

My Senior Project

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A Senior Thesis  
Presented to  
The Faculty

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In Partial Fulfillment  
of the Requirements for the Degree  
Bachelor of Arts  
in  
Statistics & Data Science  
Yale University

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Your R. Name

October 20xx



# Acknowledgements

I want to thank a few people.



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# Abstract

The preface pretty much says it all.



# Introduction

Welcome to the *R Markdown* comprehensive evaluation report template. For illustration purposes, the template uses multiple chapters and sections. You should modify this setup based on your own needs. We recommend that you retain the following sections:

1. Abstract
2. Introduction/Background
3. Data
4. Analysis
5. Conclusion
6. Appendix
7. References

## 0.1 Notes about the Appendix

We highly recommend that lengthy chunks in the code should be pushed to the appendix. Note that you will not need to retype code chunks in full in the appendix. You just have to refer to them by name. See the bottom of `conclusion.Rmd` for details on this.

## 0.2 Notes about References

We use BibTeX for references here. By default, the BibTeX file used lies in `bib/thesis.bib`. You should take a look at this file to get a sense for the structure of BibTeX references. You can export citations in BibTeX form from Google Scholar, for example.

*R Markdown* uses *pandoc* (<http://pandoc.org/>) to build its bibliographies. One nice caveat of this is that you won't have to do a second compile to load in references as standard L<sup>A</sup>T<sub>E</sub>X requires. To cite references in your thesis (after creating your bibliography database), place the reference name inside square brackets and precede it by the “at” symbol. For example, here's a reference to a book about worrying: (Molina & Borkovec, 1994). This `Molina1994` entry appears in a file called `thesis.bib` in the `bib` folder. This bibliography database file was created by a program called BibTeX. You can call this file something else if you like (look at the YAML header in the main `.Rmd` file) and, by default, is to placed in the `bib` folder.

If you look at the YAML header at the top of the main .Rmd file you can see that we can specify the style of the bibliography by referencing the appropriate csl file. You can download a variety of different style files at <https://www.zotero.org/styles>. Make sure to download the file into the csl folder.

### 0.2.1 Tips

- Like with thesis formatting, the sooner you start compiling your bibliography for something as large as thesis, the better. Typing in source after source is mind-numbing enough; do you really want to do it for hours on end in late April? Think of it as procrastination.
- The cite key (a citation's label) needs to be unique from the other entries.
- When you have more than one author or editor, you need to separate each author's name by the word "and" e.g. `Author = {Noble, Sam and Youngberg, Jessica},.`
- Bibliographies made using BibTeX (whether manually or using a manager) accept L<sup>A</sup>T<sub>E</sub>X markup, so you can italicize and add symbols as necessary.
- To force capitalization in an article title or where all lowercase is generally used, bracket the capital letter in curly braces.

# Chapter 1

## R Markdown Basics

Here is a brief introduction into using *R Markdown*. *Markdown* is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. *R Markdown* provides the flexibility of *Markdown* with the implementation of **R** input and output. For more details on using *R Markdown* see <http://rmarkdown.rstudio.com>.

Be careful with your spacing in *Markdown* documents. While whitespace largely is ignored, it does at times give *Markdown* signals as to how to proceed. As a habit, try to keep everything left aligned whenever possible, especially as you type a new paragraph. In other words, there is no need to indent basic text in the Rmd document (in fact, it might cause your text to do funny things if you do).

### 1.1 Lists

It's easy to create a list. It can be unordered like

- Item 1
- Item 2

or it can be ordered like

1. Item 1
2. Item 2

Notice that I intentionally mislabeled Item 2 as number 4. *Markdown* automatically figures this out! You can put any numbers in the list and it will create the list. Check it out below.

To create a sublist, just indent the values a bit (at least four spaces or a tab). (Here's one case where indentation is key!)

