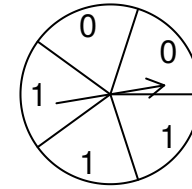


Population mean and standard deviation

- ▶ e.g. A Bernoulli variable with $p = \frac{3}{5}$



- ▶ Mean

$$\mu = \frac{0 + 0 + 1 + 1 + 1}{5} = \frac{3}{5} = 0.6$$

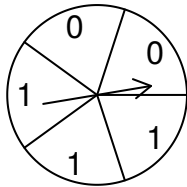
- ▶ Standard Deviation

$$\sigma = \sqrt{\frac{\left(0 - \frac{3}{5}\right)^2 + \left(0 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2}{5}}$$

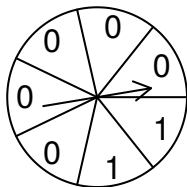
Binary Random Variable

Bernoulli Random Variable

- ▶ A Bernoulli random variable is a binary variable with two possible outcomes: 0 and 1.
- ▶ e.g. A Bernoulli random variable with $p = \frac{3}{5}$



- ▶ e.g. A Bernoulli random variable with $p = \frac{2}{7}$



Simplification...

$$\sigma = \sqrt{\frac{\left(0 - \frac{3}{5}\right)^2 + \left(0 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2 + \left(1 - \frac{3}{5}\right)^2}{5}}$$

$$= \sqrt{\frac{\left(\frac{3}{5}\right)^2 + \left(\frac{3}{5}\right)^2 + \left(\frac{2}{5}\right)^2 + \left(\frac{2}{5}\right)^2 + \left(\frac{2}{5}\right)^2}{5}}$$

$$= \sqrt{\frac{2\left(\frac{3}{5}\right)^2 + 3\left(\frac{2}{5}\right)^2}{5}}$$

$$= \sqrt{\frac{2}{5}\left(\frac{3}{5}\right)^2 + \frac{3}{5}\left(\frac{2}{5}\right)^2}$$

Continuation of simplification...

$$\begin{aligned}\sigma &= \sqrt{\frac{2}{5} \left(\frac{3}{5}\right)^2 + \frac{3}{5} \left(\frac{2}{5}\right)^2} \\ &= \sqrt{\frac{2}{5} \cdot \frac{3}{5} \cdot \left(\frac{3}{5} + \frac{2}{5}\right)} \\ &= \sqrt{\frac{2}{5} \cdot \frac{3}{5} \cdot 1} \\ &= \sqrt{\frac{2}{5} \cdot \frac{3}{5}} = 0.4898979\end{aligned}$$

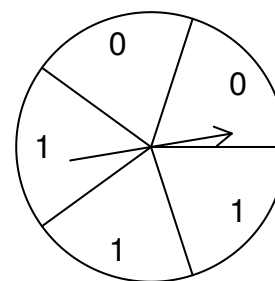
Generalization

- You can show that any Bernoulli variable has simple formulas for mean and standard deviation.

$$\begin{aligned}\mu &= p \\ \sigma &= \sqrt{p(1-p)}\end{aligned}$$

Sample mean and standard deviation

- If we spin this Bernoulli variable 25 times...



sample:

```
1 0 1 1 0
1 1 0 0 1
1 1 1 1 1
1 1 0 1 0
1 1 1 1 0
```

- We calculate the sample mean...

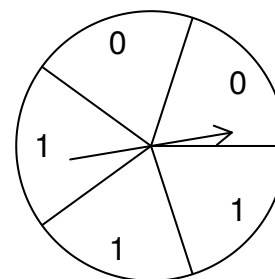
$$\bar{x} = \frac{18}{25} = 0.72$$

- We calculate the sample standard deviation...

$$s = \sqrt{\frac{7 \cdot (0 - 0.72)^2 + 18 \cdot (1 - 0.72)^2}{25 - 1}} = 0.4582576$$

Sample mean and standard deviation again

- If we spin this Bernoulli variable 25 times...



