MONASH University

ETC5523: Communicating with Data

Statistical model outputs

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Week 5A

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Aim

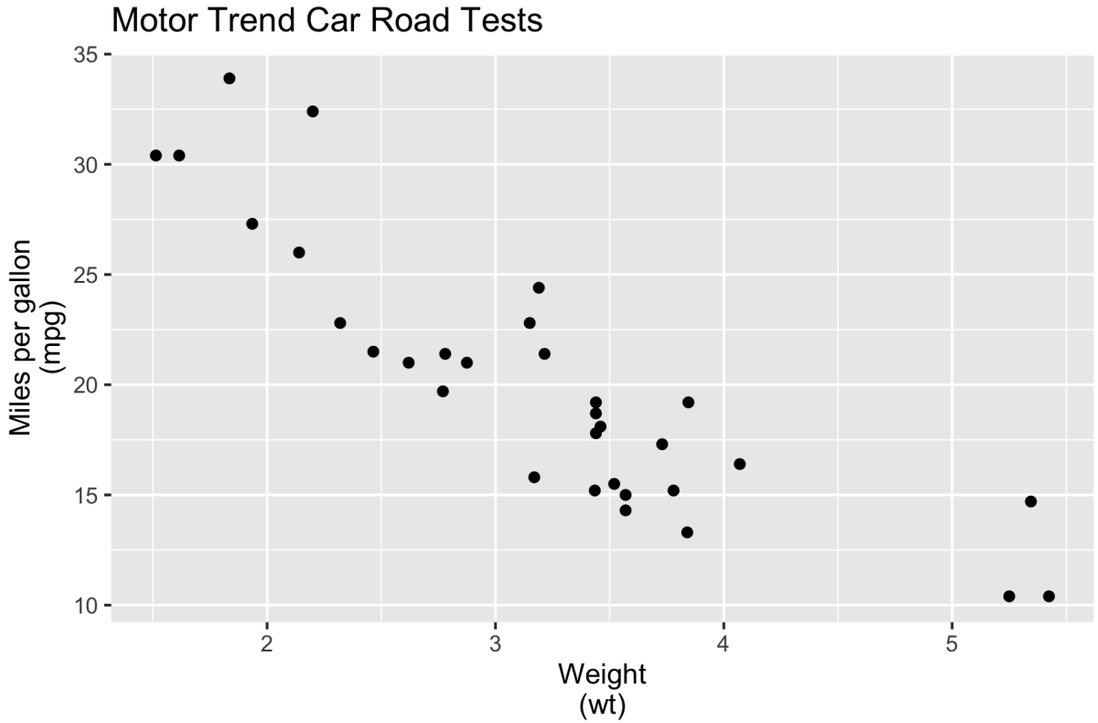
- Extract information from model objects
- Understand and create functions in R
- Understand and apply S3 object-oriented programming in R

Why

- Working with model objects is necessary for you to get the information you need for communication
- These concepts will be helpful later when we start developing R-packages

📈 Statistical models

- All models are approximations of the unknown data generating process
- How good of an approximation depends on the collected data and the model choice



🎯 Characterise `mpg` in terms of `wt`.

- We fit the model:

$$\texttt{mpg}_i = \beta_0 + \beta_1 \texttt{wt}_i + e_i$$

▶ Parameter details

Fitting linear models in R

$$\texttt{mpg}_i = \beta_0 + \beta_1 \texttt{wt}_i + e_i$$

In R we fit this as

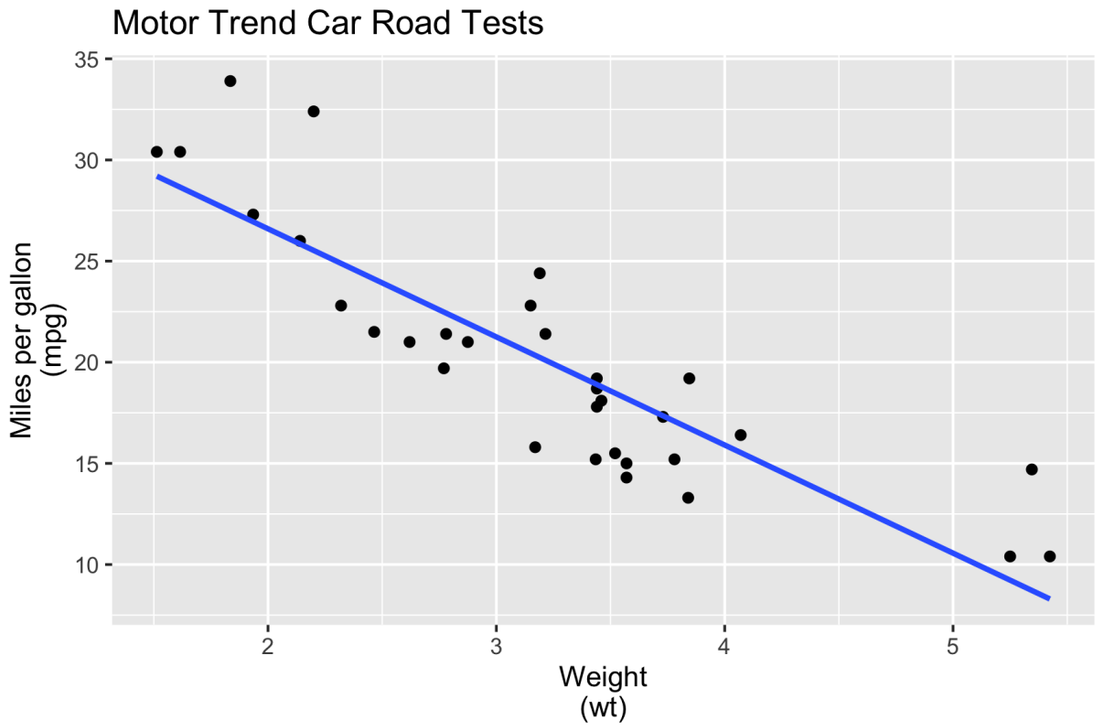
```
fit <- lm(mpg ~ wt, data = mtcars)
```

which is the same as

```
fit <- lm(mpg ~ 1 + wt, data = mtcars)
fit
```

```
Call:
lm(formula = mpg ~ 1 + wt, data = mtcars)

Coefficients:
(Intercept)           wt
     37.285       -5.344
```



$\hat{\beta}_0 = 37.285$ and $\hat{\beta}_1 = -5.344$

ℹ️ Extracting information from the fitted model

- When you fit a model, there would be a number of information you will be interested in extracting from the fit including:
  - the model parameter estimates,
  - model-related summary statistics, e.g. R^2, AIC and BIC,
  - model-related values, e.g. residuals, fitted values and predictions.
- So how do you extract these values from the `fit`?
- What does `fit` even contain?

Extracting information from the fitted model

```
str(fit)
```

```
List of 12
 $ coefficients : Named num [1:2] 37.29 -5.34
  ..- attr(*, "names")= chr [1:2] "(Intercept)" "wt"
 $ residuals    : Named num [1:32] -2.28 -0.92 -2.09 1.3 -0.2 ...
  ..- attr(*, "names")= chr [1:32] "Mazda RX4" "Mazda RX4 Wag" "Datsun 710" "Hornet 4 Drive" ...
 $ effects      : Named num [1:32] -113.65 -29.116 -1.661 1.631 0.111 ...
  ..- attr(*, "names")= chr [1:32] "(Intercept)" "wt" "" "" ...
 $ rank         : int 2
 $ fitted.values: Named num [1:32] 23.3 21.9 24.9 20.1 18.9 ...
  ..- attr(*, "names")= chr [1:32] "Mazda RX4" "Mazda RX4 Wag" "Datsun 710" "Hornet 4 Drive" ...
 $ assign       : int [1:2] 0 1
 $ qr           :List of 5
  ..$ qr   : num [1:32, 1:2] -5.657 0.177 0.177 0.177 0.177 ...
  .. ..- attr(*, "dimnames")=List of 2
  .. .. ..$ : chr [1:32] "Mazda RX4" "Mazda RX4 Wag" "Datsun 710" "Hornet 4 Drive" ...
```

Extracting information from the fitted model

Accessing model parameter estimates:

```
fit$coefficients
```

```
(Intercept)          wt
  37.285126   -5.344472
```

```
# OR using
coef(fit)
```

```
(Intercept)          wt
  37.285126   -5.344472
```

This gives us the estimates of β_0 and β_1.

