Probability 1

A reminder of Mathematics

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(based on the notes of Prof. Davide La Vecchia)

Spring Semester 2021

Outline

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Powers and Logs

- $a^m \cdot a^n = a^{m+n}$
- $(a^n)^m = a^{m \cdot n}$
- The exponential (exp) and the natural logarithm (ln) are **reciprocal**

$$a = \ln(\exp(a)) = \ln(e^a)$$

- $\ln(a^n) = n \cdot \ln a$
- $\ln(a \cdot b) = \ln(a) + \ln(b)$;

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Derivatives

The **derivatives** will also play a pivotal role. For instance:

$$\frac{dx^n}{dx} = n \cdot x^{n-1}, \quad \frac{d \exp^x}{dx} = \exp^x, \quad \frac{d \ln(x)}{dx} = \frac{1}{x},$$

and we will make use of some fundamental rules, like e.g.

- Product rule:

$$\begin{aligned} \frac{d[f(x) \cdot g(x)]}{dx} &= \frac{df(x)}{dx} g(x) + \frac{dg(x)}{dx} f(x) \\ &= f'(x)g(x) + f(x)g'(x); \end{aligned}$$

- Chain rule:

$$\frac{df[g(x)]}{dx} = (f \circ g)'(x) = f'[g(x)] \cdot g'(x).$$

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Integrals

- $$\int_a^b [c \cdot f(x) + d \cdot g(x)]\, dx = c \cdot \int_a^b f(x)dx + d \cdot \int_a^b g(x)dx;$$
- If $f(x) \geq 0, \forall x \in \mathbb{R}$, then
$$\int_{\mathbb{R}} f(x)dx \geq 0.$$
- For a continuous function $f(x)$, the indefinite integral is
$$\int f(x)dx = F(x) + \text{const}$$
while the definite integral is
$$F(b) - F(a) = \int_a^b f(x)dx, \quad b \geq a.$$

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Sums

Besides integrals we are also going to use **sums**:

- $$\sum_{i=1}^{n} X_i = X_1 + X_2 + ... + X_n,$$
- For every $\alpha_i \in \mathbb{R}$,
$$\sum_{i=1}^{n} \alpha_i X_i = \alpha_1 X_1 + \alpha_2 X_2 + ... + \alpha_n X_n;$$
- Double sum: a sum with two indices. For instance,

$$\begin{aligned}
\sum_{i=1}^{n}\sum_{j=1}^{m} x_i y_j &= x_1 y_1 + x_1 y_2 + ... + x_2 y_1 + x_2 y_2 + ... \\
&= \left(\sum_{i=1}^{n} x_i\right) y_1 + \left(\sum_{i=1}^{n} x_i\right) y_2 + ... + \left(\sum_{i=1}^{n} x_i\right) y_m \\
&= \sum_{i=1}^{n} x_i \sum_{j=1}^{m} y_j.
\end{aligned}$$

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Combinatorial Formulas

Finally, we also rely on some **combinatorial formulas**. Specifically,

- Factorial

$$n! = n \cdot (n-1) \cdot (n-2) \cdot ... \cdot 1;$$

  where $0! = 1$, by definition;

- Binomial coefficient, for $n \geq k$

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} = C_n^k$$

Some mathematical formulas (cont'd)

Example

Let us compute:

- for $n = 2$ we have

$$\begin{aligned}(x+y)^2 &= \binom{2}{0}x^2y^0 + \binom{2}{1}x^1y^1 + \binom{2}{2}x^0y^2 \\ &= x^2 + 2xy + y^2\end{aligned}$$

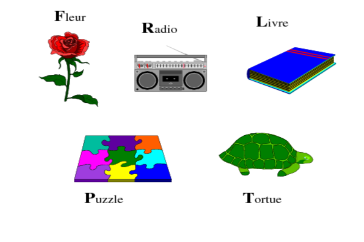
- for $n = 3$ we have

$$\begin{aligned}(x+y)^3 &= \binom{3}{0}x^3y^0 + \binom{3}{1}x^2y^1 + \cdots + \binom{3}{2}x^1y^2 + \binom{3}{3}x^0y^3 \\ &= y^3 + 3xy^2 + 3x^2y + x^3\end{aligned}$$

Some mathematical formulas (cont'd)

Example

How many ways can we select 3 presents among the 5 available presents (see figure below)? Assume the order does not matter!



