What’s the difference between sampling with replacement and sampling without replacement?

Authored by

stats writer

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In the field of statistics, the method used for selecting data points significantly impacts the validity and analysis of results. The fundamental distinction lies between two core techniques: **sampling with replacement** and **sampling without replacement**.

Sampling with replacement is a procedure where an item is randomly selected from a population and then immediately returned to that population before the next selection is made. This means the pool of available items remains constant throughout the selection process. Consequently, the same item can be chosen multiple times.

Conversely, **sampling without replacement** involves selecting an item and then permanently removing it from the population before the subsequent draw. Consequently, the population size decreases with each selection, ensuring that any single item can only be chosen once for inclusion in the final dataset.

Setting the Statistical Stage: Populations and Samples

When conducting quantitative research, the goal is often to collect data that can accurately address specific research questions or test hypotheses. This process relies on understanding the relationship between the complete group of interest and the subset we actually measure.

We are always interested in learning about the entire target group, known as the population, which encompasses every possible individual element relevant to the study. However, measuring every element in a large population is usually impractical, often due to constraints related to cost, time, and resources.

Instead of conducting a complete census, researchers typically gather information from a smaller, manageable subset called a sample. The careful selection of this sample is paramount, as the chosen sampling technique--whether with or without replacement--determines the probabilistic nature and analytical methods appropriate for interpreting the results.

Research Questions Driving Data Collection

Effective data collection strategies are shaped by the research questions they aim to answer. These questions often focus on specific parameters of the target population, such as measures of central tendency or frequency distributions. Examples of typical statistical inquiries include:

What is the **median household income** in a specific metropolitan area, such as Cincinnati, Ohio?
What is the **mean weight** of a specific population cohort, such as a localized species of turtles?
What **percentage of residents** in a designated county support a newly introduced piece of legislation?

In each scenario, we are interested in answering some question about a population. The chosen sampling methodology dictates how representative the resulting sample is and how inferences are drawn back to the parent population.

Understanding Sampling with Replacement (SWR)

Sampling with replacement (SWR) is characterized by the constant size of the population pool. This method ensures that the probability of selecting any particular item remains identical throughout the sequence of draws, regardless of what items were previously selected. This technique is often conceptually easier to model mathematically because the sample space is static.

Consider a simple, illustrative scenario: We have a hat containing the names of five distinct students:

Andy
Karl
Tyler
Becca
Jessica

If we aim to draw a sample of two students **with replacement**, the procedure is as follows: We perform the first random draw and select, perhaps, the name Tyler. Crucially, we then record the selection and immediately place Tyler's name back into the hat. When we proceed to the second draw, all five names are available again. If we happen to select Tyler's name a second time, the resulting sample would be: {Tyler, Tyler}.

This procedure confirms that SWR allows the same individual element to be included in the final sample multiple times. The replacement step is key, maintaining a uniform probability distribution across all selections.

Characteristics of Sampling with Replacement: Independence

A primary statistical consequence of using sampling with replacement is that the individual selections are always independent. In the context of probability theory, **independence** means that the outcome of one random draw does not influence or alter the probabilities associated with any subsequent draws.

Returning to our student example, the probability of choosing the name Tyler on the first draw is 1/5. Because his name is replaced, the probability of choosing Tyler (or any other student) on the second draw remains exactly 1/5. The outcome of the first draw does not affect the probability of the outcome on the second draw. This property of independence simplifies many forms of statistical modeling and calculation.

Practical Applications of Sampling with Replacement

While standard survey sampling often avoids replacement to ensure each individual contributes unique information, SWR is foundational in several crucial areas of computational statistics and machine learning. It is particularly valuable when analysts need to generate multiple simulated datasets from a single observed dataset.

One of the most prominent uses of SWR is in the bootstrap method (resampling with replacement). This technique involves drawing many samples of the same size as the original data, allowing researchers to estimate the sampling distribution of a **statistic**, such as the mean or median, without making strong distributional assumptions about the population.

SWR is also a cornerstone of ensemble methods in machine learning, such as **bagging** (Bootstrap Aggregating). In these methods, multiple models are trained on different synthetic datasets generated via resampling with replacement from the original data. This process is highly beneficial because it allows researchers to leverage the same finite dataset repeatedly to build robust models, avoiding the time-consuming and expensive process of gathering new data for every iteration or model variant.

In each of these methods, **sampling with replacement** is utilized because it enables the efficient utilization of the existing data, allowing the creation of multiple varied datasets necessary for techniques like cross-validation and bias reduction in predictive modeling.

Understanding Sampling without Replacement (SWOR)

Sampling without replacement (SWOR) is the standard technique employed when the objective is to select a unique subset of elements from a population. The definitive characteristic of this method is the continuous reduction of the available pool of items after each successful draw.

Again, suppose we have the names of five students in a hat:

Andy
Karl
Tyler
Becca
Jessica

If we seek a sample of two students **without replacement**, the process changes significantly. Upon the first random draw, we might select the name Tyler. We would then leave his name out of the hat. On the second draw, we might select the name Andy. Thus our sample would be: {Tyler, Andy}.

This is an example of obtaining a sample without replacement because we do not replace the name we choose after each random draw. This example clearly demonstrates that SWOR ensures that every entity within the defined population contributes uniquely to the sample.

Characteristics of Sampling without Replacement: Dependence

When sampling without replacement, the resulting selections are statistically dependent. **Dependence** implies that the outcome of a prior draw directly influences the probabilities of subsequent draws, since the sample space changes over time.

For example, the probability of choosing the name Tyler is 1/5 on the first draw. Since Tyler is removed, the probability of choosing the name Andy on the second draw changes to 1/4. The outcome of the first draw affects the probability of the outcome on the second draw because the total number of items available has decreased. The probability of the second event is conditional upon the result of the first event.

When to Choose Sampling without Replacement

Sampling without replacement is the default and most common method used when researchers aim to select a representative, non-redundant sample from a large finite population for the purpose of making generalizations (inferences) about that population.

For example, if we want to estimate the median household income in Cincinnati, Ohio, there might be a total of 500,000 different households. Thus, we might want to collect a random sample of 2,000 households, but we don't want the data for any given household to appear twice in the sample, so we would sample without replacement.

In other words, once we've chosen a certain household to be included in the sample, we don't want there to be any chance of selecting that household to be included again. This method maintains the integrity of the sample, ensuring that the selected elements are distinct individuals or entities, providing the most accurate basis for drawing inferences about the broader city population.