

# Confidence Intervals

UCLA Soc 114

# Concepts for today

## Statistical concepts

- ▶ Sampling distribution
- ▶ Standard error
- ▶ Confidence interval
- ▶ Bootstrap

## Coding concepts

- ▶ Writing a custom function
- ▶ Writing a for loop

## Example: Mean salary of MLB players

Load data:

```
baseball <- read_csv("https://soc114.github.io/data/baseball.csv")
# Keep only a few variables for simplicity
select(player, team, salary)
```

```
# A tibble: 944 x 3
  player              team    salary
  <chr>             <chr>   <dbl>
1 Bumgarner, Madison Arizona 21882892
2 Marte, Ketel        Arizona 11600000
3 Ahmed, Nick        Arizona 10375000
# i 941 more rows
```

## Example: Mean salary of MLB players

True mean in population of all players

## Example: Mean salary of MLB players

True mean in population of all players

```
baseball |> summarize(population_mean = mean(salary))
```

```
# A tibble: 1 x 1
  population_mean
  <dbl>
1 4965481.
```

## Estimate from a sample

## Estimate from a sample

Draw a sample of 10 players.

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Draw a sample of 10 players.

```
sampled_players <- baseball |>  
  slice_sample(n = 10) |>  
  print(n = 3)
```

```
# A tibble: 10 x 3  
  player              team      salary  
  <chr>               <chr>     <dbl>  
1 Montgomery, Jordan St. Louis 10000000  
2 Barnes, Matt          Miami    7500000  
3 Eflin, Zach           Tampa Bay 11000000  
# i 7 more rows
```

## Estimate from a sample

Take the mean among sampled players.

## Estimate from a sample

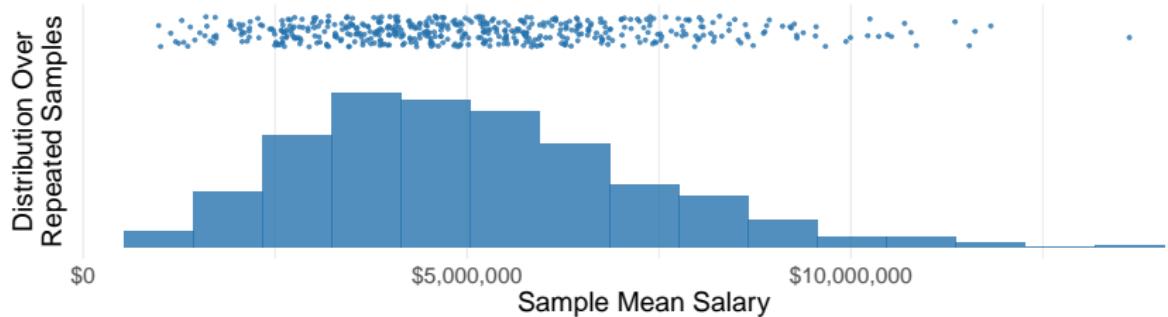
Take the mean among sampled players.

```
sampled_players <- sampled_players |>  
  summarize(sample_estimate = mean(salary)) |>  
  print()
```

```
# A tibble: 1 x 1  
  sample_estimate  
  <dbl>  
1 3435960
```

# Many times

Each dot is the mean from one sample of 10 players.

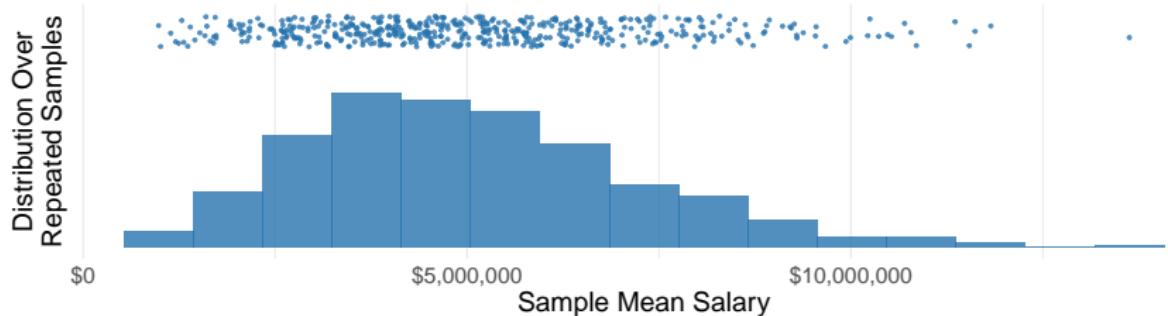


If you are following, these are in `many_samples.csv`.

```
many_samples <- read_csv("https://soc114.github.io/data/man
```

# Many times

Each dot is the mean from one sample of 10 players.



