

Chapter 5: Foundations for inference

STA 101, Summer I 2021, Duke University

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Point estimates and sampling variability

Point estimates and error

- We are often interested in *population parameters*.
- Complete populations are difficult to collect data on, so we use *sample statistics* as *point estimates* for the unknown population parameters of interest.
- *Error* in the estimate = difference between population parameter and sample statistic
- *Bias* is systematic tendency to over- or under-estimate the true population parameter.
- *Sampling error* describes how much an estimate will tend to vary from one sample to the next.
- Much of statistics is focused on understanding and quantifying sampling error, and *sample size* is helpful for quantifying this error.

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Not the same, but only somewhat different.

Young, Underemployed and Optimistic

Coming of Age, Slowly, in a Tough Economy

Young adults hit hard by the recession. A plurality of the public (41%) believes young adults, rather than middle-aged or older adults, are having the toughest time in today's economy. An analysis of government economic data suggests that this perception is correct. The recent indicators on the nation's labor market show a decline in the

Tough economic times altering young adults' daily lives, long-term plans. While negative trends in the labor market have been felt most acutely by the youngest workers, many adults in their late 20s and early 30s have also felt the impact of the weak economy. Among all 18- to 34-year-olds, fully half (49%) say they have taken a job they didn't want just to pay the bills, with 24% saying they have taken an unpaid job to gain work experience. And more than one-third (35%) say that, as a result of the poor economy, they have gone back to school. Their personal lives have also been affected: 31% have postponed either getting married or having a baby (22% say they have postponed having a baby and 20% have put off getting married). One-in-four (24%) say they have moved back in with their parents after living on their own.

Margin of error

The general public survey is based on telephone interviews conducted Dec. 6-19, 2011, with a nationally representative sample of 2,048 adults ages 18 and older living in the continental United States, including an oversample of 346 adults ages 18 to 34. A total of 769 interviews were completed with respondents contacted by landline telephone and 1,279 with those contacted on their cellular phone. Data are weighted to produce a final sample that is representative of the general population of adults in the continental United States. Survey interviews were conducted under the direction of Princeton Survey Research Associates International, in English and Spanish. Margin of sampling error is plus or minus 2.9 percentage points for results based on the total sample and 4.4 percentage points for adults ages 18-34 at the 95% confidence level.

- $41\% \pm 2.9\%$: We are 95% confident that 38.1% to 43.9% of the public believe young adults, rather than middle-aged or older adults, are having the toughest time in today's economy.
- $49\% \pm 4.4\%$: We are 95% confident that 44.6% to 53.4% of 18-34 years olds have taken a job they didn't want just to pay the bills.

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More likely.

Suppose that you don't have access to the population of all American adults, which is a quite likely scenario. In order to estimate the proportion of American adults who support solar power expansion, you might sample from the population and use your sample proportion as the best guess for the unknown population proportion.

- Sample, with replacement, 1000 American adults from the population, and record whether they support or not solar power expansion.
- Find the sample proportion.
- Plot the distribution of the sample proportions obtained by members of the class.

```
# 1. Create a set of 250 million entries, where 88\% of  
# them are "support" and 12\% are "not".
```

```
pop_size <- 2500000000  
possible_entries <- c(rep("support", 0.88 * pop_size),  
                      rep("not", 0.12 * pop_size))
```

```
# 2. Sample 1000 entries without replacement.
```

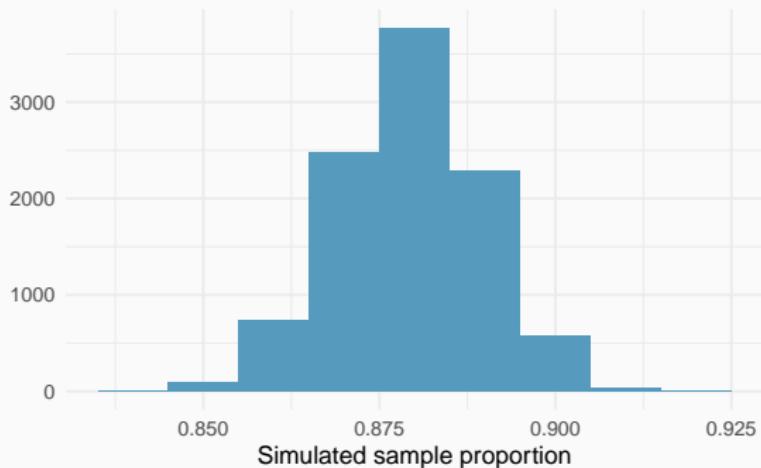
```
sampled_entries <- sample(possible_entries, size = 1000)
```

```
# 3. Compute p-hat: count the number that are "support",  
# then divide by # the sample size.
```

