1. Course Introduction

PUBH 6199: Visualizing Data with R, Summer 2025

Xindi (Cindy) Hu, ScD

2025-05-20

Outline for today

- **Who?**
- How?
- What?
- Why?
- Introduction to {ggplot2}

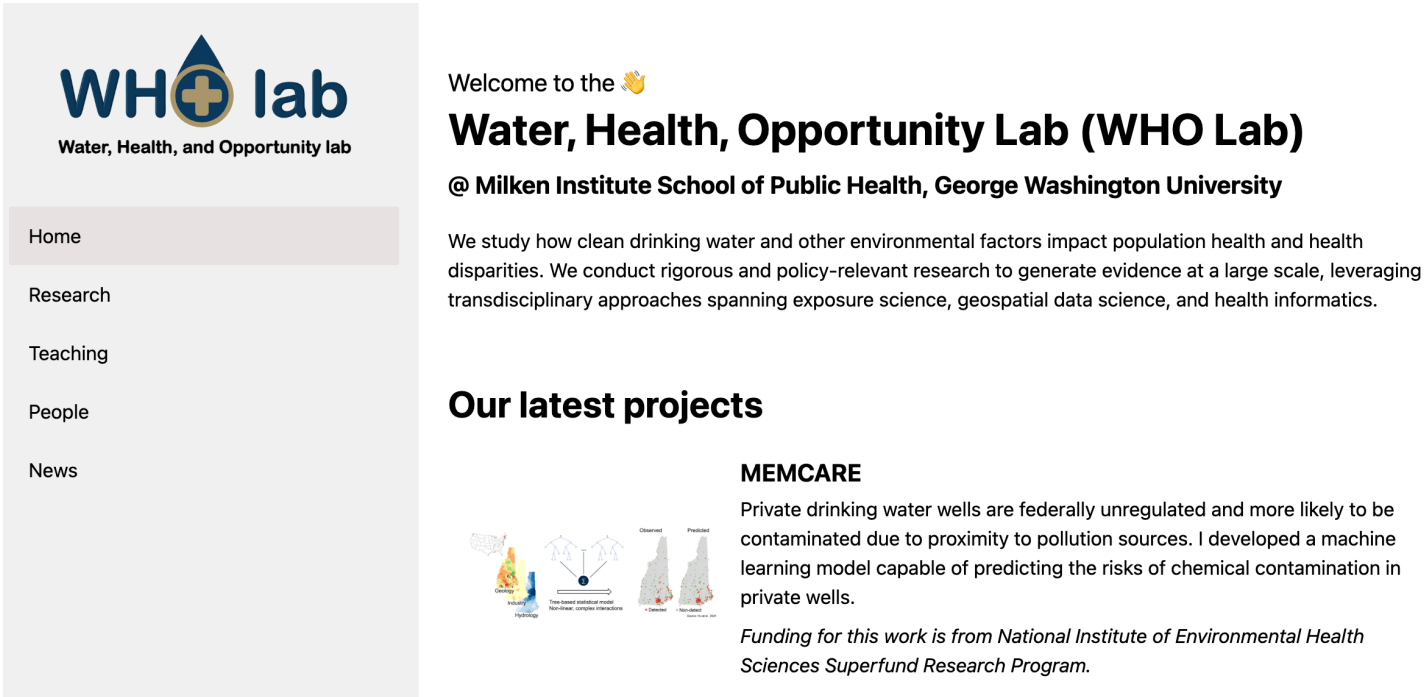
Meet your instructor

Xindi (Cindy) Hu, ScD

Assistant Professor, Department of Environmental and Occupational Health

ScD in Environmental Health, Harvard University

Water, Health, and Opportunity Lab



Our Research:

Environmental Data Science, Drinking Water Quality, Health Equity, Climate Change, Geospatial Analysis, Machine Learning

Meet your TAs

Silas Horn

MPH Candidate

Environmental Health Science and Policy

GW SPH

Sayam Palrecha

MS Candidate

Data Science

GW CCAS

About you

Outline for today

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- **How?**
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PUBH 6199 Goals

Theory

- Apply fundamental principles & techniques

Design Skills

- Create, evaluate, and critique visualization designs

Coding Skills

- Implement static and interactive data visualizations

Develop a substantial visualization project!

Course component

- **Lectures**: Tuesdays 3:10-5:10 PM
- **Lab**: Thursdays 3:10-5:10 PM
- **Homework**: Weekly assignments due Mondays
- **Final project**: Team of 2-3 people

What about gradings???

Grading

- **Class Participation** (attendance, contribution to in-class activities, completion of end-of-class surveys): 10%
- **Homework** (5 weekly assignments): 35%
- **Lab** (5 weekly lab notebooks): 15%
- **Final Project** (team of 2): 40%
  - 25% for the final data visualization product
  - 10% for the presentation
  - 5% for peer evaluation

Prerequisites

- Programming experience at the level of PUBH 6131 or similar
- Willingness to learn new software & tools
  - This can be time consuming
  - Learning by doing is the best way of acquiring new skills, get on the bike

Course policies

- Be respectful and inclusive
- Get on the bike
- Don’t cheat!

Device policy

- Bring laptop to lecture, lab, and office hour
- Please only use it for in-class activities!

Generative AI policy

- Generative AI is another tool in your toolbox, use it but be prepared to be responsible.
- Usage of GenAI tools is permitted but please be transparent about it.
- Lazy usage of GenAI tools (homework prompt -> output -> submission) is **prohibited**.
- Include a “How I used GenAI” section in your homework and final project (include prompt, date, model version, and link to chat history).

Communication

- Slack: PUBH 6199 channel
- Course website https://pubh6199-data-viz-with-r.github.io/
- Blackboard
- Office hours:
  - Cindy: Mondays 4-5 PM
  - Silas: Wednesdays 2-3 PM
- Email:
  - Cindy: xindi.hu@gwu.edu
  - Silas: silas.horn@gwmail.gwu.edu
- Boundaries:
  - Please allow 24 hrs for slack/email response
  - Replies in the after hours (after 6pm ET) and over the weekends are not guaranteed

Class Mascot

Rubber Duck Debugging 🐤

Explain your problem out loud — as if you're talking to a rubber duck.