sample:

```
1 1 0 1 0
1 0 1 0 1
0 0 0 0 1
0 1 0 1 0
0 1 0 1 1
```

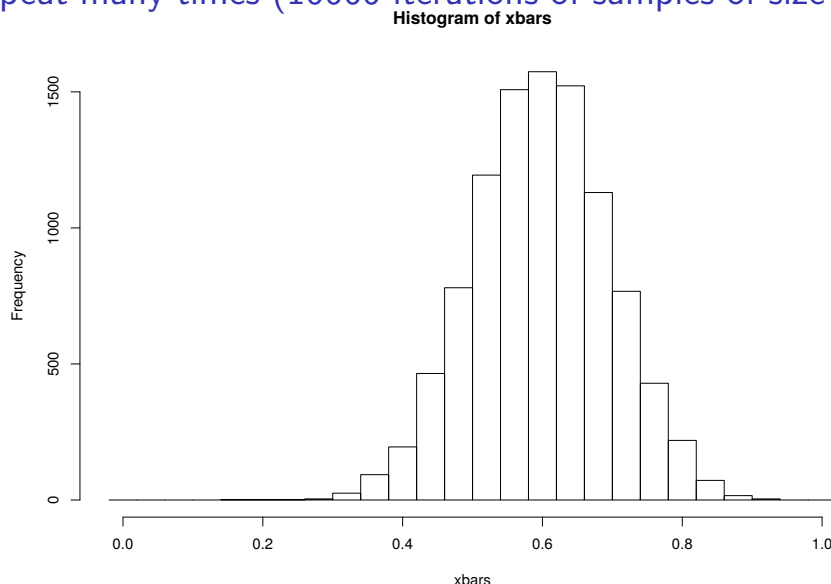
- We calculate the sample mean...

$$\bar{x} = \frac{12}{25} = 0.48$$

- We calculate the sample standard deviation...

$$s = \sqrt{\frac{13 \cdot (0 - 0.48)^2 + 12 \cdot (1 - 0.48)^2}{25 - 1}} = 0.509902$$

Repeat many times (10000 iterations of samples of size 25) Interval of typical sample means



- Estimate **the standard error** (the standard deviation of repeated sample means)

Standard error

- The standard error is the standard deviation of repeated sample means.
- We will use SE and $\sigma_{\bar{x}}$ to denote the standard error.
- We learned that standard deviation of a bell is approximately range/6.

$$\frac{0.9 - 0.3}{6} = 0.1$$

- We will later show that we can calculate standard error if we know σ .

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

- Notice, in our example, we can calculate the standard error using this formula.

$$\sigma_{\bar{x}} = \frac{0.4898979}{\sqrt{25}} = 0.0979796$$

We will define the **interval of typical sample means** as:

$$\text{interval of typical means} = \left(\mu - \frac{2\sigma}{\sqrt{n}}, \mu + \frac{2\sigma}{\sqrt{n}} \right)$$

- We expect about 95% of sample means to be in the interval of typical sample means.
- This is more true when n is larger or when the random variable is nearly normal.

Back to example.

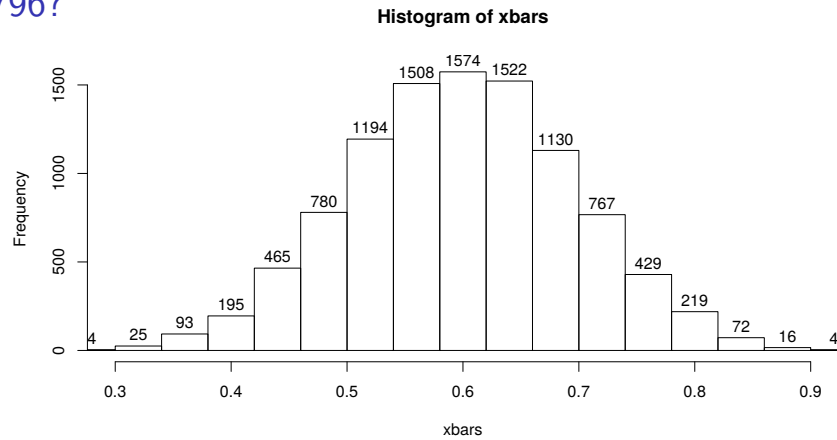
$$\mu = p = \frac{3}{5} = 0.6$$

$$\sigma = \sqrt{\frac{3}{5} \cdot \frac{2}{5}} = 0.4898979$$

$$n = 25$$

$$\begin{aligned} \text{interval of typical means} &= \left(\mu - \frac{2\sigma}{\sqrt{n}}, \mu + \frac{2\sigma}{\sqrt{n}} \right) \\ &= \left(0.6 - 2 \cdot \frac{0.4898979}{\sqrt{25}}, 0.6 + 2 \cdot \frac{0.4898979}{\sqrt{25}} \right) \\ &= (0.404, 0.796) \end{aligned}$$

What percent of sample means were between 0.404 and 0.796?



$$\frac{465 + 780 + 1194 + 1508 + 1574 + 1522 + 1130 + 767 + 429}{10000}$$

$$0.9369 = 93.69\%$$

Derivation of standard error

$$SD\left(\frac{X_1 + X_2 + X_3 + \cdots + X_{24} + X_{25}}{25}\right)$$

$$\sqrt{\frac{SD(X_1)^2}{25^2} + \frac{SD(X_2)^2}{25^2} + \cdots + \frac{SD(X_{25})^2}{25^2}}$$

$$\sqrt{\frac{25 \cdot SD(X)^2}{25^2}}$$

$$\frac{SD(X)}{5}$$