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Inclusion-Exclusion and its various Applications

Difficulty Level : Easy • Last Updated : 17 Aug, 2021



In the field of Combinatorics, it is a counting method used to compute the cardinality of the union set. According to basic **Inclusion-**

Exclusion principle:

- For 2 finite sets A_1 and A_2 , which are subsets of Universal set, then $(A_1 - A_2)$, $(A_2 - A_1)$ and $(A_1 \cap A_2)$ are disjoint sets.

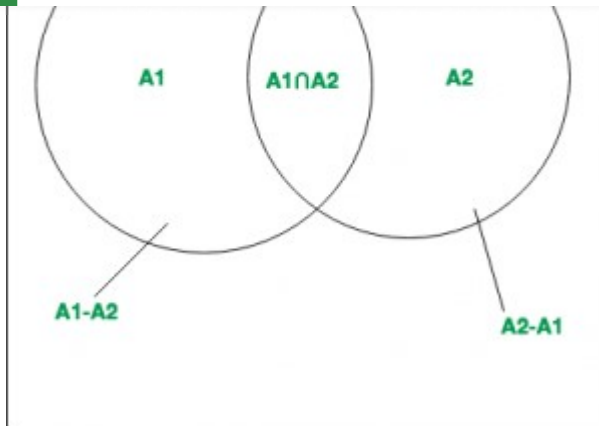
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- Hence it can be said that,

$$|(A_1 - A_2) \cup (A_2 - A_1) \cup (A_1 \cap A_2)| = |A_1| - |A_1 \cap A_2| + |A_2| - |A_1 \cap A_2| + |A_1 \cap A_2|$$

$$|A_1 \cup A_2| = |A_1| + |A_2| - |A_1 \cap A_2|.$$

- Similarly for 3 finite sets A_1 , A_2 and A_3 ,

$$|A_1 \cup A_2 \cup A_3| = |A_1| + |A_2| + |A_3| - |A_1 \cap A_2| - |A_2 \cap A_3| - |A_1 \cap A_3| + |A_1 \cap A_2 \cap A_3|$$

— . . .

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sets – Sum of all 2-set intersections + Sum of all the 3-set

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In general it can be said that,

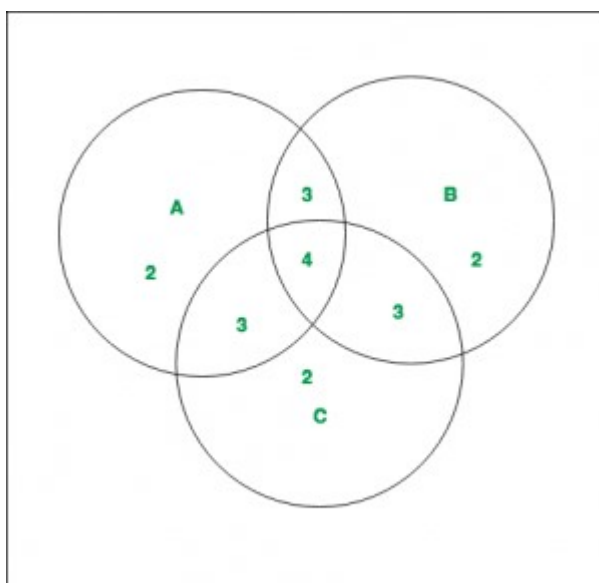
$$|A_1 \cup A_2 \cup A_3 \dots \cup A_i| = \sum_{1 \leq k \leq i} |A_k| + (-1) \sum_{1 \leq k_1 < k_2 \leq i} |A_{k_1} \cap A_{k_2}| + (-1)^2 \sum_{1 \leq k_1 < k_2 < k_3 \leq i} |A_{k_1} \cap A_{k_2} \cap A_{k_3}| \dots + (-1)^{i+1} \sum_{1 \leq k_1 < k_2 < k_3 \dots k_i \leq i} |A_{k_1} \cap A_{k_2} \cap A_{k_3} \dots \cap A_{k_i}|$$

Properties :

1. Computes the total number of elements that satisfy at least one of several properties.
2. It prevents the problem of double counting.

Example 1:

As shown in the diagram, 3 finite sets A, B and C with their corresponding values are given. Compute $|A \cup B \cup C|$.



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The values of the corresponding regions, as can be noted from the

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$$|A \cap C| = 3, |A \cap B \cap C| = 4$$

By applying Inclusion-Exclusion principle,

$$|A_1 \cup A_2 \cup A_3| = |A_1| + |A_2| + |A_3| - |A_1 \cap A_2| - |A_2 \cap A_3| - |A_1 \cap A_3| + |A_1 \cap A_2 \cap A_3|$$

$$|A_1 \cup A_2 \cup A_3| = 2 + 2 + 2 - 3 - 3 - 3 + 4 = 1$$

Applications :

- **Derangements**

To determine the number of derangements (or permutations) of n objects such that no object is in its original position (like Hat-check problem).

As an example we can consider the derangements of the number in the following cases:

For i = 1, the total number of derangements is 0.

For i = 2, the total number of derangements is 1. This is 21.

For i = 3, the total number of derangements is 2. These are 231 and 312.

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