Report on Fuel Consumption of automobiles

May 13th, 2015

Introduction

We investigate data that extracted from the 1974 *Motor Trend* US magazine. They comprises fuel consumption and 10 aspects of automobile design and performance for 32 automobiles (1973-74 models). We are particularly interested in the following questions:

- Is an automatic or manual transmission better for MPG?
- Quantify the MPG difference between automatic and manual transmissions.

```
ggplot(cs.dt, aes(am, mpg)) + geom_boxplot() +
    theme_tufte() + scale_x_discrete(labels = c("manual",
    "automatic"))
```

```
ggplot(cs.dt, aes(wt, mpg, colour = am)) + geom_point() +
    theme_tufte() + geom_text(aes(label = cyl,
    colour = NULL), vjust = -0.6) + geom_smooth(method = "lm")
```

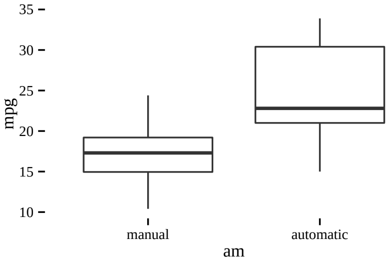


Figure 1: Automatic vs. manual transmission.

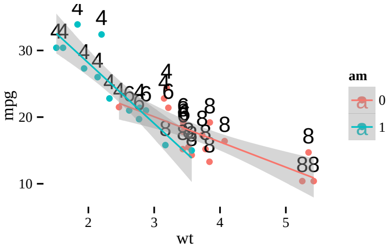


Figure 2: Impact of weight, transmission and number of cylinders on fuel consumption.

The boxplot on Figure 1 suggests that manual transmission is better for mpg. However, Figure 2 shows that actually weight or number of gears can be the most important factor.

Model Selection

Let us try to identify the subset of the predictors that can be related to the mpg response. For that we use `regsubsets` function from `leaps` library which select the best model with n predictors, for $n = 1 \ldots 8$.

```
regfit <- regsubsets(mpg ~ ., cs.dt)
reg.summary <- summary(regfit)
print(xtable(reg.summary$outmat), size = "\\tiny")
```

	cyl6	cyl8	disp	hp	drat	wt	qsec	vs1	am1	gear4	gear5	carb2	carb3	carb4	carb6	carb8
1 (1)						*										
2 (1)				*		*										
3 (1)						*	*		*							
4 (1)	*			*		*			*							
5 (1)	*			*		*		*	*							
6 (1)	*			*		*		*	*		*					
7 (1)		*		*		*	*	*	*		*					
8 (1)	*		*	*		*				*	*	*				*

```
ggplot(data = NULL, aes(x = 1:length(reg.summary$rsq),
    y = reg.summary$rsq)) + geom_line() + theme_bw() +
    labs(x = "n", y = "R2 statistic")
```

If we take a look at Figure 3 where we plot R^2 statistic for the best model with $n = 1, ..., 8$ predictors, we see that $n = 5$ would be the best choice. Therefore our regression model is the following.

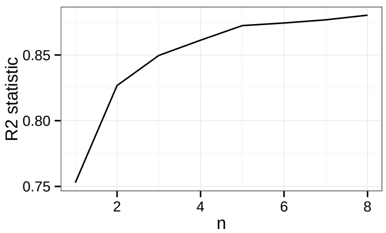


Figure 3: R^2 statistic for the best model with $n = 1, \ldots, 8$.

```
fit <- lm(mpg ~ hp + wt + am + I(cyl == 6) + I(vs ==
    1), data = cs.dt)
print(xtable(summary(fit)$coefficients))
```

