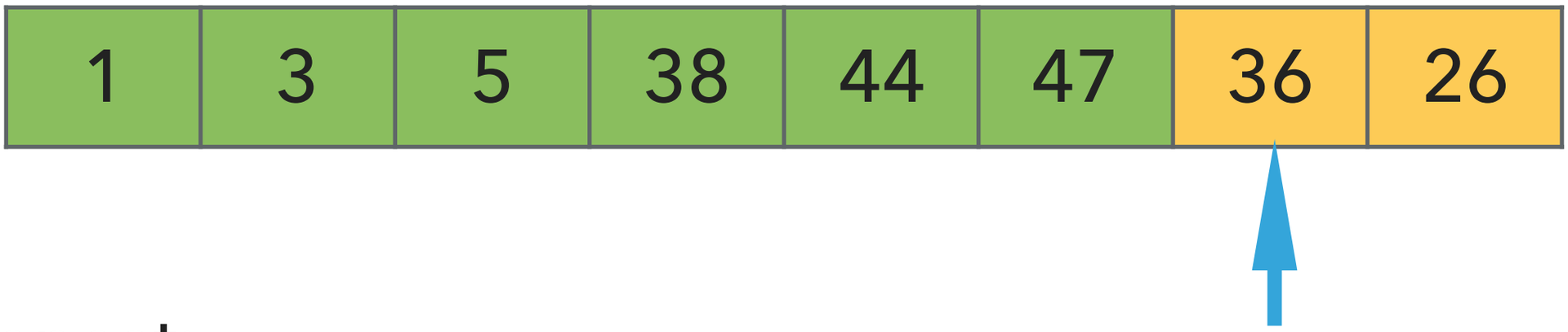

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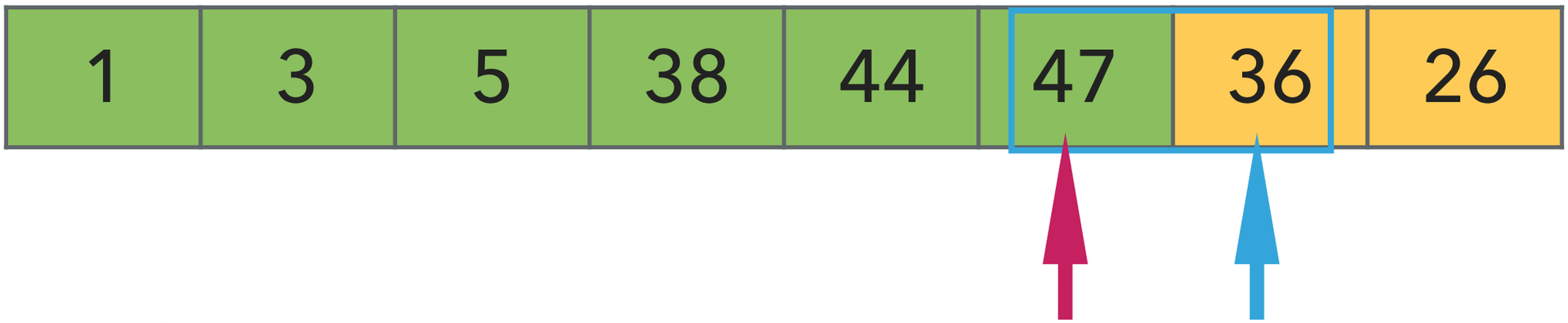

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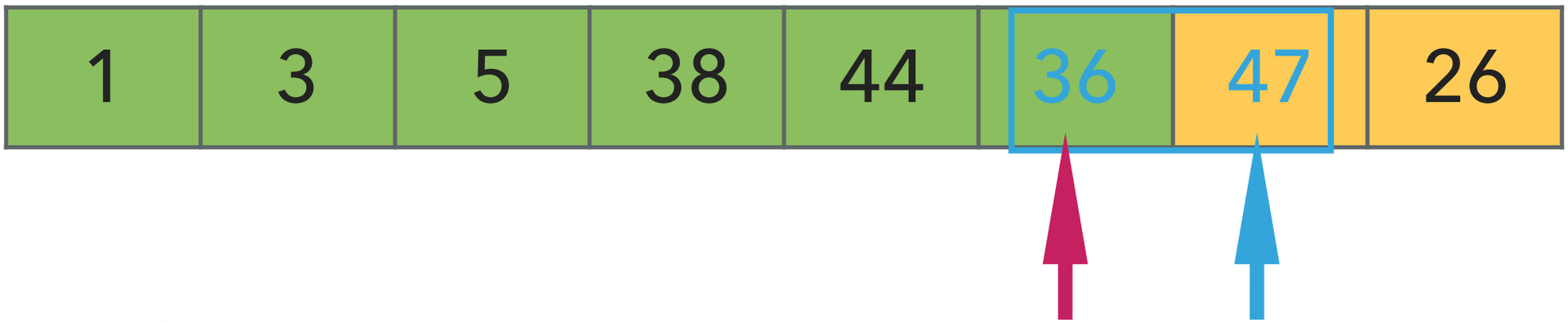