1. Item 1
2. Item 2
3. Item 3
  - Item 3a
  - Item 3b

## 1.2 Line breaks

Make sure to add white space between lines if you'd like to start a new paragraph. Look at what happens below in the outputted document if you don't:

Here is the first sentence. Here is another sentence. Here is the last sentence to end the paragraph. This should be a new paragraph.

*Now for the correct way:*

Here is the first sentence. Here is another sentence. Here is the last sentence to end the paragraph.

This should be a new paragraph.

## 1.3 R chunks

When you click the **Knit** button above a document will be generated that includes both content as well as the output of any embedded **R** code chunks within the document. You can embed an **R** code chunk like this (`cars` is a built-in **R** dataset):

```
summary(cars)
```

speed	dist
Min. : 4.0	Min. : 2.00
1st Qu.:12.0	1st Qu.: 26.00
Median :15.0	Median : 36.00
Mean :15.4	Mean : 42.98
3rd Qu.:19.0	3rd Qu.: 56.00
Max. :25.0	Max. :120.00

## 1.4 Inline code

If you'd like to put the results of your analysis directly into your discussion, add inline code like this:

The `cos` of  $2\pi$  is 1.

Another example would be the direct calculation of the standard deviation:

The standard deviation of `speed` in `cars` is 5.2876444.

One last neat feature is the use of the `ifelse` conditional statement which can be used to output text depending on the result of an **R** calculation:

The standard deviation is less than 6.

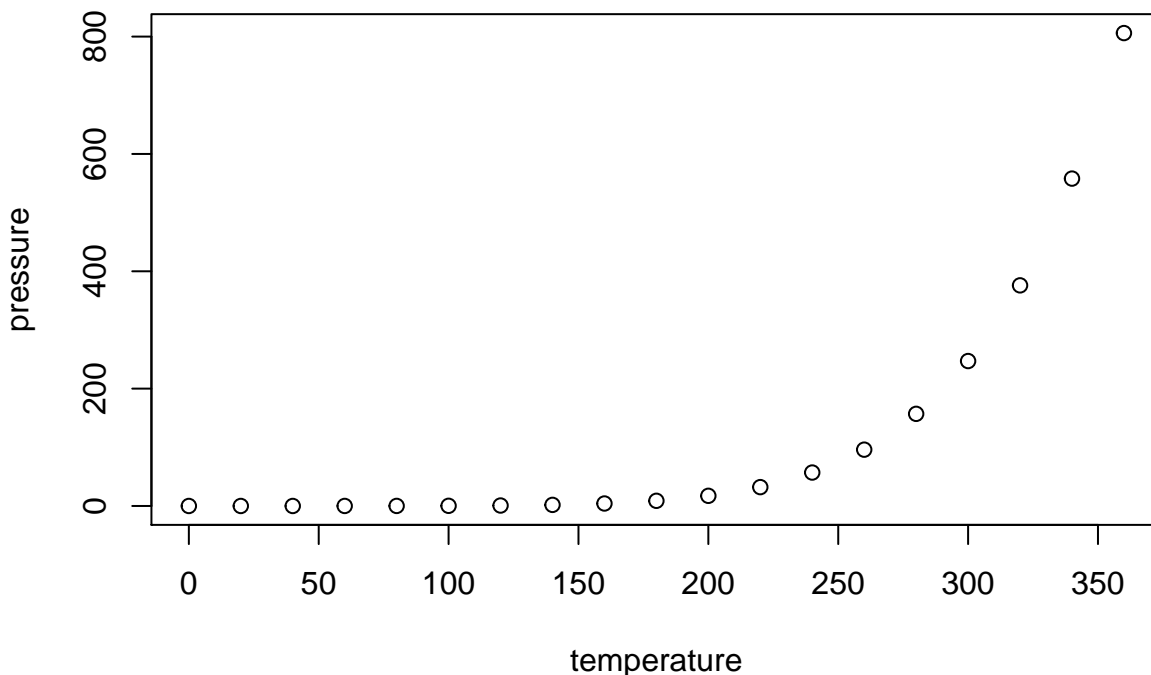
Note the use of `>` here, which signifies a quotation environment that will be indented.