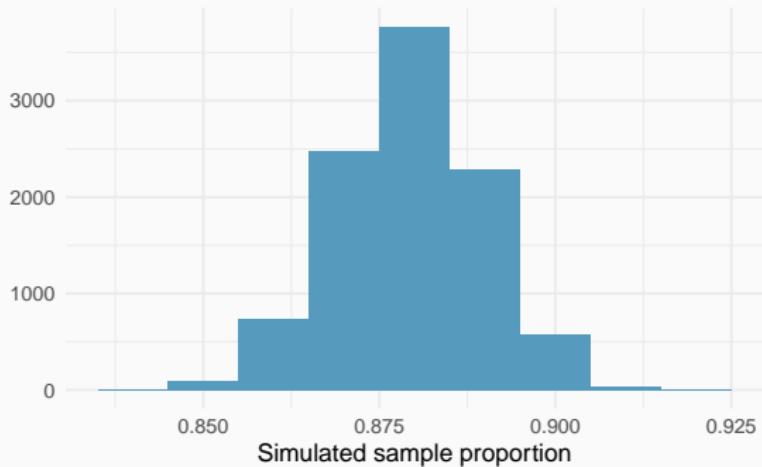
```
sum(sampled_entries == "support") / 1000
```

Sampling distribution

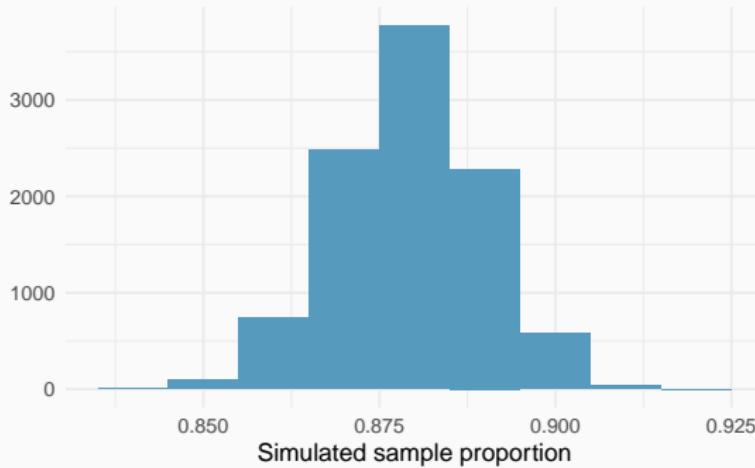
Suppose you were to repeat this process many times and obtain many \hat{p} s. This distribution is called a *sampling distribution*.



What is the shape and center of this distribution? Based on this distribution, what do you think is the true population proportion?



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The distribution is unimodal and roughly symmetric. A reasonable guess for the true population proportion is the center of this distribution, approximately 0.88.

Sampling distributions are never observed

- In real-world applications, we never actually observe the sampling distribution, yet it is useful to always think of a point estimate as coming from such a hypothetical distribution.
- Understanding the sampling distribution will help us characterize and make sense of the point estimates that we do observe.

Central Limit Theorem

Central limit theorem

Sample proportions will be nearly normally distributed with mean equal to the population proportion, p , and standard error equal to $\sqrt{\frac{p(1-p)}{n}}$.

$$\hat{p} \sim N\left(\text{mean} = p, SE = \sqrt{\frac{p(1-p)}{n}}\right)$$

- It wasn't a coincidence that the sampling distribution we saw earlier was symmetric, and centered at the true population proportion.

