

# Inference and Permutations With An Application to the Gender Pay Gap in the United States

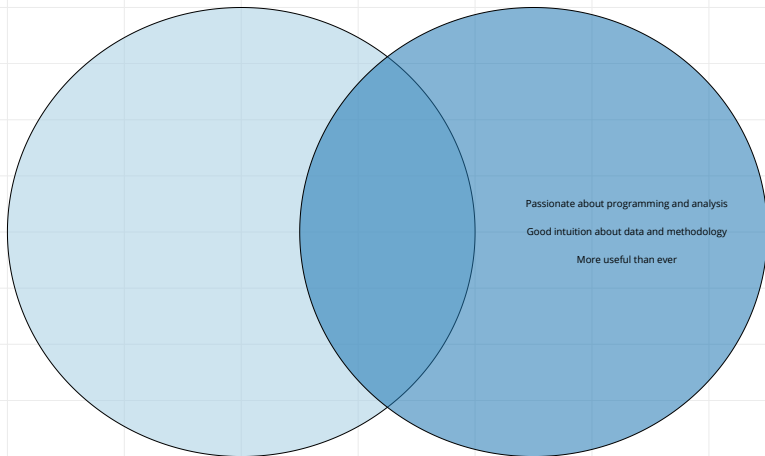
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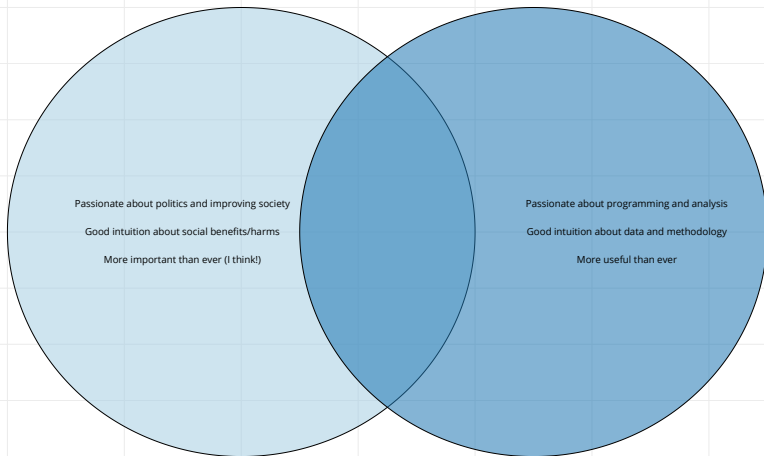


# Goals for Today

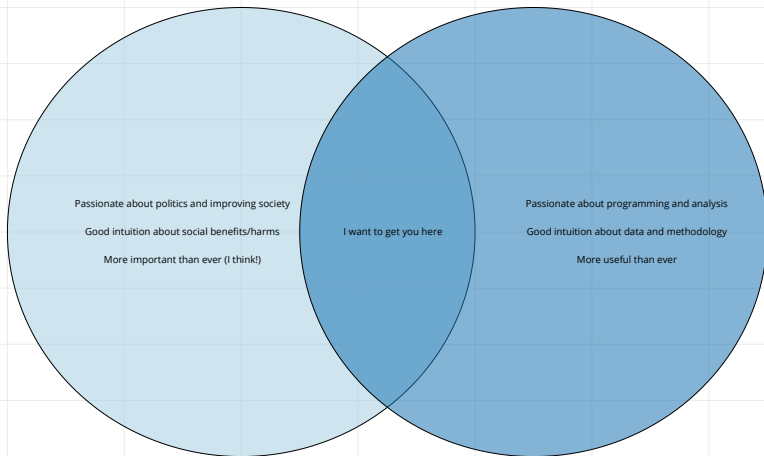
1. Learn more about the gender pay gap (in the U.S.)
2. Discuss two paths to statistical inference
3. Tell you a bit more about myself



