

## Number Theory

**Factorial Factors:** The factorials:  $n! = 1 \cdot 2 \cdot \dots \cdot n = \prod_{k=1}^n k$ , integer  $n \geq 0$

We can find out factorial of an integer  $n$  using following recursive formula:

$$0! = 1$$

$$n! = n(n-1)! \quad , \quad \text{for } n > 0$$

Here are the first few values of the factorial function.

$n$	0	1	2	3	4	5	6	7	8	9	10
$n!$	0	1	2	6	24	120	720	5040	40320	362880	3628800

Because of it's exponential nature it's very difficult to find a closed form of factorial. To approximate  $n!$  more accurately for large  $n$  we can use Stirling's formula:

$$n! \approx \sqrt{2\pi n} \left(\frac{n}{e}\right)^n$$

We would like to determine, for any given prime  $p$ , the largest power of  $p$  that divides  $n!$ ; that is we want the exponent of  $p$  in  $n!$ 's unique factorization. We denote this number by  $e_p(n!)$ , and we start our investigations with the small case  $p = 2$  and  $n = 10$ .

	1	2	3	4	5	6	7	8	9	10	Powers of 2
Divisible by 2		X		X		X		X		X	$5 = \lfloor \frac{10}{2} \rfloor$
Divisible by 4				X				X			$2 = \lfloor \frac{10}{4} \rfloor$
Divisible by 8								X			$1 = \lfloor \frac{10}{8} \rfloor$
Powers of 2	0	1	0	2	0	1	0	3	0	1	8

For general  $n$  this method gives,  $e_2(n!) = \left\lfloor \frac{n}{2} \right\rfloor + \left\lfloor \frac{n}{4} \right\rfloor + \left\lfloor \frac{n}{8} \right\rfloor + \dots = \sum_{i=1}^{\infty} \left\lfloor \frac{n}{2^i} \right\rfloor$

This sum is actually finite, since the summand is zero when  $2^i > n$ . Therefore it has only  $\lfloor \lg n \rfloor$  nonzero terms, and it's computationally quite easy. For instance, if  $n = 100$ ,

$$e_2(100!) = \left\lfloor \frac{100}{2} \right\rfloor + \left\lfloor \frac{100}{4} \right\rfloor + \left\lfloor \frac{100}{8} \right\rfloor + \left\lfloor \frac{100}{16} \right\rfloor + \left\lfloor \frac{100}{32} \right\rfloor + \left\lfloor \frac{100}{64} \right\rfloor = 50 + 25 + 12 + 6 + 3 + 1 = 97$$

Let's look at the binary representation of all numbers to find out what's going on.

$$\begin{array}{l}
 100 = (1100100)_2 = 100 \\
 \left\lfloor \frac{100}{2} \right\rfloor = (110010)_2 = 50 \\
 \left\lfloor \frac{100}{4} \right\rfloor = (11001)_2 = 25 \\
 \left\lfloor \frac{100}{8} \right\rfloor = (1100)_2 = 12 \\
 \left\lfloor \frac{100}{16} \right\rfloor = (110)_2 = 6 \\
 \left\lfloor \frac{100}{32} \right\rfloor = (11)_2 = 3 \\
 \left\lfloor \frac{100}{64} \right\rfloor = (1)_2 = 1
 \end{array}$$

# First Course In Theory Of Numbers

**Rosina Ehmman**



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