Continuous x Categorical data (1 of 2)

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1. THIS CHAPTER explains how to summarize and visualize *bivariate continuous data across categories*. Here, we delve into the intersection of continuous data and categorical variables, examining how the former can be split, summarized, and compared across different levels of one or more categorical variables.

2. We bring to light methods for generating statistics per group and sophisticated data manipulation techniques. This includes processes like grouping, filtering, and summarizing continuous data, contingent on categorical variables. When it comes to visualizations, our focus shifts towards creating juxtaposed box plots, segmented histograms, and density plots that reveal the distribution of continuous data across varied categories.

3. Incorporating categorical variables into our analysis elevates the depth of our comprehension of the data. It allows us to shift from a broad, holistic view to a more concentrated inspection of specific data segments. This approach empowers us to produce a more granular and nuanced interpretation of our data.

4. **Data**: Let us work with the same `mtcars` data from the previous chapter. Suppose we run the following code to prepare the data for subsequent analysis and save it in a tibble called `tb`:

```r
# Load the required libraries, suppressing annoying startup messages
library(tibble)
suppressPackageStartupMessages(library(dplyr))
# Read the mtcars dataset into a tibble called tb
data(mtcars)
tb <- as_tibble(mtcars)
# Convert several numeric columns into factor variables
tb$cyl <- as.factor(tb$cyl) # cyl = {4,6,8}, number of cylinders
tb$am <- as.factor(tb$am) # am = {0,1}, 0:automatic, 1: manual transmission
tb$vs <- as.factor(tb$vs) # vs = {0,1}, v-shaped engine, 0:no, 1:yes
tb$gear <- as.factor(tb$gear) # gear = {3,4,5}, number of gears
# Directly access the data columns of tb, without tb$mpg
attach(tb)
```

Summarizing Continuous Data

Across one Category

- R has a variety of functions that can be used to summarize continuous data split across a category.
- We review the use of the inbuilt functions (i) `aggregate()`; (ii) `tapply()`; and the function (iii) `describeBy()` from package `pysch`.

1. **Using `aggregate()`**

- We can use the `aggregate()` function to investigate the bivariate Relationship between Miles Per Gallon (`mpg`) and Cylinders (`cyl`). The following code will display a summary table showing the average mileage of the cars broken down by number of cylinders (`cyl` = 4, 6, 8) using `aggregate()`.

```
agg <- aggregate(tb$mpg,
          by = list(tb$cyl),
          FUN = mean)
names(agg) <- c("Cylinders", "Mean_mpg")
agg
```

```
  Cylinders Mean_mpg
1         4 26.66364
2         6 19.74286
3         8 15.10000
```

2. Discussion:

- The first argument in `aggregate()` is `tb$mpg`, which is the data vector we want to apply the function to.
- The second argument, `by`, denotes a list of variables to group by. Here, we've supplied `tb$cyl`, implying that we wish to partition our data based on the unique values of `cyl`.
- The third argument, `FUN`, is the function we want to apply to each subset of data. We are using `mean` here, meaning we're calculating the average mpg for each unique cyl value.
- The output of `aggregate()` is saved in a new tibble named `agg`.
- Finally, we utilize the `names()` function to rename the columns and display `agg`. [1]

3. **Using `tapply()`**

- The `tapply()` function is a convenient tool to apply a function to subsets of a vector, grouped by some factors.

```r
tapply(tb$mpg, tb$cyl, mean)
```

```
       4        6        8 
26.66364 19.74286 15.10000 
```

4. Discussion:

- In this code, `tapply(tb$mpg, tb$cyl, mean)` calculates the average miles per gallon (`mpg`) for each unique number of cylinders (`cyl`) within the `tb` tibble.
- `tb\$mpg` represents the vector to which we want to apply the function.
- `tb\$cyl` serves as our grouping factor. We are partitioning our data based on the unique values within the `cyl` column in our `tb` tibble.
- `mean` is the function that we're applying to each subset of our data.
- The result will be a vector where each element is the average `mpg` for a unique number of cylinders (`cyl`), as determined by the unique values of `tb$cyl`. [1]

5. **Using `describeBy()` from package `psych`**

- The `describeBy()` function, part of the `psych` package, can be used to compute descriptive statistics of a numeric variable, broken down by levels of a grouping variable.

```r
library(psych)
stats0 <- describeBy(mpg, cyl)
stats0
```

```
 Descriptive statistics by group 
group: 4
   vars  n  mean   sd median trimmed  mad  min  max range skew kurtosis   se
X1    1 11 26.66 4.51     26   26.44 6.52 21.4 33.9  12.5 0.26    -1.65 1.36
------------------------------------------------------------ 
group: 6
   vars n  mean   sd median trimmed  mad  min  max range  skew kurtosis   se
X1    1 7 19.74 1.45   19.7   19.74 1.93 17.8 21.4   3.6 -0.16    -1.91 0.55
------------------------------------------------------------ 
group: 8
   vars  n mean   sd median trimmed  mad  min  max range  skew kurtosis   se
X1    1 14 15.1 2.56   15.2   15.15 1.56 10.4 19.2   8.8 -0.36    -0.57 0.68
```

