Statistical Foundations

Code

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Content Credit- Dr. Matthew Beckman and Olivia Beck

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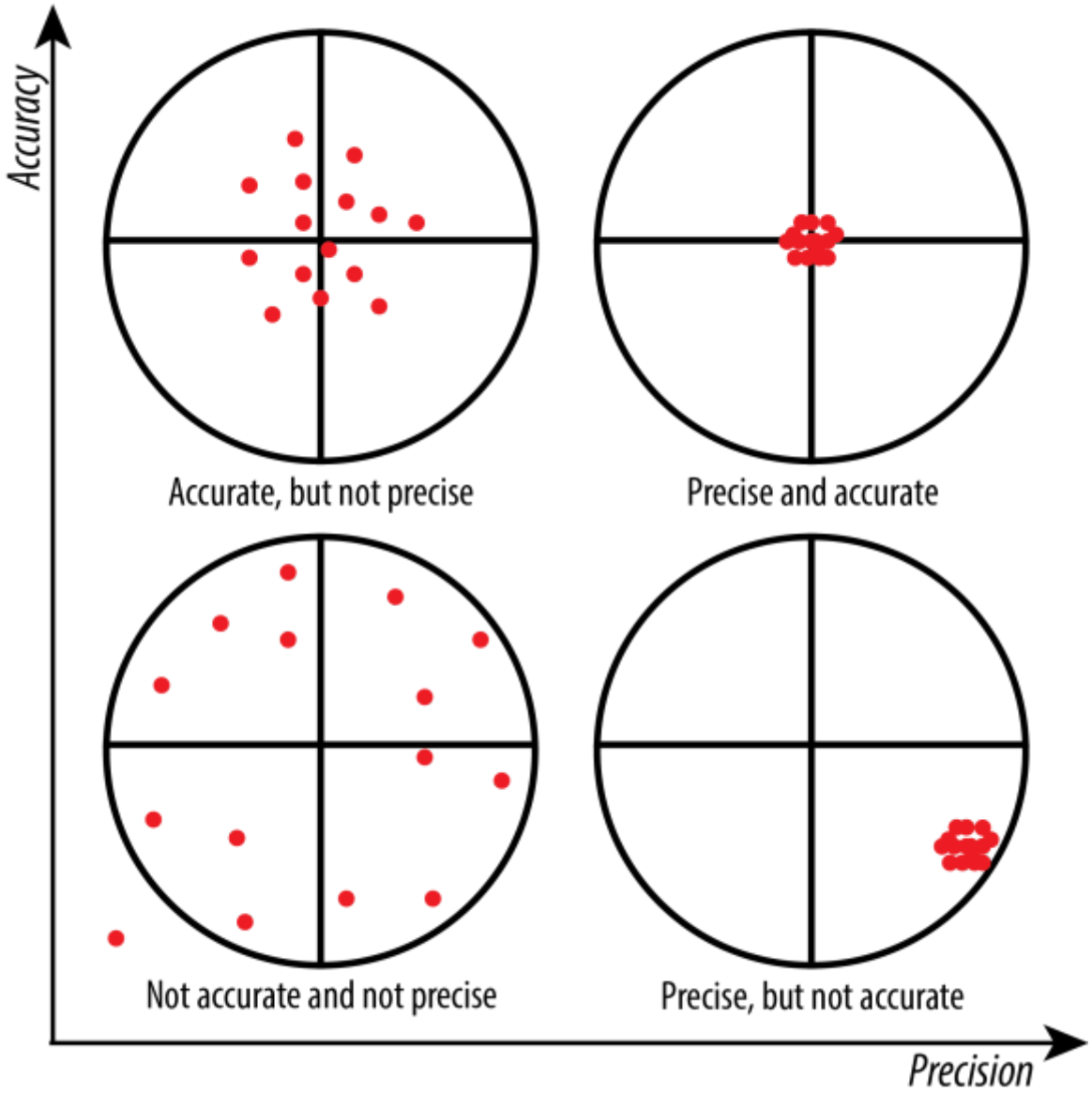
Key Ideas

- Statistics is the area of science concerned with characterizing case-to-case variation and the collective properties of cases
- It's one thing to simply calculate quantities from data, but a central topic in statistics is the **precision** with which we can estimate those quantities
- **Accommodating and quantifying uncertainty due to randomness** is perhaps the backbone of inferential statistics
- You **ALWAYS** need to report uncertainty and/or variation



Key Ideas (continued)

- it's often useful to look at distributions of data graphically, and you were presented several useful ways to do so
    - density plots (perhaps overlaid or faceted to highlight group comparisons)

    - box plots (again, side-by-side or faceted to highlight group comparisons)
    - violin plots (alternative to box plots with greater detail in the density)
    - note, all of these plots show variation
- model functions help describe a relationship between an “input” (X, explanatory, independent) variable and an “output” (Y, response, dependent) variable
    - smoothers show relationships between variables that bend with the data collectively
    - linear functions are also useful in some contexts, but sometimes miss important features of the relationship between variables
- confidence intervals (when estimating a single quantity) and confidence bands (when estimating model functions) are **essential** to communicate uncertainty
    - small sample sizes result in a great deal of uncertainty
    - we can be more confident in estimates produced by large sample sizes (asymptotic/ large sample theory)
    - error bars, notched box plots, and confidence bands all help communicate uncertainty in a graph.

Recall: Key goals of a careful Exploratory Data Analysis

1. **Examine the data source:** variable types, coding, missingness, summary statistics/plots, who/what/when/where/why/how data were collected
2. **Discover features that influence may modeling decisions:** investigate potential outliers, consideration for recoding variables (e.g., numeric data that’s functionally dichotomous), evaluate correlation structure (e.g., autocorrelation, hierarchy, spatial/temporal proximity)
3. **Address research questions:** build intuition and note preliminary observations/conclusions related to each research question. Also, note observations that prompt you to refine your research questions or add new questions to investigate

…this is often an iterative process, but the order shown might help you organize your approach.

Examples of Graphs

Means

Hide

```r
#Set up data
#?AirPassengers
class(AirPassengers)
```

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[1]

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```r
```r
dat_passengers <- data.frame(1949:1960,
                             matrix(AirPassengers, ncol = 12))
colnames(dat_passengers) <- c(\Year\, month.abb)

head(dat_passengers)
````

Hide

```
# Wrangle
GlyphReadyData <- dat_passengers %>%
  pivot_longer(!Year, names_to = \Month\, values_to = \Val\) %>%
  group_by(Year) %>%
  summarise(Mean = mean(Val, na.rm = T),
            SD = stats::sd(Val, na.rm = T))
head(GlyphReadyData)
```

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Here are multiple ways of displaying the same data


