Data Representation and Manipulation

Recursion, Sorting and Searching Algorithms

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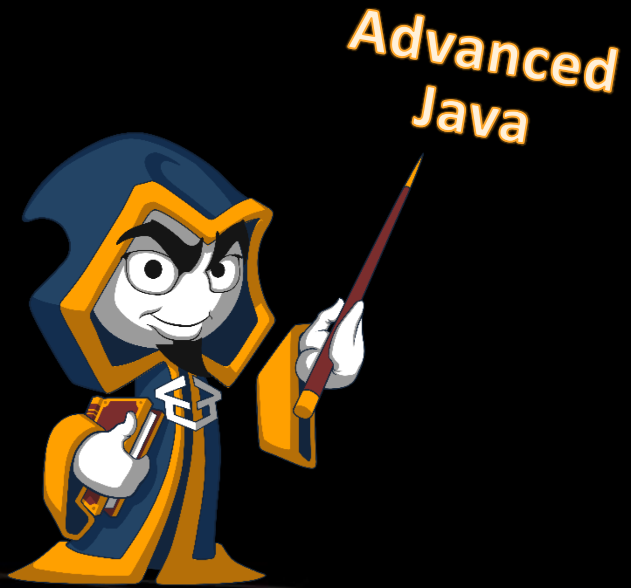

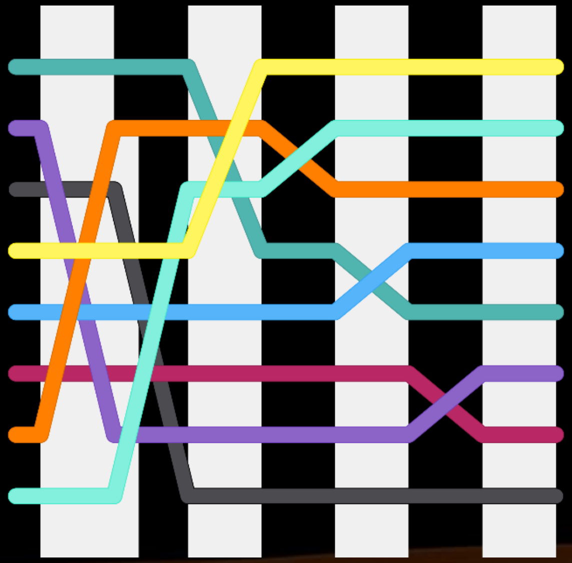

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Have a Question?

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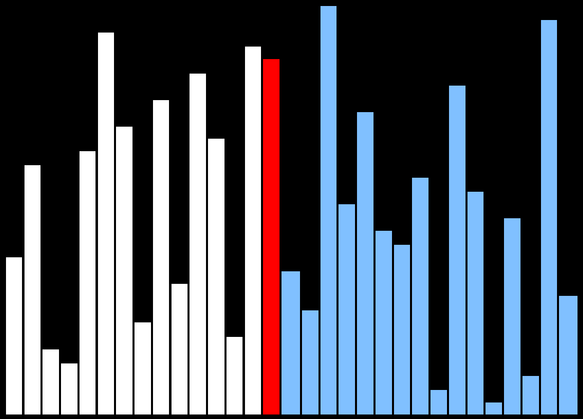
#JavaAdvanced

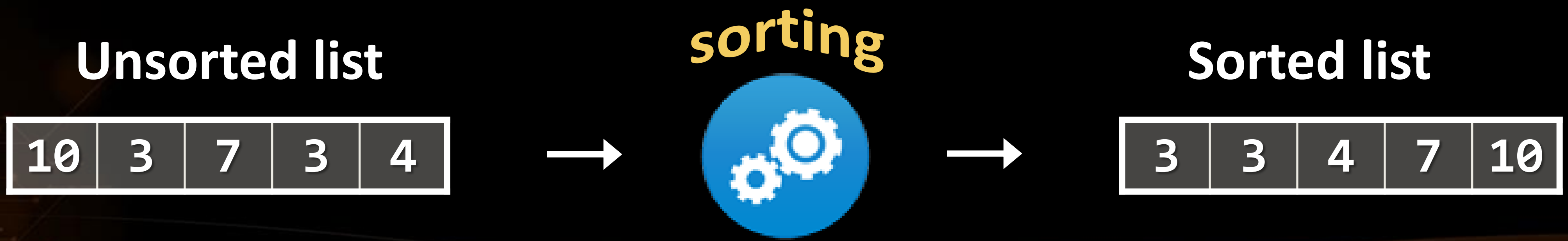
Simple Sorting Algorithms

Selection Sort and Bubble Sort

What is a Sorting Algorithm?

- **Sorting algorithm**
  - An algorithm that rearranges elements in a collection
    - In non-decreasing order
  - Elements must be **comparable**





Unsorted list

10	3	7	3	4

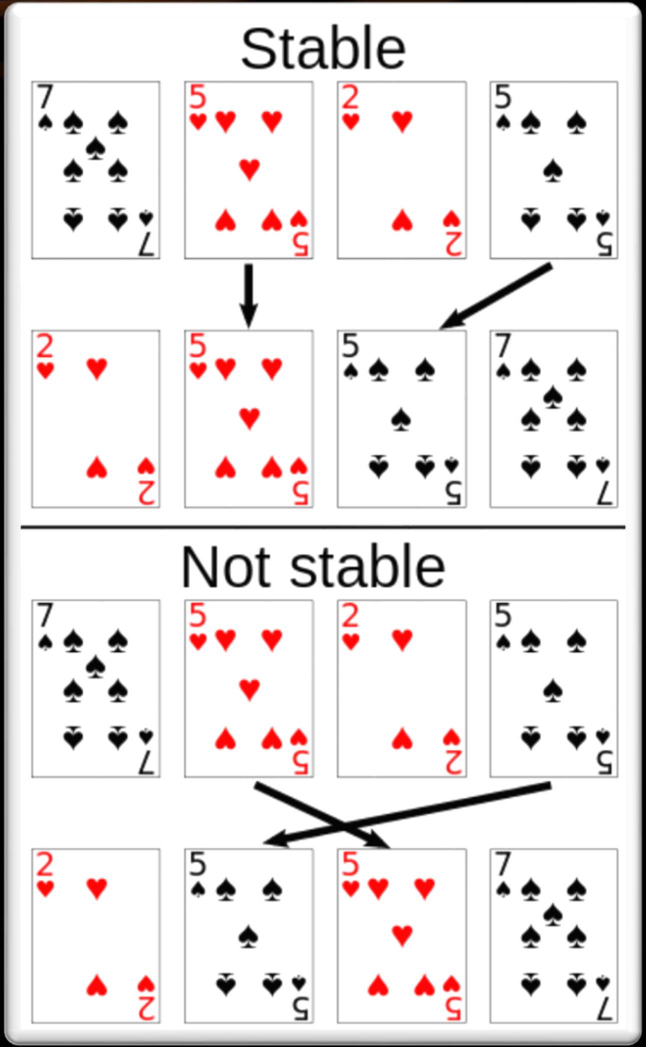
→ sorting →

Sorted list

3	3	4	7	10

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



Selection Sort

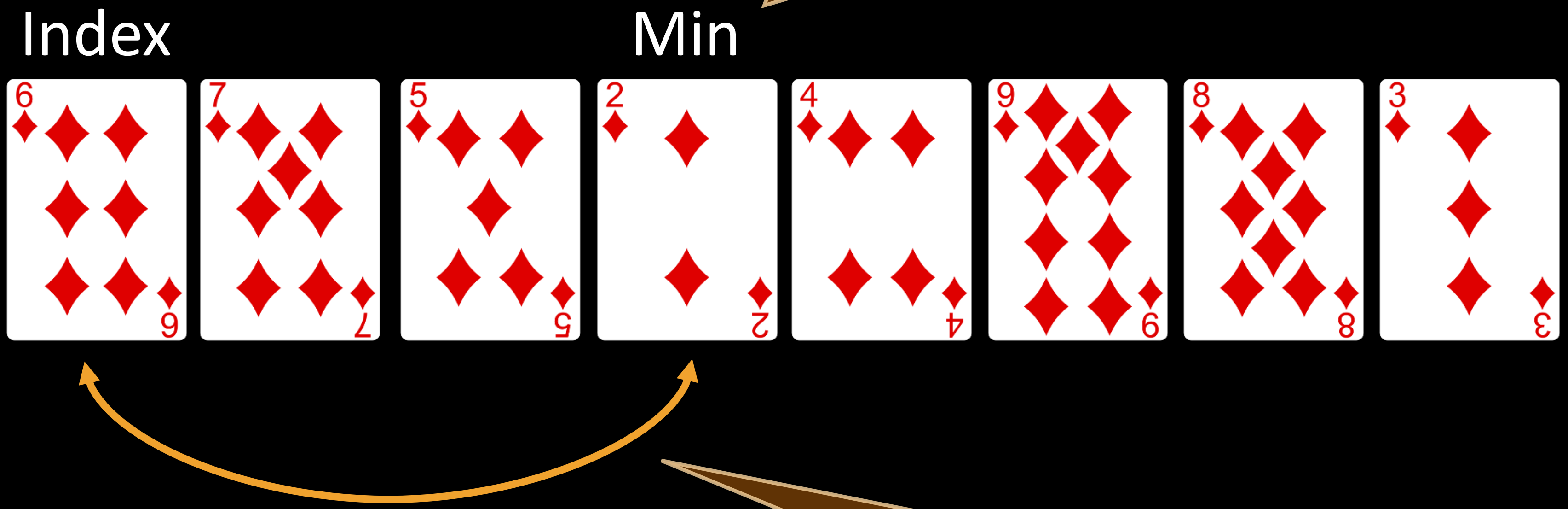
- Swap each element with the min element on its right
- Visualize

```
repeat (numOfElements - 1) times
  set the first element as min
  for each of the next elements
    if element < currentMinimum
      set element as new minimum
  swap minimum with first element
```

Selection Sort Visualization

Steps count: 8 + 1 ⇨ 9

Finding the **smallest** element takes **8** steps

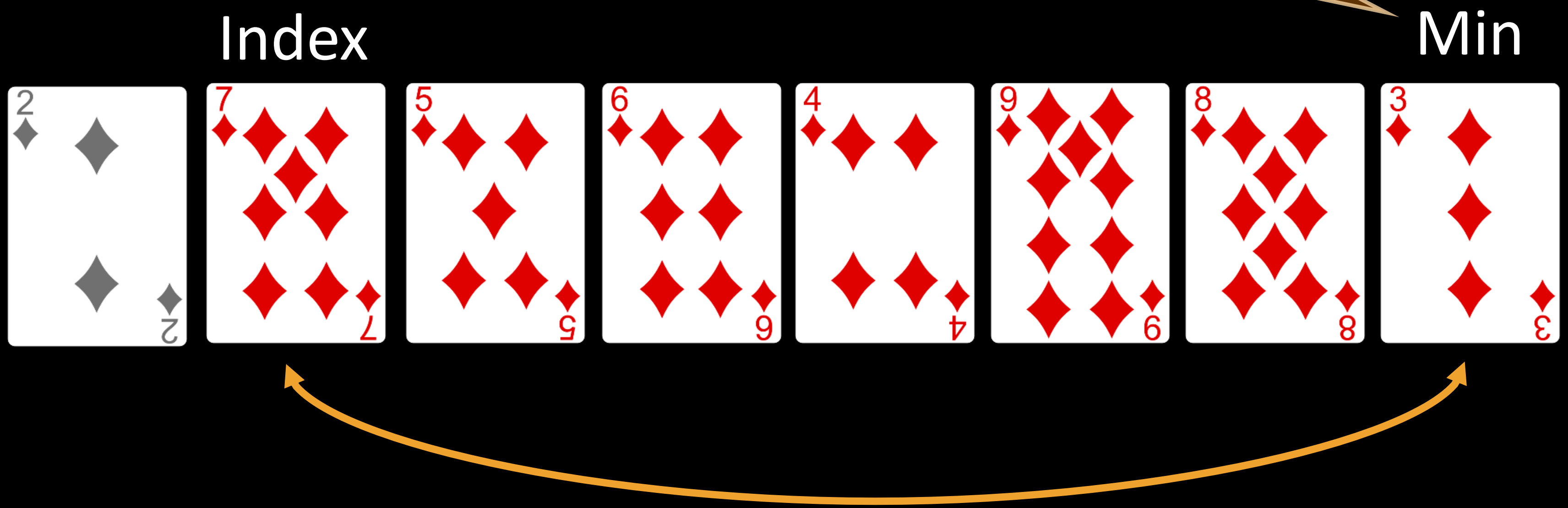


Swapping elements counts as an extra step

Selection Sort Visualization

Steps count: 9 + 7 + 1 ⇨ 17

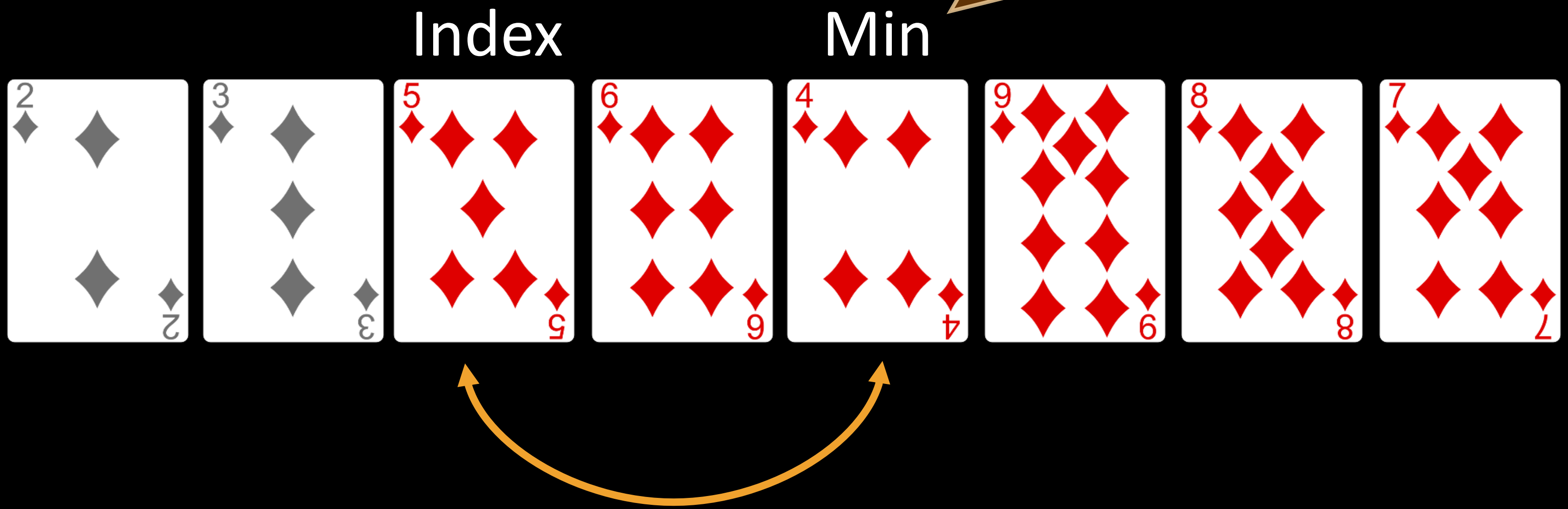
Finding the **smallest** element takes **7** steps



Selection Sort Visualization

Steps count: 17 + 6 + 1 ⇨ 24

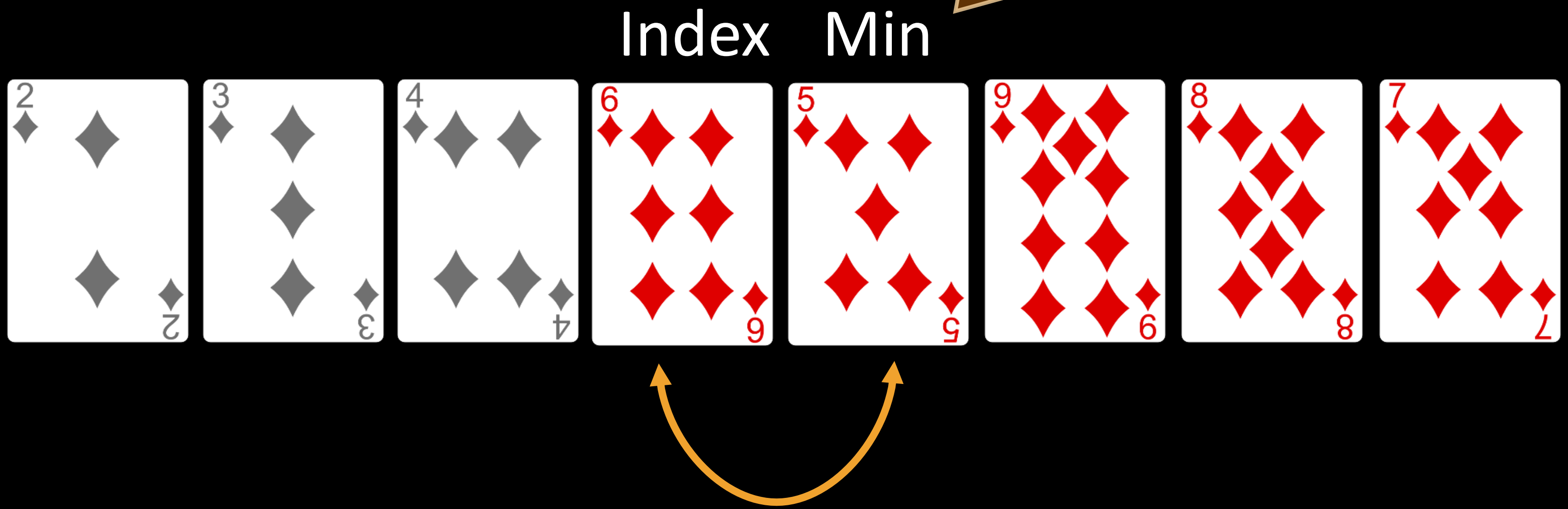
Finding the **smallest** element takes **6** steps



