Probability

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Table of Contents

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A lot of games have an element of chance. For example, knowing the probabilities of landing on different spaces in Monopoly will tell you which properties will make the most money.

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Introduction

A quick overview of sets

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- A set with k elements has 2^k subsets.
- The cardinality of a set A, written as $n(A)$ is the number of elements in A. For example, $n(A) = 3$.

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Event An event is a subset of the sample space. We will call this set E.

Table of Contents

Basics
Equal probability

If every possible outcome of an experiment has the same chance of occurring, then we can easily calculate the probability of an event (subset of the sample space) occurring.

The probability function, $p(E)$ gives us the probability of an event occurring.

$$p(E) = \frac{n(E)}{n(S)}$$

Probability is usually written as a number in the range $[0, 1]$.

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Example

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Definition

$$n! = 1 \times 2 \times \cdots \times n - 1 \times n$$

$0! = 1$, because otherwise you would break a lot of math.

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Example

$$5! = 1 \times 2 \times 3 \times 4 \times 5 = 120$$

Table of Contents

The student body of Mackenzie is voting on their 3 favourite parts of math at the school.

They have 5 options: calculus, vectors, $\LaTeX$, Moodle, and math club.

Everyone votes for their favourite part, second favourite part, and third favourite part of math at the school.

These are three separate votes, taken one after another.

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Math Elections

Ordered number of options

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1. There are 5 choices for the first spot.
2. Whatever wins first cannot place second, so we are left with 4 choices for second place.
3. Whatever options placed first or second cannot place third, so we are left with 3 options for third place.

This means there are $5 \times 4 \times 3 = 60$ possible combinations.

We can develop the formula for this with factorials:

$$5 \times 4 \times 3 = 5 \times 4 \times 3 \times \frac{2!}{2!} = \frac{5 \times 4 \times 3 \times 2!}{2!} = \frac{5!}{2!} = 60$$

If we are only interested in what people's favourite parts of math at the school are, and not the ordering, we can can instead calculate how many combinations of 3 elements there are, with no regard to the order.

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Take for example, these 6 outcomes:

First	**Second**	**Third**
Math club	Moodle	$\LaTeX$
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If we do not care about ordering, these 6 options become 1 option.
This means that there are $\frac{60}{3!} = 10$ options for favourite parts of math at Mackenzie when we ignore the ordering.

Table of Contents

We can calculate the number of ordered subsets of size k from a set of cardinality n with the following formula:

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These ordered sets are called permutations of n things taken k at a time.

Generalizations
Number of unordered options

We can calculate the number of unordered subsets of size k from a set of cardinality n with the following formula:

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This formula is also written as:

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

And is read as "n choose k".

Table of Contents

Yahtzee

Probability of rolling a Yahtzee

Problem

Yahtzee, a game popular with my senior relatives, involves rolling 5 dice. In this game, you get a Yahtzee, which is worth a lot of points, if you roll 5 of a kind.

All of the dice have six sides.

Question

What is the probability of rolling a Yahtzee?

First, we will calculate the number of combinations of dice that can be rolled:

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We know that the set of Yahtzee rolls is:

$$Y = \{(1,1,1,1,1),(2,2,2,2,2),(3,3,3,3,3),$$
$$(4,4,4,4,4),(5,5,5,5,5),(6,6,6,6,6)\}$$

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$$p(Y) = \frac{n(Y)}{n(R)} = \frac{6}{7776} = \frac{1}{1296} \doteq 0.00077 = 0.077\%$$

$\therefore$ the chance of rolling a Yahtzee is about 0.077%.

Question 2

How likely is it to roll four of a kind when rolling 5 dice?

We are looking at the change of rolling exactly four of a kind. 5 of a kind does not count.

Let's consider the case of rolling quadruple ones.

Yahtzee
Quadruples solution

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The chance this happening is with four dice is:

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But we have five dice, so we must multiply this by the chance of rolling something other than one, and we must multiply by the number of different ways to arrange 4 ones and 1 other die:

$$\left(\frac{1}{6}\right)^4 \times \frac{5}{6} \times 5 = \frac{25}{7776}$$

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The chance of rolling quadruple ones is the same as rolling quadruple twos, threes, etc.. So:

$$\left(\frac{1}{6}\right)^4 \times \frac{5}{6} \times 5 \times 6 = \frac{25}{1296} \doteq 0.0193$$

Question 3

How likely is it to roll three of a kind when rolling 5 dice?

We are looking at the change of rolling exactly three of a kind. 4 or 5 of a kind do not count. We will count a 2 of a kind and a 3 of a kind as a triple.

This is similar to the last problem, so we will some steps for the sake of brevity.

Yahtzee
Triples solution setup

This is similar to the last problem, so we will some steps for the sake of brevity.

The main difference is that we don't know how many ways we can order three of a kind with two other numbers. With 4 of a kind, this was trivial. It is not longer trivial with three of a kind.

$$\left(\frac{1}{6}\right)^3 \times \left(\frac{5}{6}\right)^2 \times c \times 6$$

This is essentially the same formula we used last time, but replacing the number of combinations with the variable c. We must use reasoning to figure out c.

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$$\left(\frac{1}{6}\right)^3 \times \left(\frac{5}{6}\right)^2 \times 10 \times 6 = \frac{125}{648} \doteq 0.193$$