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```r
```r
ggplot(GlyphReadyData, aes(x = Year, y = Mean)) +
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  xlab(\Year\) +
  ylab(\Passengers\)
```
```

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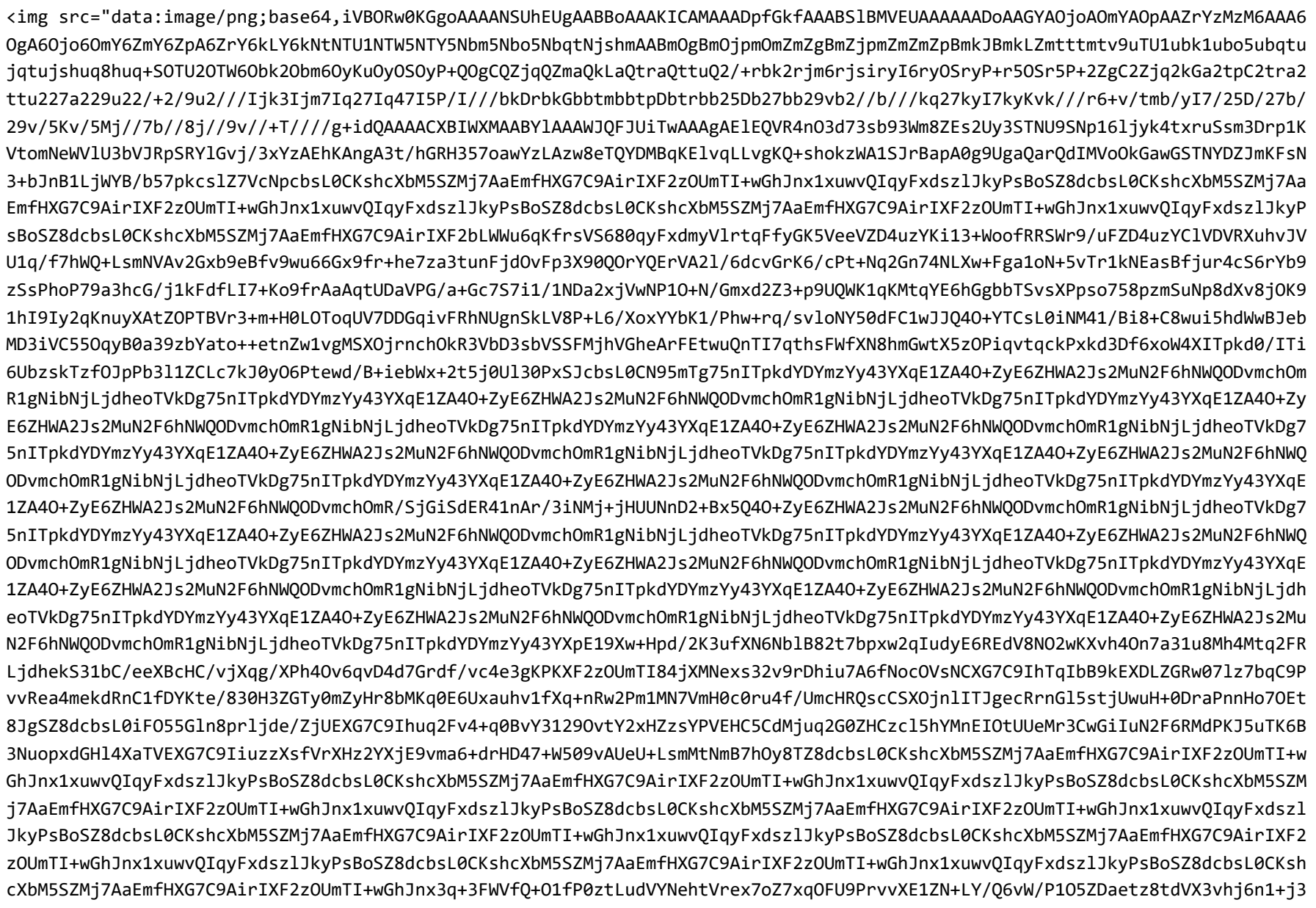

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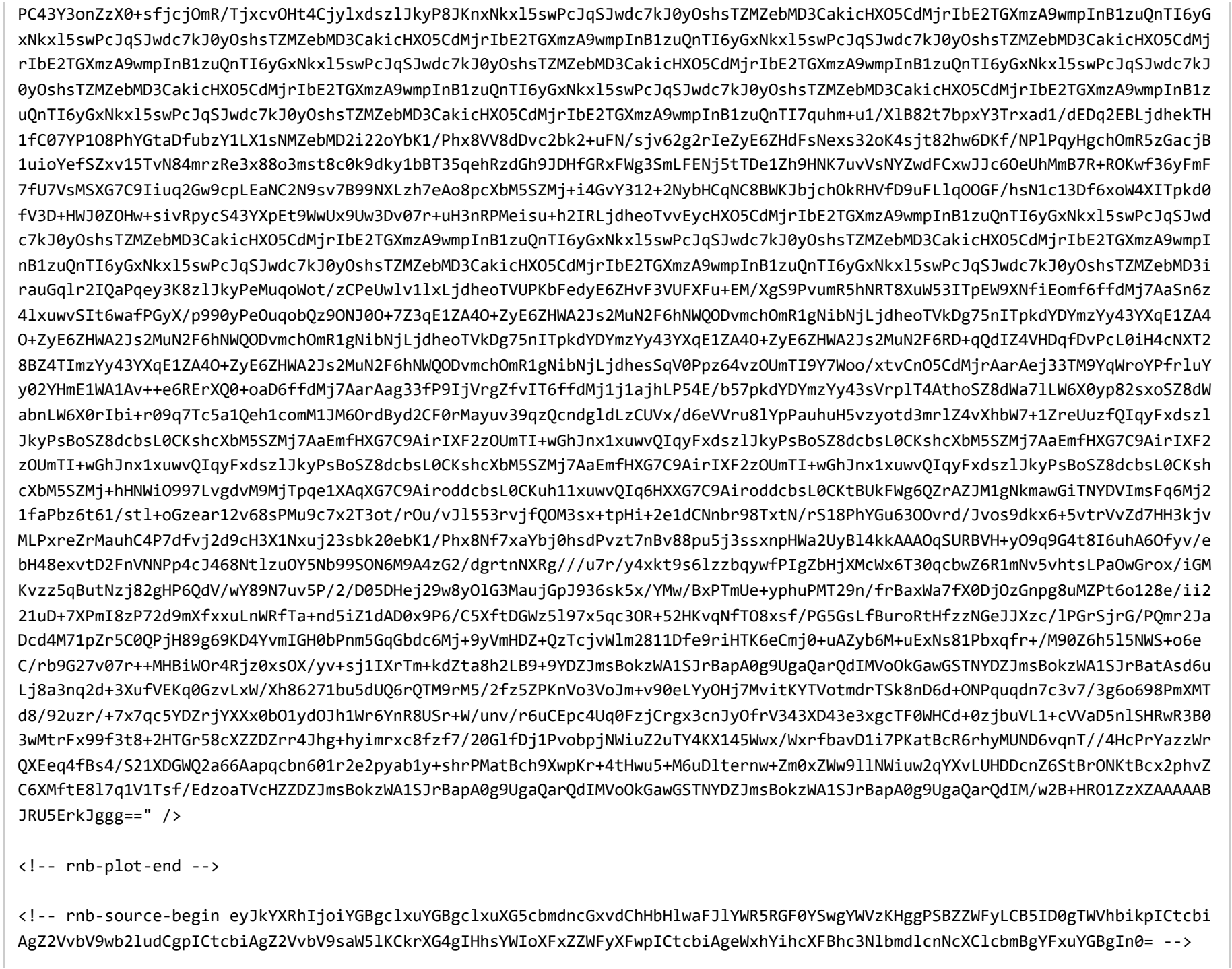
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<!-- rnb-plot-end -->
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<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxuXG5kYXRfcGFzc2VuZ2VycyAlPiVcbiAgcGl2b3RfbG9uZ2VyKCFZZWFyLCBuYW1lc190byA9IFxcTW9udGhcXCwgdmFsdWVzX3RvID0gXFxWYWxcXCkgJT4lXG4gIGdncGxvdCggYWVzKHggPSBhcy5mYWN0b3IoWWVhciksIHkgPSBWYWwpKSArXG4gIGdlb21fYm94cGxvdCgpICtcbiAgZ2VvbV9wb2ludChhZXMoeSA9IG1lYW4oVmFsKSksIGNvbCA9IDIpICtcbiAgeGxhYihcXFllYXJcXCkgK1xuICB5bGFiKFxcUGFzc2VuZ2Vyc1xcKVxuYGBg -->

