Basic Algorithms

Recursion, Greedy, Sorting and Searching

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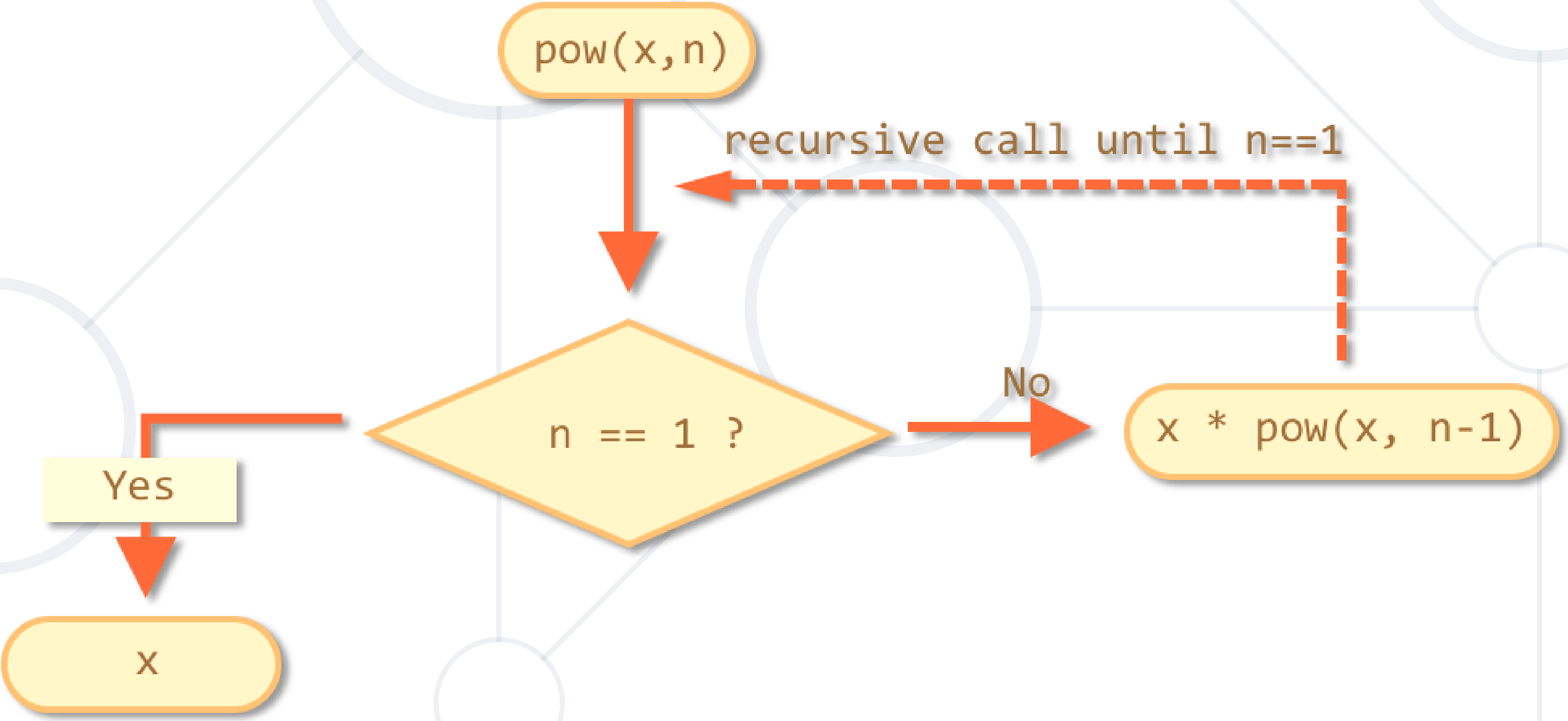
Recursion

What is Recursion?

- A function or a method that **calls itself one or more** times until a specified **condition** is **met**
- When it is, the rest of **each** repetition is processed **from** the **last** one called **to** the **first**

How Does It Work?

- The function or method has a **base case**
- **Each step** of the recursion should **move towards** the **base case**



Example: Array Sum

$$\overbrace{\boxed{1}\,\boxed{2}\,\boxed{3}\,\boxed{4}}^{\text{Sum(n)}} \Rightarrow \boxed{1} + \overbrace{\boxed{2}\,\boxed{3}\,\boxed{4}}^{\text{Sum(n - 1)}}$$

$$\boxed{1} + \boxed{2} + \overbrace{\boxed{3}\,\boxed{4}}^{\text{Sum((n – 1) - 1)}}$$

$$\boxed{1} + \boxed{2} + \boxed{3} + \overbrace{\boxed{4}}^{\text{Sum(((n – 1) - 1) – 1)}}$$

Base case

Example: Recursive Factorial

- Recursive definition of n! (n factorial):

`5` → `120`

`10` → `3628800`

N!

- Pseudocode

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

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
}
```

Direct and Indirect Recursion

- Direct recursion
  - a method directly calls itself
- Indirect recursion
  - Method a calls b, method b calls a
  - Or even a → b → c → a

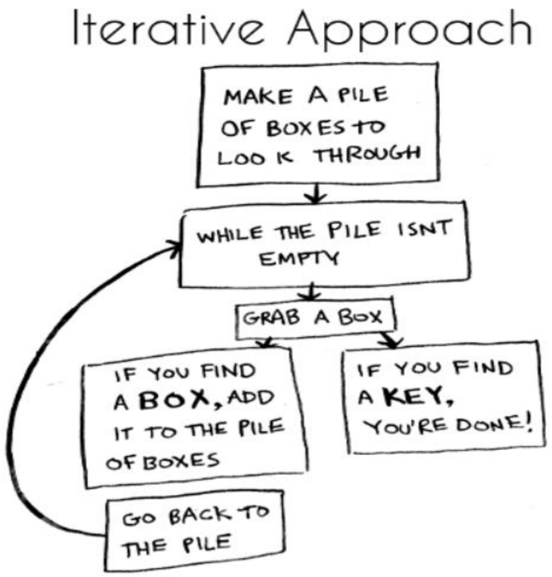
```
void a() {
  …
  a();
}
```

```
void a() {
  …
  b();
}
```

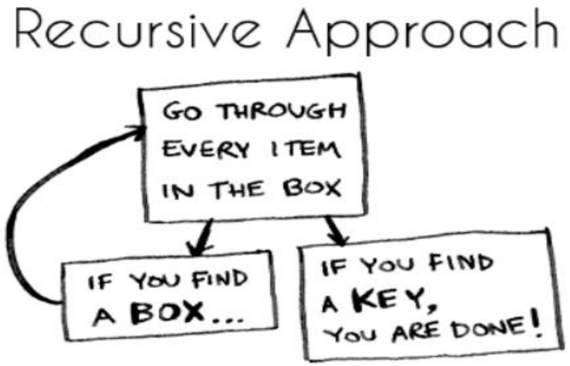
```
void b() {
  …
  a();
}
```

Iterative vs. Recursive Approach

- A function repeats a defined process until a condition fails



- A function that calls itself repeatedly until a certain condition is met



Recursion

Problem: Recursive Array Sum

- Write a **recursive method** that:
  - Finds the sum of all numbers stored in an `int[] array`
  - Read numbers from the console

Input	Output
`1 2 3 4`	`10`
`-1 0 1`	`0`

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Solution: Recursive Array Sum

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

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Problem: Recursive Factorial

- Create a **recursive method** that calculates **n!**
  - Read n from the console

5	→	120
10	→	3628800

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

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/1701/Basic-Algorithms-Lab

Brute-Force Algorithms

Brute-Force Algorithms

- Trying all possible combinations
- Picking the best solution
- Usually slow and inefficient

0 0 0 0 0

Brute-Force Algorithms

0	0	0	0	0

Brute-Force Algorithms

0	0	0	0	1

Brute-Force Algorithms

0	0	0	0	2

Brute-Force Algorithms

9 9 9 9 9

10 x 10 x 10 x 10 x 10 = 100,000 combinations

Greedy Algorithms

Greedy Algorithms

- Used for solving optimization problems
- Usually more efficient than the other algorithms
- Can produce a **non-optimal** (incorrect) result
- Pick the **best local** solution
  - The optimum for a **current** position and point of view
- Greedy algorithms assume that always choosing a **local** optimum leads to the **global** optimum

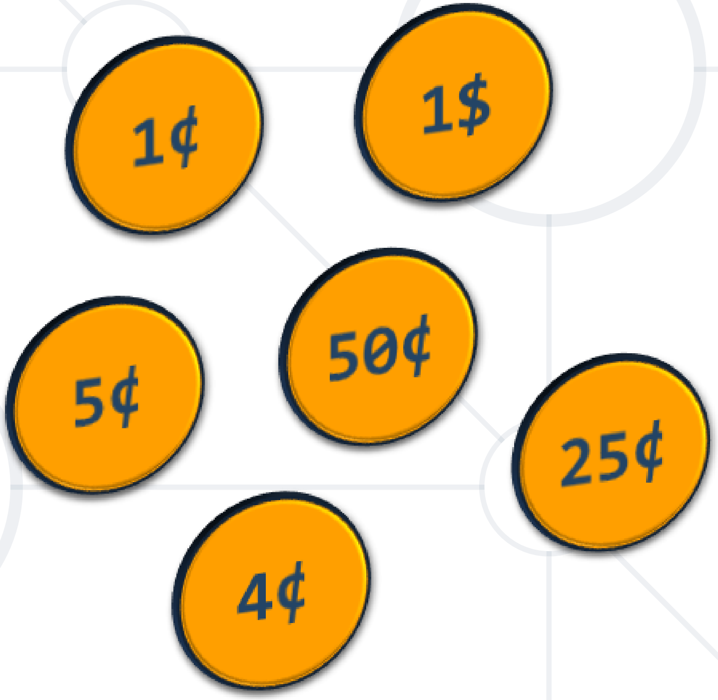
Optimization Problems

- Finding the best solution from all possible solutions
- Examples:
  - Find the **shortest** path from Sofia to Varna
  - Find the **maximum increasing subsequence**
  - Find the shortest route that visits each city and returns to the origin city

Greedy Algorithms

Problem: Sum of Coins

- Write a program, which gathers a sum of money, using the least possible number of coins
- Consider the US **currency coins**
  - **0.01**, **0.02**, **0.05**, **0.10**
- **Greedy algorithm** for "Sum of Coins":
  - Take the largest coin while possible
  - Then take the second largest
  - Etc.



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Sum of Coins Visualization

Target: 18

Actual: 0

Sum of Coins Visualization

Target: 18

Actual: 10

Sum of Coins Visualization

Target: 18

Actual: 15

Sum of Coins Visualization

Target: 18

Actual: 17

Sum of Coins Visualization

Target: 18

Actual: 18

Greedy Algorithm for Sum of Coins

Solution: Sum of Coins