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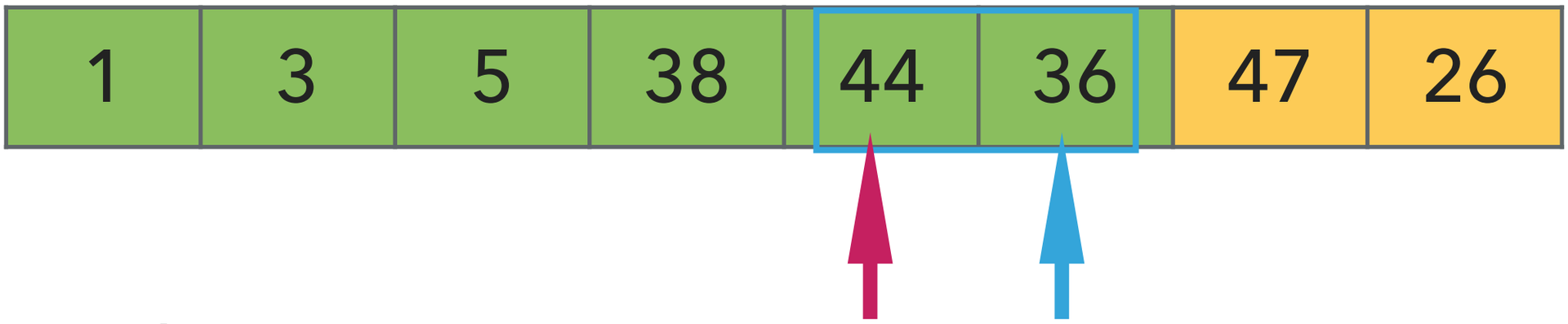

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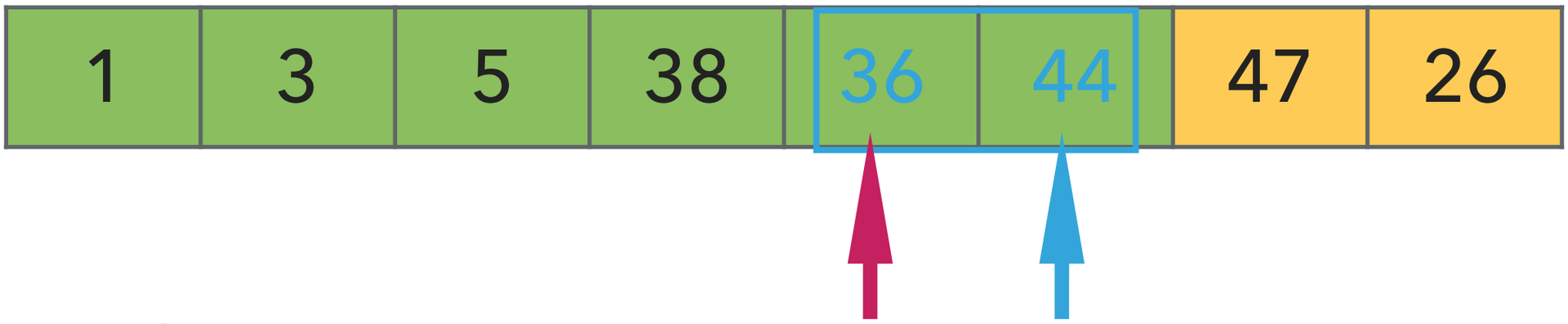

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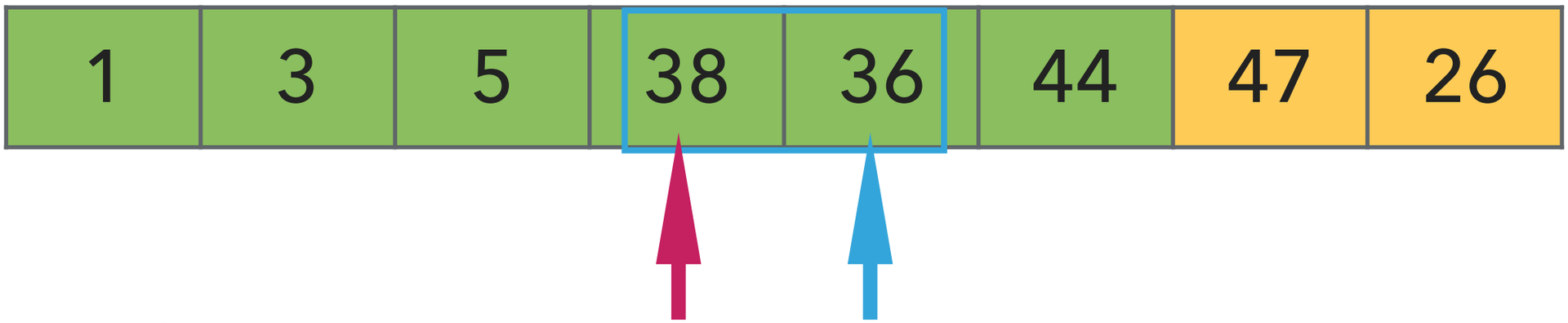

