

Bootstrap again

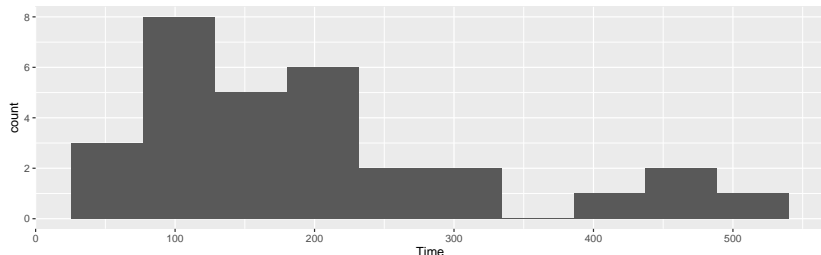
packages

```
library(tidyverse)
library(bootstrap)
library(rsample)
library(conflicted)
conflict_prefer("filter", "dplyr")
```

Is my sampling distribution normal enough?

- Recall the IRS data that we used as a motivation for the sign test:

```
ggplot(irs, aes(x=Time))+geom_histogram(bins=10)
```



- We said that a t procedure for the mean would not be a good idea because the distribution is skewed.

What *actually* matters

- ▶ It's not the distribution of the *data* that has to be approx normal (for a *t* procedure).
- ▶ What matters is the *sampling distribution of the sample mean*.
- ▶ If the sample size is large enough, the sampling distribution will be normal enough even if the data distribution is not.
 - ▶ This is why we had to consider the sample size as well as the shape.
- ▶ But how do we know whether this is the case or not? We only have *one* sample.

The (nonparametric) bootstrap

- ▶ Typically, our sample will be reasonably representative of the population.
- ▶ Idea: pretend the sample *is* the population, and sample from it *with replacement*.
- ▶ Calculate test statistic, and repeat many times.
- ▶ This gives an idea of how our statistic might vary in repeated samples: that is, its sampling distribution.
- ▶ Called the **bootstrap distribution** of the test statistic.
- ▶ If the bootstrap distribution is approx normal, infer that the true sampling distribution also approx normal, therefore inference about the mean such as t is good enough.
- ▶ If not, we should be more careful.

Why it works

- ▶ We typically estimate population parameters by using the corresponding sample thing: eg. estimate population mean using sample mean.
- ▶ This called **plug-in principle**.
- ▶ The fraction of sample values less than a value x called the **empirical distribution function** (as a function of x).
- ▶ By plug-in principle, the empirical distribution function is an estimate of the population CDF.
- ▶ In this sense, the sample *is* an estimate of the population, and so sampling from it is an estimate of sampling from the population.

Bootstrapping the IRS data

- ▶ Sampling with replacement is done like this (the default sample size is as long as the original data):

```
boot=sample(irs$Time, replace=T)  
mean(boot)
```

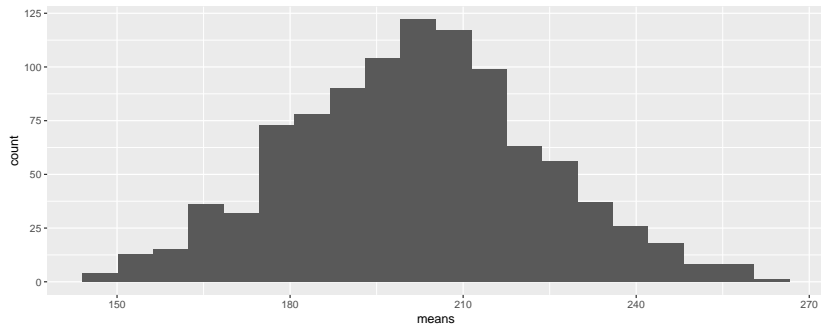
```
[1] 182.5667
```

- ▶ That's one bootstrapped mean. We need a whole bunch.
- ▶ Use the same idea as for simulating power:

```
rerun(1000, sample(irs$Time, replace=T)) %>%  
  map_dbl(~mean(.)) -> means
```

Sampling distribution of sample mean

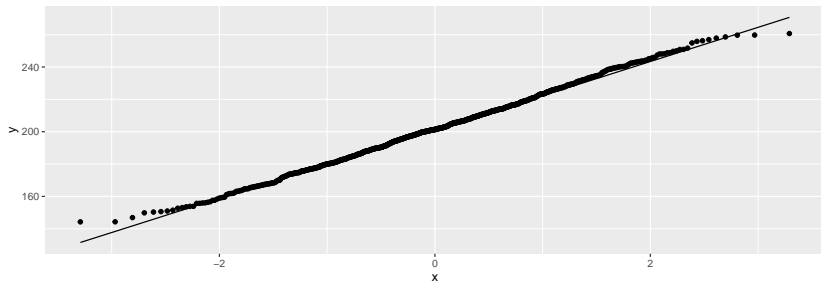
```
ggplot(tibble(means), aes(x=means))+geom_histogram(bins=20)
```



Comments

This is not so bad: a long right tail, maybe:

```
ggplot(tibble(means), aes(sample=means))+  
  stat_qq()+stat_qq_line()
```



or not so much.