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- It wasn't a coincidence that the sampling distribution we saw earlier was symmetric, and centered at the true population proportion.
- We won't go through a detailed proof of why $SE = \sqrt{\frac{p(1-p)}{n}}$, but note that as n increases SE decreases.
 - As n increases samples will yield more consistent \hat{p} s, i.e. variability among \hat{p} s will be lower.

CLT - conditions

Certain conditions must be met for the CLT to apply:

1. *Independence*: Sampled observations must be independent.
This is difficult to verify, but is more likely if
 - random sampling/assignment is used, and
 - if sampling without replacement, $n < 10\%$ of the population.

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This is difficult to verify, but is more likely if
 - random sampling/assignment is used, and
 - if sampling without replacement, $n < 10\%$ of the population.
2. *Sample size*: There should be at least 10 expected successes and 10 expected failures in the observed sample.
This is difficult to verify if you don't know the population proportion (or can't assume a value for it). In those cases we look for the number of observed successes and failures to be at least 10.

When p is unknown

- The CLT states $SE = \sqrt{\frac{p(1-p)}{n}}$, with the condition that np and $n(1 - p)$ are at least 10, however we often don't know the value of p , the population proportion
- In these cases we substitute \hat{p} for p

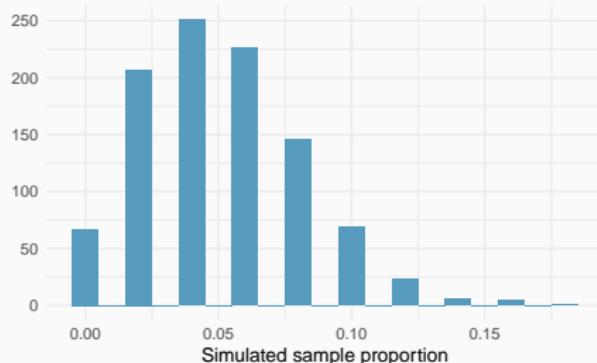
When p is low

Suppose we have a population where the true population proportion is $p = 0.05$, and we take random samples of size $n = 50$ from this population. We calculate the sample proportion in each sample and plot these proportions. Would you expect this distribution to be nearly normal? Why, or why not?

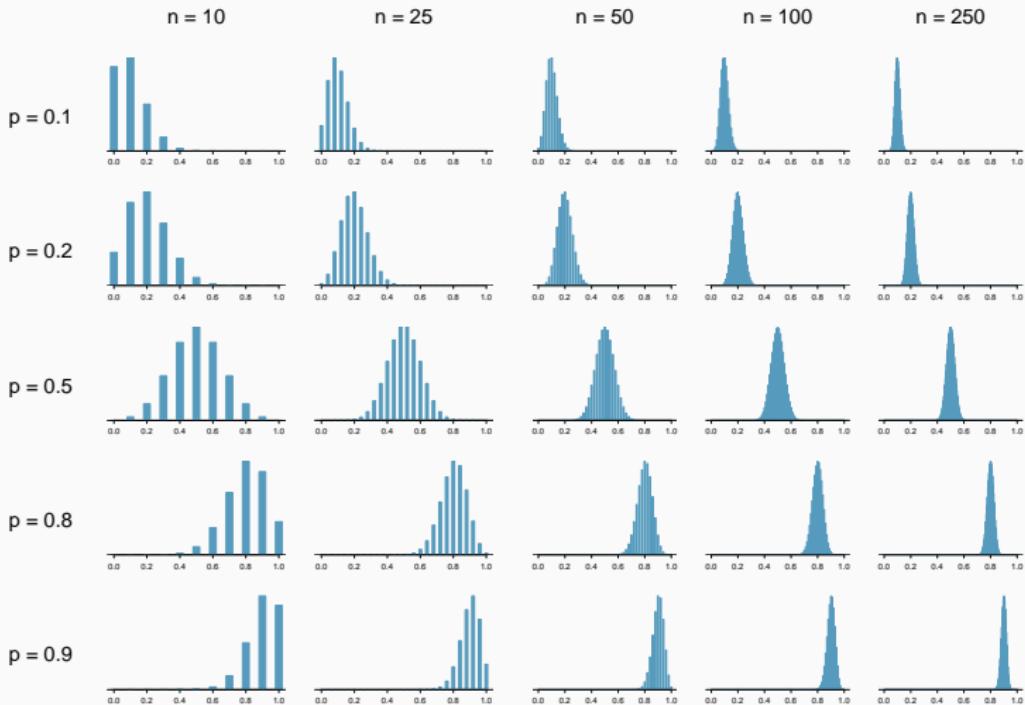
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*No, the success-failure condition is not met ($50 * 0.05 = 2.5$), hence we would not expect the sampling distribution to be nearly normal.*