- Slows down your thinking
- Reveals skipped steps
- Helps you find mistakes
- Works even without another person!

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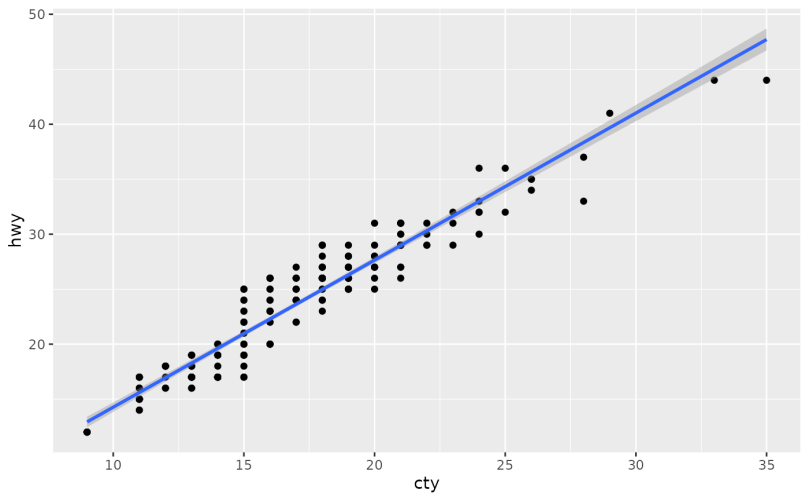
What is data visualization?

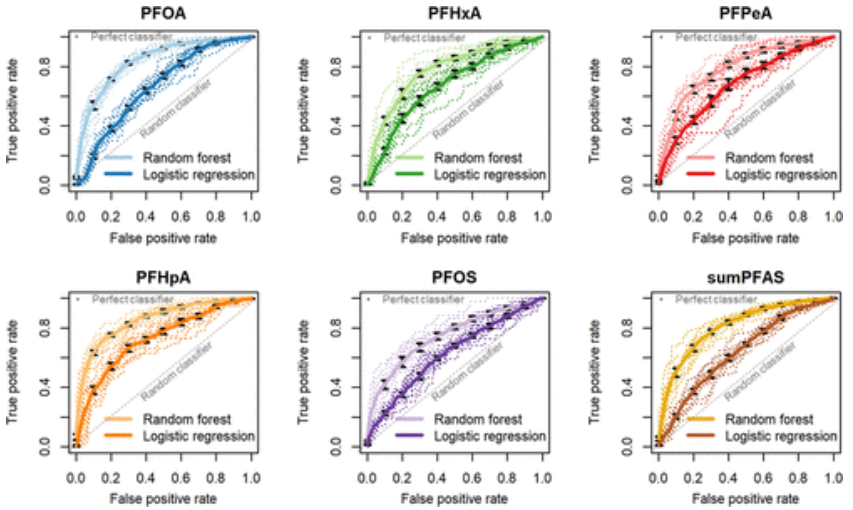
> "The practice of designing and creating graphic or visual representations of a large amount of complex quantitative and qualitative data and information with the help of static, dynamic or interactive visual items."

-from Wikipedia

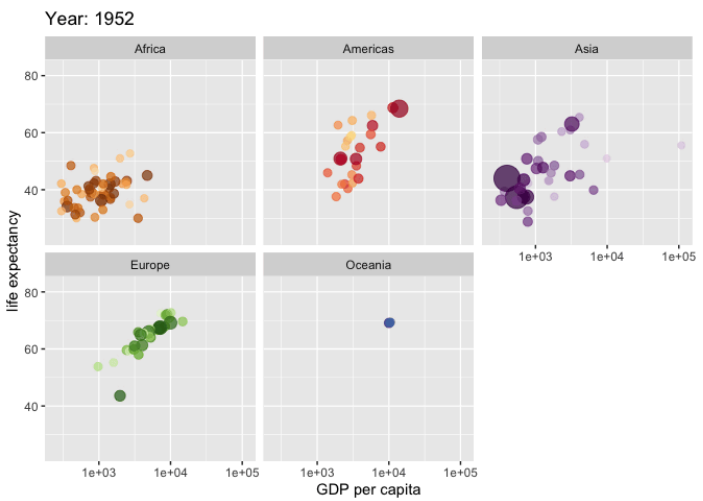
Made with {ggplot2}



Made with {ggplot2} and publication ready



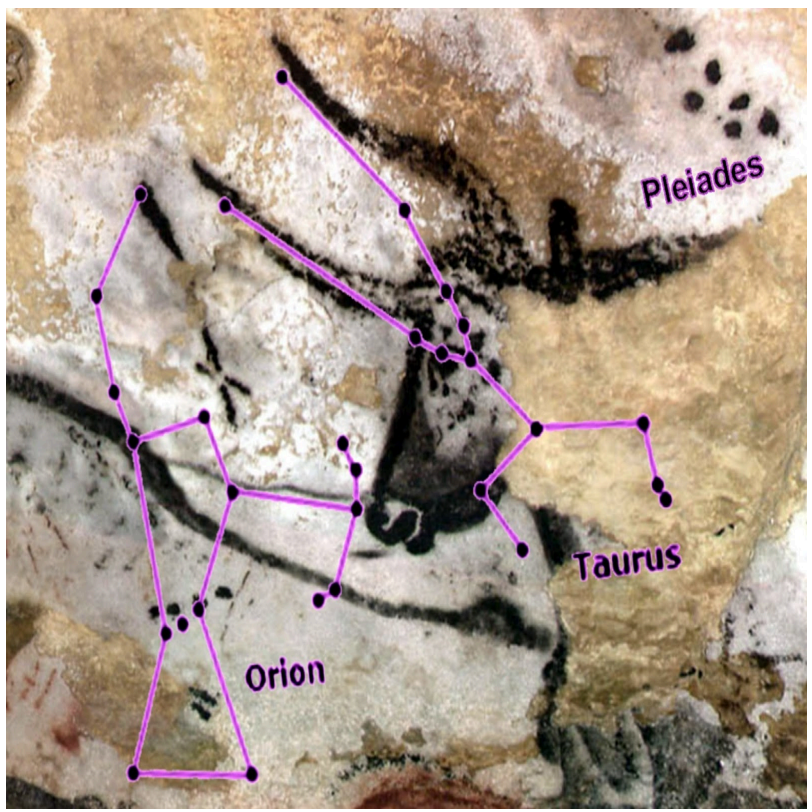
Made with {gganimate}



Made with Shiny

A brief history of Data Visualization (Adapted from EDS 240)