Confidence interval from the bootstrap distribution

There are two ways (at least):

- ▶ percentile bootstrap interval: take the 2.5 and 97.5 percentiles (to get the middle 95%). This is easy, but not always the best:

```
(b_p=quantile(means, c(0.025, 0.975)))
```

| 2.5% | 97.5% |
|----------|----------|
| 159.5292 | 244.1075 |

- ▶ bootstrap t : use the SD of the bootstrapped sampling distribution as the SE of the estimator of the mean and make a t interval:

```
n=length(irs$Time)
t_star=qt(0.975, n-1)
(b_t=mean(means)+c(-1, 1)*t_star*sd(means))
```

```
[1] 157.9020 245.4334
```

Comparing

- ▶ get ordinary t interval:

```
my_names=c("LCL", "UCL")  
o_t=t.test(irs$Time)$conf.int
```

- ▶ Compare the 2 bootstrap intervals with the ordinary t -interval:

```
tibble(limit=my_names, o_t, b_t, b_p)
```

```
# A tibble: 2 x 4  
  limit  o_t    b_t    b_p  
  <chr> <dbl> <dbl> <dbl>  
1 LCL   155.  158.  160.  
2 UCL   247.  245.  244.
```

- ▶ The bootstrap t and the ordinary t are very close
- ▶ The percentile bootstrap interval is noticeably shorter (common) and higher (skewness).

Which to prefer?

- ▶ If the intervals agree, then they are all good.
- ▶ If they disagree, they are all bad!
- ▶ In that case, use BCA interval (over).

Bias correction and acceleration

- ▶ this from “An introduction to the bootstrap”, by Brad Efron and Robert J. Tibshirani.
- ▶ there is way of correcting the CI for skewness in the bootstrap distribution, called the BCa method
- ▶ complicated (see the Efron and Tibshirani book), but implemented in bootstrap package.

Run this on the IRS data:

```
bca=bcanon(irs$Time, 1000, mean)
bca$confpoints
```

| | alpha | bca point |
|------|-------|-----------|
| [1,] | 0.025 | 162.8000 |
| [2,] | 0.050 | 166.8000 |
| [3,] | 0.100 | 174.4667 |
| [4,] | 0.160 | 179.5667 |
| [5,] | 0.840 | 224.6000 |
| [6,] | 0.900 | 234.3000 |
| [7,] | 0.950 | 247.4333 |
| [8,] | 0.975 | 256.3000 |

use 2.5% and 97.5% points for CI

```
bca$confpoints %>% as_tibble() %>%  
  filter(alpha %in% c(0.025, 0.975)) %>%  
  pull(`bca point`) -> b_bca  
b_bca
```

```
[1] 162.8 256.3
```

Comparing

```
tibble(limit=my_names, o_t, b_t, b_p, b_bca)
```

```
# A tibble: 2 x 5
```

| | limit | o_t | b_t | b_p | b_bca |
|---|-------|-------|-------|-------|-------|
| | <chr> | <dbl> | <dbl> | <dbl> | <dbl> |
| 1 | LCL | 155. | 158. | 160. | 163. |
| 2 | UCL | 247. | 245. | 244. | 256. |

- ▶ The BCA interval says that the mean should be estimated even higher than the bootstrap percentile interval does.
- ▶ The BCA interval is the one to trust.

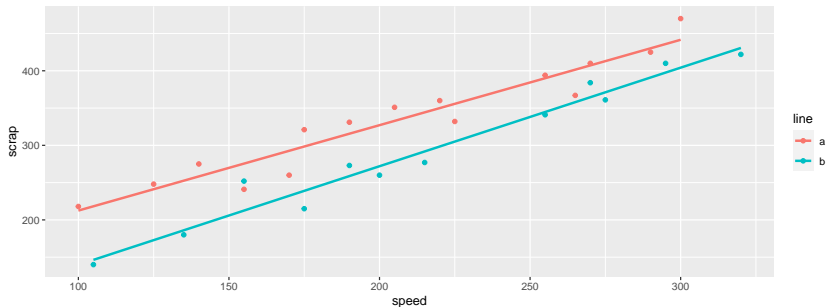
Bootstrapping the correlation

Recall the soap data:

```
url="http://ritsokiguess.site/datafiles/soap.txt"  
soap=read_delim(url," ")
```

The data

```
ggplot(soap, aes(x=speed, y=scrap, colour=line))+  
  geom_point()+geom_smooth(method="lm", se=F)
```



Comments

- ▶ Line B produces less scrap for any given speed.
- ▶ For line B, estimate the correlation between speed and scrap (with a confidence interval.)

