

Probability Distributions

What is a Probability Distribution?

Definition:

- Describes all possible outcomes
- Assigns probability to each
- Different types for different data
- Mathematical formulation

Examples:

- Binomial (success/failure)
- Normal (continuous)
- Poisson (counts)

```
# Create example distributions
x <- seq(-4, 4, length.out = 100)
normal_df <- data.frame(
  x = x,
  y = dnorm(x),
  type = "Normal"
)

x <- 0:10
poisson_df <- data.frame(
  x = x,
  y = dpois(x, lambda = 3),
  type = "Poisson"
)

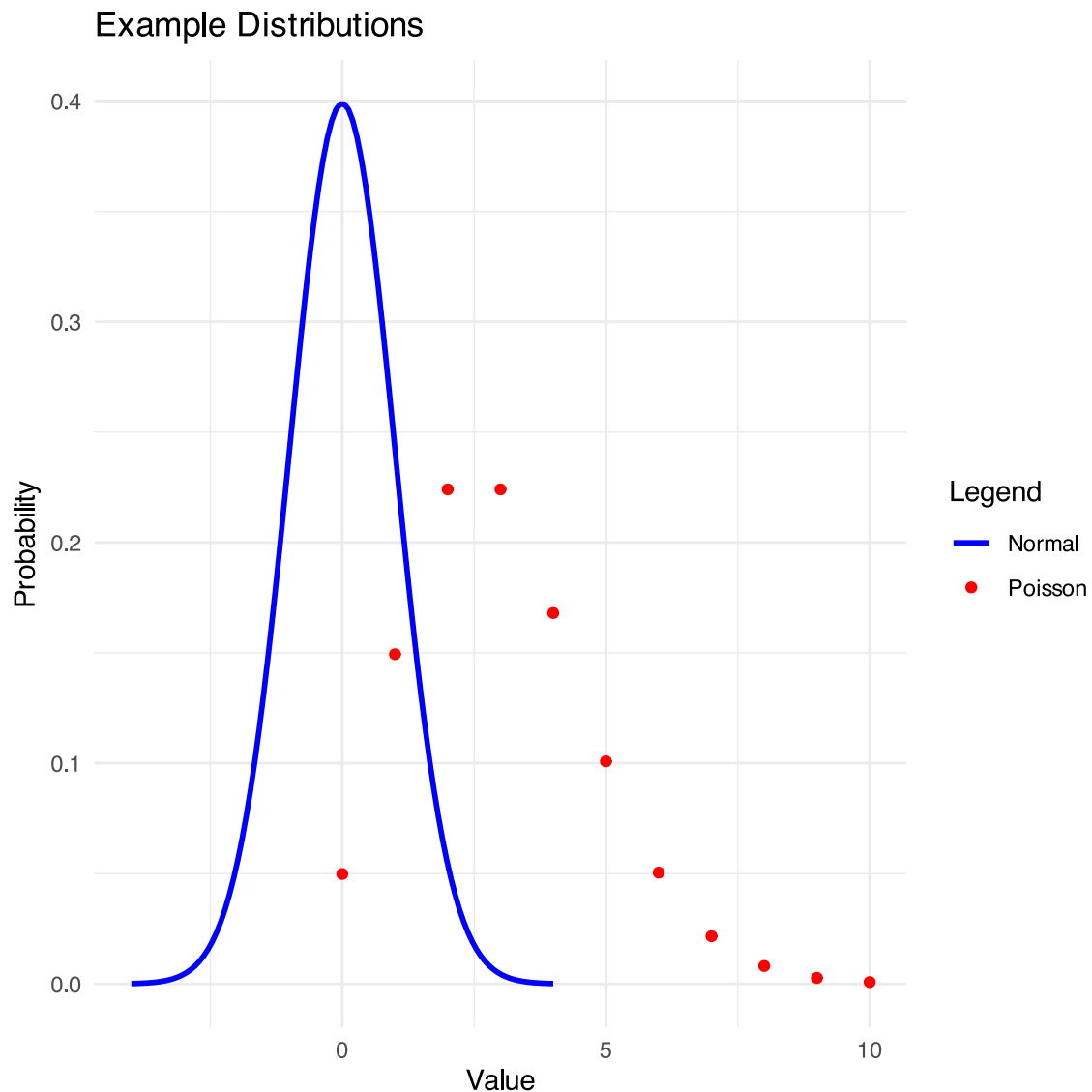
colors <- c(
  "Normal" = "blue",
  "Poisson" = "red"
)

# Plot distributions
ggplot() +
  geom_line(data = normal_df, aes(x = x, y = y, color = "Normal"), size = 1) +
  geom_point(
    data = poisson_df,
    aes(x = x, y = y, color = "Poisson"),
    size = 1.5
  ) +
  labs(
    title = "Example Distributions",
    x = "Value",
    y = "Probability",
  )
```

```

    color = "Legend"
  ) +
  theme(legend.position = "top") +
  scale_color_manual(values = colors) +
  theme_minimal()