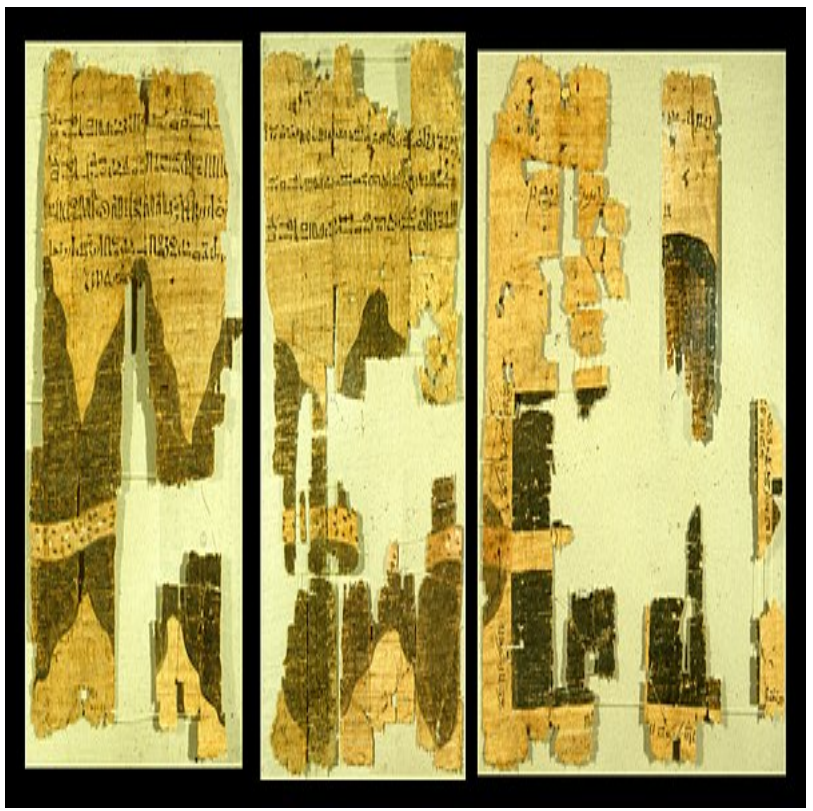
16,500 years ago, Pleistocene



Source: BBC

A brief history of Data Visualization

~1150 BC, Ancient Egypt



Source: Wikipedia

A brief history of Data Visualization

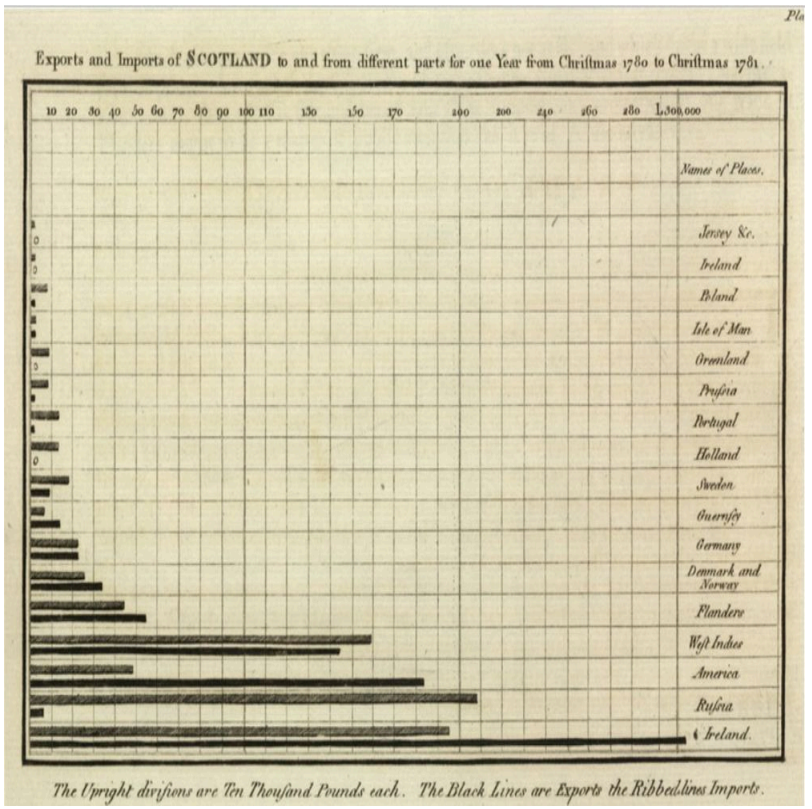
1400 - 1532 AD, Inca Empire

Quipus (kee-poos) were recording devices for data collection, census records, calendaring…