 Political Science Students  Statistics/Computer Science Students



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$$-V_{eq} \frac{dM}{dt}$$

$$dM = -V_{eq} dM$$

$$du = -V_{eq} \frac{dM}{M}$$

$$\Delta u = -V_{eq} \ln(\tau) \Big|_{rf}^{re}$$

$$\sum_{i=1}^{100} i = \frac{n(n+1)}{2} = \frac{1000+1001}{2} =$$

$$PV = nRT$$

$$\omega = 2\pi f$$

instantaneous mass of rocket  
velocity of rocket  
time

$$F = \text{net force} = \text{thrust} = \dot{m} V_{eq}$$

$$\text{equivalent engine exhaust velocity} = I_{sp} g_0$$

$$M = \bar{F} d \cos \alpha$$

$$\frac{m_1 + m_2}{r^2}$$

$$\int \frac{1}{x^2 + 3x} dx$$

$$\iint$$

$$\sum_{i=1}^{100} i^2$$

Newton's second law of motion:

$$\frac{dM}{dt} = F = V_{eq} \frac{dM}{dt}$$

$$M^2 du + u dM = V_{eq} dM$$

$$M du = -V_{eq} dM$$

$$du = -V_{eq} \frac{dM}{M}$$

$$\Delta u = -V_{eq} \ln(\tau) \Big|_{rf}^{re}$$

Assume the rocket  
with rocket  
→ u = 0

$$\sum_{i=1}^{100} i$$

$$\Delta u = V_{eq} \ln\left(\frac{m_i}{m_e}\right) = V_{eq} \ln MR = I_{sp} g_0$$

$$F = \text{net force} = \text{thrust} = \dot{m} V_{eq}$$

Newton's second law of motion:

$$\frac{dM}{dt} = F = V_{eq} \frac{dM}{dt}$$

$$2 M du + u dM = V_{eq} dM$$

# My Perspective

1. *If you can learn about programming a computer to do something, you have direct access to the deepest, most fundamental ideas in statistics.*
2. Statistics aren't *that* mystifying (but the notation can be unintuitive).

You just need a problem you want to solve.

- Your computer will solve it for you.

## Motivating Issue: The Gender Pay Gap





# UNCONTROLLED GENDER PAY GAP

THIS MEASURES MEDIAN SALARY FOR ALL MEN AND ALL WOMEN

WOMEN EARN

81¢

FOR EVERY \$1  
EARNED BY MEN

# The Data

Let's bring individual-level survey data to bear on this topic.

- *Data*: General Social Survey (2010-2018). *N*: 914.
- *Outcome*: respondent's income (in 2019 USD)
- *Treatment*: respondent's gender (male, female)

Other notes:

- Data subset to those single/never married, with no children, and working full time.
- Data processed/matched to be identical in expectation for age, occupational prestige, college education.
- Raw data available in `gss_wages` in my `{stevedata}` R package.

Table 1: Income Averages for Men and Women in the General Social Survey (2010-2018)

<b>Gender</b>	<b>Average Income</b>	<b>Std. Dev.</b>	<b>N</b>
Female	51086	55360	457
Male	61756	76753	457

On average, women earn \$10,670 less than men (or 82% of the average man's income).

**Skeptic's argument:** A \$10,670 difference in income between men and women could have been observed just by random chance.

**Advocate's argument:** A \$10,670 difference in income between men and women is an important difference and is unlikely to have been observed by random chance.

1. The STAT 101 (analytical) method
2. The computational method

# The STAT 101 (Analytical) Method

To do a (two-sample [Welch's])  $t$ -test, you'll need to calculate:

- $t$ -statistic
- degrees of freedom
- critical value for rejecting skeptic's argument.