```r
```r

dat_passengers %>%
  pivot_longer(!Year, names_to = \Month\, values_to = \Val\) %>%
  ggplot( aes(x = as.factor(Year), y = Val)) +
  geom_boxplot() +
  geom_point(aes(y = mean(Val)), col = 2) +
  xlab(\Year\) +
  ylab(\Passengers\)
```
```

<!-- rnb-source-end -->

<!-- rnb-plot-begin -->

<!-- rnb-plot-end -->

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<!-- rnb-plot-end -->

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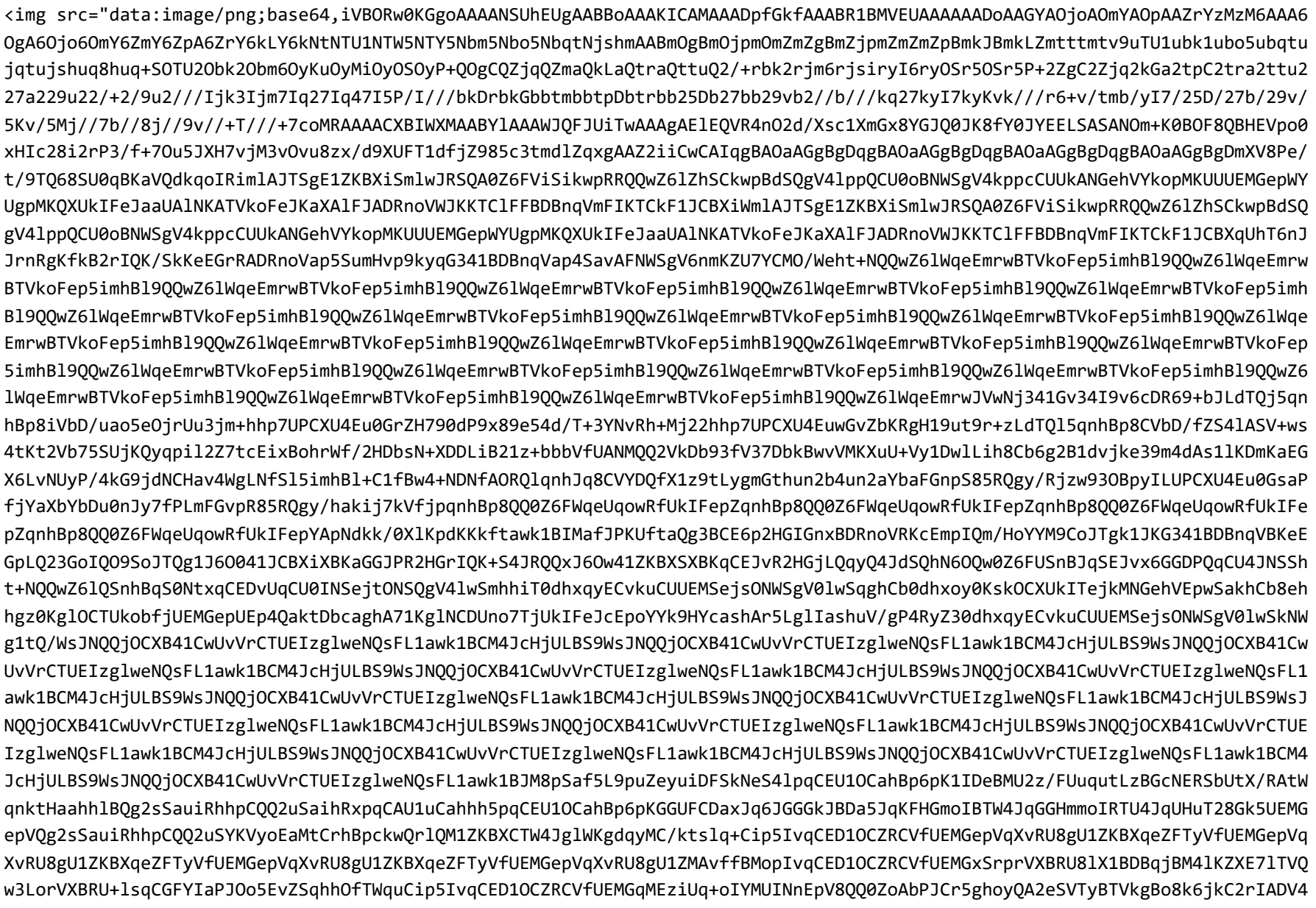
```r
```r

#color 2 is red, 3 is green, 4 is blue, 5 is cyan, 6 is purple, 7 is yellow, and so on.....
# R also understands HEX codes as colors

ggplot(GlyphReadyData, aes(x = Year, y = Mean)) +
  geom_point()+
  geom_errorbar(aes(ymin = Mean - 2 * SD, ymax = Mean + 2 * SD))+
  xlab(\Year\) +
  ylab(\Passengers\)
```
```

<!-- rnb-source-end -->

<!-- rnb-plot-begin -->



<!-- rnb-plot-end -->

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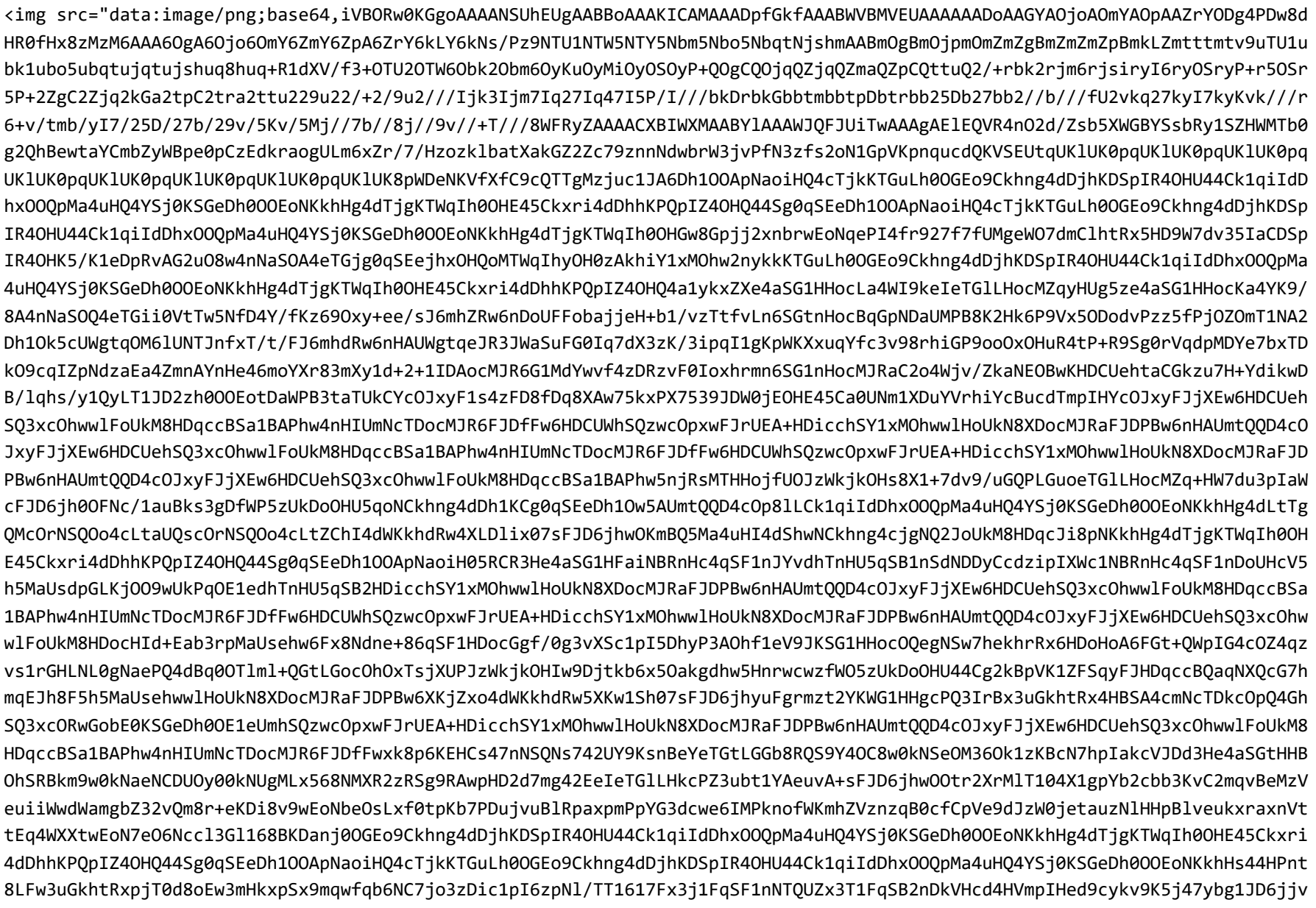
```r
```r

dat_passengers %>%
  pivot_longer(!Year, names_to = \Month\, values_to = \Val\) %>%
  ggplot()+
  geom_point(aes(x = as.factor(Year), y = Val), alpha = 0.5) +
  geom_point(data = GlyphReadyData, aes(x = as.factor(Year), y = Mean), col = 2, shape = 4, size = 4) +
  xlab(\Year\)
```
```

<!-- rnb-source-end -->

<!-- rnb-plot-begin -->



<!-- rnb-plot-end -->

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<!-- rnb-text-begin -->


##### Questions

- Which graph would you choose to display? why?
- How does your perception of the data change between each graph?
- What other graphs might you want to make?
- Would this information better be displayed as a table? Why or why not?


## Guided Example: SAT Data exploration


**Statement of Research Question**

Are higher teacher salaries associated with better state-wide SAT scores?




#### Examine the data source

for example:

- who/what/when/where/why/how data were collected
- review data intake
- variable types,
- coding,
- missingness,
- basic summary statistics and plots to learn about variables
```