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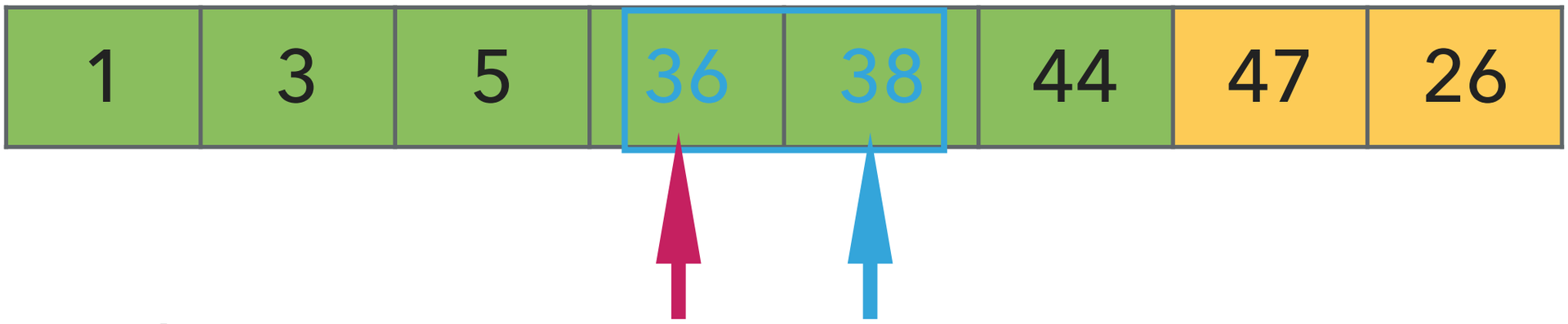

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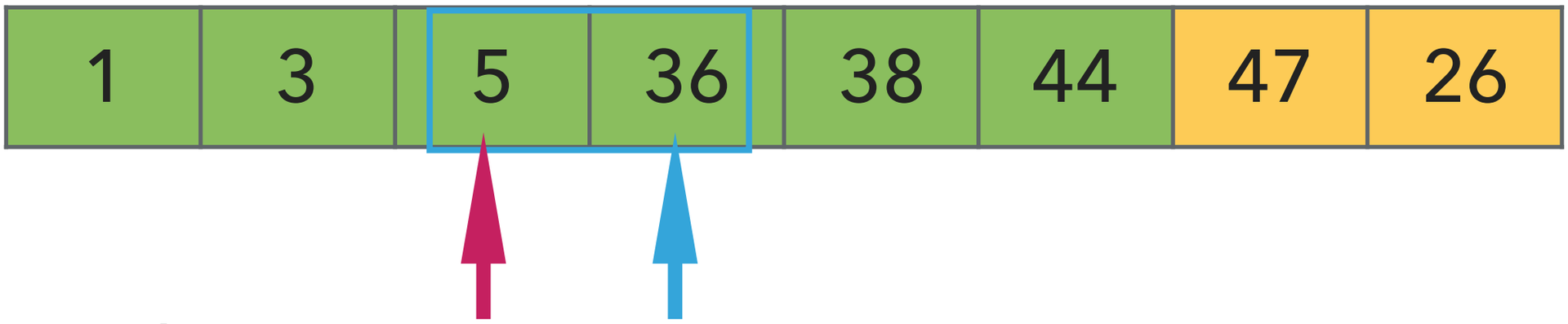

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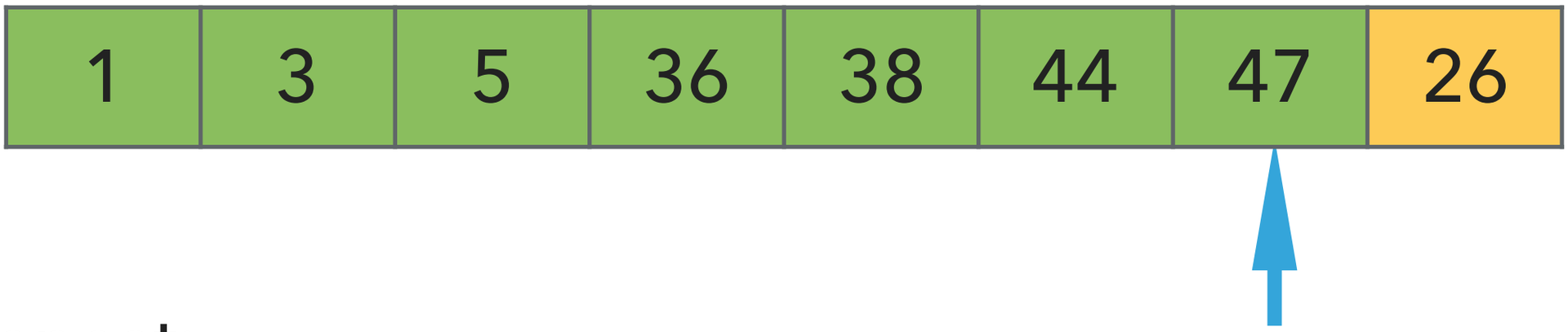

