Introduction to Data Science - 1MS041

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- The subsets of Ω are called **events** events.
- Given an outcome $\omega \in \Omega$ we say that the event $E \subset \Omega$ **occured** if $\omega \in E$.

Some standard examples of experiments are the following:

1. $\Omega = \{$Defective, Non-defective$\}$ if our experiment is to inspect a light bulb.

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3. If our experiment is to roll a die then there are six outcomes corresponding to the number that shows on the top. For this experiment, $\Omega = \{1, 2, 3, 4, 5, 6\}$.
   Some examples of events are the set of odd numbered outcomes $A = \{1, 3, 5\}$, and the set of even numbered outcomes $B = \{2, 4, 6\}$.
   The simple events of Ω are $\{1\}, \{2\}, \{3\}, \{4\}, \{5\}$, and $\{6\}$.

The long-term relative frequency (LTRF) idea

Suppose we are interested in the fairness of a coin, i.e. if landing Heads has the same “probability” as landing Tails.

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- We expect that if a coin is fair, then roughly half the times we should see Head and the other half Tails. Thus we expect that $N(\{\mathtt{H}\},\mathtt{n})$ should as n is very large, be close to 0.5.
- If it is not, then intuitively we would say that it is not a fair coin.

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3. **Independence**: The outcome of any individual coin-toss does not affect that of another.

Formalisation of these concepts

We saw that if we have events, we can take their union and it is still fine. We have the following rules

Definition

Let Ω be a set: We say that a collection of subsets of Ω, $\mathcal{F}$ is a **sigma-algebra**/ **sigma-field**/ σ-**algebra** if it satisfies the following properties:

1. $\mathcal{F}$ contains Ω, i.e. $\Omega \in \mathcal{F}$.
2. The collection $\mathcal{F}$ is closed under complementation
$$A \in \mathcal{F} \implies A^C \in \mathcal{F}.$$
3. The collection $\mathcal{F}$ is closed under countable unions
$$A_1, A_2, \ldots \in \mathcal{F} \implies \bigcup_i A_i \in \mathcal{F}.$$

Probability

Definition

Let us have an experiment with sample space Ω. Let $\mathcal{F}$ denote σ-algebra. A **probability measure** is a function $\mathbb{P} : \mathcal{F} \to [0, 1]$ satisfying the following conditions:

1. The 'Something Happens' axiom holds, i.e. $\mathbb{P}(\Omega) = 1$.
2. The 'Addition Rule' axiom holds, i.e. for $A, B \in \mathcal{F}$:

$$A \cap B = \emptyset \quad \Longrightarrow \quad \mathbb{P}(A \cup B) = \mathbb{P}(A) + \mathbb{P}(B)\ .$$

We call elements of $\mathcal{F}$, events and we will call $(\Omega, \mathcal{F}, \mathbb{P})$ a **probability triple**.

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Now consider the following problem:

Example

Suppose that you toss a coin at the same time that your friend tosses another coin in the building next doors. You cannot see your friends coin, but it got flipped nontheless. The sample space is $\Omega = \{\mathtt{HH}, \mathtt{TH}, \mathtt{HT}, \mathtt{TT}\}$, but which events can we observe has happened or not?

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Note: we could in this case completely ignore what our friend is up to and re-define $\Omega = \{\mathtt{H}, \mathtt{T}\}$.

Conditional probability

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Consider a probability triple $(\Omega, \mathcal{F}, \mathbb{P})$. Let $A, B \in \mathcal{F}$ (events), such that $\mathbb{P}(A) \neq 0$. Then, we define the **conditional probability** of B given A by,

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

Model problem: SMS spam filtering

Recall the SMS spam filter problem, i.e. you would like to filter your SMS (or similar instant messaging) texts as "Spam" or not.
We asked the following questions

1. What is the probability that an incoming text is spam?
2. Given that you see the word "free" in the text, what is now the probability that it is spam?

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$$N(A, 1) = 1.$$

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4. This becomes for our example $N(\{''free, spam''\}, 1)/N(\{''free, spam'', ''free, not\ spam''\}, 1) = 0$.