6. Discussion:

- `describeBy(mpg, cyl)` computes descriptive statistics of miles per gallon `mpg` variable, broken down by the unique values in the number of cylinders (`cyl`).
- It calculates statistics such as the mean, standard deviation, and quartiles for `mpg`, separately for each unique number of cylinders (`cyl`). [2]

Across two Categories

- We extend the above discussion and study how to summarize continuous data split across **two** categories.
- We review the use of the inbuilt functions (i) `aggregate()`; (ii) `tapply()`; and the function (iii) `describeBy()` from package `pysch`.

1. **Using `aggregate()`**

- Distribution of Mileage (`mpg`) by Cylinders (`cyl` = {4,6,8}) and Transmisson Type (`am` = {0,1})

```
agg2 <- aggregate(tb$mpg,
          by = list(tb$cyl, tb$am),
          FUN = mean)
names(agg2) <- c("Cylinders","Transmission","Mean_mpg")
agg2
```

```
  Cylinders Transmission Mean_mpg
1         4            0 22.90000
2         6            0 19.12500
3         8            0 15.05000
4         4            1 28.07500
5         6            1 20.56667
6         8            1 15.40000
```

2. Discussion:

- In our code, the first argument of `aggregate()` is `tb$mpg`, indicating that we want to perform computations on the `mpg` variable.
- The by argument is a list of variables by which we want to group our data, specified as `list(tb$cyl, tb$am)`. This means that separate computations are done for each unique combination of `cyl` and `am`.

- The `FUN` argument indicates the function to be applied to each subset of our data. Here, we use mean, meaning that we compute the mean mpg for each group.

3. Consider this extension of the above code for calculating the mean of three variables - mpg, wt, and hp, grouped by both am and cyl variables:

- Distribution of Mileage (`mpg`), Weight (`wt`), Horsepower (`hp`) by Cylinders (`cyl` = {4,6,8}) and Transmisson Type (`am` = {0,1})

```r
agg3 <- aggregate(list(tb$mpg, tb$wt, tb$hp),
          by = list(tb$am, tb$cyl),
          FUN = mean)
names(agg3) <- c("Transmission","Cylinders","Mean_mpg","Mean_wt","Mean_hp")
agg3
```

```
  Transmission Cylinders Mean_mpg  Mean_wt   Mean_hp
1            0         4 22.90000 2.935000  84.66667
2            1         4 28.07500 2.042250  81.87500
3            0         6 19.12500 3.388750 115.25000
4            1         6 20.56667 2.755000 131.66667
5            0         8 15.05000 4.104083 194.16667
6            1         8 15.40000 3.370000 299.50000
```

4. Discussion:

- In this code, the `aggregate()` function takes a list of the three variables as its first argument, indicating that the mean should be calculated for each of these variables separately within each combination of `am` and `cyl`.
- The sequence of the categorizing variables also varies - initially, the data is grouped by `cyl`, followed by a subdivision based on `am`.

5. **Using `tapply()`**

- While the `tapply()` function can theoretically be employed for this task, the resulting code tends to be long and lacks efficiency. Therefore, we opt to exclude it from practical use.