As you see with `$2 \pi$` above, mathematics can be added by surrounding the mathematical text with dollar signs. More examples of this are in [Mathematics and Science] if you uncomment the code in `Math`.



## 1.5 Including plots

You can also embed plots. For example, here is a way to use the base **R** graphics package to produce a plot using the built-in `pressure` dataset:



Note that the `echo = FALSE` parameter was added to the code chunk to prevent printing of the **R** code that generated the plot. There are plenty of other ways to add chunk options. More information is available at <http://yihui.name/knitr/options/>.

Another useful chunk option is the setting of `cache = TRUE` as you see here. If document rendering becomes time consuming due to long computations or plots that are expensive to generate you can use knitr caching to improve performance. Later in this file, you'll see a way to reference plots created in **R** or external figures.

## 1.6 Loading and exploring data

Included in this template is a file called `flights.csv`. This file includes a subset of the larger dataset of information about all flights that departed from Seattle and Portland in 2014. More information about this dataset and its **R** package is available at <http://github.com/ismayc/pnwflights14>. This subset includes only Portland flights and only rows that were complete with no missing values. Merges were also done with the `airports` and `airlines` data sets in the `pnwflights14` package to get more descriptive airport and airline names.

We can load in this data set using the following command:

```
flights <- read.csv("data/flights.csv")
```

The data is now stored in the data frame called `flights` in **R**. To get a better feel for the variables included in this dataset we can use a variety of functions. Here we can see the dimensions (rows by columns) and also the names of the columns.

```
dim(flights)
```

```
[1] 52808    16
```

```
names(flights)
```

```
[1] "month"      "day"        "dep_time"   "dep_delay"
[5] "arr_time"   "arr_delay"  "carrier"    "tailnum"
[9] "flight"     "dest"       "air_time"   "distance"
[13] "hour"       "minute"     "carrier_name" "dest_name"
```

We begin by checking to ensure that needed packages are installed and then we load them into our current working environment:

```
# List of packages required for this analysis
pkg <- c("dplyr", "ggplot2", "knitr", "devtools")
# Check if packages are not installed and assign the
# names of the packages not installed to the variable new.pkg
new.pkg <- pkg[!(pkg %in% installed.packages())]
# If there are any packages in the list that aren't installed,
# install them
if (length(new.pkg))
  install.packages(new.pkg, repos = "http://cran.rstudio.com")
# Load packages
library(dplyr)
```

Warning: package 'dplyr' was built under R version 3.4.4

```
library(ggplot2)
```

Warning: package 'ggplot2' was built under R version 3.4.4

```
library(knitr)
```

Warning: package 'knitr' was built under R version 3.4.3

The example we show here does the following:

- Selects only the `carrier_name` and `arr_delay` from the `flights` dataset and then assigns this subset to a new variable called `flights2`.
- Using `flights2`, we determine the largest arrival delay for each of the carriers.

```
flights2 <- flights %>% select(carrier_name, arr_delay)
max_delays <- flights2 %>% group_by(carrier_name) %>%
  summarize(max_arr_delay = max(arr_delay, na.rm = TRUE))
```

We next introduce a useful function in the `knitr` package for making nice tables in *R Markdown* called `kable`. It produces the  $\text{\LaTeX}$  code required to make the table and is much easier to use than manually entering values into a table by copying and pasting values into Excel or  $\text{\LaTeX}$ . This again goes to show how nice reproducible documents can be! There is no need to copy-and-paste values to create a table. (Note the use of `results = "asis"` here which will produce the table instead of the code to create the table. You'll learn more about the `\label` later.)

```
kable(max_delays, col.names = c("Airline", "Max Arrival Delay"),
      caption = "Max Delays by Airline \\label{tab:max_delay}")
```

Table 1.1: Max Delays by Airline

Airline	Max Arrival Delay
Alaska Airlines Inc.	338
American Airlines Inc.	1539
Delta Air Lines Inc.	651
Frontier Airlines Inc.	575
Hawaiian Airlines Inc.	407
JetBlue Airways	273
SkyWest Airlines Inc.	421
Southwest Airlines Co.	694
United Air Lines Inc.	472
US Airways Inc.	347
Virgin America	366

We can further look into the properties of the largest value here for American Airlines Inc. To do so, we can isolate the row corresponding to the arrival delay of 1539 minutes for American in our original `flights` dataset.