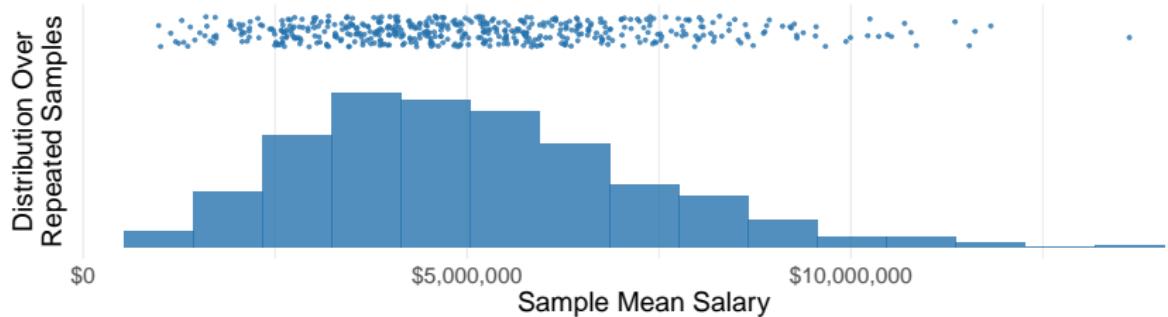
If you are following, these are in `many_samples.csv`.

```
many_samples <- read_csv("https://soc114.github.io/data/man...
```

Because each sample produces a different estimate, there is a **distribution** of different estimates across repeated samples.

# Many times

Each dot is the mean from one sample of 10 players.



If you are following, these are in `many_samples.csv`.

```
many_samples <- read_csv("https://soc114.github.io/data/man...
```

Because each sample produces a different estimate, there is a **distribution** of different estimates across repeated samples.

Can you propose a summary statistic for this distribution?

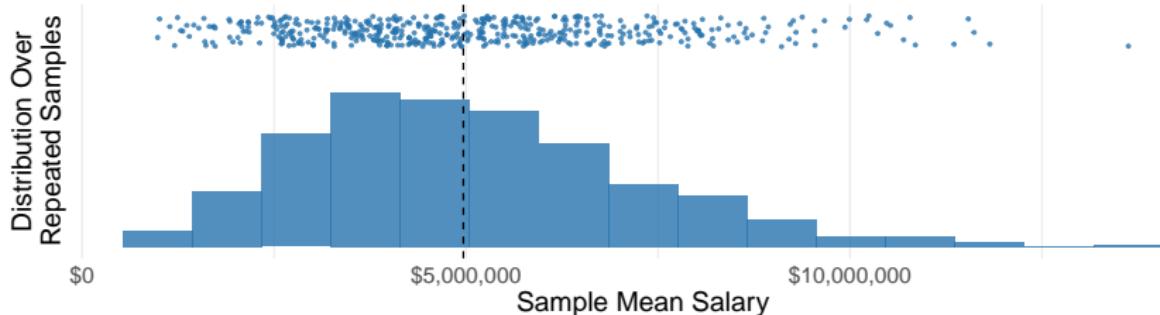
# Mean of the distribution

Also called the **expected value**.

```
many_samples |>  
  summarize(estimator_mean = mean(sample_estimate))
```

```
# A tibble: 1 x 1  
estimator_mean  
      <dbl>  
1       5077653.
```

Each dot is the mean from one sample of 10 players.