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	31.28	3.19	9.81	0.00
hp	-0.03	0.01	-3.25	0.00
wt	-2.37	0.87	-2.73	0.01
am1	2.62	1.30	2.02	0.05
I(cyl == 6)TRUE	-2.21	1.03	-2.14	0.04
I(vs == 1)TRUE	1.88	1.25	1.50	0.14

```
names(summary(regfit))
```

```
## [1] "which"  "rsq"    "rss"    "adjr2"
## [5] "cp"     "bic"    "outmat" "obj"
```

```
reg.summary$rsq
```

```
## [1] 0.7528328 0.8267855 0.8496636 0.8612516
## [5] 0.8723598 0.8743388 0.8767613 0.8802830
```

```
reg.summary$which
```

```
##   (Intercept)  cyl6  cyl8  disp    hp  drat
## 1        TRUE FALSE FALSE FALSE FALSE FALSE
## 2        TRUE FALSE FALSE FALSE  TRUE FALSE
## 3        TRUE FALSE FALSE FALSE FALSE FALSE
## 4        TRUE  TRUE FALSE FALSE  TRUE FALSE
## 5        TRUE  TRUE FALSE FALSE  TRUE FALSE
## 6        TRUE  TRUE FALSE FALSE  TRUE FALSE
## 7        TRUE FALSE  TRUE FALSE  TRUE FALSE
## 8        TRUE  TRUE FALSE  TRUE  TRUE FALSE
##     wt  qsec   vs1   am1 gear4 gear5 carb2
## 1 TRUE FALSE FALSE FALSE FALSE FALSE FALSE
## 2 TRUE FALSE FALSE FALSE FALSE FALSE FALSE
## 3 TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE
## 4 TRUE FALSE FALSE  TRUE FALSE FALSE FALSE
## 5 TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE
## 6 TRUE FALSE  TRUE  TRUE FALSE  TRUE FALSE
## 7 TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE
## 8 TRUE FALSE FALSE FALSE  TRUE  TRUE  TRUE
##   carb3 carb4 carb6 carb8
## 1 FALSE FALSE FALSE FALSE
## 2 FALSE FALSE FALSE FALSE
## 3 FALSE FALSE FALSE FALSE
## 4 FALSE FALSE FALSE FALSE
## 5 FALSE FALSE FALSE FALSE
## 6 FALSE FALSE FALSE FALSE
## 7 FALSE FALSE FALSE FALSE
## 8 FALSE FALSE FALSE  TRUE
```

```
## plot(regfit.full ,scale ='r2')
## plot(regfit.full , scale ='adjr2') ##
## plot(regfit.full, scale ='Cp')

fit.full <- lm(mpg ~ ., data = cs.dt)
summary(fit.full)
```

```
##
## Call:
## lm(formula = mpg ~ ., data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.5087 -1.3584 -0.0948  0.7745  4.6251
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept) 23.87913   20.06582   1.190
## cyl6        -2.64870    3.04089  -0.871
## cyl8        -0.33616    7.15954  -0.047
## disp         0.03555    0.03190   1.114
## hp          -0.07051    0.03943  -1.788
## drat         1.18283    2.48348   0.476
## wt          -4.52978    2.53875  -1.784
## qsec         0.36784    0.93540   0.393
## vs1          1.93085    2.87126   0.672
## am1          1.21212    3.21355   0.377
## gear4        1.11435    3.79952   0.293
## gear5        2.52840    3.73636   0.677
## carb2       -0.97935    2.31797  -0.423
## carb3        2.99964    4.29355   0.699
## carb4        1.09142    4.44962   0.245
## carb6        4.47757    6.38406   0.701
## carb8        7.25041    8.36057   0.867
##             Pr(>|t|)
## (Intercept)   0.2525
## cyl6          0.3975
## cyl8          0.9632
## disp          0.2827
## hp            0.0939 .
## drat          0.6407
## wt            0.0946 .
## qsec          0.6997
## vs1           0.5115
## am1           0.7113
## gear4         0.7733
## gear5         0.5089
## carb2         0.6787
## carb3         0.4955
## carb4         0.8096
## carb6         0.4938
## carb8         0.3995
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.833 on 15 degrees of freedom
## Multiple R-squared:  0.8931, Adjusted R-squared:  0.779
## F-statistic:  7.83 on 16 and 15 DF,  p-value: 0.000124
```

```
fit.wt <- lm(mpg ~ wt * am, data = cs.dt)
summary(fit.wt)
```

```
##
## Call:
## lm(formula = mpg ~ wt * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.6004 -1.5446 -0.5325  0.9012  6.0909
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept)  31.4161     3.0201  10.402