6. **Using `describeBy()` from package `psych`**

- The `describeBy()` function, part of the `psych` package, can be used to compute descriptive statistics of continuous variable, broken down by levels of a two categorical varaibles.
- Consider the following code:

```r
tb_columns <- tb[c("mpg", "wt", "hp")]
tb_factors <- list(tb$am, tb$cyl)
# Use describeBy()
stats <- describeBy(tb_columns, tb_factors)
print(stats)
```

```
 Descriptive statistics by group 
: 0
: 4
    vars n  mean    sd median trimmed  mad   min   max range  skew kurtosis
mpg    1 3 22.90  1.45  22.80   22.90 1.93 21.50 24.40  2.90  0.07    -2.33
wt     2 3  2.94  0.41   3.15    2.94 0.06  2.46  3.19  0.73 -0.38    -2.33
hp     3 3 84.67 19.66  95.00   84.67 2.97 62.00 97.00 35.00 -0.38    -2.33
       se
mpg  0.84
wt   0.24
hp  11.35
------------------------------------------------------------ 
: 1
: 4
    vars n  mean    sd median trimmed   mad   min    max range  skew kurtosis
mpg    1 8 28.08  4.48  28.85   28.08  4.74 21.40  33.90 12.50 -0.21    -1.66
wt     2 8  2.04  0.41   2.04    2.04  0.36  1.51   2.78  1.27  0.35    -1.15
hp     3 8 81.88 22.66  78.50   81.88 20.76 52.00 113.00 61.00  0.14    -1.81
      se
mpg 1.59
wt  0.14
hp  8.01
------------------------------------------------------------ 
: 0
: 6
    vars n   mean   sd median trimmed  mad    min    max range  skew kurtosis
mpg    1 4  19.12 1.63  18.65   19.12 1.04  17.80  21.40  3.60  0.48    -1.91
wt     2 4   3.39 0.12   3.44    3.39 0.01   3.21   3.46  0.25 -0.73    -1.70
hp     3 4 115.25 9.18 116.50  115.25 9.64 105.00 123.00 18.00 -0.09    -2.33
      se
mpg 0.82
wt  0.06
hp  4.59
------------------------------------------------------------ 
: 1
: 6
    vars n   mean    sd median trimmed  mad    min    max range  skew kurtosis
mpg    1 3  20.57  0.75  21.00   20.57 0.00  19.70  21.00  1.30 -0.38    -2.33
wt     2 3   2.76  0.13   2.77    2.76 0.16   2.62   2.88  0.25 -0.12    -2.33
hp     3 3 131.67 37.53 110.00  131.67 0.00 110.00 175.00 65.00  0.38    -2.33
       se
mpg  0.43
wt   0.07
hp  21.67
------------------------------------------------------------
: 0
: 8
    vars  n   mean    sd median trimmed   mad    min    max range  skew
mpg    1 12  15.05  2.77  15.20   15.10  2.30  10.40  19.20  8.80 -0.28
wt     2 12   4.10  0.77   3.81    4.04  0.41   3.44   5.42  1.99  0.85
hp     3 12 194.17 33.36 180.00  193.50 40.77 150.00 245.00 95.00  0.28
    kurtosis   se
mpg    -0.96 0.80
wt     -1.14 0.22
hp     -1.44 9.63
------------------------------------------------------------
: 1
: 8
    vars n   mean    sd median trimmed   mad    min    max range skew kurtosis
mpg    1 2  15.40  0.57  15.40   15.40  0.59  15.00  15.80   0.8    0    -2.75
wt     2 2   3.37  0.28   3.37    3.37  0.30   3.17   3.57   0.4    0    -2.75
hp     3 2 299.50 50.20 299.50  299.50 52.63 264.00 335.00  71.0    0    -2.75
      se
mpg  0.4
wt   0.2
hp  35.5
```

7. Discussion:

- We first specify a subset of the dataframe `tb` that includes only the columns `mpg`, `wt`, and `hp` and save it into a variable `tb_columns`.
- Next, we create a list, `tb_factors`, that contains the factors `am` and `cyl`.
- After that, we call the `describeBy()` function from the `psych` package. This function calculates descriptive statistics, such as mean, standard deviation, and median, for each combination of levels of the factors `am` and `cyl` and for each of the continouous variables `mpg`, `wt`, and `hp`.

Visualizing Continuous Data

Let’s take a closer look at some of the most effective ways of visualizing univariate continuous data, including

(i) Histograms;

(ii) PDF and CDF Density plots;

(iii) Box plots;

(iv) Bee Swarm plots;

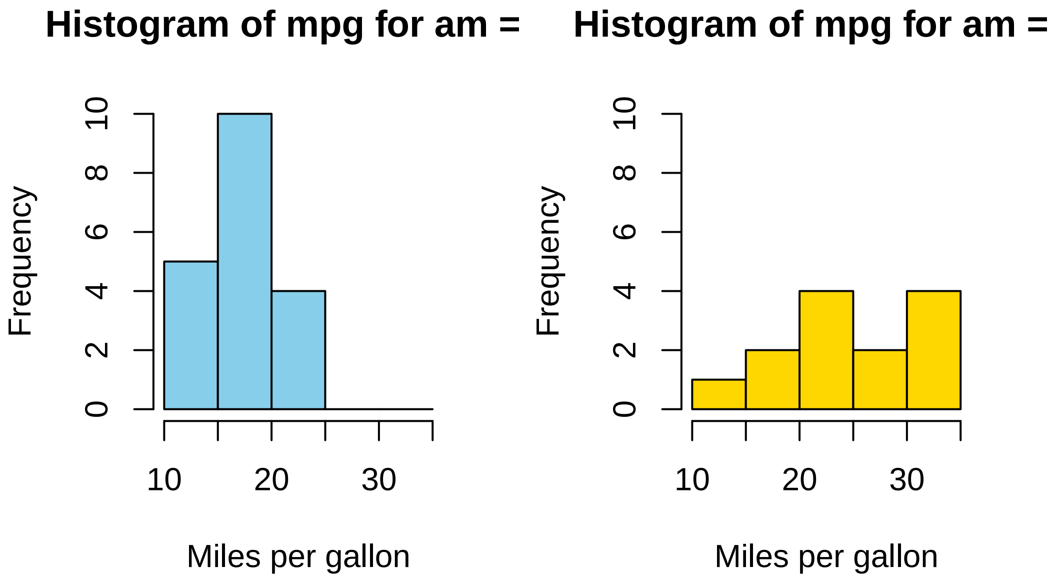
(v) Violin plots;