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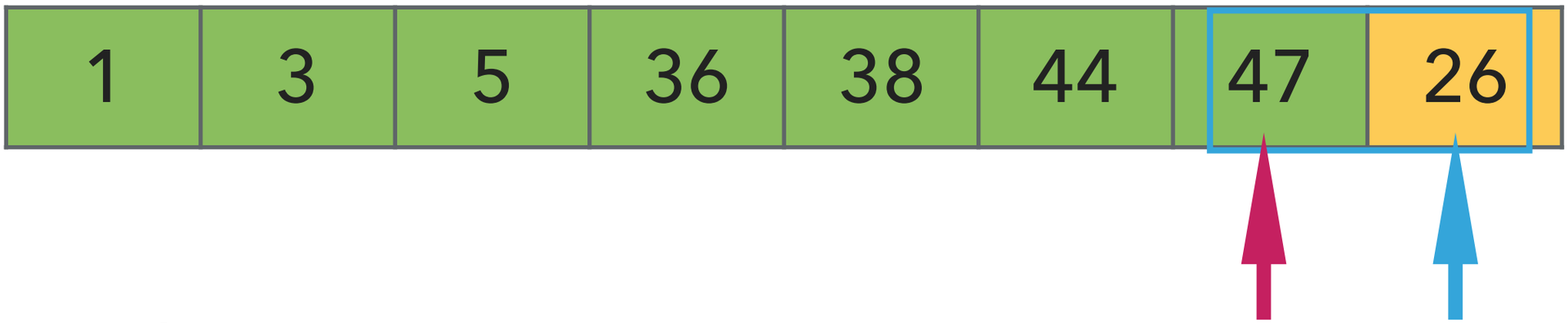

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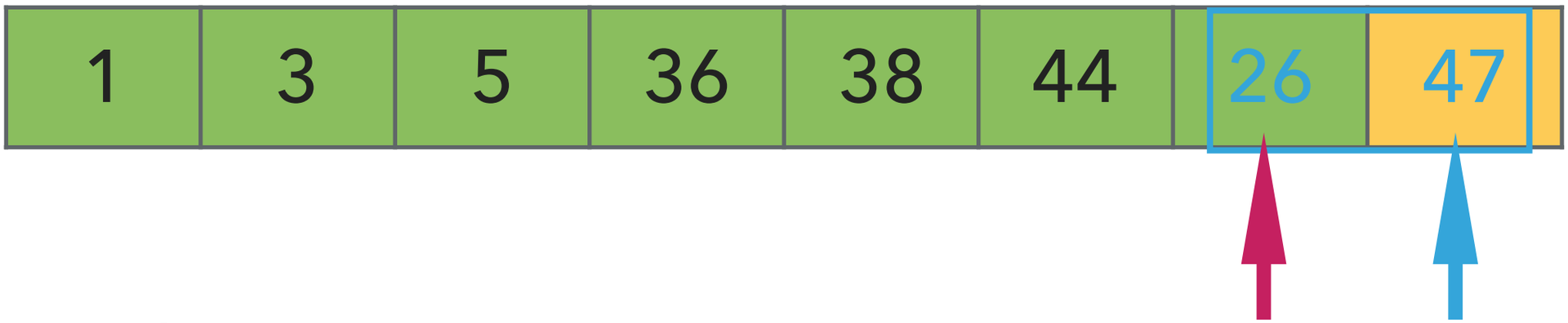