What happens when np and/or $n(1 - p) < 10$?



When the conditions are not met...

- When either np or $n(1 - p)$ is small, the distribution is more discrete.
- When np or $n(1 - p) < 10$, the distribution is more skewed.
- The larger both np and $n(1 - p)$, the more normal the distribution.
- When np and $n(1 - p)$ are both very large, the discreteness of the distribution is hardly evident, and the distribution looks much more like a normal distribution.

Extending the framework for other statistics

- The strategy of using a sample statistic to estimate a parameter is quite common, and it's a strategy that we can apply to other statistics besides a proportion.
 - Take a random sample of students at a college and ask them how many extracurricular activities they are involved in to estimate the average number of extra curricular activities all students in this college are interested in.
- The principles and general ideas are from this chapter apply to other parameters as well, even if the details change a little.

Confidence intervals for a proportion

Confidence intervals

- A plausible range of values for the population parameter is called a *confidence interval*.
- Using only a sample statistic to estimate a parameter is like fishing in a murky lake with a spear, and using a confidence interval is like fishing with a net.



We can throw a spear where we saw a fish but we will probably miss. If we toss a net in that area, we have a good chance of catching the fish.



- If we report a point estimate, we probably won't hit the exact population parameter. If we report a range of plausible values we have a good shot at capturing the parameter.

Photos by Mark Fischer (<http://www.flickr.com/photos/fischerotos/7439791462>) and Chris Penny

(<http://www.flickr.com/photos/clearlydived/7029109617>) on Flickr.

Facebook's categorization of user interests

Most commercial websites (e.g. social media platforms, news outlets, online retailers) collect data about their users' behaviors and use these data to deliver targeted content, recommendations, and ads. To understand whether Americans think their lives line up with how the algorithm-driven classification systems categorizes them, Pew Research asked a representative sample of 850 American Facebook users how accurately they feel the list of categories Facebook has listed for them on the page of their supposed interests actually represents them and their interests. 67% of the respondents said that the listed categories were accurate.

Estimate the true proportion of American Facebook users who think the Facebook categorizes their interests accurately.

Facebook's categorization of user interests

$$\hat{p} = 0.67 \quad n = 850$$

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$$\begin{aligned}\hat{p} \pm 1.96 \times SE &= 0.67 \pm 1.96 \times 0.016 \\ &= (0.67 - 0.03, 0.67 + 0.03)\end{aligned}$$

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$$\begin{aligned}\hat{p} \pm 1.96 \times SE &= 0.67 \pm 1.96 \times 0.016 \\ &= (0.67 - 0.03, 0.67 + 0.03) \\ &= (0.64, 0.70)\end{aligned}$$

Which of the following is the correct interpretation of this confidence interval?

We are 95% confident that

- (a) 64% to 70% of American Facebook users in this sample think Facebook categorizes their interests accurately.
- (b) 64% to 70% of all American Facebook users think Facebook categorizes their interests accurately
- (c) there is a 64% to 70% chance that a randomly chosen American Facebook user's interests are categorized accurately.
- (d) there is a 64% to 70% chance that 95% of American Facebook users' interests are categorized accurately.

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- (d) there is a 64% to 70% chance that 95% of American Facebook users' interests are categorized accurately.

What does 95% confident mean?

- Suppose we took many samples and built a confidence interval from each sample using the equation
point estimate $\pm 1.96 \times SE$.
- Then about 95% of those intervals would contain the true population proportion (p).

