

# Introduction to Probability and Statistics

*26 June 2020*



# recap

Suppose we want to estimate household size, where a “household” is defined as people living together in the same dwelling, and sharing living accommodations.

If we select students at random at an elementary school and ask them what their family size is, **will this be a good measure of household size?** Or will our average be biased? If so, will it overestimate or underestimate the true value?

*(OpenIntro Statistics, exercise 1.26)*

# *Summarizing data*

```
# load food consumption dataset
food_consumption <-
  readr::read_csv(
    paste0('https://raw.githubusercontent.com/',
           'rfordatascience/tidytuesday/master/',
           'data/2020/2020-02-18/food_consumption.csv')
  )
```

## Food Consumption data

Data from the the United Nations on the **annual per-capita** consumption of eleven categories of food for 130 countries.

```
unique(food_consumption$country)
```

```
##      [1] "Argentina"      "Australia"
##      [3] "Albania"        "Iceland"
##      [5] "New Zealand"    "USA"
##      [7] "Uruguay"        "Luxembourg"
##      [9] "Brazil"         "Kazakhstan"
##     [11] "Sweden"         "Bermuda"
##     [13] "Denmark"        "Finland"
##     [15] "Ireland"        "Greece"
##     [17] "France"         "Canada"
##     [19] "Norway"         "Hong Kong SAR. China"
##     [21] "French Polynesia" "Israel"
##     [23] "Switzerland"    "Netherlands"
##     [25] "Kuwait"         "United Kingdom"
##     [27] "Austria"        "Oman"
##     [29] "Italy"          "Bahamas"
##     [31] "Portugal"       "Malta"
##     [33] "Armenia"        "Slovenia"
##     [35] "Chile"          "Venezuela"
##     [37] "Belgium"        "Germany"
```

## Food Consumption data

```
food_consumption %>%
  filter(country == "USA")
```

```
## # A tibble: 11 x 4
```

	country	food_category	consumption	co2_emmission
	<chr>	<chr>	<dbl>	<dbl>
## 1	USA	Pork	27.6	97.8
## 2	USA	Poultry	50.0	53.7
## 3	USA	Beef	36.2	1118.
## 4	USA	Lamb & Goat	0.43	15.1
## 5	USA	Fish	12.4	19.7
## 6	USA	Eggs	14.6	13.4
## 7	USA	Milk - inc. cheese	255.	363.
## 8	USA	Wheat and Wheat Products	80.4	15.3
## 9	USA	Rice	6.88	8.8
## 10	USA	Soybeans	0.04	0.02
## 11	USA	Nuts inc. Peanut Butter	7.86	13.9

## Food Consumption data

```
unique(food_consumption$food_category)
```

```
## [1] "Pork"           "Poultry"  
## [3] "Beef"          "Lamb & Goat"  
## [5] "Fish"          "Eggs"  
## [7] "Milk - inc. cheese" "Wheat and Wheat Products"  
## [9] "Rice"          "Soybeans"  
## [11] "Nuts inc. Peanut Butter"
```



## Food Consumption data

```
food_consumption %>%  
  filter(food_category == "Rice")
```

```
## # A tibble: 130 x 4  
##   country      food_category consumption co2_emmission  
##   <chr>        <chr>             <dbl>         <dbl>  
## 1 Argentina   Rice                8.77          11.2  
## 2 Australia   Rice               11.0           14.1  
## 3 Albania     Rice                7.78           9.96  
## 4 Iceland     Rice                3.89           4.98  
## 5 New Zealand Rice                9.16          11.7  
## 6 USA         Rice                6.88           8.8  
## 7 Uruguay     Rice               11.5           14.7  
## 8 Luxembourg  Rice                4.2            5.37  
## 9 Brazil      Rice               32.1           41.1  
## 10 Kazakhstan Rice                7.32           9.37  
## # ... with 120 more rows
```

## **Descriptive statistics...**

or: how do we make sense of a long list of numbers?