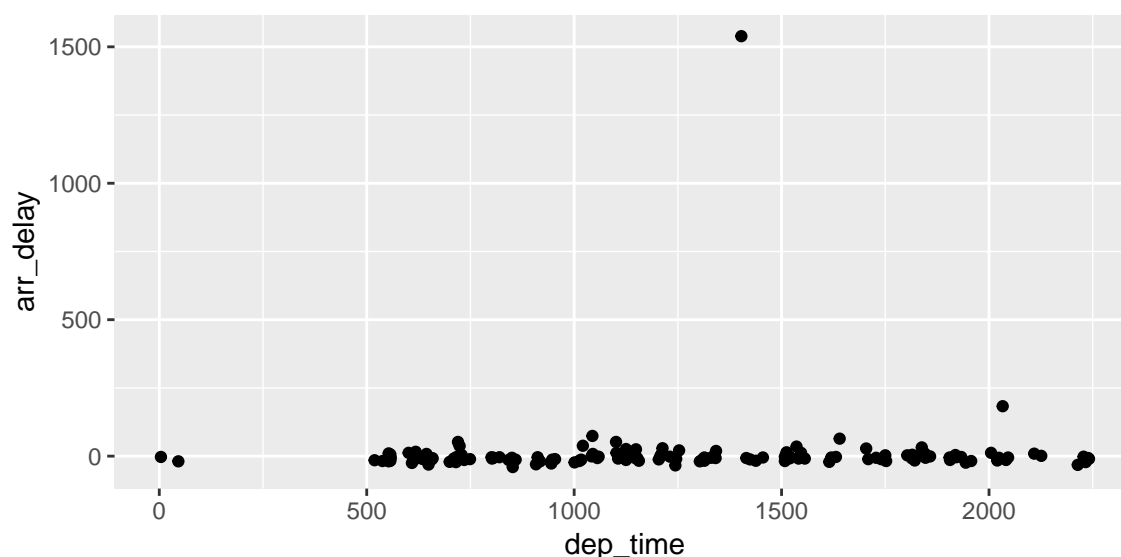
```
flights %>% filter(arr_delay == 1539,
                  carrier_name == "American Airlines Inc.") %>%
  select(-c(month, day, carrier, dest_name, hour,
            minute, carrier_name, arr_delay))
```

Warning: package 'bindrcpp' was built under R version 3.4.4

	dep_time	dep_delay	arr_time	tailnum	flight	dest	air_time	distance
1	1403	1553	1934	N595AA	1568	DFW	182	1616

We see that the flight occurred on March 3rd and departed a little after 2 PM on its way to Dallas/Fort Worth. Lastly, we show how we can visualize the arrival delay of all departing flights from Portland on March 3rd against time of departure.

```
flights %>% filter(month == 3, day == 3) %>%  
  ggplot(aes(x = dep_time, y = arr_delay)) +  
  geom_point()
```



## 1.7 Additional resources

- *Markdown* Cheatsheet - <https://github.com/adam-p/markdown-here/wiki/Markdown-Cheatsheet>
- *R Markdown* Reference Guide - <https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf>
- Introduction to dplyr - <https://cran.rstudio.com/web/packages/dplyr/vignettes/introduction.html>
- ggplot2 Documentation - <http://docs.ggplot2.org/current/>

# Chapter 2

## Typesetting Equations

### 2.1 Math

$\text{\TeX}$  is the best way to typeset mathematics. Donald Knuth designed  $\text{\TeX}$  when he got frustrated at how long it was taking the typesetters to finish his book, which contained a lot of mathematics. One nice feature of *R Markdown* is its ability to read  $\text{\LaTeX}$  code directly.