(vi) Q-Q plots.

Histograms across one Category

Visualizing histograms of car milegage (`mpg`) broken down by transmission (`am`=0,1)

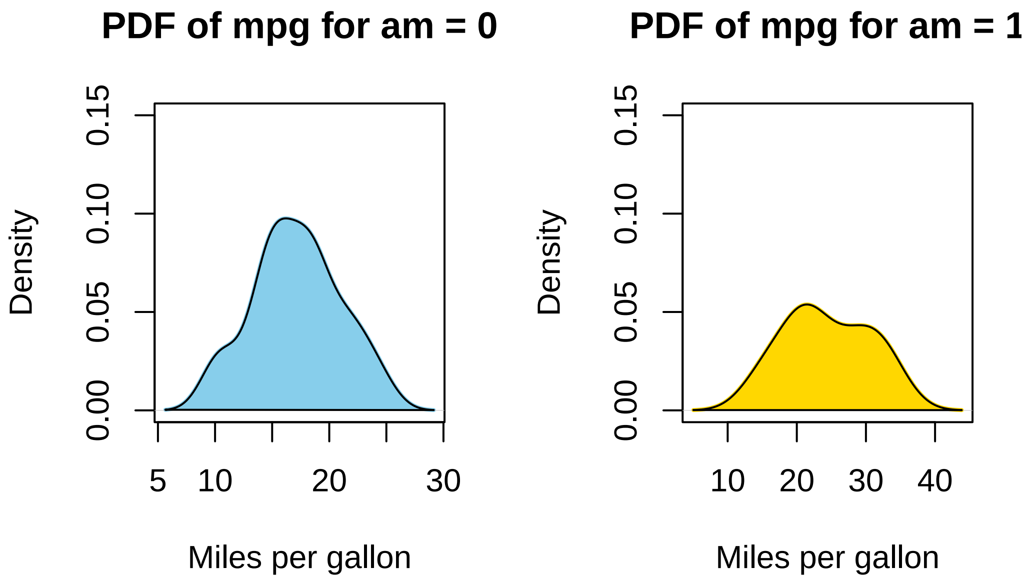
```r
# Split the data by 'am' variable
split_data <- split(tb$mpg, tb$am)

# Create a 1-row 2-column layout
par(mfrow = c(1, 2))

# Define the color vector
color_vector <- c("skyblue", "gold")

# Create a histogram for each subset
for (i in 1:length(split_data)) {
  hist(split_data[[i]],
       main = paste("Histogram of mpg for am =", i - 1),
       breaks = seq(10, 35, by = 5), # This creates bins with ranges 10-15, 15-20, etc.
       xlab = "Miles per gallon",
       col = color_vector[i], # Use the color vector,
       border = "black",
       ylim = c(0, 10))
}
```



Probability Density Function (PDF) across one Category

Visualizing Probability Density Function (PDF) of car milegage (`mpg`) broken down by transmission (`am`=0,1)