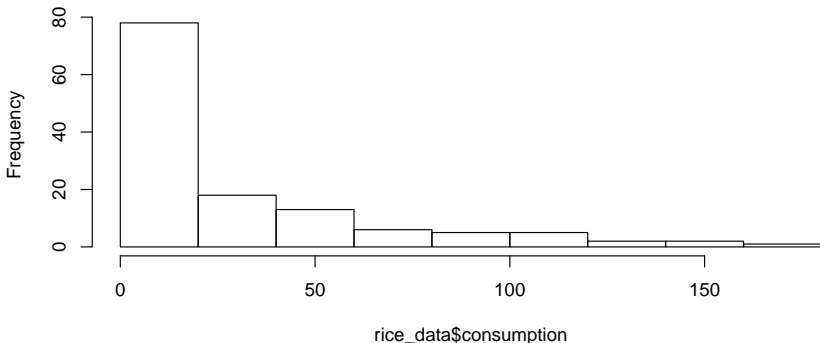
# *Visualizing distributions*

## Histogram

Histograms illustrate the “**distribution of data**” for **one** variable at a time, showing which values are relatively more common in our dataset.

```
rice_data <- food_consumption %>%  
  filter(food_category == "Rice")  
hist(rice_data$consumption)
```

**Histogram of rice\_data\$consumption**



## Histogram

Which range of values is most common in our dataset?

```
hist(rice_data$consumption,  
     xlab = "Consumption (kg/person/year)",  
     main = "Histogram of Rice Consumption")
```



## Histogram

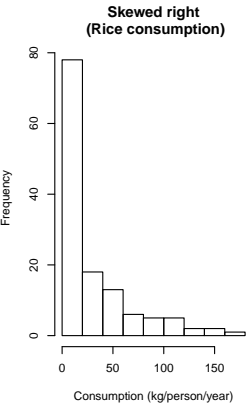
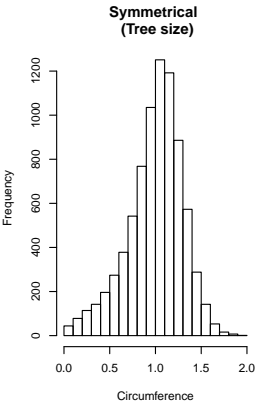
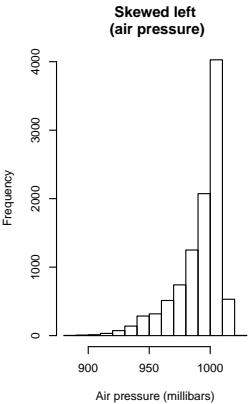
Can we use this plot to make any generalizations about rice consumption habits in the world?

## Histogram

Can we use this plot to make any generalizations about rice consumption habits in the world?

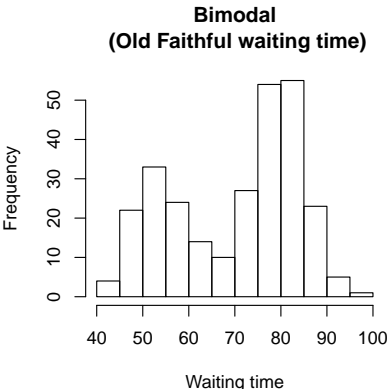
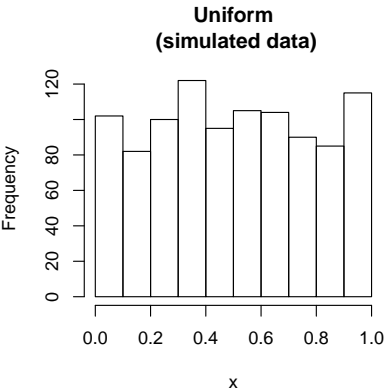
Only if we make statements that are connected to the types of countries that are well represented in the dataset.