Source: Smithsonian

A brief history of Data Visualization

1786, William Playfair

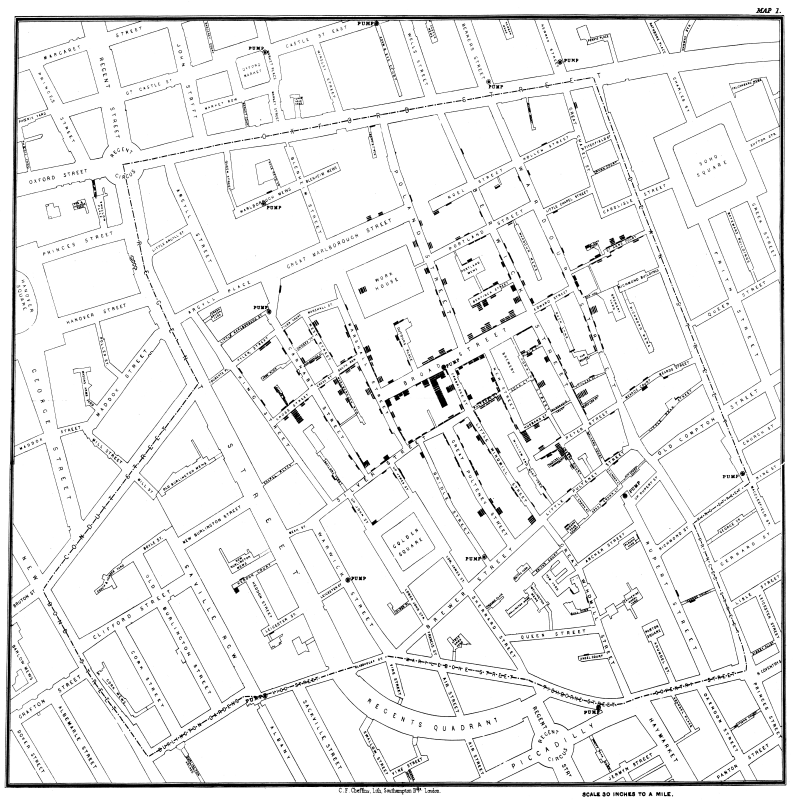


Created first bar chart (featuring Scottish trade data, 1780 - 1781), as well as line and pie charts.

Source: Wikipedia

A brief history of Data Visualization

1854, John Snow

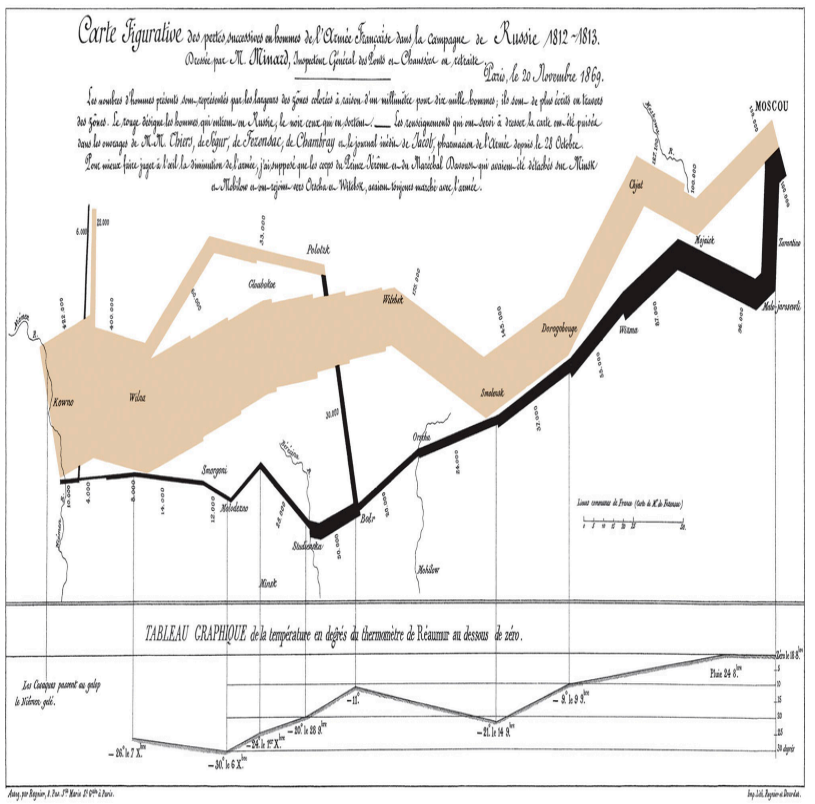


Used a dot map and showed the clusters of cholera cases in the London epidemic of 1854

Source: Wikipedia

A brief history of Data Visualization

1869, Charles Minard



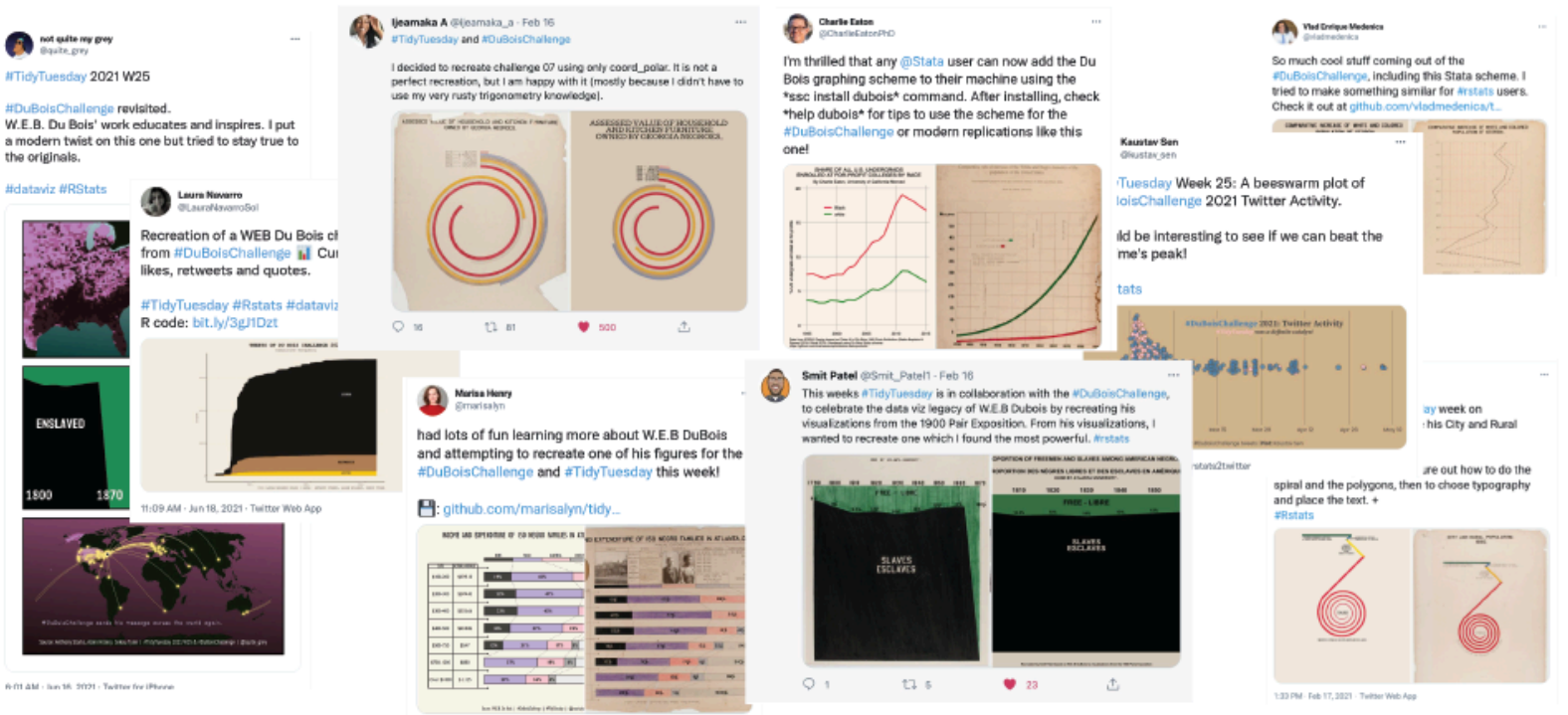
Created a flow map showing the number of troops lost during Napoleon's 1812 Russian campaign.

