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A Remarkable Story of Survival: Understanding Rare Events Through Mathematics

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Abstract. This article presents a remarkable real-life story of survival and uses it as a foundation to explore important ideas in probability theory. Throughout the article, standard mathematical notation is used, with variables consistently typeset in italic form and inline expressions clearly distinguished for readability. Through a careful blend of narrative, intuition, and mathematical reasoning, we examine how rare events are modeled and understood. The article is designed for undergraduate students and aims to demonstrate how abstract mathematical ideas connect meaningfully with real-world phenomena.

Keywords. probability; rare events; conditional probability; extreme events; mathematical modeling.

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1. Introduction

Mathematics is often viewed as a collection of formulas, symbols, and computations. However, one of its most powerful roles is to help us understand real-world events, especially those that seem unlikely or surprising.

In everyday life, we frequently encounter events that appear almost impossible. Yet mathematics teaches us an important lesson: events that seem impossible are often merely extremely unlikely.

In this article, we explore the mathematics of rare events using a powerful real-life story. Our goal is to bridge intuition and formal reasoning, showing how probability theory helps us understand extraordinary occurrences.

2. A Story of Extraordinary Survival

In August 1945, during World War II, two atomic bombs were dropped on Japan, one on Hiroshima and another on Nagasaki. Among the survivors was Tsutomu Yamaguchi, who survived both bombings. He was present in Hiroshima during the first explosion. Despite being injured, he managed to travel back to Nagasaki, his hometown. Remarkably, just three days later, he experienced the second bombing and survived again.

At first glance, this event appears almost impossible. How can a single individual survive two such catastrophic events? This question leads naturally to mathematics.

Mathematics does not remove the human meaning of such a story. Instead, it gives us a way to think carefully about uncertainty, chance, and rare events. It helps us distinguish between what is impossible and what is extraordinarily unlikely.

3. What Does "Rare" Mean in Mathematics?

In mathematics, an event is called rare if it has a very small probability of occurring. However, it is crucial to understand that a rare event is not the same as an impossible event.

For example, winning a lottery is rare. Being struck by lightning is rare. Meeting someone with exactly the same birthday in a small group may seem surprising, but it is not impossible. Probability theory gives us a precise language for describing such events.

In finite or countable discrete probability models, events with probability zero are impossible. However, in continuous probability models, an event may have probability zero and still remain theoretically possible.

For example, if one chooses a real number uniformly at random from the interval $[0, 1]$, the probability of selecting exactly the number $1/2$ is zero. Nevertheless, selecting $1/2$ is still possible.

This distinction is important because probability zero does not always mean impossibility; its interpretation depends on the mathematical model being used. On the other hand, if an event has probability

$$0.0001,$$

then it is very unlikely, but it can still happen.

4. Basic Probability: A Careful Explanation

Let us define two events:

$$A = \text{survival in the first event},$$

and

$$B = \text{survival in the second event}.$$

The notation

$$A \cap B$$

means that both events occur. In this context, it means survival in both events.

4.1. Independent Events

If two events are independent, then the occurrence of one event does not affect the probability of the other. In that case,

$$P(A \cap B) = P(A)P(B).$$

Example 4.2. Suppose

$$P(A) = 0.05$$

and

$$P(B) = 0.02.$$

Then

$$P(A \cap B) = 0.05 \times 0.02 = 0.001.$$

This means the probability is

$$0.001 = 0.1\%.$$

Equivalently, this is about 1 in 1000.

This example illustrates an important point: when small probabilities are multiplied, the result becomes even smaller.

5. Conditional Probability

In real life, events are rarely completely independent. The probability of surviving a second event may depend on many factors related to the first event. For example, a person may be injured, displaced, more cautious, or located in a different place after the first event.

This leads to the idea of conditional probability. The probability of event B, given that event A has already occurred, is written as

$$P(B|A).$$

The multiplication rule becomes

$$P(A \cap B) = P(A)P(B|A).$$

Example 5.1. Suppose

$$P(A) = 0.01$$

and

$$P(B|A) = 0.02.$$

Then

$$P(A \cap B) = 0.01 \times 0.02 = 0.0002.$$

This is

$$0.0002 = 0.02\%.$$

Equivalently, this is about 1 in 5000.

Thus, although the event is extremely rare, it is not mathematically impossible.

6. Why Rare Events Still Occur

Students often ask: if the probability is so small, why do rare events happen at all?

The answer is that rare events become more visible when there are many opportunities for them to occur.

Suppose an event has probability

$$\frac{1}{1,000,000}.$$

If there is only one trial, the event is very unlikely. But if there are 10,000,000 trials, then the expected number of occurrences is

$$10,000,000 \times \frac{1}{1,000,000} = 10.$$

So, even though the probability is tiny for one trial, we may still expect the event to occur several times when the number of trials is large.

Remark 6.1. For events with positive probability, mutually exclusive events cannot be independent.

Indeed, if A and B are mutually exclusive, then

$$P(A \cap B) = 0.$$

However, if they were independent, we would have

$$P(A \cap B) = P(A)P(B).$$

Thus,

$$P(A)P(B) = 0,$$

which implies that at least one of the events must have probability zero. Therefore, two events with positive probability cannot be both mutually exclusive and independent.