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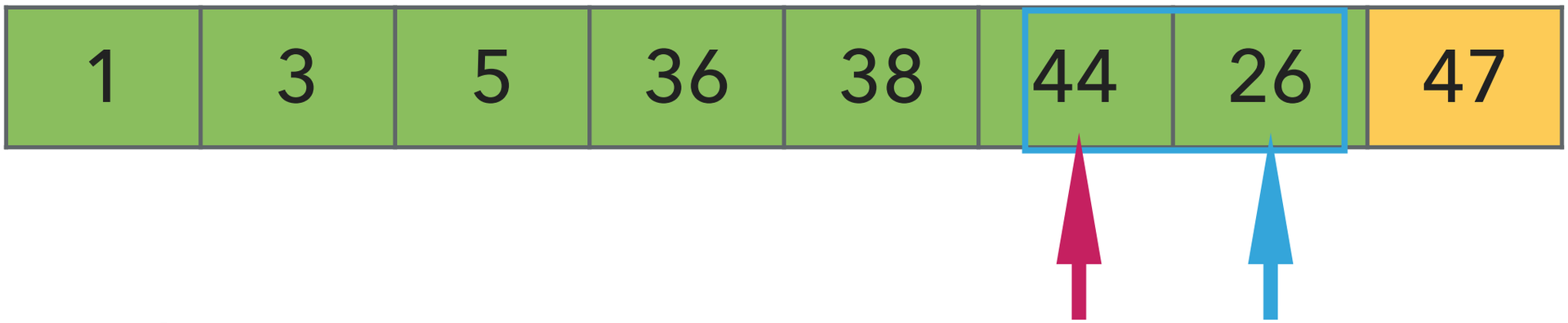

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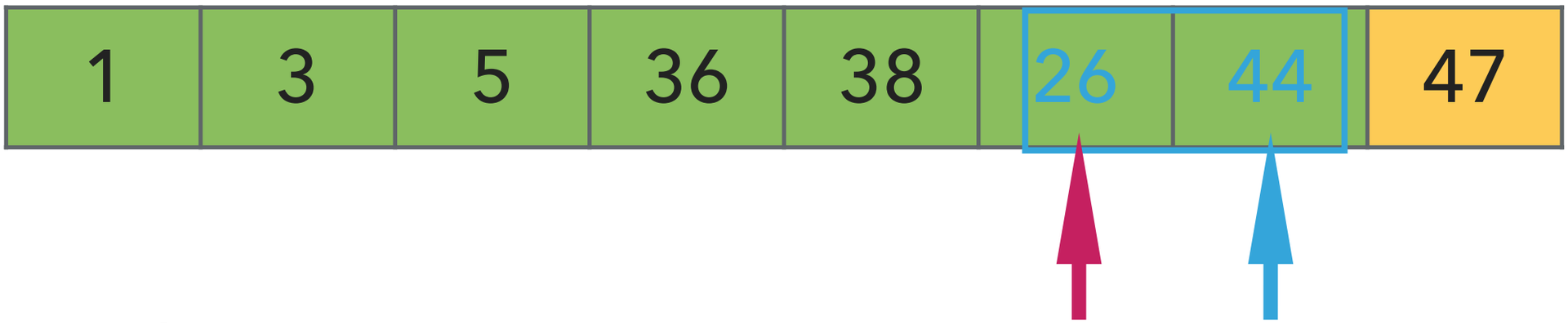

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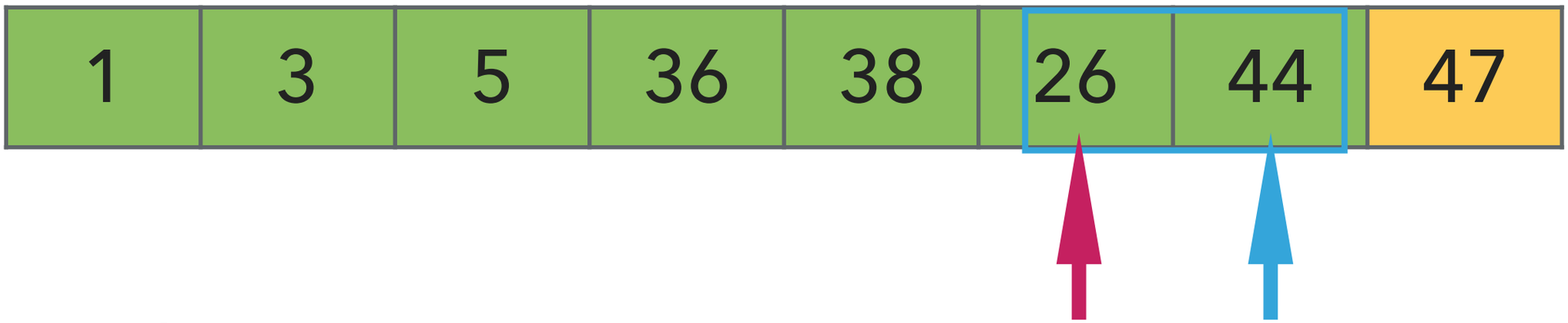

