

Probability & Statistics 1

A-Level Mathematics

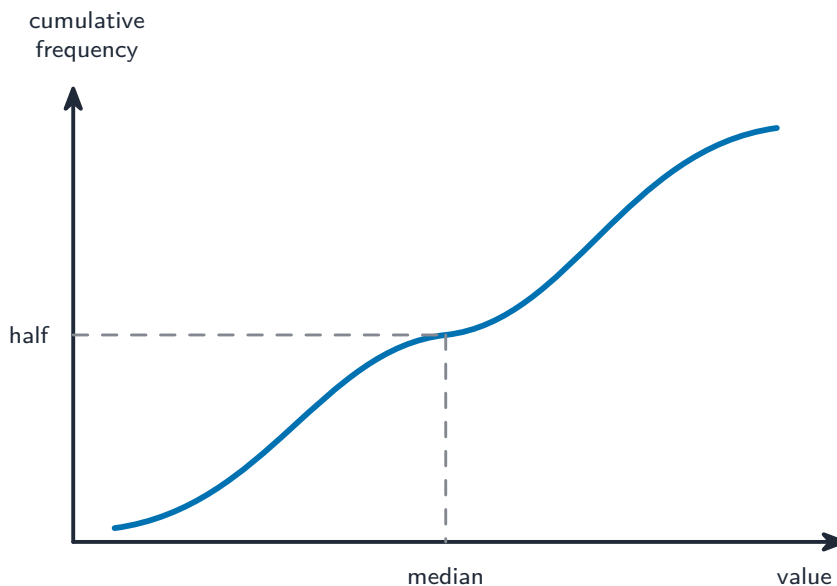
This handout covers Topic 5: **Probability & Statistics**

1. It is about describing data, counting choices, and working out the chance of events.

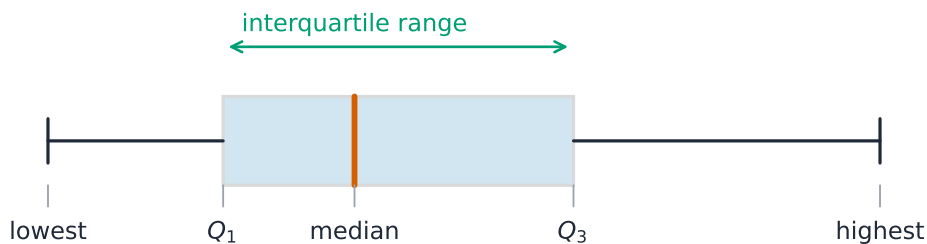
Representation of data

Choose a diagram that suits the data. You should be able to draw and read:

- a **stem-and-leaf diagram** (keeps the original values and shows the shape);
two data sets are compared with a **back-to-back** version – a shared central stem, one set's leaves increasing to the left and the other's to the right, so you can compare their medians and spreads at a glance;
- a **box-and-whisker plot** (shows the lowest value, the three quartiles, and the highest value);
- a **histogram** (for grouped data, where the **area** of each bar shows the frequency);
- a **cumulative frequency** graph (running totals, used to estimate the median and quartiles).



A cumulative frequency curve is S-shaped; read the median across from half the total frequency, and the quartiles from one and three quarters



box: Q_1 – Q_3 · median line · whiskers: min/max

The box spans the quartiles Q_1 to Q_3 ; the whiskers reach the lowest and highest values.

■ Averages and spread

A **measure of central tendency** is a single “middle” value:

- the **mean** $\bar{x} = \frac{\sum x}{n}$ (the average);
- the **median** (the middle value when the data is in order);
- the **mode** (the most common value).

A measure of **variation** shows how spread out the data is:

- the **range (of data)** (highest – lowest);
- the **interquartile range** (upper quartile – lower quartile);
- the **standard deviation** $\sigma = \sqrt{\frac{\sum x^2}{n} - \bar{x}^2}$.

You often work from the totals $\sum x$ and $\sum x^2$. The square of the standard deviation is the **variance**.

Worked example. For 10 values, $\sum x = 50$ and $\sum x^2 = 300$. Find the mean and standard deviation.

$$\bar{x} = \frac{50}{10} = 5, \quad \sigma = \sqrt{\frac{300}{10} - 5^2} = \sqrt{30 - 25} = \sqrt{5} = 2.24.$$

Coding makes big numbers easier. Replace each value by $t = x - a$ for a convenient **assumed mean** a . Then $\bar{x} = a + \bar{t}$, while the standard deviation is **unchanged** (shifting every value does not spread the data). So from the coded totals $\sum(x - a)$ and $\sum(x - a)^2$ you get $\bar{x}$ and σ directly, and two data sets can be compared through their coded totals.