Selection Sort Visualization

Steps count: 24 + 5 + 1 ⇨ 30

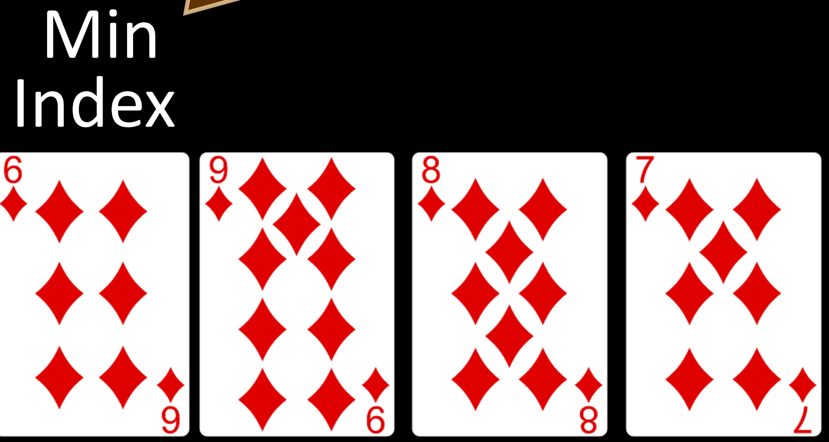
Finding the **smallest** element takes **5** steps



Selection Sort Visualization

Steps count: 30 + 4 ⇨ 34

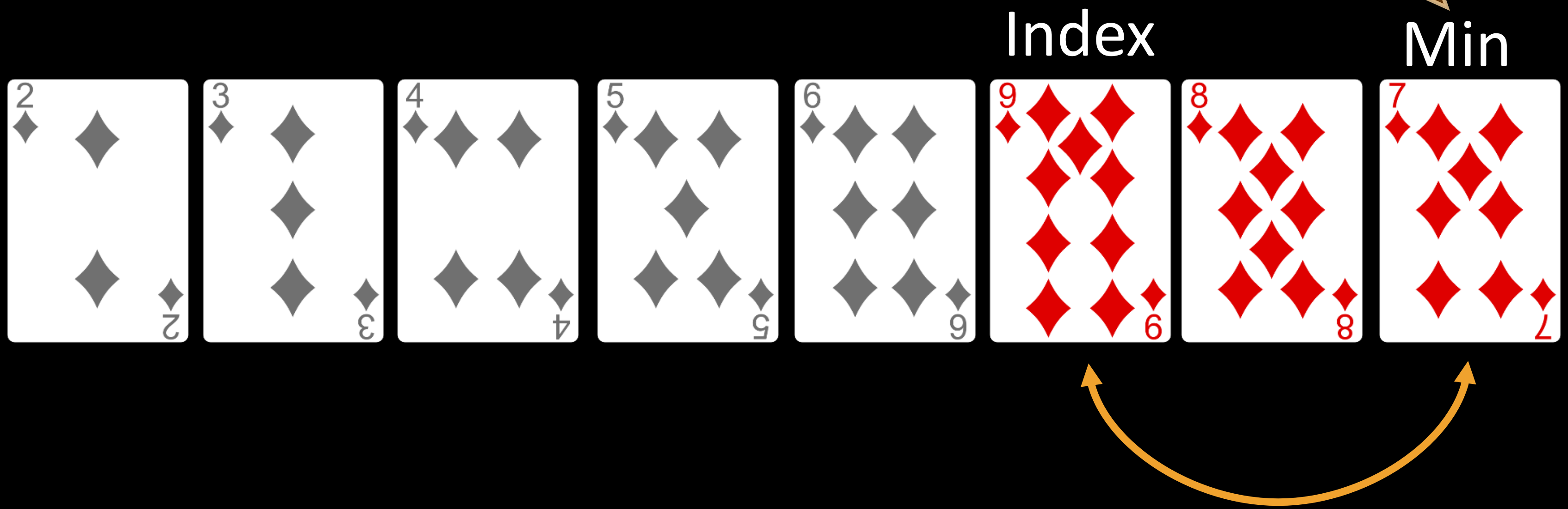
Finding the **smallest** element takes **4** steps



Selection Sort Visualization

Steps count: 34 + 3 + 1 ⇨ 38

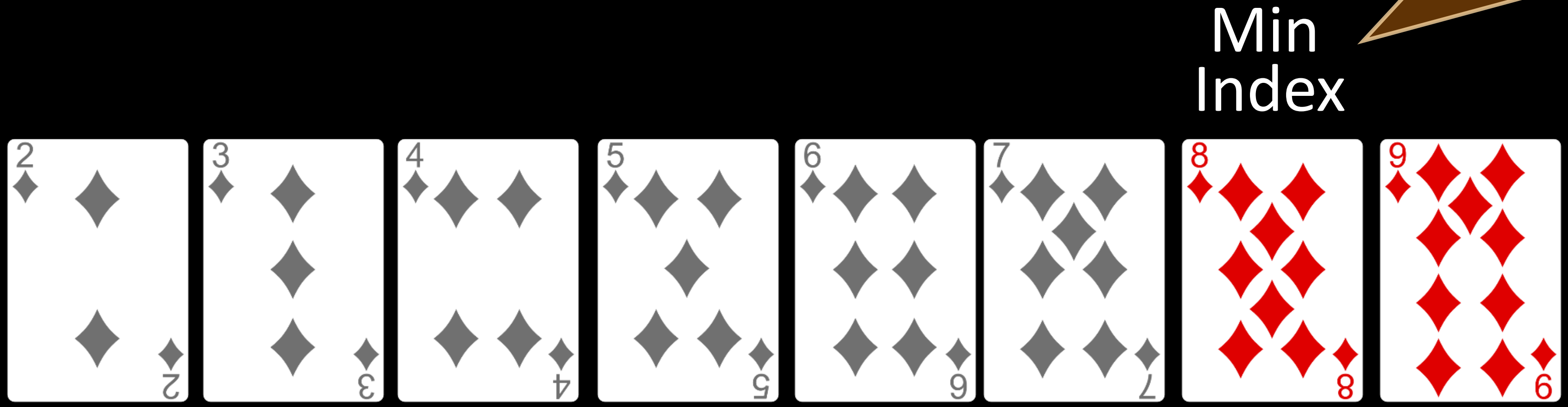
Finding the **smallest** element takes **3** steps



Selection Sort Visualization

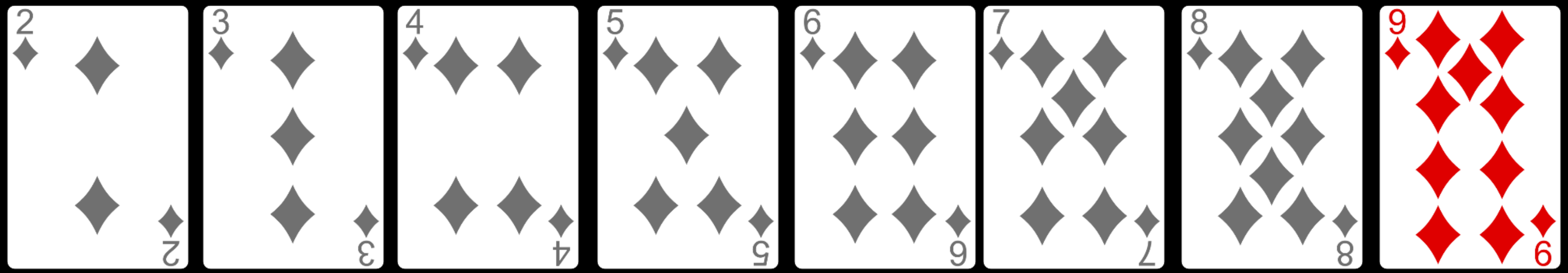
Steps count: 38 + 2 ⇨ 40

Finding the **smallest** element takes **2** steps



Selection Sort Visualization

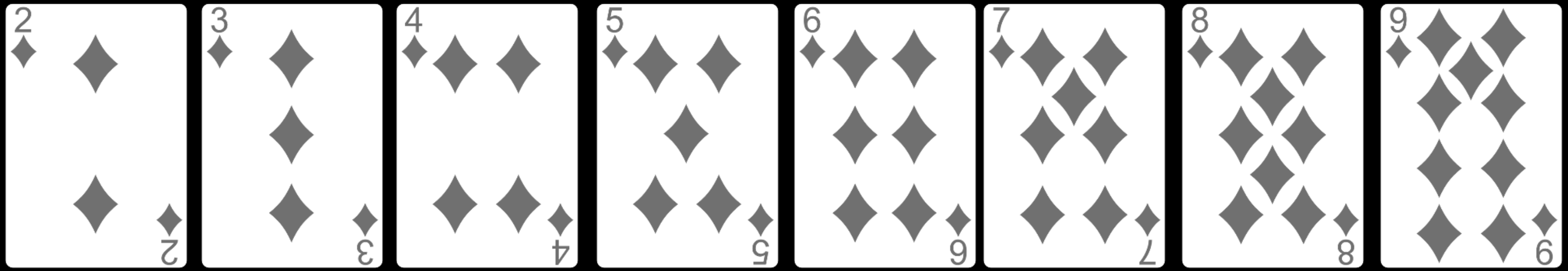
Steps count: 40 + 1 ⇨ 41



Finding the **smallest** element takes **1** step

Selection Sort Visualization

Total count of steps : 41



Selection Sort Code

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

Find the **smallest** element

Swap current with it

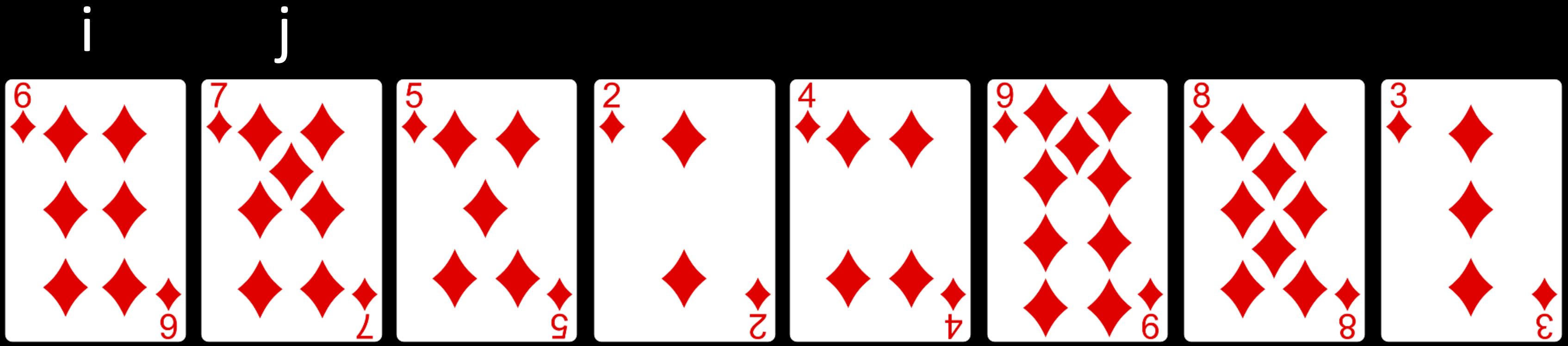
Bubble Sort

- Swaps neighbor elements when not in order until sorted
- Visualize

```
do
 swapped = false
 for i = 1 to collection length
  if leftElement > rightElement
   swap(leftElement, rightElement)
   swapped = true
while swapped
```

Bubble Sort Visualization

Steps count: 1



Bubble Sort Visualization

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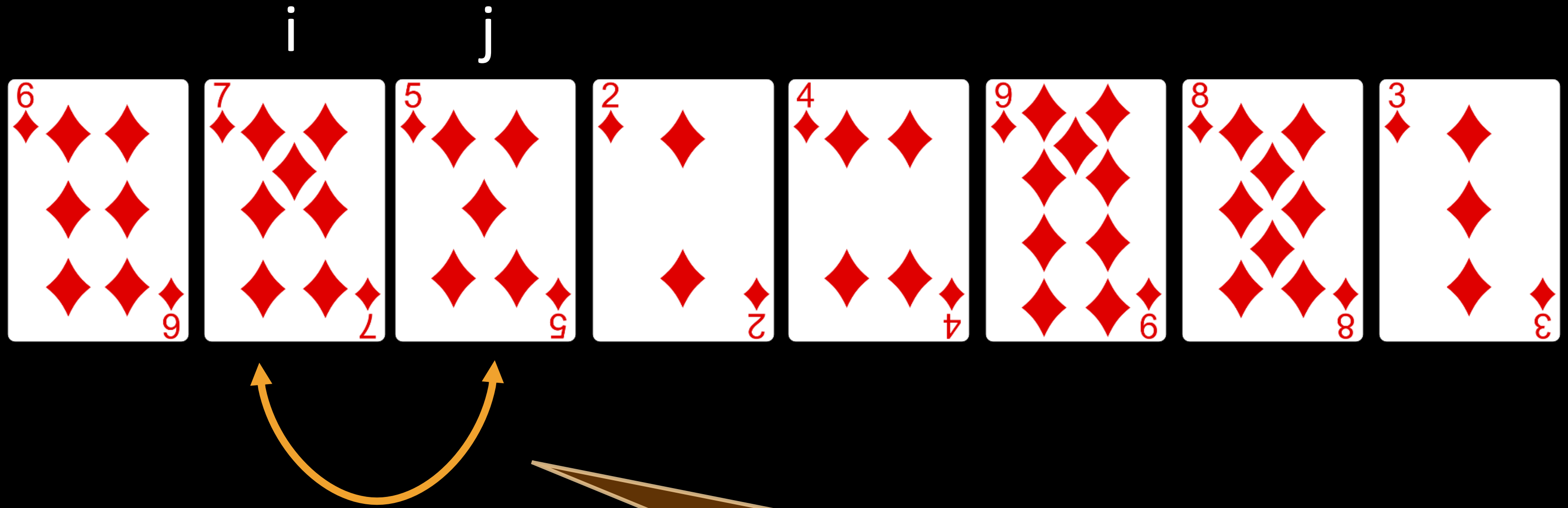
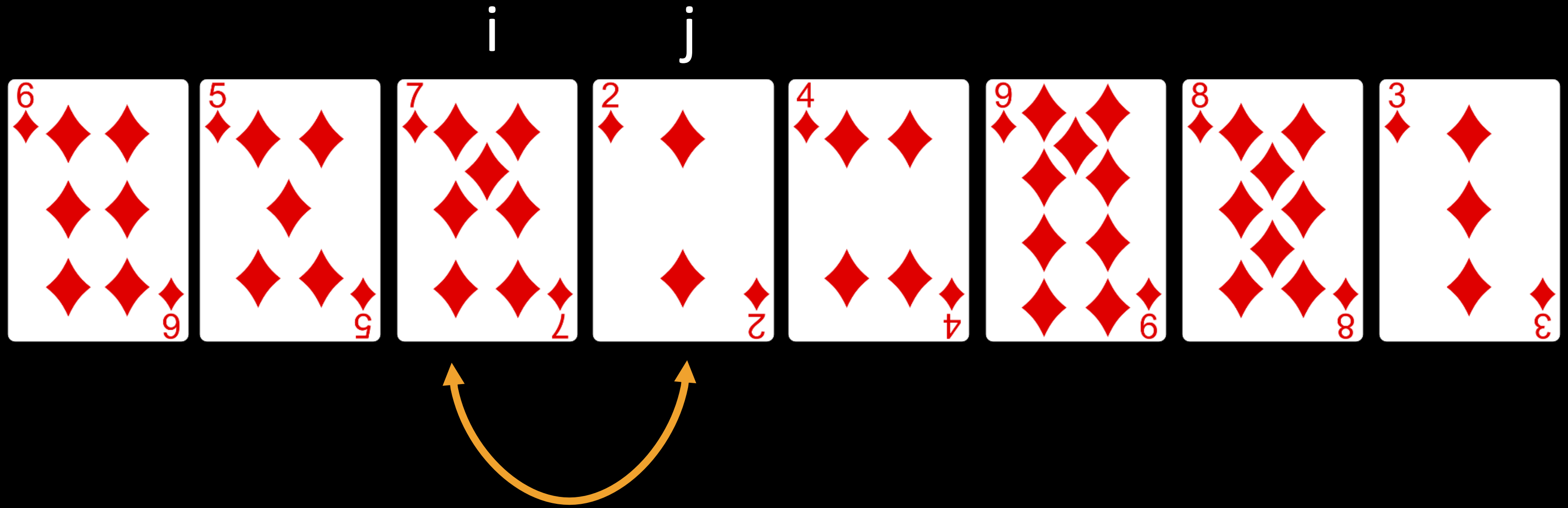
Steps count: 1 + 1 + 1 ⇨ 3