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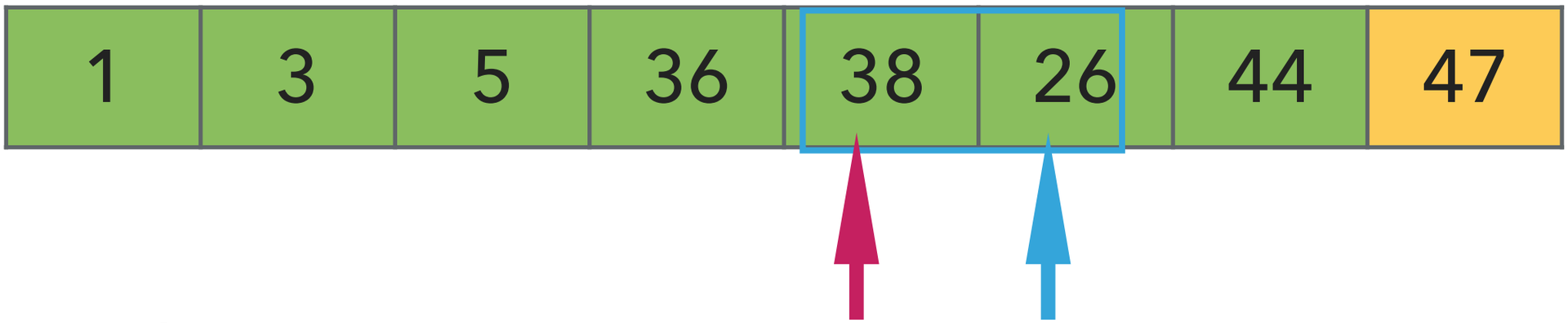

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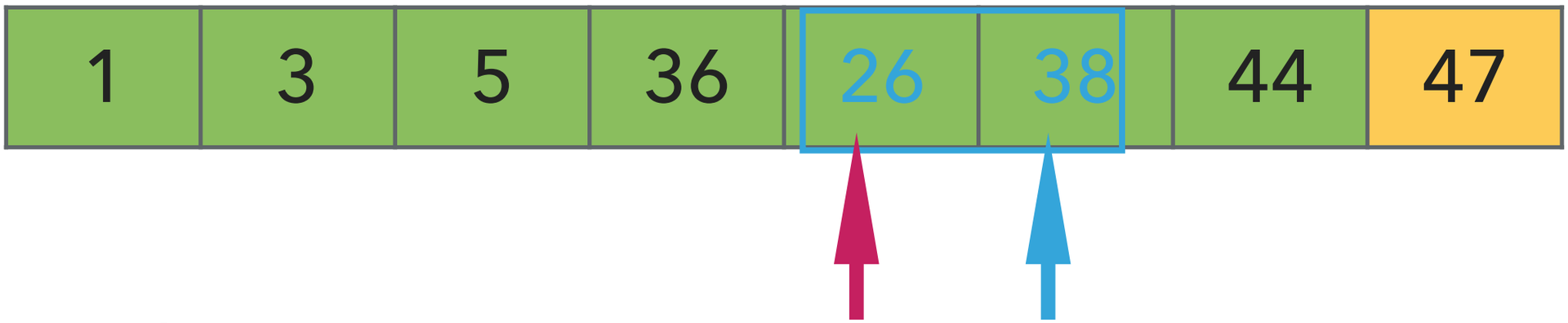

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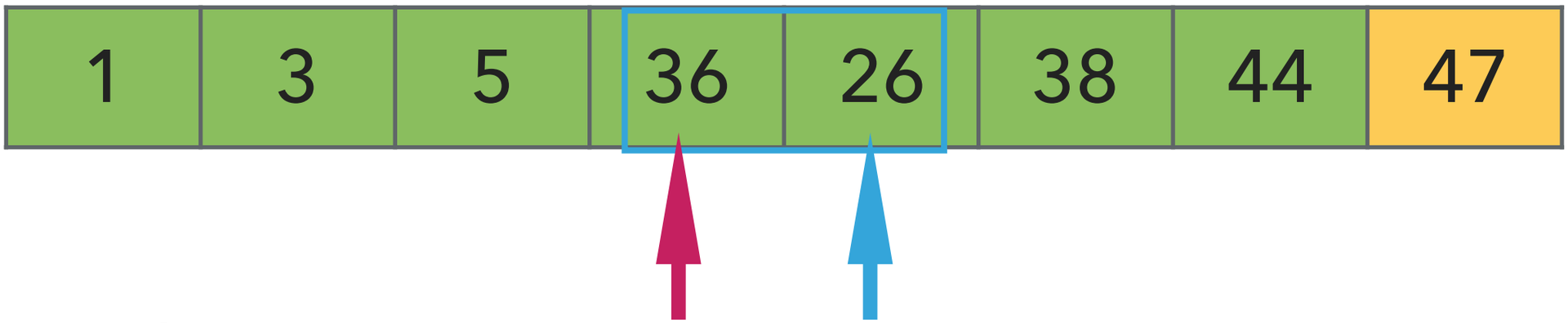