## wt           -3.7859     0.7856  -4.819
## am1          14.8784     4.2640   3.489
## wt:am1       -5.2984     1.4447  -3.667
##             Pr(>|t|)
## (Intercept) 4.00e-11 ***
## wt          4.55e-05 ***
## am1          0.00162 **
## wt:am1       0.00102 **
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.591 on 28 degrees of freedom
## Multiple R-squared:  0.833,  Adjusted R-squared:  0.8151
## F-statistic: 46.57 on 3 and 28 DF,  p-value: 5.209e-11
```

```
fit.hp <- lm(mpg ~ hp * am, data = cs.dt)
summary(fit.hp)
```

```
##
## Call:
## lm(formula = mpg ~ hp * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.3818 -2.2696  0.1344  1.7058  5.8752
##
## Coefficients:
##               Estimate Std. Error t value
## (Intercept) 26.6248479  2.1829432  12.197
## hp          -0.0591370  0.0129449  -4.568
## am1          5.2176534  2.6650931   1.958
## hp:am1       0.0004029  0.0164602   0.024
##             Pr(>|t|)
## (Intercept) 1.01e-12 ***
## hp          9.02e-05 ***
## am1           0.0603 .
## hp:am1        0.9806
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.961 on 28 degrees of freedom
## Multiple R-squared:  0.782,  Adjusted R-squared:  0.7587
## F-statistic: 33.49 on 3 and 28 DF,  p-value: 2.112e-09
```

```
fit.wthp <- lm(mpg ~ (hp + wt) * am, data = cs.dt)
summary(fit.wthp)
```

```
##
## Call:
## lm(formula = mpg ~ (hp + wt) * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.9873 -1.4467 -0.5355  1.2614  5.5987
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept) 30.70393    2.67515  11.477
## hp          -0.04094    0.01363  -3.004
## wt          -1.85591    0.94511  -1.964
## am1         13.74000    4.22337   3.253
## hp:am1       0.02779    0.01921   1.447
## wt:am1      -5.76895    2.07201  -2.784
##             Pr(>|t|)
## (Intercept) 1.12e-11 ***
## hp           0.00583 **
## wt           0.06034 .
## am1          0.00316 **
## hp:am1       0.15983
## wt:am1       0.00987 **
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.286 on 26 degrees of freedom
## Multiple R-squared:  0.8793, Adjusted R-squared:  0.8561
## F-statistic: 37.89 on 5 and 26 DF,  p-value: 3.901e-11
```

```
summary(fit.full)$coef
```

```
##                Estimate  Std. Error
## (Intercept) 23.87913244 20.06582026
## cyl6        -2.64869528  3.04089041
## cyl8        -0.33616298  7.15953951
## disp         0.03554632  0.03189920
## hp          -0.07050683  0.03942556
## drat         1.18283018  2.48348458
## wt          -4.52977584  2.53874584
## qsec         0.36784482  0.93539569
## vs1          1.93085054  2.87125777
## am1          1.21211570  3.21354514
## gear4        1.11435494  3.79951726
## gear5        2.52839599  3.73635801
## carb2       -0.97935432  2.31797446
## carb3        2.99963875  4.29354611
## carb4        1.09142288  4.44961992
## carb6        4.47756921  6.38406242
## carb8        7.25041126  8.36056638
##                 t value   Pr(>|t|)
## (Intercept)  1.19004018 0.25252548
## cyl6        -0.87102622 0.39746642
## cyl8        -0.04695316 0.96317000
## disp         1.11433290 0.28267339
## hp          -1.78835344 0.09393155
## drat         0.47627845 0.64073922
## wt          -1.78425732 0.09461859
## qsec         0.39325050 0.69966720
## vs1          0.67247551 0.51150791
## am1          0.37718957 0.71131573
## gear4        0.29328856 0.77332027
## gear5        0.67670068 0.50889747
## carb2       -0.42250436 0.67865093
## carb3        0.69863900 0.49546781
## carb4        0.24528452 0.80956031
## carb6        0.70136677 0.49381268
## carb8        0.86721532 0.39948495
```