```java
public static Map<Integer, Integer>
                        chooseCoins(int[] coins, int targetSum) {
  List<Integer> sortedCoins = Arrays.stream(coins).boxed()
            .sorted(Collections.reverseOrder())
            .collect(Collectors.toList());
  Map<Integer, Integer> chosenCoins = new LinkedHashMap<>();
  int currentSum = 0; int coinIndex = 0;
  // Next slide
  if (currentSum != targetSum)
    throw new IllegalArgumentException();
  return chosenCoins;
}
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Solution: Sum of Coins

```
while (currentSum != targetSum && coinIndex < sortedCoins.size()) {
  int currentCoin = sortedCoins.get(coinIndex);
  int remainder = targetSum - currentSum;
  int numberOfCoins = remainder / currentCoin;
  if (currentSum + currentCoin <= targetSum) {
    chosenCoins.put(currentCoin, numberOfCoins);
    currentSum += numberOfCoins * currentCoin;
  }
  coinIndex++;
}
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Problem: Set Cover

- Write a program that finds the smallest subset of S, the union of which = **U** (if it exists)
- You will be given a **set** of integers **U** called "**the Universe**"
- And a set **S** of **n** integer sets whose union = **U**

```
Universe: 1, 2, 3, 4, 5
Number of sets: 4
1
2, 4
5
3
```

```
Sets to take (4):
{ 2, 4 }
{ 1 }
{ 5 }
{ 3 }
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Solution: Set Cover

```java
public static List<int[]> chooseSets(
                List<int[]> sets, List<Integer> universe) {
  List<int[]> selectedSets = new ArrayList<>();
  Set<Integer> universeSet = new HashSet<>();
  for (int element : universe) { universeSet.add(element);}
  while (!universeSet.isEmpty()) {
    // Next Slide
  }
  return selectedSets;
}
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Solution: Set Cover

```java
int notChosenCount = 0;
int[] chosenSet = sets.get(0);
for (int[] set : sets) {
  // Next slide
}
selectedSets.add(chosenSet);
for (int elem : chosenSet) {
  universeSet.remove(elem);
}
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Solution: Set Cover

```java
int count = 0;
for (int elem : set) {
  if (universeSet.contains(elem)) {
    count++;
  }
}
if (notChosenCount < count) {
  notChosenCount = count;
  chosenSet = set;
}
```

Check your solution here: https://judge.softuni.bg/Contests/1701/Basic-Algorithms-Lab

Greedy Failure Cases

Sum of Coins Failure

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Target: 18

Actual: 0

Sum of Coins Failure

Target: 18

Actual: 10

Sum of Coins Failure

Target: 18

Actual: 15

Sum of Coins Failure

Target: 18

Actual: 16

Sum of Coins Failure

Target: 18

Actual: 17

Sum of Coins Failure

Target: 18

Actual: 18

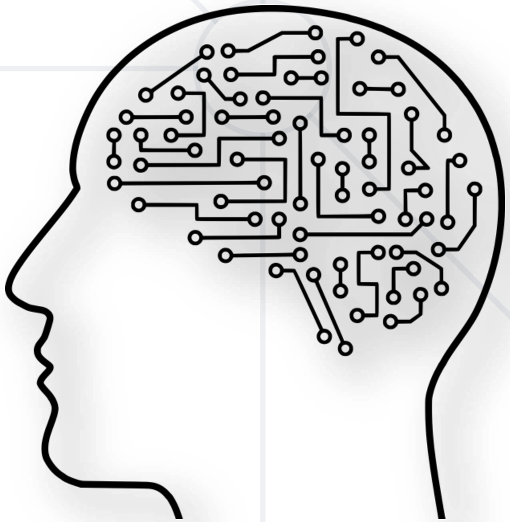
Sum of Coins Failure

Target: 18

Optimal Greedy Algorithms

Optimal Greedy Algorithms

- Suitable problems for greedy algorithms have these properties:
  - **Greedy choice property**
  - **Optimal substructure**
- Any problem having the above properties is guaranteed to have an optimal greedy solution

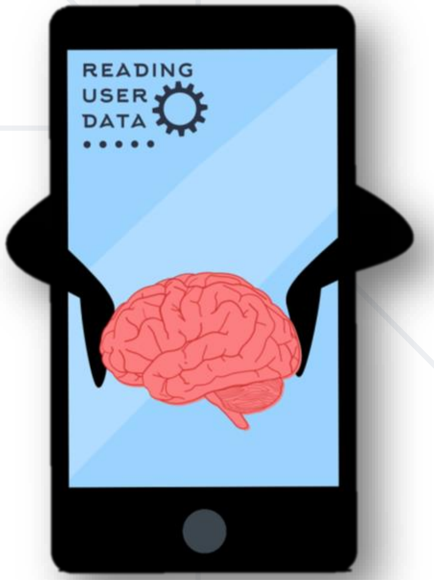


Greedy Choice Property

- **Greedy choice** property
  - **A global optimal solution** can be obtained by greedily selecting a **locally optimal** choice
  - Sub-problems that arise are solved by consequent greedy choices
    - Enforced by optimal substructure

Optimal Substructure Property

- **Optimal substructure** property
  - After each greedy choice the problem remains an optimization problem of the same form as the original problem
  - **An optimal global solution contains the optimal solutions of all its sub-problems**



Greedy Algorithms: Example

- The "**Max Coins**" game
  - You are given a set of coins
  - You play against another player, alternating turns
  - Per each turn, you can take up to three coins
  - Your goal is to have as many coins as possible at the end

Max Coins – Greedy Algorithm

- A simple **greedy strategy** exists for the "Max Coins" game

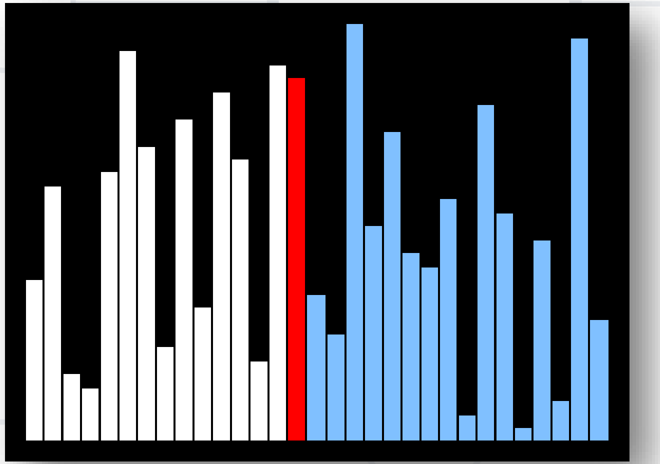
```
At each turn take the maximum number of coins
```

- Always choose the local maximum (at each step)
  - You don't consider what the other player does
  - You don't consider your actions' consequences
- The **greedy algorithm** works optimally here
  - It takes as many coins as possible

Simple Sorting Algorithms

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

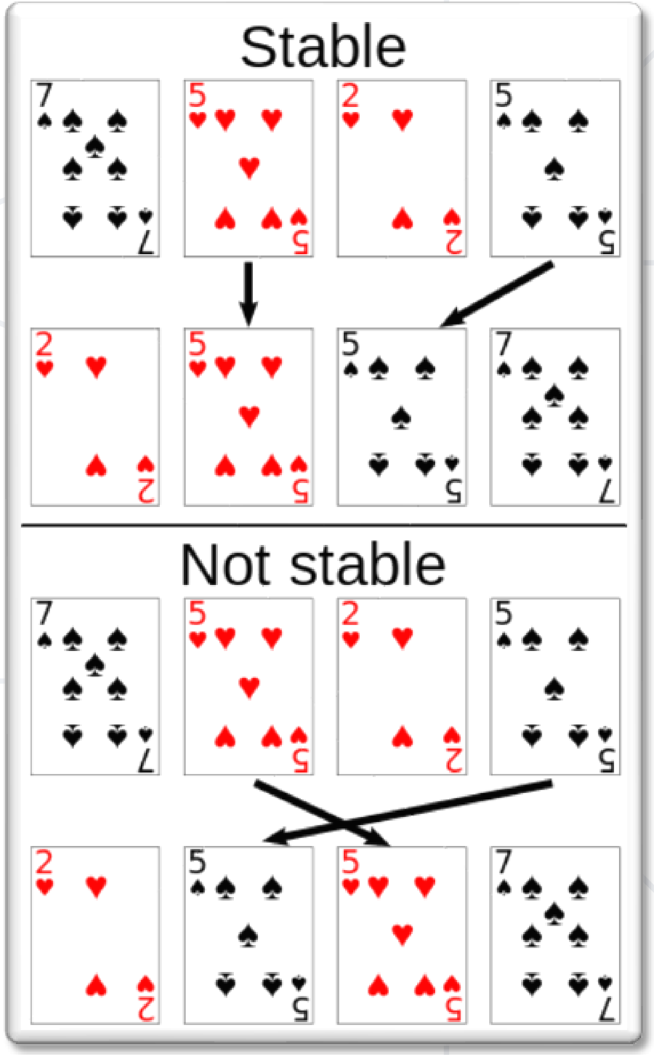
- Efficient sorting algorithms are important for:
  - Producing human-readable output
  - Canonicalizing data – making data uniquely arranged
  - In conjunction with other algorithms, like binary searching
- Example of sorting:

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

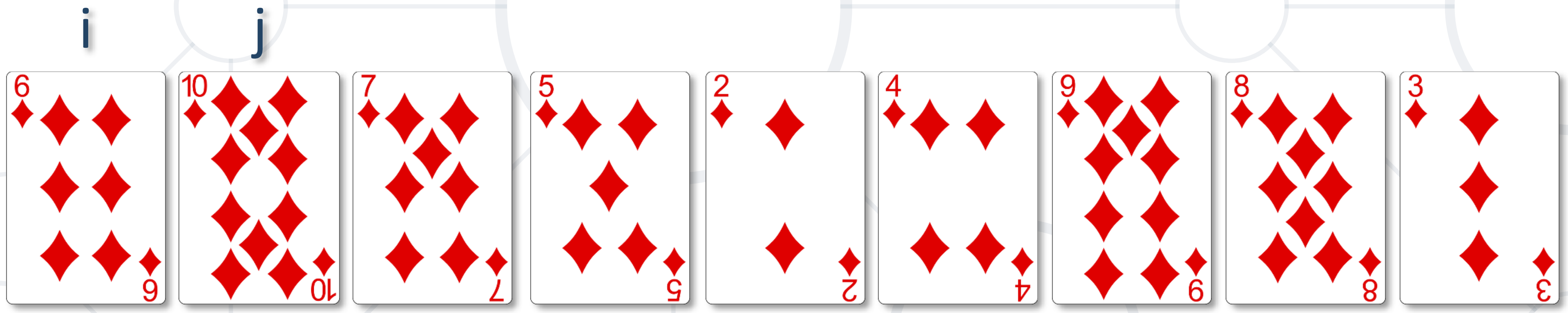
- **Stable** sorting algorithms
  - Maintain the order of equal elements
  - If two items compare as equal, their relative order is preserved
- **Unstable** sorting algorithms
  - Rearrange the equal elements in unpredictable order
- Often **different elements** have **same key** used for equality comparing