But what about σ^2? Recall $e_i \sim NID(0, \sigma^2)$.

```
sigma(fit)^2
```

```
[1] 9.277398
```

ℹ️ Extracting information from the fitted model

You can also get a summary of the model object:

```
summary(fit)
```

```
Call:
lm(formula = mpg ~ 1 + wt, data = mtcars)

Residuals:
    Min      1Q  Median      3Q     Max 
-4.5432 -2.3647 -0.1252  1.4096  6.8727 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  37.2851     1.8776  19.858  < 2e-16 ***
wt           -5.3445     0.5591  -9.559 1.29e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

So how do I extract these summary values out?

Model objects to tidy data

```
broom::tidy(fit)
```

```
# A tibble: 2 × 5
  term        estimate std.error statistic  p.value
  <chr>          <dbl>     <dbl>     <dbl>    <dbl>
1 (Intercept)    37.3      1.88      19.9  8.24e-19
2 wt             -5.34     0.559     -9.56 1.29e-10
```

```
broom::glance(fit)
```

```
# A tibble: 1 × 12
  r.squared adj.r.squa…¹ sigma stati…²  p.value    df logLik   AIC   BIC devia…³
      <dbl>        <dbl> <dbl>   <dbl>    <dbl> <dbl>  <dbl> <dbl> <dbl>   <dbl>
1     0.753        0.745  3.05    91.4 1.29e-10     1  -80.0  166.  170.    278.
# … with 2 more variables: df.residual <int>, nobs <int>, and abbreviated
#   variable names ¹adj.r.squared, ²statistic, ³deviance
# ℹ Use `colnames()` to see all variable names
```

```
broom::augment(fit)
```

```
# A tibble: 32 × 9
   .rownames          mpg    wt .fitted .resid   .hat .sigma   .cooksd .std.r…¹
   <chr>            <dbl> <dbl>   <dbl>  <dbl>  <dbl>  <dbl>     <dbl>    <dbl>
 1 Mazda RX4         21    2.62    23.3 -2.28  0.0433   3.07 0.0133     -0.766
 2 Mazda RX4 Wag     21    2.88    21.9 -0.920 0.0352   3.09 0.00172    -0.307
 3 Datsun 710        22.8  2.32    24.9 -2.09  0.0584   3.07 0.0154     -0.706
 4 Hornet 4 Drive    21.4  3.22    20.1  1.30  0.0313   3.09 0.00302     0.433
```

```
 5 Hornet Sportabout  18.7  3.44    18.9 -0.200 0.0329   3.10 0.0000760  -0.0668
 6 Valiant            18.1  3.46    18.8 -0.693 0.0332   3.10 0.000921   -0.231
 7 Duster 360         14.3  3.57    18.2 -3.91  0.0354   3.01 0.0313     -1.31
 8 Merc 240D          24.4  3.19    20.2  4.16  0.0313   3.00 0.0311      1.39
 9 Merc 230           22.8  3.15    20.5  2.35  0.0314   3.07 0.00996     0.784
10 Merc 280           19.2  3.44    18.9  0.300 0.0329   3.10 0.000171    0.100
# … with 22 more rows, and abbreviated variable name ¹.std.resid
```

But how do these functions work?

Functions in 

Revise about functions at Learn R

Functions in R

- Functions can be broken into three components:
  - `formals()`, the list of arguments,
  - `body()`, the code inside the function, and
  - `environment()`[1].
- Functions in R are created using `function()` with binding to a name using `<-` or `=`

1. This is outside the scope of this course.

Functions in R

```
f1 <- function(x) sum(x) / length(x)
```

```
formals(f1)
```

```
$x
```

```
body(f1)
```

```
sum(x)/length(x)
```

```
environment(f1)
```

```
<environment: R_GlobalEnv>
```

🏭 Function Example 1

```
1  f1 <- function(x) sum(x) / length(x)
```

```
x1 <- c(1, 1, 2, 2)
f1(x1)
```

```
[1] 1.5
```

🔧 What if there are missing values in the vector or the values are dates?