If you are doing a thesis that will involve lots of math, you will want to read the following section.

$$\sum_{j=1}^n (\delta\theta_j)^2 \leq \frac{\beta_i^2}{\delta_i^2 + \rho_i^2} \left[ 2\rho_i^2 + \frac{\delta_i^2 \beta_i^2}{\delta_i^2 + \rho_i^2} \right] \equiv \omega_i^2$$

After  $n$  such encounters the posterior density for  $\theta$  is

$$\pi(\theta|X_1 < y_1, \dots, X_n < y_n) \propto \pi(\theta) \prod_{i=1}^n \int_{-\infty}^{y_i} \exp\left(-\frac{(x-\theta)^2}{2\sigma^2}\right) dx$$

Another equation:

$$\det \begin{vmatrix} c_0 & c_1 & c_2 & \dots & c_n \\ c_1 & c_2 & c_3 & \dots & c_{n+1} \\ c_2 & c_3 & c_4 & \dots & c_{n+2} \\ \vdots & \vdots & \vdots & & \vdots \\ c_n & c_{n+1} & c_{n+2} & \dots & c_{2n} \end{vmatrix} > 0$$

Exponent or Superscript:  $x^2$

Subscript:  $x_1, x_2, \dots, x_n$

Both combined:  $x_1^{k+1}$ .

### 2.2 Statistics Symbols and Expressions

Our favorite Greeks:  $\sigma, \epsilon, \mu$

Defining a normally distributed random variable:  $X \sim N(\mu, \sigma)$

How do we compute sample variance again?

$$s^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}$$

Sometimes you'll need to consider asymptotics, that is, what happens as  $n \rightarrow \infty$ .

# Chapter 3

## Tables, Graphics, References, and Labels

### 3.1 Tables

In addition to the tables that can be automatically generated from a data frame in **R** that you saw in R Markdown Basics using the `kable` function, you can also create tables using *pandoc*. (More information is available at <http://pandoc.org/README.html#tables>.) This might be useful if you don't have values specifically stored in **R**, but you'd like to display them in table form. Below is an example. Pay careful attention to the alignment in the table and the use of the hyphens to create the rows and columns.

Table 3.1: Correlation of Inheritance Factors for Parents and Child

Factors	Correlation between Parents & Child	Inherited
Education	-0.49	Yes
Socio-Economic Status	0.28	Slight
Income	0.08	No
Family Size	0.18	Slight
Occupational Prestige	0.21	Slight

We can also create a link to the table by doing the following: Table 3.1. If you go back to Loading and exploring data and look at the `kable` function code, you'll see that I added in a similar `\\label` to be able to reference that table later. (The extra backslash there is a way that *Markdown* interfaces with *L<sup>A</sup>T<sub>E</sub>X*.) We can create a reference to the max delays table: Table 1.1.

The addition of the `\\label{}` option to the end of the table caption allows us to then use the *L<sup>A</sup>T<sub>E</sub>X* `autoref` function to produce the link. The `ref` function in **R** allows for tables and figures to be referenced in the document easily without having to directly use the `autoref` function. It will automatically add "Table" before your number if you add the "tab:" prefix to your label. Note that this reference could

appear anywhere throughout the document.



## 3.2 Figures

If your thesis has a lot of figures, *R Markdown* might behave better for you than that other word processor. One perk is that it will automatically number the figures accordingly in each chapter. You'll also be able to create a label for each figure, add a caption, and then reference the figure in a way similar to what we saw with tables earlier. If you label your figures, you can move the figures around and *R Markdown* will automatically adjust the numbering for you. No need for you to remember! So that you don't have to get too far into L<sup>A</sup>T<sub>E</sub>X to do this, a couple **R** functions have been created for you to assist. You'll see their use below.

