

Basic Statistics

You live near a freeway, and someone asks you, “How fast do cars on that freeway drive?”

You say “Pretty fast.”

And they say, “Can you be more specific?”

And you point your radar gun at a car, and say “That one is going 32.131 meters per second.”

And they say, “I don’t want to know about that specific car. I want to know about all the cars.”

So, you spend the day beside the freeway measuring the speed of every car that goes by. And you get a list of a thousand numbers. Here is part of the list:

| | | |
|------------|------------|------------|
| 30.462 m/s | 29.550 m/s | 29.227 m/s |
| 37.661 m/s | 27.899 m/s | 28.113 m/s |
| 24.382 m/s | 35.668 m/s | 43.797 m/s |
| 31.312 m/s | 37.637 m/s | 30.891 m/s |

There are 12 numbers here. We say that there are 12 *samples*.

1.1 Mean

We often talk about the *average* of a set of samples, which is the same as the *mean*. To get the mean, sum up the samples and divide that number by the number of samples.

The numbers in that table sum to 388.599. If you divide that by 12, you find that the mean of those samples is 32.217 m/s.

We typically use the greek letter μ (“mu”) to represent the mean.

Definition of Mean

If you have a set of samples x_1, x_2, \dots, x_n , the mean is:

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

This may be the first time you are seeing a summation (\sum). The equation above is equivalent to:

$$\mu = \frac{1}{n} (x_1 + x_2 + \dots + x_n)$$

Exercise 1 Mean Grade

Working Space

Teachers often use the mean for grading. For example, if you took six quizzes in a class, your final grade might be the mean of the six scores. Find the mean of these six grades: 87, 91, 98, 65, 87, 100.

Answer on Page 9

If you tell your friend “I measured the speed of 1000 cars, and the mean is 31.71 m/s”, your friend will wonder “Are most of the speeds clustered around 31.71? Or are they all over the place and just happen to have a mean of 31.71?” To answer this question we use variance.

1.2 Variance

Definition of Variance

If you have n samples x_1, x_2, \dots, x_n that have a mean of μ , the *variance* is defined to be:

$$v = \frac{1}{n} \sum_{i=1}^n (x_i - \mu)^2$$

That is, you figure out how far each sample is from the median, you square that, and then

you take the mean of all those squared distances.

| x | $x - \mu$ | $(x - \mu)^2$ |
|-------------------------------------|-----------|---|
| 30.462 | -1.755 | 3.079 |
| 29.550 | -2.667 | 7.111 |
| 29.227 | -2.990 | 8.938 |
| 37.661 | 5.444 | 29.642 |
| 27.899 | -4.318 | 18.642 |
| 28.113 | -4.104 | 16.839 |
| 24.382 | -7.835 | 61.381 |
| 35.668 | 3.451 | 11.912 |
| 43.797 | 11.580 | 134.106 |
| 31.312 | -0.905 | 0.818 |
| 37.637 | 5.420 | 29.381 |
| 30.891 | -1.326 | 1.757 |
| $\sum x = 386.599$ mean = 32.217 | | $\sum (x - \mu)^2 = 323.605$ variance = 26.967 |

Thus, the variance of the 12 samples is 26.967. The bigger the variances, the farther the samples are spread apart; the smaller the variances, the closer samples are clustered around the mean.

Notice that most of the data points deviate from the μ by 1 to 5 m/s. Isn't it odd that the variance is a big number like 26.967? Remember that it represents the average of the squares. Sometimes, to get a better feel for how far the samples are from the mean, we use the square root of the variance, which is called *the standard deviation*.

The standard deviation of your 12 samples would be $\sqrt{26.9677} = 5.193$ m/s.

The standard deviation is used to figure out a data point is an outlier. For example, if you are asked "That car that just sped past. Was it going freakishly fast?" You might respond, "No, it was within a standard deviation of the mean." or "Yes, it's speed was 2 standard deviations more than the mean. They will probably get a ticket."

A singular μ usually represents the mean. σ usually represents the standard deviation. So σ^2 represents the variance.