Edward Tufte called this the greatest visualization created, displaying 6 types of data in 2D (# of troops, distance traveled, temperature, lat/lon, direction of travel, location relative to specific dates)

Source: Wikipedia

A brief history of Data Visualization

1900, William Edward Burghardt Du Bois



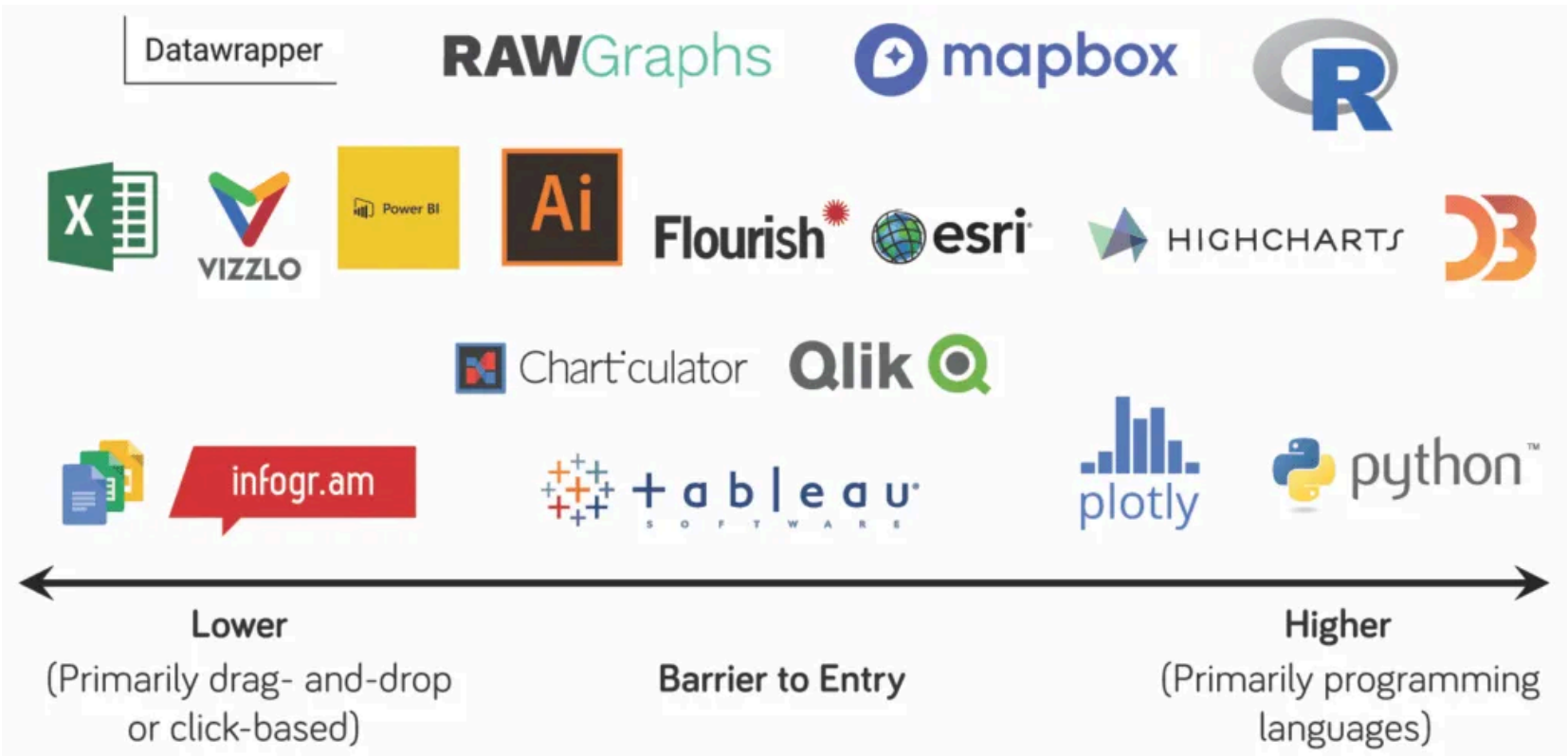
Organized an exhibit at the Paris 1900 Exposition, showcasing photographs, charts, and maps that documented the lives of African Americans at the time.

In 2021, people on Twitter recreated his historicall data visualizations using modern tools.

Source: Nightingale

A brief history of Data Visualization

Modern day



Source: Jonathan Schwabish

What will you learn in this class?