Swapping elements counts as an extra step

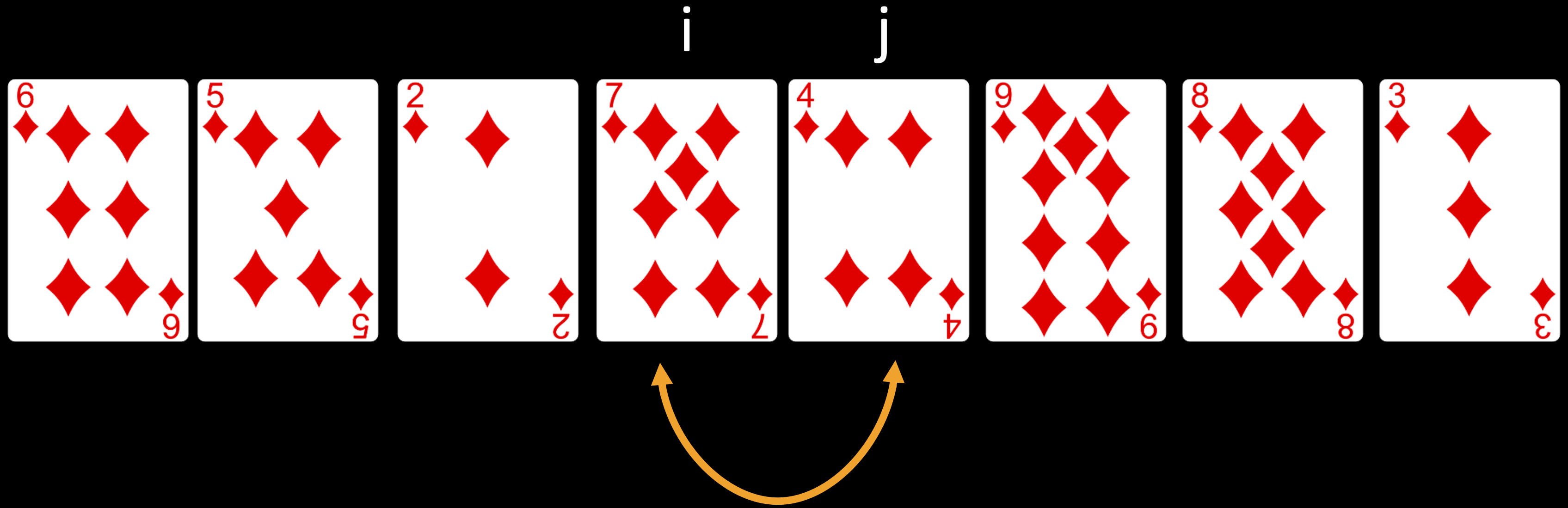
Bubble Sort Visualization

Steps count: 3 + 1 + 1 ⇨ 5



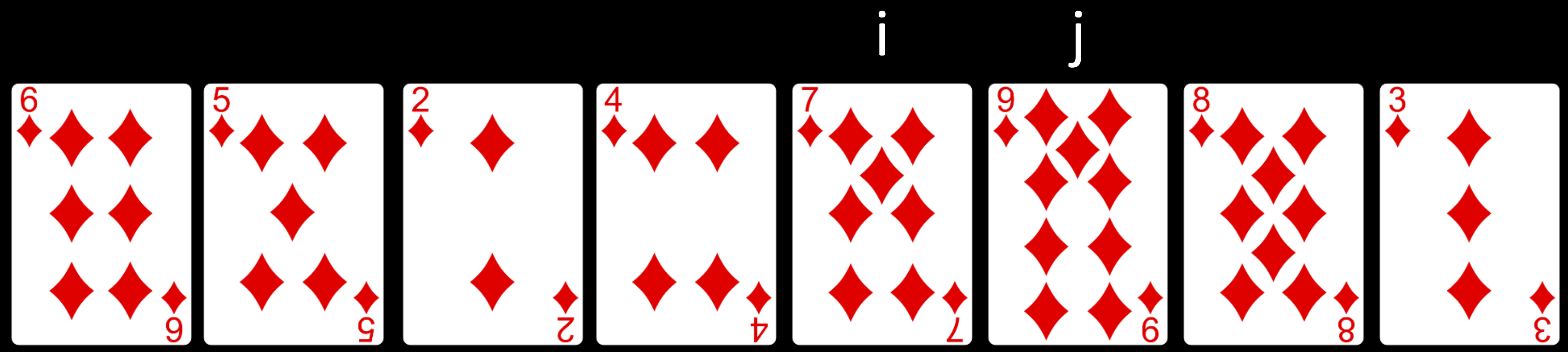
Bubble Sort Visualization

Steps count: 5 + 1 + 1 ⇨ 7



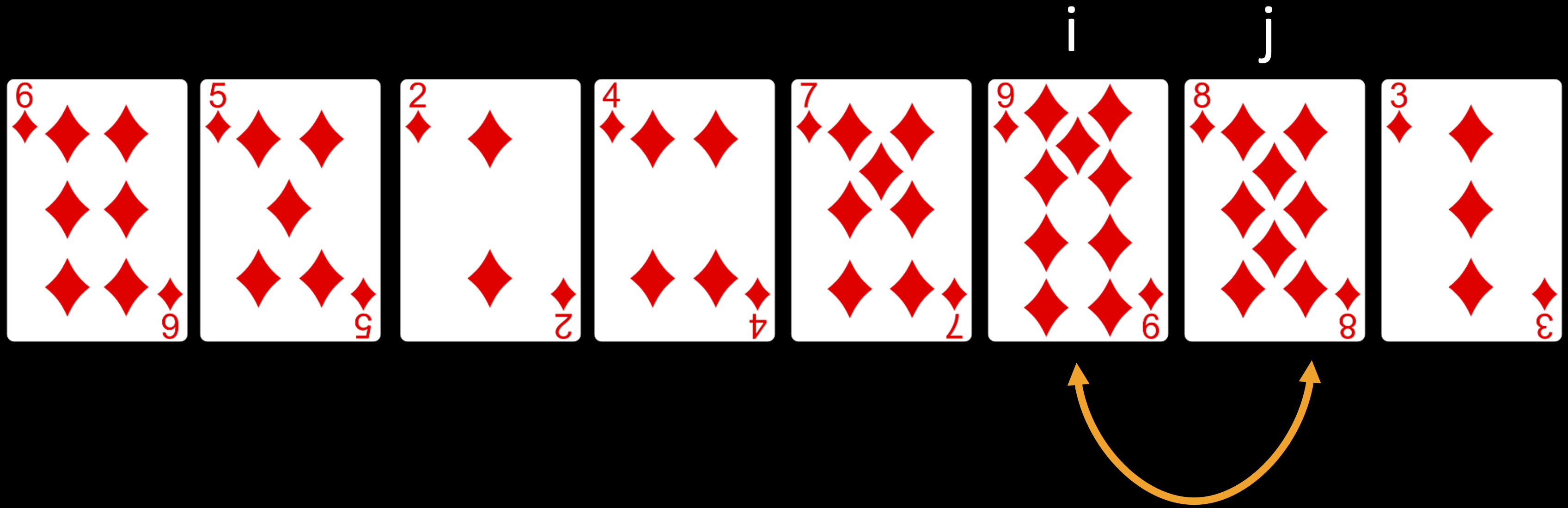
Bubble Sort Visualization

Steps count: 7 + 1 ⇨ 8



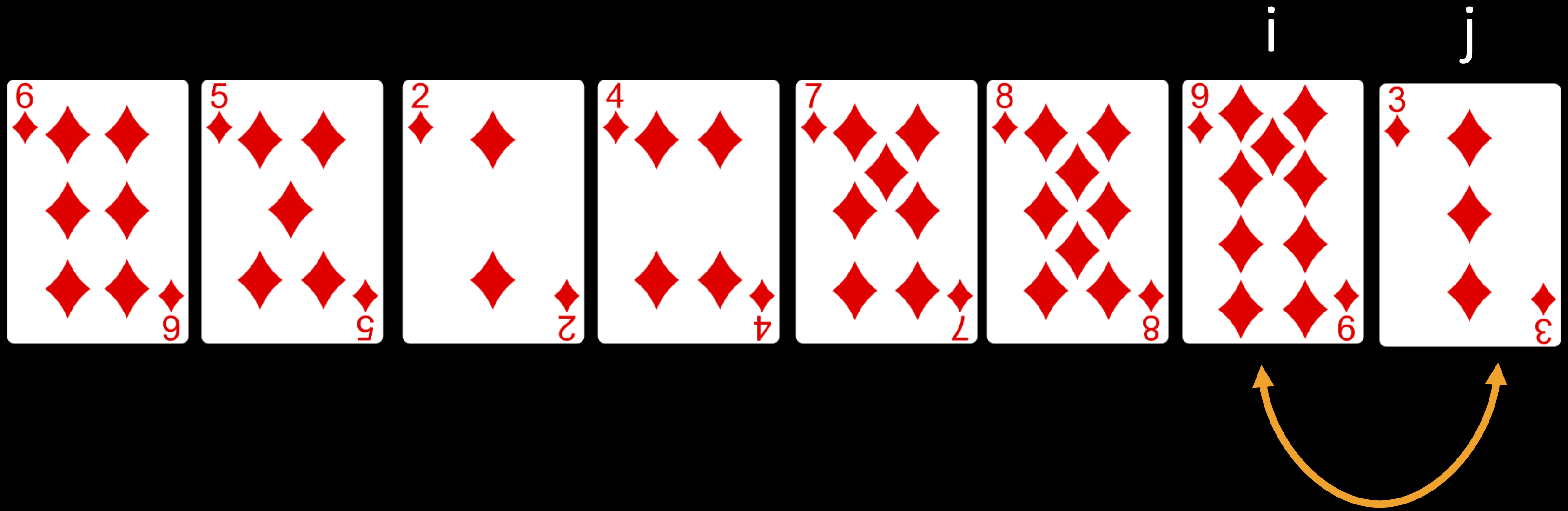
Bubble Sort Visualization

Steps count: 8 + 1 + 1 ⇨ 10



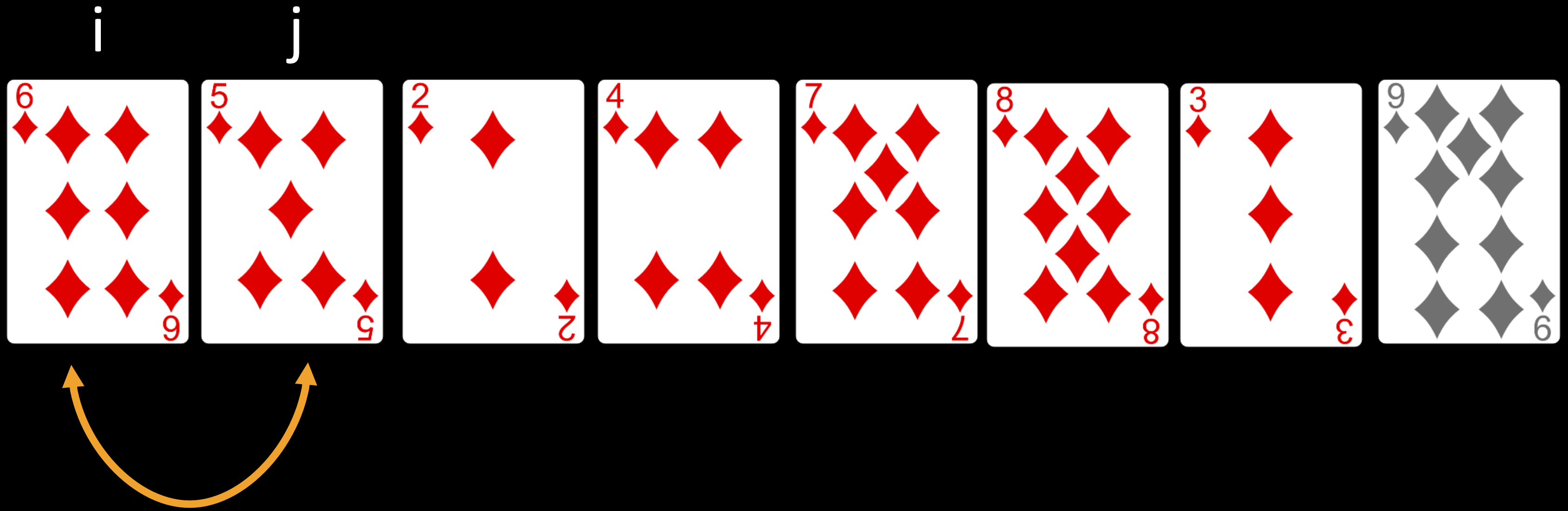
Bubble Sort Visualization

Steps count: 10 + 1 + 1 ⇨ 12



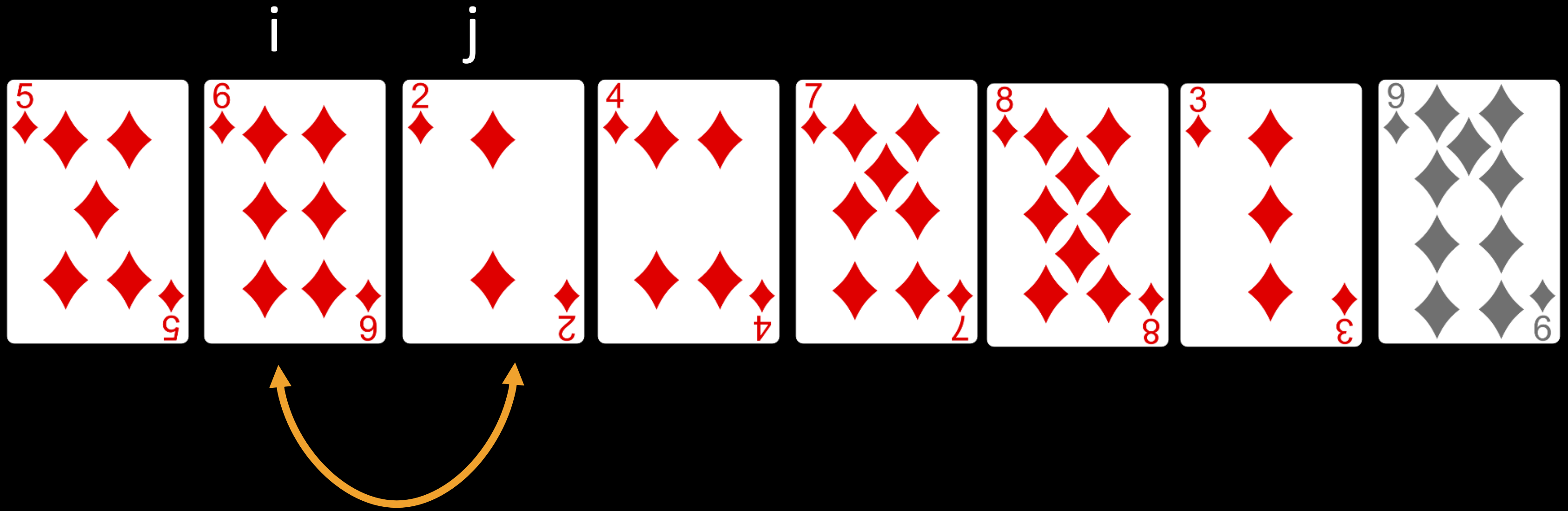
Bubble Sort Visualization

Steps count: 12 + 1 + 1 ⇨ 14



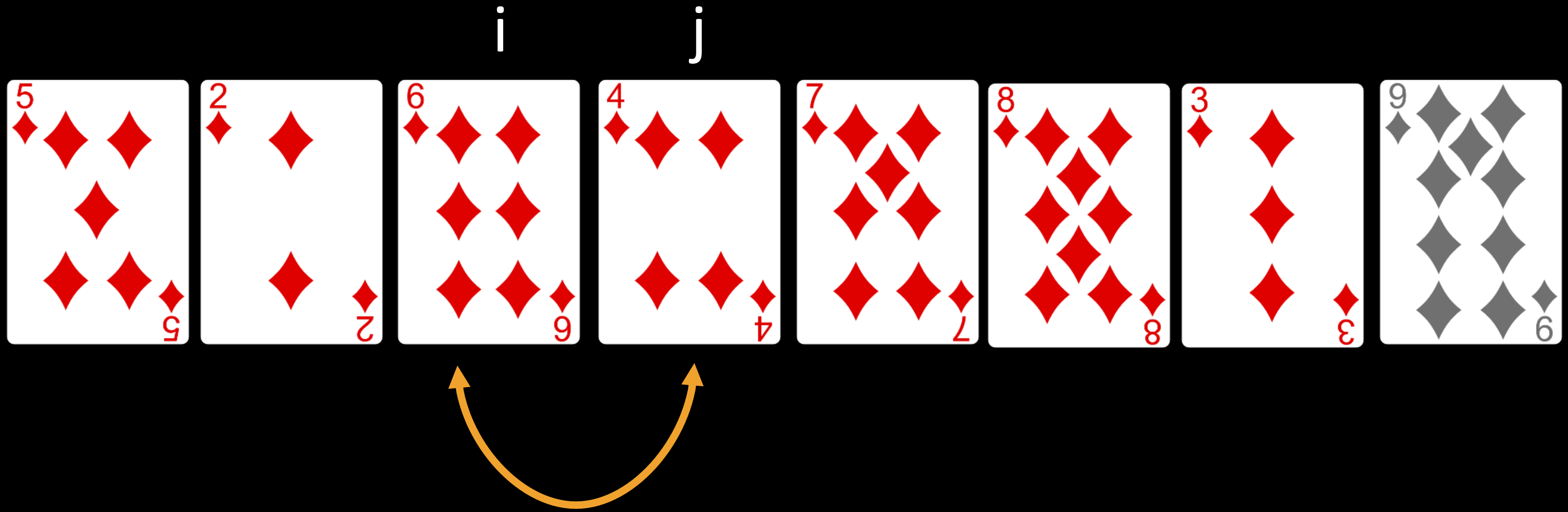
Bubble Sort Visualization

Steps count: 14 + 1 + 1 ⇨ 16



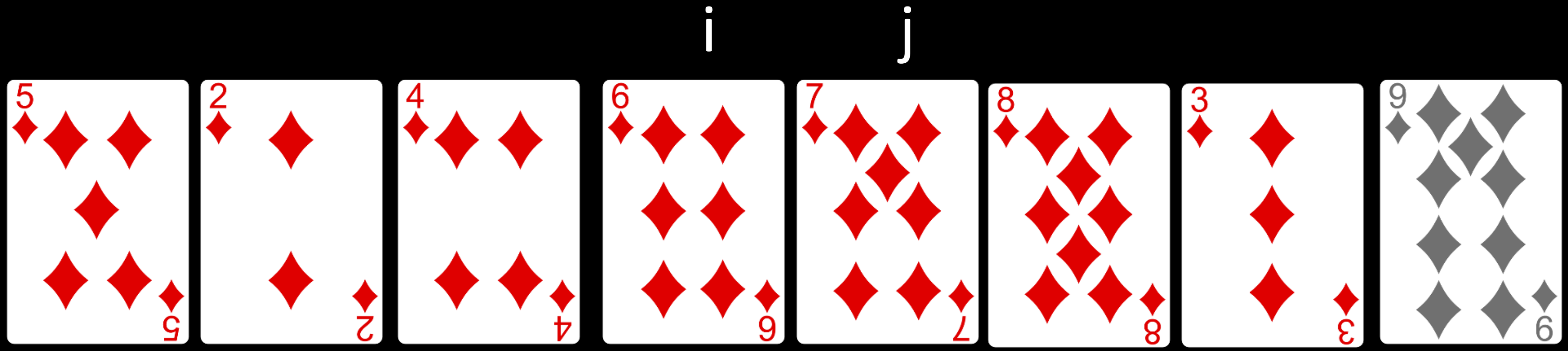
Bubble Sort Visualization

Steps count: 16 + 1 + 1 ⇨ 18



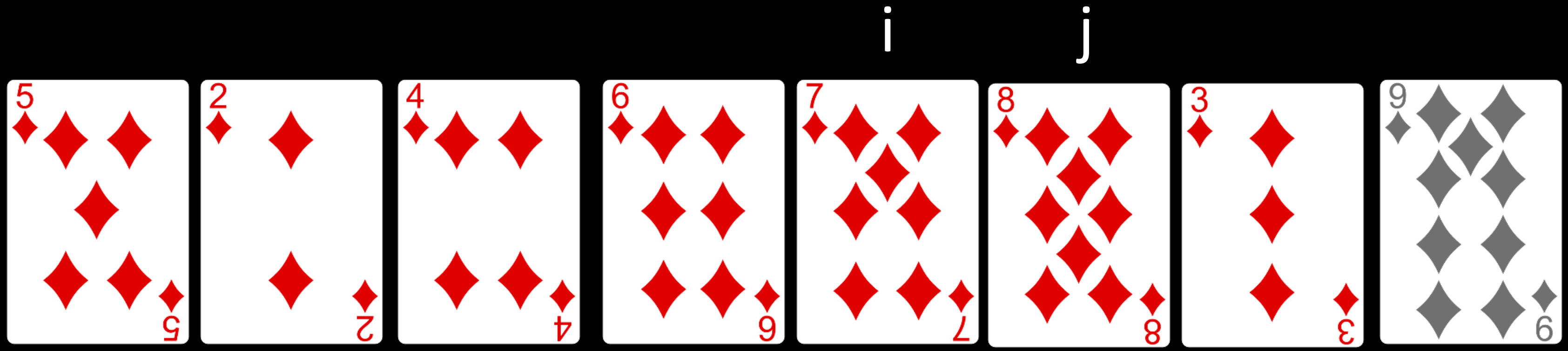
Bubble Sort Visualization

Steps count: 18 + 1 ⇨ 19



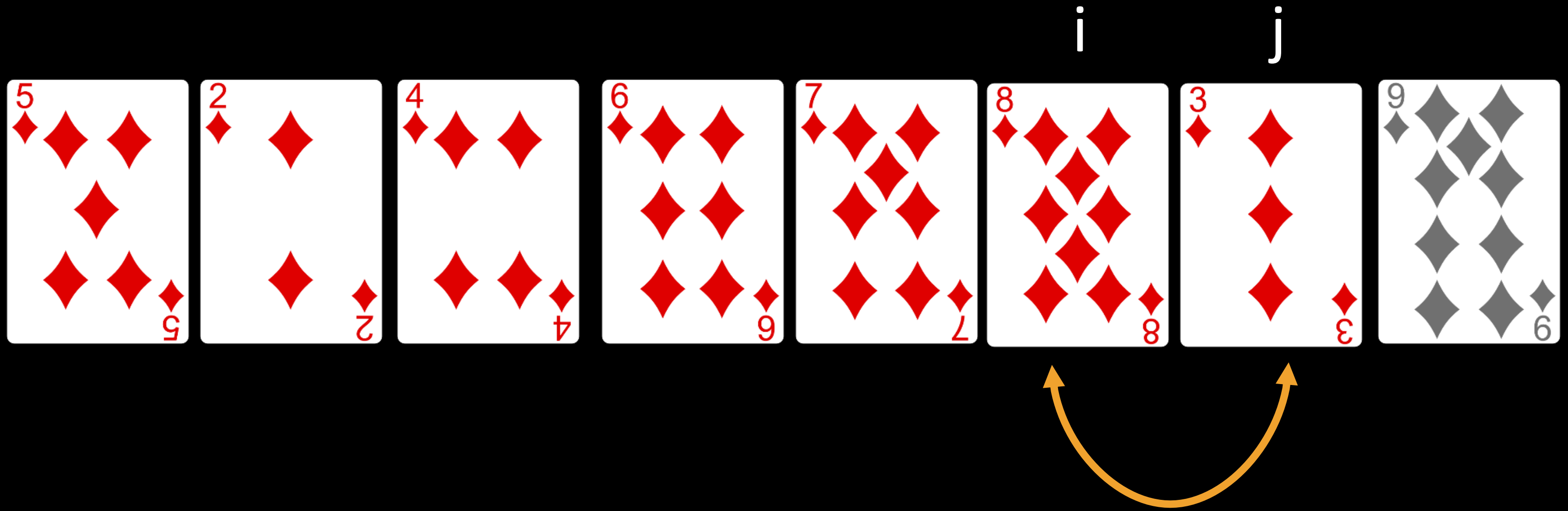
Bubble Sort Visualization

Steps count: 19 + 1 ⇨ 20



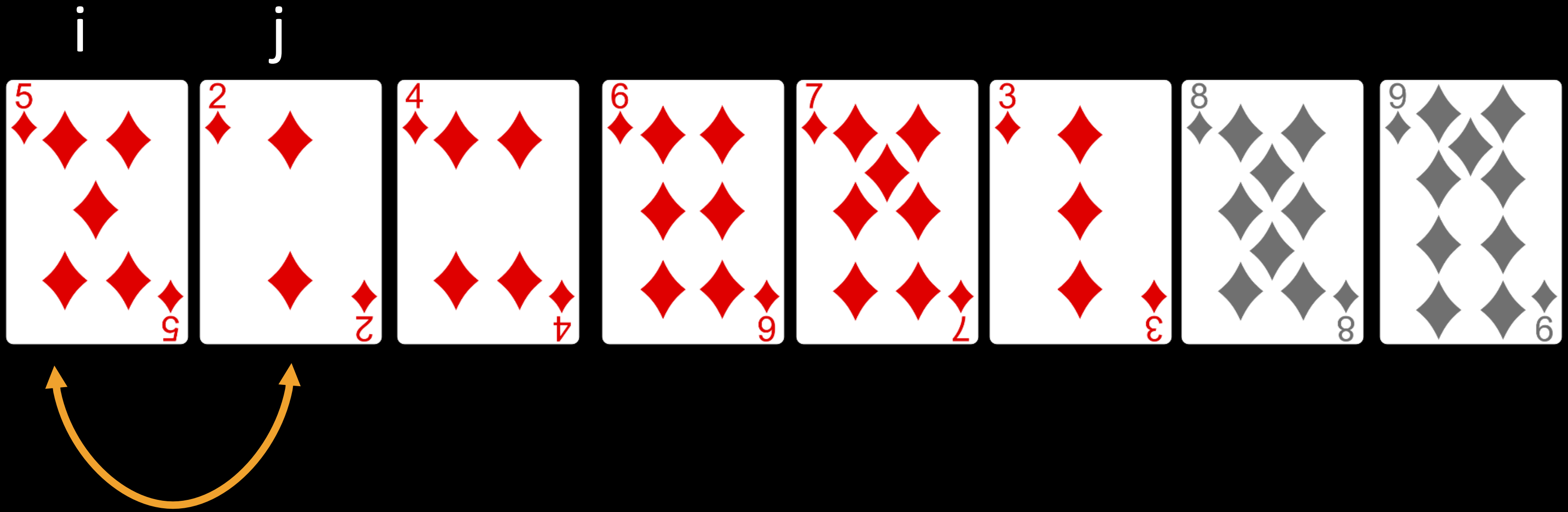
Bubble Sort Visualization

Steps count: 20 + 1 + 1 ⇨ 22



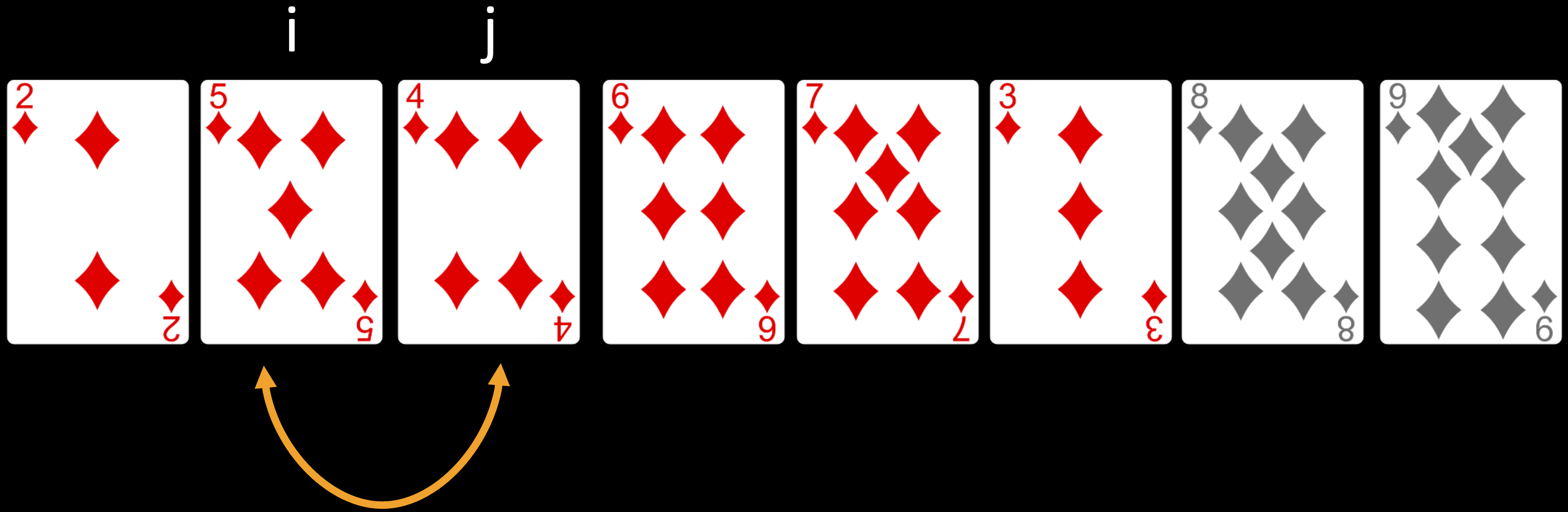
Bubble Sort Visualization

Steps count: 22 + 1 + 1 ⇨ 24



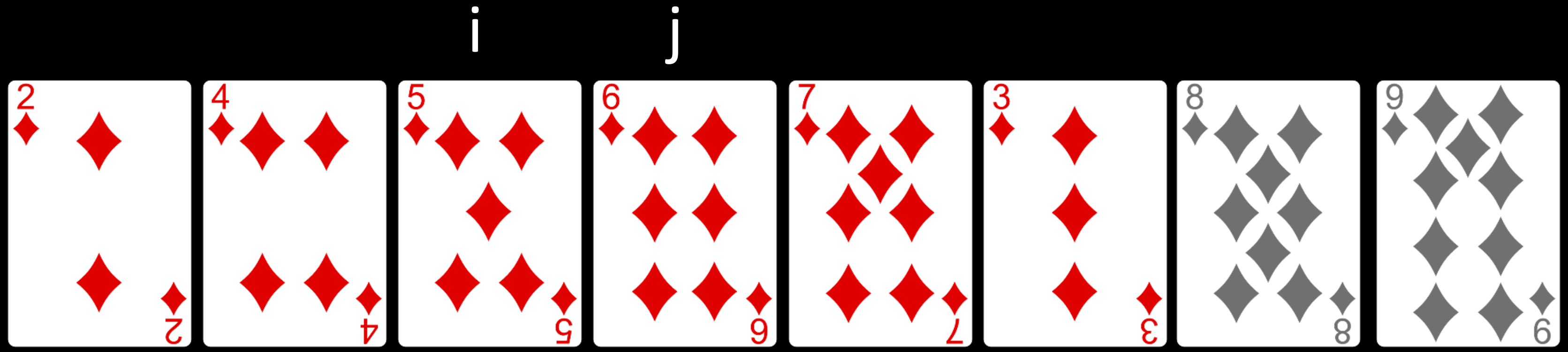
Bubble Sort Visualization

Steps count: 24 + 1 + 1 ⇨ 26



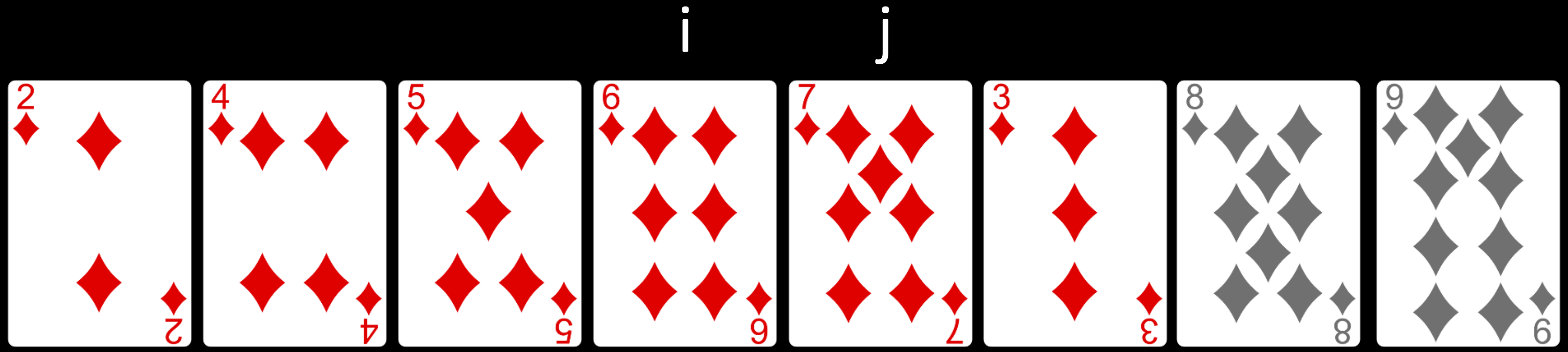
Bubble Sort Visualization

Steps count: 26 + 1 ⇨ 27



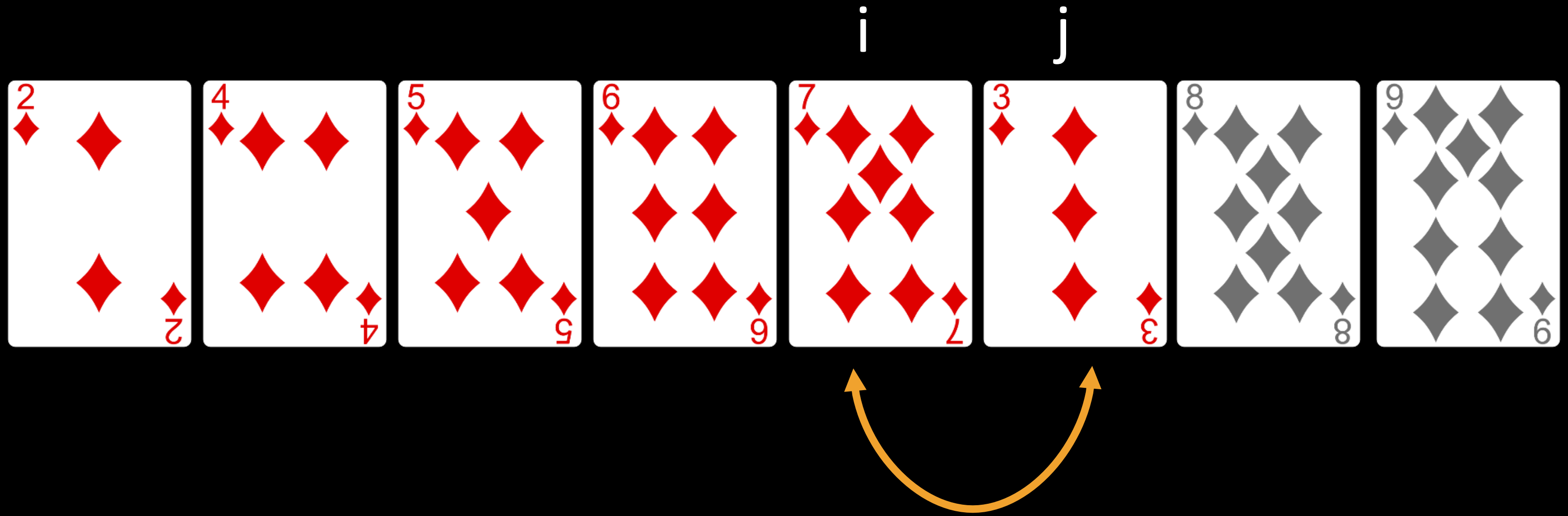