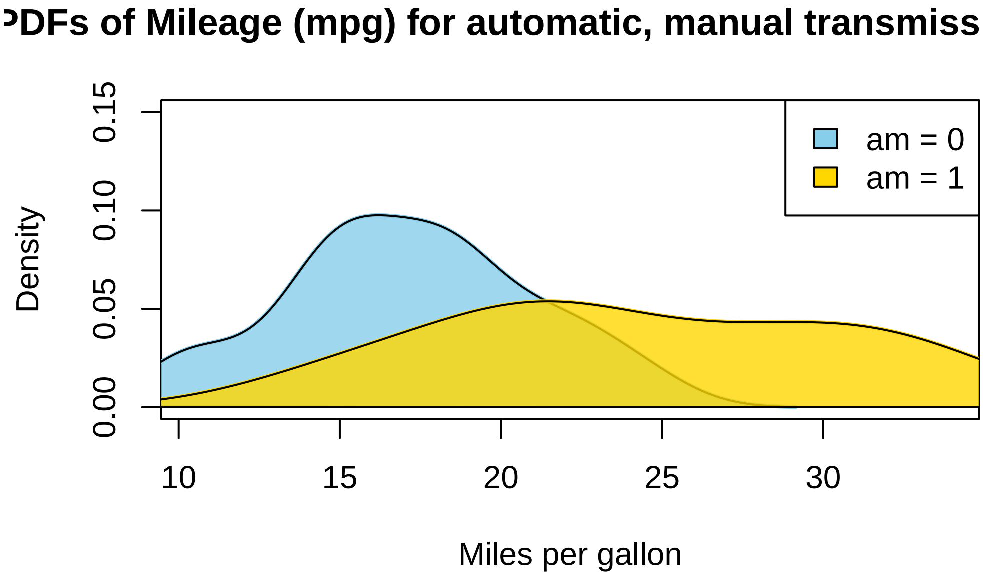
```
# Split the data by 'am' variable
split_data <- split(tb$mpg, tb$am)

# Create a 1-row 2-column layout
par(mfrow = c(1, 2))

# Define the color vector
color_vector <- c("skyblue", "gold")

# Create a density plot for each subset
for (i in 1:length(split_data)) {
  # Calculate density
  dens <- density(split_data[[i]])

  # Plot density
  plot(dens,
       main = paste("PDF of mpg for am =", i - 1),
       xlab = "Miles per gallon",
       col = color_vector[i],
        border = "black",
        ylim = c(0, 0.15), # Adjust this value if necessary
        lwd = 2) # line width

  # Add a polygon to fill under the density curve
  polygon(dens, col = color_vector[i], border = "black")
}
```



- We can alternately draw overlapping PDFs on the same plot.

```
# Split the data by 'am' variable
split_data <- split(tb$mpg, tb$am)

# Define the color vector
color_vector <- c("skyblue", "gold")

# Define the legend labels
legend_labels <- c("am = 0", "am = 1")

# Create a density plot for each subset
# Start with an empty plot with ranges accommodating both data sets
plot(0, 0, xlim = range(tb$mpg), ylim = c(0, 0.15), type = "n",
     xlab = "Miles per gallon", ylab = "Density",
     main = "PDFs of Mileage (mpg) for automatic, manual transmissions (am)")
```

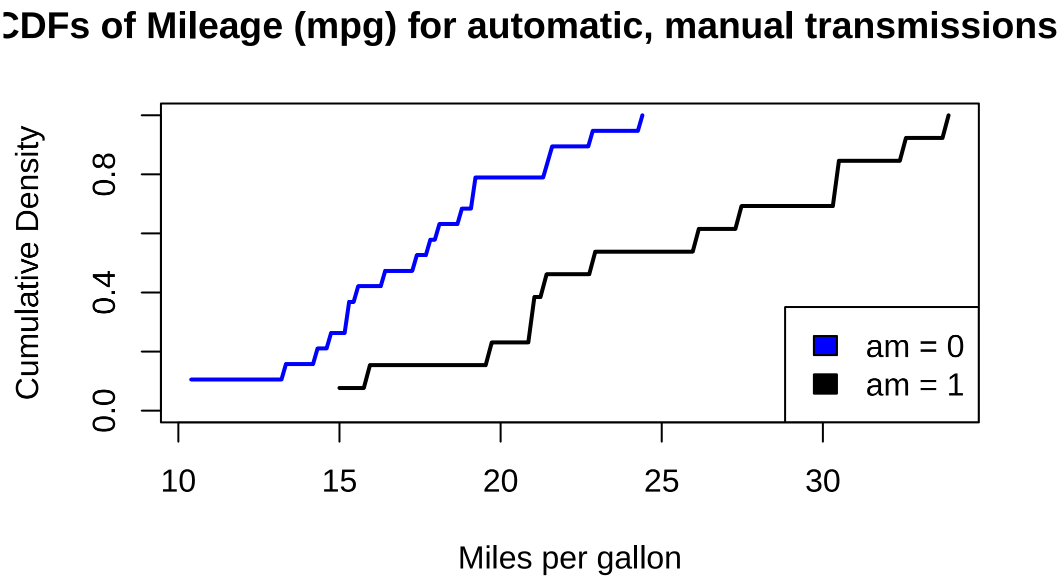
```
for (i in 1:length(split_data)) {
  # Calculate density
  dens <- density(split_data[[i]])

  # Add density plot
  lines(dens,
        col = color_vector[i],
        lwd = 2) # line width

  # Add a polygon to fill under the density curve
  polygon(dens, col = adjustcolor(color_vector[i], alpha.f = 0.8), border = "black")
}

# Add legend to the plot
legend("topright", legend = legend_labels, fill = color_vector, border = "black")
```



