

Combinatorics 2 - More on Enumerative Combinatorics

Henry Liu, 29 November 2010

This set of notes acts as a sort of addendum to the previous set titled 'Combinatorics'. In the previous notes, many techniques on counting are covered. However, one method that is absent is the idea of *recurrence relations*. The idea is simple. If we have some parameter n , and a_n is the number of certain objects in relation to n , then we may be able to derive a recurrence relation for a_n . This will enable us to calculate a_n for small values of n .

Let us look at an example.

Example. *How many anagrams of the word 'orange' are there such that no letter is in its original position?*

Solution. This problem can be interpreted as follows. We would like to find the number of permutations of $\{1, 2, 3, 4, 5, 6\}$ with no fixed points. Recall that if S is a set and $f : S \rightarrow S$ is a permutation of S , then $i \in S$ is a *fixed point* of f if $f(i) = i$.

We consider the more general problem with n in place of 6. Let a_n be the number of permutations of $\{1, 2, \dots, n\}$ with no fixed points. We shall derive a recurrence relation for a_n . The number of permutations fixing at least one element is $n! - a_n$. Also, for $1 \leq k \leq n-1$, the number of permutations fixing exactly k elements is $\binom{n}{k} a_{n-k}$, since there are $\binom{n}{k}$ choices for the positions of the k fixed elements, and there are a_{n-k} ways to position the other $n-k$ elements so that there is no fixed point among them. There is also one permutation fixing every element (the identity permutation). It follows that $n! - a_n = 1 + \sum_{k=1}^{n-1} \binom{n}{k} a_{n-k}$, and hence the required recurrence relation is

$$a_n = n! - 1 - \sum_{k=1}^{n-1} \binom{n}{k} a_{n-k}.$$

In particular, we have

$$a_1 = 0,$$

$$a_2 = 2! - 1 - \binom{2}{1} a_1 = 2 - 1 - 0 = 1,$$

$$a_3 = 3! - 1 - \binom{3}{1} a_2 - \binom{3}{2} a_1 = 6 - 1 - 3 \cdot 1 - 0 = 2,$$

$$a_4 = 4! - 1 - \binom{4}{1} a_3 - \binom{4}{2} a_2 - \binom{4}{3} a_1 = 24 - 1 - 4 \cdot 2 - 6 \cdot 1 - 0 = 9,$$

$$\begin{aligned} a_5 &= 5! - 1 - \binom{5}{1} a_4 - \binom{5}{2} a_3 - \binom{5}{3} a_2 - \binom{5}{4} a_1 \\ &= 120 - 1 - 5 \cdot 9 - 10 \cdot 2 - 10 \cdot 1 - 0 = 44, \end{aligned}$$

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