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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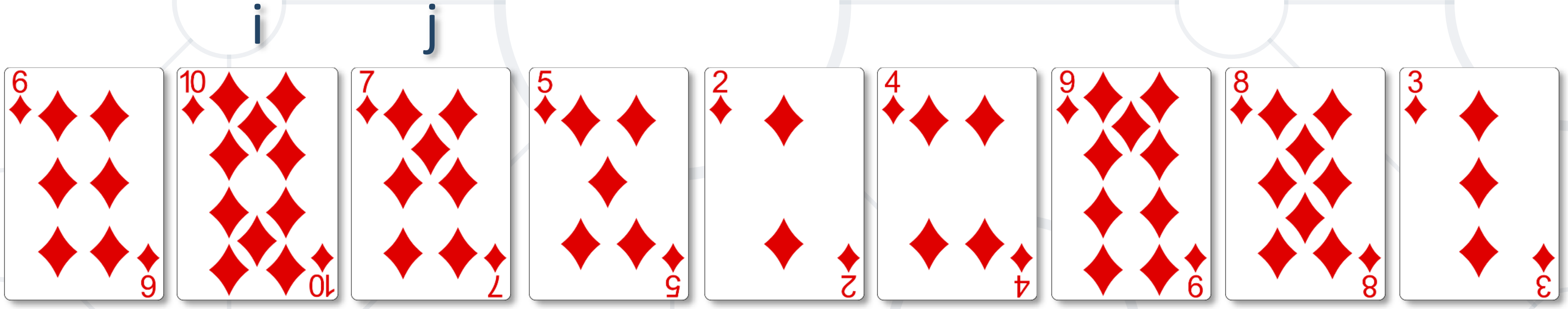

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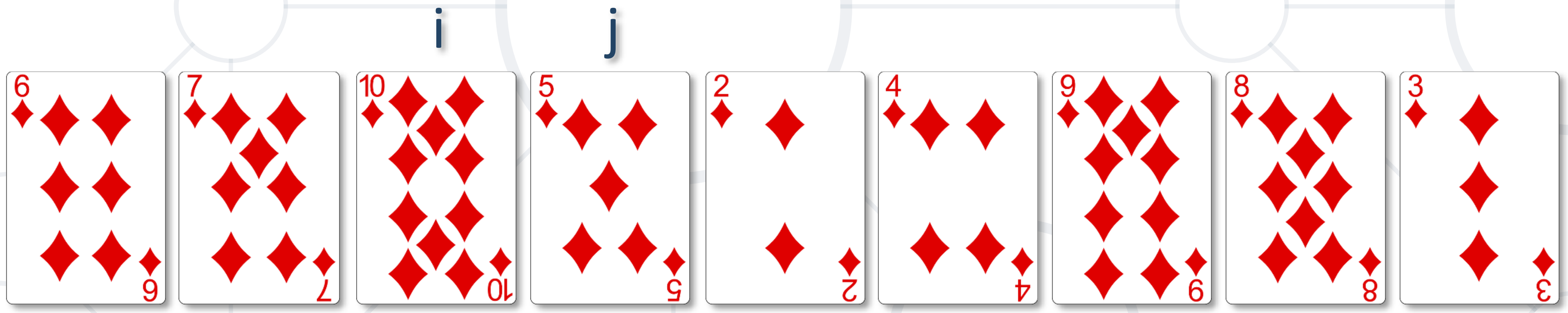
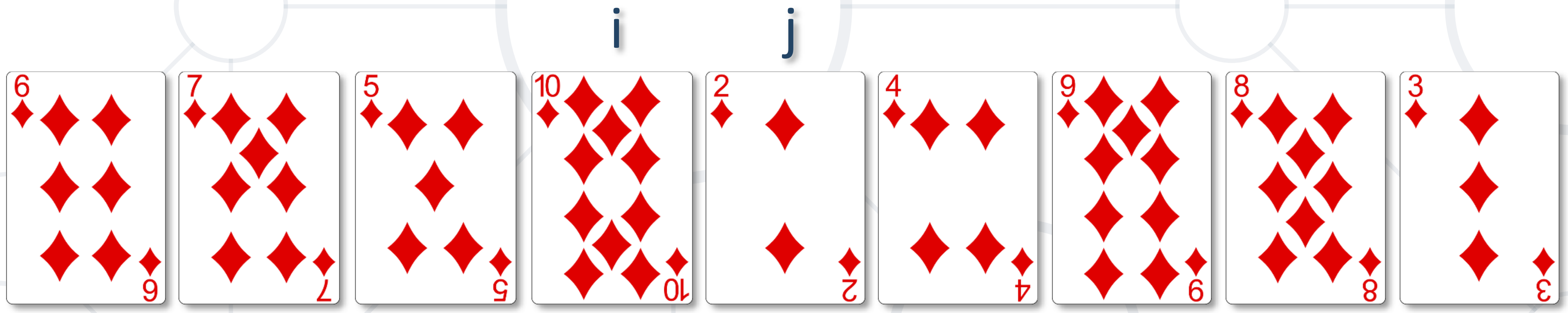
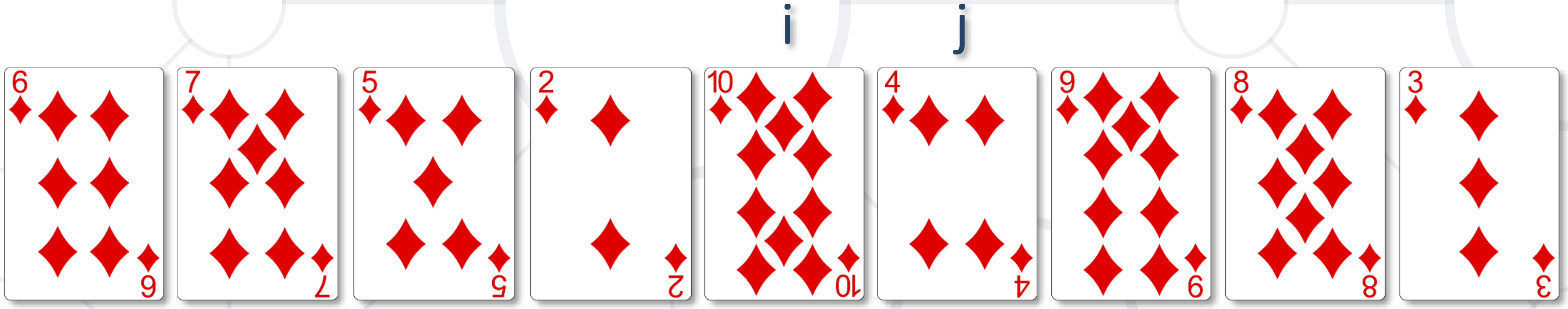


Bubble Sort Visualization



Bubble Sort Visualization



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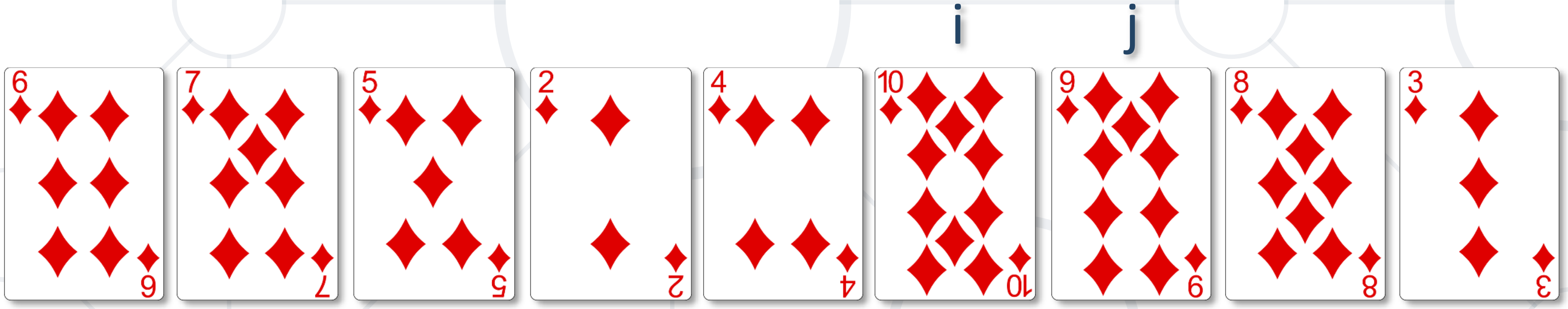

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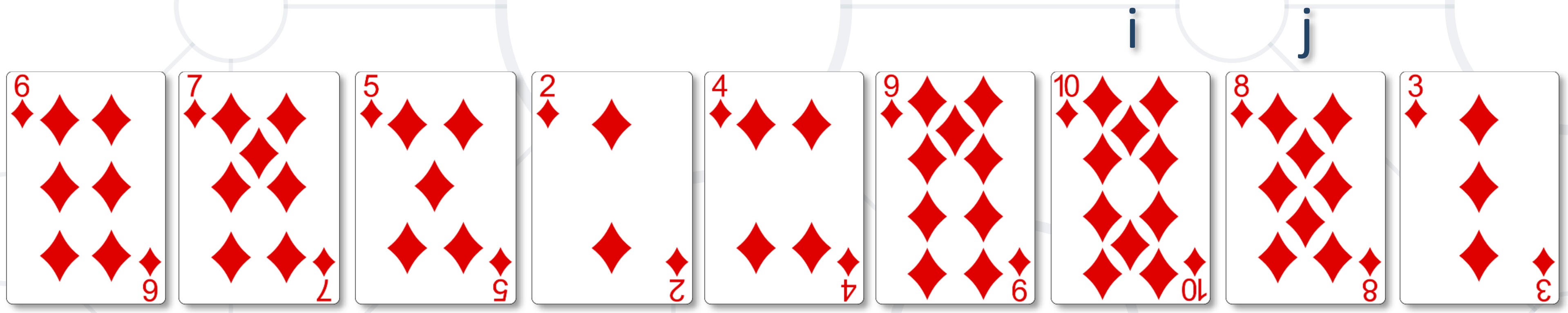