Cumulative Density Function (CDF) across one Category

```
# Split the data by 'am' variable
split_data <- split(tb$mpg, tb$am)

# Define the color vector
color_vector <- c("blue", "black")
```

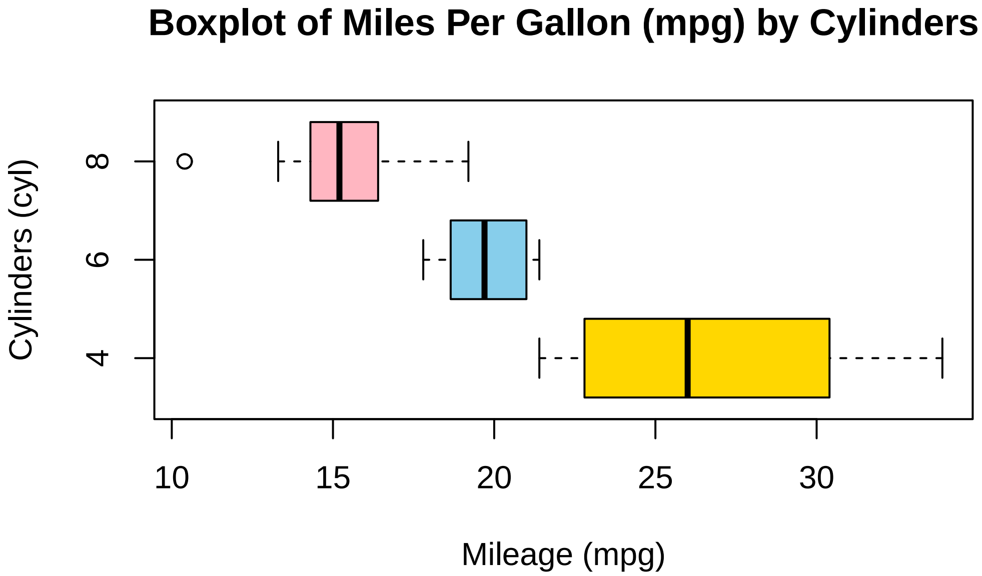
```
# Define the legend labels
legend_labels <- c("am = 0", "am = 1")

# Create a cumulative density plot for each subset
# Start with an empty plot with ranges accommodating both data sets
plot(0, 0, xlim = range(mtcars$mpg), ylim = c(0, 1), type = "n",
     xlab = "Miles per gallon", ylab = "Cumulative Density",
     main = "CDFs of Mileage (mpg) for automatic, manual transmissions (am)")

for (i in 1:length(split_data)) {
  # Calculate empirical cumulative density function
  ecdf_func <- ecdf(split_data[[i]])

  # Add CDF plot using curve function
  curve(ecdf_func(x),
        from = min(split_data[[i]]), to = max(split_data[[i]]),
        col = color_vector[i],
        add = TRUE,
        lwd = 2) # line width
}
# Add legend to the plot
legend("bottomright", legend = legend_labels, fill = color_vector, border = "black")
```



Box Plots across one Category

Visualizing Median using Box Plot – median weight of the cars broken down by cylinders (`cyl`=4,6,8)

