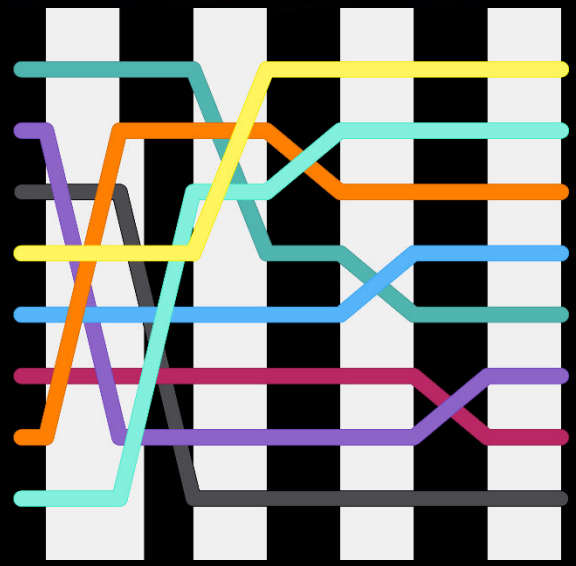
Sorting and Searching Algorithms

Sorting, Searching, Shuffling



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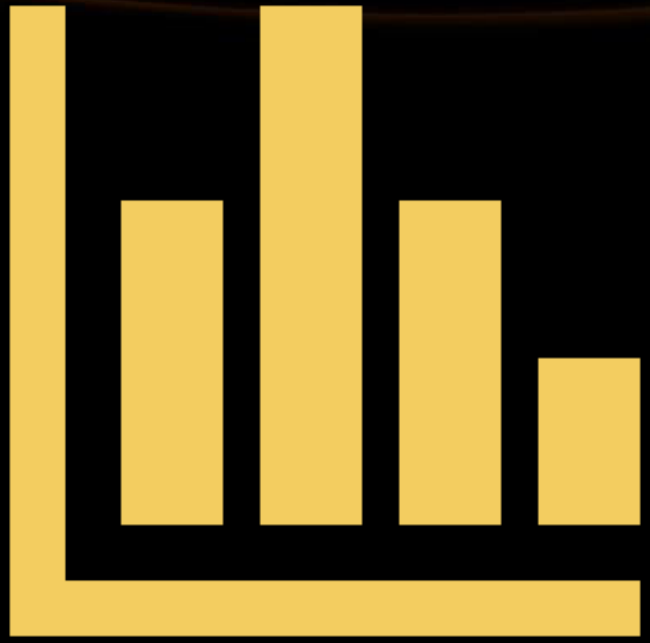
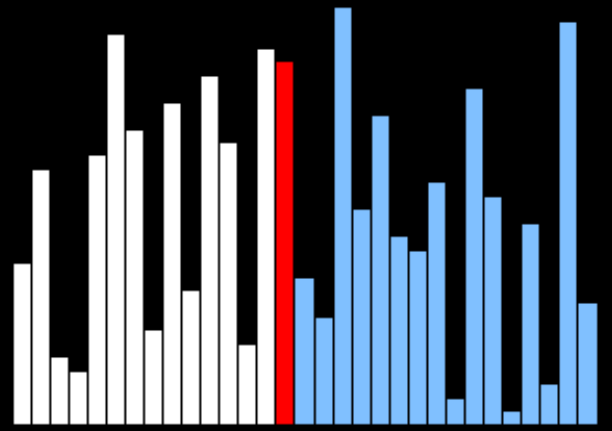


Simple Sorting Algorithms

BubbleSort, InsertionSort, SelectSort

What is a Sorting Algorithm?

- Sorting algorithm
  - An algorithm that rearranges elements in a list
    - In non-decreasing order
  - Elements must be comparable
- More formally
  - The input is a sequence / list of elements
  - The output is an rearrangement / permutation of elements
    - In non-decreasing order



Sorting – Example

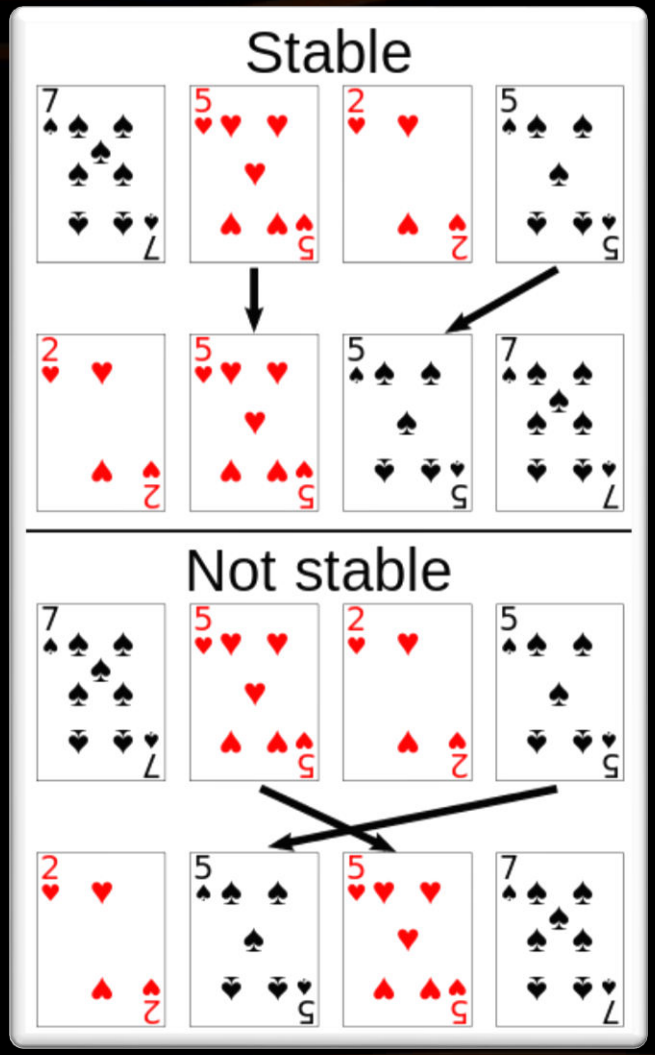
- Efficient sorting algorithms are important for
  - Producing human-readable output
  - Canonicalizing data – making data uniquely arranged
  - In conjunction with other algorithms, like binary searching
- Example of sorting:

Sorting Algorithms: Classification

- Sorting algorithms are often classified by
  - Computational complexity and memory usage
    - Worst, average and best case behavior
  - Recursive / non-recursive
  - Stability – stable / unstable
  - Comparison-based sort / non-comparison based
  - Sorting method: insertion, exchange (bubble sort and quicksort), selection (heapsort), merging, serial / parallel, etc.

Stability of Sorting

- Stable sorting algorithms
  - Maintain the order of equal elements
  - If two items compare as equal, their relative order is preserved
- Unstable sorting algorithms
  - Rearrange the equal elements in unpredictable order
- Often different elements have same key used for equality comparing



Sorting Helper Methods

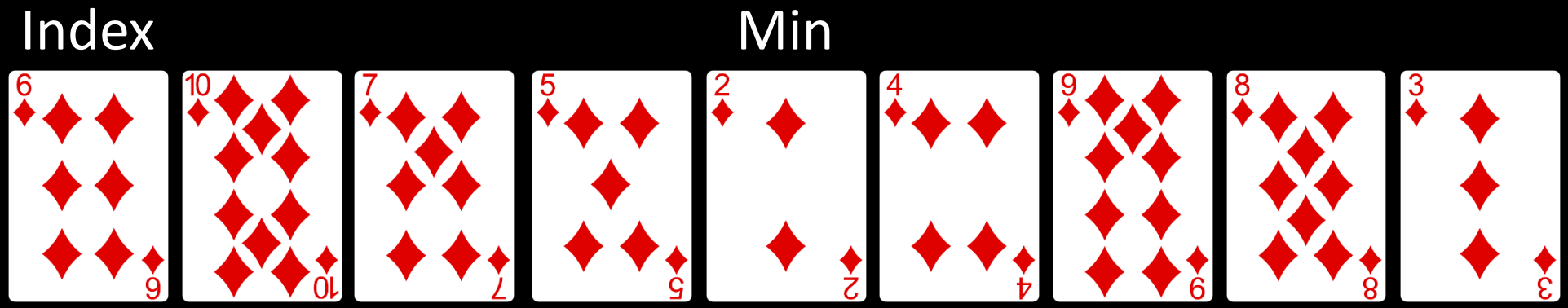

```
static void Swap<T>(T[] collection, int from, int to)
{
  //TODO: Swap the elements
}
```

```
static bool Less(IComparable first, IComparable second)
{
  return first.CompareTo(second) < 0;
}
```

Selection Sort

- Selection sort – simple, but inefficient algorithm (visualize)
  - Swap the first with the min element on the right, then the second, etc.
  - Memory: O(1)
  - Stable: No
  - Method: Selection

Selection Sort Visualization



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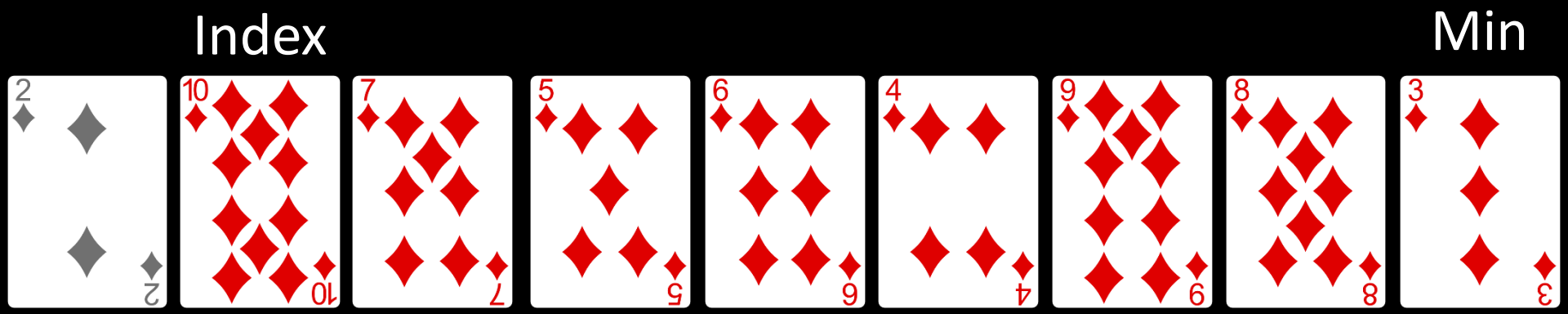

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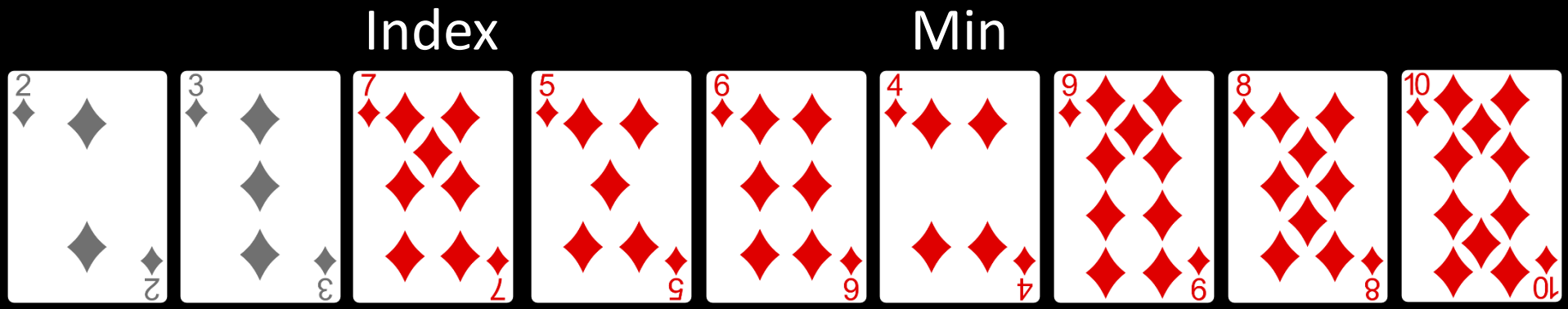

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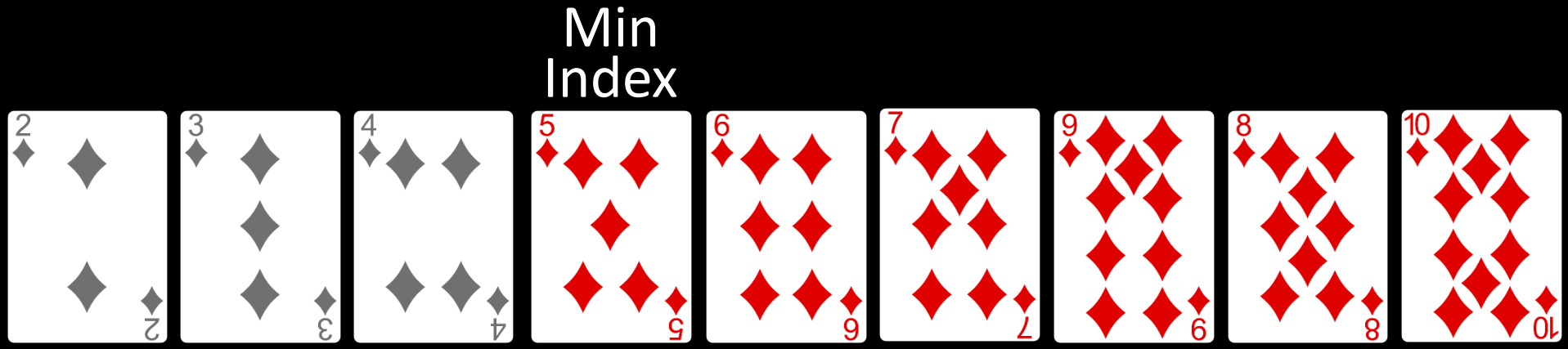

