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“Bayes’ Theorem in Real Life: Application to Probability Calculations”

AN INDIVIDUAL TASK

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Bayes' Theorem in Real Life: Application in Medical Testing

Introduction to Probability and Bayes' Theorem

1.1 Introduction

In real life, we constantly make decisions under uncertainty. Doctors diagnose diseases, banks detect fraud, and email systems filter spam. All these systems rely on probability theory. One of the most powerful tools in probability is Bayes' Theorem.

Bayes' Theorem helps us calculate the probability of an event after observing new evidence. It updates our prior belief using new data.

1.2 Conditional Probability

Conditional probability is the probability of an event occurring given that another event has already occurred.

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

Where:

- $P(A \mid B)$**= Probability of A given B**
- $P(A \cap B)$**= Probability of both A and B occurring**
- $P(B)$**= Probability of B**

1.3 Bayes' Theorem Formula Bayes'

Theorem is written as:

$$P(A \mid B) = \frac{P(B \mid A) \cdot P(A)}{P(B)}$$

Where:

- **P(A) = Prior probability**
- **P(B|A) = Likelihood**
- **P(B) = Evidence**

P(A|B) = Posterior probability

This theorem helps revise our prediction based on new evidence.

Page 2: Real-World Scenario – Medical Testing

2.1 Scenario Description

Suppose a disease a ects 1% of the population.

A diagnostic test has:

- **99% Sensitivity (True Positive Rate)**
- **95% Specificity (True Negative Rate) We want to calculate:**

If a person tests positive, what is the probability they actually have the disease?

2.2 Understanding Key Terms

Sensitivity

Probability that the test correctly detects disease:

$$P(Positive \mid Disease) = 0.99$$

Specificity

Probability that the test correctly detects healthy people:

$$P(Negative \mid NoDisease) = 0.95$$

False Positive Rate

$$P(Positive \mid NoDisease) = 1 - 0.95 = 0.05$$

Page 3: Step-by-Step Calculation

3.1 Given Data

P(Disease) = 0.01

- **P(No Disease) = 0.99**
- **P(Positive | Disease) = 0.99**
- **P(Positive | No Disease) = 0.05**

3.2 Step 1: Calculate Total Probability of Positive Test Using the law of total probability:

$$P(Positive) = P(Positive \mid Disease)P(Disease) + P(Positive \mid NoDisease)P(NoDisease)$$

$$P(Positive) = (\mathbf{0.99} \times \mathbf{0.01}) + (\mathbf{0.05} \times \mathbf{0.99})$$

$$P(Positive) = \mathbf{0.0099} + \mathbf{0.0495}$$

$$P(Positive) = \mathbf{0.0594}$$

3.3 Step 2: Apply Bayes' Theorem

$$P(Disease \mid Positive) = \frac{\mathbf{0.99} \times \mathbf{0.01}}{\mathbf{0.0594}}$$

$$P(Disease \mid Positive) = \frac{\mathbf{0.0099}}{\mathbf{0.0594}}$$

$$P(Disease \mid Positive) \approx \mathbf{0.1667}$$

Page 4: Interpretation Using Population Table To understand clearly, assume 10,000 people.

Step 1: Calculate number of diseased people

1% of 10,000 = 100 people

Step 2: Healthy people

9,900 people

Step 3: Apply test accuracy

- **True Positives = 99% of 100 = 99**

  False Negatives = 1
- **False Positives = 5% of 9,900 = 495**
- **True Negatives = 9,405**

4.1 **Total Positive Tests**

True Positives + False Positives
= 99 + 495
= 594

4.2 **Probability of Actually Having Disease**

$$\frac{99}{594} = \mathbf{0.1667 = 16.67\%}$$

4.3 **Important Observation**

Even though the test is 99% accurate, most positive results are false positives because the disease is rare.

This is called the Base Rate E ect.

Page 5: Applications of Bayes' Theorem

Bayes' Theorem is widely used in many real-life fields:

5.1 **Medical Diagnosis**

Doctors update diagnosis probability after lab tests.

5.2 **Email Spam Filtering Email systems calculate:**

$$P(Spam \mid Words)$$

to classify emails.

5.3 **Fraud Detection Banks calculate:**

$$P(Fraud \mid TransactionPattern)$$

5.4 **Machine Learning**

Naïve Bayes Classifier is based on Bayes' Theorem.

5.5 **Weather Forecasting**

Probabilities of rain are updated using new atmospheric data.

Page 6: Advantages, Limitations and Conclusion

6.1 Advantages

- **Helps make decisions under uncertainty**
- **Incorporates prior knowledge**
- **Improves predictions with new evidence**
- **Widely used in AI and data science**

6.2 Limitations

- **Requires accurate prior probability**
- **Can be di icult when data is limited**
- **Misinterpretation can lead to wrong conclusions**

6.3 Conclusion

Bayes' Theorem is a powerful statistical tool that helps update probabilities using new evidence. In medical testing, it shows that even highly accurate tests may produce misleading results if the disease prevalence is low.

This demonstrates the importance of considering prior probability (base rate) in decisionmaking.

Bayesian reasoning is essential in healthcare, artificial intelligence, finance, and everyday decision-making.

Final Answer Summary

If a person tests positive:

$$P(Disease \mid Positive) = \mathbf{16.67\%}$$

Thus, a positive result does not necessarily mean the person has the disease.