# Shapes of Histograms





# Other Shapes of Histograms



## Scatter plot

Scatter plots illustrate the **joint distribution** of **two** variables at a time, showing which values are relatively more common in our dataset.

```
wheat_data <- food_consumption %>%
  filter(food_category == "Wheat and Wheat Products")
wheat_data
```

```
## # A tibble: 130 x 4
##   country      food_category      consumption co2_emmission
##   <chr>        <chr>                <dbl>          <dbl>
## 1 Argentina   Wheat and Wheat Products    103.           19.7
## 2 Australia   Wheat and Wheat Products     70.5           13.4
## 3 Albania     Wheat and Wheat Products    139.           26.4
## 4 Iceland     Wheat and Wheat Products     72.9           13.9
## 5 New Zealand Wheat and Wheat Products     76.9           14.7
## 6 USA         Wheat and Wheat Products     80.4           15.3
## 7 Uruguay     Wheat and Wheat Products    109.           20.8
## 8 Luxembourg   Wheat and Wheat Products    103.           19.7
## 9 Brazil      Wheat and Wheat Products     53            10.1
## 10 Kazakhstan Wheat and Wheat Products     92.3           17.6
## # ... with 120 more rows
```

## Joining data tables

In order to produce a scatter plot, we need to match countries' wheat and rice consumption.

```
grains_data <- wheat_data %>%
  bind_rows(rice_data)
grains_data
```

```
## # A tibble: 260 x 4
##   country      food_category      consumption co2_emmission
##   <chr>        <chr>                <dbl>         <dbl>
## 1 Argentina   Wheat and Wheat Products    103.          19.7
## 2 Australia   Wheat and Wheat Products     70.5          13.4
## 3 Albania     Wheat and Wheat Products    139.          26.4
## 4 Iceland     Wheat and Wheat Products     72.9          13.9
## 5 New Zealand Wheat and Wheat Products     76.9          14.7
## 6 USA         Wheat and Wheat Products     80.4          15.3
## 7 Uruguay     Wheat and Wheat Products    109.          20.8
## 8 Luxembourg   Wheat and Wheat Products    103.          19.7
## 9 Brazil      Wheat and Wheat Products     53           10.1
## 10 Kazakhstan Wheat and Wheat Products     92.3          17.6
## # ... with 250 more rows
```

## Joining data tables

What we really want is each row to represent a country, and each column to represent a type of food. The `pivot_wider` function comes in handy here:

```
grains_data <- grains_data %>%  
  select(-co2_emission) %>% # remove co2 variable  
  pivot_wider(names_from = food_category, values_from = consumption) %>%  
  rename(Wheat = `Wheat and Wheat Products`) # make column name shorter
```

## Joining data tables

What we really want is each row to represent a country, and each column to represent a type of food.

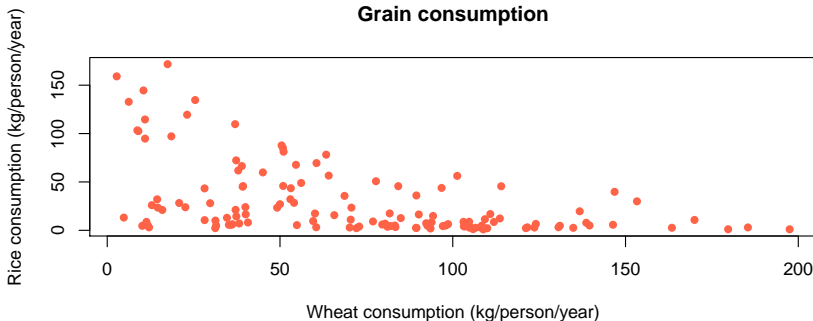
```
head(grains_data)
```

```
## # A tibble: 6 x 3
##   country      Wheat  Rice
##   <chr>      <dbl> <dbl>
## 1 Argentina  103.   8.77
## 2 Australia   70.5  11.0
## 3 Albania    139.   7.78
## 4 Iceland     72.9   3.89
## 5 New Zealand  76.9   9.16
## 6 USA         80.4   6.88
```