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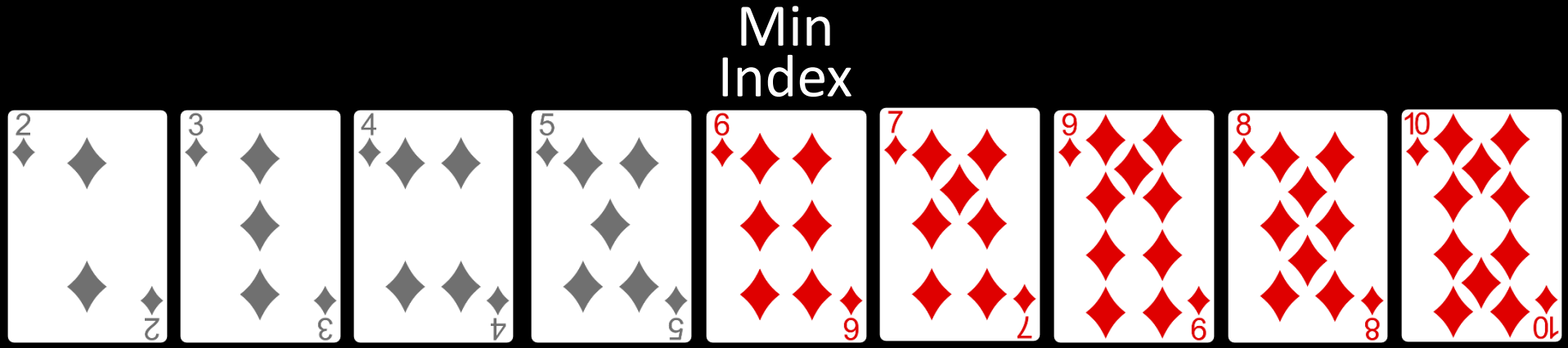

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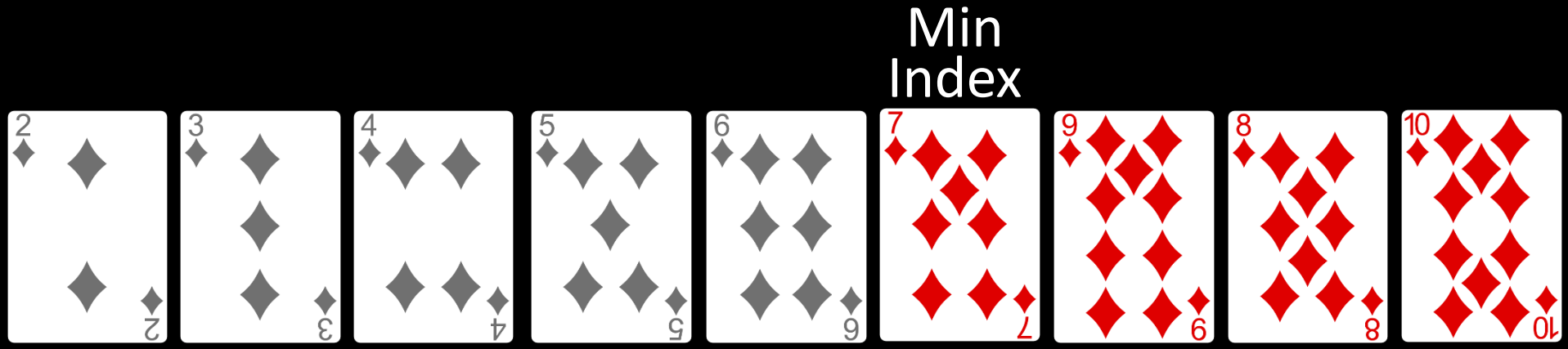

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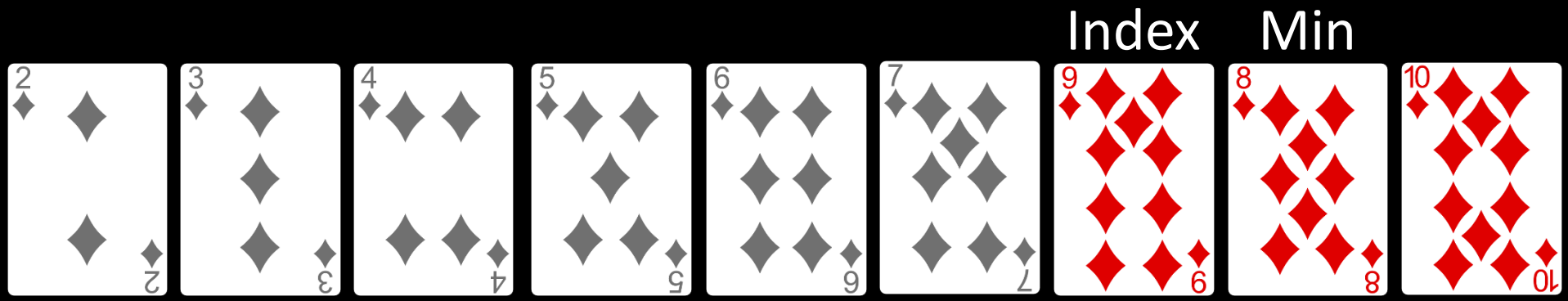

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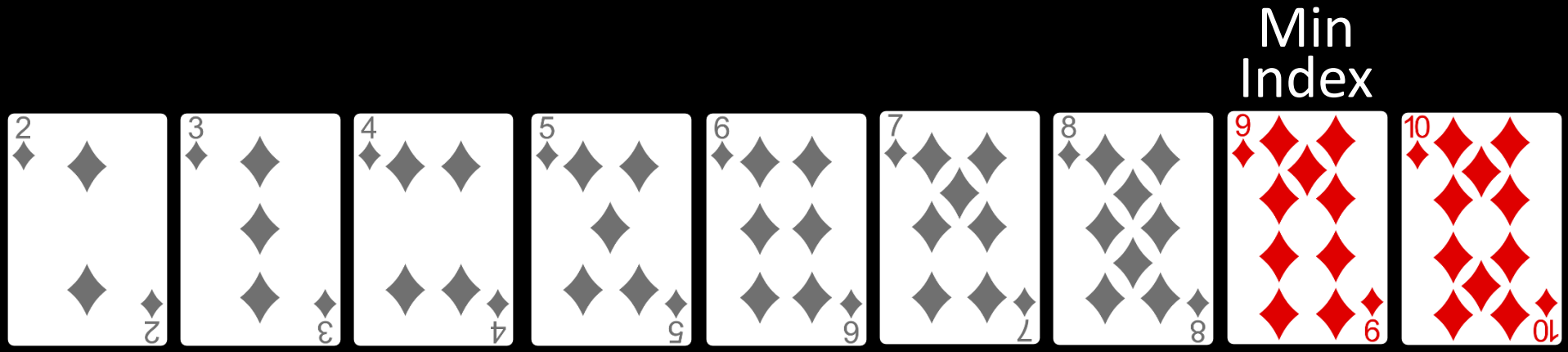

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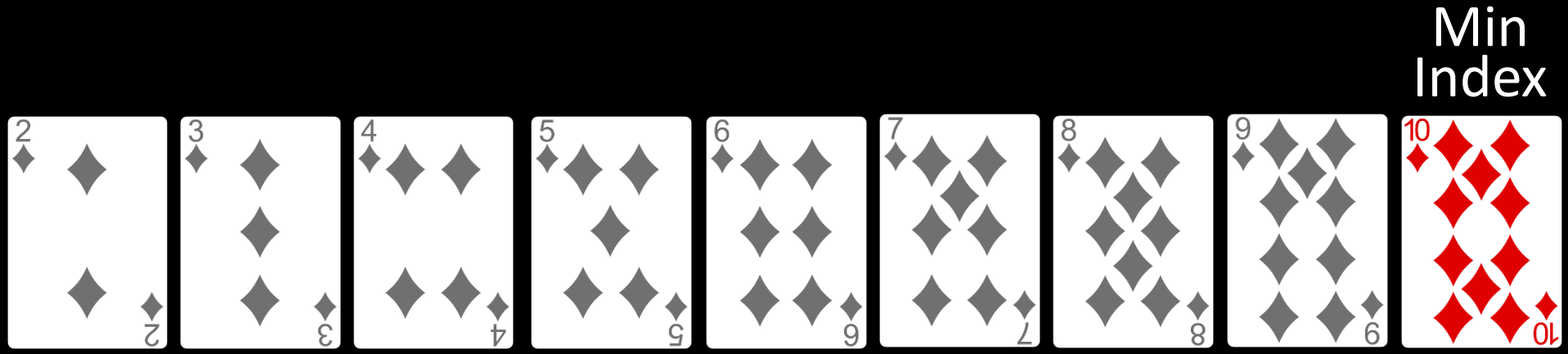

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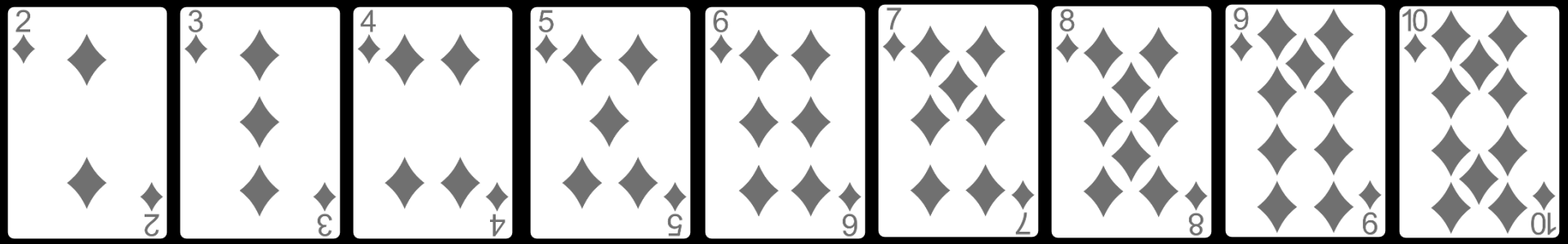

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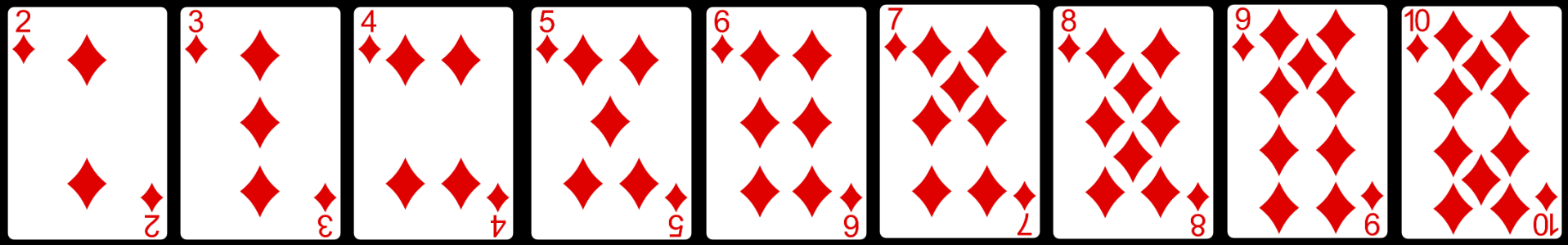
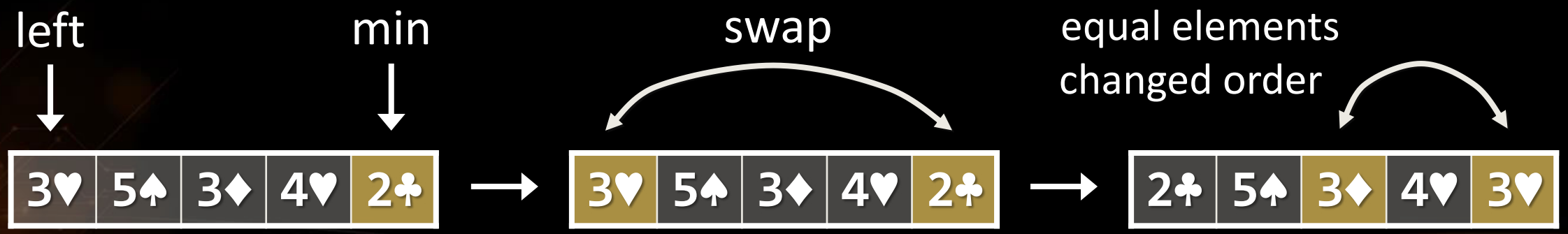


Selection Sort: Why Unstable?