(In practice, the mean of the distribution is unknown)

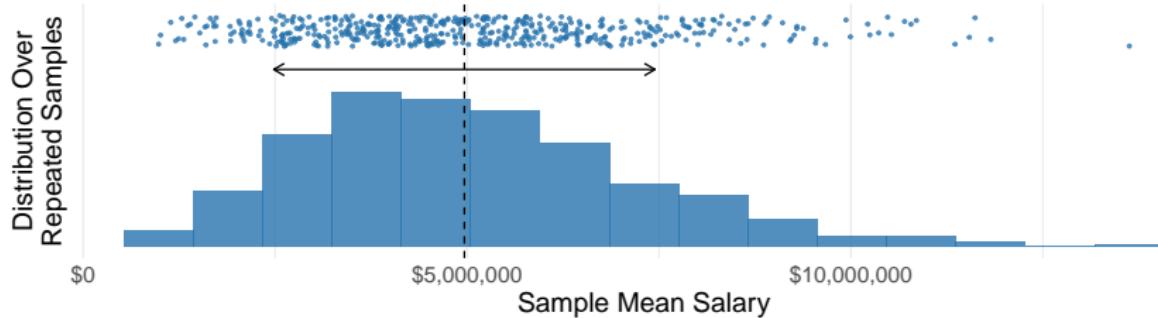
# Standard Error

A measure of dispersion for the distribution of sample mean estimates.

```
many_samples |>  
  summarize(standard_error = sd(sample_estimate))
```

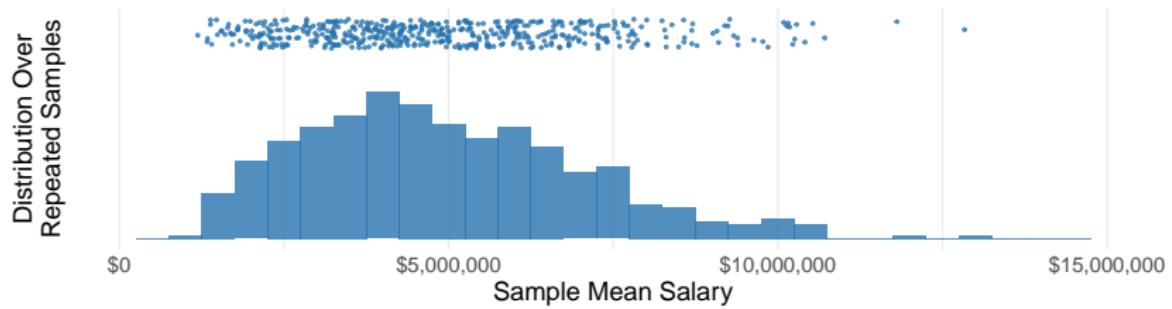
```
# A tibble: 1 x 1  
  standard_error  
  <dbl>  
1 2158282.
```

Each dot is the mean from one sample of 10 players.



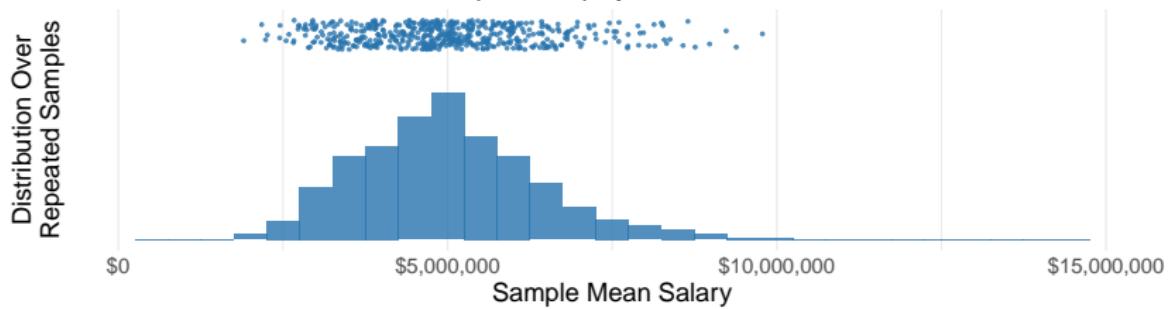
# As the sample size grows

Each dot is the mean from one sample of 10 players.