Exercise 2 **Variance of Grades**

Working Space

Now find the variance for your six grades.
As a reminder, they were: 87, 91, 98, 65,
87, 100.

What is your standard deviation?

Answer on Page 9

1.3 Median

Sometimes you want to know where the middle is. For example, you want to know the speed at which half the cars are going faster and half are going slower. To get the median, you sort your samples from smallest to largest. If you have an odd number of samples, the one in the middle is the median. If you have an even number of samples, we take the mean of the two numbers in the middle.

In our example, you would sort your numbers and find the two in the middle:

| | |
|----------------------------|--|
| 24.382 | |
| 27.899 | |
| 28.113 | |
| 29.227 | |
| 29.550 | |
| <hr style="width: 100%;"/> | |
| 30.462 | |
| 30.891 | |
| <hr style="width: 100%;"/> | |
| 31.312 | |
| 35.668 | |
| 37.637 | |
| 37.661 | |
| 43.797 | |

You take the mean of the two middle numbers: $(30.462 + 30.891)/2 = 30.692$. The median speed would be 30.692 m/s.

Medians are often used when a small number of outliers majorly skew the mean. For example, income statistics usually use the median income because a few hundred billionares

raise the mean a lot.

Exercise 3 Median Grade

Find the median of your six grades: 87, 91, 98, 65, 87, 100.

Working Space

Answer on Page 9

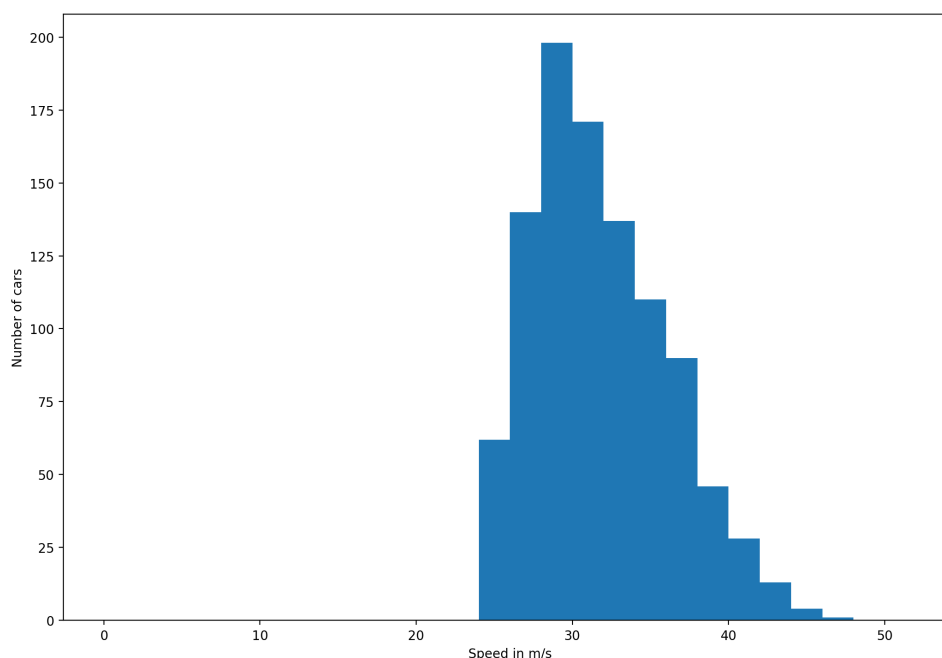
1.4 Histograms

A histogram is a bar chart that shows how many samples are in each group. In our example, we group cars by speed. Maybe we count the number of cars going between 30 and 32 m/s. And then we count the cars going between 32 and 34 m/s. And then we make a bar chart from that data.