```
x2 <- c(1, 1, 2, 2, NA)
f1(x2)
```

```
[1] NA
```

```
x3 <- as.Date(c("2021-08-04", "2021-08-11"))
f1(x3)
```

```
Error in Summary.Date(structure(c(18843, 18850), class = "Date"), na.rm = FALSE): sum not
defined for "Date" objects
```

Function Example 2

```
1 f2 <- function(x, na.rm = TRUE) {
2   n <- sum(!is.na(x))
3   sum(x, na.rm = na.rm) / n
4 }
```

```
f2(x1)
```

```
[1] 1.5
```

```
f2(x2)
```

```
[1] 1.5
```

```
f2(x3)
```

```
Error in Summary.Date(structure(c(18843, 18850), class = "Date"), na.rm = TRUE): sum not defined
for "Date" objects
```

Function Example 3

```
f3 <- function(x, na.rm = TRUE) {
  n <- sum(!is.na(x))
  out <- sum(as.numeric(x), na.rm = na.rm) / n
  if(class(x)=="Date") {
    return(as.Date(out,
                   origin = "1970-01-01"))
  }
  out
}
```

```
f3(x1)
```

```
[1] 1.5
```

```
f3(x2)
```

```
[1] 1.5
```

```
f3(x3)
```

```
[1] "2021-08-07"
```

- What about for another object class?

```
x4 <- as.POSIXct(c("2021-08-11 18:00", "2021-08-11 20:00"), tz = "UTC")
```

S3 Object oriented programming (OOP)

- The ***S3 system*** is the most widely used OOP system in R but there are other OOP systems in R, e.g. the S4 system is used for model objects in `lme4` R-package, but it will be out of scope for this unit

```
class(x1)
```

```
[1] "numeric"
```

```
class(x2)
```

```
[1] "numeric"
```

```
class(x3)
```

```
[1] "Date"
```

```
class(x4)
```

```
[1] "POSIXct" "POSIXt"
```

S3 Object oriented programming (OOP)

- Here I create a generic called `f4`:

```
f4 <- function(x, ...) UseMethod("f4")
```

- And an associated default **method**:

```
f4.default <- function(x, na.rm = TRUE) {
  sum(x, na.rm = na.rm) / sum(!is.na(x))
}
```

- And an associated specific **method** for the `Date` class:

```
f4.Date <- function(x, na.rm = TRUE) {
  out <- f4.default(as.numeric(x), na.rm = na.rm)
  as.Date(out, origin = "1970-01-01")
}
```

S3 Object oriented programming (OOP)

```
f4(x1)
```

```
[1] 1.5
```

```
f4(x2)
```

```
[1] 1.5
```

```
f4(x3)
```

```
[1] "2021-08-07"
```

```
class(x4)
```

```
[1] "POSIXct" "POSIXt"
```

```
f4.POSIXct <- function(x, na.rm = TRUE) {
  out <- f4.default(as.numeric(x), na.rm = na.rm)
  as.POSIXct(out,
             tz = attr(x, "tzone"),
             origin = "1970-01-01")
}
```