## Calculating a $t$ -statistic

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$

$$t = \frac{51086 - 61756}{\sqrt{\frac{55360^2}{457} + \frac{76753^2}{457}}}$$

$$t \approx -2.41$$





## Obtaining Degrees of Freedom

$$\nu \approx \frac{\left( \frac{s_1^2}{N_1} + \frac{s_2^2}{N_2} \right)^2}{\frac{s_1^4}{N_1^2 \nu_1} + \frac{s_2^4}{N_2^2 \nu_2}}$$



## Obtaining Degrees of Freedom

$$\nu \approx \frac{\left( \frac{s_1^2}{N_1} + \frac{s_2^2}{N_2} \right)^2}{\frac{s_1^4}{N_1^2 \nu_1} + \frac{s_2^4}{N_2^2 \nu_2}}$$

$$\nu \approx \frac{\left( \frac{55360^2}{457} + \frac{76753^2}{457} \right)^2}{\frac{55360^4}{457^2 456} + \frac{76753^4}{457^2 456}}$$

$$\nu \approx 829.39$$

# The $t$ -distribution

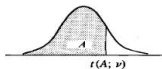
$$\frac{\Gamma(\frac{\nu+1}{2})}{\sqrt{\nu\pi} \Gamma(\frac{\nu}{2})} \left(1 + \frac{x^2}{\nu}\right)^{-\frac{\nu+1}{2}}$$

where

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x} dx$$



Entry is  $t(A; \nu)$  where  $P\{t(\nu) \leq t(A; \nu)\} = A$



$\nu$	$A$						
	.60	.70	.80	.85	.90	.95	.975
1	0.325	0.727	1.376	1.963	3.078	6.314	12.706
2	0.289	0.617	1.061	1.386	1.886	2.920	4.303
3	0.277	0.584	0.978	1.250	1.638	2.353	3.182
4	0.271	0.569	0.941	1.190	1.533	2.132	2.776
5	0.267	0.559	0.920	1.156	1.476	2.015	2.571
6	0.265	0.553	0.906	1.134	1.440	1.943	2.447
7	0.263	0.549	0.896	1.119	1.415	1.895	2.365
8	0.262	0.546	0.889	1.108	1.397	1.860	2.306
9	0.261	0.543	0.883	1.100	1.383	1.833	2.262
10	0.260	0.542	0.879	1.093	1.372	1.812	2.228
11	0.260	0.540	0.876	1.088	1.363	1.796	2.201
12	0.259	0.539	0.873	1.083	1.356	1.782	2.179
13	0.259	0.537	0.870	1.079	1.350	1.771	2.160
14	0.258	0.537	0.868	1.076	1.345	1.761	2.145
15	0.258	0.536	0.866	1.074	1.341	1.753	2.131
16	0.258	0.535	0.865	1.071	1.337	1.746	2.120
17	0.257	0.534	0.863	1.069	1.333	1.740	2.110
18	0.257	0.534	0.862	1.067	1.330	1.734	2.101
19	0.257	0.533	0.861	1.066	1.328	1.729	2.093
20	0.257	0.533	0.860	1.064	1.325	1.725	2.086
21	0.257	0.532	0.859	1.063	1.323	1.721	2.080
22	0.256	0.532	0.858	1.061	1.321	1.717	2.074
23	0.256	0.532	0.858	1.060	1.319	1.714	2.069
24	0.256	0.531	0.857	1.059	1.318	1.711	2.064
25	0.256	0.531	0.856	1.058	1.316	1.708	2.060
26	0.256	0.531	0.856	1.058	1.315	1.706	2.056
27	0.256	0.531	0.855	1.057	1.314	1.703	2.052
28	0.256	0.530	0.855	1.056	1.313	1.701	2.048
29	0.256	0.530	0.854	1.055	1.311	1.699	2.045
30	0.256	0.530	0.854	1.055	1.310	1.697	2.042
40	0.255	0.529	0.851	1.050	1.303	1.684	2.021
60	0.254	0.527	0.848	1.045	1.296	1.671	2.000
120	0.254	0.526	0.845	1.041	1.289	1.658	1.980
$\infty$	0.253	0.524	0.842	1.036	1.282	1.645	1.960

What distribution?

[t-Student ▼](#)

What type of test?

[Two-tailed ▼](#)

Degrees of freedom (d)

829.39

Significance level

0.05

The test statistic follows the t-distribution with 829.39 degrees of freedom.

Critical value:  $\pm 1.9628$

Critical region:

$(-\infty, -1.9628] \cup [1.9628, \infty)$

# The STAT 101 (Analytical) Method

Since  $|-2.41| > 1.9628$ , we can reject the skeptic's argument.