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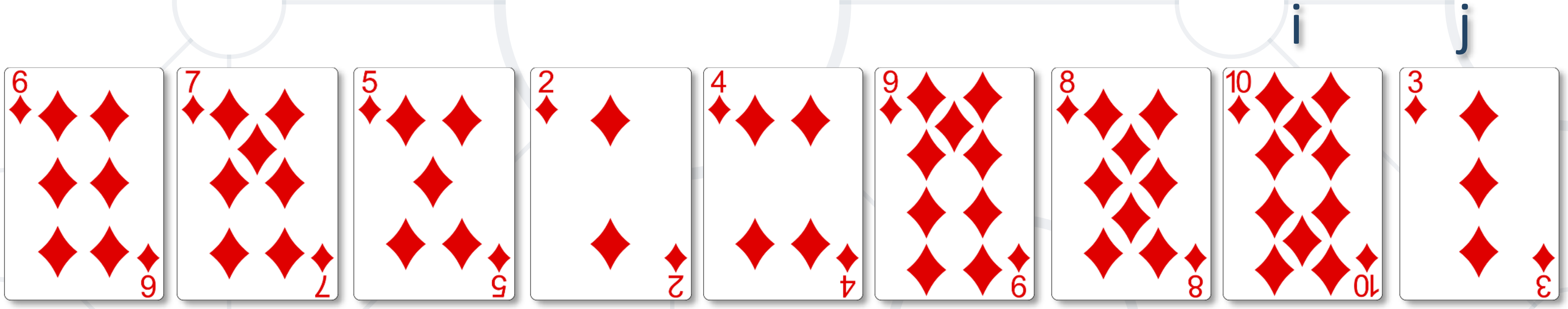

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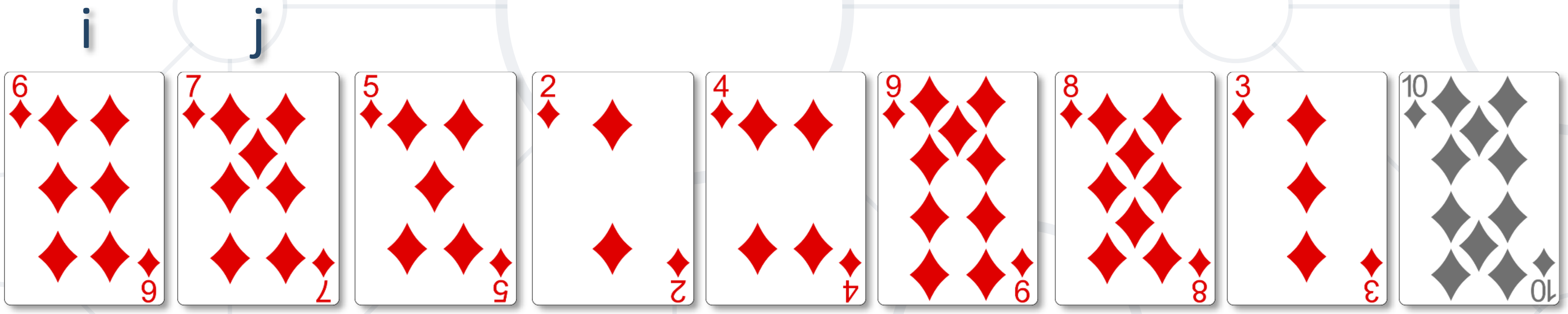

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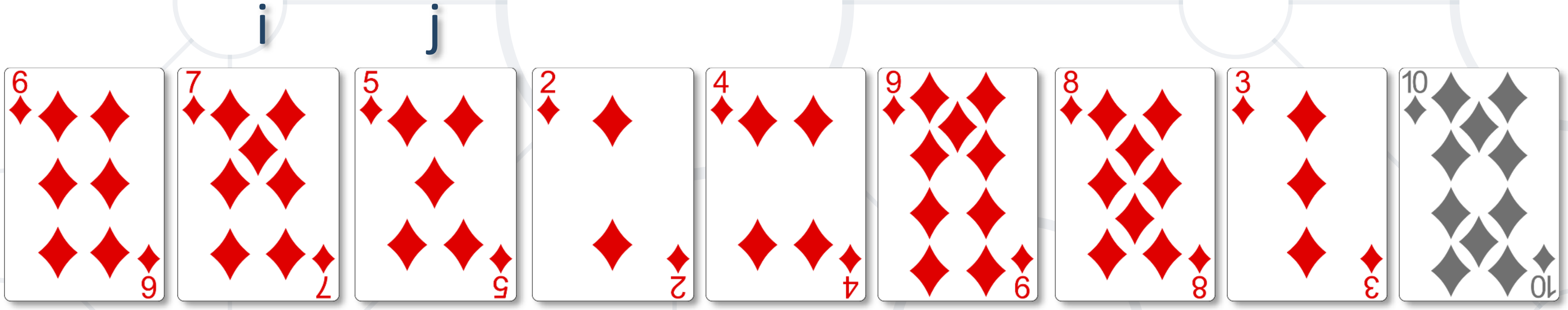

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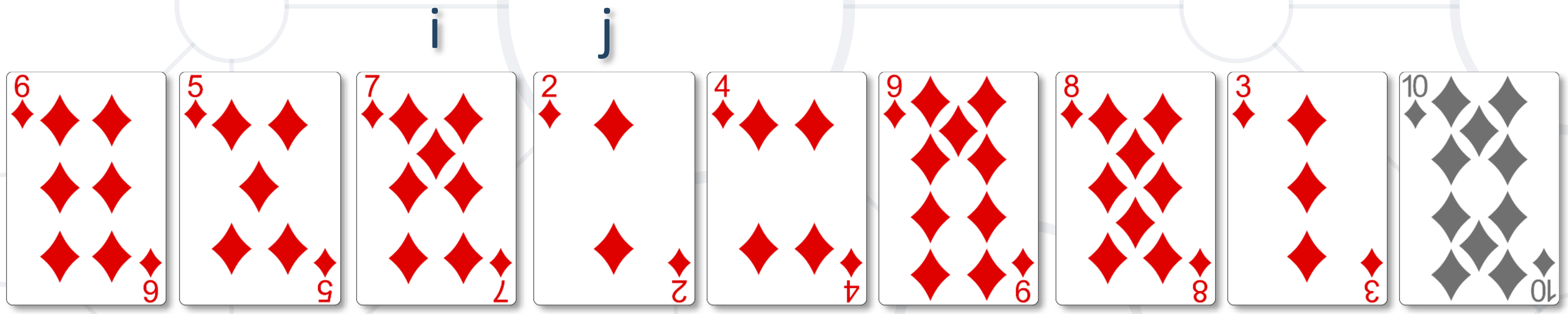

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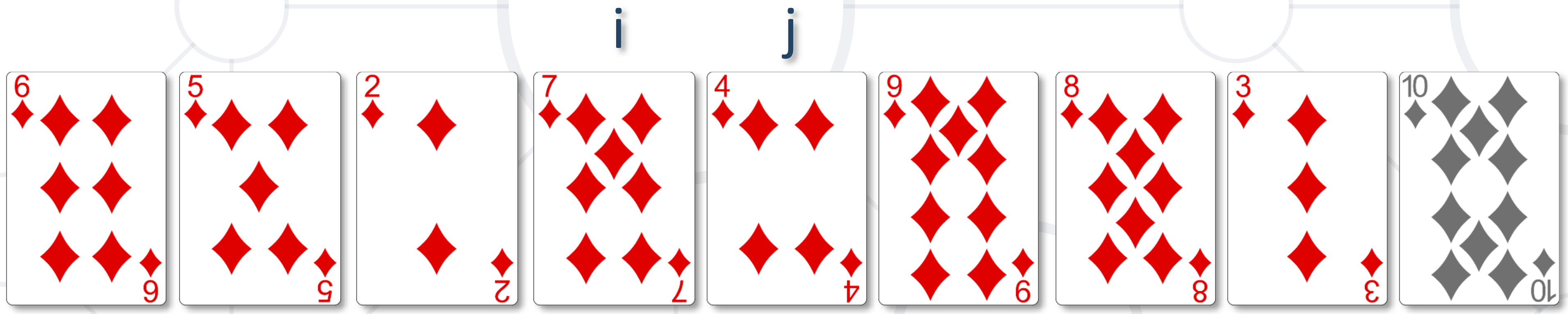

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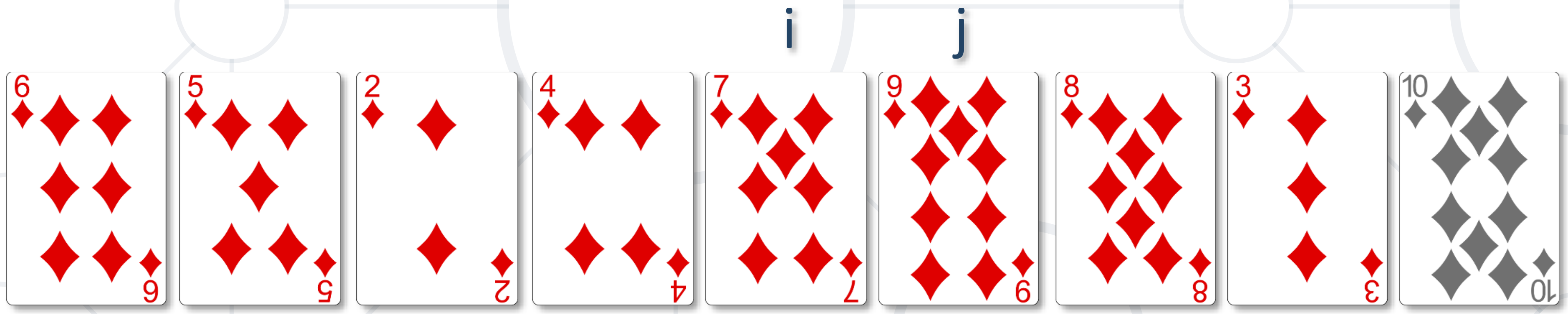