- Identify the effective types of data visualization for the data at hand and the intended audience
- Critique data visualizations and provide constructive feedback
- Prepare dataset for developing data visualization
- Create effective, ethical, and aesthetically-pleasing visualizations using R programming language
- Collaborate with classmates from diverse disciplinary background to carry out a visualization project

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- **Why?**
- Introduction to {ggplot2}

In-Class Activity:

In small group of 2, discuss your favorite example of data visualization, why do you like it? what functionality does that data visualization serve?

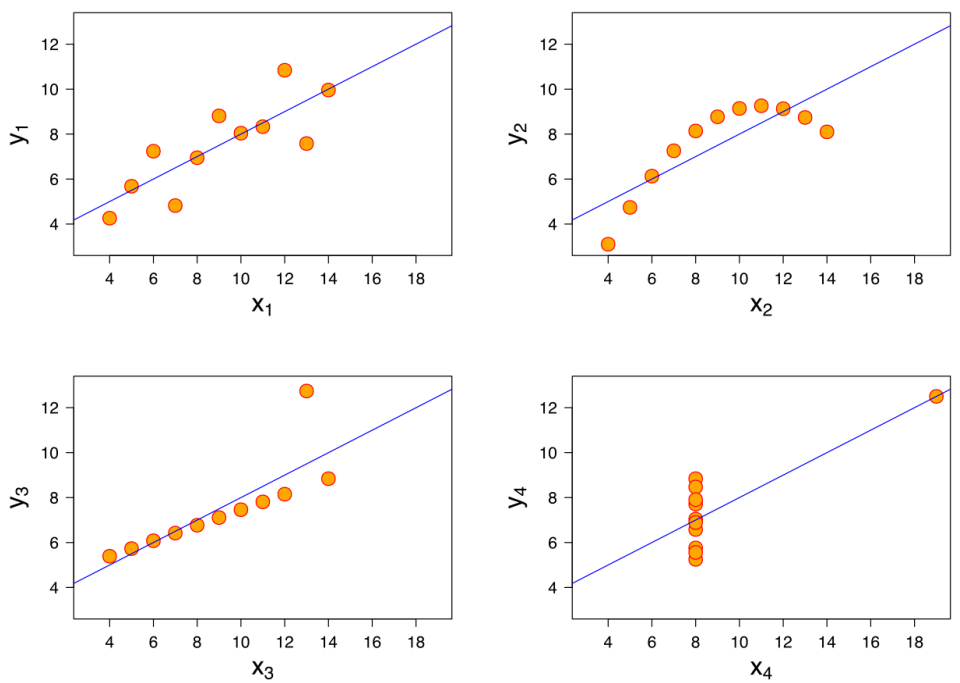
05:00

Why do we visualize data?

To reveal patterns that are hard to see in raw numbers…

Anscombe's Quartet: Raw Data

	I		II		III		IV	
	x	y	x	y	x	y	x	y
	10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
	8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
	13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
	9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
	11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
	14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
	6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
	4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
	12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
	7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
	5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89
mean	9.0	7.5	9.0	7.5	9.0	7.5	9.0	7.5
var.	10.0	3.75	10.0	3.75	10.0	3.75	10.0	3.75
corr.		0.816		0.816		0.816		0.816