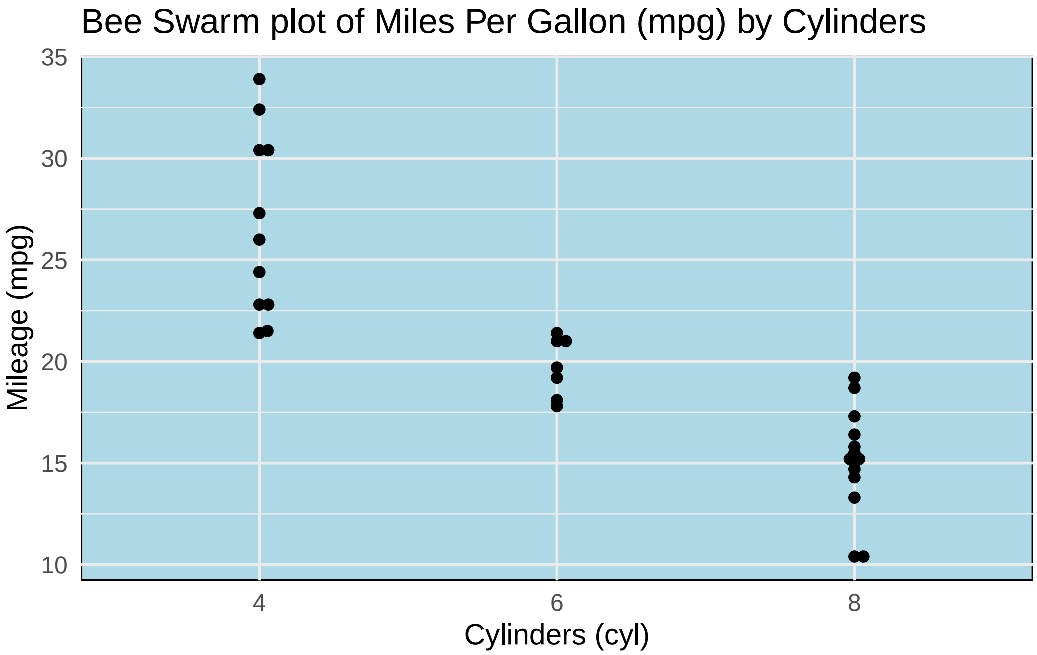
```
boxplot(mpg~cyl,
        main = "Boxplot of Miles Per Gallon (mpg) by Cylinders",
        ylab = "Cylinders (cyl)",
        xlab = "Mileage (mpg)",
        col = c("gold","skyblue","lightpink"),
        horizontal = TRUE
        )
```



```
library(ggplot2)
```

```
Attaching package: 'ggplot2'

The following objects are masked from 'package:psych':

    %+%, alpha

The following object is masked from 'tb':

    mpg
```

```
library(ggbeeswarm)
# Create the beeswarm plot
ggplot(tb,
       aes(x = cyl,
           y = mpg)) +
  geom_beeswarm() +
  labs(title = "Bee Swarm plot of Miles Per Gallon (mpg) by Cylinders",
       x = "Cylinders (cyl)",
       y = "Mileage (mpg)") +
  theme_minimal() +
  theme(panel.background = element_rect(fill = "lightblue"))
```



Means Plot across one Category

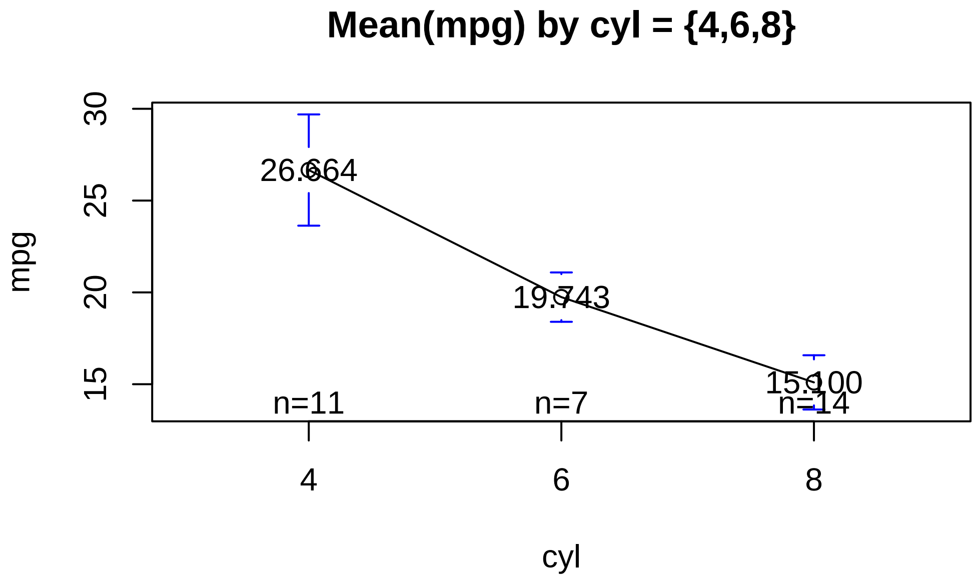
Visualizing Means – mean plot showing the average weight of the cars, broken down by transmission (`am`= 0 or 1)

```
library(gplots)
```

```
Attaching package: 'gplots'
```

```
The following object is masked from 'package:stats':

    lowess
```

```
plotmeans(data = tb,
          mpg ~ cyl,
          mean.labels = TRUE,
          digits=3,
          main = "Mean(mpg) by cyl = {4,6,8}"
          )
```