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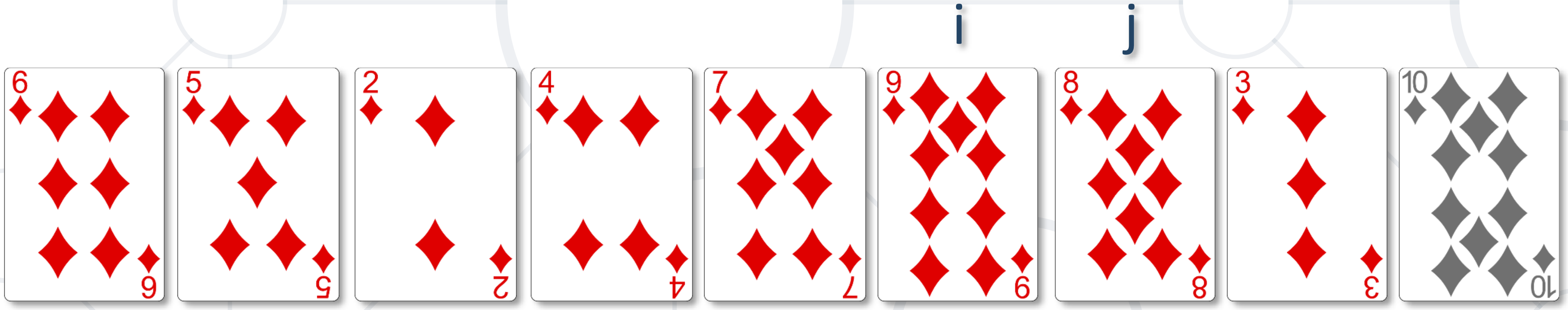

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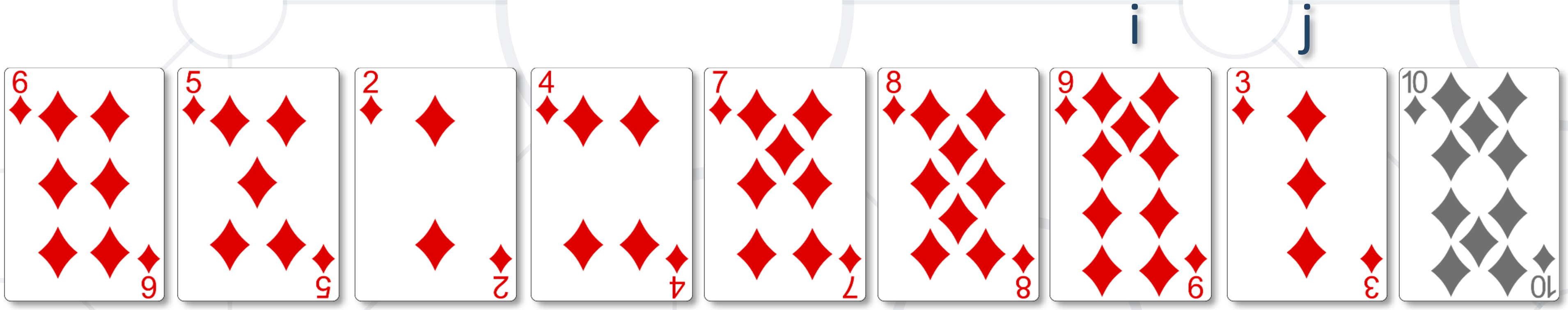

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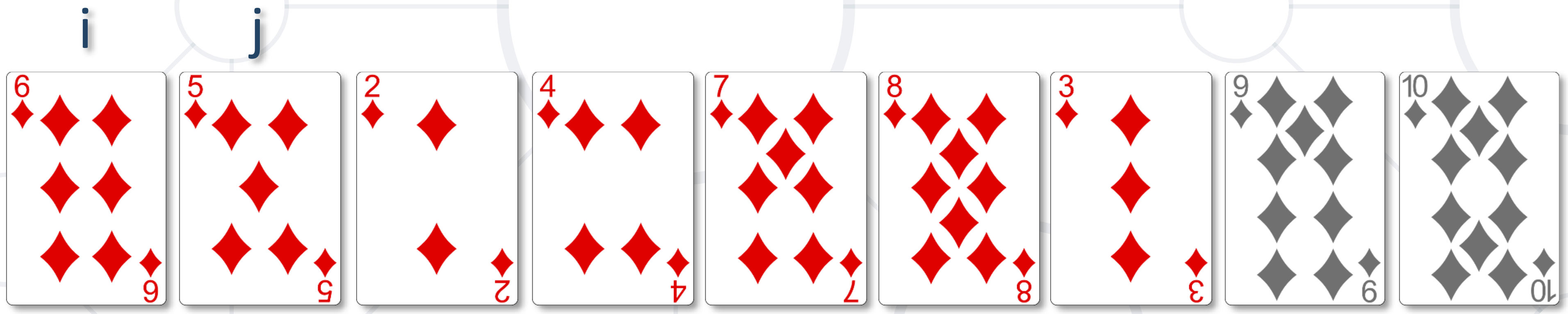

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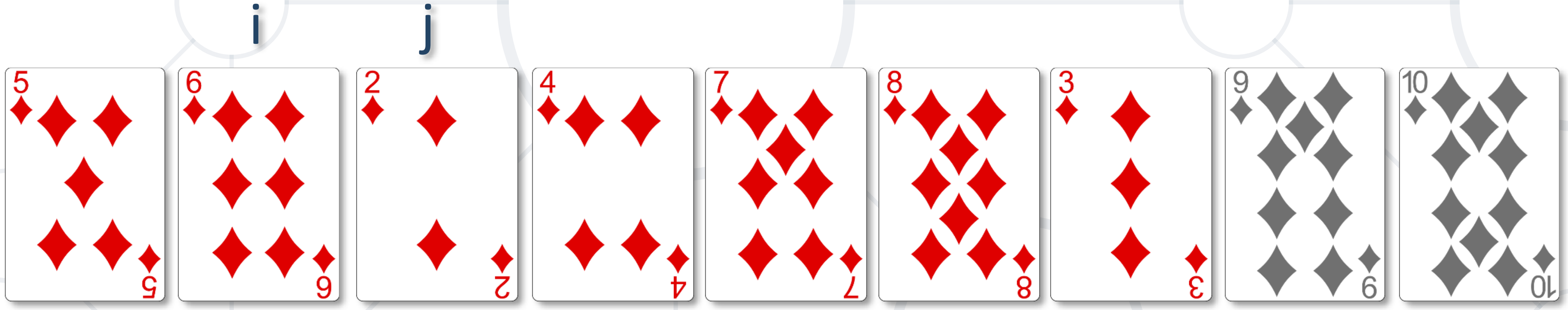

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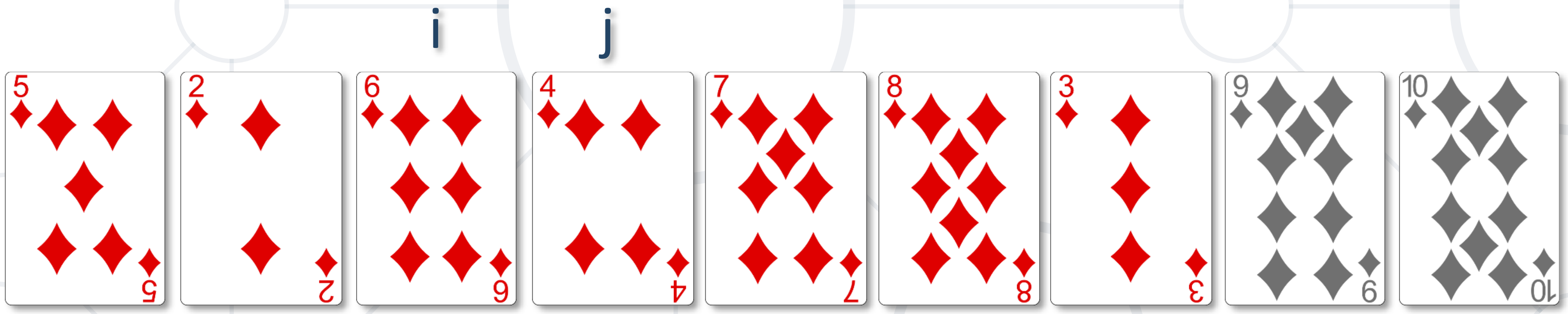

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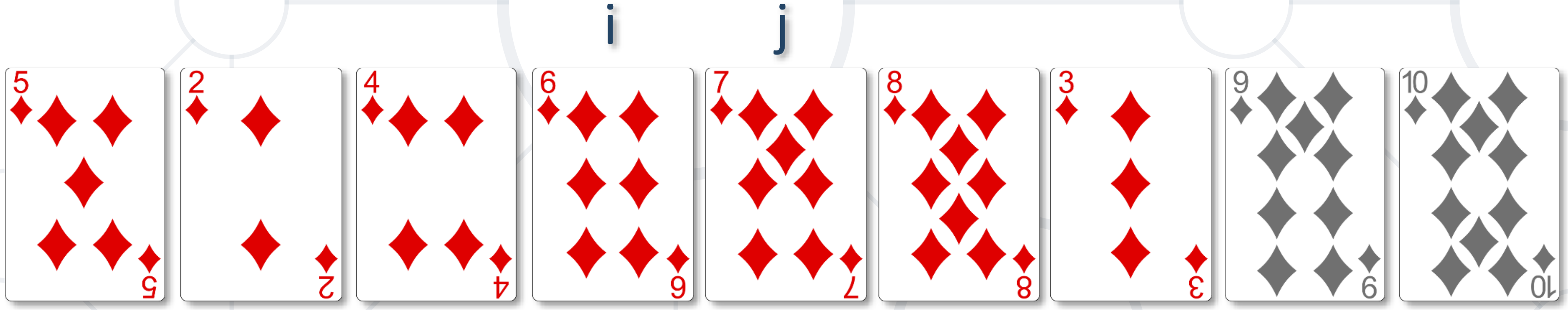