- Why the "selection sort" is **unstable**?
  1. Swaps the first element with the min element on the right
  2. Swaps the second element with the min element on the right
  3. …
- During the swaps equal elements can jump over each other



Selection Sort Code

```
for (int index = 0; index < collection.Length; index++)
{
  int min = index;
  for (int curr = index + 1; curr < collection.Length; curr++)
  {
    if (Less(collection[curr], collection[min]))
    {
       min = curr;
    }
  }
  Swap(collection, index, min);
}
```

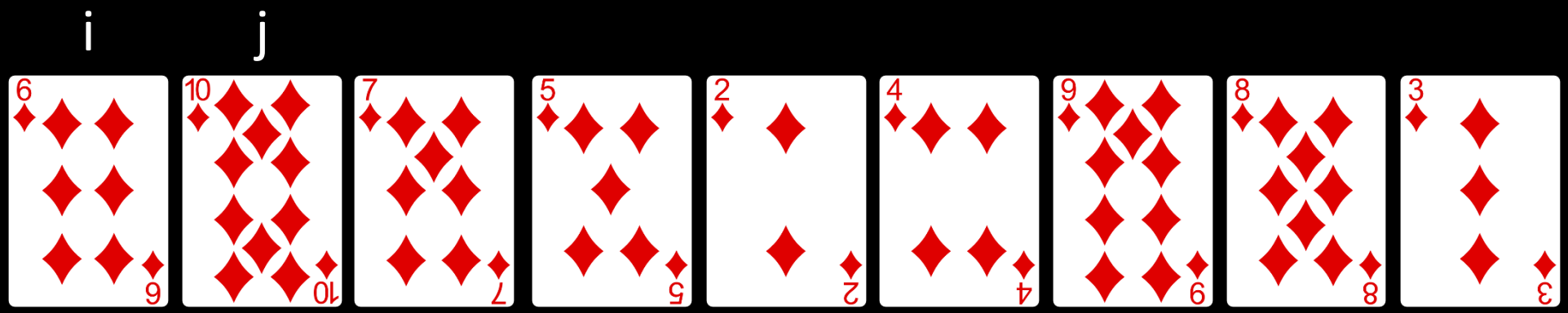
Comparison of Sorting Algorithms

Name	Best	Average	Worst	Memory	Stable	Method
SelectionSort	n^2	n^2	n^2	1	No	Selection

Bubble Sort

- Bubble sort – simple, but inefficient algorithm (visualize)
  - Swaps to neighbor elements when not in order until sorted
  - Memory: O(1)
  - Stable: Yes
  - Method: Exchanging

Bubble Sort Visualization



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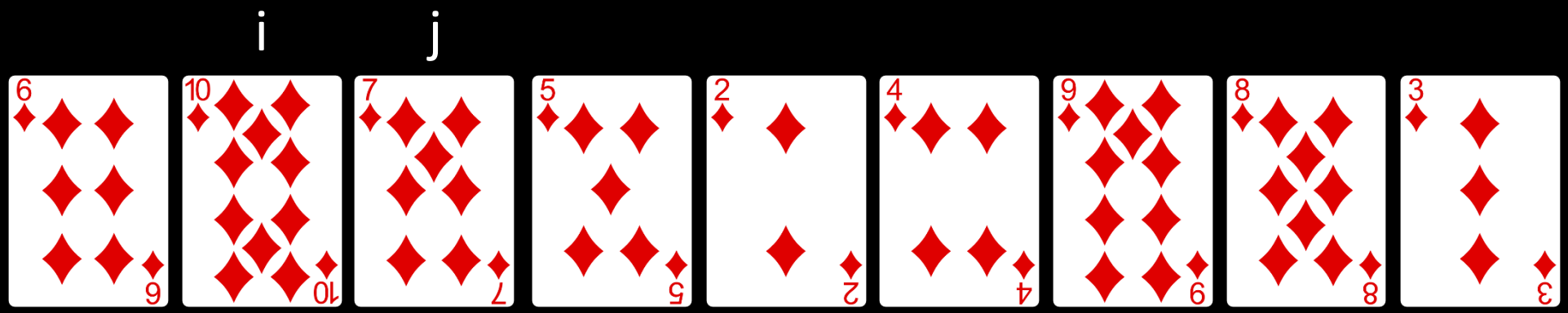

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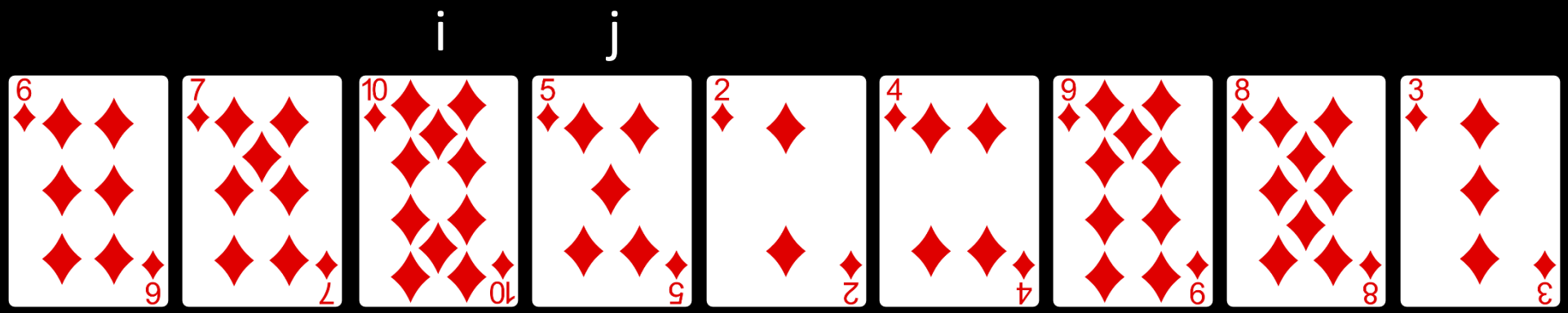

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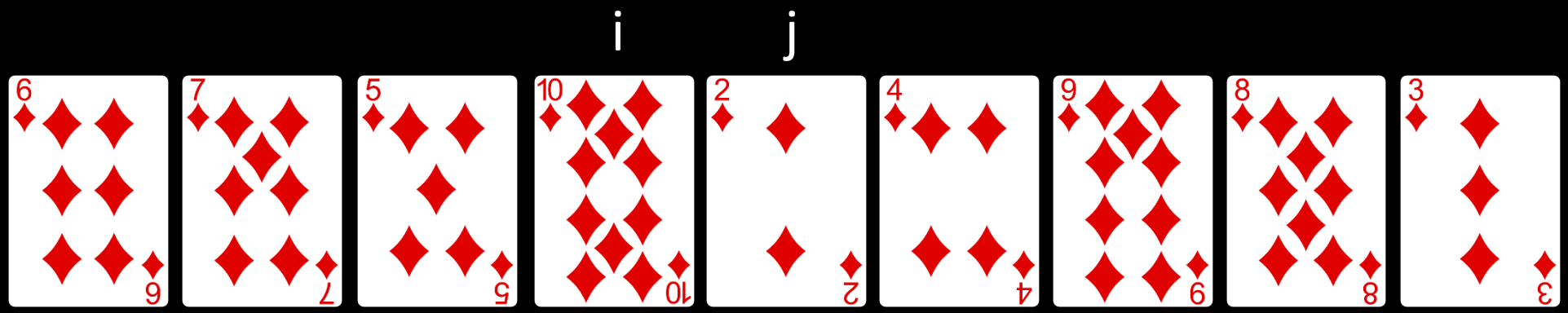

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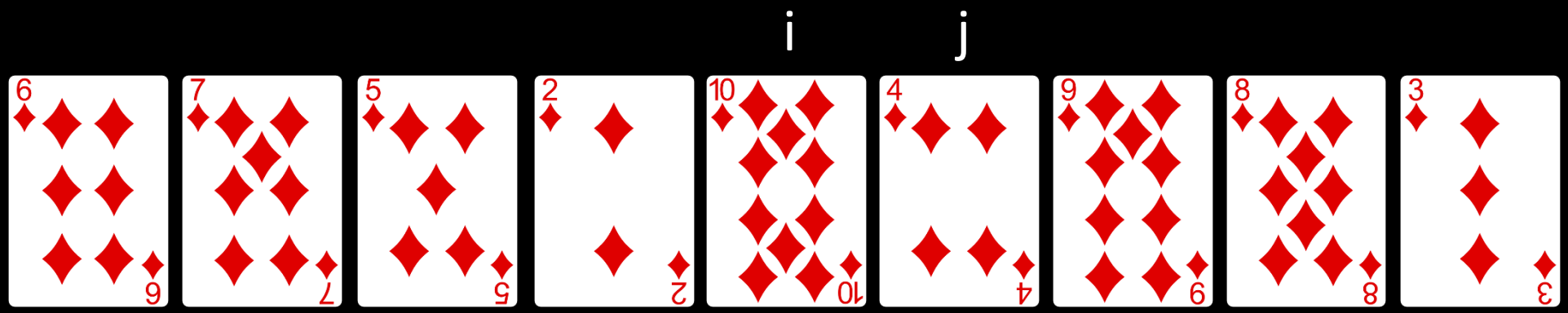

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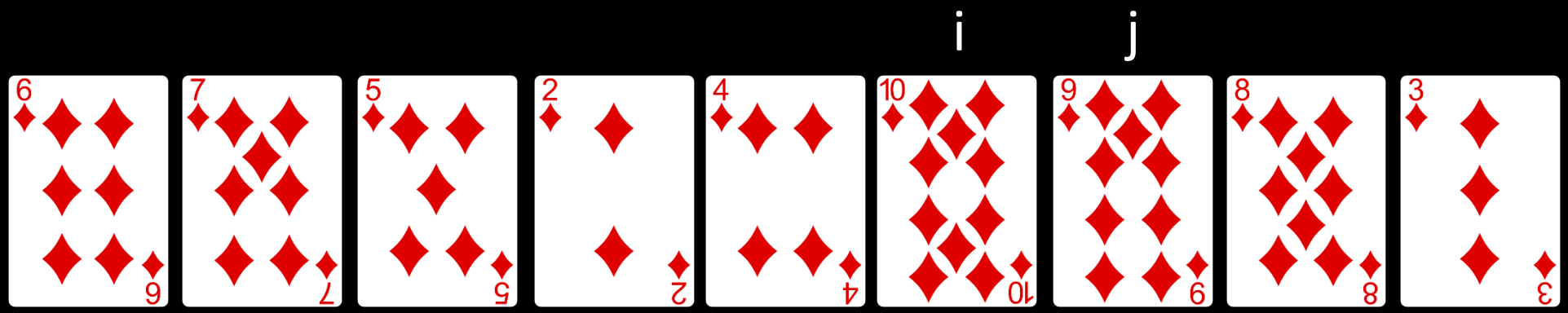

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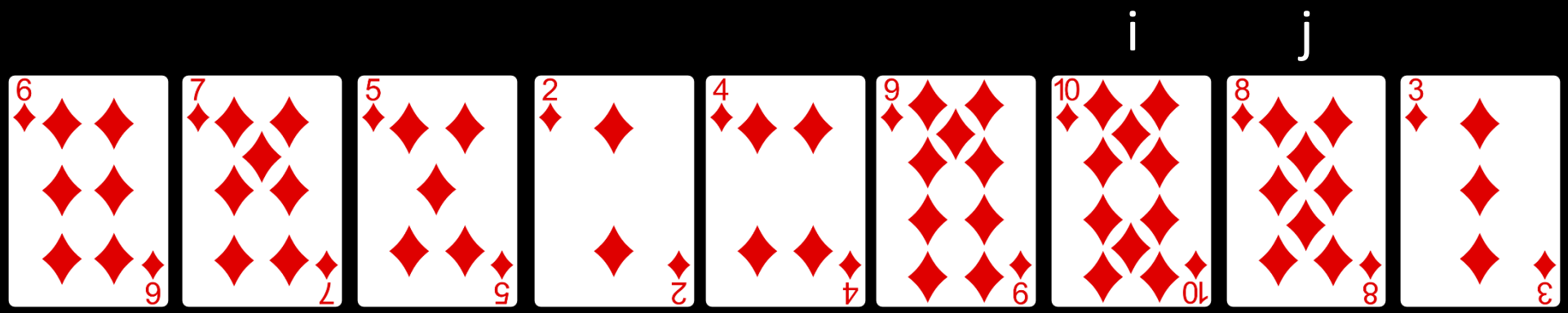

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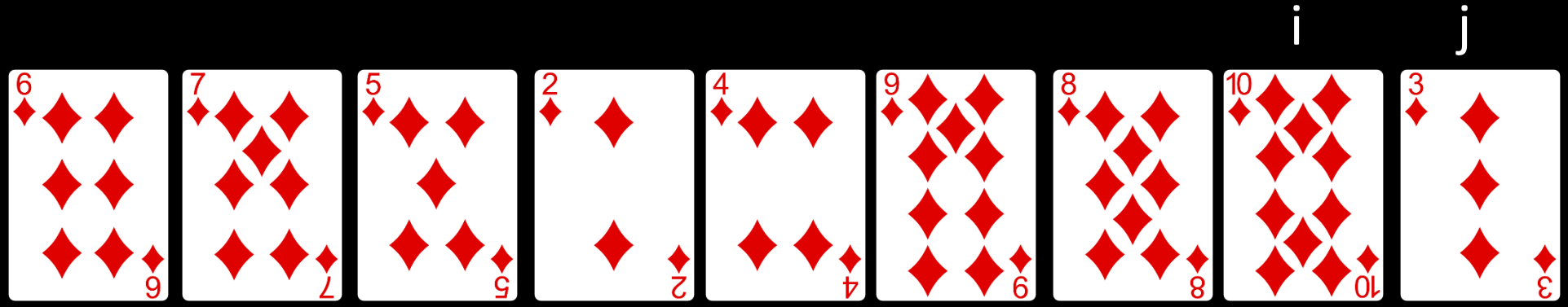