<!-- rnb-text-end -->

<!-- rnb-chunk-begin -->

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```r
```r
data(\SAT_2010\)

# review data intake & variable coding
glimpse(SAT_2010)
```

<!-- rnb-source-end -->

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Rows: 50 Columns: 9 $ state Alabama, Alaska, Arizona, Ark… $ expenditure 10, 17, 9, 10, 10, 10, 16, 13… $ pupil_teacher_ratio 15.3, 16.2, 21.4, 14.1, 24.1,… $ salary 49948, 62654, 49298, 49033, 7… $ read 556, 518, 519, 566, 501, 568,… $ math 550, 515, 525, 566, 516, 572,… $ write 544, 491, 500, 552, 500, 555,… $ total 1650, 1524, 1544, 1684, 1517,… $ sat_pct 8, 52, 28, 5, 53, 19, 87, 74,…
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->

```r
```r
head(SAT_2010)
```

Hide

```
tail(SAT_2010)
```
```

<!-- rnb-source-end -->

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```r
```r
NA
```
```

<!-- rnb-source-end -->

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QRWprbVorSWI0amZpQjhvYXlJV0Vua0I4M0ZRWGtDZnpuZmNJN3hONVkzNlpCM3hLTTdYbWVCeUdUa01xU2xqMlRDVkJtM2VlNGFlQmhUblc0ZTIyK2VETUdEK2t
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<!-- rnb-frame-end -->

<!-- rnb-chunk-end -->

<!-- rnb-text-begin -->

<!-- rnb-text-end -->

<!-- rnb-chunk-begin -->

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```r
```r
# missingness & summary statistics
favstats( ~ salary, data = SAT_2010)
```

Hide

```
favstats( ~ total, data = SAT_2010)
```
```

<!-- rnb-source-end -->

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BcbmBgYCJ9 -->

```r
```r


SAT_2010 %>%
    ggplot(aes(x = salary)) +
    geom_density() +
```
```

```
    geom_rug() +
    xlab(\State average teacher salary (US dollars)\)
```

```
<!-- rnb-source-end -->

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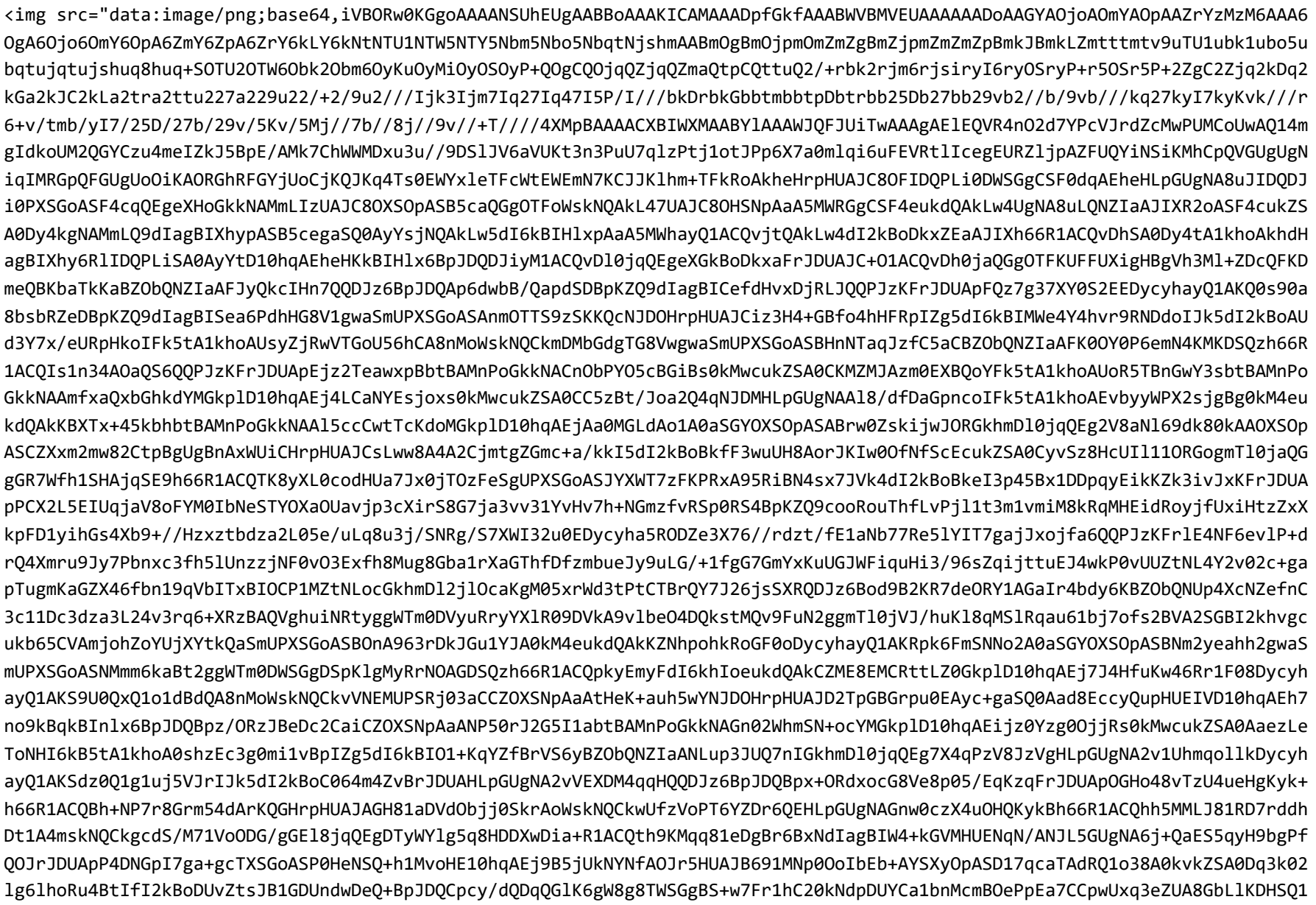
```r
```r


SAT_2010 %>%
    ggplot(aes(x = total)) +
    geom_density() +
    geom_rug() +
    xlab(\State average total SAT score\)
```
```

<!-- rnb-source-end -->

<!-- rnb-plot-begin -->



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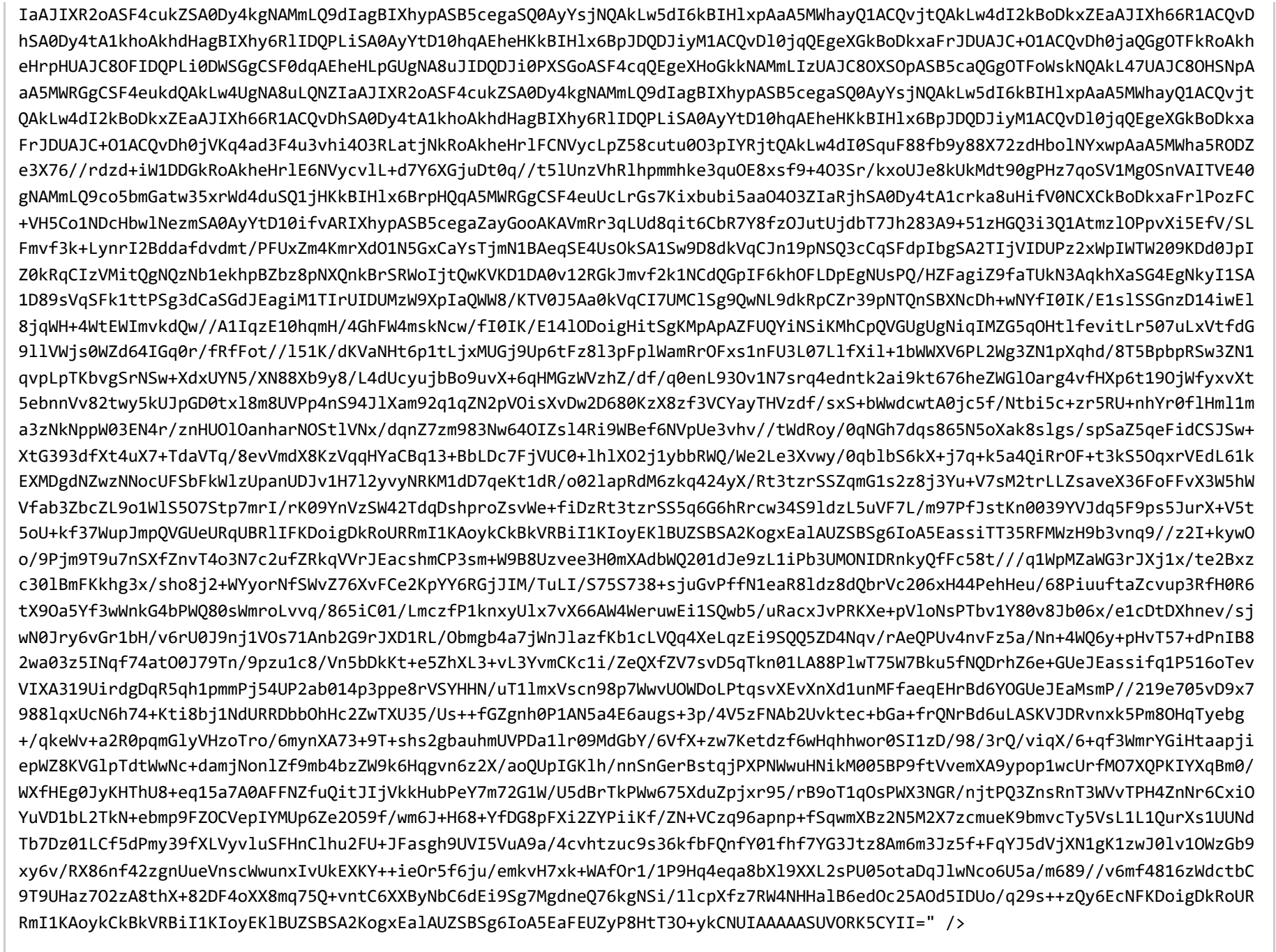
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## Discover features in the data that may impact modeling decisions

Some of this is based on scrutiny of the data collection practices (and study design), but much of it can be substantiated i
n EDA

- investigate outliers
- functionally dichotomous variables--e.g., survey asks people to rate job approval of president on scale of 1-7, but most p
eople choose either 1 or 7 and the options in between are rarely used
- highly correlated predictor variables
- hierarchy or nesting--e.g., data from students within classrooms within schools
- repeated observations of the same "case"--e.g., medical study follows up with the same group of patients every 6 months



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VkZW50XFwpICtcbiAgICB5bGFiKFxcUGVyY2VudGFnZSBvZiBzdHVkZW50cyB3aG8gdGFrZSB0aGUgU0FUXFwpXG5cblNBVF8yMDEwICU+JVxuICAgIGdncGxvdC
hhZXMoeCA9IGV4cGVuZGl0dXJlLCB5ID0gc2F0X3BjdCkpICtcbiAgICBnZW9tX3BvaW50KCkgK1xuICAgIGdlb21fc21vb3RoKG1ldGhvZCA9IFxcbG1cXCkgK1
xuICAgIHhsYWIoXFxTdGF0ZSBhdmVyYWdlIGV4cGVuZGl0dXJlIHBlciBzdHVkZW50XFwpICtcbiAgICB5bGFiKFxcUGVyY2VudGFnZSBvZiBzdHVkZW50cyB3aG
8gdGFrZSB0aGUgU0FUXFwpXG5cblNBVF8yMDEwICU+JVxuICAgIGZpbHRlcihzYXRfcGN0IDwgMjUsIGV4cGVuZGl0dXJlID4gMTUpXG5gYGBcbmBgYCJ9 -->