- The observed test statistic exceedingly rare, far from typical.

But there's got to be a better way.



## In R

For one, make the computer do it for you.

```
broom::tidy(t.test(realrinc20 ~ gender,  
                  data = wages10_matched)) %>%  
  # estimate1 = mean for women. estimate2 = mean for men  
  rename(diff = estimate,  
         t_stat = statistic,  
         df = parameter) %>%  
  select(diff:df)
```

```
## # A tibble: 1 x 6  
##       diff estimate1 estimate2 t_stat p.value    df  
##   <dbl>      <dbl>      <dbl> <dbl>   <dbl> <dbl>  
## 1 -10670.    51086.    61756.  -2.41  0.0162  829.
```

# The Computational Method

A computational alternative, called “permutations”, may be more accessible.

- Permutations randomly shuffle the outcome variable and recalculate statistics of interest.

Recall the skeptic’s argument: there are no meaningful differences by gender; the difference is due to chance.

- Permutation allows us to regenerate data to test the skeptic’s argument.

Table 2: Ten Select Gender-Income Pairings

Gender	Income
Female	45674
Female	82214
Female	33494
Female	23633
Female	48037
Male	100484
Male	28927
Male	66989
Male	61169
Male	72056

Table 3: Ten Select Gender-Income Pairings, with a Permutation

Gender	Income	Perm. 1
Female	45674	23633
Female	82214	33494
Female	33494	45674
Female	23633	100484
Female	48037	48037
Male	100484	61169
Male	28927	28927
Male	66989	66989
Male	61169	82214
Male	72056	72056

Table 4: Ten Select Gender-Income Pairings, with Two Permutations

Gender	Income	Perm. 1	Perm. 2
Female	45674	23633	82214
Female	82214	33494	33494
Female	33494	45674	100484
Female	23633	100484	23633
Female	48037	48037	66989
Male	100484	61169	61169
Male	28927	28927	28927
Male	66989	66989	45674
Male	61169	82214	72056
Male	72056	72056	48037

Table 5: Ten Select Gender-Income Pairings, with Three Permutations

Gender	Income	Perm. 1	Perm. 2	Perm. 3
Female	45674	23633	82214	61169
Female	82214	33494	33494	33494
Female	33494	45674	100484	28927
Female	23633	100484	23633	100484
Female	48037	48037	66989	23633
Male	100484	61169	61169	45674
Male	28927	28927	28927	82214
Male	66989	66989	45674	72056
Male	61169	82214	72056	48037
Male	72056	72056	48037	66989

Table 6: Ten Select Gender-Income Pairings, with Four Permutations

Gender	Income	Perm. 1	Perm. 2	Perm. 3	Perm. 4
Female	45674	23633	82214	61169	66989
Female	82214	33494	33494	33494	61169
Female	33494	45674	100484	28927	72056
Female	23633	100484	23633	100484	23633
Female	48037	48037	66989	23633	82214
Male	100484	61169	61169	45674	48037
Male	28927	28927	28927	82214	100484
Male	66989	66989	45674	72056	33494
Male	61169	82214	72056	48037	28927
Male	72056	72056	48037	66989	45674

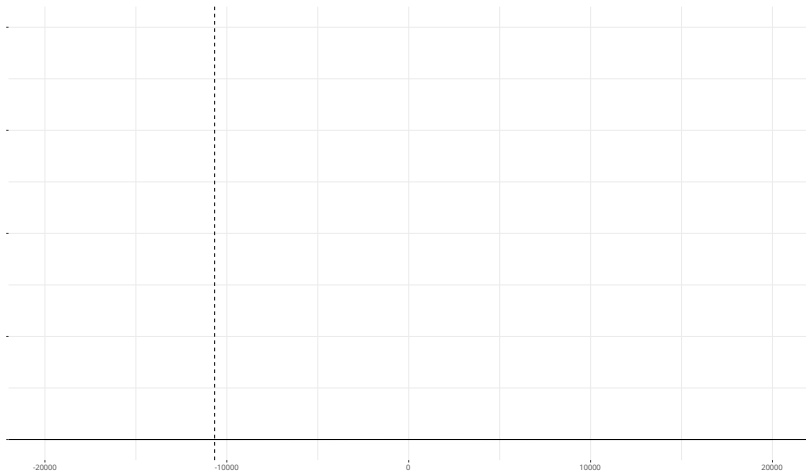
Table 7: Ten Select Gender-Income Pairings, with Five Permutations