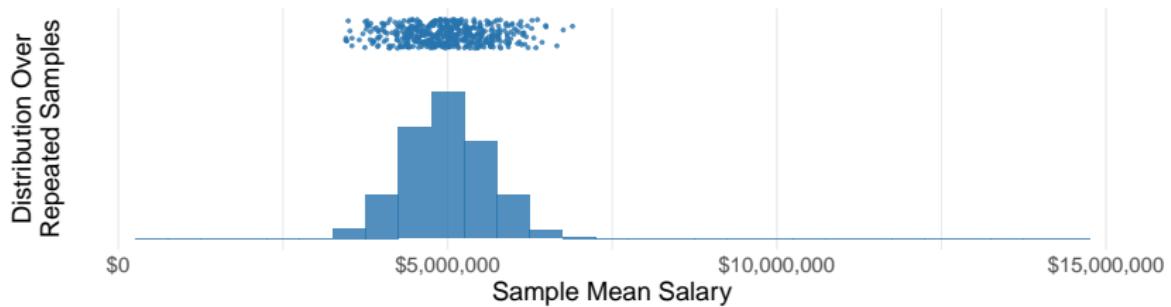
# As the sample size grows

Each dot is the mean from one sample of 25 players.



# As the sample size grows

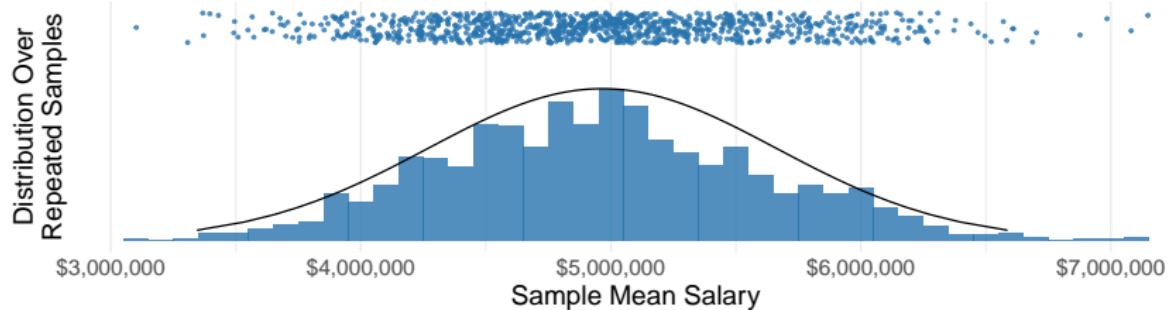
Each dot is the mean from one sample of 100 players.



# Asymptotic Normality

- ▶ As the sample size gets large (asymptotic)
- ▶ This becomes a Normal distribution

Each dot is the mean from one sample of 100 players.