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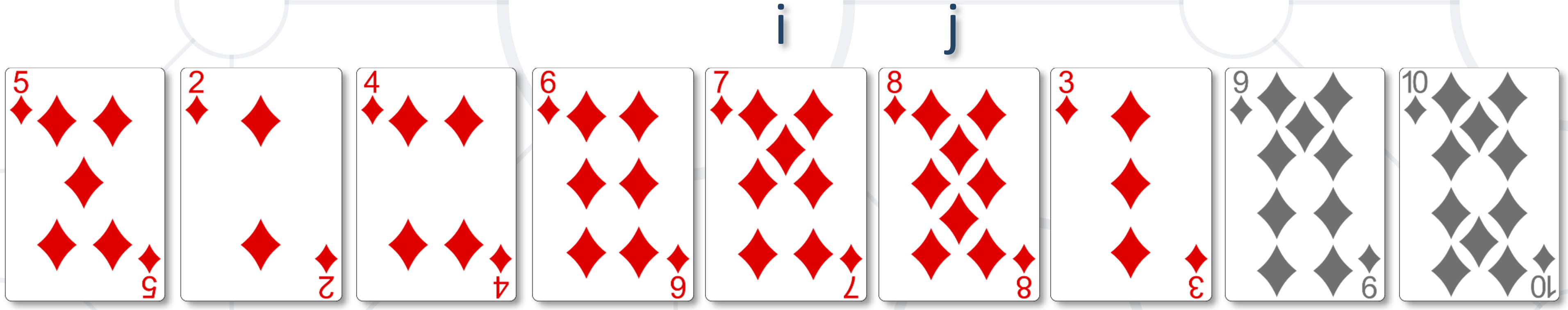

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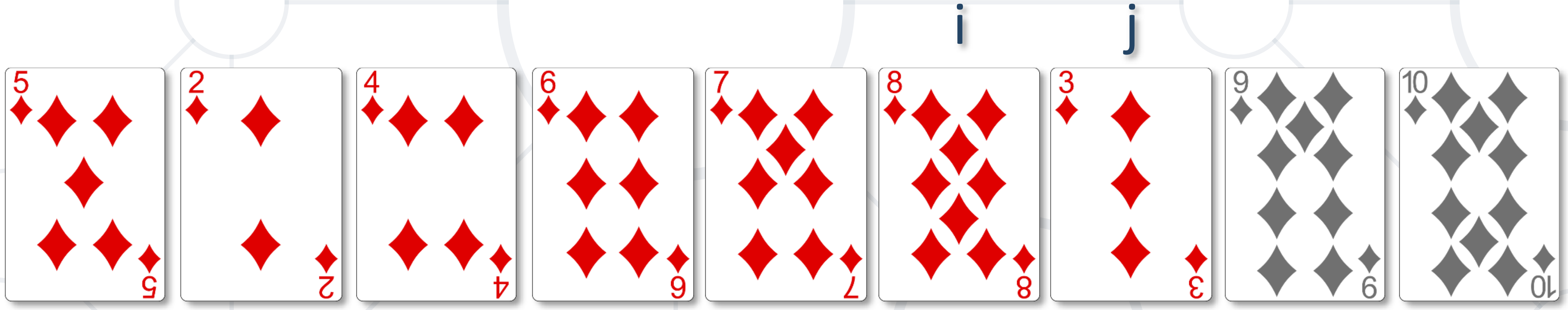

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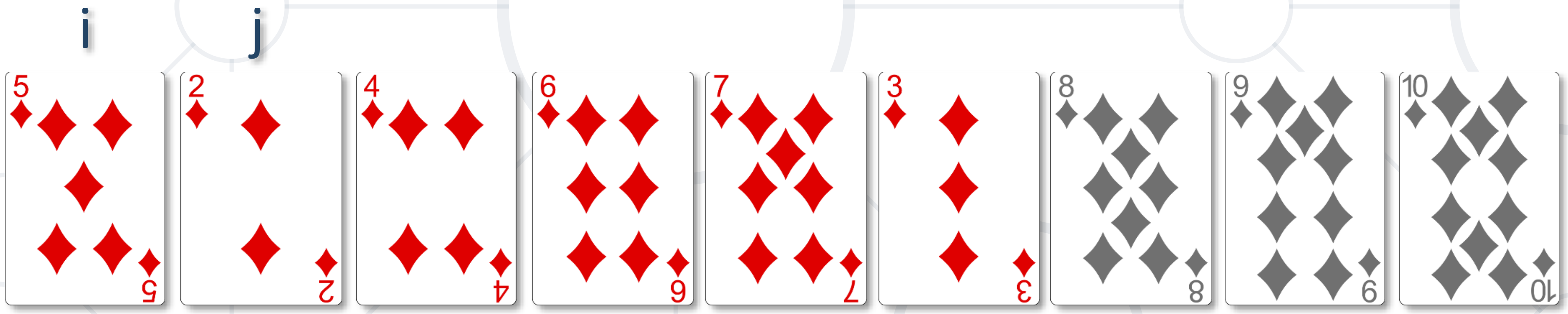

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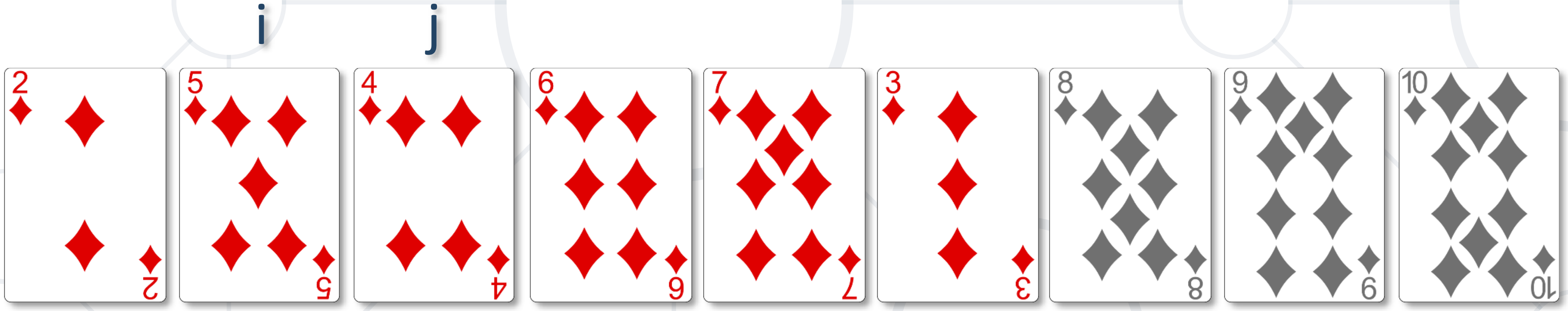

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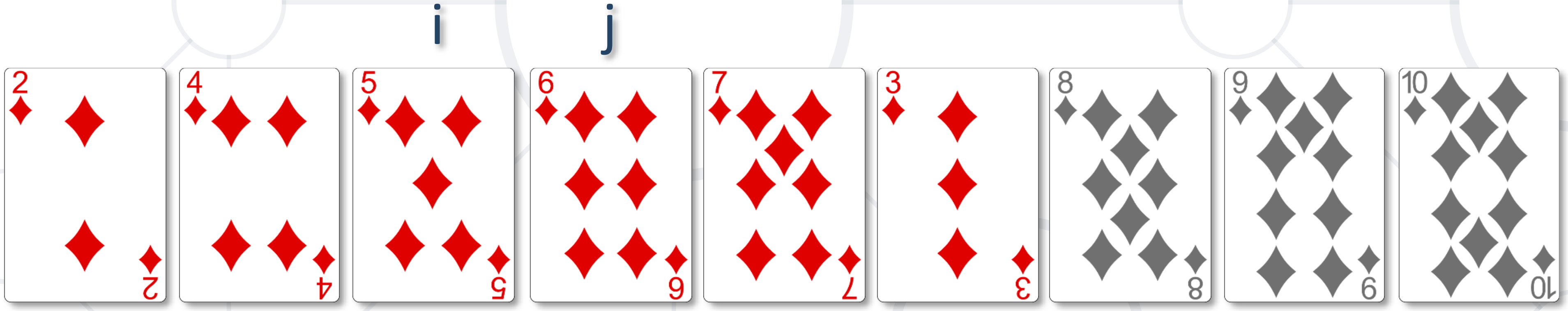

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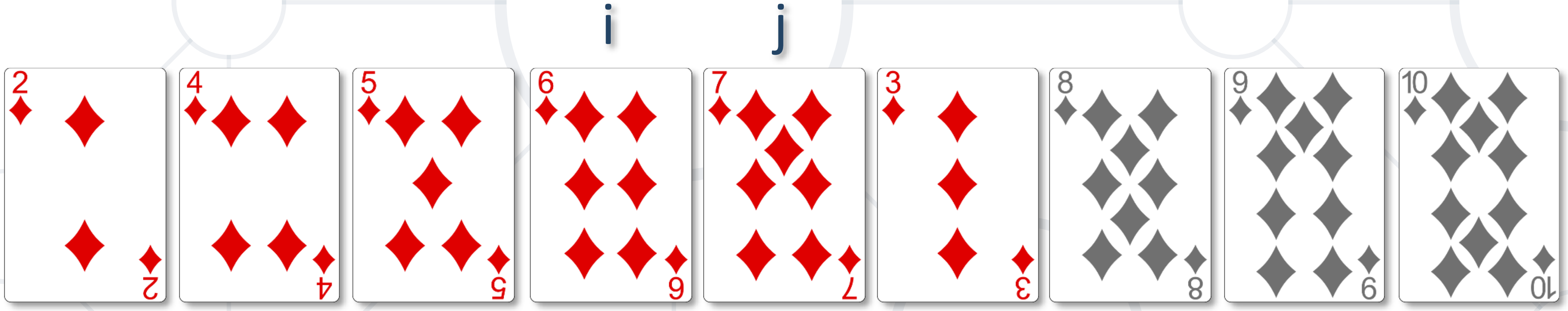

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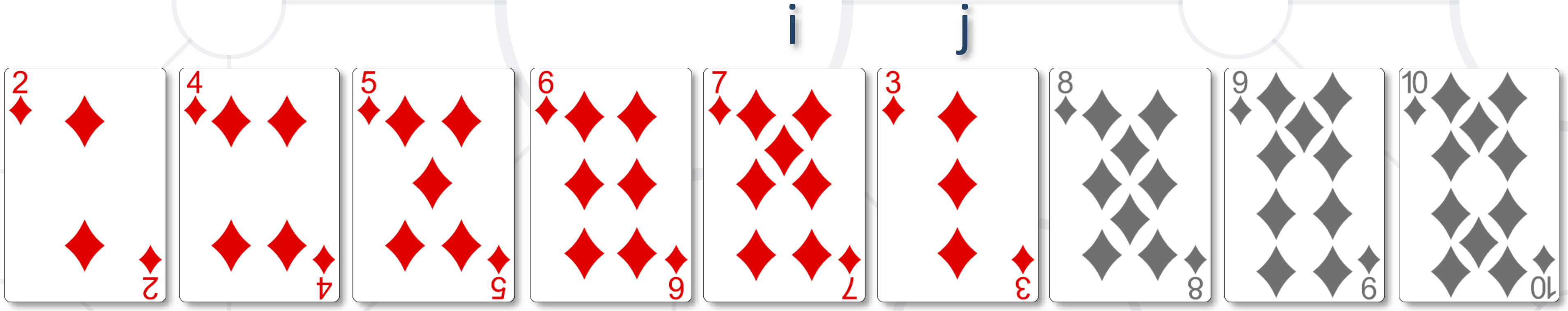