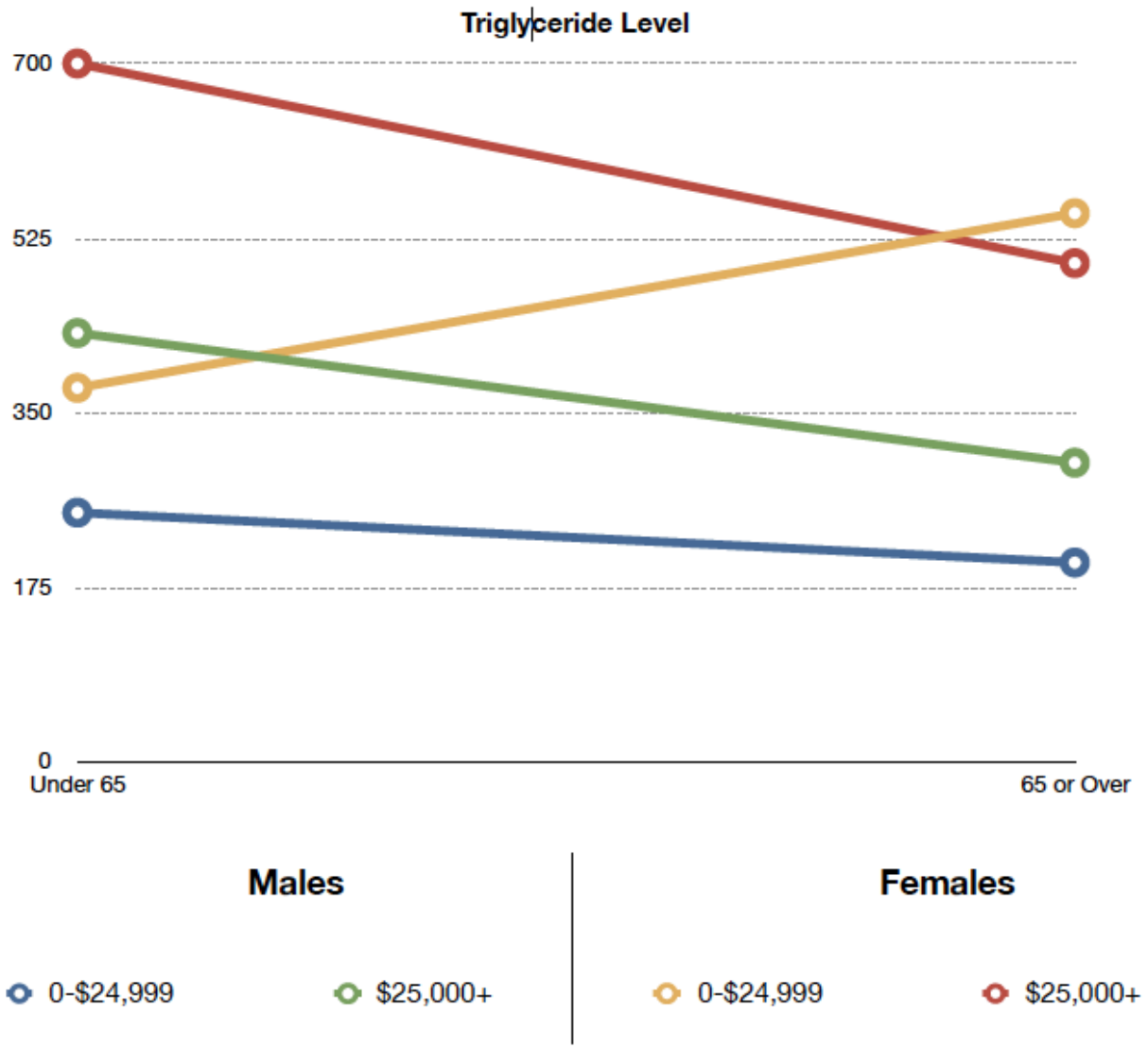


To communicate complex ideas quickly…

Income Group	Males: Under 65	Males: 65 or Over	Females: Under 65	Females: 65 or Over
0–$24,999	250	200	375	550
$25,000+	430	300	700	500

Is the effect of age on cholesterol levels the same for all subgroups defined by sex and income?

To communicate complex ideas quickly…

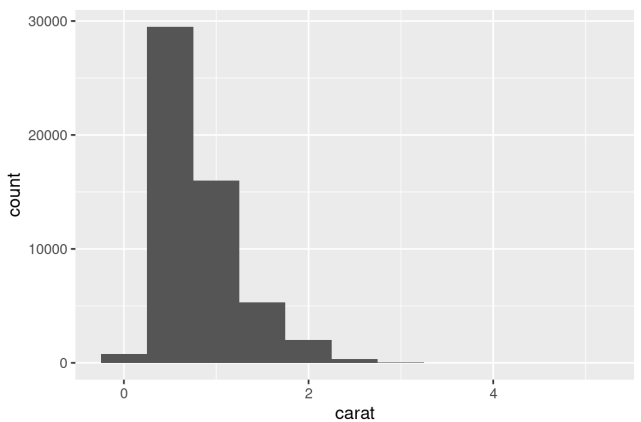


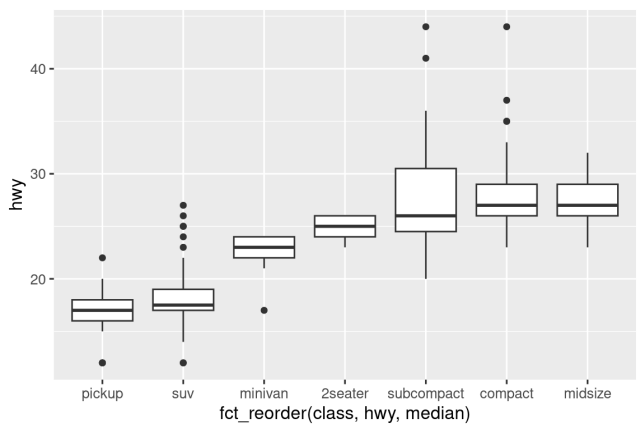
Source: SM Kosslyn: Clear and to the point

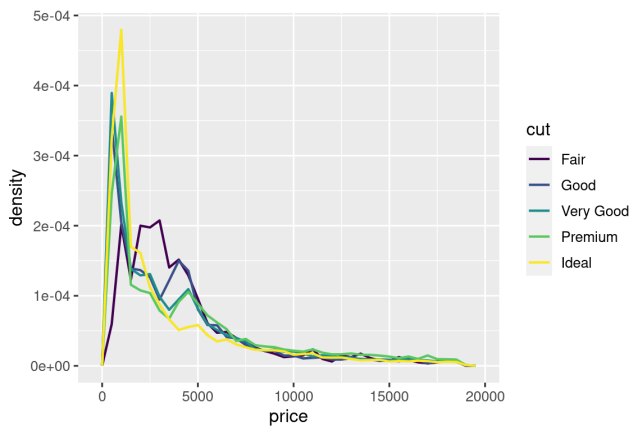
To explore and generate new questions

> "Exploratory Data Analysis, or EDA, is a process to use visualization and transformation to explore your data in a systemic way. EDA is not a formal process with a strict set of rules. More than anything, EDA is a state of mind. During the initial phases of EDA you should feel free to investigate every idea that occurs to you. Some of these ideas will pan out, and some will be dead ends. As your exploration continues, you will home in on a few particularly productive areas that you'll eventually write up and communicate to others."