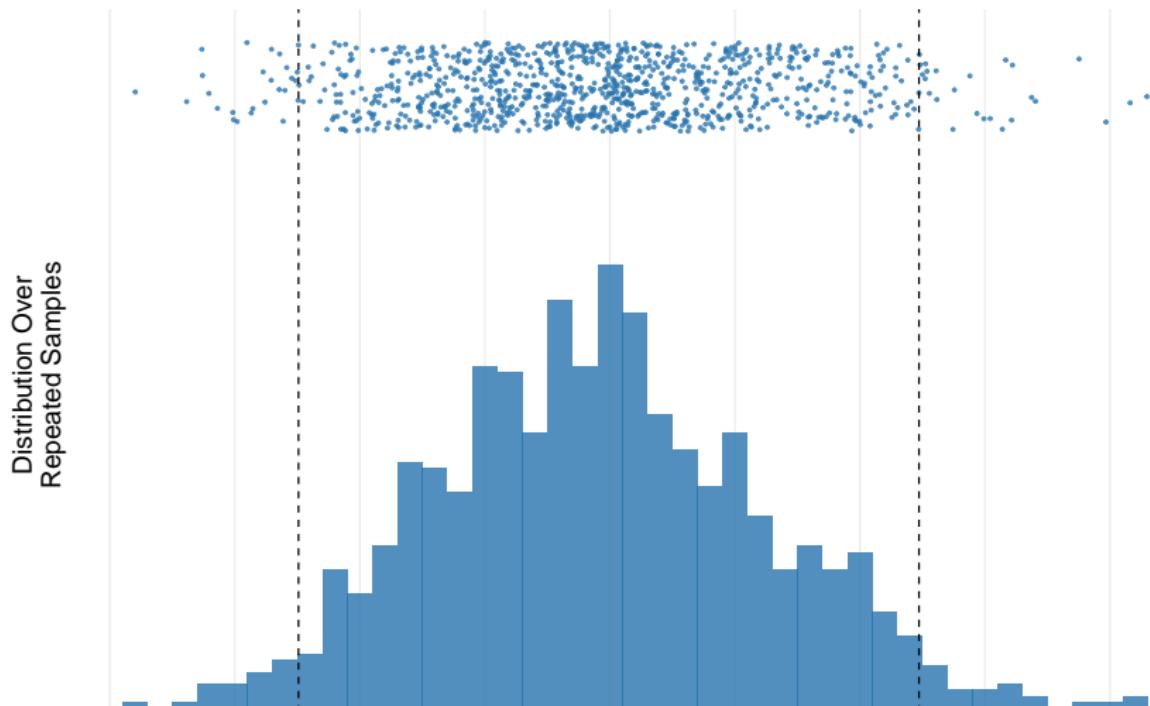


## Middle 95% sampling interval

We might want to summarize:

- ▶ The mean of the estimator
- ▶ A range containing the middle 95% of sample estimates

Each dot is the mean from one sample of 100 players.



# Confidence interval via the bootstrap

What we want:

1. We would want many samples: sample\_1, sample\_2, sample\_3,...
2. We estimate with each
3. We summarize the middle 95%

## Confidence interval via the bootstrap

What we can do:

1. We get only one sample
  - ▶ So we simulate hypothetical `sample_sim_1`, `sample_sim_2`, ...
2. We estimate with each
3. We summarize the middle 95%

## How to generate bootstrap samples

Start with your one sample.

```
sampled_players <- baseball |>  
  slice_sample(n = 100)
```

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Start with your one sample.

```
sampled_players <- baseball |>  
  slice_sample(n = 100)
```

Resample  $n$  players with replacement.

```
sampled_players_bootstrap <- sampled_players |>  
  slice_sample(prop = 1, replace = TRUE)
```

## How to generate bootstrap samples: Example

Here is a sample of 3 players:

```
a_small_sample <- baseball |>
  slice_sample(n = 3) |>
  print()
```

```
# A tibble: 3 x 3
  player           team      salary
  <chr>          <chr>     <dbl>
1 Bohm, Alec    Philadelphia 748000
2 Ginkel, Kevin Arizona    746600
3 Bednar, David Pittsburgh  745000
```

## How to generate bootstrap samples: Example

Here is a bootstrap sample of those 3 players.

```
a_small_sample |>  
  slice_sample(prop = 1, replace = TRUE) |>  
  print()
```

```
# A tibble: 3 x 3  
  player      team    salary  
  <chr>       <chr>   <dbl>  
1 Bednar, David Pittsburgh 745000  
2 Bohm, Alec    Philadelphia 748000  
3 Bednar, David Pittsburgh 745000
```

## How to generate bootstrap samples: Example

Here is a bootstrap sample of those 3 players.

```
a_small_sample |>  
  slice_sample(prop = 1, replace = TRUE) |>  
  print()
```

```
# A tibble: 3 x 3  
  player           team      salary  
  <chr>          <chr>     <dbl>  
1 Bednar, David Pittsburgh  745000  
2 Bohm, Alec       Philadelphia 748000  
3 Bednar, David Pittsburgh  745000
```

## How to generate bootstrap samples: Example

Here is a bootstrap sample of those 3 players.

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  player      team    salary  
  <chr>       <chr>   <dbl>  
1 Bednar, David Pittsburgh 745000  
2 Bednar, David Pittsburgh 745000  
3 Bednar, David Pittsburgh 745000
```

## How to generate bootstrap samples: Example

Here is a bootstrap sample of those 3 players.

```
a_small_sample |>  
  slice_sample(prop = 1, replace = TRUE) |>  
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# A tibble: 3 x 3  
  player           team      salary  
  <chr>            <chr>     <dbl>  
1 Bohm, Alec     Philadelphia 748000  
2 Bednar, David Pittsburgh   745000  
3 Ginkel, Kevin Arizona    746600
```

## Coding concepts

We will analyze hundreds of bootstrap samples.

We need two coding concepts.

1. How to write an estimator function
2. How to write a for loop

## How to write an estimator function

A function (like `mean`) takes an input and returns an output. You can write your own.