```
f4(x4)
```

```
[1] "2021-08-11 19:00:00 UTC"
```

S3 Object oriented programming (OOP)

- A method is created by using the form `generic.class`.
- When using a method for `class`, you can omit the `.class` from the function.
- E.g. `f4(x4)` is the same as `f4.POSIXct(x4)` since the class of `x4` is `POSIXct` (and `POSIXt`).
- But notice `f4.numeric` doesn't exist, instead there is `f4.default`.
- `default` is a special class and when a generic doesn't have a method for the corresponding class, it falls back to `generic.default`

Working with *model objects* in 

Modelling in R

- There are many R-packages that fit all kinds of models, e.g.
  - `mgcv` fits generalized additive models,
  - `rstanarm` fits Bayesian regression models using Stan, and
  - `fable` fits forecast models,
  - many other contributions by the community.
- There are a lot of new R-packages contributed — some implementing the latest research results.
- This means that if you want to use the state-of-the-art research, then you need to work with model objects beyond the standard `lm` and `glm`.

Example with Bayesian regression

```
library(rstanarm)
fit_stan <- stan_lm(mpg ~ 1 + wt, data = mtcars,
                    prior = R2(0.7528, what = "mean"))
```

```
SAMPLING FOR MODEL 'lm' NOW (CHAIN 1).
Chain 1:
Chain 1: Gradient evaluation took 5.2e-05 seconds
Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.52 seconds.
Chain 1: Adjust your expectations accordingly!
Chain 1:
Chain 1:
Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
```

```
broom::tidy(fit_stan)
```

```
Error in warn_on_stanreg(x): The supplied model object seems to be outputted from the rstanarm
package. Tidiers for mixed model output now live in the broom.mixed package.
```

Huh?

S3 Object classes

- So how do you find out the functions that work with model objects?

- First notice the class of the object `fit`:

```
class(fit)
```

```
[1] "lm"
```

- The methods associated with this can be found using:

```
methods(class = "lm")
```

```
 [1] add1            alias           anova           augment         case.names
 [6] coerce          confint         cooks.distance  deviance        dfbeta
[11] dfbetas         drop1           dummy.coef      effects         extractAIC
[16] family          formula         fortify         glance          hatvalues
[21] influence       initialize      kappa           labels          logLik
[26] model.frame     model.matrix    nobs            plot            predict
[31] print           proj            qqnorm          qr              res
[36] rstandard       rstudent        show            simulate        slo
```

Where is `coef()`?

Case study `broom::tidy`

```
class(fit_stan)
```

```
[1] "stanreg" "glm"     "lm"
```

```
broom::tidy
```

```
function (x, ...)
{
    UseMethod("tidy")
}
<bytecode: 0x7fcf4cb44ae0>
<environment: namespace:generics>
```

There is no `tidy.stanreg` method so uses the `broom:::tidy.glm` instead.

Case study `broom::tidy`

```
 1  library(broom)
 2
 3  tidy.stanreg <- function(x, ...) {
 4    est <- x$coefficients
 5    tibble(term = names(est),
 6           estimate = unname(est),
 7           std.error = x$ses)
 8  }
 9
10  tidy(fit_stan)
```

```
# A tibble: 2 × 3
  term        estimate std.error
  <chr>          <dbl>     <dbl>
1 (Intercept)    30.4      1.34
2 wt             -3.20     0.347
```

Working with model objects

- Is this only for R though?
- How do you work with model objects in general?

Python

```python
import pandas as pd
import numpy as np
from sklearn.linear_model import LinearRegression
x = np.array(r.mtcars['wt']).reshape(-1, 1)
y = np.array(r.mtcars['mpg'])
model = LinearRegression().fit(x, y)

[model.intercept_, model.coef_]
```

```
[37.28512616734204, array([-5.34447157])]
```

```
(Intercept)          wt
  37.285126   -5.344472
```

Week 5A Lesson

Summary

- Model objects are usually a `list` returning multiple output from the model fit
- When working with model objects, check the object structure and find the methods associated with it (and of course check the documentation)
- You should be able to work (or at least know how to get started) with all sort of model objects
- We revised how to create functions in R
- We applied S3 object-oriented programming in R

Resources

- Wickham (2019) Advanced R, 2nd edition, Chapman & Hall, Chapter 13
- Create your own broom tidier methods
- Learn R Chapter 2: R Programming Basics and Chapter 7: Linear Regression with R