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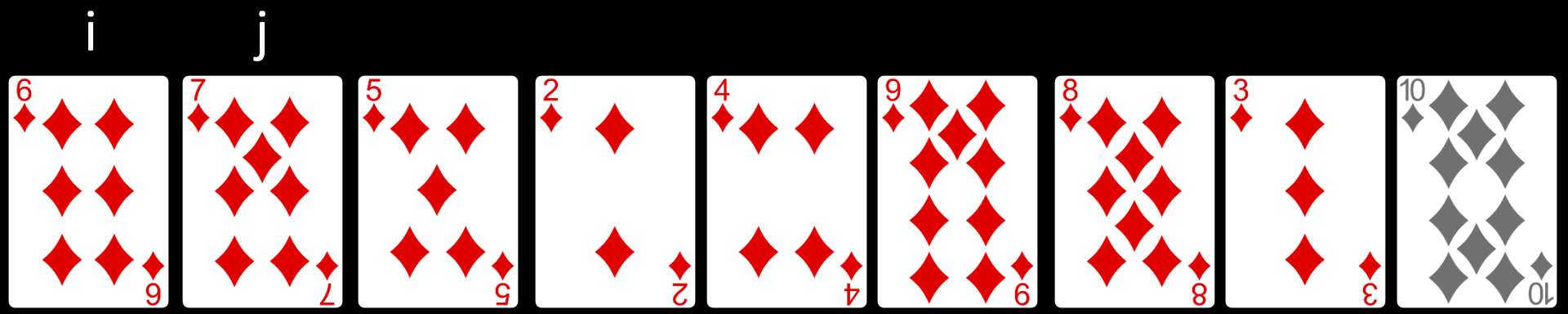

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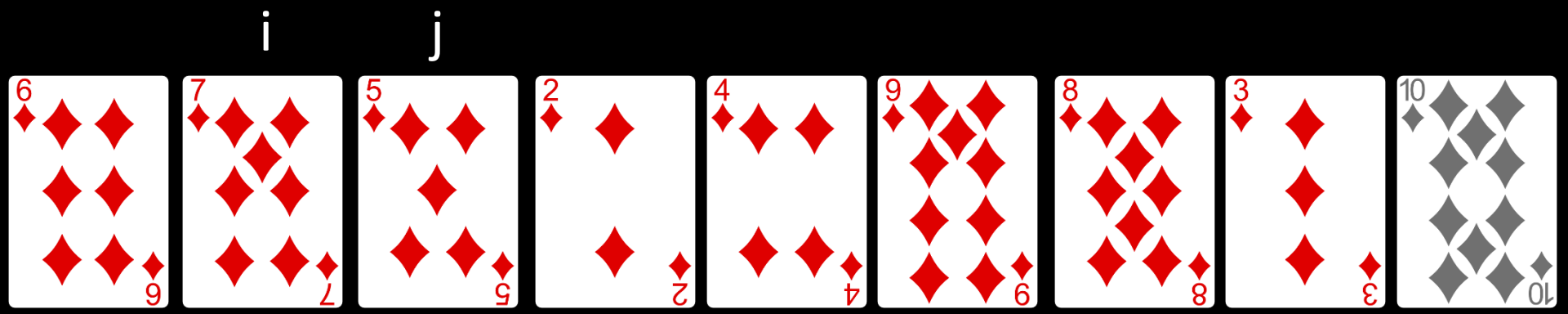

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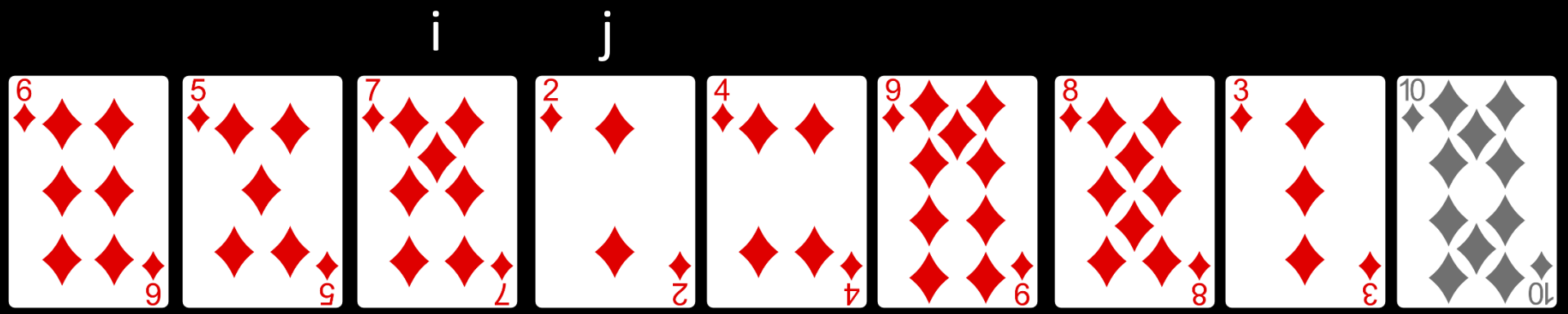

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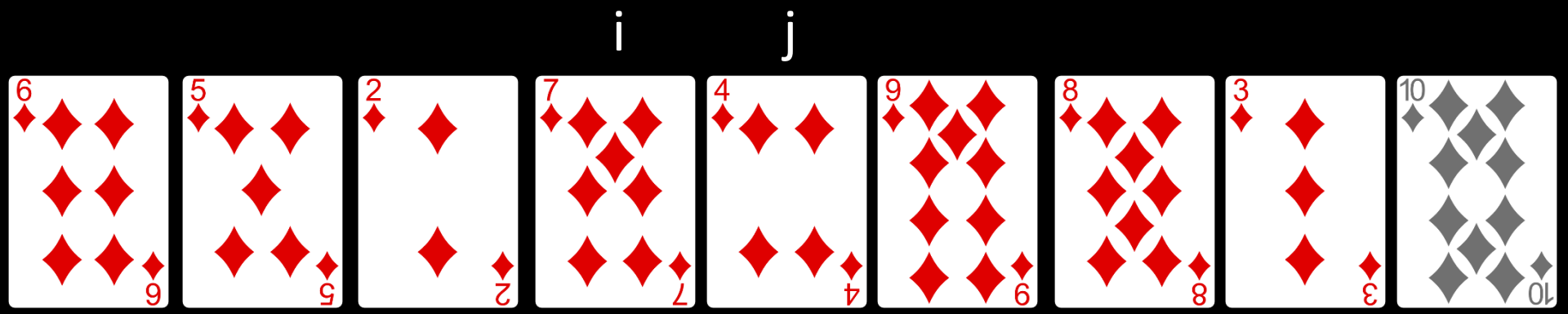

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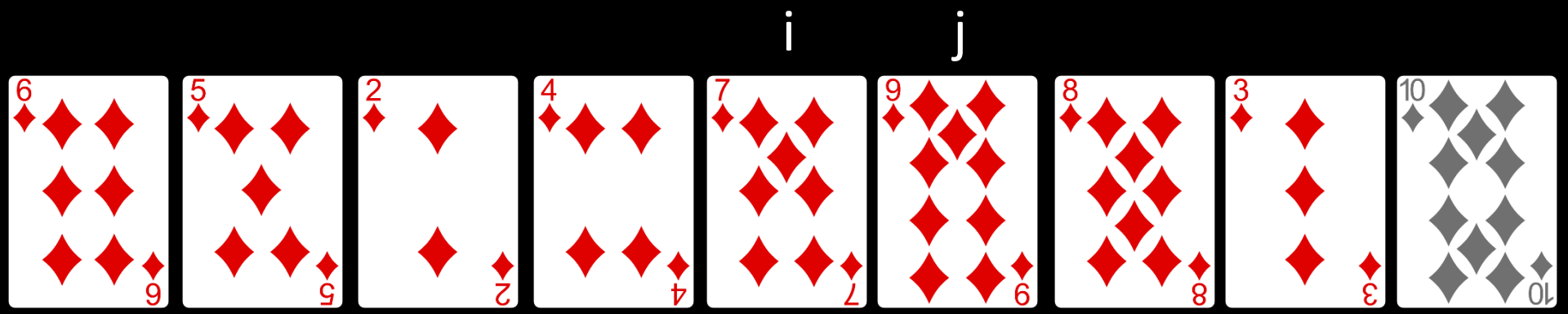

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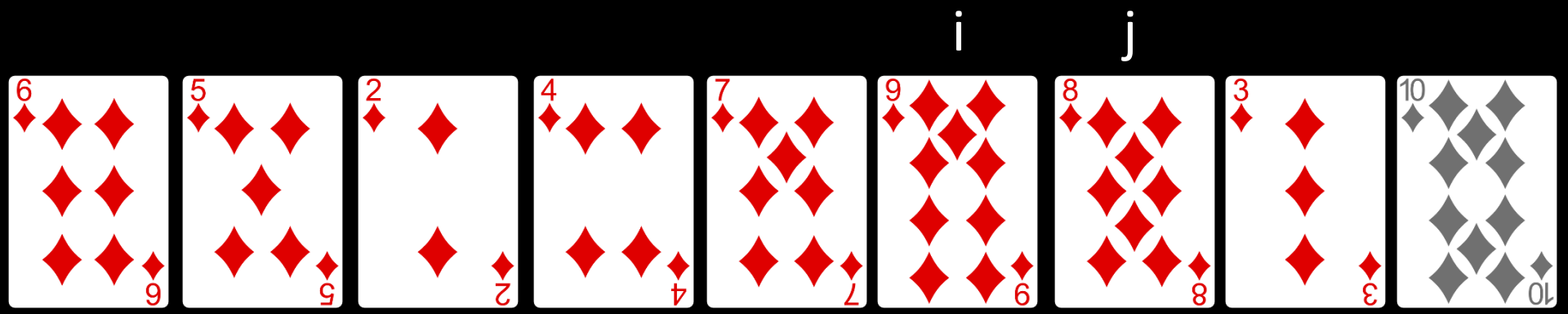

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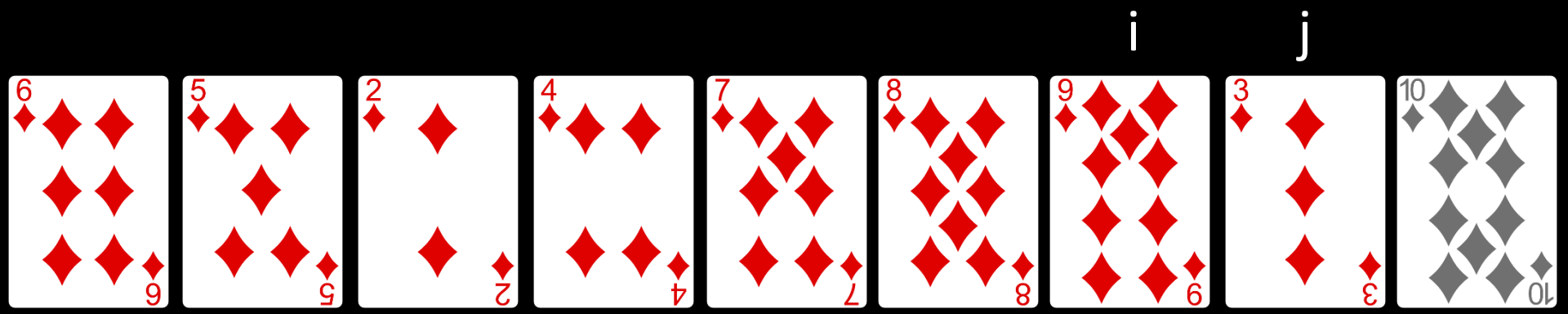

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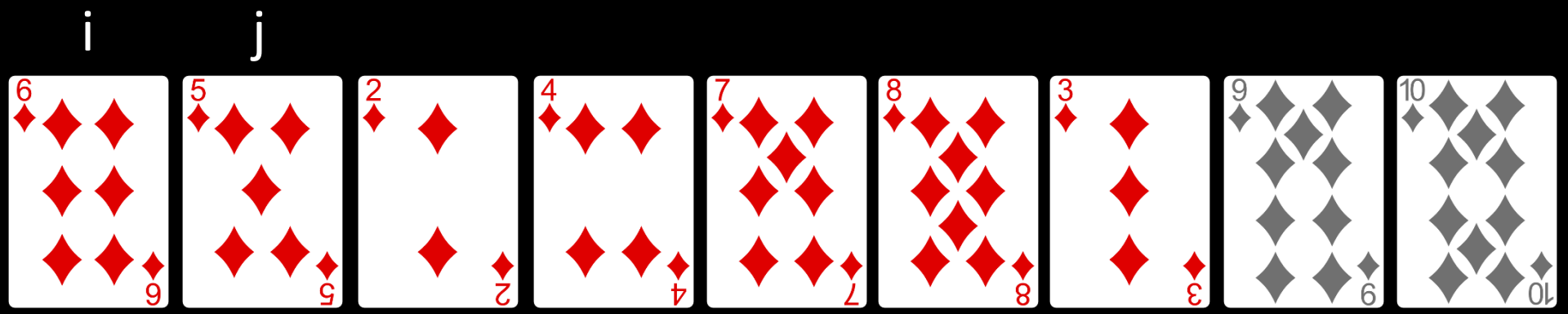