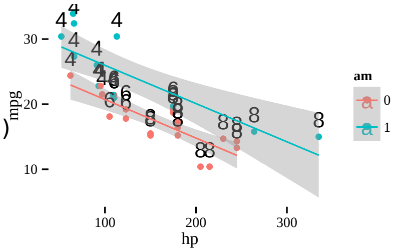


Figure 4: Sepal length vs. petal length, colored by species

```
ggplot(cs.dt, aes(hp, mpg, colour = am)) + geom_point() +
    geom_text(aes(label = cyl, colour = NULL),
        vjust = -0.6) + theme_tufte() + geom_smooth(method = "lm")
```

```
ggplot(cs.dt, aes(hp, wt, colour = am)) + geom_point() +
    geom_text(aes(label = cyl, colour = NULL),
        vjust = -0.6) + theme_tufte() + geom_smooth(method = "lm")
```

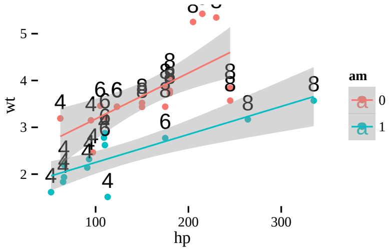


Figure 5: Sepal length vs. petal length, colored by species

```
ggplot(cs.dt, aes(disp, mpg, colour = am)) + geom_point() +
    theme_tufte() + geom_smooth(method = "lm")
```

```
ggplot(cs.dt, aes(wt, disp, colour = am)) + geom_point() +
    theme_tufte() + geom_smooth(method = "lm")
```

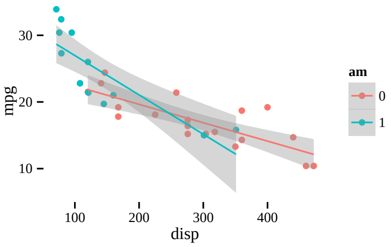


Figure 6: Sepal length vs. petal length,

Is an automatic or manual transmission better for MPG?

It seems so.

```
fit.wt <- lm(mpg ~ wt * am, data = cs.dt)
summary(fit.wt)
```

```
##
## Call:
## lm(formula = mpg ~ wt * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.6004 -1.5446 -0.5325  0.9012  6.0909
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept)  31.4161     3.0201  10.402
## wt           -3.7859     0.7856  -4.819
## am1          14.8784     4.2640   3.489
## wt:am1       -5.2984     1.4447  -3.667
##             Pr(>|t|)
## (Intercept) 4.00e-11 ***
## wt          4.55e-05 ***
## am1          0.00162 **
## wt:am1       0.00102 **
## ---
## Signif. codes:
##   0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1  ' ' 1
##
## Residual standard error: 2.591 on 28 degrees of freedom
## Multiple R-squared:  0.833,  Adjusted R-squared:  0.8151
## F-statistic: 46.57 on 3 and 28 DF,  p-value: 5.209e-11
```

```
fit.hp <- lm(mpg ~ hp * am, data = cs.dt)
summary(fit.hp)
```

```
##
## Call:
## lm(formula = mpg ~ hp * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.3818 -2.2696  0.1344  1.7058  5.8752
##
## Coefficients:
```

```
##                Estimate Std. Error t value
## (Intercept) 26.6248479  2.1829432  12.197
## hp          -0.0591370  0.0129449  -4.568
## am1          5.2176534  2.6650931   1.958
## hp:am1       0.0004029  0.0164602   0.024
##             Pr(>|t|)
## (Intercept) 1.01e-12 ***
## hp          9.02e-05 ***
## am1           0.0603 .
## hp:am1        0.9806
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.961 on 28 degrees of freedom
## Multiple R-squared:  0.782,  Adjusted R-squared:  0.7587
## F-statistic: 33.49 on 3 and 28 DF,  p-value: 2.112e-09
```

```
fit.hpwt <- lm(mpg ~ (hp + wt) * am, data = cs.dt)
summary(fit.hpwt)
```

```
##
## Call:
## lm(formula = mpg ~ (hp + wt) * am, data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.9873 -1.4467 -0.5355  1.2614  5.5987
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept) 30.70393    2.67515  11.477
## hp          -0.04094    0.01363  -3.004
## wt          -1.85591    0.94511  -1.964
## am1         13.74000    4.22337   3.253
## hp:am1       0.02779    0.01921   1.447
## wt:am1      -5.76895    2.07201  -2.784
##             Pr(>|t|)
## (Intercept) 1.12e-11 ***
## hp           0.00583 **
## wt           0.06034 .
## am1          0.00316 **
## hp:am1       0.15983
## wt:am1       0.00987 **
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.286 on 26 degrees of freedom
## Multiple R-squared:  0.8793, Adjusted R-squared:  0.8561
## F-statistic: 37.89 on 5 and 26 DF,  p-value: 3.901e-11
```

```
fit2 <- lm(mpg ~ wt + hp, data = cs.dt)
summary(fit2)
```

```
##
## Call:
## lm(formula = mpg ~ wt + hp, data = cs.dt)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -3.941 -1.600 -0.182  1.050  5.854
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept) 37.22727    1.59879  23.285
## wt          -3.87783    0.63273  -6.129
## hp          -0.03177    0.00903  -3.519
##             Pr(>|t|)
## (Intercept)  < 2e-16 ***
## wt          1.12e-06 ***
## hp           0.00145 **
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.593 on 29 degrees of freedom
## Multiple R-squared:  0.8268, Adjusted R-squared:  0.8148
## F-statistic: 69.21 on 2 and 29 DF,  p-value: 9.109e-12
```

```
fit1 <- lm(mpg ~ wt, data = cs.dt)
fit <- lm(mpg ~ ., data = cs.dt)
summary(fit)
```

```
##
## Call:
## lm(formula = mpg ~ ., data = cs.dt)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -3.5087 -1.3584 -0.0948  0.7745  4.6251
```