Bubble Sort Visualization

Steps count: 27 + 1 ⇨ 28



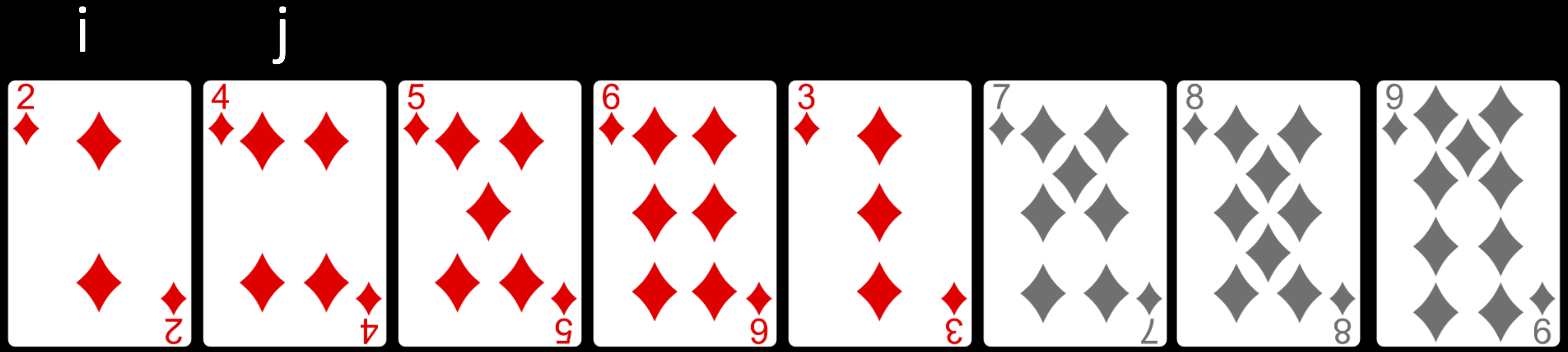
Bubble Sort Visualization

Steps count: 28 + 1 + 1 ⇨ 30



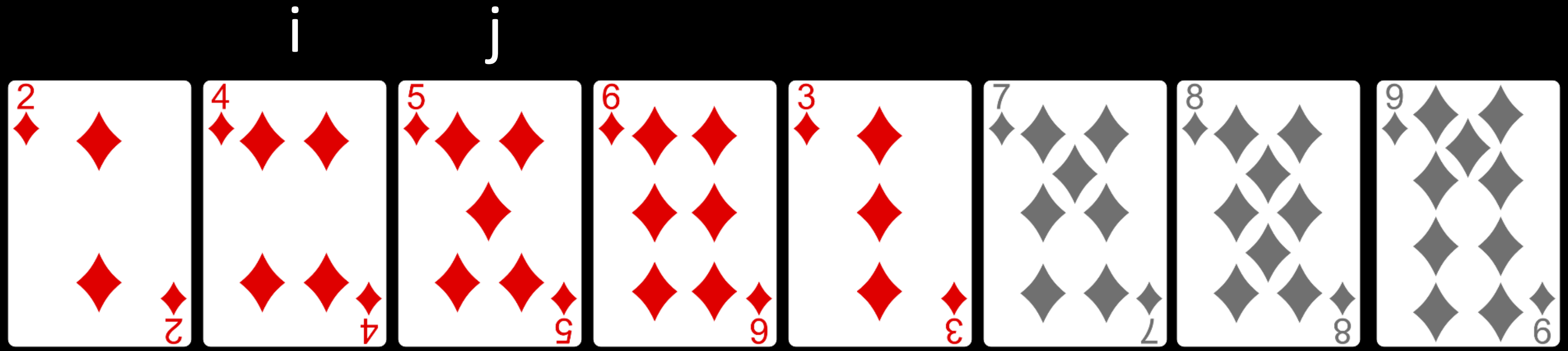
Bubble Sort Visualization

Steps count: 30 + 1 ⇨ 31



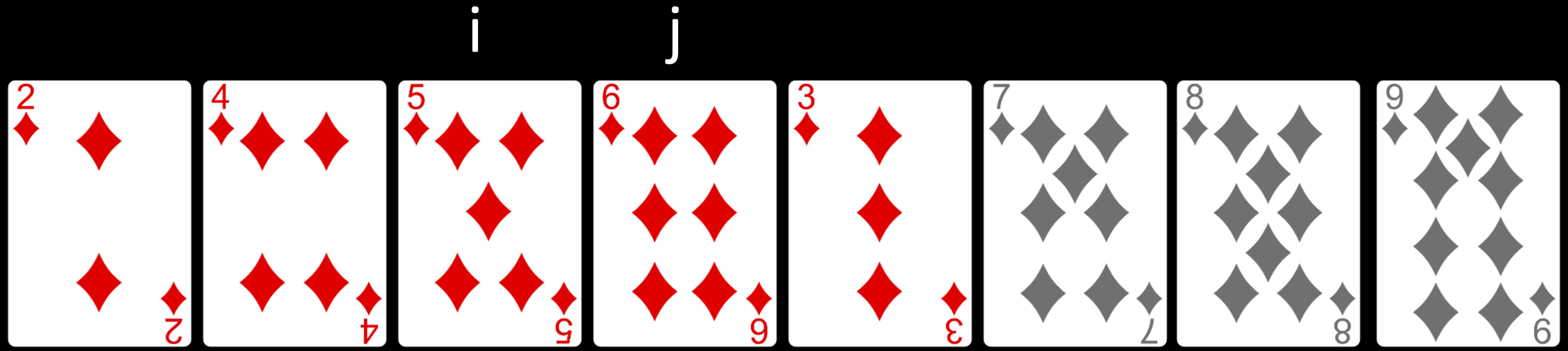
Bubble Sort Visualization

Steps count: 31 + 1 ⇨ 32



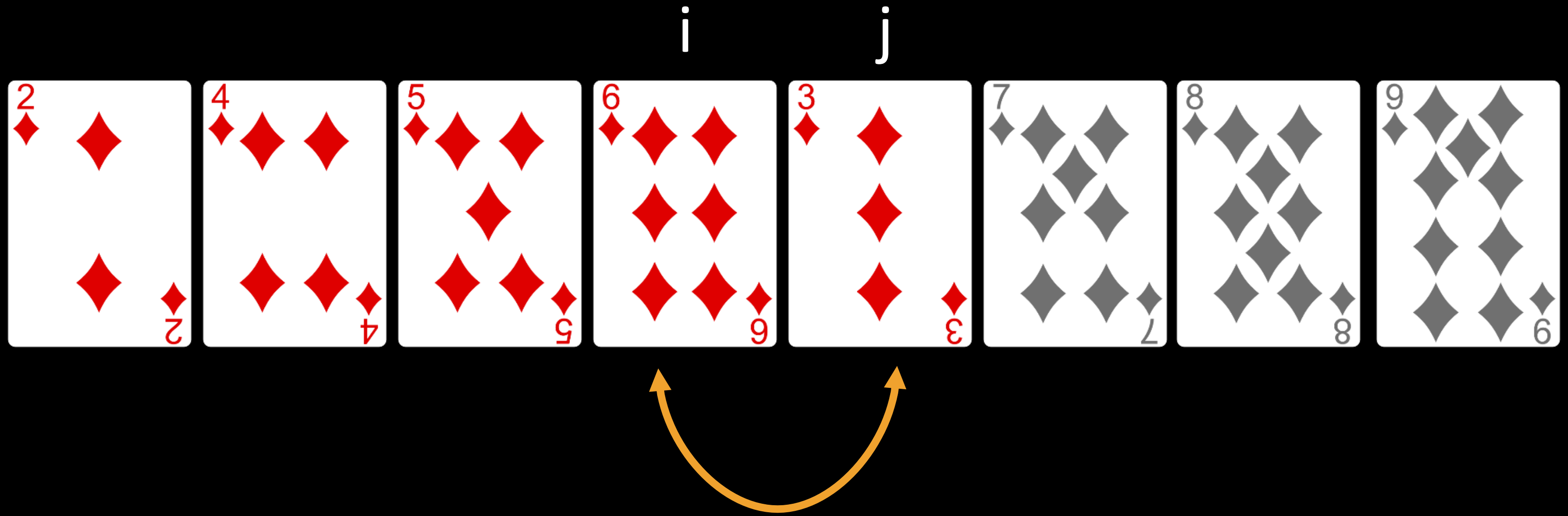
Bubble Sort Visualization

Steps count: 32 + 1 ⇨ 33



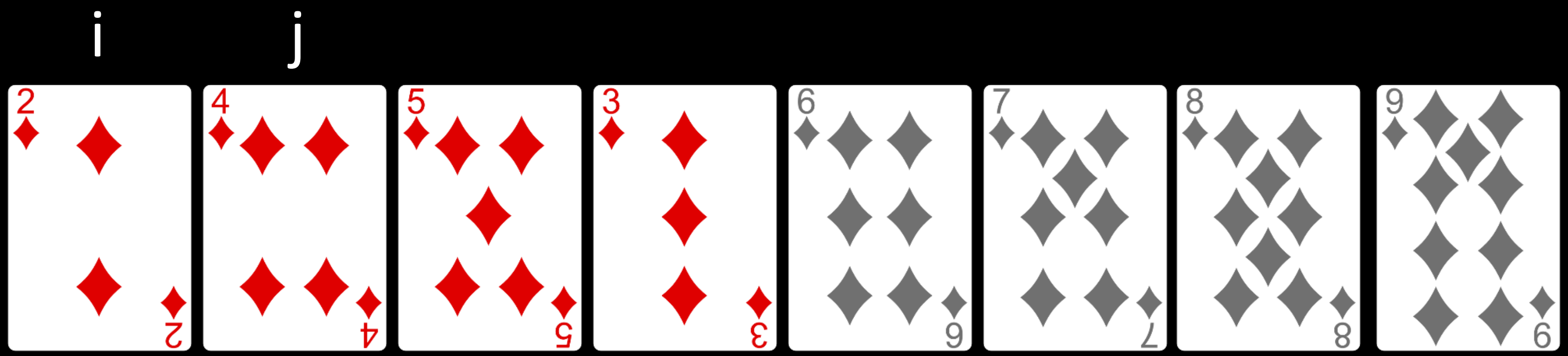
Bubble Sort Visualization

Steps count: 33 + 1 + 1 ⇨ 35



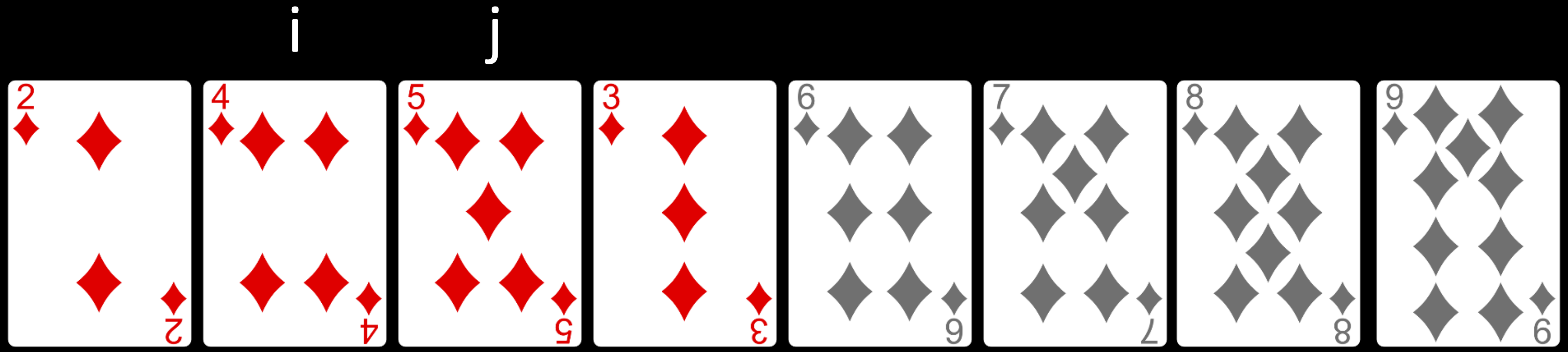
Bubble Sort Visualization

Steps count: 35 + 1 ⇨ 36



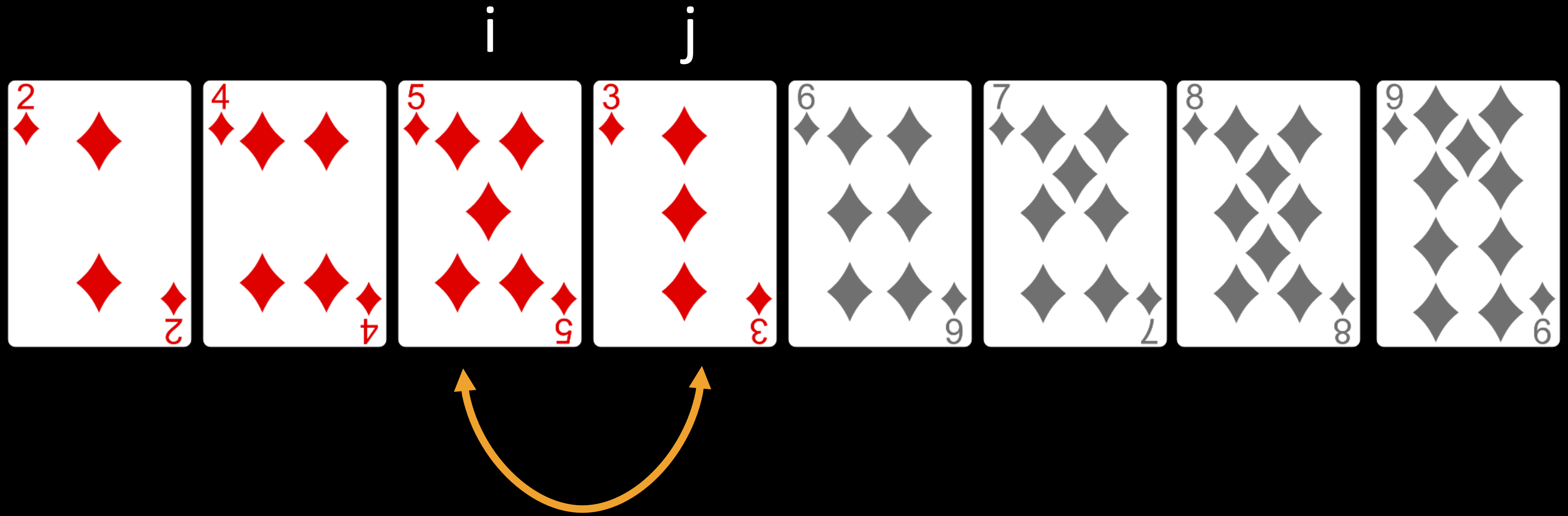
Bubble Sort Visualization

Steps count: 36 + 1 ⇨ 37



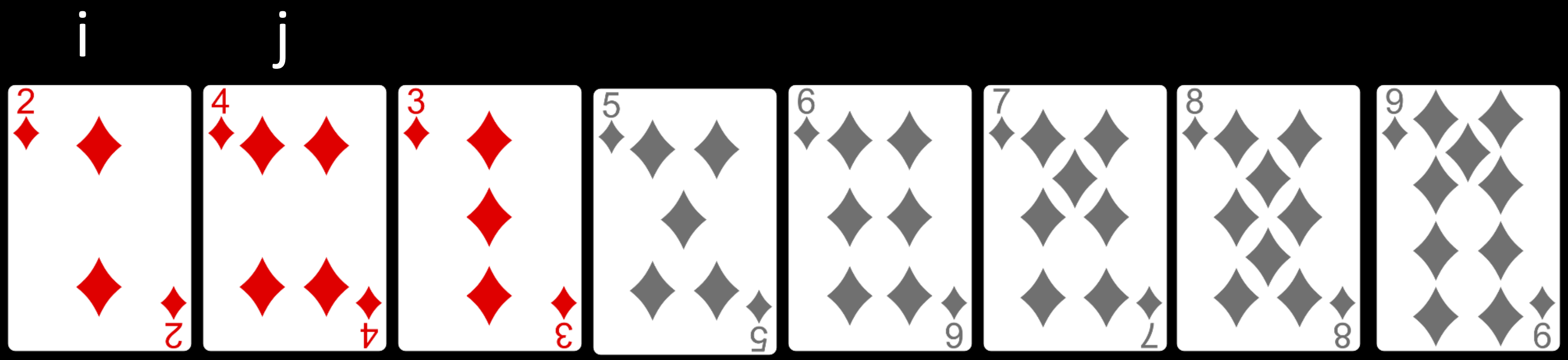
Bubble Sort Visualization

Steps count: 37 + 1 + 1 ⇨ 39



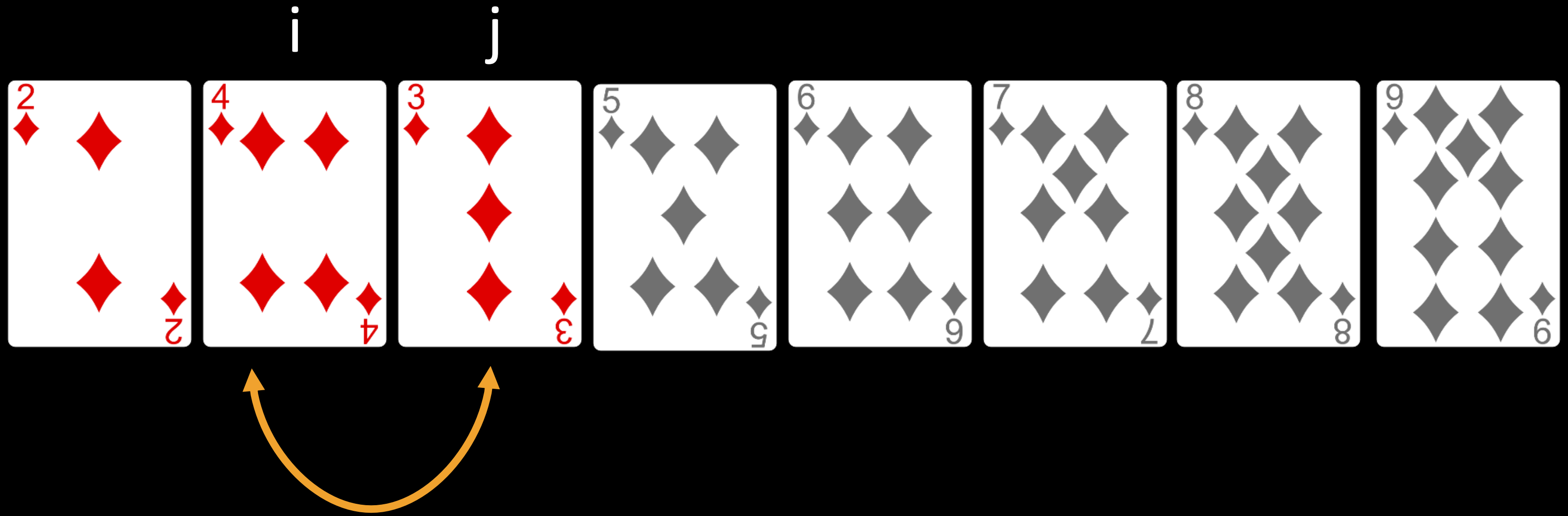
Bubble Sort Visualization

Steps count: 39 + 1 ⇨ 40



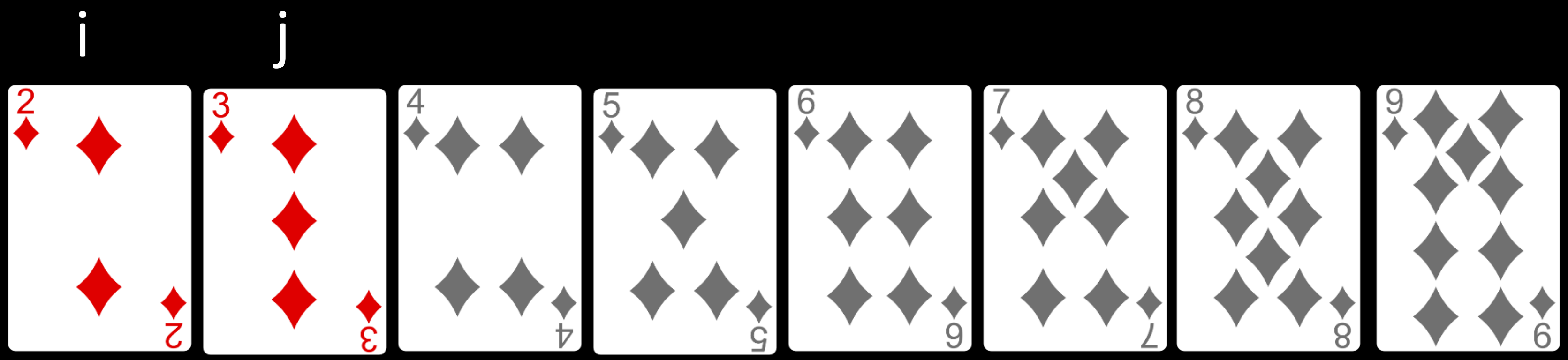
Bubble Sort Visualization

Steps count: 40 + 1 + 1 ⇨ 42



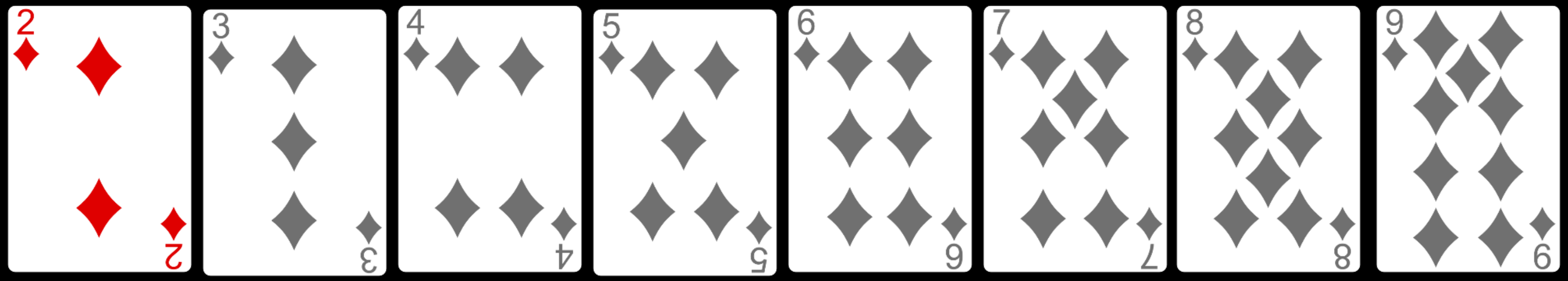
Bubble Sort Visualization

Steps count: 42 + 1 ⇨ 43



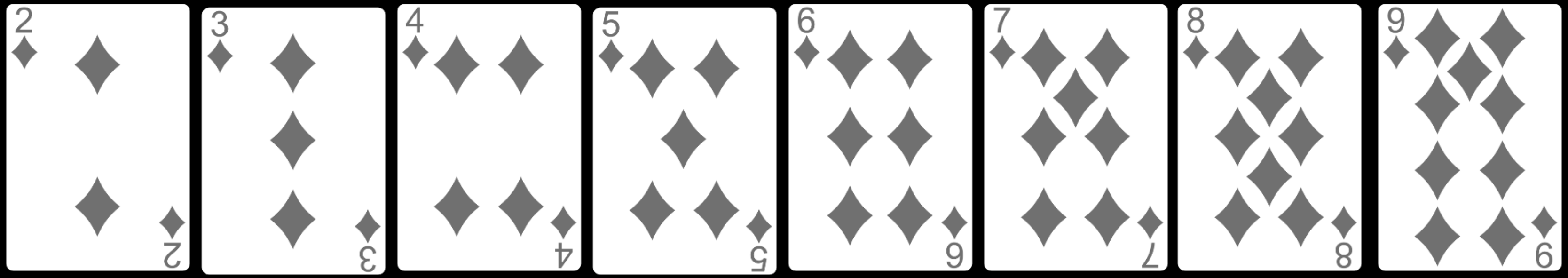
Bubble Sort Visualization

Steps count: 43 + 1 ⇨ 44



Bubble Sort Visualization

Total count of steps : 44



Bubble Sort Code

```
boolean swapped = true;
  do {
    swapped = false;
    for (int ind = 0; ind < collection.length - 1; ind++){
      if (collection[ind] > collection[ind + 1]){