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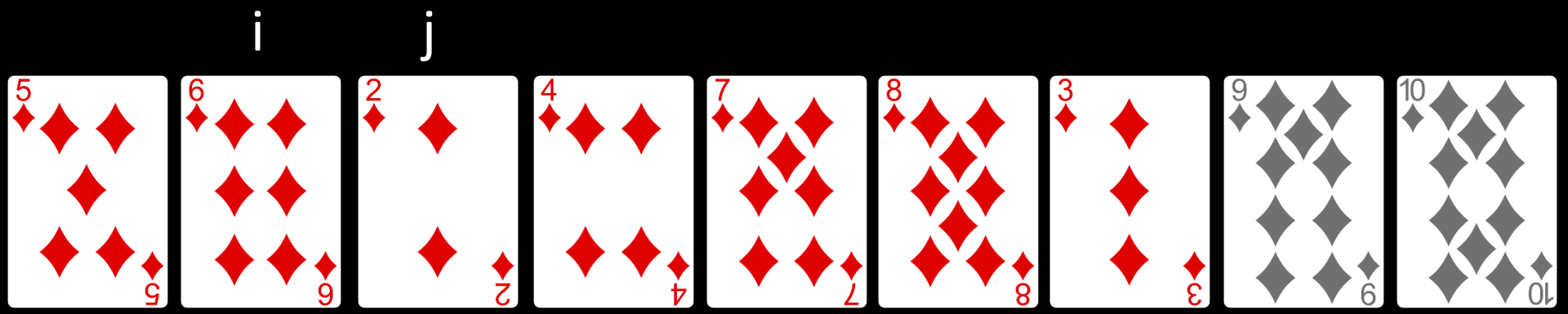

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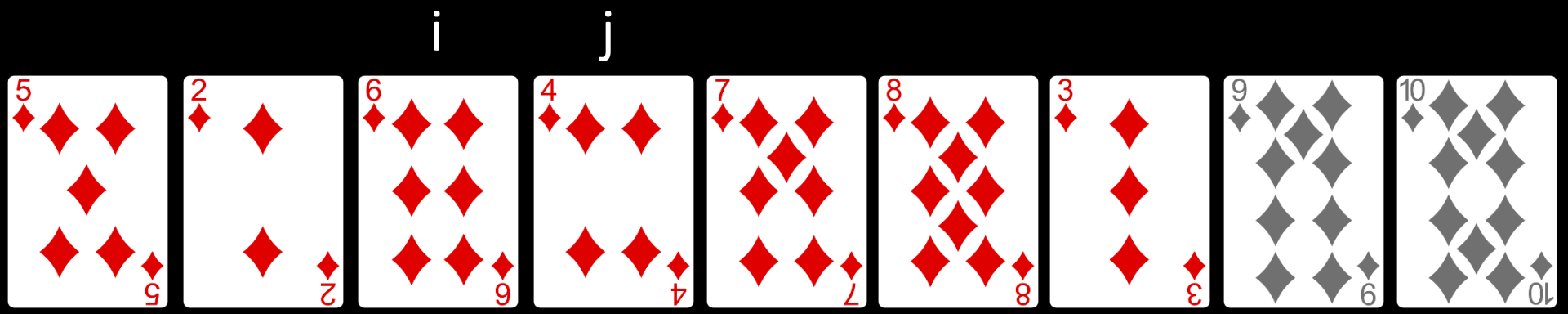

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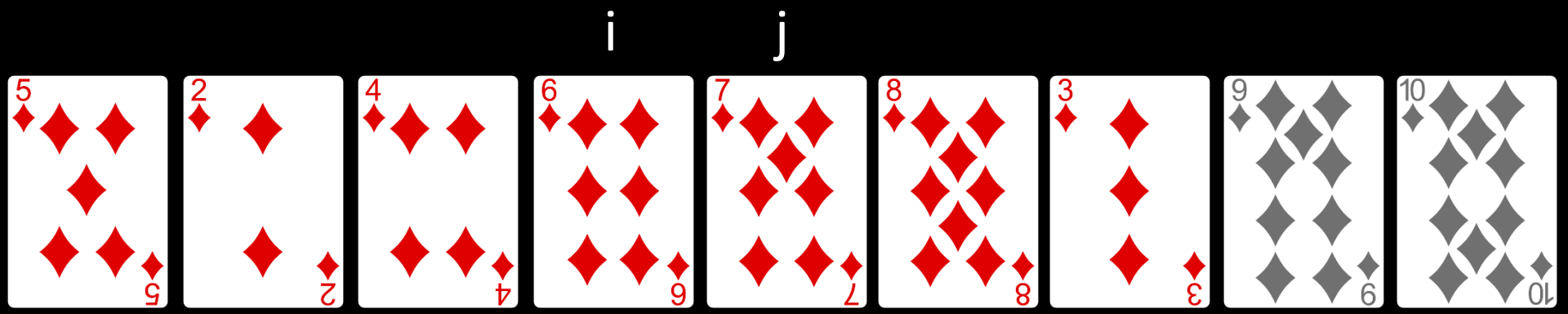

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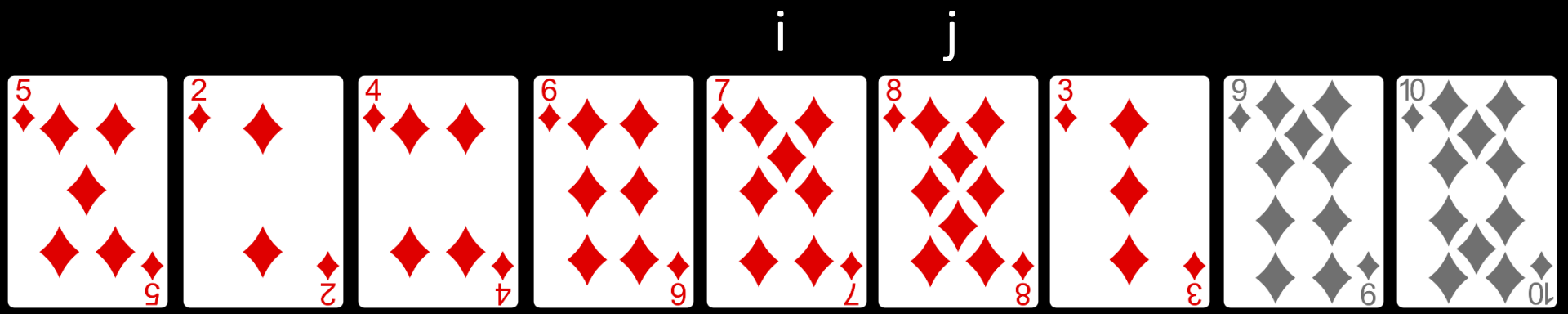

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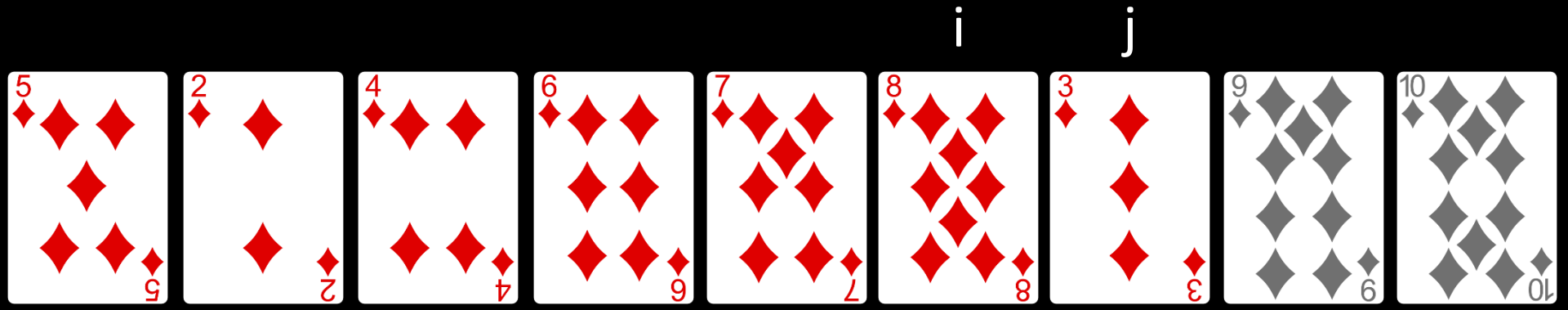

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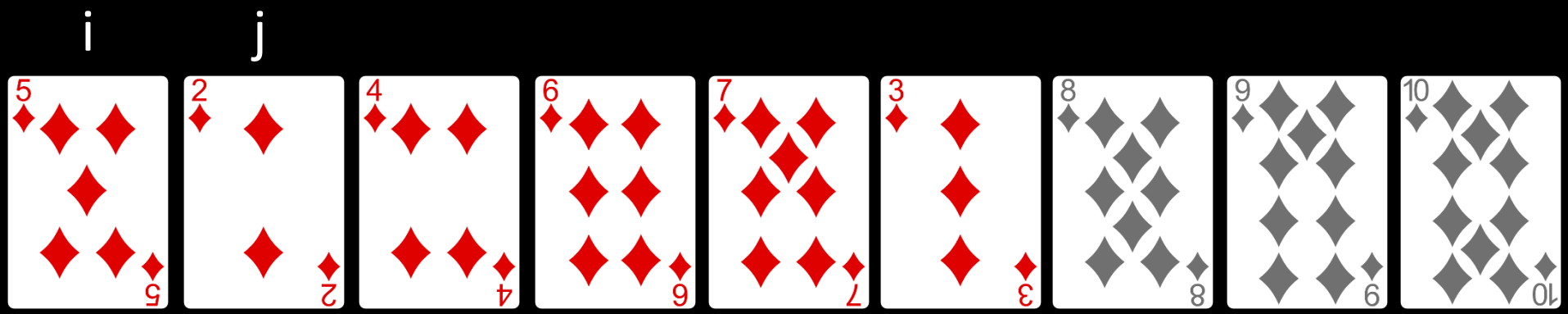

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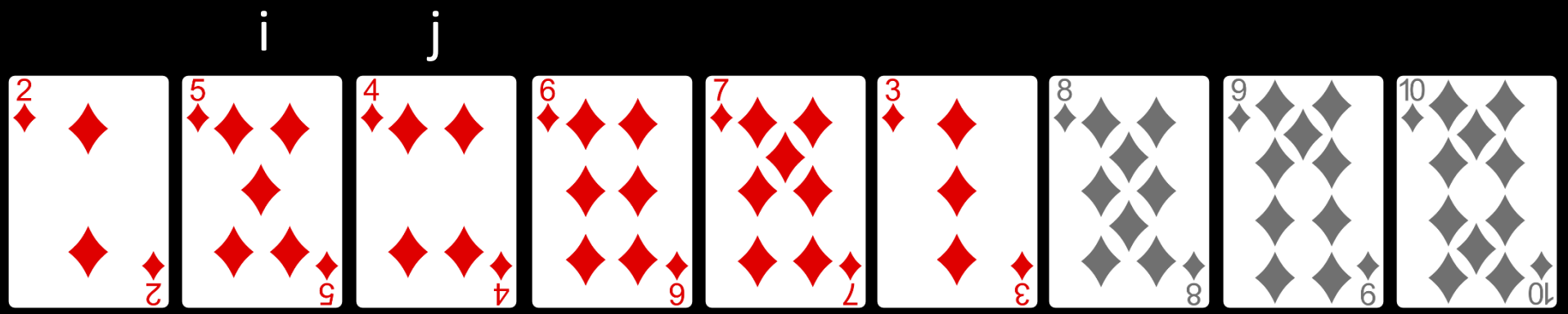

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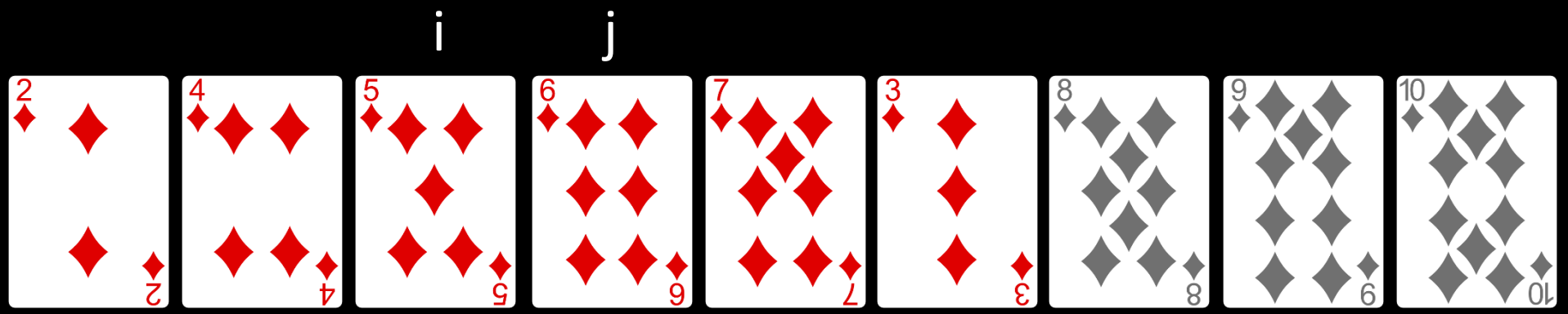