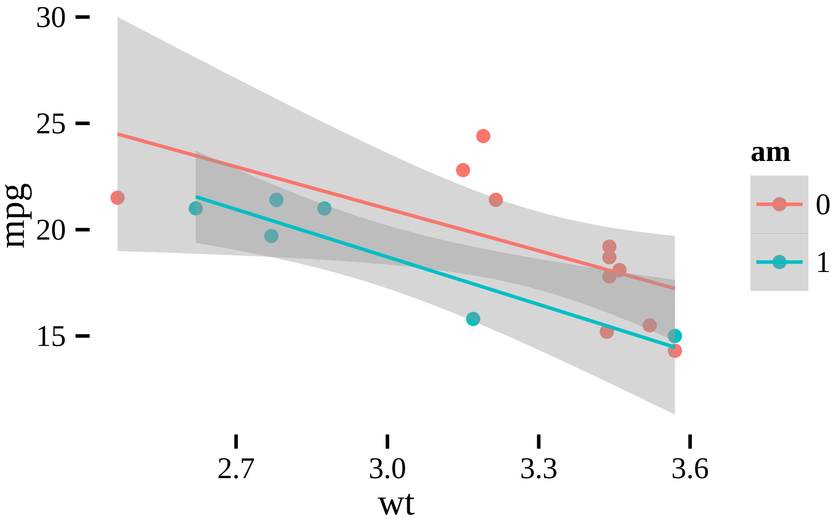
```
##
## Coefficients:
##             Estimate Std. Error t value
## (Intercept) 23.87913   20.06582   1.190
## cyl6        -2.64870    3.04089  -0.871
## cyl8        -0.33616    7.15954  -0.047
## disp         0.03555    0.03190   1.114
## hp          -0.07051    0.03943  -1.788
## drat         1.18283    2.48348   0.476
## wt          -4.52978    2.53875  -1.784
## qsec         0.36784    0.93540   0.393
## vs1          1.93085    2.87126   0.672
## am1          1.21212    3.21355   0.377
## gear4        1.11435    3.79952   0.293
## gear5        2.52840    3.73636   0.677
## carb2       -0.97935    2.31797  -0.423
## carb3        2.99964    4.29355   0.699
## carb4        1.09142    4.44962   0.245
## carb6        4.47757    6.38406   0.701
## carb8        7.25041    8.36057   0.867
##             Pr(>|t|)
## (Intercept)   0.2525
## cyl6          0.3975
## cyl8          0.9632
## disp          0.2827
## hp            0.0939 .
## drat          0.6407
## wt            0.0946 .
## qsec          0.6997
## vs1           0.5115
## am1           0.7113
## gear4         0.7733
## gear5         0.5089
## carb2         0.6787
## carb3         0.4955
## carb4         0.8096
## carb6         0.4938
## carb8         0.3995
## ---
## Signif. codes:
##   0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1  ’ ’ 1
##
## Residual standard error: 2.833 on 15 degrees of freedom
## Multiple R-squared:  0.8931, Adjusted R-squared:  0.779
## F-statistic:  7.83 on 16 and 15 DF,  p-value: 0.000124
```