        swap(collection, ind, ind + 1);
        swapped = true;
      }
    }
  } while (swapped)
}
```

Swap with next element, if its **smaller**

Stop if the collection is already sorted

Comparing Sorting Algorithms

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Counting steps helps defininig the algoirthm‘s **efficiency**

Name	Steps Count
Selection Sort	41
Bubble Sort	44
Merge Sort	24
Quick Sort	35

The number of steps is **always similar**

There are **sorting algorithms** that can sort the **same deck** of cards with much less steps

What is algorithm complexity?

- A rough estimation of the **number of steps**
- Steps count depends on the **quantity of data** being processed
  - The **bigger** the collection, the **slower** the algorithm
  - Numbers can’t **accurately** describe it
- Instead we use **functions** to notate complexity:

n is the problem size

$$f(n) = 2n$$

Number of instructions needed in the **worst-case**, given a **n**

Comparing Sorting Algorithms (2)

Name	Complexity	n	f(n)
Selection Sort	n^2	100	≈ 100 00
Bubble Sort	n^2	100	≈ 100 00
Merge Sort	n * log(n)	100	≈ 200
Quick Sort	n * log(n)	100	≈ 200

Merge Sort and **Quick Sort** have much better **performance** when processing big amounts of data

Why should we analyze algorithms?

- The expected **running time** of an algorithm is:
  - The total number of **primitive operations** executed
  - The algorithm **efficiency**

Less steps == higher **efficiency**