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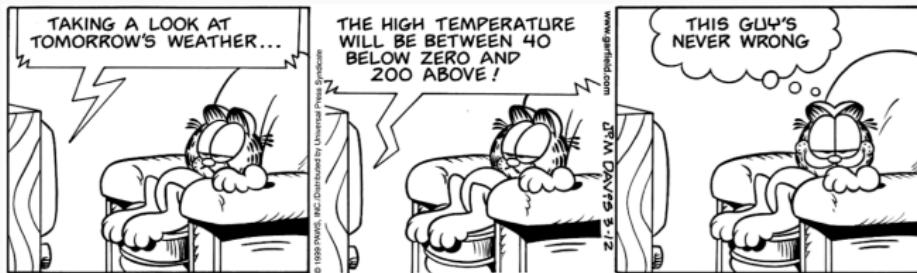
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A wider interval.

Can you see any drawbacks to using a wider interval?

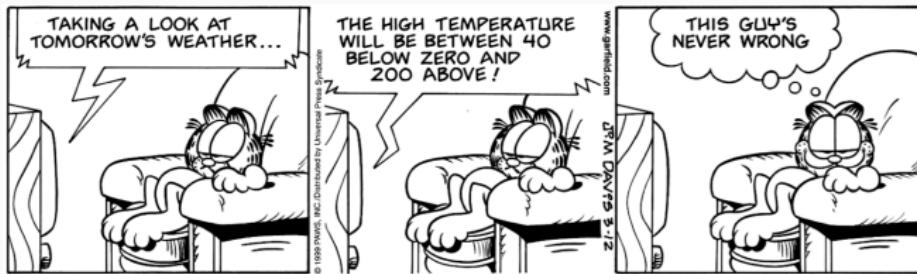


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A wider interval.

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If the interval is too wide it may not be very informative.

Changing the confidence level

$$\text{point estimate} \pm z^* \times SE$$

- In a confidence interval, $z^* \times SE$ is called the *margin of error*, and for a given sample, the margin of error changes as the confidence level changes.
- In order to change the confidence level we need to adjust z^* in the above formula.
- Commonly used confidence levels in practice are 90%, 95%, 98%, and 99%.
- For a 95% confidence interval, $z^* = 1.96$.
- However, using the standard normal (z) distribution, it is possible to find the appropriate z^* for any confidence level.

Which of the below Z scores is the appropriate z^* when calculating a 98% confidence interval?

(a) $Z = 2.05$

(b) $Z = 1.96$

(c) $Z = 2.33$

(d) $Z = -2.33$

(e) $Z = -1.65$

Which of the below Z scores is the appropriate z^* when calculating a 98% confidence interval?

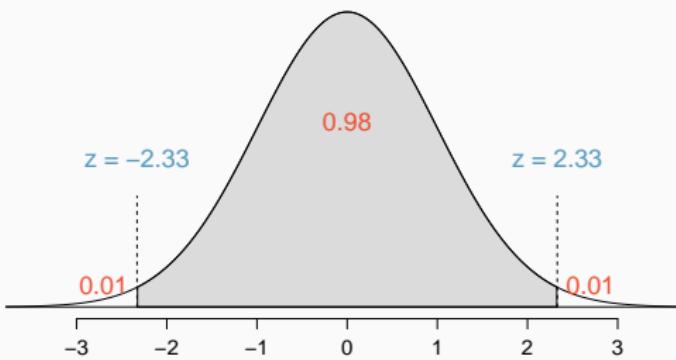
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Interpreting confidence intervals

Confidence intervals are ...

- always about the population
- not probability statements
- only about population parameters, not individual observations
- only reliable if the sample statistic they're based on is an unbiased estimator of the population parameter

Hypothesis testing for a proportion

Remember when...