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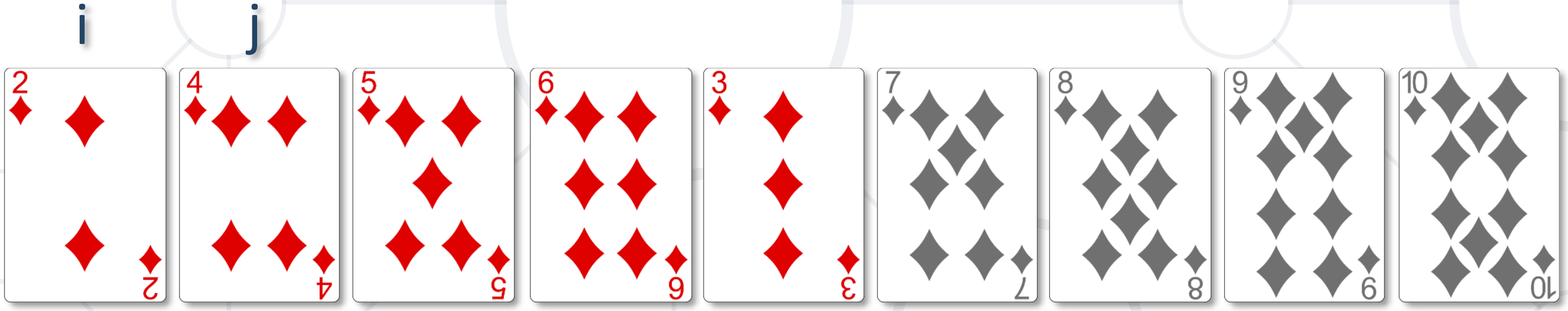

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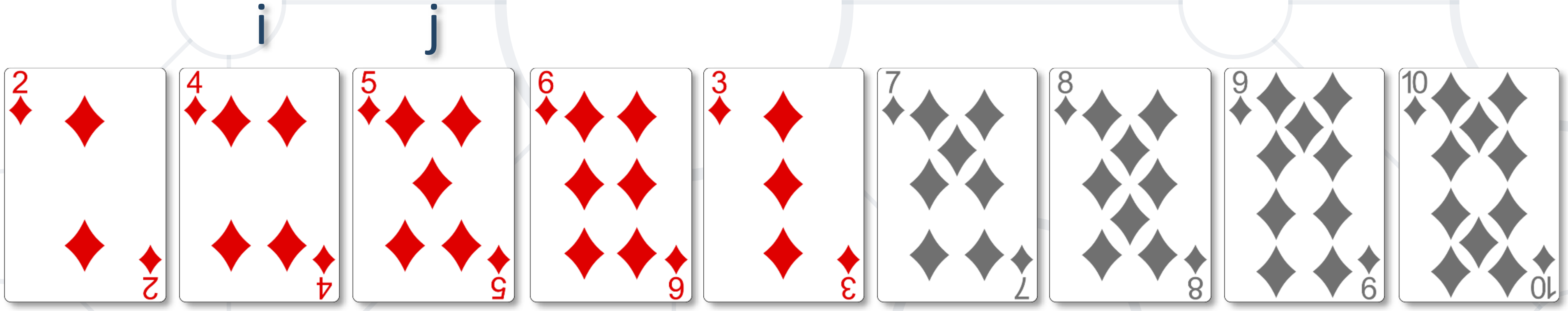

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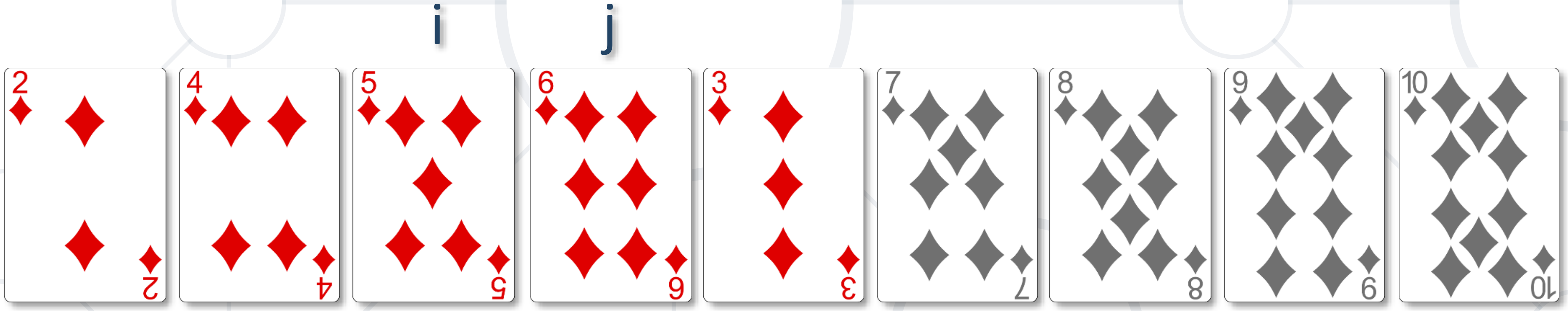

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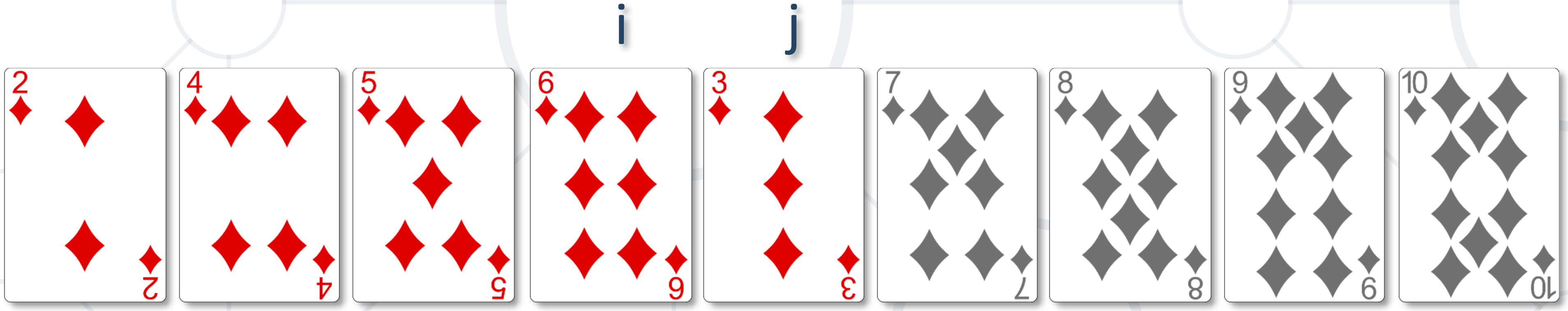

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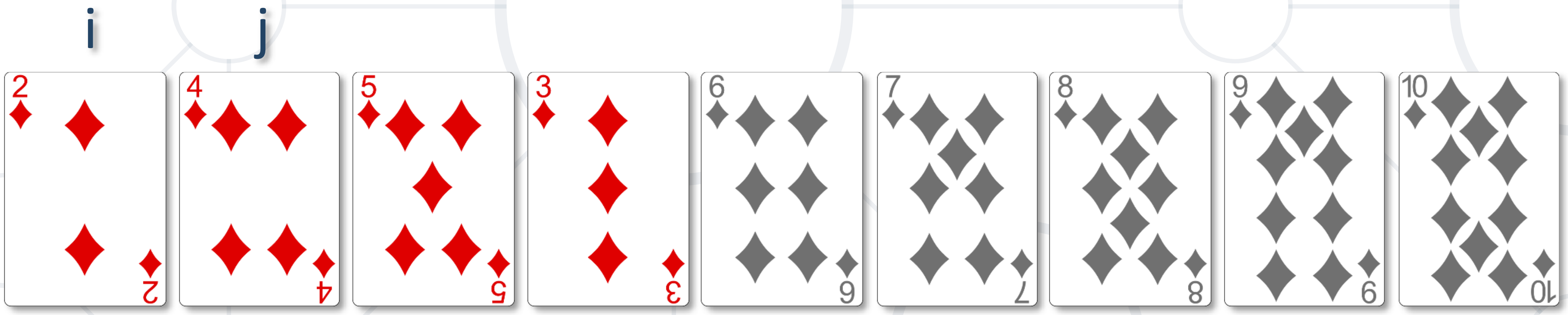

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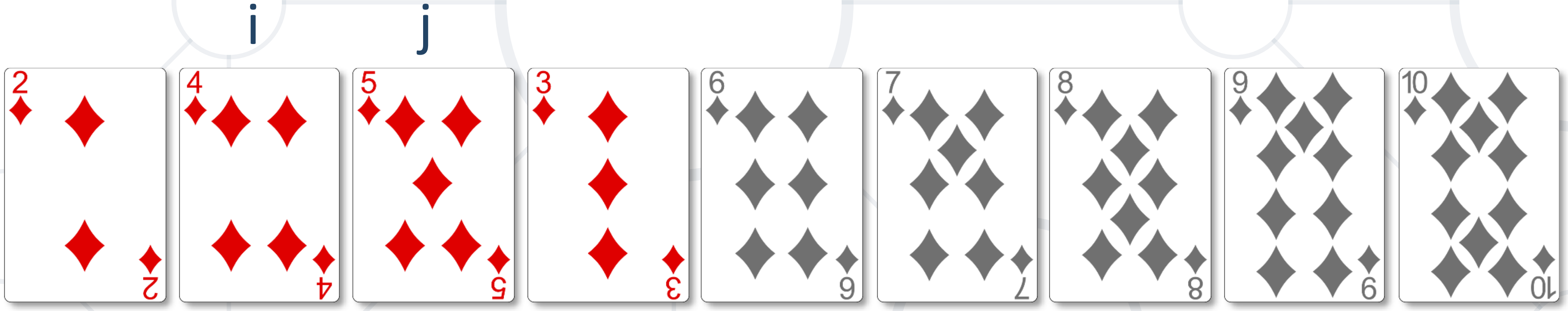