The MPG difference between automatic and manual transmissions

```
wt.max <- max(cs.dt[am == 1, wt])
wt.min <- min(cs.dt[am == 0, wt])
wt.min
```

```
## [1] 2.465
```

```
cs.dt.res <- cs.dt[wt >= wt.min & wt <= wt.max]
ggplot(cs.dt.res, aes(wt, mpg, colour = am)) +
    geom_point() + theme_tufte() + geom_smooth(method = "lm")
```



```
ggplot(cs.dt.res, aes(am, mpg, colour = am)) +
    geom_boxplot() + theme_tufte()
```

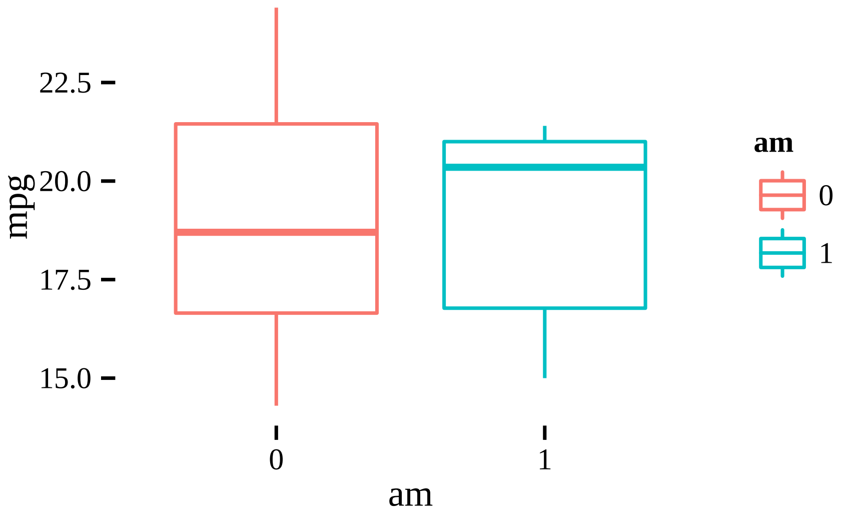
Appendix

```
pairs(cs.dt[, .(mpg, cyl, disp, hp, drat, wt,
    qsec, vs, am, gear, carb)], panel = panel.smooth)
```

This style provides a- and b-heads (that is, # and ##), demonstrated above. An error is emitted if you try to use ### and smaller headings.

IN HIS LATER BOOKS[1], Tufte starts each section with a bit of vertical space, a non-indented paragraph, and sets the first few words of the sentence in small caps. To accomplish this using this style, use the \newthought command as demonstrated at the beginning of this paragraph.

[1] http://www.edwardtufte.com/tufte/books_be



Figures

Margin Figures

Images and graphics play an integral role in Tufte's work. To place figures or tables in the margin you can use the `fig.margin` knitr chunk option. For example:

```
library(ggplot2)
qplot(Sepal.Length, Petal.Length, data = iris,
    color = Species)
```

