Tuples and Permutations

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Outline

Number of Tuples

Licence Plates

Tuples with Restrictions

Permutations

Number of Passwords

Problem

How many different 5-symbol passwords can we create using lower case Latin letters only? (the size of the alphabet is 26)

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How many different 5-symbol passwords can we create using lower case Latin letters only? (the size of the alphabet is 26)

- It turns out that the rule of product is all we need to solve this problem
- But we need to do it step by step

Number of Passwords

- Let’s start with 1 letter password

*

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- Clearly, then the answer is 26

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- What about two letters?
- Then we can choose both letters in 26 ways

26 26

$*$ $*$

Number of Passwords

- Let's start with 1 letter password
- Clearly, then the answer is 26
- What about two letters?
- Then we can choose both letters in 26 ways
- Use the rule of product: the answer is 676

$$26 \times 26 = 676$$

$$* \quad *$$

Number of Passwords

- Let's move on to the case of 3 letters

$*\quad *\quad *$

Number of Passwords

- Let's move on to the case of 3 letters
- We already know that we can choose the first two letters in 676 ways

676

* * *

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- Let's move on to the case of 3 letters
- We already know that we can choose the first two letters in 676 ways
- We apply the rule of product again!

$$\underbrace{676}_{} \times 26$$

$$\boxed{*\quad *}\quad *$$

Number of Passwords

- Let's move on to the case of 3 letters
- We already know that we can choose the first two letters in 676 ways
- We apply the rule of product again!
- And the answer is 17 576

$$\underbrace{676}_{* \quad *} \times \underbrace{26}_{*} = 17\,576$$

Number of Passwords

- Now we can proceed in the same way

$$26 \times 26 \times 26$$

$$* \quad * \quad * \quad * \quad *$$

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- Now we can proceed in the same way
- And the answer is 11 881 376

$$26 \times 26 \times 26 \times 26 \times 26 = 11\,881\,376$$

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These sequences are usually called tuples

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These sequences are usually called tuples

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- There are n possibilities to pick the first letter
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- Thus the answer is a product of n by itself k times, that is n^k

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- Russian license plate: 3 digits, 3 letters; 78 is a regional code
- We have: 10 options for digits, 12 options for letters (only those Cyrillic letters that are similar to Latin ones are used)

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- Now we are ready to get back to our motivating example
- Russian license plate: 3 digits, 3 letters; 78 is a regional code
- We have: 10 options for digits, 12 options for letters (only those Cyrillic letters that are similar to Latin ones are used)
- How many plates are there for one region?

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- Each digit can be chosen in 10 ways

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- Thus a sequence of digits can be chosen in $10 \times 10 \times 10 = 1\,000$ ways

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- Thus a sequence of three letters can be chosen in $12 \times 12 \times 12 = 1\,728$ ways
- Overall, there are 1 728 000 license plates for a region

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- There are 1 728 000 license plates for a region
- Is it enough?
- No, it’s not: for example, there are about 5 600 000 vehicles in Moscow (as of 2016)
- Does it mean that by the Pigeonhole principle there are vehicles with identical license plates?

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- No, several regional codes were introduced for the same region

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- No, several regional codes were introduced for the same region
- But this required introduction of three-digit regional codes

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Tuples with Restrictions

Permutations

Tuples with Restrictions

- We have shown how using the rule of product we can compute the number of tuples or a certain length of a fixed set of symbols

Tuples with Restrictions

- We have shown how using the rule of product we can compute the number of tuples or a certain length of a fixed set of symbols
- But the rule of product can also give us other things too

Numbers with exactly one digit 7

Problem

How many integer numbers between 0 and 9999 are there that have exactly one 7 digit?

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How many integer numbers between 0 and 9999 are there that have exactly one 7 digit?

- Numbers between 0 and 9999 are sequences of digits of length 4
- Three digital numbers correspond to sequences starting with 0

Numbers with exactly one 7 digit

$$* \quad * \quad * \quad *$$

- We can place the unique 7 at any of four positions

Numbers with exactly one 7 digit

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- Consider one of the cases

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- We can place the unique 7 at any of four positions
- This gives us 4 cases; if we compute the number of sequences in all four cases, we can get the answer by the rule of sum
- Consider one of the cases
- Each of other three digits can be picked out of 9 options! (digit 7 is forbidden)

Numbers with exactly one 7 digit

$$* \quad 7 \quad * \quad *$$

- Thus there are $9 \times 9 \times 9 = 729$ sequences in this case

Numbers with exactly one 7 digit

$$* \quad * \quad * \quad *$$

- Thus there are $9 \times 9 \times 9 = 729$ sequences in this case
- And in all other cases as well!