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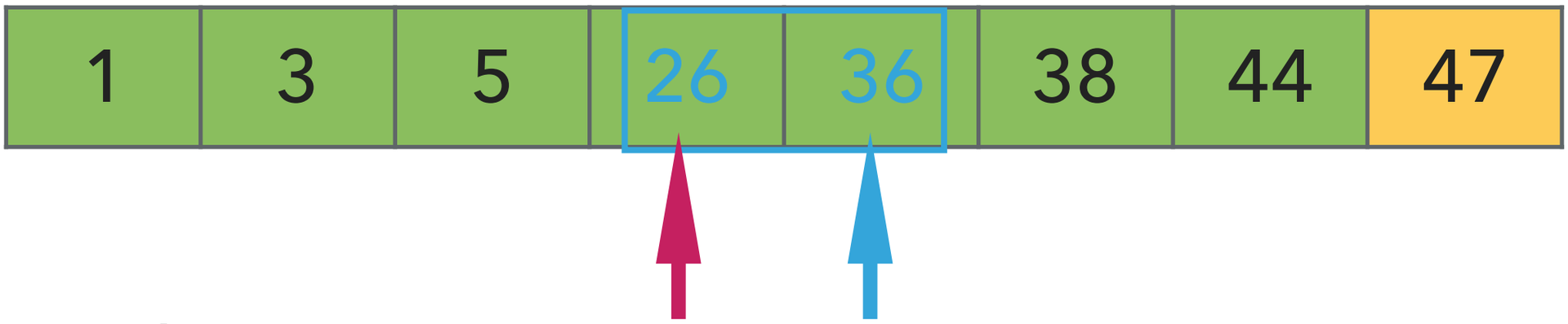

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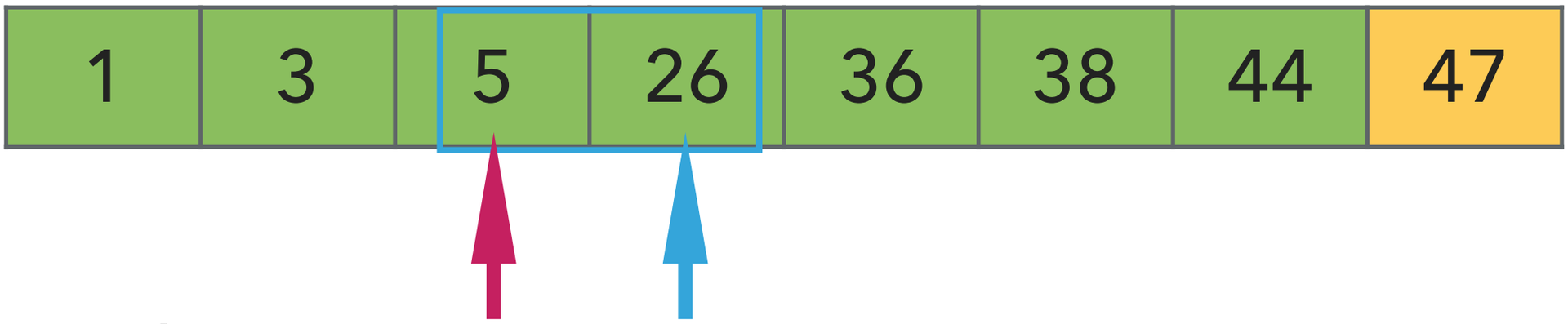

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http://algs4.cs.princeton.edu

2.1 INSERTION SORT DEMO

In case you didn’t get this…

- https://www.youtube.com/watch?v=ROalU379l3U

Insertion sort

```
public static void sort(Comparable[] a) {



}
```

Insertion sort

```
public static void sort(Comparable[] a) {
        int n = a.length;
        for (int i = 0; i < n; i++) {
            for (int j = i; j > 0; j--) {
                if(less(a[j], a[j-1]))
                    exch(a, j, j-1);
                else
                    break;
            }
        }
    }
```

- Invariants: At the end of each iteration `i`:
  - the array `a` is sorted in ascending order for the first `i+1` elements `a[0…i]`

Insertion sort: mathematical analysis for worst-case

```
public static void sort(Comparable[] a) {
        int n = a.length;
        for (int i = 0; i < n; i++) {
           for (int j = i; j > 0; j--) {
               if(less(a[j], a[j-1]))
                  exch(a, j, j-1);
               else
                  break;
           }
        }
    }
```

- Comparisons: $0 + 1 + 2 + \ldots + (n - 2) + (n - 1) \sim n^2/2$, that is $O(n^2)$.
- Exchanges: $0 + 1 + 2 + \ldots + (n - 2) + (n - 1) \sim n^2/2$, that is $O(n^2)$.
- Worst-case running time is quadratic.
- In-place, requires almost no additional memory.
- Stable

Insertion sort: average and best case

```
public static void sort(Comparable[] a) {
        int n = a.length;
        for (int i = 0; i < n; i++) {
            for (int j = i; j > 0; j--) {
                if(less(a[j], a[j-1]))
                    exch(a, j, j-1);
                else
                    break;
            }
        }
    }
```

- Average case: quadratic for both comparisons and exchanges $\sim n^2/4$ when sorting a randomly ordered array.