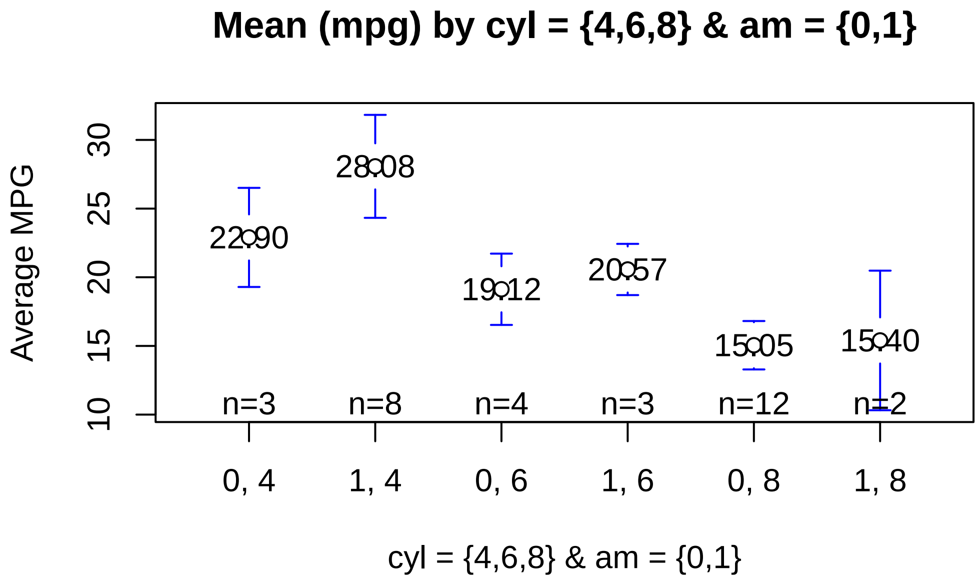


Means Plot across two Categories

We show a mean plot showing the mean weight of the cars broken down by Transmission Type (`am`= 0 or 1) & cylinders (`cyl` = 4,6,8).

```
library(gplots)
plotmeans(mpg ~ interaction(am, cyl, sep = ", ")
          , data = mtcars
          , mean.labels = TRUE
          , digits=2
          , connect = FALSE
          , main = "Mean (mpg) by cyl = {4,6,8} & am = {0,1}"
          , xlab= "cyl = {4,6,8} & am = {0,1}"
```

```
            , ylab="Average MPG"
            )
```



Stem-and-Leaf Plot across one Category

1. The provided R code first selects the `mpg` and `cyl` columns from `tb`, then it segments the data into groups based on `cyl` values, and lastly, it generates a stem-and-leaf plot for the `mpg` values in each separate group.

```
# Use the 'select()' function from 'dplyr' to choose 'mpg' and 'cyl' columns from 'tb' tib
tb3 <- select(tb, mpg, cyl)

# Split the 'tb3' tibble into subsets based on 'cyl'. Each subset consists of rows with th
tb_split <- split(tb3, tb3$cyl)

# Apply a function to each subset of 'tb_split' using 'lapply()'.
# The function takes a subset 'x' and creates a stem-and-leaf plot of the 'mpg' values in
lapply(tb_split,
       function(x)
         stem(x$mpg))
```

```
  The decimal point is 1 digit(s) to the right of the |
  2 | 12334
  2 | 67
  3 | 0024


  The decimal point is at the |

  17 | 8
  18 | 1
  19 | 27
  20 |
  21 | 004


  The decimal point is at the |

  10 | 44
  12 | 3
  14 | 3702258
  16 | 43
  18 | 72

$`4`
NULL

$`6`
NULL

$`8`
NULL
```

2. Discussion:

- `tb3 <- select(tb, mpg, cyl)`: In this line, we're using the `select()` function from the `dplyr` package to pick out the `mpg` and `cyl` columns from the tibble `tb`. We then store this newly created subset of the original tibble into a new tibble `tb3`.
- `tb_split <- split(tb3, tb3$cyl)`: With the `split()` function, we're segmenting the `tb3` tibble into subsets based on the `cyl` column. This action groups all rows with identical `cyl` values together into the same subset. We then store this list of new, smaller tibbles as `tb_split`.
- `lapply(tb_split, function(x) stem(x$mpg))`: Here we employ the `lapply()` function to apply a specified function to each element within a list. The function we've

elected to apply is `function(x) stem(x$mpg)`, which plots a stem-and-leaf display for the mpg column of each tibble `x` in `tb_split`. As `tb_split` is a list of tibbles that have been grouped according to `cyl` values, this step will generate a separate stem-and-leaf plot for each group of `cyl` values.

References

[1] R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Fox, J. and Weisberg, S. (2011). An R Companion to Applied Regression, Second Edition. Thousand Oaks CA: Sage.

[2] Revelle, W. (2020). psych: Procedures for Psychological, Psychometric, and Personality Research. Northwestern University, Evanston, Illinois. R package version 2.0.9. https://CRAN.R-project.org/package=psych

[10] Chambers, J. M., Freeny, A. E., & Heiberger, R. M. (1992). Analysis of variance; designed experiments. In Statistical Models in S (pp. 145–193). Pacific Grove, CA: Wadsworth & Brooks/Cole.