

## Bootstrap for sampling distribution of sample mean

# Assessing assumptions

- Our  $t$ -tests assume normality of variable being tested
- but, Central Limit Theorem says that normality matters less if sample is “large”
- in practice “approximate normality” is enough, but how do we assess whether what we have is normal enough?
- so far, use histogram/boxplot and make a call, allowing for sample size.

# What actually has to be normal

- is: **sampling distribution of sample mean**
- the distribution of sample mean over *all possible samples*
- but we only have *one* sample!
- Idea: assume our sample is representative of the population, and draw samples from our sample (!), with replacement.
- This gives an idea of what different samples from the population might look like.
- Called *bootstrap*, after expression “to pull yourself up by your own bootstraps”.

# Packages

```
library(tidyverse)
```

# Blue Jays attendances

```
jays$attendance
```

```
[1] 48414 17264 15086 14433 21397 34743 44794 14184 15606  
[10] 18581 19217 21519 21312 30430 42917 42419 29306 15062  
[19] 16402 19014 21195 33086 37929 15168 17276
```

- A bootstrap sample:

```
s <- sample(jays$attendance, replace = TRUE)  
s
```

```
[1] 21195 34743 21312 44794 16402 19014 34743 21195 17264  
[10] 18581 19014 19217 34743 19217 14433 15062 16402 15062  
[19] 34743 15062 15086 15168 15086 48414 30430
```

# Sorting

- It is easier to see what is happening if we sort both the actual attendances and the bootstrap sample:

```
sort(jays$attendance)
```

```
[1] 14184 14433 15062 15086 15168 15606 16402 17264 17276  
[10] 18581 19014 19217 21195 21312 21397 21519 29306 30430  
[19] 33086 34743 37929 42419 42917 44794 48414
```

```
sort(s)
```

```
[1] 14433 15062 15062 15062 15086 15086 15168 16402 16402  
[10] 17264 18581 19014 19014 19217 19217 21195 21195 21312  
[19] 30430 34743 34743 34743 34743 44794 48414
```

## Getting mean of bootstrap sample

- A bootstrap sample is same size as original, but contains repeated values (eg. 15062) and missing ones (42917).
- We need the mean of our bootstrap sample:

```
mean(s)
```

```
[1] 23055.28
```

- This is a little different from the mean of our actual sample:

```
mean(jays$attendance)
```

```
[1] 25070.16
```

- Want a sense of how the sample mean might vary, if we were able to take repeated samples from our population.
- Idea: take lots of *bootstrap* samples, and see how *their* sample means vary.

## Setting up bootstrap sampling

- Begin by setting up a dataframe that contains a row for each bootstrap sample. I usually call this column `sim`. Do just 4 to get the idea:

```
tibble(sim = 1:4)
```

```
# A tibble: 4 x 1
```

```
  sim
```

```
<int>
```

```
1     1
```

```
2     2
```

```
3     3
```

```
4     4
```



## Drawing the bootstrap samples

- Then set up to work one row at a time, and draw a bootstrap sample of the attendances in each row:

```
tibble(sim = 1:4) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(jays$attendance,  
                             replace = TRUE)))
```

```
# A tibble: 4 x 2
```

```
# Rowwise:
```

```
      sim sample  
  <int> <list>  
1       1 <dbl [25]>  
2       2 <dbl [25]>  
3       3 <dbl [25]>  
4       4 <dbl [25]>
```

- Each row of our dataframe contains *all* of a bootstrap sample of 25

## Sample means

- Find the mean of each sample:

```
tibble(sim = 1:4) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(jays$attendance,  
                             replace = TRUE))) %>%  
  mutate(my_mean = mean(sample))
```

# A tibble: 4 x 3

# Rowwise:

	sim	sample	my_mean
	<int>	<list>	<dbl>
1	1	<dbl [25]>	28472.
2	2	<dbl [25]>	28648.
3	3	<dbl [25]>	23329.
4	4	<dbl [25]>	24808.