In the **R** chunk below, we will load in a picture stored as `Yale.png` in our main directory. We then give it the caption of "Yale logo", the label of "yale", and specify that this is a figure. Note again the use of the `results = "asis"` specification to automatically include and compile the L<sup>A</sup>T<sub>E</sub>X code.

```
label(path = "figure/Yale.png", caption = "Yale logo",  
      label = "yale", type = "figure")
```



Figure 3.1: Yale logo

Here is a reference to the Yale logo: Figure 3.1. Note the use of the inline **R** code here. By default "figure" is specified as the type. For clarity, we could have also added the `label` and `type` to the parameter specifications and this would give us the same result: Figure 3.1.

Below we will investigate how to save the output of an **R** plot and label it in a way similar to that done above. Recall the `flights` dataset from . (Note that we've shown a different way to reference a section or chapter here.) We will next explore a bar graph with the mean flight departure delays by airline from Portland for 2014. Note also the use of the `scale` parameter which is discussed on the next page.

```
delay_airline <- flights %>% group_by(carrier) %>%
  summarize(mean_dep_delay = mean(dep_delay)) %>%
  ggplot(aes(x = carrier, y = mean_dep_delay)) +
  geom_bar(position = "identity", stat = "identity", fill = "red")
ggsave("figure/delays.png", plot = delay_airline,
       width = 5, height = 3)

label(path = "figure/delays.png",
      caption = "Mean Delays by Airline",
      label = "delays", type = "figure",
      scale = 0.3)
```

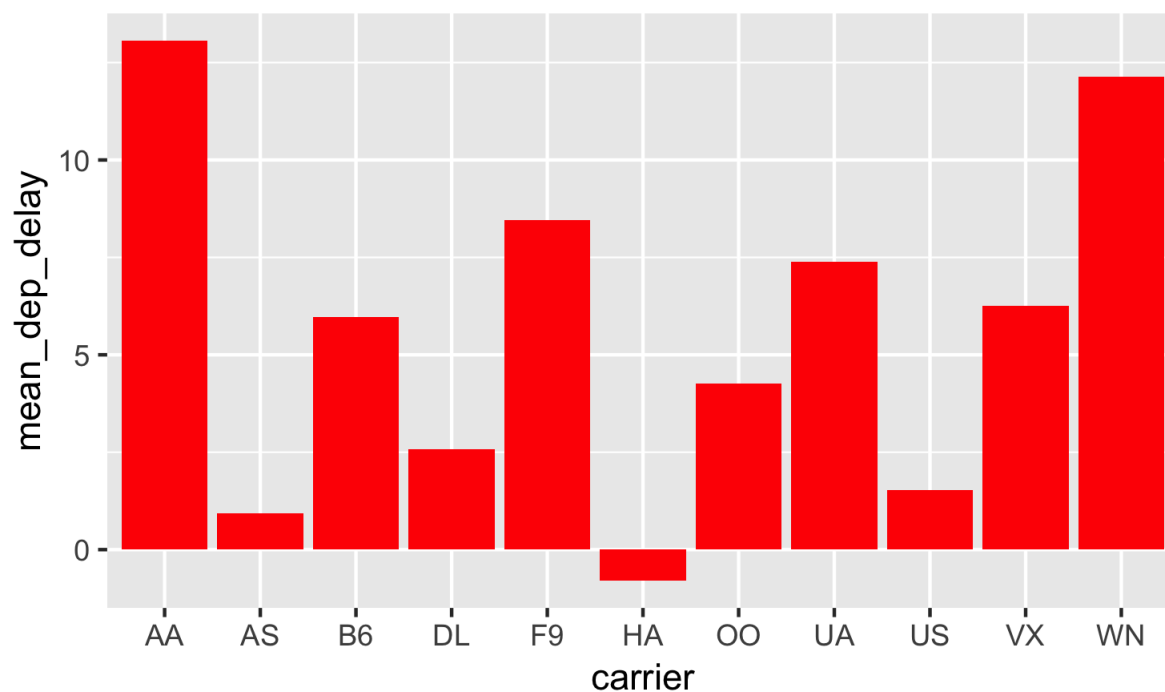


Figure 3.2: Mean Delays by Airline

A table linking these carrier codes to airline names is available at <https://github.com/ismayc/pnwflights14/blob/master/data/airlines.csv>.