## Scatter plot

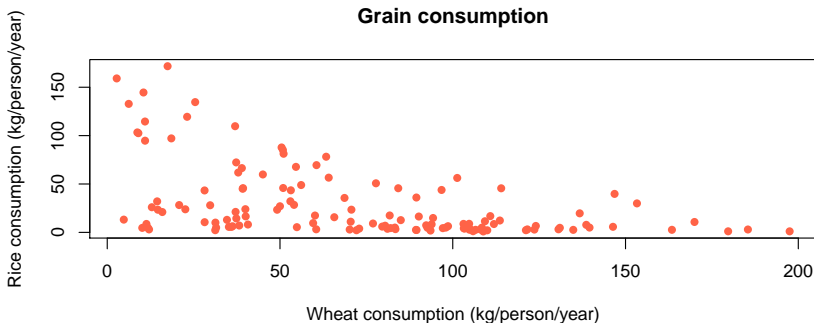
Finally, we can make our scatter plot. What do we observe?

```
plot(grains_data$Wheat, grains_data$Rice,  
     xlab = "Wheat consumption (kg/person/year)",  
     ylab = "Rice consumption (kg/person/year)",  
     main = "Grain consumption",  
     pch = 16, col = 'tomato')
```



## Scatter plot

For countries in our dataset, there is a **negative association** between rice consumption and wheat consumption. Countries that consume relatively more rice tend to consume relatively less wheat.





## Revisiting the histogram

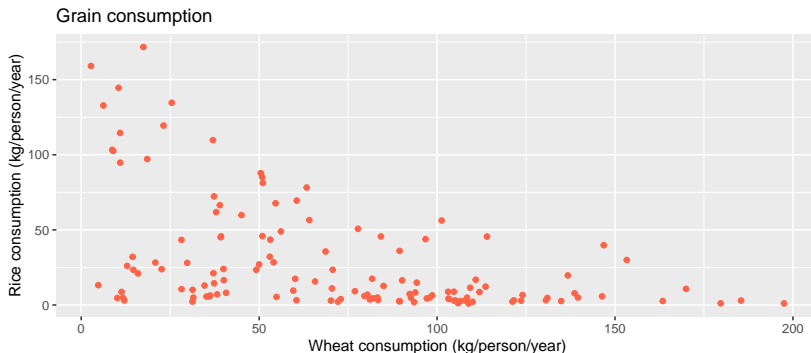
```
hist(grains_data$Wheat + grains_data$Rice,  
     xlab = "Consumption (kg/person/year)",  
     main = "Wheat and Rice consumption")
```



## Scatter plot in ggplot2

In case you wanted code to do this in ggplot2.

```
ggplot(grains_data) +  
  geom_point(aes(x = Wheat, y = Rice), color = 'tomato') +  
  xlab("Wheat consumption (kg/person/year)") +  
  ylab("Rice consumption (kg/person/year)") +  
  ggtitle("Grain consumption")
```



# *Summary statistics*

## Summary statistics

Sometimes we don't want the full **distribution**: we may just want a few numbers that summarize our data.

The full distribution will give us more information, but **summary statistics** take up less space and can speed up decision making.

**ex.** GPA

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Sometimes we don't want the full **distribution**: we may just want a few numbers that summarize our data.

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**ex.** GPA

Note that these are all computed based on **samples** and that we will focus on statistics for single variables for now.

*“Location”*

## Location statistics

Some statistics describe the **location** of our data.

Crudely speaking, these statistics tell us what possible values of our variable are the most representative/common/important.

## Notation

Let  $x_1, \dots, x_n$  denote the  $n$  observations of our variable of interest.