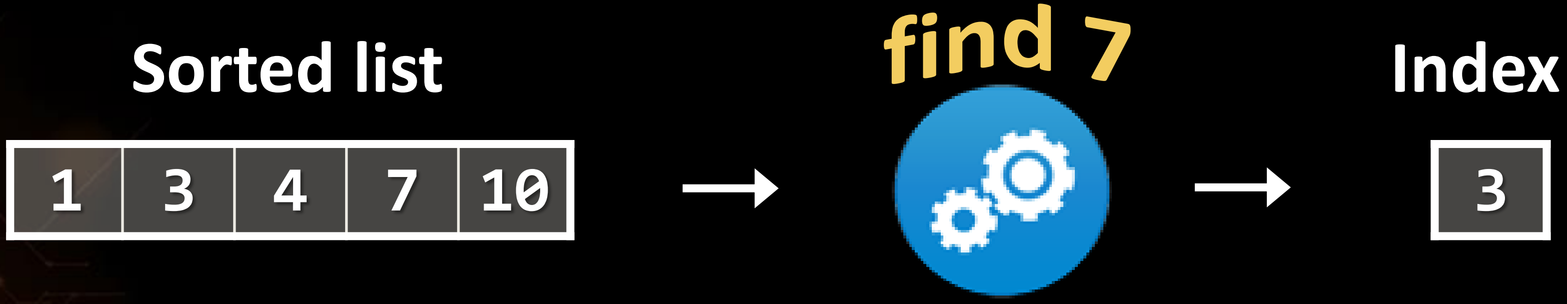
- Predict the **resources** the algorithm will need
  - Computational time (**CPU** consumption)
  - **Hard disk** operations

Searching Algorithms

Linear, Binary and Interpolation

Searching Algorithm

- **Searching algorithm** == an algorithm for finding an item with specified properties among a collection of items
  - Returns the **index** of the item
  - Returns **-1** if the element is not present



Sorted list

1	3	4	7	10

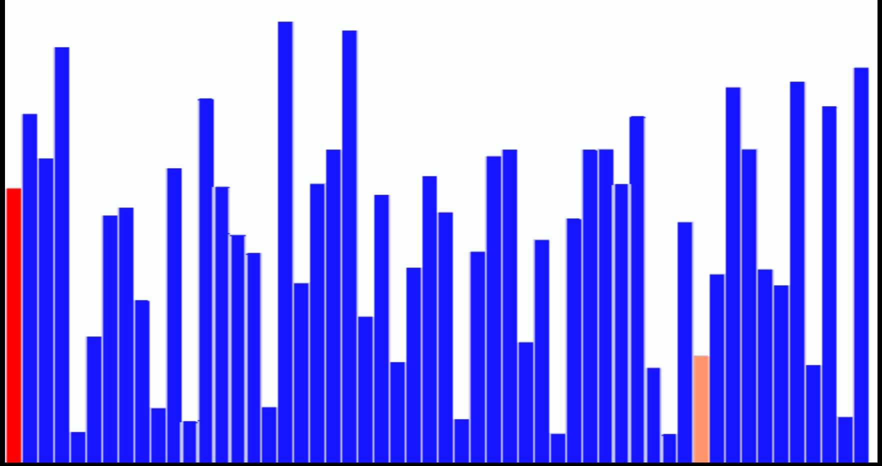
find 7

Index

3

Linear Search

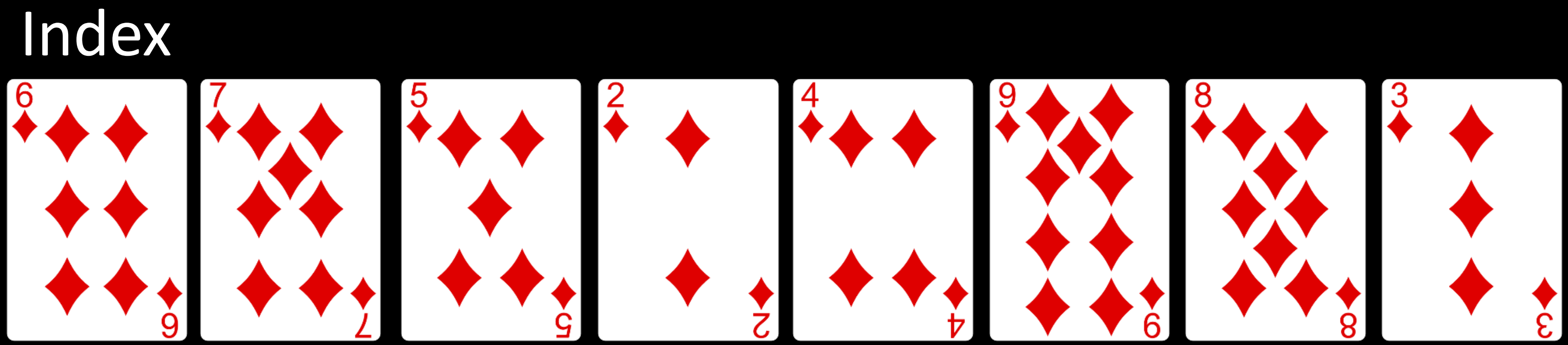
- Linear search finds an item within a **unordered data structure**
- Check every element
  - One at a time, in sequence
- Stop if the desired one is found
- Visualize



```
for each item in the list:
  if that item has the desired value
    return the item's index
return -1
```

Linear Search Visualization

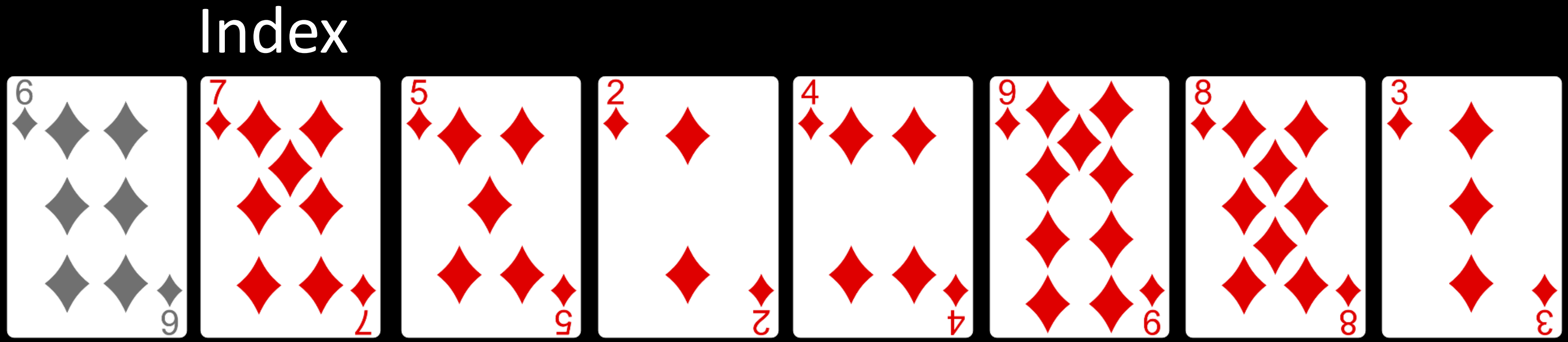
Steps count: 1



Look for **9**

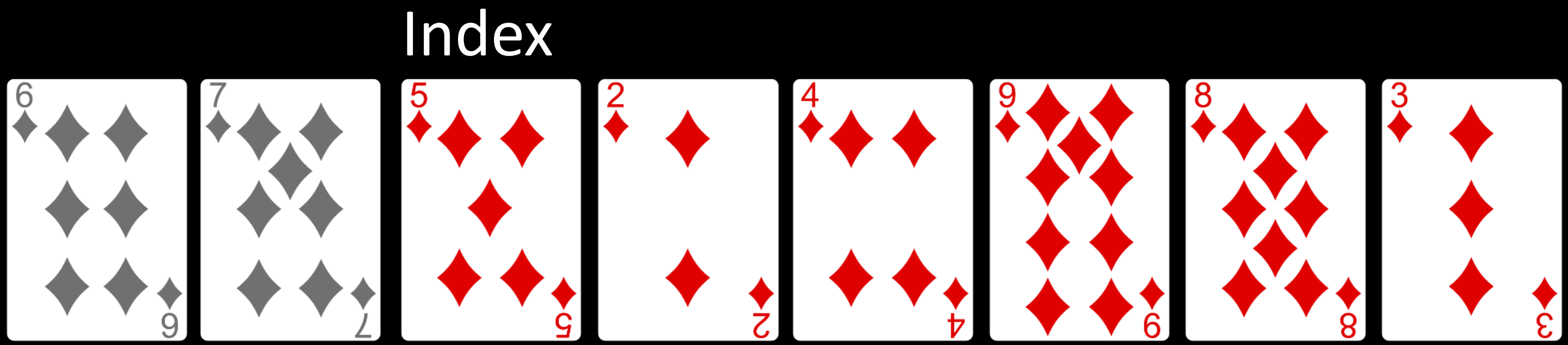
Linear Search Visualization

Steps count: 2



Linear Search Visualization

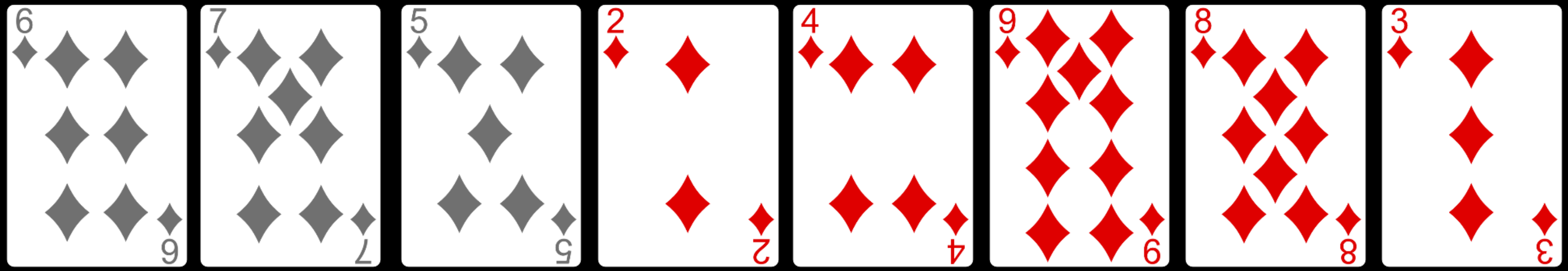
Steps count: 3



Linear Search Visualization

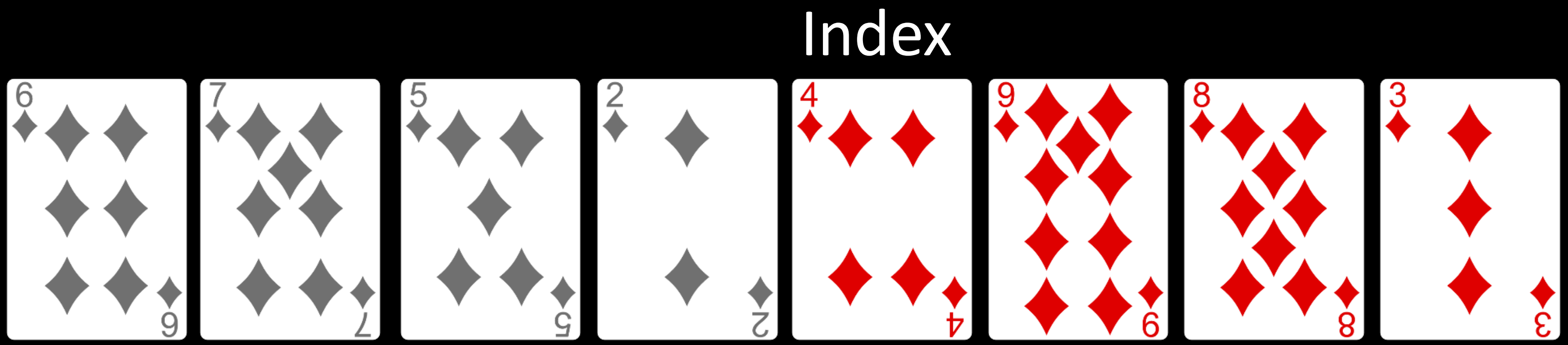
Steps count: 4

Index



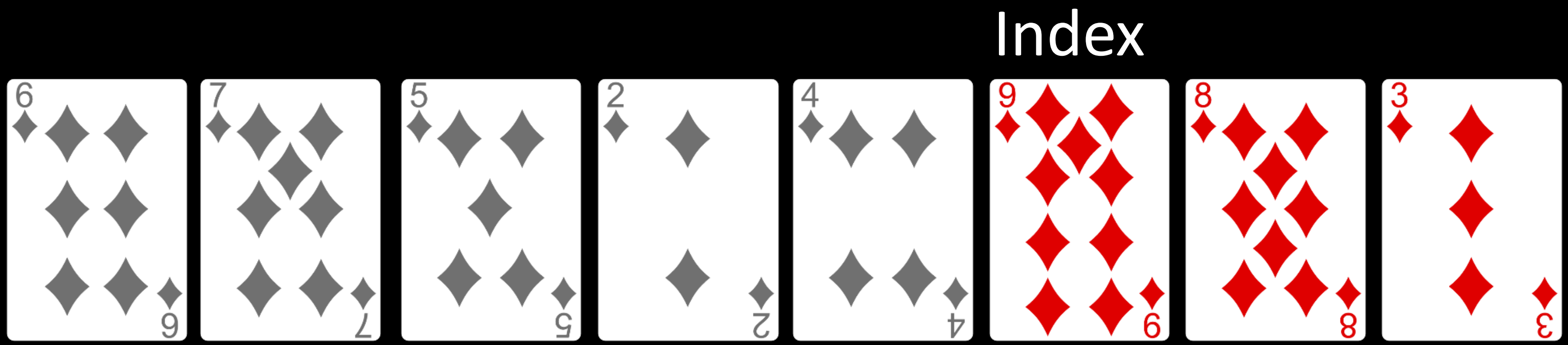
Linear Search Visualization

Steps count: 5



Linear Search Visualization

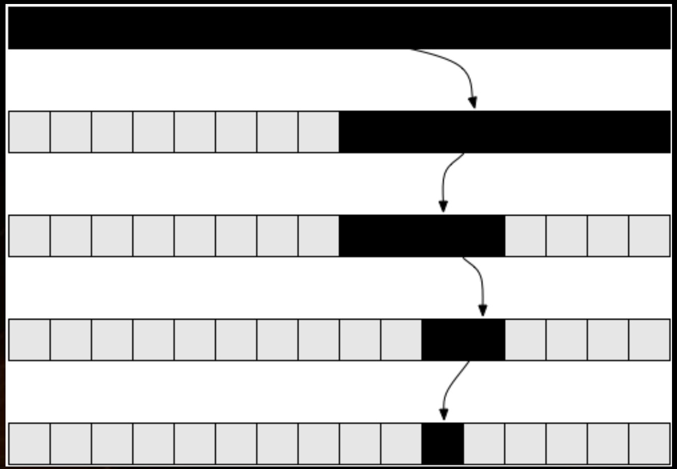
Steps count: 6 ➡ Total count of steps : 6