````
```r
```r
SAT_2010 %>%
    ggplot(aes(x = salary, y = sat_pct)) +
    geom_point() +
    # geom_smooth() +     # if linear is reasonable, consider method = \lm\
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\Percentage of students who take the SAT\)

SAT_2010 %>%
    ggplot(aes(x = salary, y = sat_pct)) +
    geom_point() +
    geom_smooth() +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\Percentage of students who take the SAT\)

SAT_2010 %>%
    ggplot(aes(x = salary, y = sat_pct)) +
    geom_point() +
    geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\Percentage of students who take the SAT\)

# density of sat_rate... apparent gap (why??)
SAT_2010 %>%
    ggplot(aes(x = sat_pct)) +
````

```
    geom_density() +
    geom_rug() +
    xlab(\Percentage of students who take SAT in each state\)

SAT_2010 <-
    SAT_2010 %>%
    mutate(sat_rate = cut(sat_pct, breaks = c(0, 30, 70, 100),
                          labels = c(\low\, \med\, \high\)))
    # mutate(sat_rate = cut(sat_pct, breaks = c(0, 40, 100),
    #                       labels = c(\lower\, \higher\)))

SAT_2010 %>%
    ggplot(aes(x = expenditure, y = sat_pct)) +
    geom_point() +
    geom_smooth() +
    xlab(\State average expenditure per student\) +
    ylab(\Percentage of students who take the SAT\)

SAT_2010 %>%
    ggplot(aes(x = expenditure, y = sat_pct)) +
    geom_point() +
    geom_smooth(method = \lm\) +
    xlab(\State average expenditure per student\) +
    ylab(\Percentage of students who take the SAT\)