Gender discrimination experiment:

Gender	Promotion		Total
	Promoted	Not Promoted	
Male	21	3	24
Female	14	10	24
Total	35	13	48

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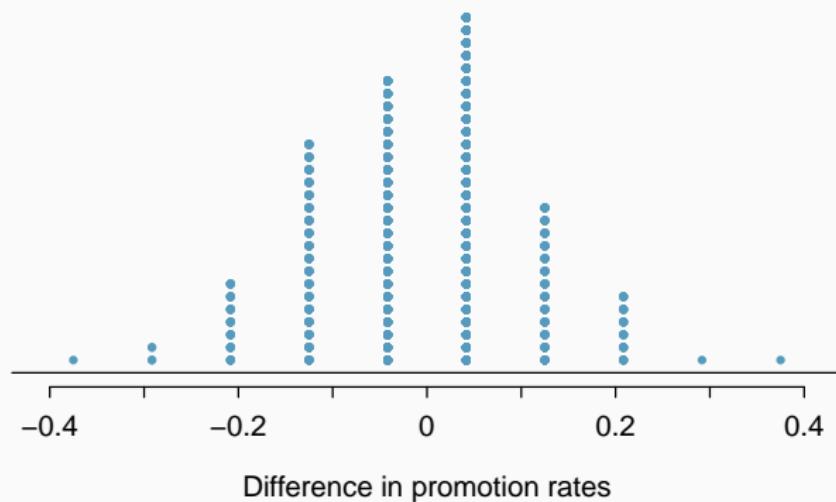
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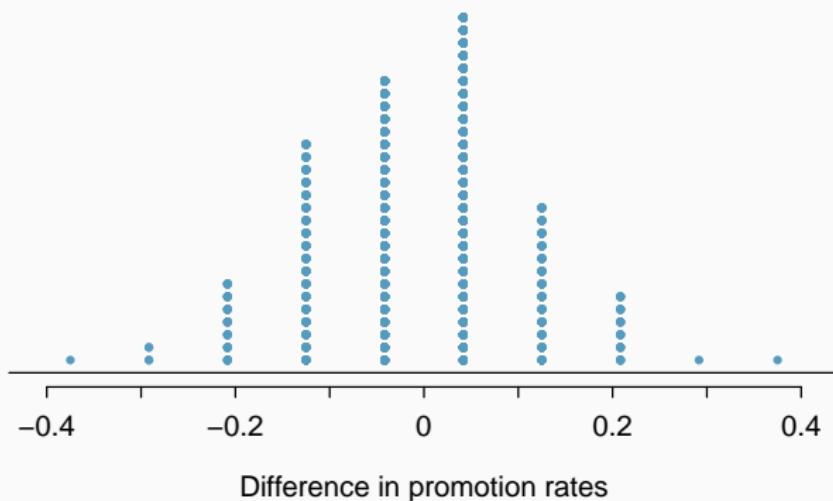
Possible explanations:

- Promotion and gender are *independent*, no gender discrimination, observed difference in proportions is simply due to chance. → *null* - (nothing is going on)
- Promotion and gender are *dependent*, there is gender discrimination, observed difference in proportions is not due to chance. → *alternative* - (something is going on)

Result



Result



Since it was quite unlikely to obtain results like the actual data or something more extreme in the simulations (male promotions being 30% or more higher than female promotions), we decided to reject the null hypothesis in favor of the alternative.

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We'll formally introduce the hypothesis testing framework using an example on testing a claim about a proportion.

Testing hypotheses using confidence intervals

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- The associated hypotheses are:

$H_0: p = 0.50$: 50% of American Facebook users think Facebook categorizes their interests accurately

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- Null value is not included in the interval → reject the null hypothesis.
- This is a quick-and-dirty approach for hypothesis testing, but it doesn't tell us the likelihood of certain outcomes under the null hypothesis (p-value).

Decision errors

- Hypothesis tests are not flawless.
- In the court system innocent people are sometimes wrongly convicted and the guilty sometimes walk free.
- Similarly, we can make a wrong decision in statistical hypothesis tests as well.
- The difference is that we have the tools necessary to quantify how often we make errors in statistics.

Decision errors (cont.)

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		Decision	
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	H_A true	Type 2 Error	✓

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- A *Type 1 Error* is rejecting the null hypothesis when H_0 is true.
- A *Type 2 Error* is failing to reject the null hypothesis when H_A is true.
- We (almost) never know if H_0 or H_A is true, but we need to consider all possibilities.