Permutations and combinations

A **permutation** is an arrangement where order matters; a **combination** is a selection where order does not matter. The numbers are

$${}^nP_r = \frac{n!}{(n-r)!}, \quad {}^nC_r = \binom{n}{r} = \frac{n!}{r!(n-r)!}.$$

To arrange objects in a line when some are repeated, divide by the factorial of each repeat count.

permutation (order matters)

AB

BA

combination (order does not)

$\{A, B\}$

Order matters for a permutation, but not for a combination

Worked example. How many different arrangements are there of the letters of the word NEEDLESS?

There are 8 letters, with E repeated 3 times and S repeated 2 times:

$$\frac{8!}{3!2!} = \frac{40320}{6 \times 2} = 3360.$$

Arranging 3 of 4 objects (${}^4P_3$)

$$\boxed{4} \times \boxed{3} \times \boxed{2} = 24$$

1st pick 2nd pick 3rd pick

Choosing 3 of 4 (order ignored): ${}^4C_3 = \frac{{}^4P_3}{3!} = 4$

$${}^nP_r = n! / (n-r)! \quad \cdot \quad {}^nC_r = {}^nP_r / r!$$

$$nPr = n! / (n-r)!; \quad nCr = nPr / r!$$

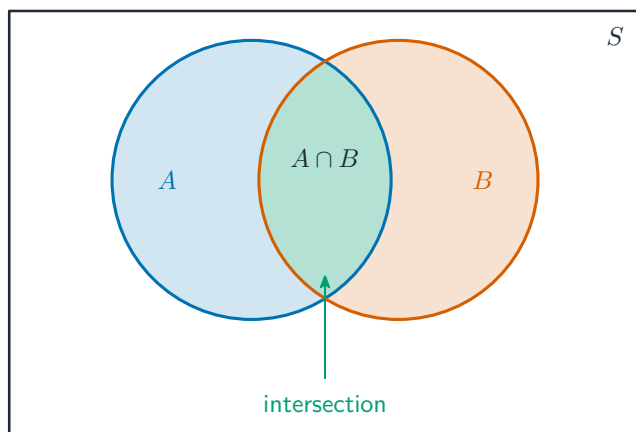
Probability



Dice: a familiar starting point for probability.

Find a probability by counting equally likely outcomes, or by using permutations and combinations. Combine probabilities with these rules:

- **addition** for "or": $P(A \cup B) = P(A) + P(B) - P(A \cap B)$;
- **multiplication** for "and" when events are independent: $P(A \cap B) = P(A)P(B)$.



The overlap of the two circles is $A \cap B$; the addition rule subtracts it once so it is not counted twice.

Two events are **mutually exclusive events** if they cannot both happen, and **independent events** if one happening does not change the chance of the other. To test independence, check whether $P(A \cap B) = P(A) \times P(B)$. A **conditional probability** is the chance of A given that B has happened:

$$P(A | B) = \frac{P(A \cap B)}{P(B)}.$$

Worked example. Events have $P(A) = 0.5$, $P(B) = 0.4$ and $P(A \cap B) = 0.2$. Are A and B independent?

Test: $P(A) \times P(B) = 0.5 \times 0.4 = 0.2 = P(A \cap B)$. The values are equal, so A and B are independent.

Discrete random variables

A **discrete random variable** X takes separate values, each with a probability. List them in a **probability distribution table**; the probabilities must add to 1. Then the **expectation** (mean) and **variance** are