```



A probability distribution describes the probability of all of the possible outcomes in an experiment. Throughout this section we will encounter a number of these probability distributions, each of which is appropriate to describe different types of data.

The Binomial Distribution

Properties:

- Independent trials
- Two outcomes
- Fixed probability
- Order doesn't matter

Formula:

$$P(k; n, p) = \binom{n}{k} p^k (1 - p)^{n-k}$$

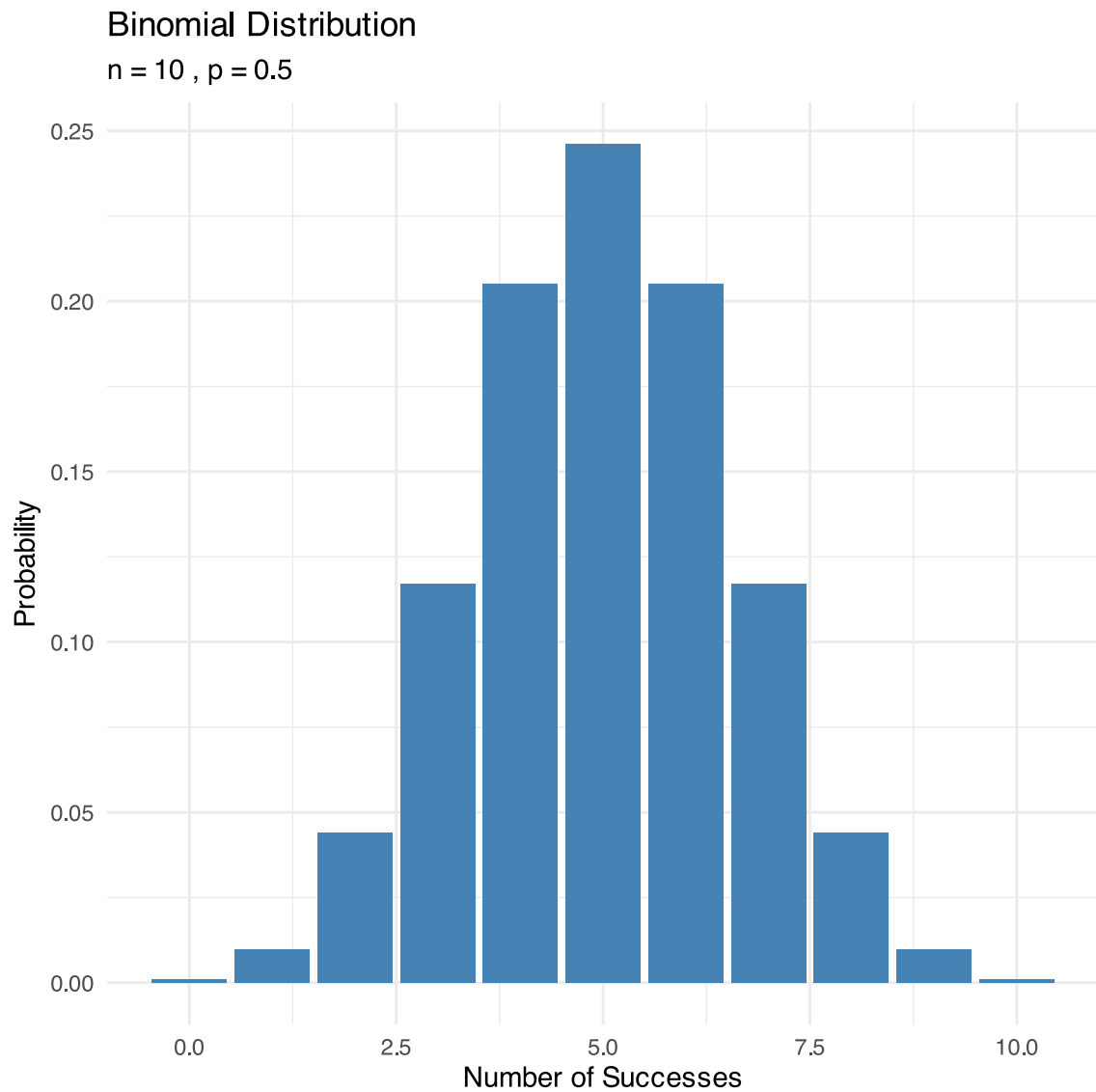
Where:

- k = successes
- n = trials
- p = probability per trial

Binomial Coefficient:

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

```
# Create binomial distribution plot
x <- 0:10
n <- 10
p <- 0.5
binom_df <- data.frame(
  x = x,
  y = dbinom(x, size = n, prob = p)
)
```



The binomial distribution provides a way to compute the probability of some number of successes out of a number of trials on which there is either success or failure and nothing in between (known as “Bernoulli trials”), given some known probability of success on each trial.

Example: Steph Curry’s Free Throws

Scenario:

- Steph Curry hits 91% of his free throws
- In a game in Jan, 2018, he hit only **2 out of 4** free throws
- It seems pretty unlikely that he would hit only 50% of his free throws in a game, but exactly how unlikely is it?

Calculation:

$$\begin{aligned}
 P(2; 4, 0.91) &= \binom{4}{2} 0.91^2 (1 - 0.91)^2 \\
 &= 6 * 0.8281 * 0.0081 \\
 &= 0.040
 \end{aligned}$$

Interpretation:

- Very unlikely (4%)
- Yet it happened
- Rare events do occur
- Don't overinterpret

On Jan 20 2018, the basketball player Steph Curry hit only 2 out of 4 free throws in a game against the Houston Rockets. We know that Curry's overall probability of hitting free throws across the entire season was 0.91, so it seems pretty unlikely that he would hit only 50% of his free throws in a game, but exactly how unlikely is it?

Cumulative Distributions

Often we want to know not just how likely a specific value is, but how likely it is to find a value that is as extreme or more than a particular value?

Definition:

- Probability of value $\leq x$
- Accumulates probabilities
- Often more useful
- Important for testing

Example:

$$P(k \leq 2) = P(k = 2) + P(k = 1) + P(k = 0)$$

Often we want to know not just how likely a specific value is, but how likely it is to find a value that is as extreme or more than a particular value?

Cumulative Distributions

```

# curry_df <- tibble(
#   numSuccesses = seq(0, 4)
# ) %>%
#   mutate(
#     Probability = dbinom(numSuccesses, size = 4, prob = 0.91),
#     CumulativeProbability = pbinom(numSuccesses, size = 4, prob = 0.91)
#   )
# Create data for Curry's free throw distributions
n_throws <- 4
curry_prob <- 0.91
x <- 0:n_throws