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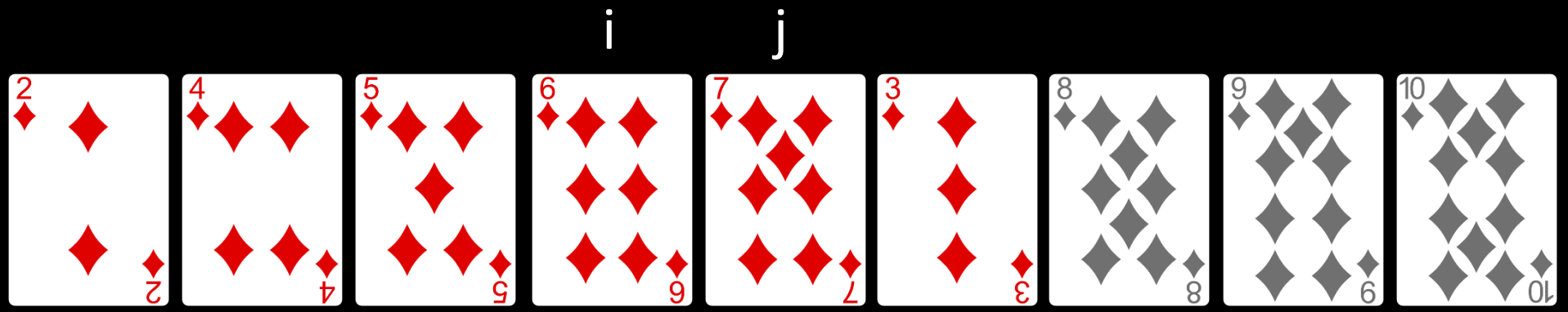

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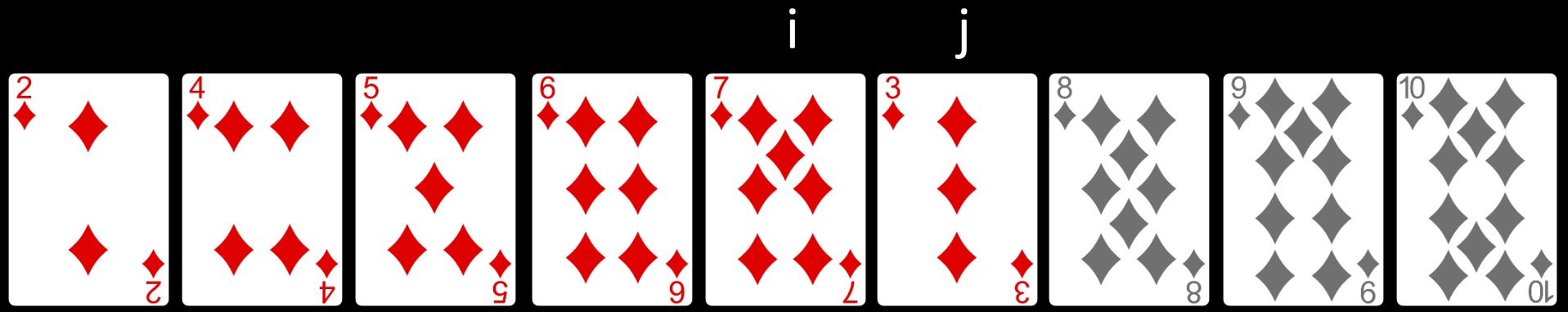

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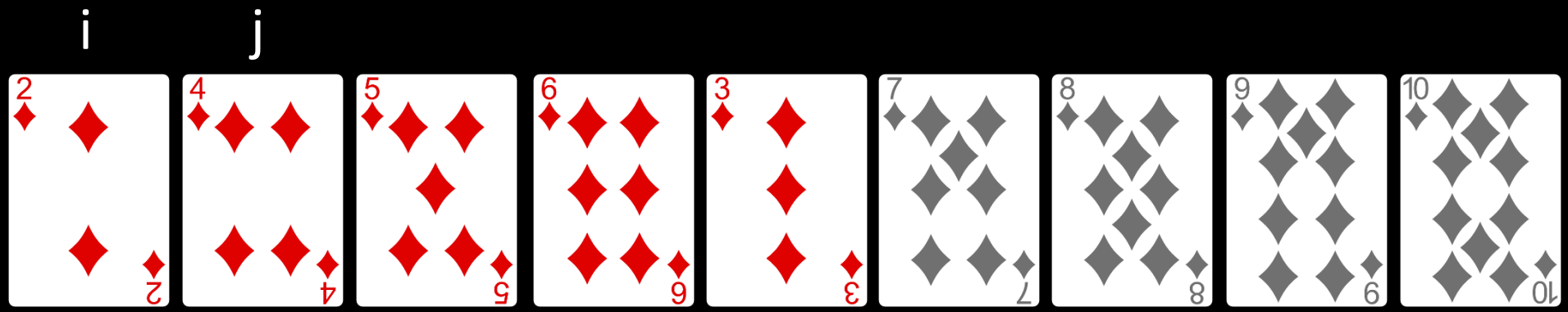

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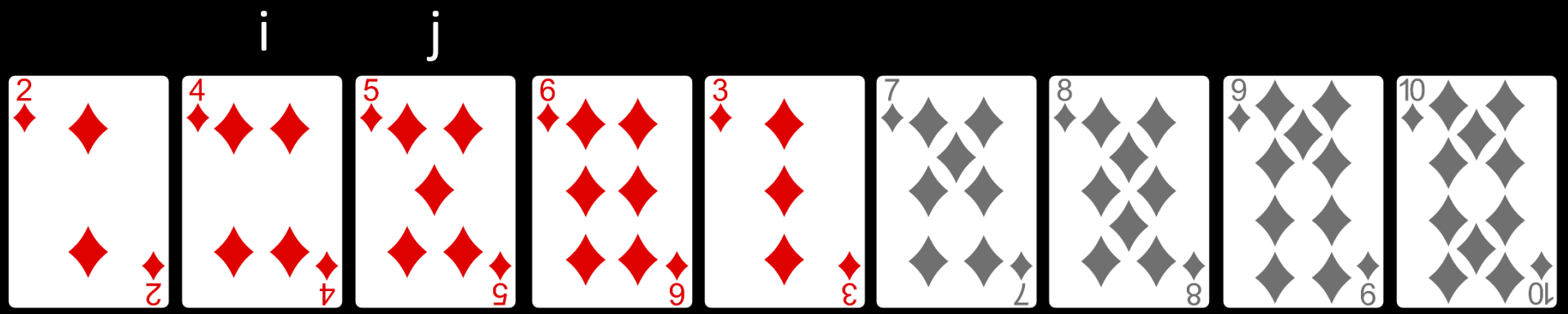

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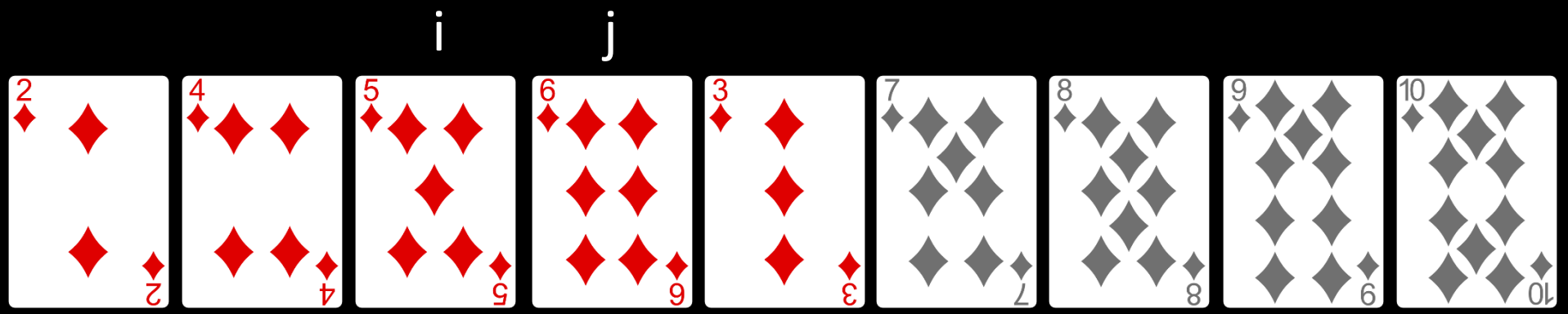

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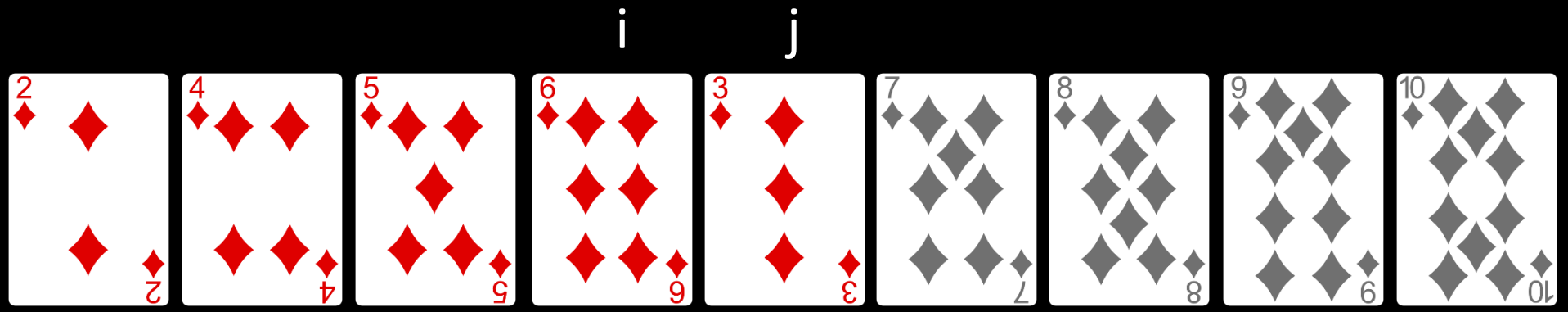
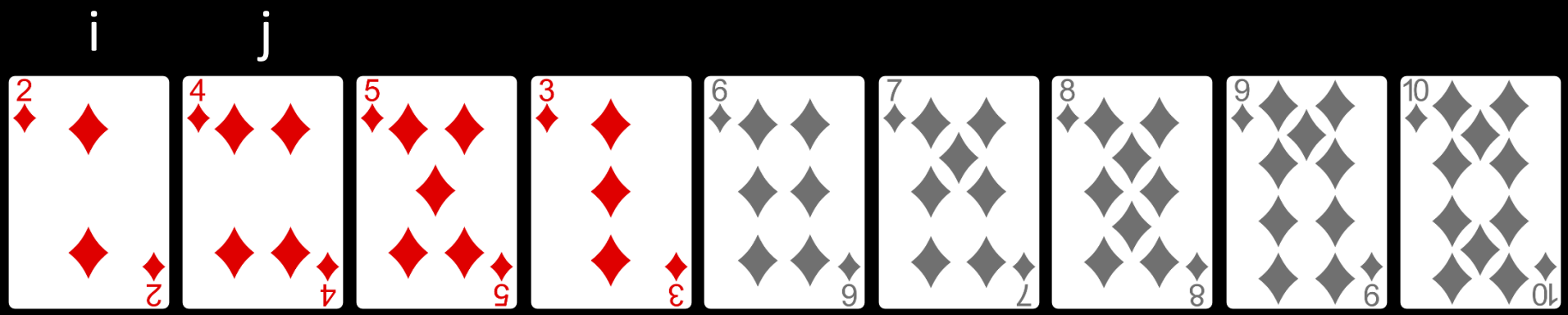
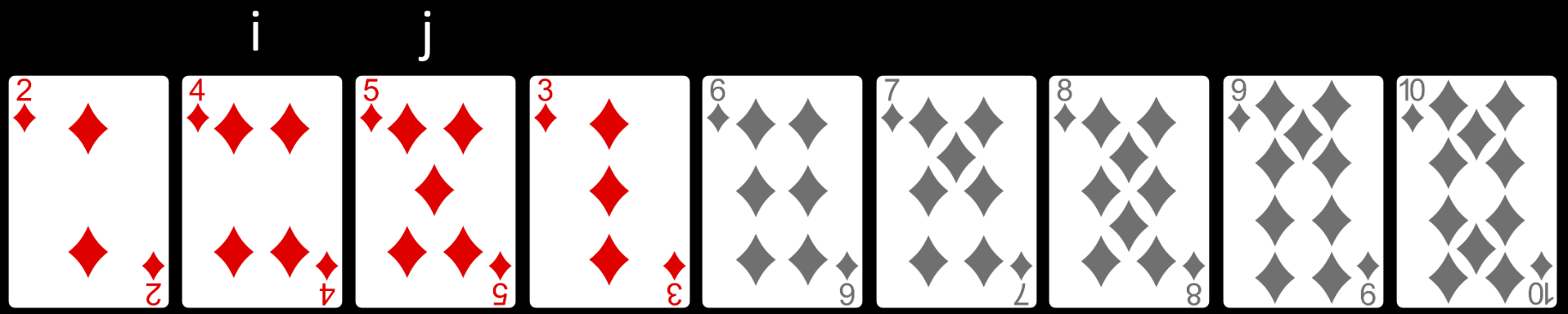