- These are (four simulated values of) the bootstrapped sampling

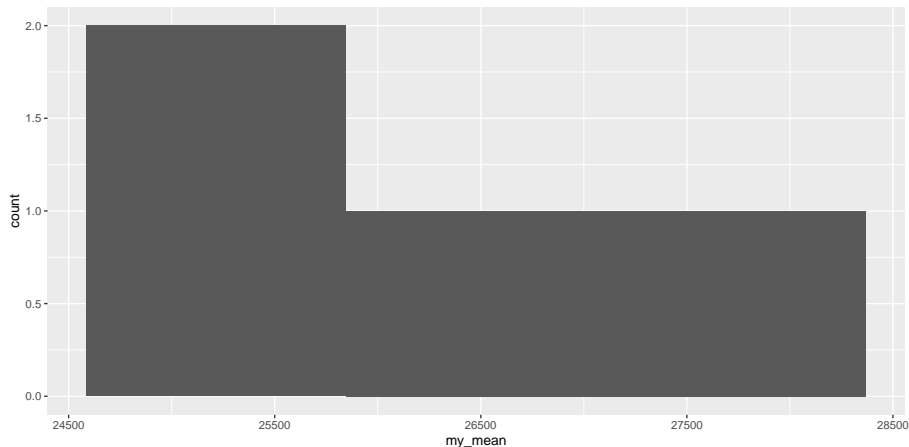
# Make a histogram of them

- rather pointless here, but to get the idea:

```
tibble(sim = 1:4) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(jays$attendance, replace = TRUE)))  
  mutate(my_mean = mean(sample)) %>%  
  ggplot(aes(x = my_mean)) + geom_histogram(bins = 3) -> g
```

# The (pointless) histogram

gg



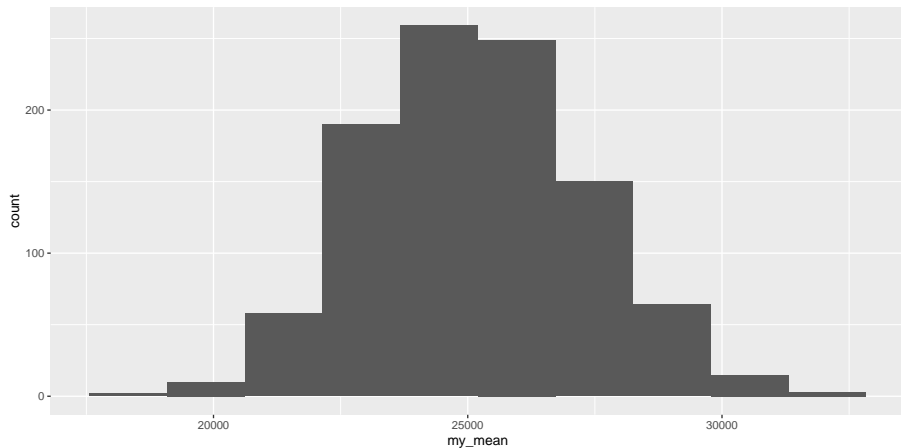
## Now do again with a decent number of bootstrap samples

- say 1000, and put a decent number of bins on the histogram also:

```
tibble(sim = 1:1000) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(jays$attendance,  
                              replace = TRUE))) %>%  
  mutate(my_mean = mean(sample)) %>%  
  ggplot(aes(x = my_mean)) + geom_histogram(bins = 10) -> g
```

# The (better) histogram

g



# Comments

- This is very close to normal
- The bootstrap says that the sampling distribution of the sample mean is close to normal, even though the distribution of the data is not
- A sample size of 25 is big enough to overcome the skewness that we saw
- This is the Central Limit Theorem in practice
- It is surprisingly powerful.
- Thus, the  $t$ -test is actually perfectly good here.

## Comments on the code 1/2

- You might have been wondering about this:

```
tibble(sim = 1:4) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(jays$attendance,  
                             replace = TRUE)))
```

```
# A tibble: 4 x 2
```

```
# Rowwise:
```

```
      sim sample  
  <int> <list>  
1      1 <dbl [25]>  
2      2 <dbl [25]>  
3      3 <dbl [25]>  
4      4 <dbl [25]>
```