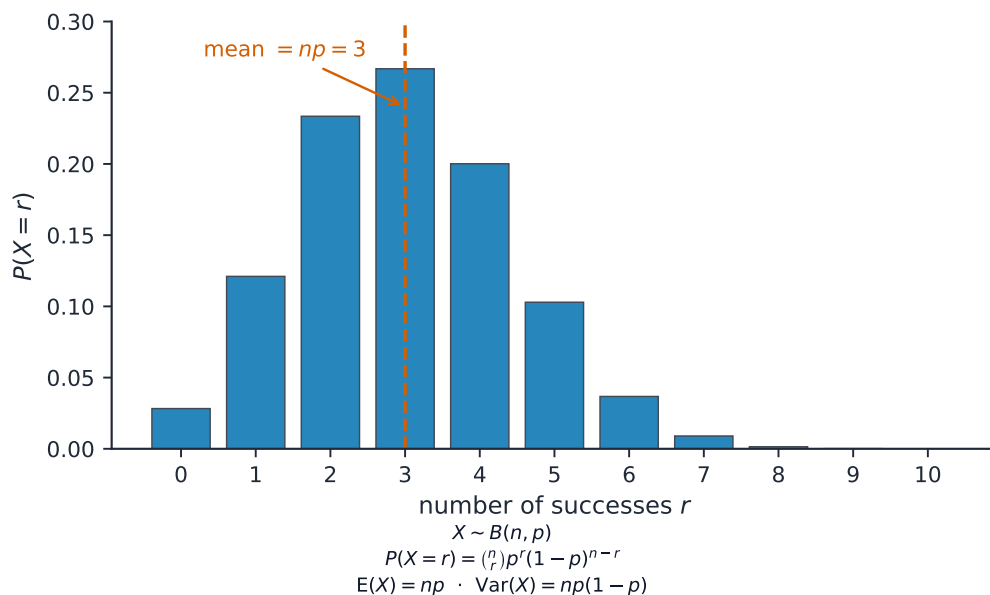
$$E(X) = \sum x P(X = x), \quad \text{Var}(X) = \sum x^2 P(X = x) - (E(X))^2.$$

Two special models:

- the **binomial distribution** $X \sim B(n, p)$, for the number of successes in n independent trials: $P(X = r) = \binom{n}{r} p^r (1 - p)^{n-r}$, with $E(X) = np$ and $\text{Var}(X) = np(1 - p)$;
- the **geometric distribution**, for the trial on which the first success happens: $P(X = r) = (1 - p)^{r-1} p$, with $E(X) = \frac{1}{p}$.

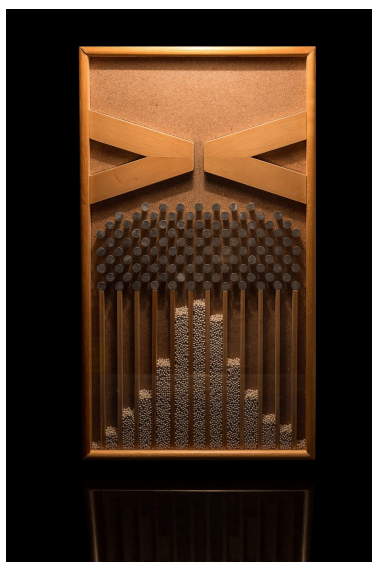
Worked example. $X \sim B(10, 0.3)$. Find $P(X = 2)$ and $E(X)$.

$$P(X = 2) = \binom{10}{2} (0.3)^2 (0.7)^8 = 45 \times 0.09 \times 0.05765 = 0.233, \quad E(X) = 10 \times 0.3 = 3.$$



The distribution $B(10, 0.3)$: each bar is $P(X = r)$, clustered around the mean $np = 3$.