Your 1000 cars would break up into these groups:

| | |
|-------------|----------|
| 0 - 2 m/s | 0 cars |
| 2 - 4 m/s | 0 cars |
| 4 - 6 m/s | 0 cars |
| ... | ... |
| 20 - 22 m/s | 0 cars |
| 22 - 24 m/s | 0 cars |
| 24 - 26 m/s | 65 cars |
| 26 - 28 m/s | 160 cars |
| 28 - 30 m/s | 175 cars |
| 30 - 32 m/s | 168 cars |
| 32 - 34 m/s | 150 cars |
| 34 - 36 m/s | 114 cars |
| 36 - 38 m/s | 79 cars |
| 38 - 40 m/s | 52 cars |
| 40 - 42 m/s | 20 cars |
| 42 - 44 m/s | 12 cars |
| 44 - 46 m/s | 4 cars |
| 46 - 48 m/s | 1 cars |
| 48 - 50 m/s | 0 cars |

Now we make a bar chart from that:



Often a histogram will tell the story of the data. Here, you can see that no one is going less than 24 m/s, but a lot of people travel at 30 m/s. There are a few people who travel over 40 m/s, but there are also a couple of people who drive a lot faster than anyone else.

1.5 Root-Mean-Squared

Scientists have a mean-like statistic that they love. It is named quadratic mean, but most just calls it Root-Mean-Squared or RMS.

Definition of RMS

If you have a list of numbers x_1, x_2, \dots, x_n , their RMS is

$$\sqrt{\frac{1}{n} (x_1^2 + x_2^2 + \dots + x_n^2)}$$

You are taking the square root of the mean of squares of the samples, thus the name Root-Mean-Squared.

Using your 12 samples:

| x | x ² |
|------------------------|----------------|
| 30.462 | 927.933 |
| 29.550 | 873.203 |
| 29.227 | 854.218 |
| 37.661 | 1418.351 |
| 27.899 | 778.354 |
| 28.113 | 790.341 |
| 24.382 | 594.482 |
| 35.668 | 1272.206 |
| 43.797 | 1918.177 |
| 31.312 | 980.441 |
| 37.637 | 1416.544 |
| 30.891 | 954.254 |
| Mean of x ² | 1064.875 |
| RMS | 32.632 |

Why is RMS useful? Let's say that all cars had the same mass m , and you need to know what the average kinetic energy per car is. If you know the RMS of the speeds of the cars is v_{rms} , the average kinetic energy for each car is

$$k = \frac{1}{2}mv_{\text{rms}}^2$$

(You don't believe me? Let's prove it. Substitute in the RMS:

$$k = \frac{1}{2}m\sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \dots + x_n^2)}^2$$

The square root and the square cancel each other out:

$$k = \frac{1}{2}m\frac{1}{n}(x_1^2 + x_2^2 + \dots + x_n^2)$$

Use the distributive property:

$$k = \frac{1}{n}\left(\frac{1}{2}mx_1^2 + \frac{1}{2}mx_2^2 + \dots + \frac{1}{2}mx_n^2\right)$$

That is all the kinetic energy divided by the number of cars, which is the mean kinetic energy per car. Quod erat demonstrandum! (That is a Latin phrase that means "which is what I was trying to demonstrate". You will sometimes see "QED" at the end of a long mathematic proof.)

Now you are ready for the punchline: kinetic energy and heat are the same thing. Instead of cars, heat is the kinetic energy of molecules moving around. More on this soon.

Video: Mean, Median, Mode: <https://www.youtube.com/watch?v=5C9LBF3b65s>

This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.

Answers to Exercises

Answer to Exercise 1 (on page 2)

$$\mu = \frac{1}{6} (87 + 91 + 98 + 65 + 87 + 100) = 88$$

Answer to Exercise 2 (on page 4)

The mean of your grades is 88.

The variance, then is

$$\sigma^2 = \frac{1}{6} \left((87 - 88)^2 + (91 - 88)^2 + (98 - 88)^2 + (61 - 88)^2 + (87 - 88)^2 + (100 - 88)^2 \right) = \frac{784}{6} = 65\frac{1}{3}$$

The standard deviation is the square root of that: $\sigma = 8.083$ points.

Answer to Exercise 3 (on page 5)

In order the grades are 65, 87, 87, 91, 98, 100. The middle two are 87 and 91. The mean of those is 89. (Speed trick: The mean of two numbers is the number that is half-way between.)



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