SAT_2010 %>%
    filter(sat_pct < 25, expenditure > 15)
```

<!-- rnb-source-end -->

<!-- rnb-chunk-end -->

<!-- rnb-text-begin -->

Address research question

- one or a few key data visualizations that are most informative to a reader/observer
- include data visualization (but not exclusively)
- often requires exploring many data visualizations to find the one or few that most effectively communicate intuition for your research question
- we may even do some exploratory modeling here

<!-- rnb-text-end -->

<!-- rnb-chunk-begin -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxuXG4jIyBSZWxhdGlvbnNoaXAgYi93IHNhbGFyeSBhbmQgQXZlcmFnZSB0b3RhbCBTQVQgc2Nvcm
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Ntb290aCgpICtcbiAgICAjIGdlb21fc21vb3RoKG1ldGhvZCA9IFxcbG1cXCkgK1xuICAgIHhsYWIoXFxTdGF0ZSBhdmVyYWdlIHRlYWNoZXIgc2FsYXJ5IChVUy
Bkb2xsYXJzKVxcKSArXG4gICAgeWxhYihcXFN0YXRlIGF2ZXJhZ2UgdG90YWwgU0FUIHNjb3JlXFwpXG5cblNBVF8yMDEwICU+JVxuICAgIGdncGxvdChhZXMoeC
A9IHNhbGFyeSwgeSA9IHRvdGFsKSkgK1xuICAgIGdlb21fcG9pbnQoKSArXG4gICAgZ2VvbV9zbW9vdGgoKSArXG4gICAgIyBnZW9tX3Ntb290aChtZXRob2QgPS
BcXGxtXFwpICtcbiAgICB4bGFiKFxcU3RhdGUgYXZlcmFnZSB0ZWFjaGVyIHNhbGFyeSAoVVMgZG9sbGFycylcXCkgK1xuICAgIHlsYWIoXFxTdGF0ZSBhdmVyYW
dlIHRvdGFsIFNBVCBzY29yZVxcKVxuXG5TQVRfMjAxMCAlPiVcbiAgICBnZ3Bsb3QoYWVzKHggPSBzYWxhcnksIHkgPSB0b3RhbCkpICtcbiAgICBnZW9tX3BvaW
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FyeSwgeSA9IHRvdGFsLCBjb2xvciA9IHNhdF9yYXRlKSkgK1xuICAgIGdlb21fcG9pbnQoKSArXG4gICAgZ2VvbV9zbW9vdGgoKSArXG4gICAgIyBnZW9tX3Ntb2
90aChtZXRob2QgPSBcXGxtXFwpICtcbiAgICB4bGFiKFxcU3RhdGUgYXZlcmFnZSB0ZWFjaGVyIHNhbGFyeSAoVVMgZG9sbGFycylcXCkgK1xuICAgIHlsYWIoXF
xTdGF0ZSBhdmVyYWdlIHRvdGFsIFNBVCBzY29yZVxcKVxuXG5TQVRfMjAxMCAlPiVcbiAgICBnZ3Bsb3QoYWVzKHggPSBzYWxhcnksIHkgPSB0b3RhbCwgY29sb3

IgPSBzYXRfcmF0ZSkpICtcbiAgICBnZW9tX3BvaW50KCkgK1xuICAgIGdlb21fc21vb3RoKG1ldGhvZCA9IFxcbG1cXCkgK1xuICAgIHhsYWIoXFxTdGF0ZSBhdm
VyYWdlIHRlYWNoZXIgc2FsYXJ5IChVUyBkb2xsYXJzKVxcKSArXG4gICAgeWxhYihcXFN0YXRlIGF2ZXJhZ2UgdG90YWwgU0FUIHNjb3JlXFwpXG5cblNBVF8yMD
EwICU+JVxuICAgIGdncGxvdChhZXMoeCA9IGV4cGVuZGl0dXJlLCB5ID0gdG90YWwpKSArXG4gICAgZ2VvbV9wb2ludCgpICtcbiAgICAjIGdlb21fc21vb3RoKC
kgK1xuICAgICMgZ2VvbV9zbW9vdGgobWV0aG9kID0gXFxsbVxcKSArXG4gICAgeGxhYihcXFN0YXRlIGF2ZXJhZ2UgZXhwZW5kaXR1cmUgcGVyIHN0dWRlbnQgKF
VTIGRvbGxhcnMpXFwpICtcbiAgICB5bGFiKFxcU3RhdGUgYXZlcmFnZSB0b3RhbCBTQVQgc2NvcmVcXClcblxuU0FUXzIwMTAgJT4lXG4gICAgZ2dwbG90KGFlcy
h4ID0gZXhwZW5kaXR1cmUsIHkgPSB0b3RhbCkpICtcbiAgICBnZW9tX3BvaW50KCkgK1xuICAgIGdlb21fc21vb3RoKCkgK1xuICAgIHhsYWIoXFxTdGF0ZSBhdm
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l0dXJlLCB5ID0gdG90YWwsIGNvbG9yID0gc2F0X3JhdGUpKSArXG4gICAgZ2VvbV9wb2ludCgpICtcbiAgICMgZ2VvbV9zbW9vdGgoKSArXG4gICAgIyBnZW9tX3
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xuICAgIHlsYWIoXFxTdGF0ZSBhdmVyYWdlIHRvdGFsIFNBVCBzY29yZVxcKVxuXG5TQVRfMjAxMCAlPiVcbiAgICBnZ3Bsb3QoYWVzKHggPSBleHBlbmRpdHVyZS
wgeSA9IHRvdGFsLCBjb2xvciA9IHNhdF9yYXRlKSkgK1xuICAgIGdlb21fcG9pbnQoKSArXG4gICAgZ2VvbV9zbW9vdGgoKSArXG4gICAgeGxhYihcXFN0YXRlIG
F2ZXJhZ2UgZXhwZW5kaXR1cmUgcGVyIHN0dWRlbnQgKFVTIGRvbGxhcnMpXFwpICtcbiAgICB5bGFiKFxcU3RhdGUgYXZlcmFnZSB0b3RhbCBTQVQgc2NvcmVcXC
lcblxuYGBgXG5gYGAifQ== -->

~~~~
```r
```r

## Relationship b/w salary and Average total SAT scores

SAT_2010 %>%
    ggplot(aes(x = salary, y = total)) +
    geom_point() +
    # geom_smooth() +
    # geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = salary, y = total)) +
    geom_point() +
    geom_smooth() +
    # geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\State average total SAT score\)
~~~~

```
SAT_2010 %>%
    ggplot(aes(x = salary, y = total)) +
    geom_point() +
    geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = salary, y = total, color = sat_rate)) +
    geom_point() +
    geom_smooth() +
    # geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = salary, y = total, color = sat_rate)) +
    geom_point() +
    geom_smooth(method = \lm\) +
    xlab(\State average teacher salary (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = expenditure, y = total)) +
    geom_point() +
    # geom_smooth() +
    # geom_smooth(method = \lm\) +
    xlab(\State average expenditure per student (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = expenditure, y = total)) +
    geom_point() +
    geom_smooth() +
    xlab(\State average expenditure per student (US dollars)\) +
    ylab(\State average total SAT score\)

# since we have state data, maybe we should map it!
```

```
library(mosaic)
mUSMap(SAT_2010, key = \state\, \fill\ = \sat_rate\)
mUSMap(SAT_2010, key = \state\, \fill\ = \total\)

## relationship between expenditure and salary
SAT_2010 %>%
    ggplot(aes(x = expenditure, y = total, color = sat_pct)) +
    geom_point() +
    # geom_smooth() +
    # geom_smooth(method = \lm\) +
    xlab(\State average expenditure per student (US dollars)\) +
    ylab(\State average total SAT score\)

SAT_2010 %>%
    ggplot(aes(x = expenditure, y = total, color = sat_rate)) +
    geom_point() +
    geom_smooth() +
    xlab(\State average expenditure per student (US dollars)\) +
    ylab(\State average total SAT score\)
```

```
<!-- rnb-source-end -->

<!-- rnb-chunk-end -->


<!-- rnb-text-begin -->


## Statistical modeling

After we have completed a thorough EDA, we are ready for inferential or predictive modeling.

Again, statistical modeling can definitely serve exploratory and descriptive purposes that are appropriate during EDA (e.g., we fit smoothers & regression lines above), but they do impose a kind of structure on the data that influences (biases) our expectations.  It's a good idea to learn as much as we can about the data while imposing as little structure as possible, an d then gradually adding more structure to progressively refine our understanding.

Ideally, we want to let the data speak for itself, and then use appropriate analytical results like models to simply refine interpretations/predictions and more precisely quantify the uncertainty of our conclusions.

## A cool side note (if we have time)

- `mUSMap` is part of the `mosaic` package, not the `tidyverse`.
- There is a way to plot maps with `ggplot` but it is slightly more complicated syntax than `mUSMap`.
- There are 2 types of ggplot maps

  - polygon maps
    - you can create very simple maps
    - this is essentially treating each border as a shape, then mapping the shape to each geographic coordinate (latitude an d longitude)
    - simple “longitude-latitude” data format is not usually used in real world mapping

  - simple features maps
    - can make beautiful maps with lots and lots of features
      - can handle map projections, labels, colors, adding additional points (like cities), and so on
    - much more versatile (at the price of complexity)
    - uses vector data maps (GIS) <https://en.wikipedia.org/wiki/Vector_Map>
```

```
      - standard by the Open Geospatial Consortium
    - uses the `sf` package
    - essentially, data contains 2 columns, first column is location name, second column contains the "sf" polygon informati
on (any additional columns are characteristics of the location)
      - these data sets are extremely tedious (and complex) to write. It is usually better to find someone else's data set a
nd adapt it to your needs. The `rnaturalearth` package is a good place to start has countries and US states. The `sf` packag
e has some starter data sets for playing around with.

  - "raster" maps
    - uses geo-spatial data
    - "Unlike the simple features format, in which geographical entities are specified in terms of a set of lines, points an
d polygons, rasters take the form of images."
    - think satellite images

- Here is a tutorial <https://ggplot2-book.org/maps.html> on polygon, sf, and raster maps.