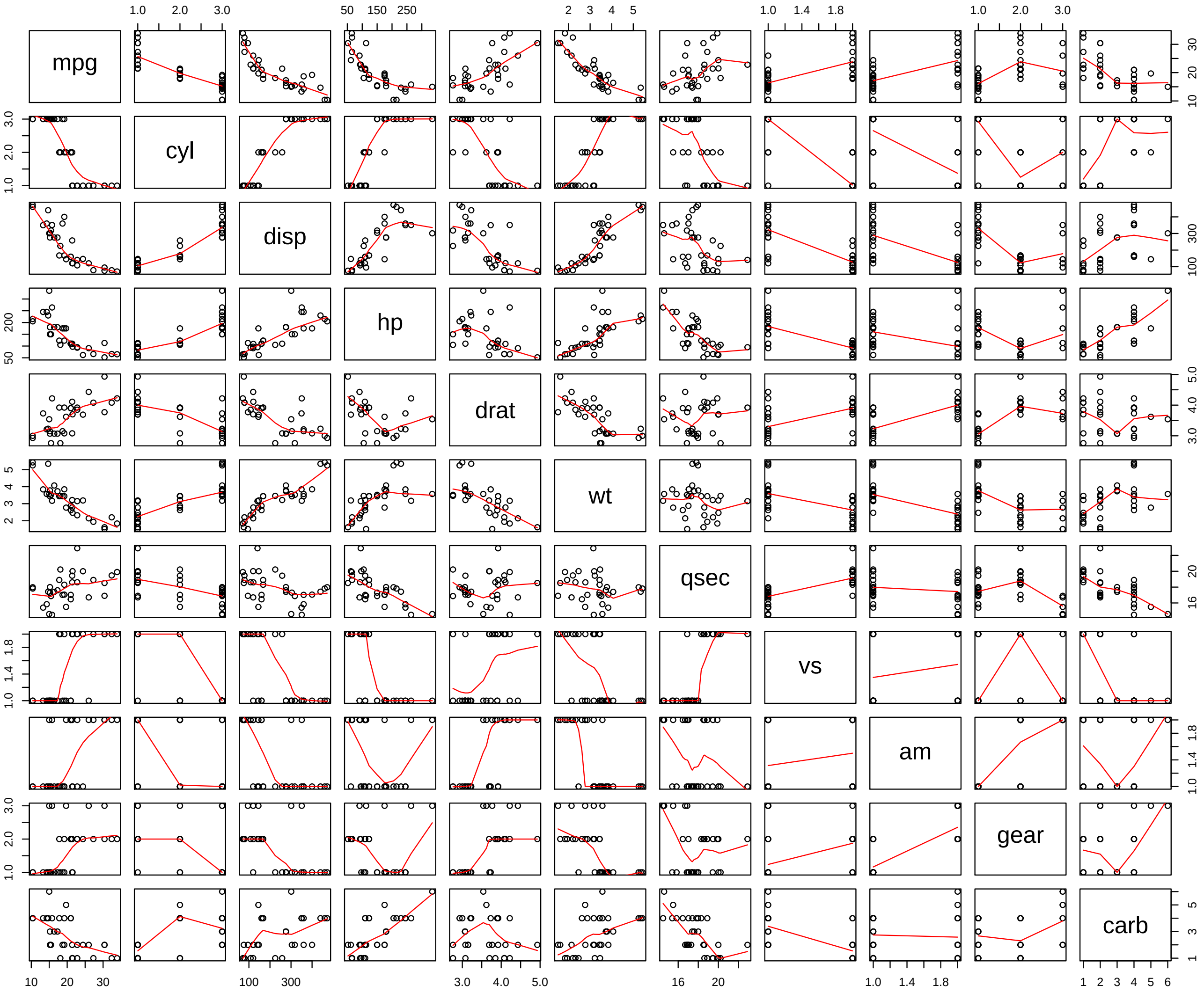


Figure 8: Full width figure

Note the use of the `fig.cap` chunk option to provide a figure caption. You can adjust the proportions of figures using the `fig.width` and `fig.height` chunk options. These are specified in inches, and will be automatically scaled down to fit within the handout margin.

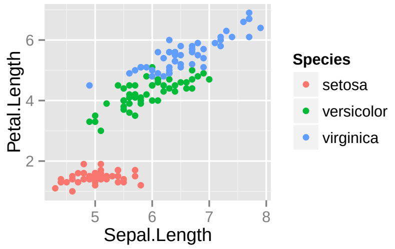


Figure 9: Sepal length vs. petal length, colored by species

Equations

You can also include LaTeX equations in the margin by explicitly invoking the `marginfigure` environment.