## Sample mean $\bar{x}$

**In words:** the sum of a collection of numbers divided by the count of numbers

**In math:**

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

**In R:**

```
mean(grains_data$Rice)
```

```
## [1] 29.37515
```

## Sample median $\tilde{x}$

**In words:** the “middle” value of a set of numbers

**In math:**

even number of numbers :  $\text{median}(\{1, 2, 3, \mathbf{3}, \mathbf{5}, 8, 8, 9\}) = \frac{3 + 5}{2} = 4$

odd number of numbers :  $\text{median}(\{3, 4, 4, \mathbf{5}, 6, 8, 9\}) = 5$

**In R:**

```
median(grains_data$Rice)
```

```
## [1] 11.875
```

## Sample mode

**In words:** the most common value of a variable

**In math:**

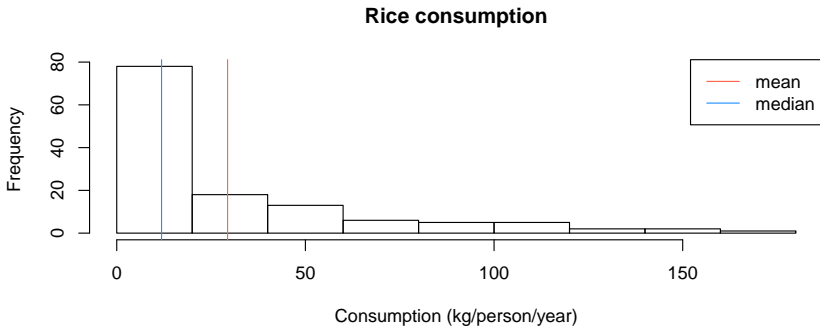
$$\text{mode}(\{1, 2, \mathbf{3}, \mathbf{3}, 5\}) = 3$$

$$\text{mode}(\{1, 2, \mathbf{3}, \mathbf{3}, 5, \mathbf{8}, \mathbf{8}, 9\}) = 3 \text{ and } 8$$

**In R:** R has no built in mode function!

## Revisiting the histogram

```
hist(grains_data$Rice,  
     xlab = "Consumption (kg/person/year)",  
     main = "Rice consumption")  
abline(v = mean(grains_data$Rice), col = 'tomato')  
abline(v = median(grains_data$Rice), col = 'dodgerblue')  
legend("topright", c("mean", "median"),  
      col = c("tomato", "dodgerblue"), lty = 1)
```



## Sensitivity to skew/outliers

Imagine that we're all in one classroom (scary!).

*A brave student says: I wonder how many Instagram followers the typical person in this room has.*

*Another over-eager student says: Let's take a sample of 10 people and find out!*

What sample location statistic should we calculate based on our sample?

## Sensitivity to skew/outliers

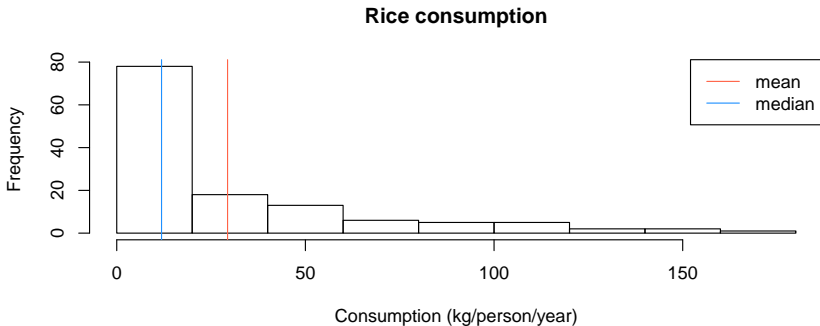
Now, suppose Cristiano Ronaldo (225 million), Ariana Grande (191.1 m), The Rock (187.3 m) walk into the room.

They would be **outliers** in our population, meaning that their values would be located abnormally far from the other values.

Suppose they all end up in our sample. What happens to the sample mean? What happens to the sample median?

## Comparing location statistics

```
hist(grains_data$Rice,  
     xlab = "Consumption (kg/person/year)",  
     main = "Rice consumption")  
abline(v = mean(grains_data$Rice), col = 'tomato')  
abline(v = median(grains_data$Rice), col = 'dodgerblue')  
legend("topright", c("mean", "median"),  
     col = c("tomato", "dodgerblue"), lty = 1)
```