Gender	Income	Perm. 1	Perm. 2	Perm. 3	Perm. 4	Perm. 5
Female	45674	23633	82214	61169	66989	82214
Female	82214	33494	33494	33494	61169	28927
Female	33494	45674	100484	28927	72056	33494
Female	23633	100484	23633	100484	23633	100484
Female	48037	48037	66989	23633	82214	48037
Male	100484	61169	61169	45674	48037	66989
Male	28927	28927	28927	82214	100484	45674
Male	66989	66989	45674	72056	33494	72056
Male	61169	82214	72056	48037	28927	23633
Male	72056	72056	48037	66989	45674	61169



## The Distribution of Possible Average Income Differences Between Men and Women

This effectively blank (for now) plot has a single dashed vertical line representing the actual difference (-\$10,670).



*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

Table 8: Average Income Differences Between Men and Women Across Permutations

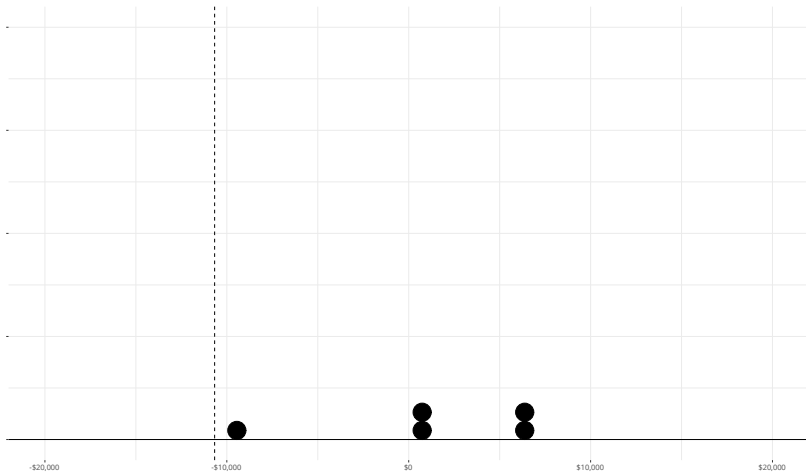
<b>Perm. No.</b>	<b>Income Diff.</b>	<b>Mean Income (Women)</b>	<b>Mean Income (Men)</b>
1	6920.9	59881.69	52960.79

Table 9: Average Income Differences Between Men and Women Across Permutations

Perm. No.	Income Diff.	Mean Income (Women)	Mean Income (Men)
1	6920.90	59881.69	52960.79
2	-9448.46	51697.01	61145.47
3	1239.81	57041.14	55801.33
4	238.46	56540.47	56302.01
5	5834.58	59338.53	53503.95

## The Distribution of Possible Average Income Differences Between Men and Women

This dot plot has five dots for five different permutation means and a vertical line representing the actual difference (-\$10,670).



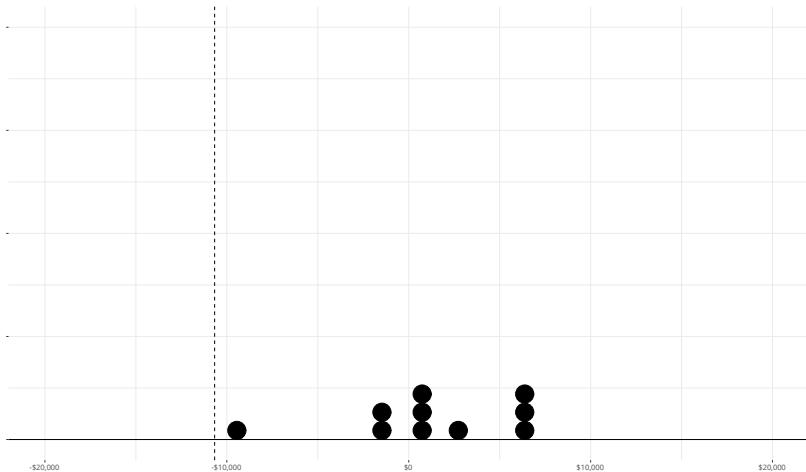
*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

