

01204211 Discrete Mathematics

Lecture 7a: Binomial Coefficients (1)

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The binomial coefficients¹

There is a reason why the term $\binom{n}{k}$ is called the binomial coefficients. In this lecture, we will discuss

- ▶ the Pascal's triangle,
- ▶ the binomial theorem

¹This lecture mostly follows Chapter 3 of [LPV].

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The table

We shall use the fact that $\binom{n}{0} = 1$ and $\binom{n}{k} = \binom{n-1}{k-1} + \binom{n-1}{k}$ to fill in the following table.

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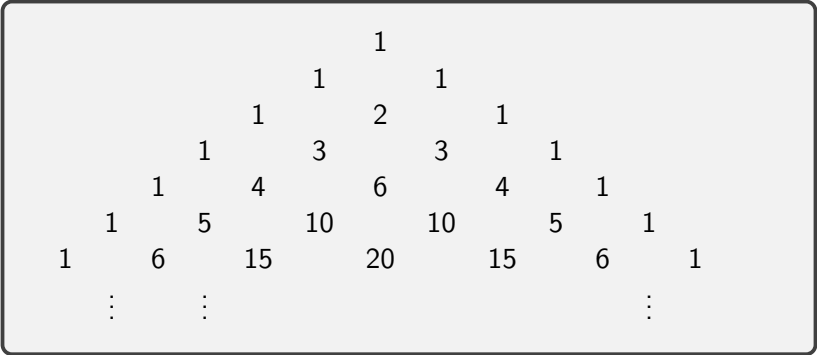
You can note that the table is left-right symmetric. This is true because of the fact that $\binom{n}{k} = \binom{n}{n-k}$.

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A diagram of Pascal's Triangle with 6 rows of numbers. The numbers are arranged in a triangular shape, with each row starting further to the left. The numbers are: Row 0: 1; Row 1: 1, 1; Row 2: 1, 2, 1; Row 3: 1, 3, 3, 1; Row 4: 1, 4, 6, 4, 1; Row 5: 1, 5, 10, 10, 5, 1. Below the first two and last two numbers of the bottom row are vertical ellipses.

				1					
			1		1				
		1		2		1			
	1		3		3		1		
1		4		6		4		1	
	1	5		10		10		5	1
	⋮		⋮					⋮	

The table and the binomial coefficients have many other interesting properties.

Polynomial expansions

Let's start by looking at polynomial of the form $(x + y)^n$. Let's start with small values of n :

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- ▶ $(x + y)^4 = x^4 + 4 \cdot x^3y + 6 \cdot x^2y^2 + 4 \cdot xy^3 + y^4.$

Let's focus on the coefficient of each term. You may notice that terms x^n and y^n always have 1 as their coefficients. *Why is that?*

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Let's focus on the coefficient of each term. You may notice that terms x^n and y^n always have 1 as their coefficients. *Why is that?* Let's look further at the coefficients of terms $x^{n-1}y$. Do you see any pattern in their coefficients? *Can you explain why?*

Another way to look at it

Let's take a look at $(x + y)^4$ again. It is

$$(x + y)(x + y)(x + y)(x + y).$$

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- ▶ How do we get x^3y in the expansion? Out of the 4 factors, you have to pick y in one of the factor (or you have to pick x in 3 of the factors). Thus there are $\binom{4}{3} = \binom{4}{1}$ ways to do so.

The binomial theorem

Theorem: If you expand $(x + y)^n$, the coefficient of the term $x^k y^{n-k}$ is $\binom{n}{k}$.

That is,

$$(x + y)^n = \sum_{k=0}^n \binom{n}{k} x^k y^{n-k} =$$
$$\binom{n}{n} x^n + \binom{n}{n-1} x^{n-1} y^1 + \binom{n}{n-2} x^{n-2} y^2 + \cdots + \binom{n}{1} x y^{n-1} + \binom{n}{0} y^n.$$

Additional applications of the binomial theorem

The binomial theorem can be used to prove various identities regarding the binomial coefficients. For example, if we let $x = 1$ and $y = 1$, we get that

$$(1 + 1)^n = 2^n = \binom{n}{0} + \binom{n}{1} + \cdots + \binom{n}{n-1} + \binom{n}{n}.$$

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Quick check. Can you prove that

$$\binom{n}{0} - \binom{n}{1} + \binom{n}{2} - \binom{n}{3} + \cdots = 0.$$

Note that this statements says that the number of odd subsets equals the number of even subsets.