Here are the basic steps for a simple features map of our state data colored by pupil-teacher-ratio:



<!-- rnb-text-end -->


<!-- rnb-chunk-begin -->


<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeShzZilcbmBgYFxuYGBgIn0= -->

```r
```r
library(sf)
```

````
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJhzZuKAmSB3YXMgYnVpbHQgdW5kZXIgUiB2ZXJzaW9uIDQuMi4zXG4ifQ== -->
````

Warning: package ‘sf’ was built under R version 4.2.3

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeShnZ3NwYXRpYWwpXG5gYGBcbmBgYCJ9 -->

```r
```r
library(ggspatial)
````

````
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJhnZ3NwYXRpYWzigJkgd2FzIGJ1aWx0IHVuZGVyIFIgdmVyc2lvbiA0LjIuM1xuIn
0= -->
````

Warning: package ‘ggspatial’ was built under R version 4.2.3

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeShybmF0dXJhbGVhcnRoKVxuYGBgXG5gYGAifQ== -->

```r
```r
library(rnaturalearth)
````

```
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJhybmF0dXJhbGVhcnRo4oCZIHdhcyBidWlsdCB1bmRlciBSIHZlcnNpb24gNC4yLjNcbiJ9 -->
```

Warning: package ‘rnaturalearth’ was built under R version 4.2.3

```
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeSh0aWR5Z2VvY29kZXIpXG5gYGBcbmBgYCJ9 -->

```r
```r
library(tidygeocoder)
```

```
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJh0aWR5Z2VvY29kZXLigJkgd2FzIGJ1aWx0IHVuZGVyIFIgdmVyc2lvbiA0LjIuM1xuIn0= -->
```

Warning: package ‘tidygeocoder’ was built under R version 4.2.3

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeShtYXBzKVxuYGBgXG5gYGAifQ== -->

```r
```r
library(maps)
````

````
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJhtYXBz4oCZIHdhcyBidWlsdCB1bmRlciBSIHZlcnNpb24gNC4yLjNcbiJ9 -->
````

Warning: package ‘maps’ was built under R version 4.2.3

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxubGlicmFyeShnZ3JlcGVsKVxuYGBgXG5gYGAifQ== -->

```r
```r
library(ggrepel)
````

````
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiV2FybmluZzogcGFja2FnZSDigJhnZ3JlcGVs4oCZIHdhcyBidWlsdCB1bmRlciBSIHZlcnNpb24gNC4yLjNcbiJ9 -
->
````

Warning: package ‘ggrepel’ was built under R version 4.2.3

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxuI0dldCBzdGF0ZSBtYXAgZGF0YSBcbnN0YXRlX21hcF9kYXRhIDwtIG1hcCgnc3RhdGUnLCBmaWxsID0gVFJVRSwgcGxvdCA9IEZBTFNFKSAlPiUgc3RfYXNfc2YoKVxuXG4jaW5zcGVjdCBzdGF0ZSBtYXAgZGF0YSBcbmNsYXNzKHN0YXRlX21hcF9kYXRhKVxuYGBgXG5gYGAifQ== -->

```r
```r
#Get state map data
state_map_data <- map('state', fill = TRUE, plot = FALSE) %>% st_as_sf()

#inspect state map data
class(state_map_data)
````

````
<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiWzFdIFxcc2ZcXCAgICAgICAgICAgIFxcZGF0YS5mcmFtZVxcXG4ifQ== -->
````

[1] .frame

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxuaGVhZChzdGF0ZV9tYXBfZGF0YSlcbmBgYFxuYGBgIn0= -->

```r
```r
head(state_map_data)
````

<!-- rnb-source-end -->

<!-- rnb-output-begin eyJkYXRhIjoiU2ltcGxlIGZlYXR1cmUgY29sbGVjdGlvbiB3aXRoIDYgZmVhdHVyZXMgYW5kIDEgZmllbGRcbkdlb21ldHJ5IHR5cG
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gwMTUgeW1heDogNDIuMDQ5Mzdcbkdlb2RldGljIENSUzogICtwcm9qPWxvbmdsYXQgK2VsbHBzPWNscms2NiArbm9fZGVmcyArdHlwZT1jcnNcbiAgICAgICAgICAg
AgICAgICAgICAgIElEICAgICAgICAgICAgICAgICAgICAgICAgICAgICAgICAgICAgZ2VvbVxuYWxhYmFtYSAgICAgICAgICAgIGFsYWJhbWEgTVVMVElQT0xZR09OICgoKC04Ny40Nj
IwMSAzLi4uXG5hcml6b25hICAgICAgICAgICAgYXJpem9uYSBNVUxUSVBPTFlHT04gKCgoLTExNC42Mzc0IDMuLi5cbmFya2Fuc2FzICAgICAgICAgICAgIGFya2Fuc2FzIE1VTF
RJUE9MWUdPTiAoKCgtOTQuMDUxMDMgMy4uLlxuY2FsaWZvcm5pYSAgIGNhbGlmb3JuaWEgTVVMVElQT0xZR09OICgoKC0xMjAuMDA2IDQyLi4uXG5jb2xvcmFkby
AgICAgICBjb2xvcmFkbyBNVUxUSVBPTFlHT04gKCgoLTEwMi4wNTUyIDQuLi5cbmNvbm5lY3RpY3V0IGNvbm5lY3RpY3V0IE1VTFRJUE9MWUdPTiAoKCgtNzMuND
k5MDIgNC4uLlxuIn0= -->

Simple feature collection with 6 features and 1 field Geometry type: MULTIPOLYGON Dimension: XY Bounding box: xmin: -124.3834 ymin: 30.24071 xmax: -71.78015 ymax: 42.04937 Geodetic CRS: +proj=longlat +ellps=clrk66 +no_defs +type=crs ID geom alabama alabama MULTIPOLYGON (((-87.46201 3… arizona arizona MULTIPOLYGON (((-114.6374 3… arkansas arkansas MULTIPOLYGON (((-94.05103 3… california california MULTIPOLYGON (((-120.006 42… colorado colorado MULTIPOLYGON (((-102.0552 4… connecticut connecticut MULTIPOLYGON (((-73.49902 4…

````
<!-- rnb-output-end -->

<!-- rnb-source-begin eyJkYXRhIjoiYGBgclxuYGBgclxuIyBNZXJnZSBpdCB3aXRoIG91ciBTQVQgZGF0YSBcblNBVDIgPC0gU0FUXzIwMTAgJT4lXG4gIG
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```r
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# Merge it with our SAT data
SAT2 <- SAT_2010 %>%
  mutate(state = tolower(state)) %>%
  filter(!(state) %in% c(\alaska\, \hawaii\))

state_map_data <- state_map_data %>%
  filter(ID != \district of columbia\)

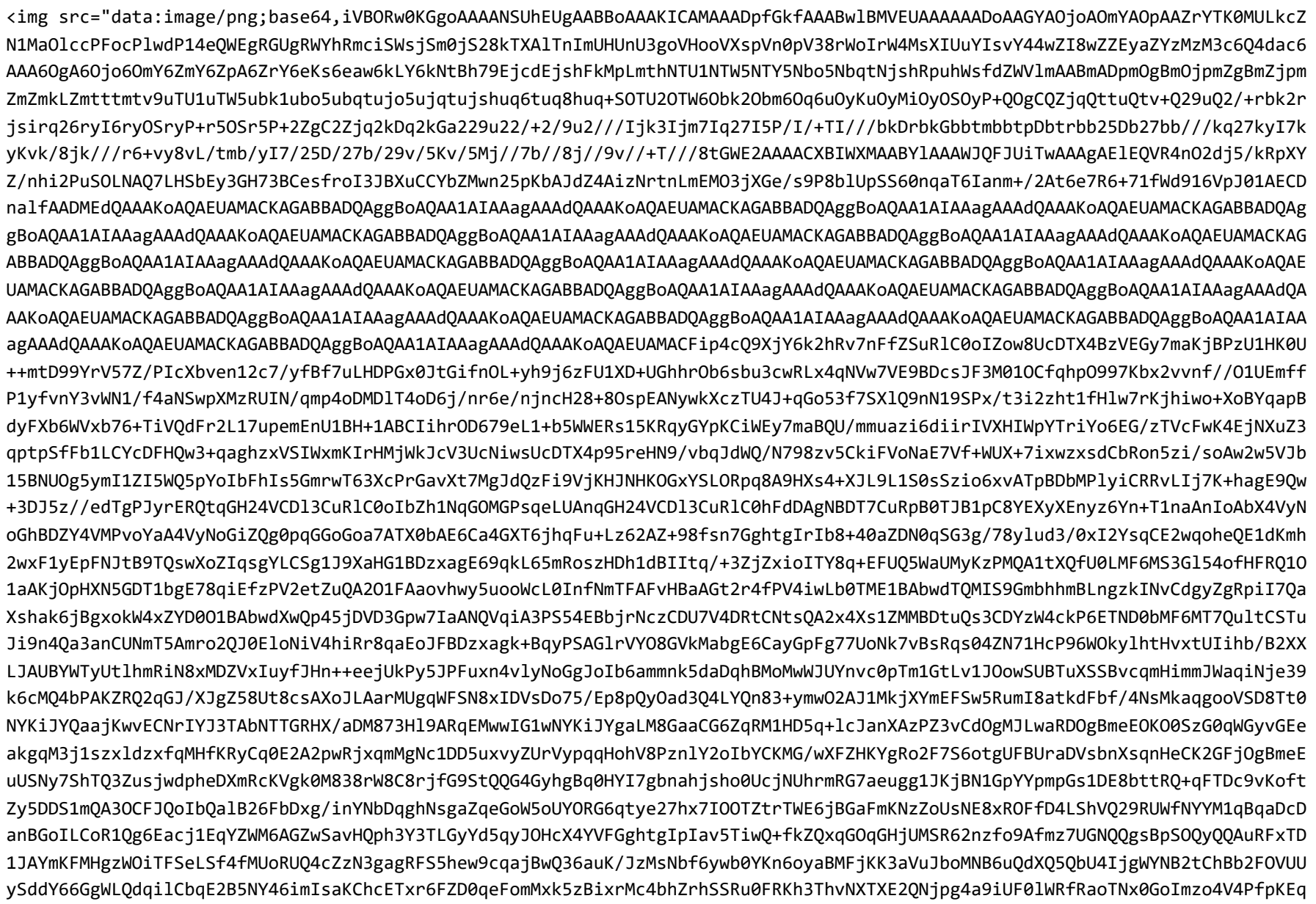
#color on the log scale
state_map_data$color <- log(SAT2$pupil_teacher_ratio)