Table 10: Average Income Differences Between Men and Women Across Permutations

Perm. No.	Income Diff.	Mean Income (Women)	Mean Income (Men)
1	6920.90	59881.69	52960.79
2	-9448.46	51697.01	61145.47
3	1239.81	57041.14	55801.33
4	238.46	56540.47	56302.01
5	5834.58	59338.53	53503.95
6	-1313.68	55764.40	57078.08
7	1229.56	57036.02	55806.46
8	-1630.85	55605.81	57236.66
9	2726.30	57784.39	55058.09
10	6921.70	59882.09	52960.39

## The Distribution of Possible Average Income Differences Between Men and Women

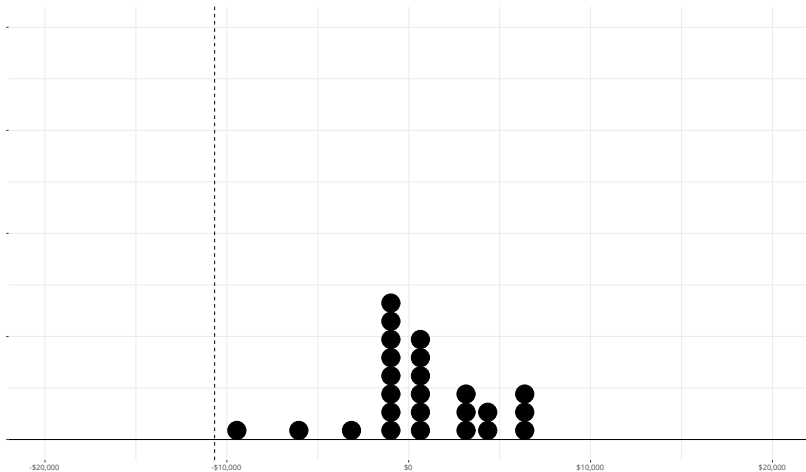
This dot plot has 10 dots for 10 different permutation means and a vertical line representing the actual difference (-\$10,670).



*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

## The Distribution of Possible Average Income Differences Between Men and Women

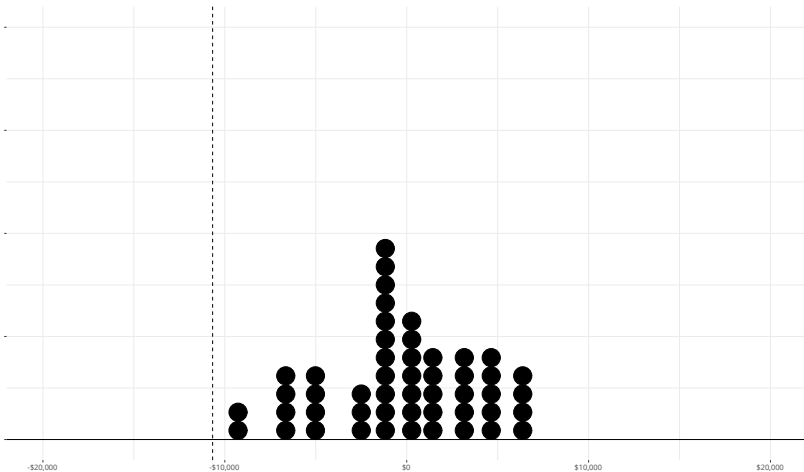
This dot plot has 25 dots for 25 different permutation means and a vertical line representing the actual difference (-\$10,670).



*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

## The Distribution of Possible Average Income Differences Between Men and Women

This dot plot has 50 dots for 50 different permutation means and a vertical line representing the actual difference (-\$10,670).