Extract the line B data; standard correlation test

```
soap %>% filter(line=="b") -> line_b  
with(line_b, cor.test(speed, scrap))
```

Pearson's product-moment correlation

data: speed and scrap

t = 15.829, df = 10, p-value = 2.083e-08

alternative hypothesis: true correlation is not equal to 0

95 percent confidence interval:

0.9302445 0.9947166

sample estimates:

cor

0.9806224

Bootstrapping a correlation

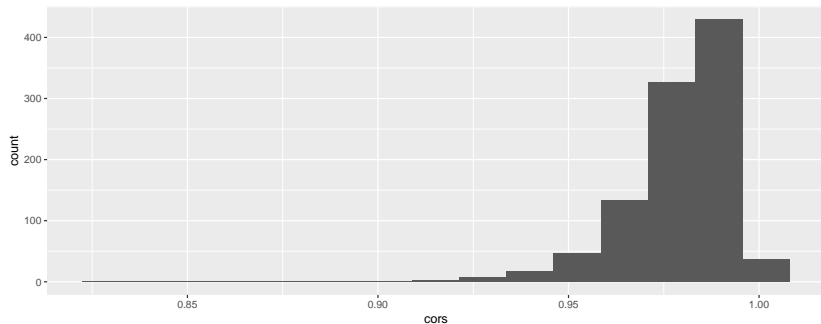
- ▶ Sample from data with replacement, but have to keep the speed-scrap *pairs* together
- ▶ Sample *rows* at random, then take the variable values that belong to those rows:

*** REDO THIS ***

```
rerun(1000, sample(1:nrow(line_b), replace=T)) %>%  
  map(~slice(line_b, .)) %>%  
  map_dbl(~with(.,cor(speed, scrap))) -> cors
```

A picture of this

```
ggplot(tibble(cors), aes(x=cors))+geom_histogram(bins=15)
```



Comments and next steps

- ▶ This is very left-skewed.
- ▶ Bootstrap percentile interval is:

```
(b_p=quantile(cors, c(0.025, 0.975)))
```

| | 2.5% | 97.5% |
|--|-----------|-----------|
| | 0.9443861 | 0.9960207 |

- ▶ We probably need the BCA interval instead.

Getting the BCA interval 1/2

- ▶ To use bcanon, write a function that takes a vector of row numbers and returns the correlation between speed and scrap for those rows:

```
theta=function(rows, d) {  
  d %>% slice(rows) %>% with(., cor(speed, scrap))  
}  
theta(1:3, line_b)
```

```
[1] 0.9928971
```

```
line_b %>% slice(1:3)
```

```
# A tibble: 3 x 4  
  case scrap speed line  
  <dbl> <dbl> <dbl> <chr>  
1     16   140   105 b  
2     17   277   215 b  
3     18   384   270 b
```


Getting the BCA interval 2/2

- ▶ Inputs to `bcanon` are now:
 - ▶ row numbers (1 through 12 in our case: 12 rows in `line_b`)
 - ▶ number of bootstrap samples
 - ▶ the function we just wrote
 - ▶ the data frame:

```
points=bcanon(1:12, 1000, theta, line_b)$confpoints
points %>% as_tibble() %>%
  filter(alpha %in% c(0.025, 0.975)) %>%
  pull(`bca point`) -> b_bca
b_bca
```

```
[1] 0.9281762 0.9945016
```

Comparing the results

```
tibble(limit=my_names, o_c, b_p, b_bca)
```

```
# A tibble: 2 x 4  
  limit    o_c    b_p b_bca  
  <chr> <dbl> <dbl> <dbl>  
1 LCL   0.930 0.944 0.928  
2 UCL   0.995 0.996 0.995
```

- ▶ The bootstrap percentile interval doesn't go down far enough.
- ▶ The BCA interval seems to do a better job than the ordinary `cor.test` interval in capturing the skewness of the distribution.

A problem

Consider this example: samples of UK and Ontario (Canada) children, and their journey times to school, in minutes:

```
my_url="http://ritsokiguess.site/datafiles/to-school.csv"
to_school=read_csv(my_url)
to_school
```

```
# A tibble: 80 x 2
  traveltime location
    <dbl> <chr>
1         30 Ontario
2         10 Ontario
3          8 Ontario
4         30 Ontario
5          5 Ontario
6          8 Ontario
7          7 Ontario
8         15 Ontario
9         10 Ontario
```

Automating the bootstrap

Let's go back to our IRS data for a moment:

```
irs
```

```
# A tibble: 30 x 1
```

```
  Time
```

```
  <dbl>
```

```
1    91
```

```
2    64
```

```
3   243
```

```
4   167
```

```
5   123
```

```
6    65
```

```
7    71
```

```
8   204
```

```
9   110
```

```
10   178
```

```
# i 20 more rows
```

What happens if we use `rsample` to resample from these? Let's