```
estimator <- function(data) {  
  data |>  
    summarize(estimate = mean(salary)) |>  
    pull(estimate)  
}
```

The function takes data and returns an estimate.

```
estimator(data = sampled_players)
```

```
[1] 5522424
```

## How to write a for loop

Useful for tasks you will repeat.

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First, initialize a vector to hold results.

```
vector_for_results <- rep(NA, 3)
```

The `rep` function repeats the value NA 3 times.

## How to write a for loop

Useful for tasks you will repeat.

First, initialize a vector to hold results.

```
vector_for_results <- rep(NA, 3)
```

The `rep` function repeats the value NA 3 times.

Second, loop through and fill your vector.

```
for (index in 1:3) {  
  vector_for_results[index] <- index  
}
```

Square brackets [] extract an element of a vector.

## Analyze 500 bootstrap samples

Initialize a vector to hold the result.

```
bootstrap_estimates <- rep(NA, times = 500)
```

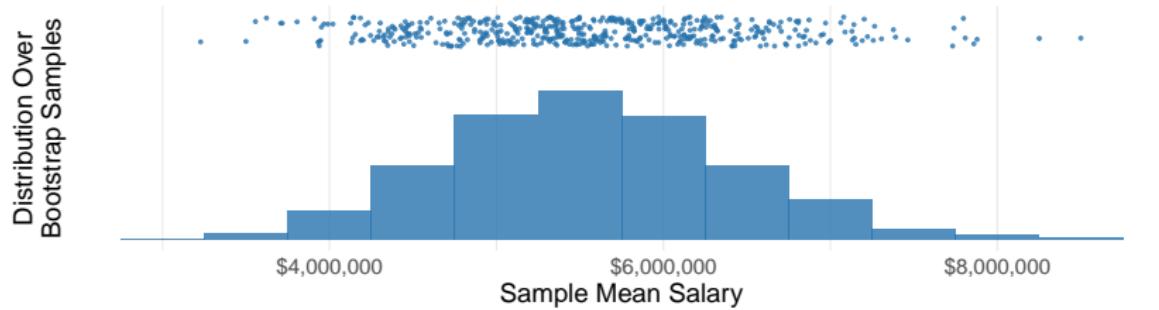
## Analyze 500 bootstrap samples

Write a for loop that will repeat 500 times.

```
for (index in 1:500) {  
  
  # Draw a bootstrap sample  
  bootstrap_sample <- sampled_players |>  
    slice_sample(prop = 1, replace = TRUE)  
  
  # Construct an estimate  
  estimate_this_index <- estimator(bootstrap_sample)  
  
  # Store that estimate  
  bootstrap_estimates[index] <- estimate_this_index  
}
```

# Bootstrap results

Each dot is the mean from one bootstrap sample of 100 players.



## Bootstrap results: Summary statistics

Bootstrap estimate of the standard error.

```
sd(bootstrap_estimates)
```

```
[1] 864362.2
```

Middle 95% of bootstrap estimates

```
quantile(x = bootstrap_estimates, prob = c(.025, .975))
```

```
2.5%    97.5%
3958991 7261108
```

## Confidence interval

An interval from lower(sample) to upper(sample) with the property: across repeated samples, 95% of intervals constructed this way would contain the population parameter.

## Confidence interval: Example

Middle 95% of bootstrap estimates is a confidence interval.

- ▶ The true population mean salary is \$4,965,481
- ▶ Our sample mean is \$5,522,424
- ▶ Our confidence interval is:

```
quantile(x = bootstrap_estimates, prob = c(.025, .975))
```

```
2.5%    97.5%
3958991 7261108
```

Across repeated samples, 95% of intervals constructed this way will contain the population mean salary.

## Recap

- ▶ Statistical concepts
- ▶ Coding concepts

# Recap: Statistical concepts

## Statistical concepts

- ▶ Sampling distribution
  - ▶ Cannot be directly observed. We have one sample.
- ▶ Standard error
  - ▶ Spread of the sampling distribution
- ▶ Confidence interval
  - ▶ Covers truth in 95% of samples
- ▶ Bootstrap
  - ▶ Method of constructing the CI with one sample

## Recap: Coding concepts

- ▶ Writing a custom function (R4DS Ch 25)
- ▶ Writing a for loop (R4DS Ch 27.5)