Numbers with exactly one 7 digit

$$* \quad * \quad * \quad *$$

- Thus there are $9\times9\times9=729$ sequences in this case
- And in all other cases as well!
- There are 4 cases, so there are $4\times729=2\,916$ four numbers below 10 000 with exactly one digit 7

Numbers with exactly one 7 digit

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- Thus there are $9 \times 9 \times 9 = 729$ sequences in this case
- And in all other cases as well!
- There are 4 cases, so there are $4 \times 729 = 2\,916$ four numbers below 10 000 with exactly one digit 7
- This is below 1/3, but above 1/4 of all four digit numbers

Numbers with exactly one 7 digit

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- Thus there are $9 \times 9 \times 9 = 729$ sequences in this case
- And in all other cases as well!
- There are 4 cases, so there are $4 \times 729 = 2\,916$ four numbers below 10 000 with exactly one digit 7
- This is below 1/3, but above 1/4 of all four digit numbers
- This is an estimation of the probability to get exactly one digit 7 if we pick a number below 10 000 “randomly”

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Tuples with Restrictions

Permutations

Permutations

- We have discussed how to count the number of tuples

Permutations

- We have discussed how to count the number of tuples
- Now we are ready to proceed to the second standard combinatorial setting: permutations

Permutations

Problem

Suppose we have a set of n symbols. How many different sequences of length k we can form out of these symbols if we are not allowed to use the same symbol twice?

- Tuples of length k without repetitions are called k-permutations

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- Observe that if $n < k$, then there are no k-permutations: there are simply not enough different letters

Permutations

Problem

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- Tuples of length k without repetitions are called k-permutations
- Observe that if $n < k$, then there are no k-permutations: there are simply not enough different letters
- So it is enough to solve the problem for the case $k \leq n$

Permutations

$$\begin{array}{ccccc} 1 & 2 & 3 & \ldots & k \\ * & * & * & \cdots & * \end{array}$$

- Let us apply rule of product

Permutations

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- How many choices there are for the second symbol?

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- Let us apply rule of product
- The first symbol can be picked in n ways
- How many choices there are for the second symbol?
- We can place anything there, except for the symbol on the first place

Permutations

$$\begin{array}{ccccc} 1 & 2 & 3 & \ldots & k \\ * & * & * & \cdots & * \\ n & n{-}1 & & & \end{array}$$

- Let us apply rule of product
- The first symbol can be picked in n ways
- How many choices there are for the second symbol?
- We can place anything there, except for the symbol on the first place
- Symbol on the first place might be arbitrary, but whatever it is there are $n{-}1$ choices for the second symbol!

Permutations

$$\begin{array}{ccccc} 1 & 2 & 3 & \ldots & k \\ * & * & * & \cdots & * \\ n & n{-}1 & & & \end{array}$$

- So we can pick the first and the second symbol in $n \times (n{-}1)$ ways

Permutations

$$\begin{array}{ccccc} 1 & 2 & 3 & \ldots & k \\ * & * & * & \cdots & * \\ n & n{-}1 & n{-}2 & & \end{array}$$

- So we can pick the first and the second symbol in $n{\times}(n{-}1)$ ways
- Now, the third symbol can be picked among $n{-}2$ options: all except the symbols in the first and the second position

Permutations

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- In the end for the last object we have $n-k+1$ options

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- Overall we have $n \times (n-1) \times \ldots \times (n-k+1)$ k-permutations

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- Convenient notation: $n! = 1 \times 2 \times \ldots \times n$; this number is called factorial of n

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- Convenient notation: $n! = 1 \times 2 \times \ldots \times n$; this number is called factorial of n
- In this notation the number of k-permutations of n symbols of length k looks nicer: it is $n!/(n-k)!$

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- What if $n-k=0$? Convention: $0!=1$

Permutations

Problem

In how many orders can we place n books on the shelf?

Permutations

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- Each book is a symbol

Permutations

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In how many orders can we place n books on the shelf?

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- By the previous result there are $n!$ of them
- This is the formula that was used in the discussion of magic square in course “What is a Proof?”

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- Still are not ready to count, say, what are the chances to get two aces in 6 card hand

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- Still are not ready to count, say, what are the chances to get two aces in 6 card hand
- More to come next week!