(F, R, L)	(F, R, P)	(F, R, T)	(F, L, P)
(F, L, T)	(F, P, T)	(R, L, P)	(R, L, T)
(R, P, T)	(L, P, T)		

Total: $N = 10$

Some mathematical formulas (cont'd)

Example (cont'd by Explanation)

1. 5! gives you the total # of possible choices when you can select 5 presents (so-called "permutations", see next slides);
2. If you're going to select 3 presents from the list, then you have $(5-3)$ presents that you're not going to select. Therefore, you need to divide out the $(5-3)!$ different ways you can order the presents you are not going to select from the 5! possible choices of all presents. In other words you have $5!/(5-3)!$ ways to select and order the 3 presents;
3. Finally, remember you don't care about the order in which you select the 3 presents. So, in how many ways can you select 3 presents from the n available ones? The problem is the same as in [1] above except that now you don't care about the order of the 3 presents, and therefore you also need to divide out the 3! different ways you can order the presents.

Some mathematical formulas (cont'd)

Example (cont'd by Explanation)

... so, in formula, you have

$$\frac{5!/(5-3)!}{3!}$$

ways to select the 3 presents:

$$\frac{5!/(5-3)!}{3!} = \frac{5!}{3!2!} = \binom{5}{3} = C_5^3.$$

This gives you the total # of possible ways to select the 3 presents when the order does not matter.

As a recommendation, redo the exercise assuming you can select 2 presents from 3 available presents (like for instance F,L,R)...

Some mathematical formulas (cont'd)

Remark

Permutations: *How many different ways can we combine n objects?*

- *In the 1st place: n possibilities*
- *In the 2nd place:* $(n-1)$ *possibilities*
- *...*
- *Finally,* 1 *possibility*

Thus, in total we have $n \cdot (n-1) \cdot (n-2) \cdot \ldots \cdot 1 = n!$

Example

How many ways can Aline, Brigitte and Carmen seat on 3 spots, from left to right? Possible outcomes:

$$(A, B, C), (A, C, B), (B, A, C), (B, C, A), (C, A, B), (C, B, A)$$

Total # of permutations: $N = 6 = 3 \cdot 2 \cdot 1 = 3!$

Some mathematical formulas (cont'd)

Remark (cont'd)

Combinations: *How many ways can we select k objects among n? To answer this question, we proceed as follows:*

1. *How many ways can we combine k objects among n?*
   - *In the 1st place: n*
   - *In the 2nd place: $(n-1)$*
   - *....*
   - *In the k-th place: $(n-k+1)$*
2. *We have $k!$ ways to permute the k objects that we selected*
3. *The number of possibilities (without considering the order) is:*

$$\frac{n!/(n-k)!}{k!} = \frac{n!}{k!(n-k)!} = C_n^k$$

Some mathematical formulas (cont'd)

Remark (cont'd)

For the Problem Set 2, you will have to make use of C_n^k in Ex2-Ex3-Ex5. Indeed, to compute the probability for an event E, will have to make use of the formula

$$P(E) = \frac{\text{number of cases in } E}{\text{number of possible cases}}. \tag{1}$$

This is a first intuitive definition of probability, which we will justify in the next lecture; see Lecture 1, slide 28. For the time being, let us say that the combinatorial calculus will be needed to express both the quantities (numerator and denominator) in (1).

Outline

Limits

- The limit of a finite sum is an infinite series:

$$\lim_{n \to \infty} \sum_{i=1}^{n} x_i = \sum_{i=1}^{\infty} x_i$$

- The exp() function, characterised as a limit:

$$e^x = \lim_{n \to \infty} \left(1 + \frac{x}{n}\right)^n$$

- The Limit of a Negative Exponential function :

$$\text{for } \alpha > 0, \quad \lim_{x \to \infty} \alpha e^{-\alpha x} = 0$$

- The Exponential function, characterised as an infinite series

$$e^x = \sum_{i=0}^{\infty} \frac{x^i}{i!} = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \cdots$$