Hypothesis Test as a trial

If we again think of a hypothesis test as a criminal trial then it makes sense to frame the verdict in terms of the null and alternative hypotheses:

H_0 : Defendant is innocent

H_A : Defendant is guilty

Which type of error is being committed in the following circumstances?

- Declaring the defendant innocent when they are actually guilty
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Type 1 error

Which error do you think is the worse error to make?

"better that ten guilty persons escape than that one innocent suffer"

– William Blackstone

Type 1 error rate

- As a general rule we reject H_0 when the p-value is less than 0.05, i.e. we use a *significance level* of 0.05, $\alpha = 0.05$.

Type 1 error rate

- As a general rule we reject H_0 when the p-value is less than 0.05, i.e. we use a *significance level* of 0.05, $\alpha = 0.05$.
- This means that, for those cases where H_0 is actually true, we do not want to incorrectly reject it more than 5% of those times.

Type 1 error rate

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- This is why we prefer small values of α – increasing α increases the Type 1 error rate.

Facebook interest categories

The same survey asked the 850 respondents how comfortable they are with Facebook creating a list of categories for them. 41% of the respondents said they are comfortable. Do these data provide convincing evidence that the proportion of American Facebook users are comfortable with Facebook creating a list of interest categories for them is different than 50%?

<https://www.pewinternet.org/2019/01/16/facebook-algorithms-and-personal-data/>

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- There may be two explanations why our sample proportion is lower than 0.50 (minority).
 - The true population proportion is different than 0.50.
 - The true population mean is 0.50, and the difference between the true population proportion and the sample proportion is simply due to natural sampling variability.

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$$H_0 : p = 0.50$$

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$$H_0 : p = 0.50$$

- We test the claim that the proportion of American Facebook users who are comfortable with Facebook creating categories of interests for them is different than 50%

$$H_A : p \neq 0.50$$

Facebook interest categories - conditions

Which of the following is not a condition that needs to be met to proceed with this hypothesis test?

- (a) Respondents in the sample should be independent of each other with respect to whether or not they feel comfortable with their interests being categorized by Facebook.
- (b) Sampling should have been done randomly.
- (c) The sample size should be less than 10% of the population of all American Facebook users.
- (d) There should be at least 30 respondents in the sample.
- (e) There should be at least 10 expected successes and 10 expected failure.

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Yes, and we can quantify how unusual it is using a *p-value*.

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- If the p-value is *high* (higher than α) we say that it is likely to observe the data even if the null hypothesis were true, and hence *do not reject H_0* .

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$$P(\hat{p} < 0.41 \text{ or } \hat{p} > 0.59 \mid p = 0.50) = P(|Z| > 5.26) < 0.0001$$

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- The data provide convincing evidence that the proportion of American FB users who are comfortable with FB creating a list of interest categories for them is different than 50%.
- The difference between the null value of 0.50 and observed sample proportion of 0.41 is *not due to chance* or sampling variability.

Choosing a significance level

- While the traditional level is 0.05, it is helpful to adjust the significance level based on the application.
- Select a level that is smaller or larger than 0.05 depending on the consequences of any conclusions reached from the test.
- If making a Type 1 Error is dangerous or especially costly, we should choose a small significance level (e.g. 0.01). Under this scenario we want to be very cautious about rejecting the null hypothesis, so we demand very strong evidence favoring H_A before we would reject H_0 .
- If a Type 2 Error is relatively more dangerous or much more costly than a Type 1 Error, then we should choose a higher significance level (e.g. 0.10). Here we want to be cautious about failing to reject H_0 when the null is actually false.

One vs. two sided hypothesis tests

- In two sided hypothesis tests we are interested in whether p is either above or below some null value p_0 : $H_A : p \neq p_0$.
- In one sided hypothesis tests we are interested in p differing from the null value p_0 in one direction (and not the other):
 - If there is only value in detecting if population parameter is less than p_0 , then $H_A : p < p_0$.
 - If there is only value in detecting if population parameter is greater than p_0 , then $H_A : p > p_0$.
- Two-sided tests are often more appropriate as we often want to detect if the data goes clearly in the opposite direction of our alternative hypothesis as well.