## Comments on the code 2/2

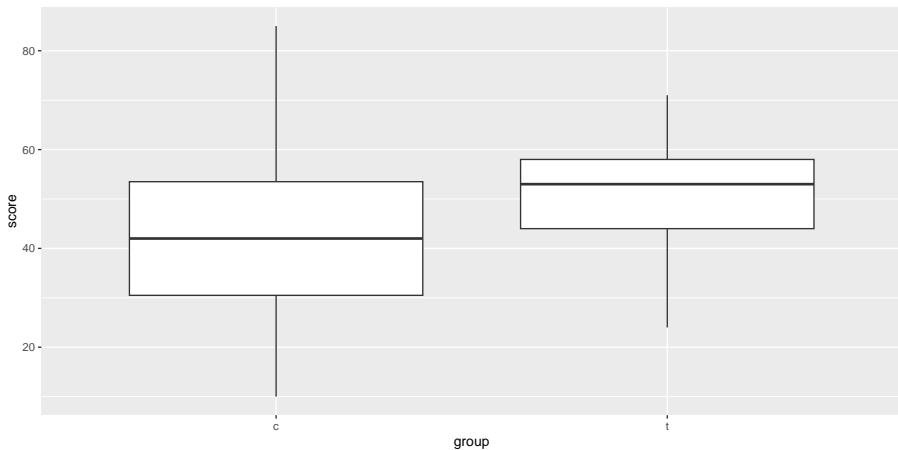
- how did we squeeze all 25 sample values into one cell?
  - ▶ `sample` is a so-called “list-column” that can contain anything.
- why did we have to put `list()` around the `sample()`?
  - ▶ because `sample` produces a collection of numbers, not just a single one
  - ▶ the `list()` signals this: “make a list-column of samples”.

## Two samples

- Assumption: *both* samples are from a normal distribution.
- In this case, each sample should be “normal enough” given its sample size, since Central Limit Theorem will help.
- Use bootstrap on each group independently, as above.

# Kids learning to read

```
ggplot(kids, aes(x=group, y=score)) + geom_boxplot()
```



## Getting just the control group

- Use filter to select rows where something is true:

```
kids %>% filter(group == "c") -> controls
controls
```

```
# A tibble: 23 x 2
```

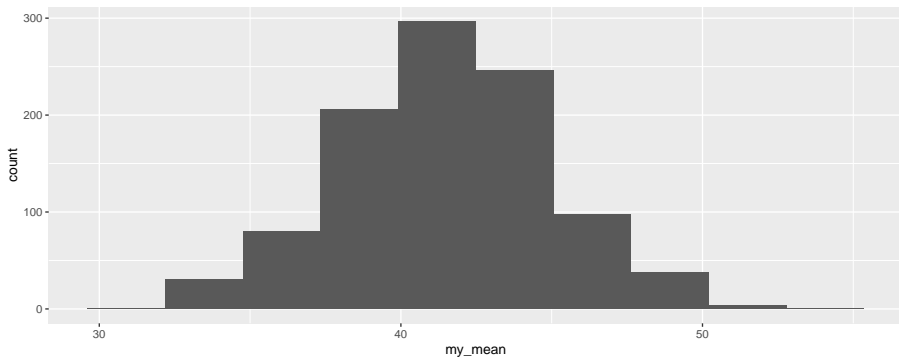
```
  group score
  <chr> <dbl>
```

```
1 c      42
2 c      33
3 c      46
4 c      37
5 c      43
6 c      41
7 c      10
8 c      42
9 c      55
10 c     19
```

```
# i 13 more rows
```

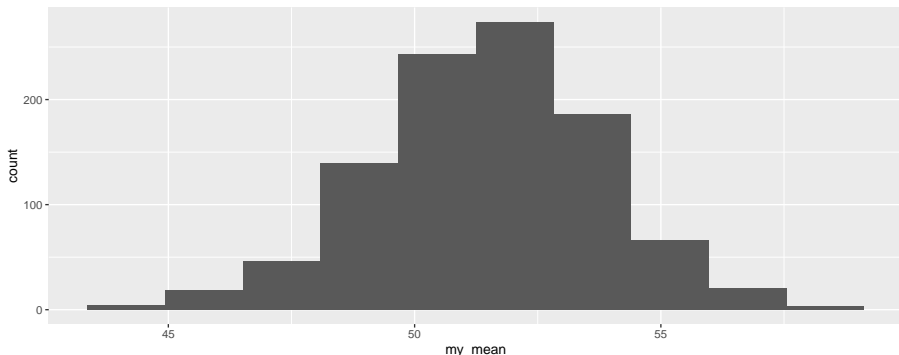
## Bootstrap these

```
tibble(sim = 1:1000) %>%  
  rowwise() %>%  
  mutate(sample = list(sample(controls$score, replace = TRUE)))  
  mutate(my_mean = mean(sample)) %>%  
  ggplot(aes(x = my_mean)) + geom_histogram(bins = 10)
```



... and the treatment group:

```
kids %>% filter(group=="t") -> treats
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(sample = list(sample(treats$score, replace = TRUE)))
  mutate(my_mean = mean(sample)) %>%
  ggplot(aes(x = my_mean)) + geom_histogram(bins = 10)
```



# Comments

- sampling distributions of sample means both look pretty normal, though treatment group is a tiny bit left-skewed
- as we thought, no problems with our two-sample  $t$  at all.