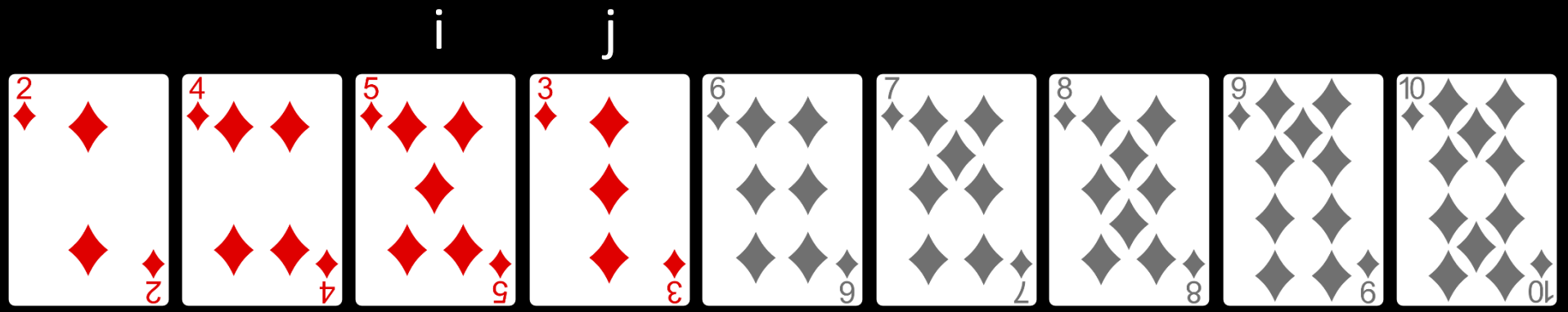
Bubble Sort Visualization



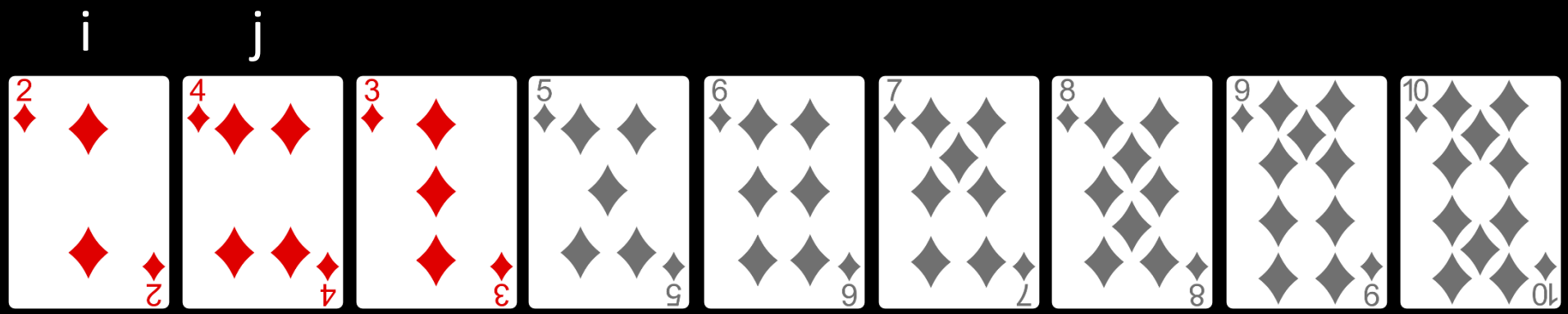
Bubble Sort Visualization



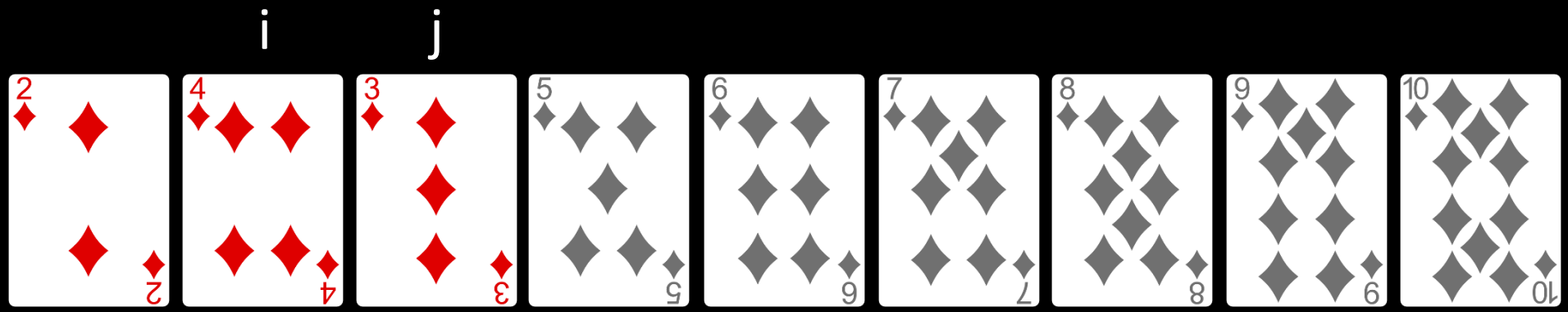
Bubble Sort Visualization



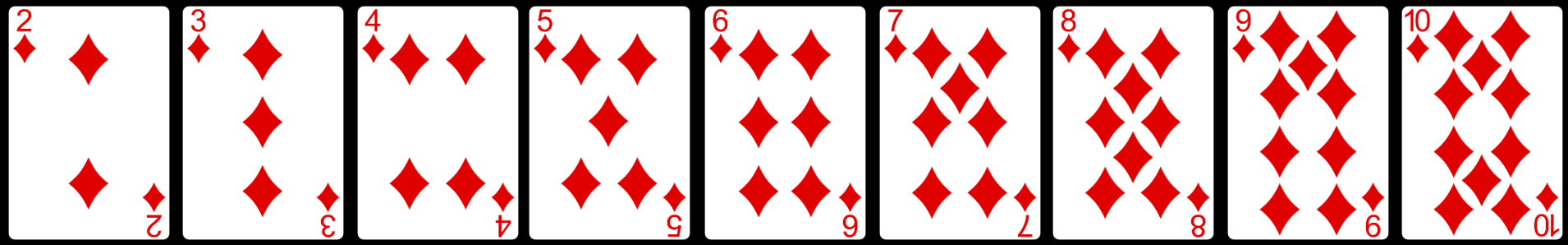
Bubble Sort Visualization



Bubble Sort Visualization



Bubble Sort Visualization



Comparison of Sorting Algorithms

Name	Best	Average	Worst	Memory	Stable	Method
SelectionSort	n^2	n^2	n^2	1	No	Selection
BubbleSort	n	n^2	n^2	1	Yes	Exchanging

Insertion Sort

- Insertion sort – simple, but inefficient algorithm (visualize)
  - Move the first unsorted element left to its place
  - Memory: O(1)
  - Stable: Yes
  - Method: Insertion

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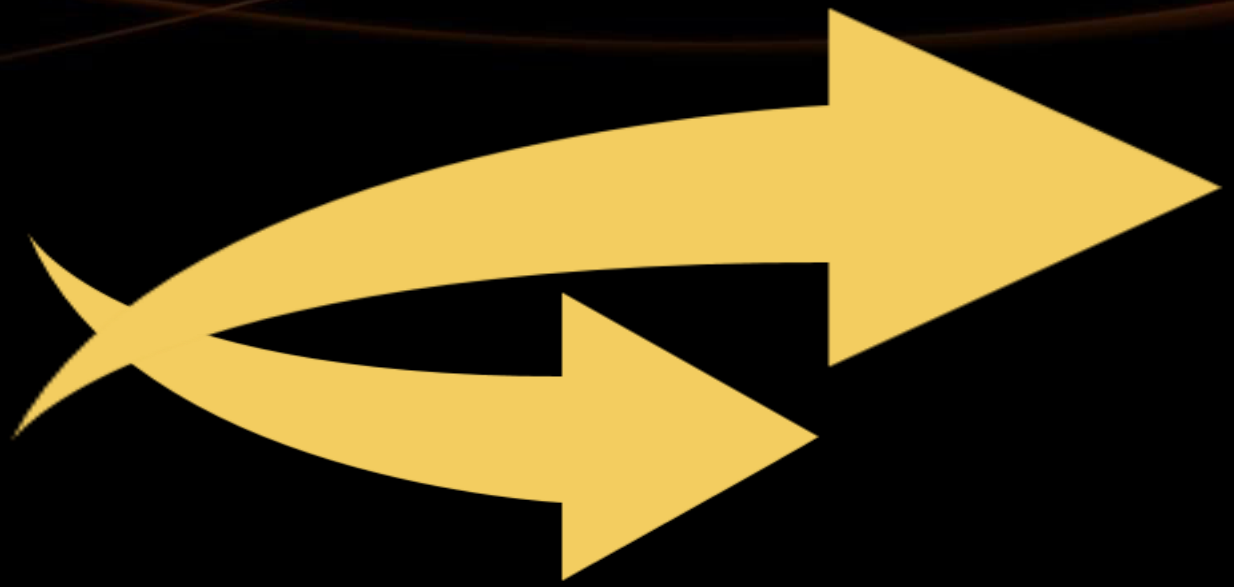

Shuffling

Fisher-Yates Shuffle

Shuffling

- Shuffling == randomizing the order of items in a collection
  - Generate a random permutation
- *The generation of random numbers is too important to be left to chance.* —Robert R. Coveyou

Fisher–Yates Shuffle Algorithm

```
public static void Shuffle<T>(T[] source)
{
  Random rnd = new Random();

  for (int i = 0; i < source.Length; i++)
  {
    // Exchange array[i] with random element in array[i … n-1]

    int r = i + rnd.Next(0, source.Length - i);

    T temp = source[i];
    source[i] = source[r];
    source[r] = temp;
  }
}
```

Shuffle algorithms: visualization

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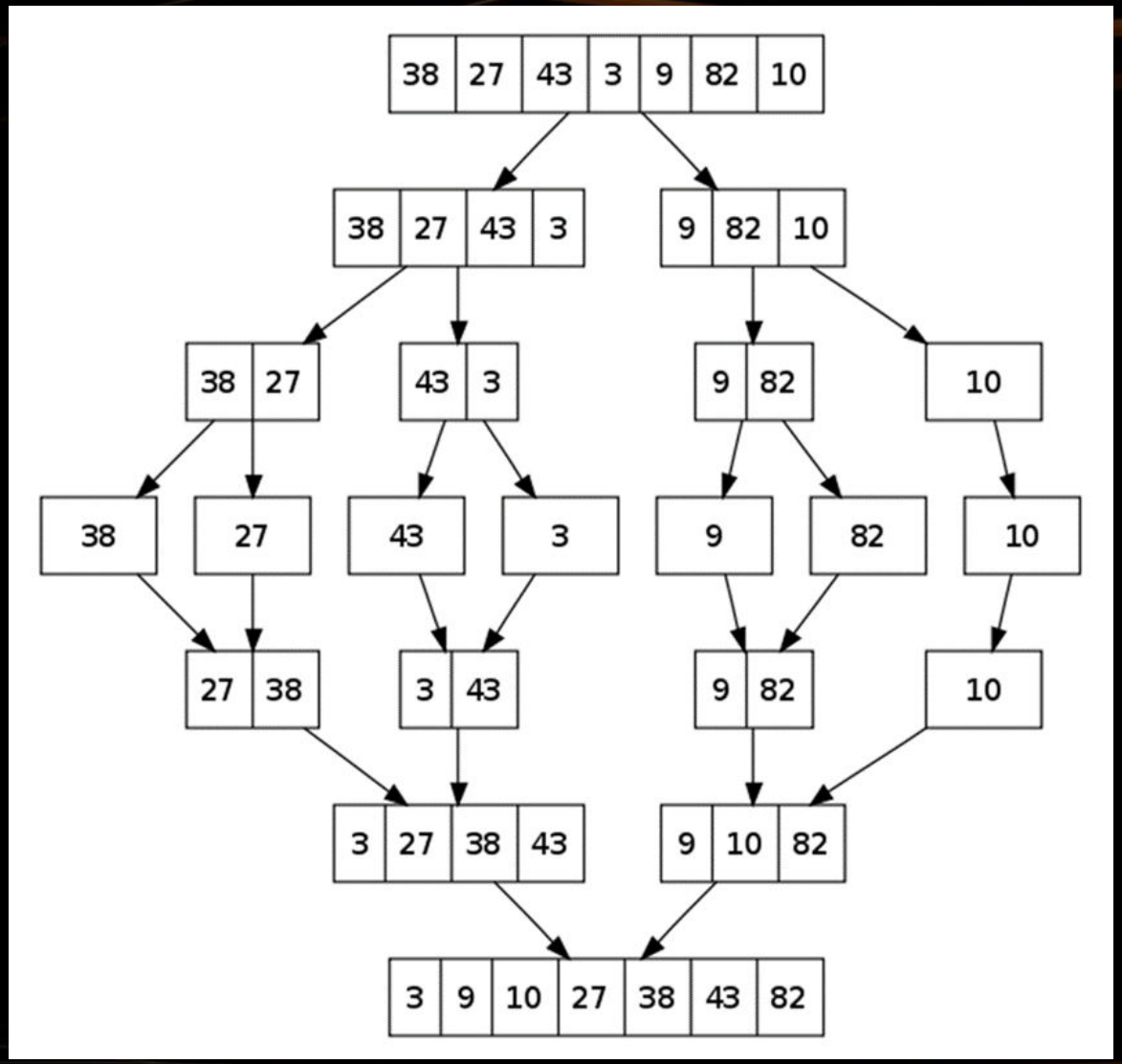
Advanced Sorting Algorithms

QuickSort, MergeSort, BucketSort

Merge Sort

- Merge sort is efficient sorting algorithm (visualize)
  1. Divide the list into sub-lists (typically 2 sub-lists)
  2. Sort each sub-list (recursively call merge-sort)
  3. Merge the sorted sub-lists into a single list
- Best, average and worst case: O(n*log(n))
- Memory:
  - Typically O(n)
  - With in-place merge can be O(1)
- Stable: Yes
- Method: Merging
- Highly parallelizable on multiple cores / machines → up to O(log(n))

Merge Sort: Hot It Works?