Next, we will explore the use of the `scale` parameter which can be used to shrink or expand an image. Here we use the mathematical graph stored in the “subdivision.pdf” file. Note that we didn’t specify the `caption =` or `label =` here, but we could have.

```
label("figure/subdivision.pdf", "Subdiv. graph", "subd",
      scale = 0.75)
```

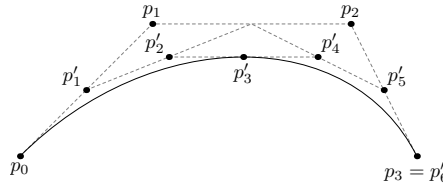


Figure 3.3: Subdiv. graph

Here is a reference to this image: Figure 3.3. (Move this around throughout the document as you wish.)

### More Figure Stuff

Lastly, we will explore how to rotate figures using the `angle` parameter.

```
label("figure/subdivision.pdf",
      "A Larger Figure, Flipped Upside Down",
      scale = 1.5,
      angle = 180,
      label = "subd2")
```

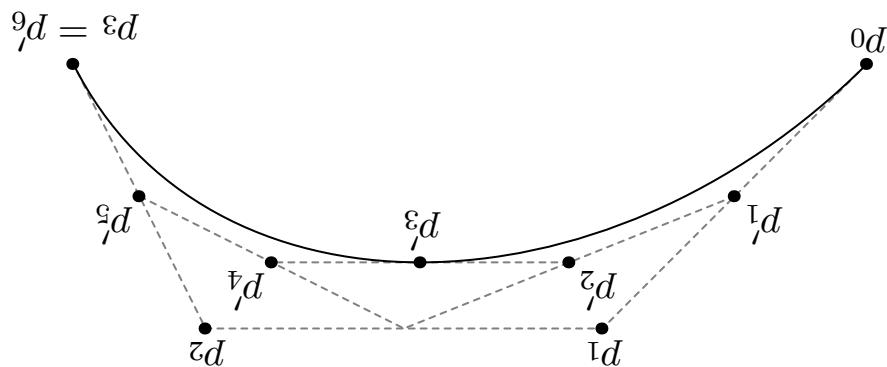


Figure 3.4: A Larger Figure, Flipped Upside Down

As another example, here is a reference to this figure: Figure 3.4.

## Common Modifications

The following figure features the more popular changes thesis students want to their figures. We can add math to the caption that displays below the picture, specify the size of our caption to display below the figure (list of sizes available at this link), and also specify that a different caption `alt.cap` be what appears in the Table of Figures for this figure.

If you'd like to make further tweaks to figures, you might need to invoke some  $\text{\LaTeX}$  code.

```
label("figure/subdivision.pdf",
      caption = "Subdivision of arc segments",
      alt.cap = "You can see that  $p_3 = p_6^{\prime}$ ",
      cap.size = "footnotesize",
      label = "subd3")
```

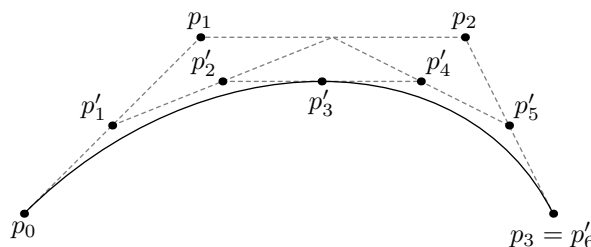


Figure 3.5: You can see that  $p_3 = p_6'$

## 3.3 Footnotes and Endnotes

You might want to footnote something.<sup>1</sup> The footnote will be in a smaller font and placed appropriately. Endnotes work in much the same way.