#make the ggplot
gg_sat <-  ggplot() +
  geom_sf(data = state_map_data, aes(fill = color)) +
  guides(fill=guide_legend(title=\log(Pupil-Teacher Ratio)\))

gg_sat
````

<!-- rnb-source-end -->

<!-- rnb-plot-begin -->



<!-- rnb-plot-end -->

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```

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I=" />

<!-- rnb-plot-end -->

<!-- rnb-chunk-end -->

<!-- rnb-text-begin -->

This is great! But it is essentially the exact same map as using `usMap` but with a ton more work.

A few notes:

- I personally prefer to plot color on the log scale (usually but not always). This is not necessary, but I find it easier t
o see broad trends as it dampens the extremity of the maximum. Not everyone prefers this method.

- Notice the order on the legend goes smallest at the top to largest at the bottom. This is counterintuitive. If I were to a

dd this graphic to a report, I would make sure the legend went largest to smallest.

- Notice this map and the `mUSMap` have different map projections. `mUSMap` defaults to a polyconic projection, and `geom_sf` defaults to whatever projection your data frame is in (here it using a Mercator projection). Both methods allow you to change the map projection.

Side, Side note about plotting in 3D

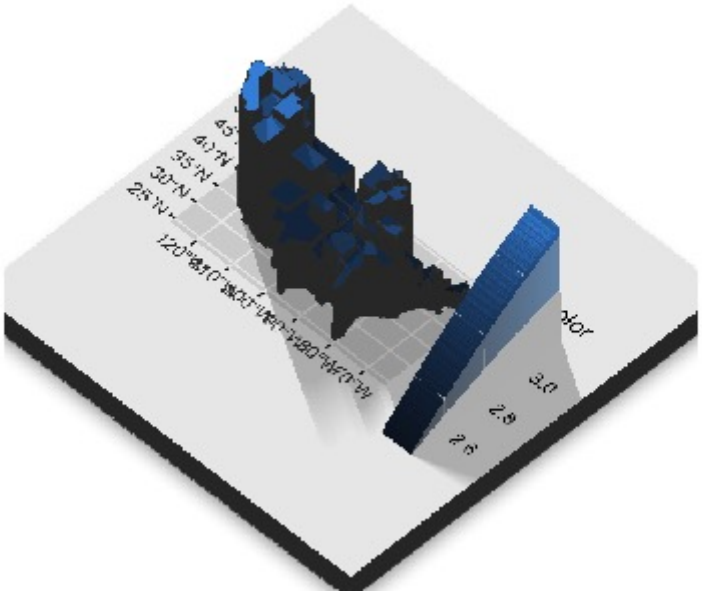
With this ggplot and sf method of plotting maps, it is possible to plot your maps in 3D using the `rayshader` package.

<!-- rnb-text-end -->

<!-- rnb-chunk-begin -->

<!-- rnb-source-begin eyJkYXRhIjpbIiNkZXZ0b29sczo6aW5zdGFsbF9naXRodWIoXCJ0eWxlcm1vcmdhbndhbGwvcmF5c2hhZGVyXCIpIiwibGlicmFyeShyYXlzaGFkZXIpICIsInBsb3RfZ2coZ2dfc2F0LCBtdWx0aWNvcmUgPSBUUlVFLCAiLCIgICAgICAgIHNjYWxlID0gMzAwLCAgem9vbSA9IDAuNzUsICIsIiAgICAgICAgcGhpID0gNTAsIHN1bmFuZ2xlID0gLTYwLCB0aGV0YSA9IDQ1KSIsInJlbmRlcl9zbmFwc2hvdCgpIl19 -->

```r
#devtools::install_github("tylermorganwall/rayshader")
library(rayshader)
plot_gg(gg_sat, multicore = TRUE,
        scale = 300,  zoom = 0.75,
        phi = 50, sunangle = -60, theta = 45)
render_snapshot()
```



While this may look super cool, did plotting in the 3D add to our interpretation of the graph? Did we just add unnecessary graphics?

In data visualization it is always important to balance glyphs with interpretability. We need to add enough so that the viewer understands the story we are trying to tell, but not so much that the graph is “messy” or “cluttered”.

Examples when adding 3D does add value

- Election Results
  - https://www.arcgis.com/apps/MinimalGallery/index.html?appid=b3d1fe0e8814480993ff5ad8d0c62c32 (https://www.arcgis.com/apps/MinimalGallery/index.html?appid=b3d1fe0e8814480993ff5ad8d0c62c32)
- Population Density
  - https://www.visualcapitalist.com/3d-mapping-the-worlds-largest-population-densities/ (https://www.visualcapitalist.com/3d-mapping-the-worlds-largest-population-densities/)
- Cartography (particularly elevation)
  - `elmat` example https://www.rayshader.com (https://www.rayshader.com)
- Contours and Joint Densities
  - https://plotly.com/r/3d-surface-plots/ (https://plotly.com/r/3d-surface-plots/)
  - https://rviews.rstudio.com/2020/12/14/plotting-surfaces-with-r/ (https://rviews.rstudio.com/2020/12/14/plotting-surfaces-with-r/)

    - http://www.countbio.com/web_pages/left_object/R_for_biology/R_fundamentals/3D_surface_plot_R.html (http://www.countbio.com/web_pages/left_object/R_for_biology/R_fundamentals/3D_surface_plot_R.html)
    - diamonds example https://www.rayshader.com (https://www.rayshader.com)

Assignments

- Reading Quiz DC Ebook Chapter 15 (due Thursday, July 27, 9:59am)
- Suggested Reading : Chapter 17 Regular expressions

A few words about the final project

- Will be individual assignements
- Similar in nature to the Activities that you are doing
- You will need to explore and analyze using EDA atleast 2 different data sets. The primary dataset should not be part of an R package (could be a csv file, could be a dataset hosted on github, could be from a webpage), but the secondary dataset could be anything.
- For now, try to think about interesting topics you might want to explore and where could you find relevant datasets.
- You will need to submit a topic for the final project within August 2.
- For some it will seem daunting to start from scratch looking for one or more “interesting” data sets. There are lots of useful repositories out there. Here are a few links to get you started, but please feel free to use any data that interest you!
    - https://www.springboard.com/blog/free-public-data-sets-data-science-project/ (https://www.springboard.com/blog/free-public-data-sets-data-science-project/)
    - https://www.dataquest.io/blog/free-datasets-for-projects/ (https://www.dataquest.io/blog/free-datasets-for-projects/)
    - https://data.cityofnewyork.us/ (https://data.cityofnewyork.us/)
    - http://www.icpsr.umich.edu/icpsrweb/ICPSR/ (http://www.icpsr.umich.edu/icpsrweb/ICPSR/)
    - https://github.com/awesomedata/awesome-public-datasets (https://github.com/awesomedata/awesome-public-datasets)
    - https://github.com/fivethirtyeight/data (https://github.com/fivethirtyeight/data)
- I repeat: **you can use any data set you want and it may not be in the above list. The list is just a starting point** .