```

```

curry_dist_df <- data.frame(
  x = x,
  Simple = dbinom(x, size = n_throws, prob = curry_prob),
  Cumulative = pbinom(x, size = n_throws, prob = curry_prob)
)

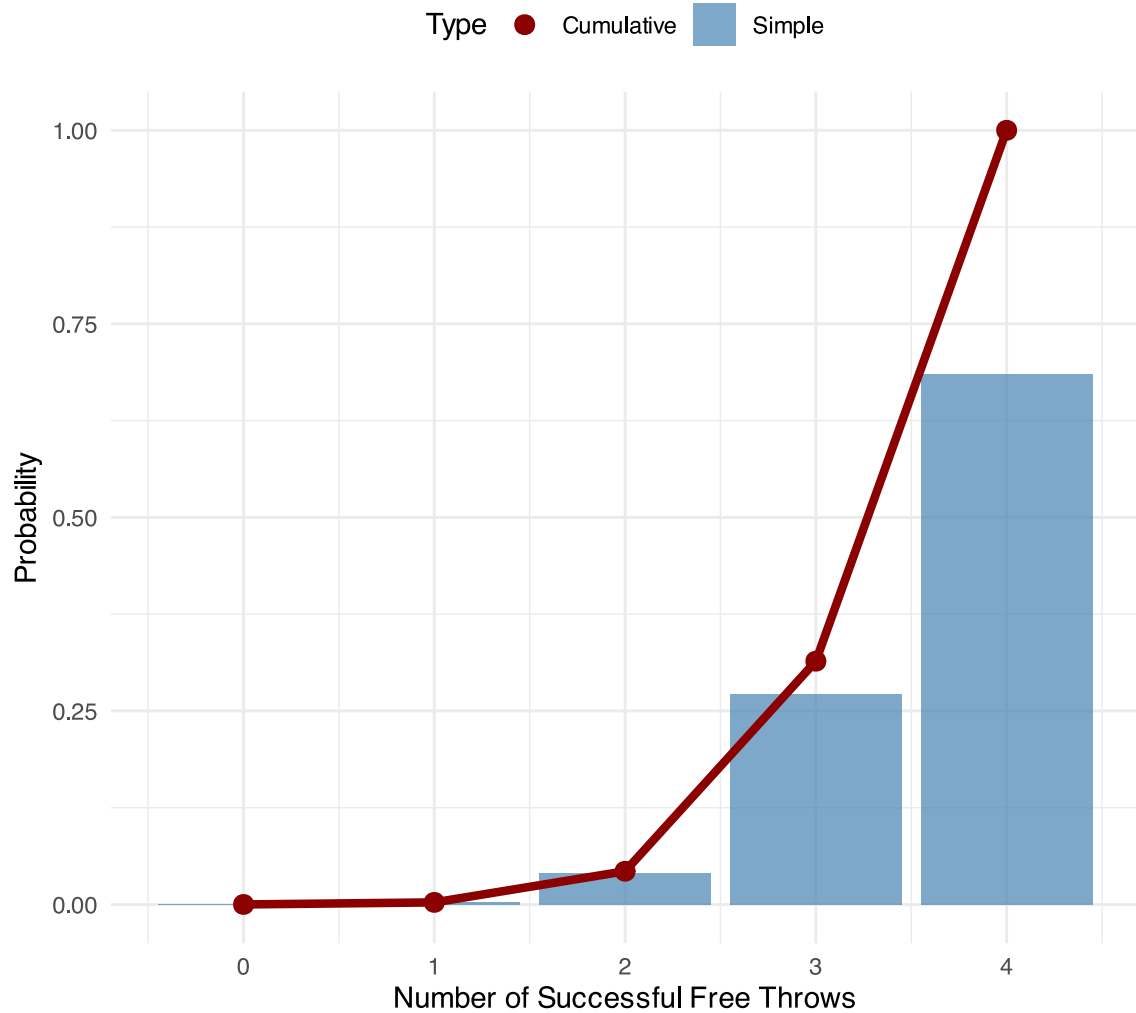
kable(
  curry_dist_df,
  caption = "Simple and cumulative probability distributions",
  digits = 3
)

```

x	Simple	Cumulative
0	0.000	0.000
1	0.003	0.003
2	0.040	0.043
3	0.271	0.314
4	0.686	1.000

Steph Curry's Free Throw Probability Distribution

4 Free Throws with 91% Success Rate



The binomial distribution is a discrete probability distribution that describes the number of successes in a sequence of independent experiments, each of which has a constant probability of success. In this example, we are looking at the probability of Steph Curry making a certain number of free throws out of 4 attempts, given that his overall success rate is 91%.

This visualization shows both the probability of making exactly k free throws (blue bars) and the probability of making k or fewer free throws (red line) for Curry's specific scenario of 4 attempts with a 91% success rate.

Summary

Core Concepts:

1. Probability measures uncertainty

2. Three approaches:
 - Personal belief
 - Empirical frequency
 - Classical probability
3. Fundamental rules:
 - Addition
 - Multiplication
 - Subtraction

Advanced Topics:

1. Conditional probability
2. Independence
3. Bayes' rule
4. Probability distributions

Applications:

- Medical screening
- Data analysis
- Decision making
- Statistical inference

These concepts form the foundation for statistical inference, which we will explore in later chapters. Having read this chapter, you should be able to:

- Describe the sample space for a selected random experiment
- Compute relative frequency and empirical probability
- Compute probabilities of single events, complementary events, and unions/intersections
- Describe the law of large numbers
- Understand conditional probability and independence
- Use Bayes' theorem

Bibliography