## 3.4 Bibliographies

Of course you will need to cite things, and you will probably accumulate an armful of sources. There are a variety of tools available for creating a bibliography database (stored with the `.bib` extension).

*R Markdown* uses *pandoc* (<http://pandoc.org/>) to build its bibliographies. One nice caveat of this is that you won't have to do a second compile to load in references as standard  $\text{\LaTeX}$  requires. To cite references in your thesis (after creating your bibliography database), place the reference name inside square brackets and precede it by the "at" symbol. For example, here's a reference to a book about worrying: (Molina & Borkovec, 1994). This `Molina1994` entry appears in a file called `thesis.bib` in the

---

<sup>1</sup>footnote text

`bib` folder. This bibliography database file was created by a program called BibTeX. You can call this file something else if you like (look at the YAML header in the main `.Rmd` file) and, by default, is to be placed in the `bib` folder.

### Tips for Bibliographies

- Like with thesis formatting, the sooner you start compiling your bibliography for something as large as thesis, the better. Typing in source after source is mind-numbing enough; do you really want to do it for hours on end in late April? Think of it as procrastination.
- The cite key (a citation's label) needs to be unique from the other entries.
- When you have more than one author or editor, you need to separate each author's name by the word "and" e.g. `Author = {Noble, Sam and Youngberg, Jessica},.`
- Bibliographies made using BibTeX (whether manually or using a manager) accept L<sup>A</sup>T<sub>E</sub>X markup, so you can italicize and add symbols as necessary.
- To force capitalization in an article title or where all lowercase is generally used, bracket the capital letter in curly braces.



# Conclusion

If we don't want Conclusion to have a chapter number next to it, we can add the `{.unnumbered}` attribute. This has an unintended consequence of the sections being labeled as 3.6 for example though instead of 4.1. The  $\text{\LaTeX}$  commands immediately following the Conclusion declaration get things back on track.

## More info

And here's some other random info: the first paragraph after a chapter title or section head *shouldn't be* indented, because indents are to tell the reader that you're starting a new paragraph. Since that's obvious after a chapter or section title, proper typesetting doesn't add an indent there.





# Appendix A

## The First Appendix

This first appendix includes all of the R chunks of code that were hidden throughout the document (using the `include = FALSE` chunk tag) to help with readability and/or setup.

In the main Rmd file:

```
# This chunk ensures that the yalestats package is  
# installed and loaded. This yalestats package includes  
# the template files for the thesis and also two functions  
# used for labeling and referencing  
if(!require(devtools))  
  install.packages("devtools", repos = "http://cran.rstudio.com")  
if(!require(yalestats)){  
  library(devtools)  
  devtools::install_github("swang87/yalestats")  
}  
library(yalestats)
```

In :

```
# This chunk ensures that the reedtemplates package is  
# installed and loaded. This reedtemplates package includes  
# the template files for the thesis and also two functions  
# used for labeling and referencing  
if(!require(devtools))  
  install.packages("devtools", repos = "http://cran.rstudio.com")  
if(!require(dplyr))  
  install.packages("dplyr", repos = "http://cran.rstudio.com")  
if(!require(ggplot2))  
  install.packages("ggplot2", repos = "http://cran.rstudio.com")
```

```
if(!require(yalestats)){  
  library(devtools)  
  devtools::install_github("swang87/yalestats")  
}  
library(yalestats)  
flights <- read.csv("data/flights.csv")
```

## Appendix B

The Second Appendix, for Fun



# References

- Angel, E. (2000). *Interactive computer graphics : A top-down approach with opengl*. Boston, MA: Addison Wesley Longman.
- Angel, E. (2001a). *Batch-file computer graphics : A bottom-up approach with quicktime*. Boston, MA: Wesley Addison Longman.
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- Molina, S. T., & Borkovec, T. D. (1994). The Penn State worry questionnaire: Psychometric properties and associated characteristics. In G. C. L. Davey & F. Tallis (Eds.), *Worrying: Perspectives on theory, assessment and treatment* (pp. 265–283). New York: Wiley.