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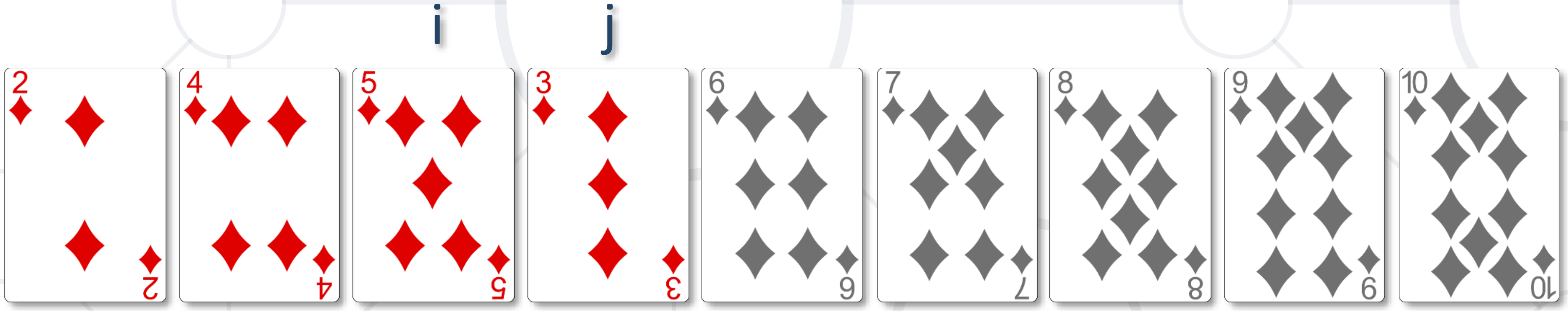

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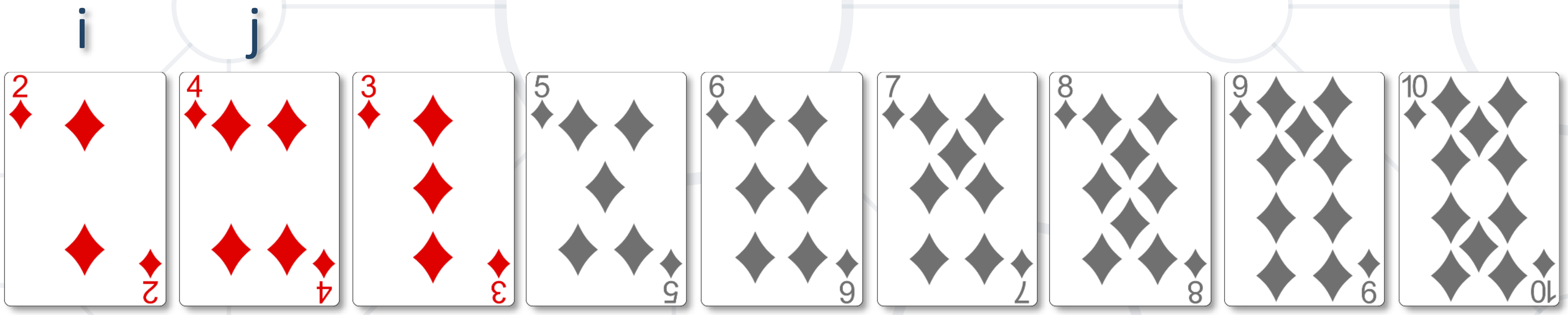
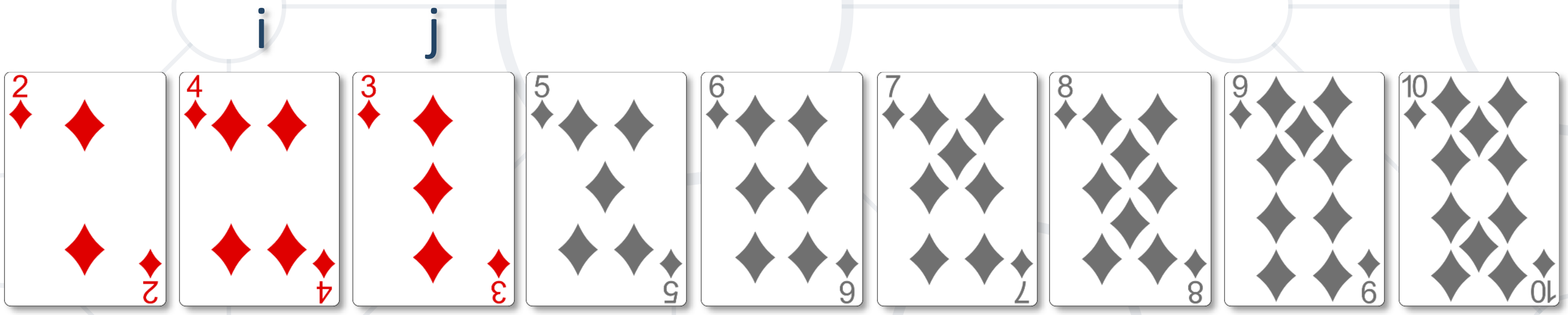
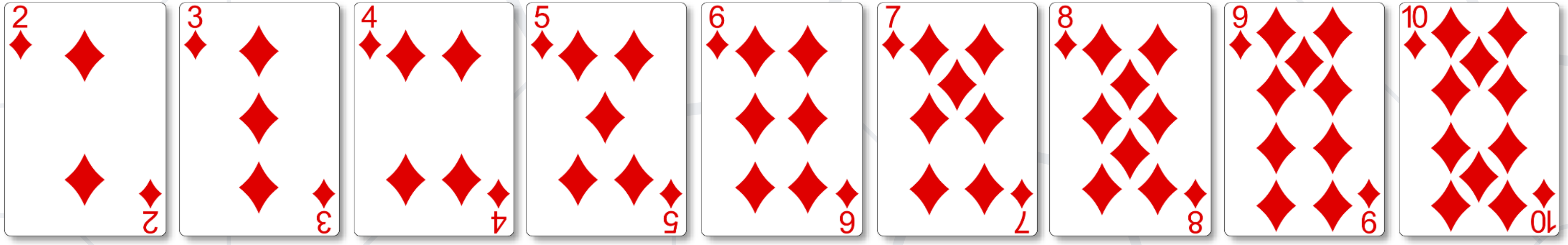


Bubble Sort Visualization



Bubble Sort Visualization



BubbleSort

```
int[] numbers = {1, 3, 4, 2, 5, 6};
for (int i = 0; i < numbers.length; i++) {
  for (int j = i + 1; j < numbers.length - 1; j++) {
    if (numbers[i] > numbers[j]) {
      int tempNumber = numbers[i];
      numbers[i] = numbers[j];
      numbers[j] = tempNumber;
    }
  }
}

//TODO: Print numbers
```

Searching Algorithms

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.

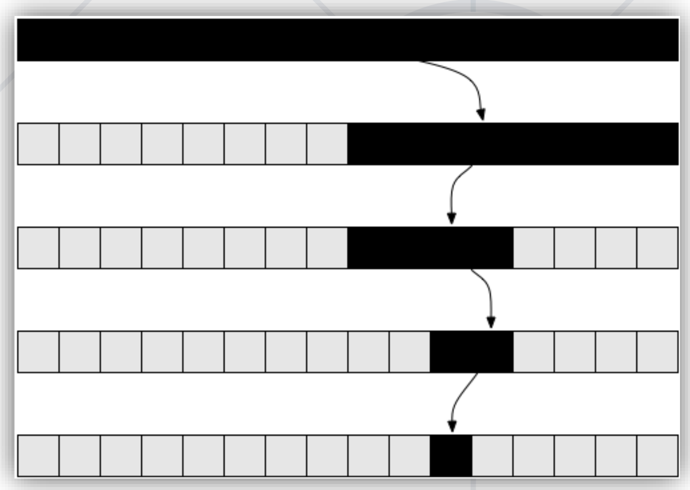
Linear Search

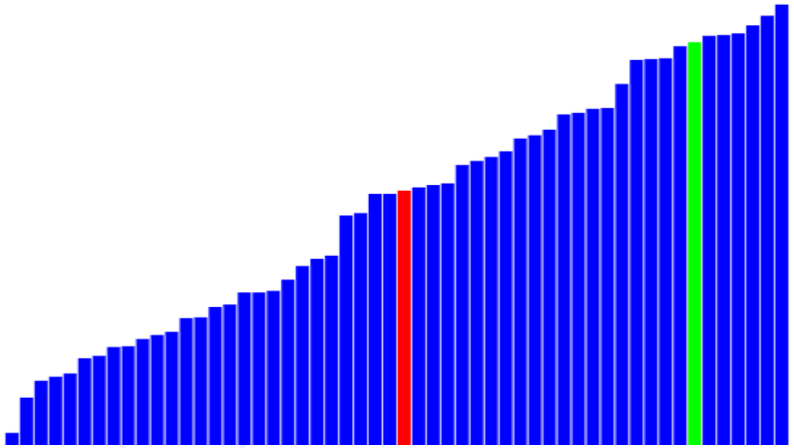
- Linear search finds a particular value in a list (visualize)
  - Checking every one of the elements
  - One at a time, in sequence
  - Until the desired one is found
- Worst & average performance: O(n)

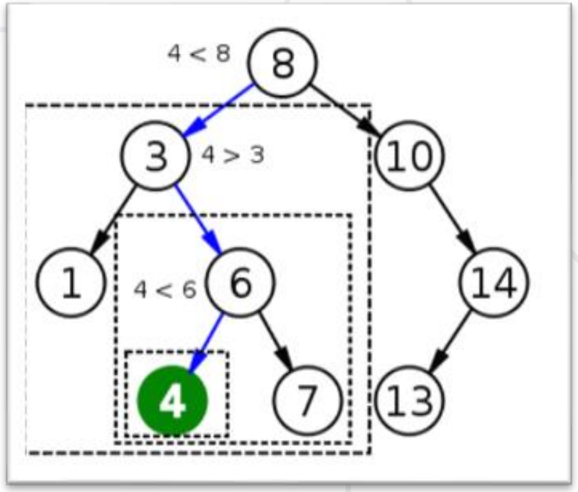
```
for each item in the list:
  if that item has the desired value,
    return the item's location
return nothing
```

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 (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;
}
```

Summary

- **Recursion** – a method or a function that calls itself
- **Brute-Force** - trying all the possible solutions
- **Greedy** - picking a locally optimal solution
- **Sorting**
  - Bubble Sort
- **Searching**
  - Linear and Binary

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