6.2. The Law of Large Numbers and Rare Events

One of the most important principles in probability theory is the Law of Large Numbers. Roughly speaking, it states that when an experiment is repeated many times, the observed average behavior tends to approach the theoretical probability.

This principle helps explain why rare events still appear in large populations. Even if an event is extremely unlikely for a single individual, a sufficiently large number of trials can produce multiple occurrences.

For example, suppose an event has probability

$$\frac{1}{10,000,000}.$$

For one trial, the event is extraordinarily unlikely. However, if billions of trials occur worldwide over long periods of time, then observing the event somewhere becomes much more plausible.

Thus, probability theory teaches an important distinction between:

- an event being unlikely for one individual, and
- the event being expected to occur somewhere in a very large population.

7. A Familiar Example: The Lottery

The lottery gives a simple example. For one individual, the probability of winning may be extremely small. However, if millions of people buy tickets, then it is not surprising that someone wins.

This teaches an important mathematical lesson:

> An event that is rare for one individual may become observable in a sufficiently large population.

Many surprising events in life can be understood in this way. When a population is large, coincidences and rare outcomes become much more likely to be observed.

8. Extreme Events and Mathematical Modeling

In probability and statistics, extreme events are events that lie far outside ordinary experience. Examples include large earthquakes, financial crashes, major floods, or unusual survival stories.

Mathematically, one often studies probabilities of the form

$$P(X > x),$$

where X is a random variable and x is a large threshold.

For example, X might represent rainfall in a region, the size of an earthquake, or the loss in a financial market. The expression $P(X > x)$ asks: what is the probability that the outcome exceeds a large value?

In more advanced studies, such extreme behavior is often modeled using specific families of distributions developed in *extreme value theory*. Two important examples are the *Generalized Extreme Value (GEV)* distribution and the *Generalized Pareto Distribution (GPD)*, which provide systematic ways to approximate the probabilities of rare and extreme outcomes. Mentioning these models gives a natural direction for further study for interested readers.

Extreme value theory plays an increasingly important role in modern science and engineering. It is widely used in flood prediction, climate modeling, insurance mathematics, structural engineering, finance, telecommunications, and risk management.

One of the central goals is to estimate the probability of catastrophic or unusually large outcomes that may occur very infrequently but have major consequences.

The mathematical study of such events helps governments, engineers, and scientists prepare for uncertainty and assess long-term risk.

This type of thinking is important in engineering, climate science, finance, public health, and risk analysis.

9. Simulation and Computation

Sometimes exact probability calculations are difficult. In such cases, mathematicians and scientists often use simulation.

A common method is called the Monte Carlo method. The basic idea is to repeat an experiment many times and count how often the event occurs.

If a rare event occurs k times in N trials, then we estimate its probability by

$$\widehat{P} = \frac{k}{N}.$$

Example 9.1. Suppose we run 10,000 simulated trials and observe the rare event 2 times. Then

$$\widehat{P} = \frac{2}{10000} = 0.0002.$$

This estimate agrees with the earlier value of 1 in 5000.

Simulation is especially useful when mathematical systems become too complicated for exact analytical formulas.

10. Common Misconceptions

There are several common misunderstandings about rare events.

First, rare does not mean impossible. A probability may be very small and still correspond to an event that can occur.

Second, if something happened, it does not mean it was likely. Unlikely events do happen.

Third, events are not always independent. In real life, one event may strongly affect the probability of another event.

These points are essential for undergraduate students studying probability, statistics, data science, or mathematical modeling.

11. Exercises for Students

Exercise 11.1. If $P(A) = 0.03$ and $P(B) = 0.02$, compute $P(A \cap B)$, assuming that A and B are independent.

Exercise 11.2. If $P(A) = 0.02$ and $P(B|A) = 0.01$, compute $P(A \cap B)$.

Exercise 11.3. Explain in your own words why rare events can become common when we consider very large populations.

Exercise 11.4. Suppose an event has probability $1/100,000$. If there are 1,000,000 independent trials, what is the expected number of occurrences?

Exercise 11.5. Give a real-life example of two dependent events and explain why they are dependent.

Exercise 11.6. Explain the difference between the statements:

- "The events are independent."
- "The events are mutually exclusive."

Can two events be both independent and mutually exclusive? Explain your answer.

Exercise 11.7. A person says:

> "Since a rare event already happened once, it is unlikely to happen again."

Explain why this statement may be mathematically misleading.

Exercise 11.8. Suppose two events A and B satisfy

$$P(B|A) > P(B).$$

What does this tell us about the relationship between the events?

12. Beyond Mathematics

While mathematics provides powerful tools, it cannot fully capture human experience. A number such as 0.0002 does not describe courage, suffering, resilience, or historical tragedy.

Therefore, mathematics should be viewed as one lens among many. It helps us understand uncertainty, but it does not replace human reflection.

13. Conclusion

This article has shown how a remarkable real-life story can lead naturally to important mathematical ideas. Through probability, conditional probability, rare events, large populations, and simulation, undergraduate students can see how mathematics connects to the real world.

The central lesson is simple but powerful:

> Mathematics does not say that rare events are impossible; it explains how rare events can happen.

This insight is valuable not only in mathematics, but also in science, engineering, data analysis, and everyday reasoning.

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