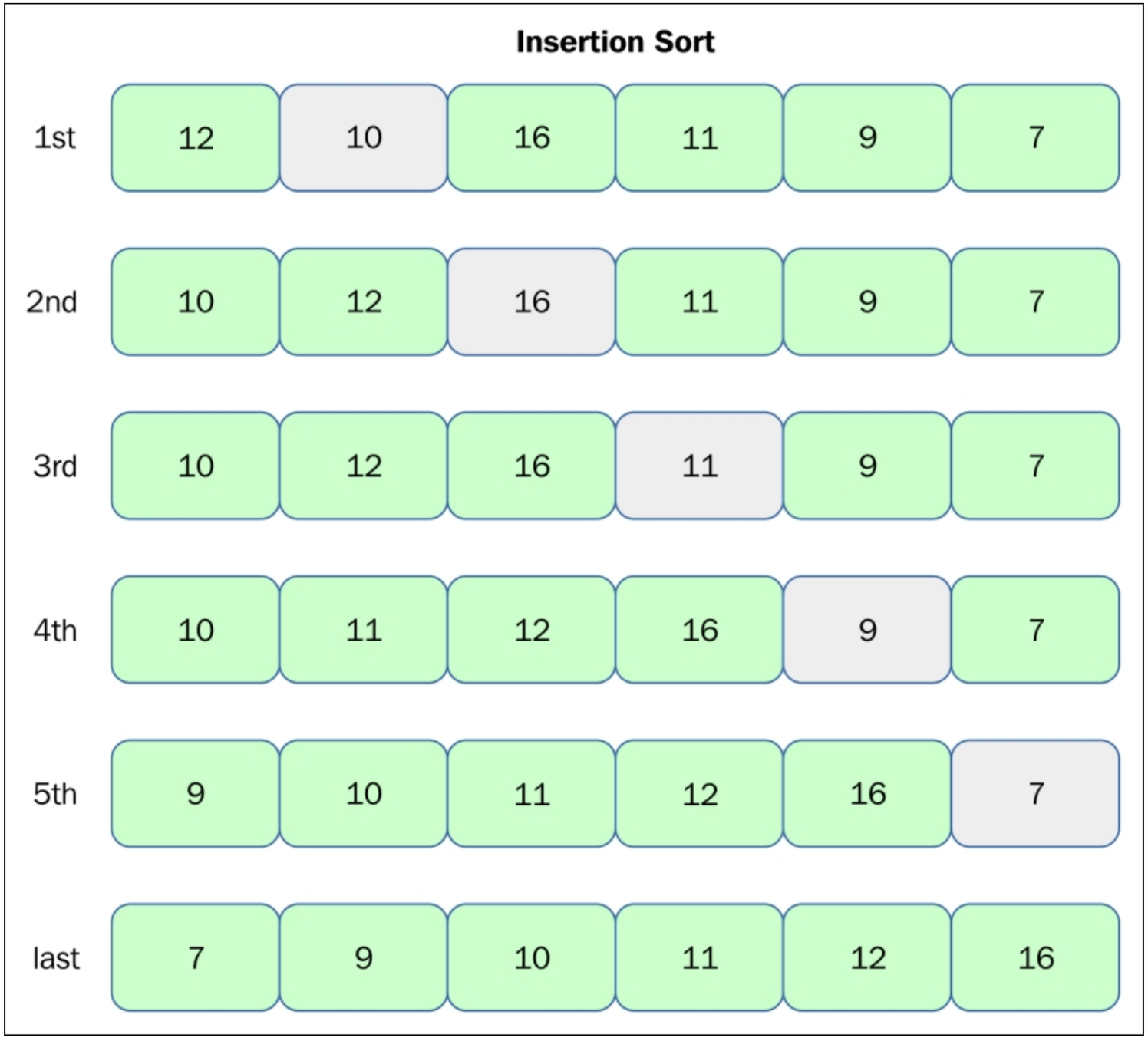
- Best case: $n - 1$ comparisons and 0 exchanges for an already sorted array.

https://www.toptal.com/developers/sorting-algorithms/insertion-sort

Practice Time

- Using insertion sort, sort the array with elements [12,10,16,11,9,7].
- Visualize your work for every iteration of the algorithm.

Answer



https://subscription.packtpub.com/book/application_development/9781785888731/13/ch13lvl1sec90/insertion-sort?query=insertion%20sort

Lecture 12: Sorting Fundamentals

- Introduction
- Selection sort
- Insertion sort

Readings:

- Textbook:
  - Chapter 2.1 (pages 244–262)
- Website:
  - Elementary sorts: https://algs4.cs.princeton.edu/21elementary/
  - Code: https://algs4.cs.princeton.edu/21elementary/Selection.java.html and https://algs4.cs.princeton.edu/21elementary/Insertion.java.html

Practice Problems:

- 2.1.1-2.1.8