## Comparing location statistics

Statistic	Mean	Median	Mode
Pros	<ul style="list-style-type: none"><li>- unique value</li><li>- good for inference</li></ul>	<ul style="list-style-type: none"><li>- unique value</li><li>- robust to outliers</li></ul>	<ul style="list-style-type: none"><li>- easy to explain</li><li>- can compute for numerical and categorical variables</li></ul>
Cons	<ul style="list-style-type: none"><li>- sensitive to outliers</li><li>- only numerical variables</li></ul>	<ul style="list-style-type: none"><li>- only numerical variables</li></ul>	<ul style="list-style-type: none"><li>- may not be unique/meaningful</li></ul>



## Other location statistics

**Quartiles** split your data up into quarters. If you think of the median as the second quartile, then the first quartile is the median of the first half of the data and third quartile is the median of the second half of the data.

So, 25% of the data fall below the first quartile and 75% fall below the third quartile.

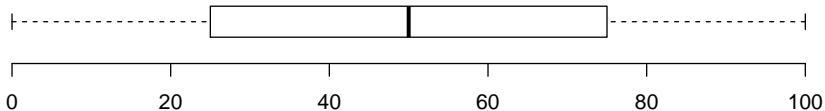
## Boxplots

We can use boxplots to summarize distributions and visualize the quartiles:

The edges of the box represent the first and third quartile

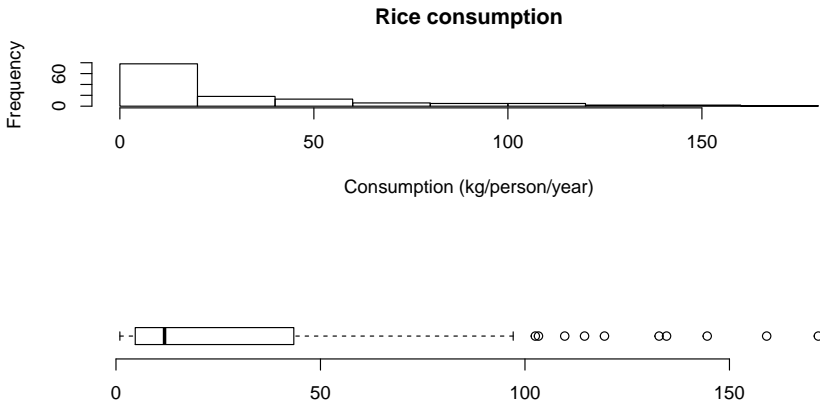
The line inside the box is the median

The edges of the “whiskers” are usually the maximum and minimum



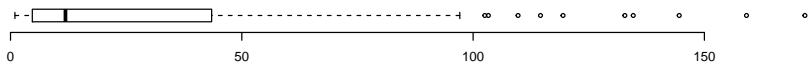
## Boxplots

Returning to our rice consumption data (the points to the right are **outliers**):

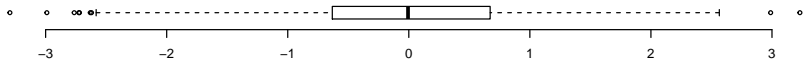


# Example Boxplots

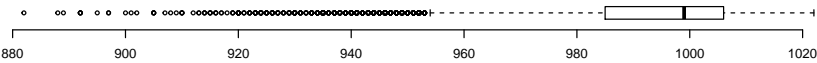
Skewed right



Symmetrical



Skewed left



*“Spread”*

## Spread statistics

Some statistics describe the **location** of our data.

Crudely speaking, these statistics tell us how far our data values tend to be from each other.

## Range

**In words:** the difference between the biggest data value and the smallest data value

**In math:**

$$\text{range}(x_1, \dots, x_n) = \max(x_1, \dots, x_n) - \min(x_1, \dots, x_n)$$

**In R:**

```
range(grains_data$Rice)
```

```
## [1] 0.95 171.73
```

## Sample Variance

Let the **sample deviation** be the distance of an observation from its sample mean. So, for now, we compute the sample deviation of  $x_i$  as  $x_i - \bar{x}$ .

We define **sample variance** as the average squared sample deviation of the observations.