The normal distribution

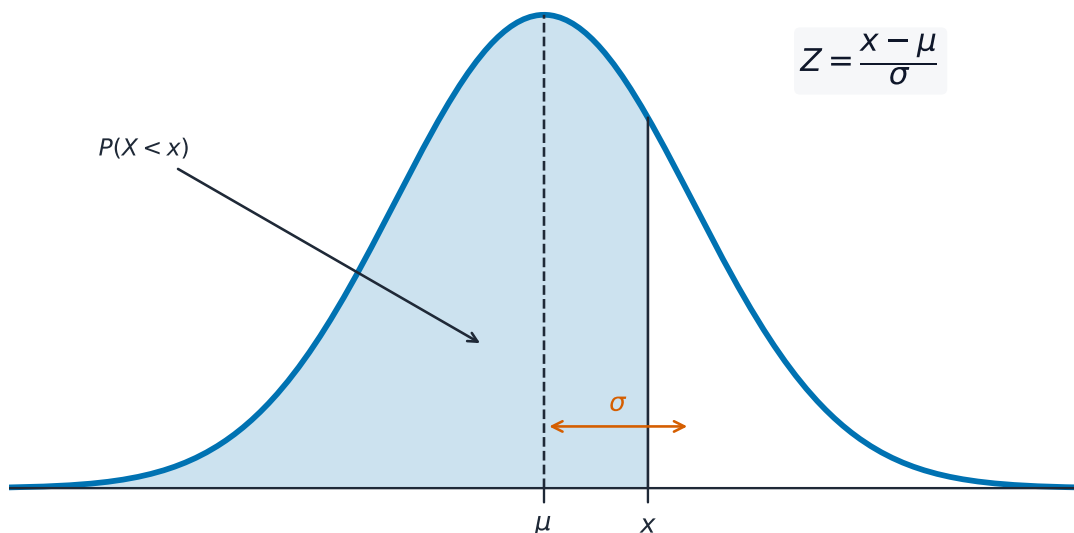


A Galton board: balls falling through pins pile up into the bell-shaped normal distribution.

The **normal distribution** models a **continuous random variable** with a symmetric bell shape. Write $X \sim N(\mu, \sigma^2)$, where μ is the mean and σ is the standard deviation. To use the tables, by **standardisation** convert to the variable $Z \sim N(0, 1)$:

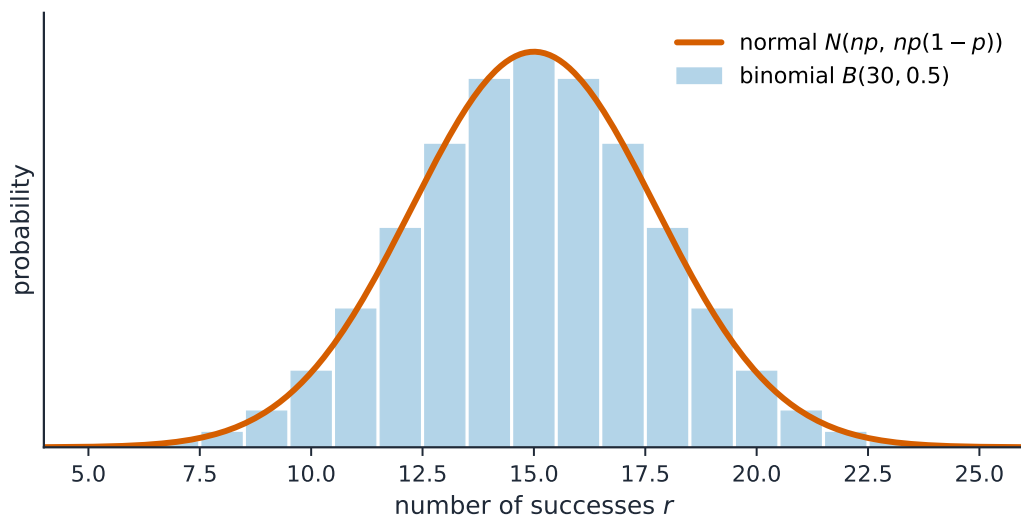
$$Z = \frac{X - \mu}{\sigma}.$$

Then $P(X < x) = P\left(Z < \frac{x - \mu}{\sigma}\right)$, which you read from the normal table Φ .



A normal probability is an area under the bell curve; standardizing rescales it to $Z \sim N(0, 1)$.

The normal distribution is also a good **approximation** to the binomial when n is large. Because you replace a discrete variable by a continuous one, apply a **continuity correction** (adjust by 0.5).



approx $N(np, np(1-p))$ when n large · continuity correction

When n is large the binomial bars follow a normal curve of the same mean and variance.

Worked example. Bags of rice have mass $X \sim N(\mu, 0.14^2)$. Given that $P(X < 1.48) = 0.22$, find μ .

From the table, $P(Z < z) = 0.22$ gives $z = -0.772$. So

$$\frac{1.48 - \mu}{0.14} = -0.772 \Rightarrow \mu = 1.48 + 0.772 \times 0.14 = 1.59 \text{ kg (3 s.f.)}.$$

Exam tips

- Decide whether order matters: **permutations** (${}^nP_r$) when it does, **combinations** (${}^nC_r$) when it does not.
- For a **discrete random variable**, check the probabilities sum to 1 and use $E(X) = \sum x P(X = x)$.
- For the **normal distribution**, standardise with $z = (x - \mu)/\sigma$, **sketch and shade**, then read the table.
- Apply a **continuity correction** when approximating a discrete variable by the normal.