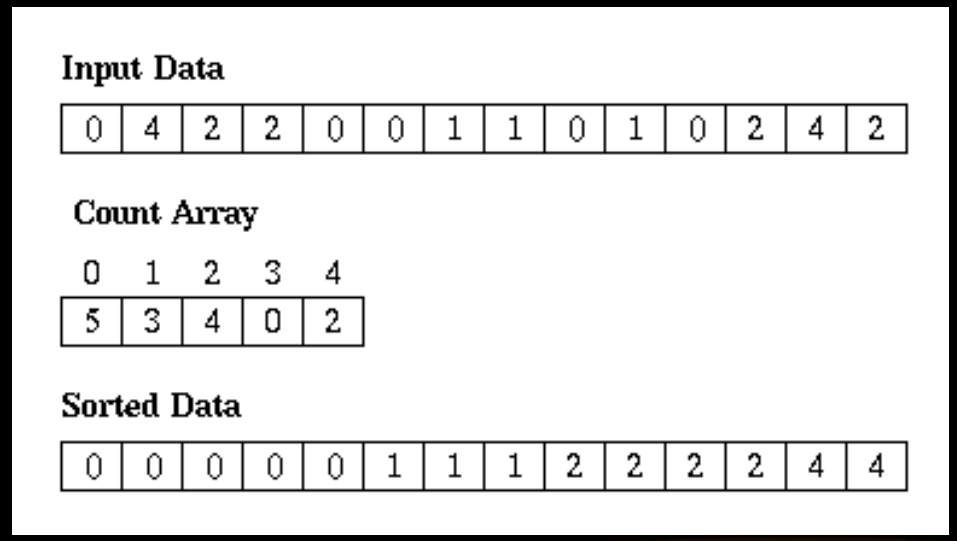


QuickSort

- QuickSort – efficient sorting algorithm (visualize)
  - Choose a pivot; move smaller elements left & larger right; sort left & right
  - Best & average case: O(n*log(n)); Worst: $O(n^2)$
  - Memory: O(log(n)) stack space (for recursion)
  - Stable: Depends
  - Method: Partitioning

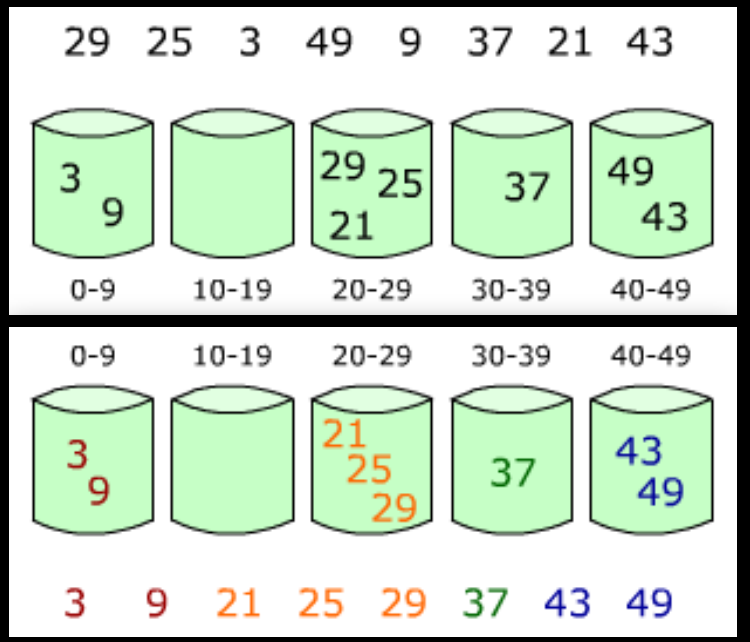
Counting Sort

- Counting sort is a very efficient sorting algorithm (visualize)
  - Sorts small integers by counting their occurrences
  - Not a comparison-based sort
- Best, average and worst case: O(n + k)
  - k is the range of numbers to be sorted
  - E.g. [-1000 ... 1000] → k = 2001
- Memory: O(n + k) Space: O(k)
- Stable: Yes
- Method: Counting



Bucket Sort

- Bucket sort partitions an array into a number of buckets
  - Each bucket is then sorted individually with a different algorithm
  - Not a comparison-based sort
- Average case: O(n + k)
  - k = the number of buckets
- Worst case: O(n * log n)
- Stable: Yes (depends on algorithm)
- Memory: O(n) – k buckets holding n elements totally



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InsertionSort	n	n^2	n^2	1	Yes	Insertion
QuickSort	n*log(n)	n*log(n)	n^2	log(n)	Depends	Partitioning
MergeSort	n*log(n)	n*log(n)	n*log(n)	1 (or n)	Yes	Merging
HeapSort	n*log(n)	n*log(n)	n*log(n)	1	No	Selection
BogoSort	n	n*n!	n*n!	1	No	Luck

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Searching Algorithms

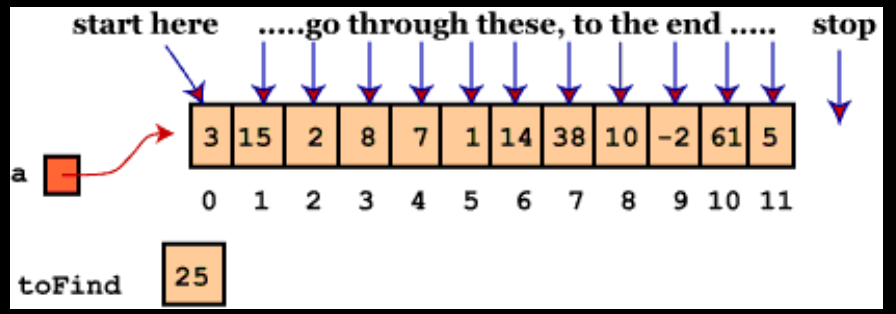
Linear, Binary and Interpolation

Search Algorithm

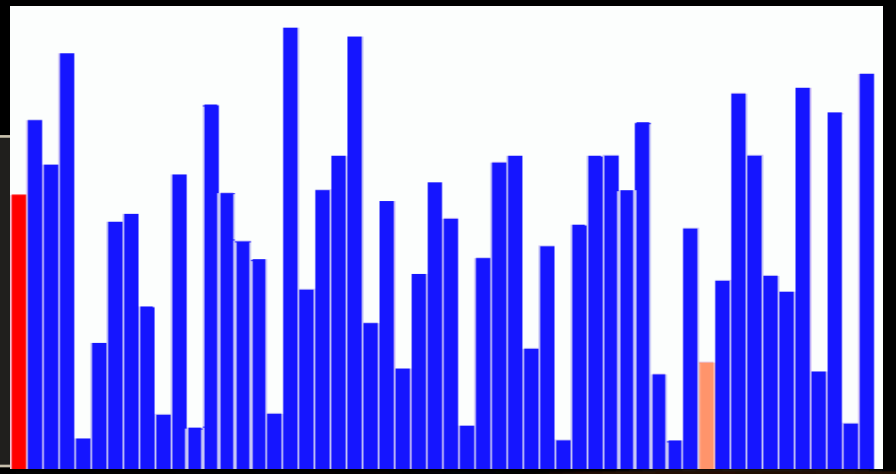
- Search algorithm == an algorithm for finding an item with specified properties among a collection of items
- Different types of searching algorithms
  - For virtual search spaces
    - Satisfy specific mathematical equations
    - Try to exploit partial knowledge about a structure
  - For sub-structures of a given structure
    - A graph, a string, a finite group
  - Search for the min / max of a function, etc.

Linear Search

- Linear search finds a particular value in a list (visualize)
  - Checking every one of the elements
  - One at a time, in sequence
  - Until the desired one is found
- Worst & average performance: O(n)

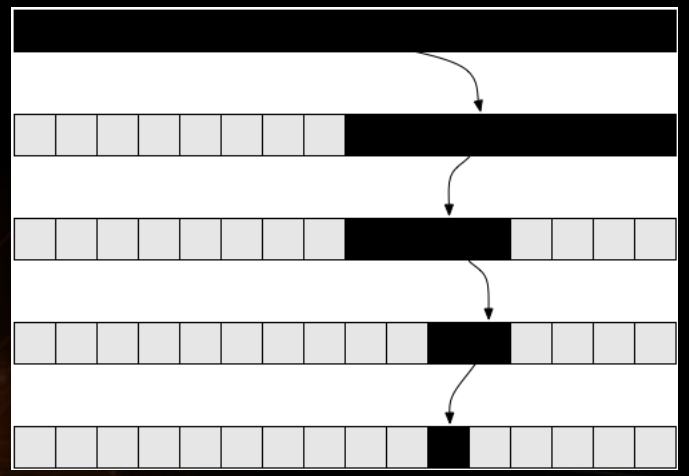


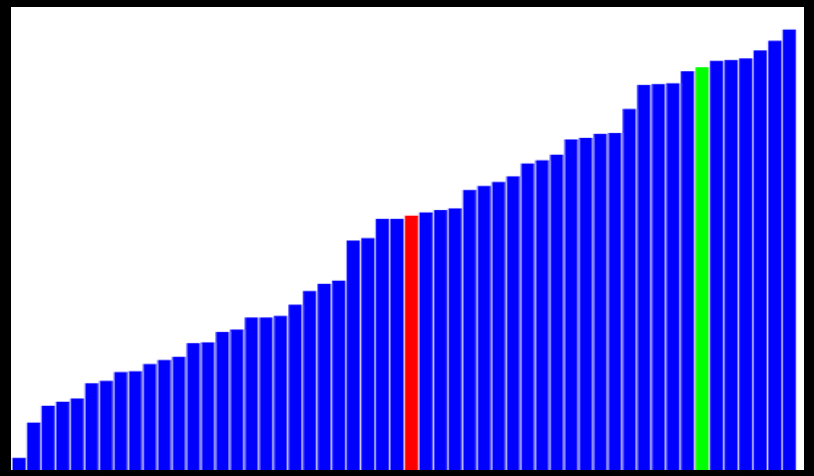

```
for each item in the list:
  if that item has the desired value,
    return the item's location
return nothing
```

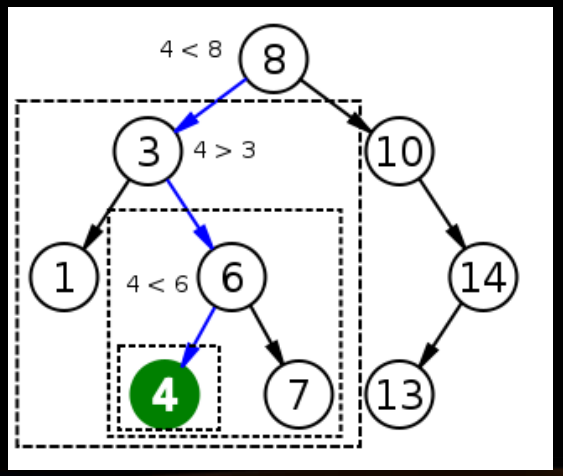


Binary Search

- Binary search finds an item within a ordered data structure
- At each step, compare the input with the middle element
  - The algorithm repeats its action to the left or right sub-structure
- Average performance: O(log(n))
- See the visualization







Binary Search (Recursive)

```
int BinarySearch(int arr[], int key, int start, int end) {
  if (end < start)
    return KEY_NOT_FOUND;
  else {
    int mid = (start + end) / 2;
    if (arr[mid] > key)
      return BinarySearch(arr, key, start, mid - 1);
    else if (arr[mid] < key)
      return BinarySearch(arr, key, mid + 1, end);
    else
      return mid;
  }
}
```

Binary Search (Iterative)

```
int BinarySearch(int arr[], int key, int start, int end) {
  while (end >= start) {
    int mid = (start + end) / 2;
    if (arr[mid] < key)
      start = mid + 1;
    else if (arr[mid] > key)
      end = mid - 1;
    else
      return mid;
  }
  return KEY_NOT_FOUND;
}
```

Interpolation Search

- Interpolation search == an algorithm for searching for a given key in an ordered indexed array
  - Parallels how humans search through a telephone book
  - Calculates where in the remaining search space the item might be
    - Binary search always chooses the middle element
    - Can we have a better hit, e.g. *Angel* in the phonebook should be at the start, not at the middle, OK?
- Average case: log(log(n)), Worst case: O(n)
- http://youtube.com/watch?v=l1ed_bTv7Hw

Interpolation Search – Sample Implementation


```
int InterpolationSearch(int[] sortedArray, int key) {
  int low = 0;
  int high = sortedArray.Length - 1;
  while (sortedArray[low] <= key && sortedArray[high] >= key) {
    int mid = low + ((key - sortedArray[low]) * (high - low))
      / (sortedArray[high] - sortedArray[low]);
    if (sortedArray[mid] < key)
      low = mid + 1;
    else if (sortedArray[mid] > key)
      high = mid - 1;
    else
      return mid;
  }
  if (sortedArray[low] == key) return low;
  else return KEY_NOT_FOUND;
}
```

Summary

- Slow sorting algorithms:
  - Selection sort, Bubble sort, Insertion sort
- Fast sorting algorithms:
  - Quick sort, Merge sort, etc.
  - How to choose the most appropriate algorithm?
    - http://stackoverflow.com/a/1934004
- Searching algorithms
  - Binary Search, Interpolation Search

Sorting and Searching Algorithms

Questions?

https://softuni.bg/opencourses/algorithms

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