## Sample Variance

**In words:** the “average” squared deviation of the observations

**In math:**

$$\text{Var}(x_1, \dots, x_n) = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

**Note: we divide by  $n - 1$  to get a better estimator**

**In R:**

```
var(grains_data$Rice)
```

```
## [1] 1393.116
```

## Sample Standard Deviation

**In words:** the square root of “average” squared deviation of the observations

**In math:**

$$\text{SD}(x_1, \dots, x_n) = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}$$

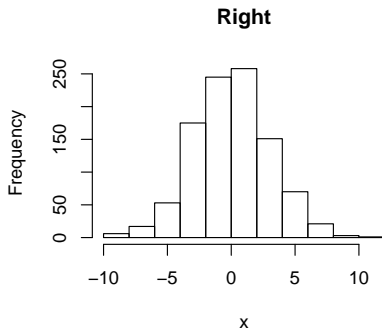
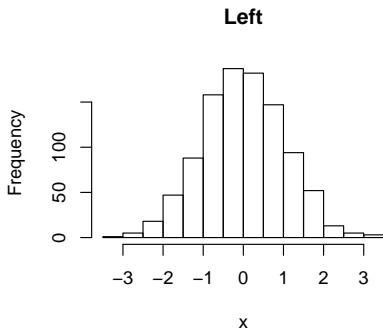
**Note: we divide by  $n - 1$  to get a better estimator**

**In R:**

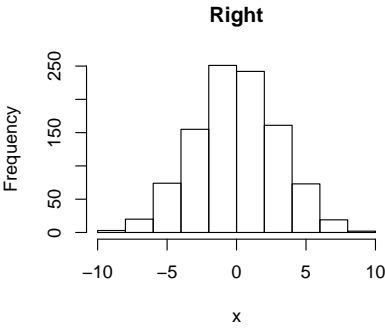
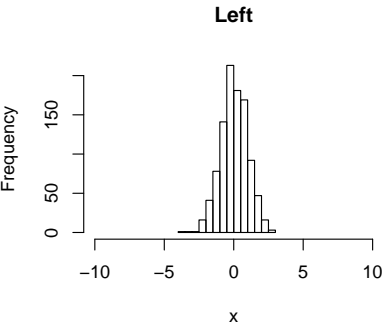
```
sd(grains_data$Rice)
```

```
## [1] 37.32447
```

Which data has the higher standard deviation?

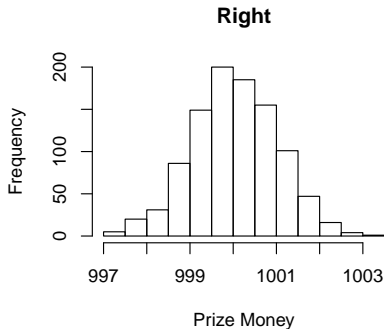
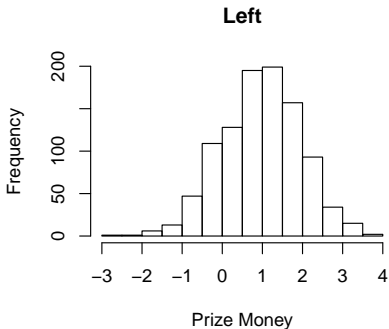


Drawn on the same scale:



## Context matters

Context matters a lot when discussing standard deviation. These two (fake) datasets have the same standard deviation:



## Coefficient of variation

**In words:** the standard deviation divided by the mean

**In math:**

$$CV(x_1, \dots, x_n) = \frac{SD(x_1, \dots, x_n)}{\bar{x}}$$

**In R:**

```
sd(grains_data$Rice) / mean(grains_data$Rice)
```

```
## [1] 1.270614
```



# *recap*

**If you only take one thing away from today:**

All of the summaries/statistics we discussed today were calculated without making **any assumptions** about our population.



# *recap*

**If you only take one thing away from today:**

All of the summaries/statistics we discussed today were calculated without making **any assumptions** about our population.

All were based entirely on our **sample**. In the next lecture we'll talk more about how we can use **sample statistics** to estimate **population parameters**.