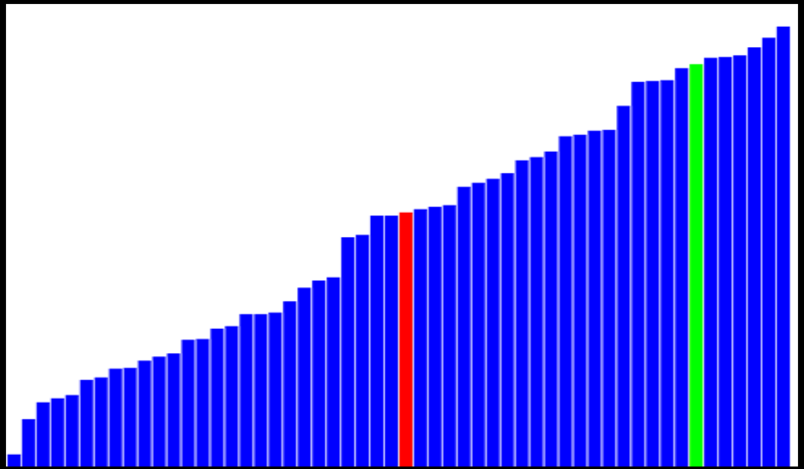


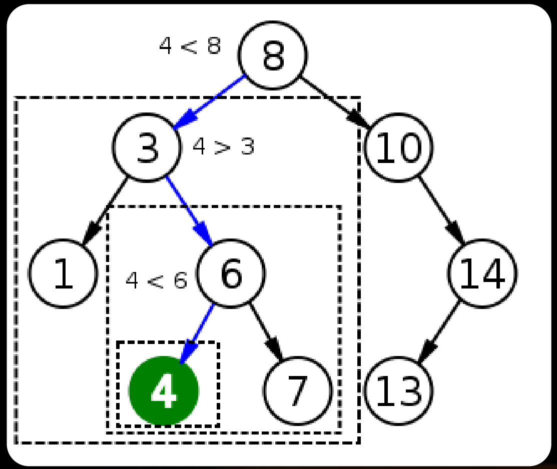
Found 9

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
- Visualization

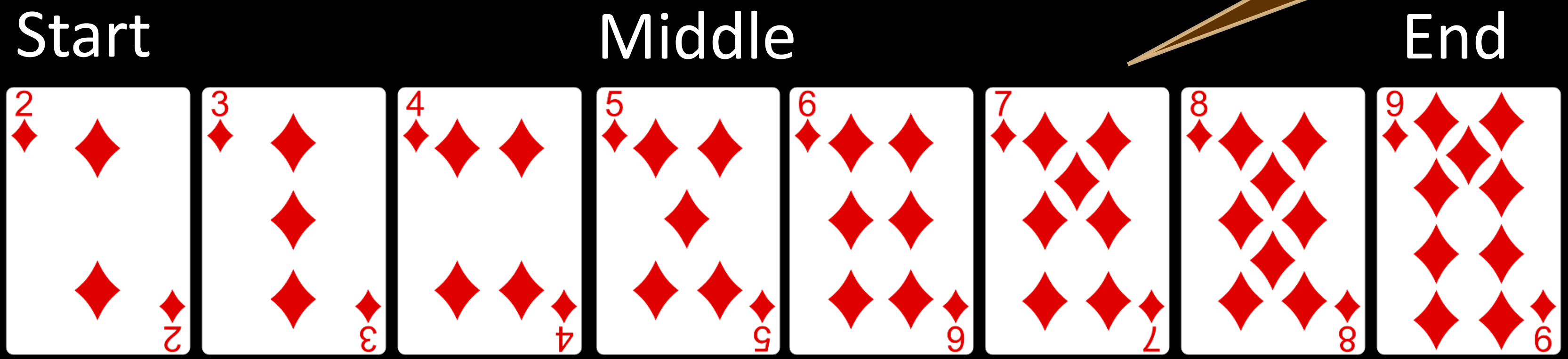






Binary Search Visualization

Steps count: 1



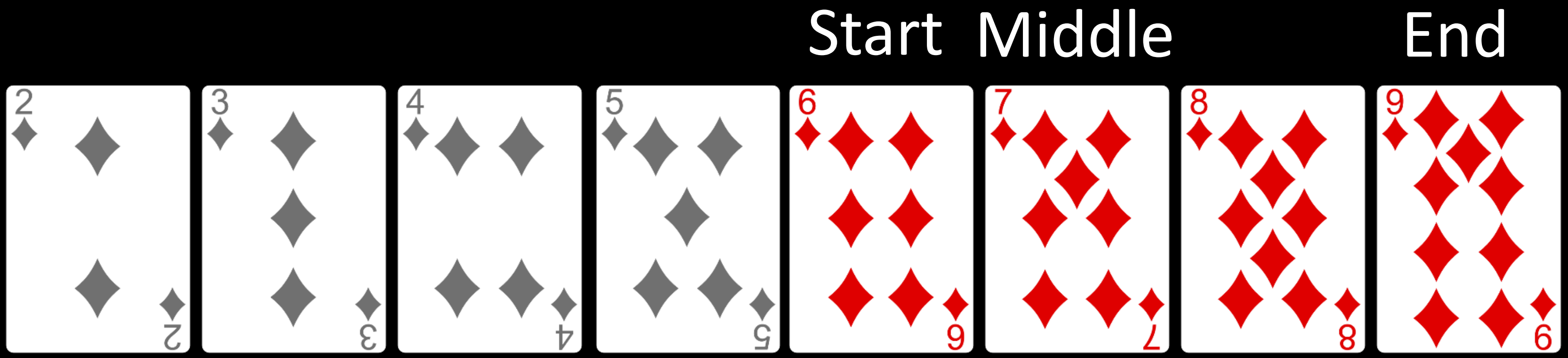
The deck is **sorted**

9 > 5 ⇨ search in the **right half**

Look for **9**

Binary Search Visualization

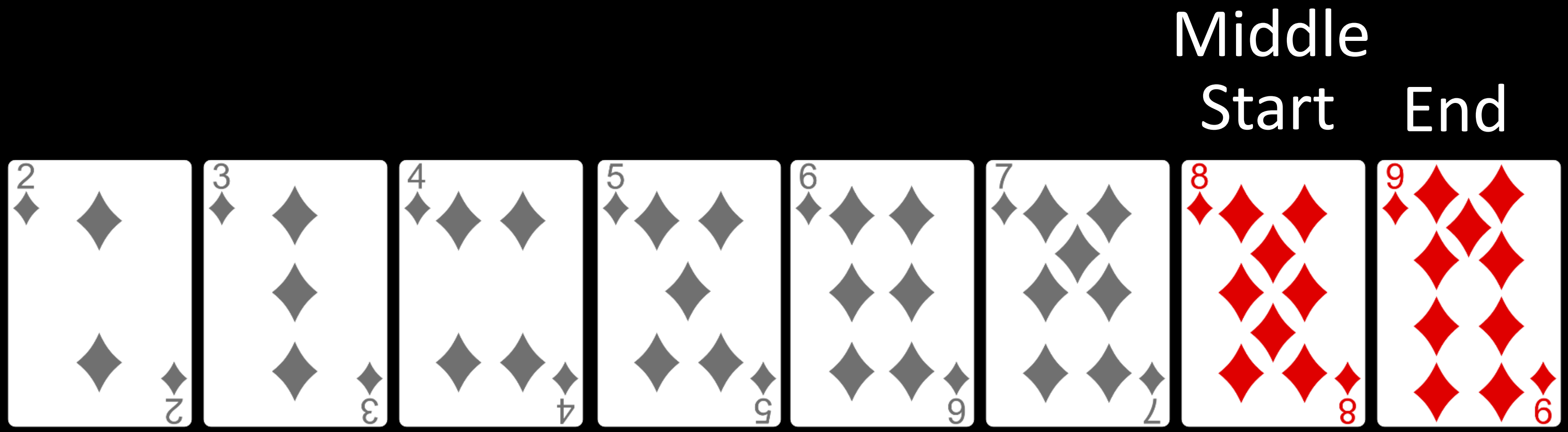
Steps count: 2



9 > 7 ⇨ search in the **right half**

Binary Search Visualization

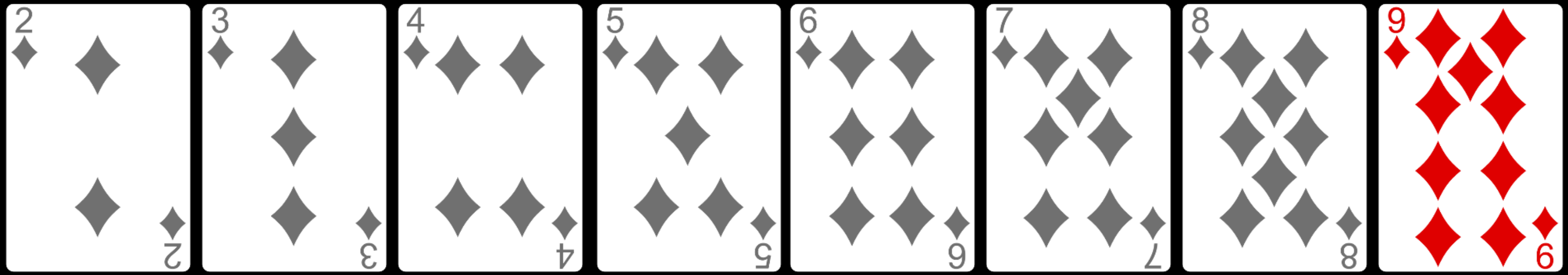
Steps count: 3



9 > 8 ⇨ search in the **right half**

Binary Search Visualization

Steps count: 4



9 == 9 ⇨ return the index 7

Binary Search

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

Search in the left half of the collection

Search in the right half of the collection

Comparing Searching Algorithms

We need go trough **every** element

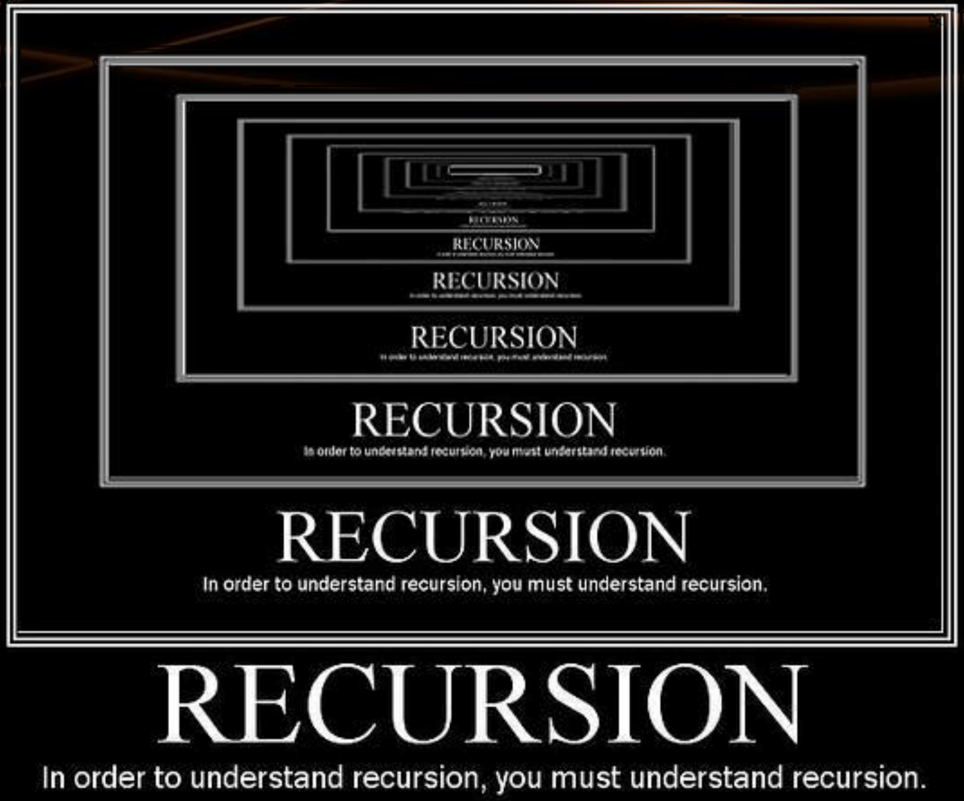
Name	Complexity	n	f(n)
Linear Search	n^2	100	≈ 100
Binary Search	n * log(n)	100	≈ 6,64

Binary search can also be implemented **iteratively** and **recursively**

On each step we **halve** the collection

Practice: Sorting and Searching Algorithms

Exercises in class (Lab)



RECURSION
In order to understand recursion, you must understand recursion.
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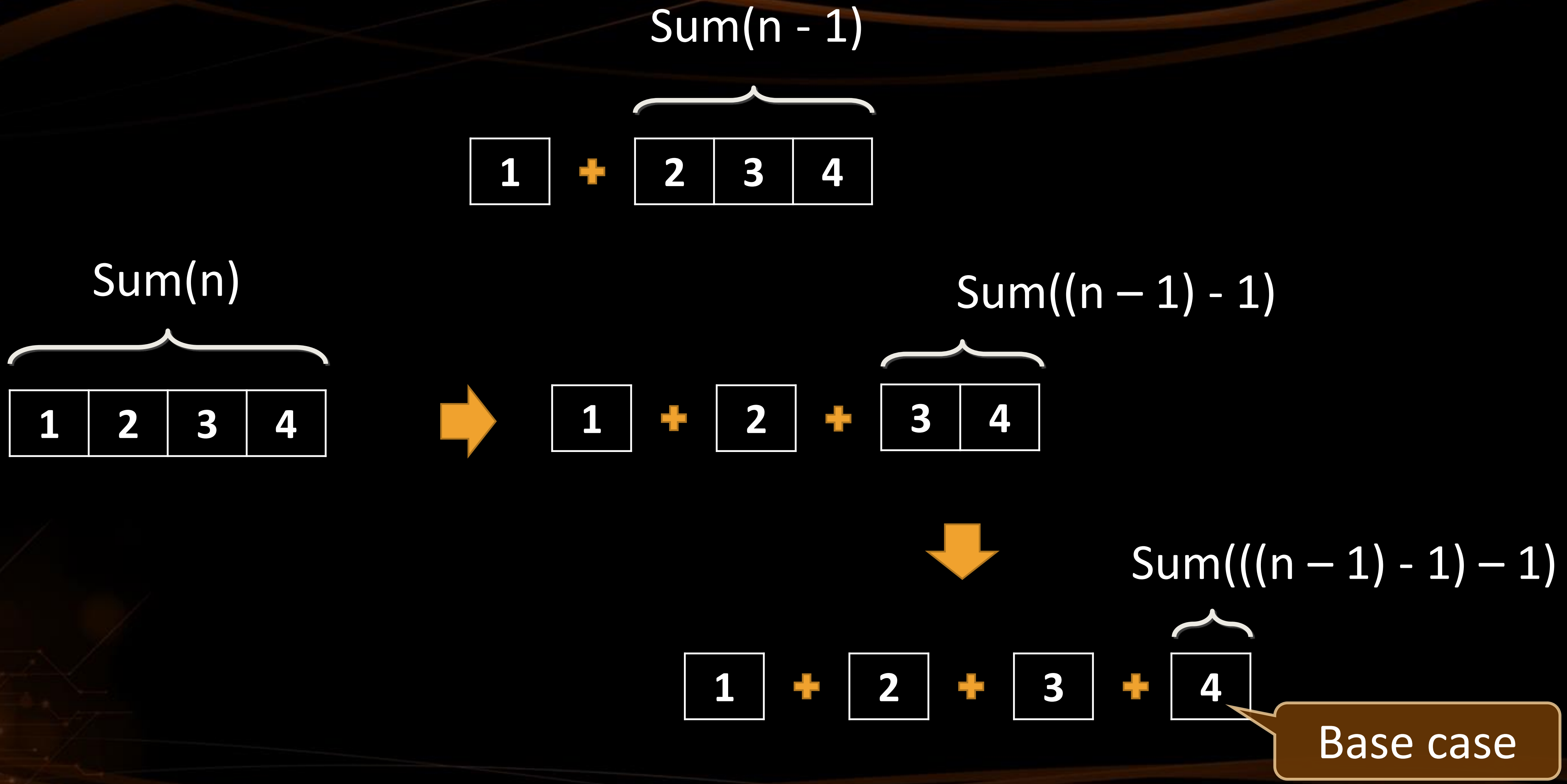
RECURSION

In order to understand recursion, you must understand recursion.