Note the use of the `\caption` command to add additional text below the equation.

$$\frac{d}{dx}\left(\int_0^x f(u)\,du\right) = f(x).$$

Figure 10: An equation

Full Width Figures

You can arrange for figures to span across the entire page by using the `fig.fullwidth` chunk option.

```r
qplot(wt, mpg, data = mtcars, colour = factor(cyl))
```

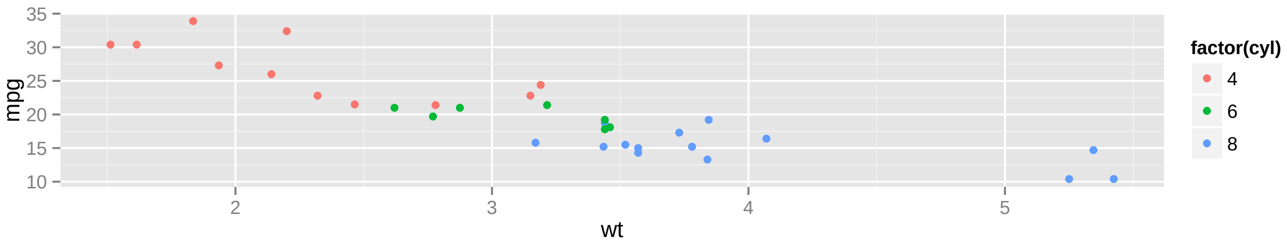


Figure 11: Full width figure

Note the use of the `fig.width` and `fig.height` chunk options to establish the proportions of the figure. Full width figures look much better if their height is minimized.

Main Column Figures

Besides margin and full width figures, you can of course also include figures constrained to the main column.

```r
qplot(factor(cyl), mpg, data = mtcars, geom = "boxplot")
```

Sidenotes

One of the most prominent and distinctive features of this style is the extensive use of sidenotes. There is a wide margin to provide

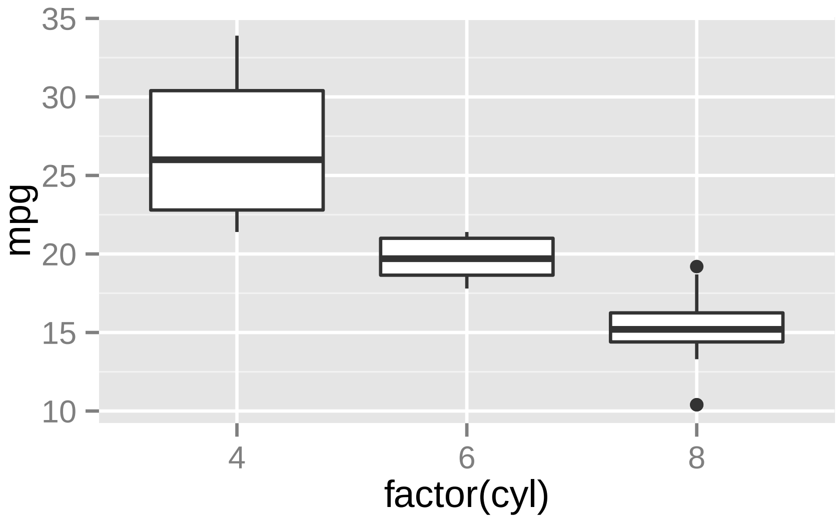


Figure 12: Another figure

ample room for sidenotes and small figures. Any use of a footnote will automatically be converted to a sidenote. [2]

If you'd like to place ancillary information in the margin without the sidenote mark (the superscript number), you can use the `\marginnote` command.

This is a margin note. Notice that there isn't a number preceding the note.

Note also that the two footnote references (`tufte_latex` and `books_be`, both defined below) were also included in the margin on the first page of this document.

Tables

You can use the **xtable** package to format LaTeX tables that integrate well with the rest of the Tufte handout style. Note that it's important to set the `xtable.comment` and `xtable.booktabs` options as shown below to ensure the table is formatted correctly for inclusion in the document.

```
library(xtable)
options(xtable.comment = FALSE)
options(xtable.booktabs = TRUE)
xtable(head(mtcars[, 1:6]), caption = "First rows of mtcars")
```

[2] This is a sidenote that was entered using a footnote.

	mpg	cyl	disp	hp	drat	wt
Mazda RX4	21.00	6.00	160.00	110.00	3.90	2.62
Mazda RX4 Wag	21.00	6.00	160.00	110.00	3.90	2.88
Datsun 710	22.80	4.00	108.00	93.00	3.85	2.32
Hornet 4 Drive	21.40	6.00	258.00	110.00	3.08	3.21
Hornet Sportabout	18.70	8.00	360.00	175.00	3.15	3.44
Valiant	18.10	6.00	225.00	105.00	2.76	3.46

Table 1: First rows of mtcars