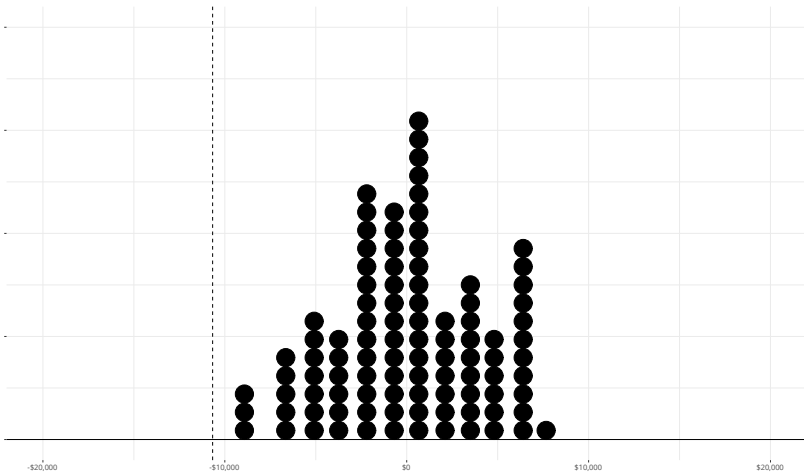


*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*



## The Distribution of Possible Average Income Differences Between Men and Women

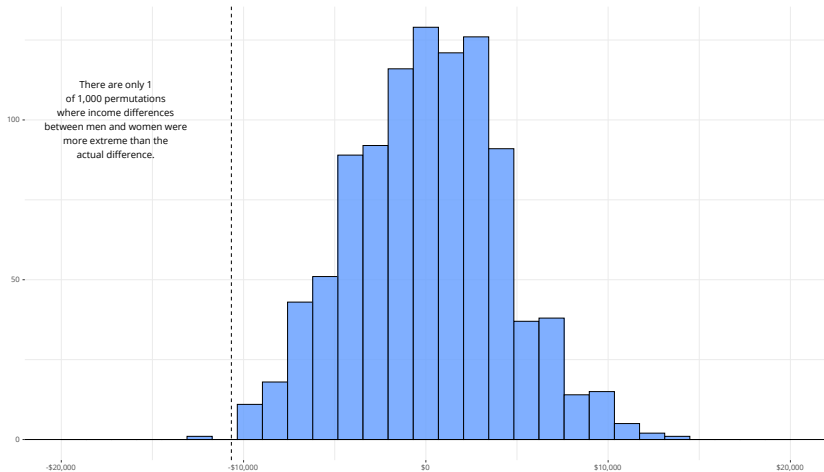
This dot plot has 100 dots for 100 different permutation means and a vertical line representing the actual difference (-\$10,670).



*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

## The Distribution of Possible Average Income Differences Between Men and Women

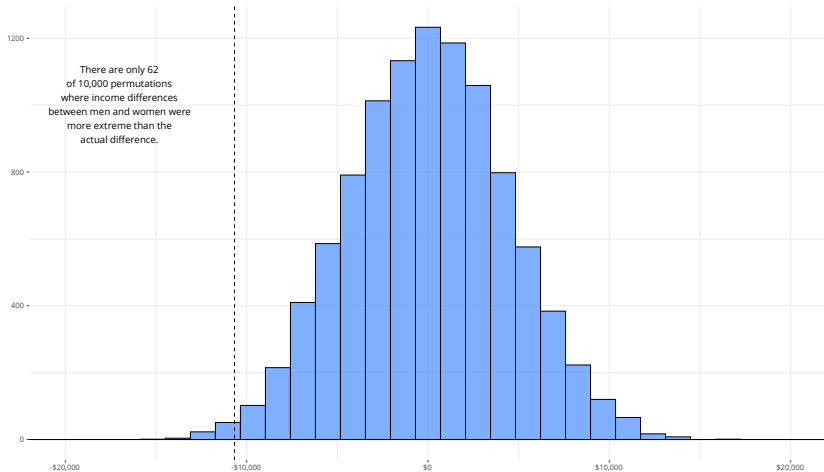
This histogram has 1,000 different permutation means and a vertical line representing the actual difference (-\$10,670).