Recursion

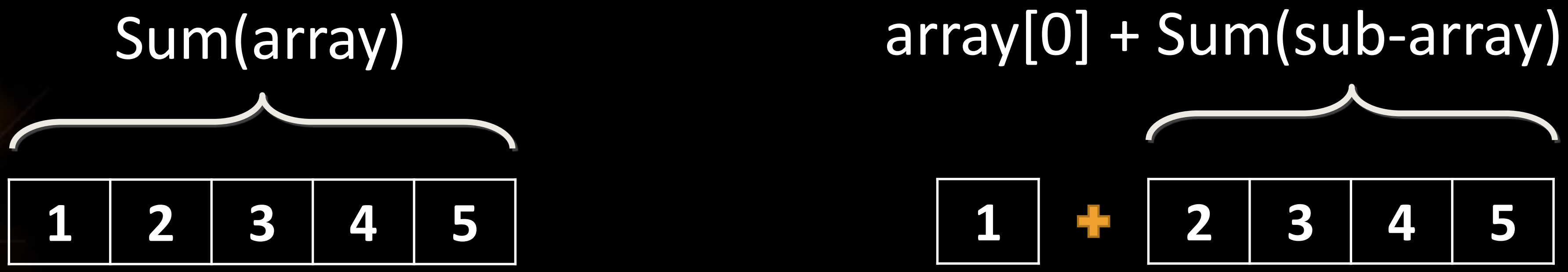
Recursive Algorithms

Array Sum – Example



What is Recursion?

- Problem solving technique
- Divides a problem into **subproblems of the same type**
  - Involves a **function calling itself**
  - The function should have a **base case**
  - **Each step** of the recursion should **move towards** the **base case**



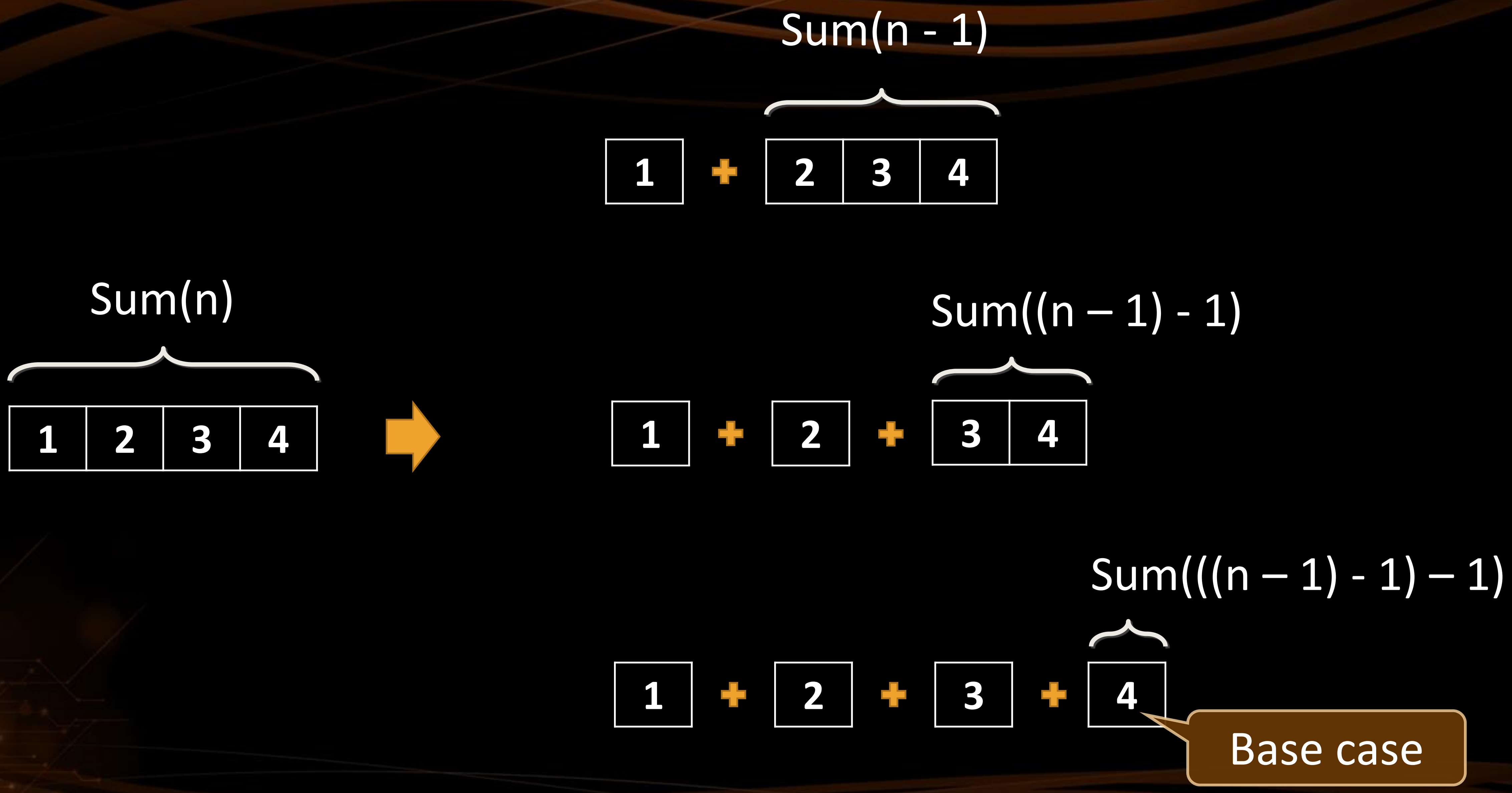
Sum(array)

1 2 3 4 5

array[0] + Sum(sub-array)

1 + 2 3 4 5

Array Sum – Example



Sum(n - 1)

1 + 2 3 4

Sum(n)

1 2 3 4

Sum((n – 1) - 1)

1 + 2 + 3 4

Sum(((n – 1) - 1) – 1)

1 + 2 + 3 + 4

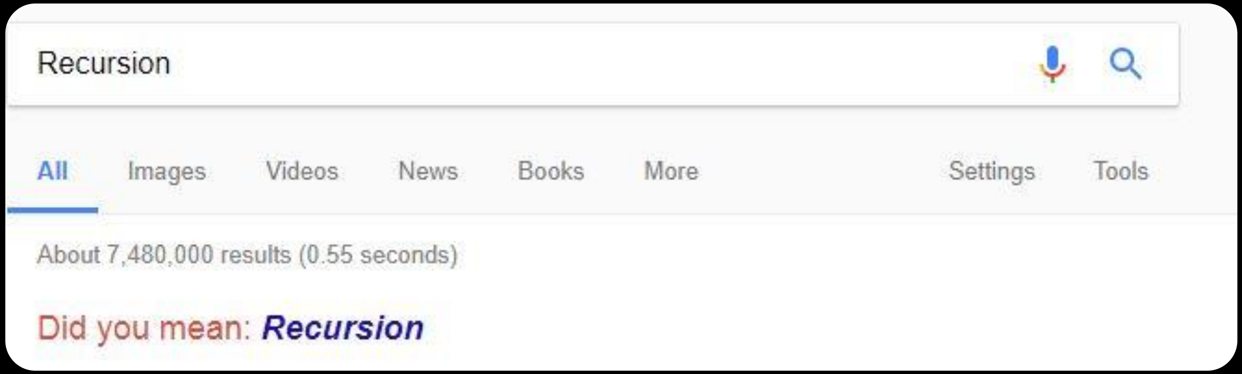
Base case

Problem: Array Sum

- Create a **recursive method** that
  - Reads numbers from the console and stores them in an **`int[] array`**
  - Finds the **sum** of all numbers

`1 2 3 4` → `10`

`-1 0 1` → `0`


Recursion

About 7,480,000 results (0.55 seconds)

Did you mean: ***Recursion***

Check your solution here: https://judge.softuni.bg/Contests/779

Solution: Array Sum

```
static int sum(int[] array, int index){
  if (index == array.length - 1)
  {
    return array[index];
  }

  return array[index] + sum(array, index + 1);
}
```

Base case

Check your solution here: https://judge.softuni.bg/Contests/779

Problem: Recursive Factorial

- Create a **recursive method** that calculates **n!**
- Recursive definition of **n!**:

```
n! = n * (n-1)! for n > 0
```

  - 5! = 5 * 4!
    - 4! = 4 * 3!
      - 3! = 3 * 2!
        - 2! = 2 * 1!
          - 1! = 1 * 0!

0! = 1

```
5 → 120
```

```
10 → 3628800
```

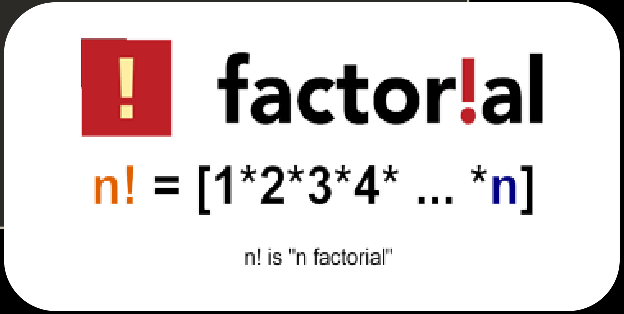
Check your solution here: https://judge.softuni.bg/Contests/779

Solution: Recursive Factorial

```
static long factorial(int num){
  if (num == 0)
  {
    return 1;
  }

  return num * factorial(num - 1);
}
```

Base case



Check your solution here: https://judge.softuni.bg/Contests/779

Recursion Pre-Actions and Post-Actions

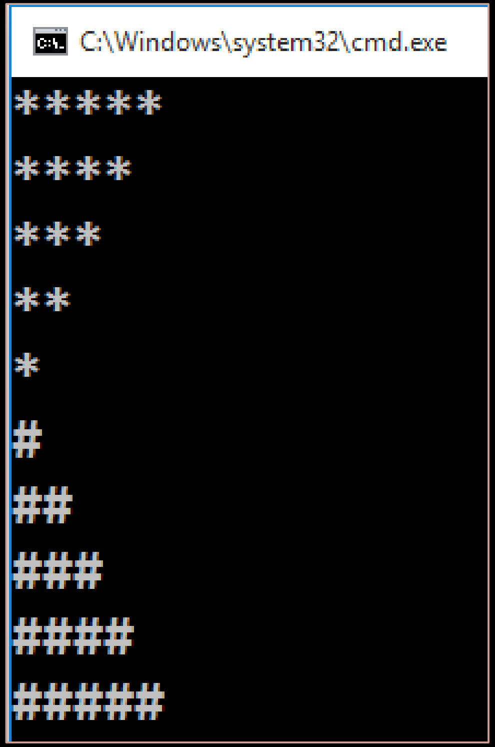
- Recursive methods have 3 parts:
  - **Pre-actions** (before calling the recursion)
  - **Recursive calls** (step-in)
  - **Post-actions** (after returning from recursion)

```
static void Recursion(){
  // Pre-actions
  Recursion();
  // Post-actions
}
```

Problem: Recursive Drawing

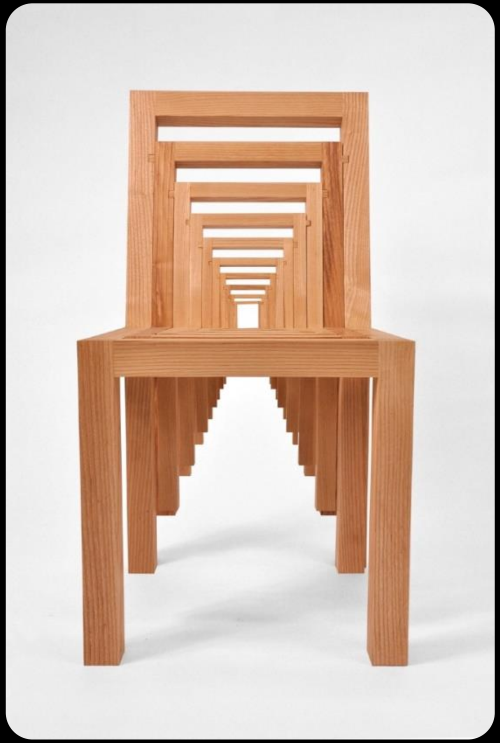
- Create a **recursive method** that draws the following figure

```
5
```



C:\Windows\system32\cmd.exe

```
*****
****
***
**
*
#
##
###
####
#####
```



Check your solution here: https://judge.softuni.bg/Contests/779

Solution: Recursive Drawing

```
static void printFigure(int n)
    if (n == 0) // Bottom of the recursion
      return;
    // Pre-action: print n asterisks
    System.out.println(
       String.join("", Collections.nCopies(n, "*")));

    // Recursive call: print figure of size n-1
    printFigure(n - 1);

    // Post-action: print n hashtags
    System.out.println(
         String.join("", Collections.nCopies(n, "#")));
```

Returns a **String** consisting of n copies of '*'.

Check your solution here: https://judge.softuni.bg/Contests/779

Performance: Recursion vs. Iteration

- Recursive calls are **slightly slower** than iteration
  - Parameters and return values travel through the stack at each step
  - Prefer iteration for linear calculations (**without branched calls**)

Recursive factorial:

```
static long fact(int n){
  if (n == 0)
    return 1;
  else
    return n * fact(n - 1);
}
```

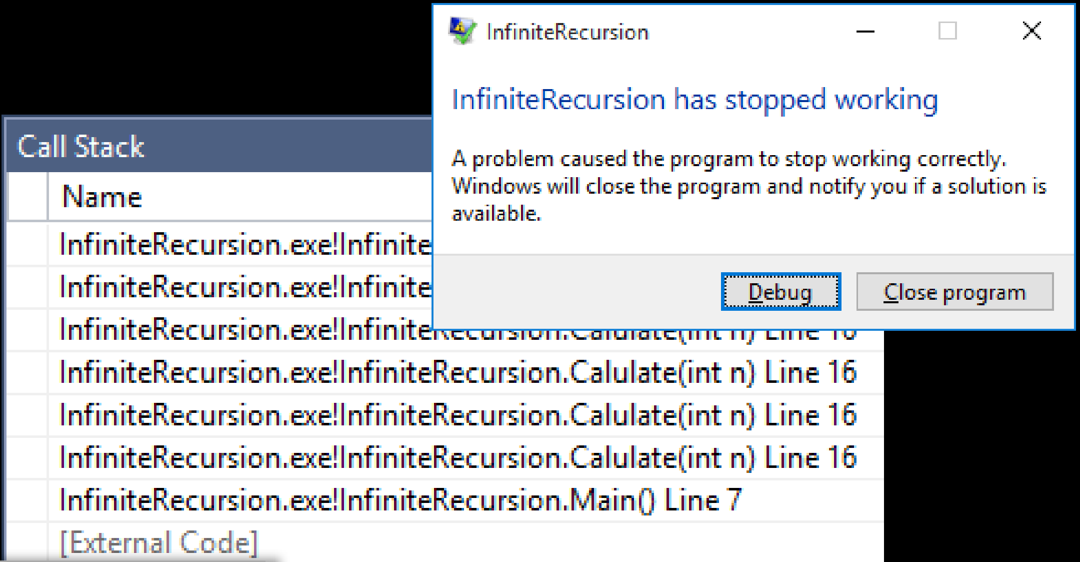
Iterative factorial:

```
static long iterFact(int num){
  long result = 1;
  for (int i = 1; i <= n; i++)
    result *= i;
  return result;
}
```

Infinite Recursion

- **Infinite recursion** == a method calls itself **infinitely**
  - Typically, infinite recursion is a bug in the program
  - The bottom of the recursion is missing or wrong
  - Causes "**stack overflow**" exception

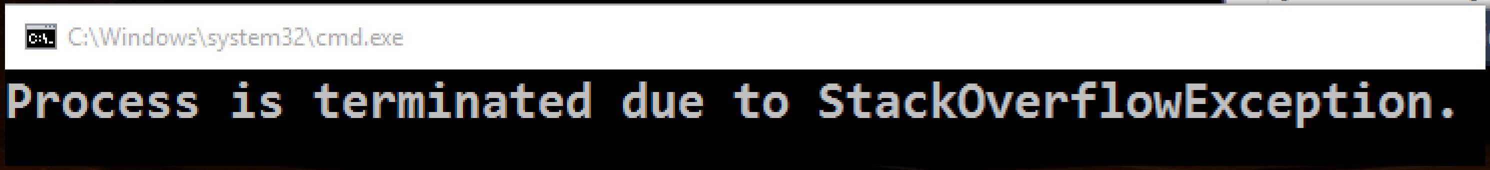
```
static long Calulate(int n){
    return Calulate(n + 1);
}
```



InfiniteRecursion has stopped working

A problem caused the program to stop working correctly. Windows will close the program and notify you if a solution is available.

```
InfiniteRecursion.exe!Infinite
InfiniteRecursion.exe!Infinite
InfiniteRecursion.exe!Infinite
InfiniteRecursion.exe!InfiniteRecursion.Calulate(int n) Line 16
InfiniteRecursion.exe!InfiniteRecursion.Calulate(int n) Line 16
InfiniteRecursion.exe!InfiniteRecursion.Calulate(int n) Line 16
InfiniteRecursion.exe!InfiniteRecursion.Main() Line 7
[External Code]
```



```
Process is terminated due to StackOverflowException.
```

Practice: Recursion

Exercises in class (Lab)

Summary

- **Sorting** == an algorithm that rearranges elements in a list
  - In non-decreasing order
- **Searching** == an algorithm for finding an item among a collection of items
- **Recursion** means to **call a method from itself**
  - It should always have a **bottom**
  - **Each step** should **move towards** the **bottom**

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