A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)

## The Distribution of Possible Average Income Differences Between Men and Women

This histogram has 10,000 different permutation means and a vertical line representing the actual difference (-\$10,670).



*A Distribution of Possible Average Income Differences between Men and Women (in 2019 USD)*

# Inference by Computation/Permutations

Recall the skeptic's argument: there are no meaningful differences by gender; the observed difference is due to chance. We retort:

- We simulated this argument through 10,000 permutations.
- The observed difference is very rare. Only 62 of 10,000 permutations yielded more extreme differences.

We reject the skeptic's argument. The advocate is right to note an important difference.

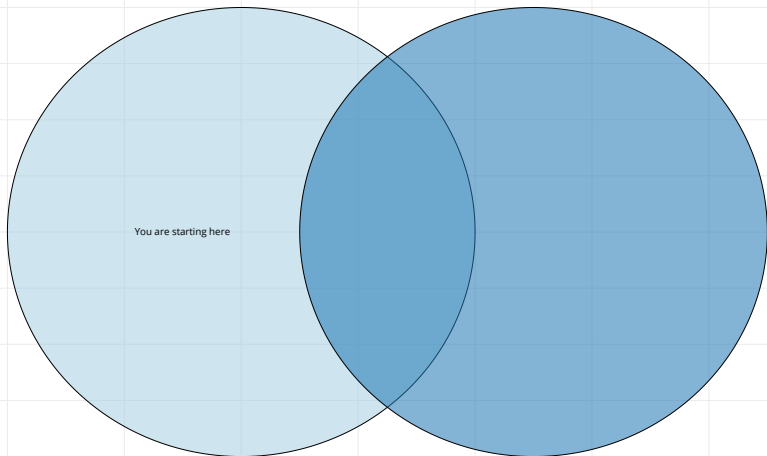
# Takeaways

To do statistics in an intuitive way, you'll need the ability to:

1. follow a simple logical argument
2. randomize/shuffle data
3. iterate

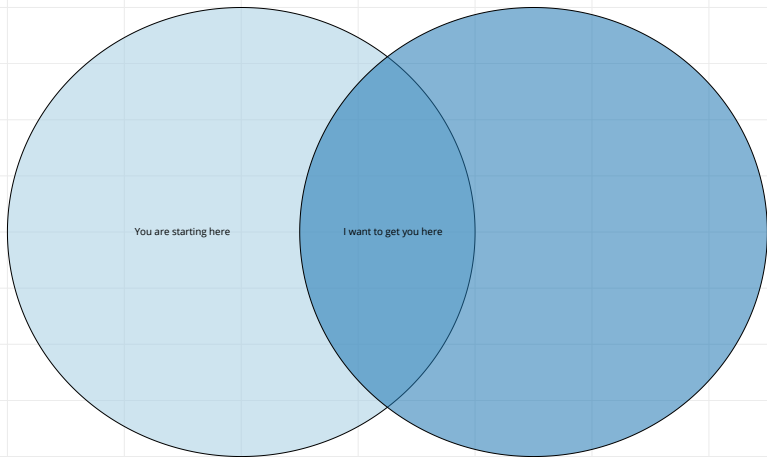
You were born with the ability to do the first.

- Any decent programming language will help you with the last two.



You are starting here

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 Political Science Students  Statistics/Computer Science Students

## Recommended Reading

Check my blog! ([svmiller.com/blog](http://svmiller.com/blog))

- "Permutations and Inference with an Application to the Gender Pay Gap in the General Social Survey"
- "What Do We Know About British Attitudes Toward Immigration? A Pedagogical Exercise of Sample Inference and Regression"
- "The Normal Distribution, Central Limit Theorem, and Inference from a Sample"

Check out the presentation as well ([svmiller.com/presentations](http://svmiller.com/presentations)).



# Table of Contents

Introduction

The Gender Pay Gap

The STAT 101 (analytical) Method

The Computational Method

Conclusion/Takeaways