-from R for Data Science





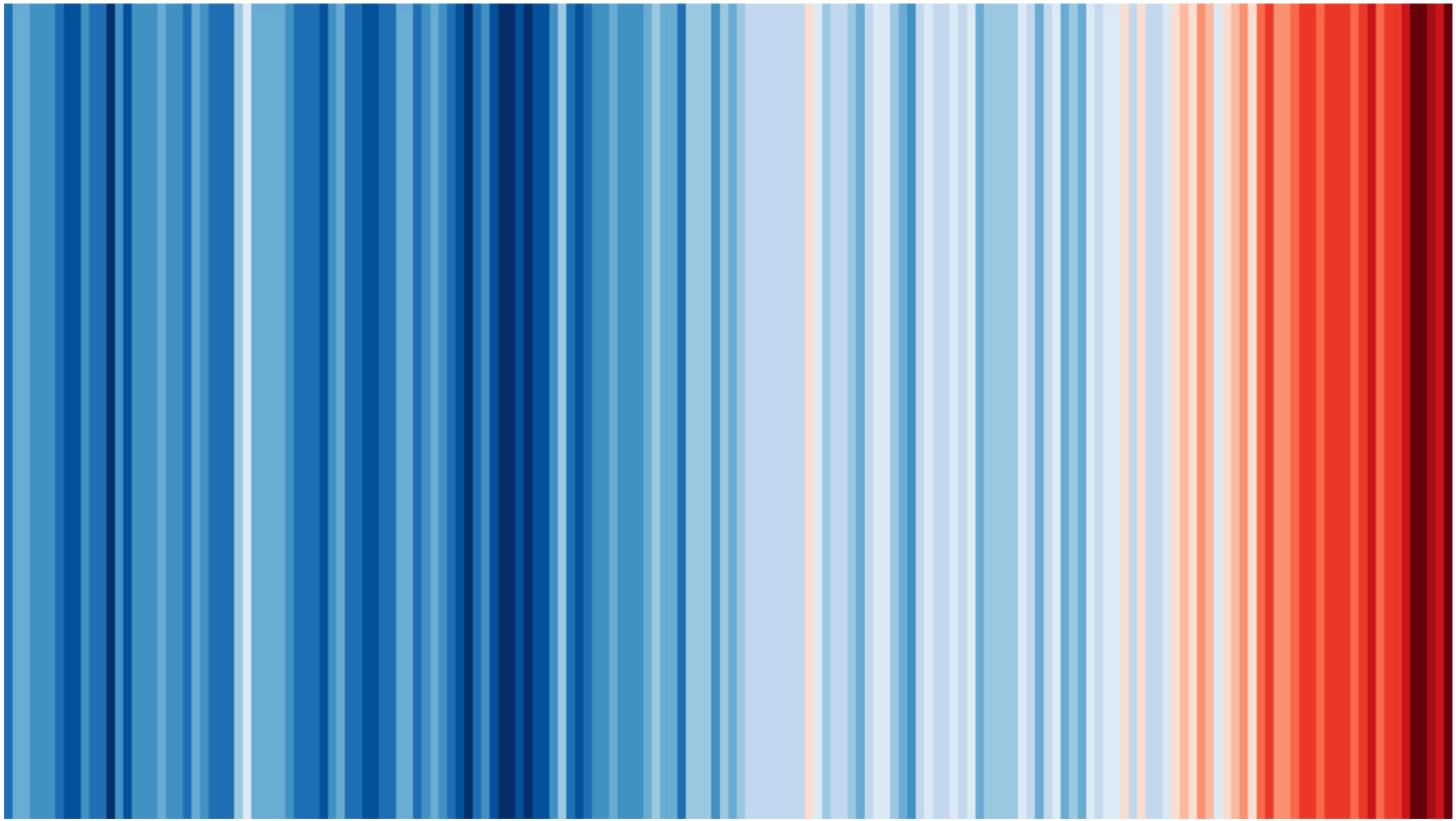



```
1 ggplot(diamonds, aes(x = carat)
2   geom_histogram(binwidth = 0.5
```

```
1 ggplot(mpg, aes(x = fct_reorder(
2   geom_boxplot()
```

```
1 ggplot(diamonds, aes(x = price,
2   geom_freqpoly(aes(color = cut
```

To tell a story and evoke emotions



Source: Ed Hawkins, Climate Stripes

Why R?

- Open-source and free
- Highly customizable
- Script-based and reproducible
- Data analysis and visualization in one language
- Large open-source community and ecosystem

Art by Allison Horst

☕ Take a Break

~ This is the end of part 1 ~

05:00

Outline for today

- Who?
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- Why?
- **Introduction to {ggplot2}**

Welcome to {ggplot2}

- Based on Grammar of Graphics (Wilkinson 2005)
- Hadley Wickham developed ggplot2 based on Wilkinson's grammar of graphics in 2009
- Allow you to compose graphs by combining independent components
- Designed to work iteratively:
  - Start with a simple layer that shows the raw data
  - Add layers of annotations and summary statistics
  - Each layer can be customized independently

Art by Allison Horst

What is the grammar of graphics?

> "A graphic maps the data to the aesthetic attribuets (color, shape, size) of geometric objects (points, lines, bars). The plot may also include statistical transformations of the data and information about the plot's coordinate system. Facetting can be used to plot for different subsets of the data. The combination of these independent components are what make up a graphic."

Wilkinson (2005)

{ggplot2} graphic layers

First these:

- **data**: in tidy format (Lab 1)
- **mapping**: how variables are mapped to aesthetic attributes
- **geom**: the geometric object used to display the data

Then these:

- **stat**: statistical transformations, e.g. binning and counting, fitting a linear model
- **scale**: maps values in data space to values in the aesthetics space, also draw the legend
- **coord**: normally the Cartesian coordinate system, but can be polar, map, etc.
- **facet**: display subsets of data as small multiples
- **theme**: non-data ink, e.g. background color, grid lines, font size, etc.

Airquality dataset

The `airquality` dataset contains daily air quality measurements in New York, May to September 1973. The data frame has 153 observations and 6 variables:

- **Ozone**: Ozone in parts per billion (ppb)
- **Solar.R**: Solar radiation in langleys
- **Wind**: Average wind speed in miles per hour (mph)
- **Temp**: Maximum daily temperature in degrees Fahrenheit (F)
- **Month**: Month of the year (1-12)
- **Day**: Day of the month (1-31)

```r
library(tidyverse)
data(airquality)
glimpse(airquality)
```

```
Rows: 153
Columns: 6
$ Ozone   <int> 41, 36, 12, 18, NA, 28, 23, 19, 8, NA,
7, 16, 11, 14, 18, 14, …
$ Solar.R <int> 190, 118, 149, 313, NA, NA, 299, 99,
19, 194, NA, 256, 290, 27…
$ Wind    <dbl> 7.4, 8.0, 12.6, 11.5, 14.3, 14.9, 8.6,
13.8, 20.1, 8.6, 6.9, 9…
$ Temp    <int> 67, 72, 74, 62, 56, 66, 65, 59, 61, 69,
74, 69, 66, 68, 58, 64…
$ Month   <int> 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5,
5, 5, 5, 5, 5, 5, 5,…
$ Day     <int> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
13, 14, 15, 16, 17, 18,…
```


Step 0: Initialize a plot object

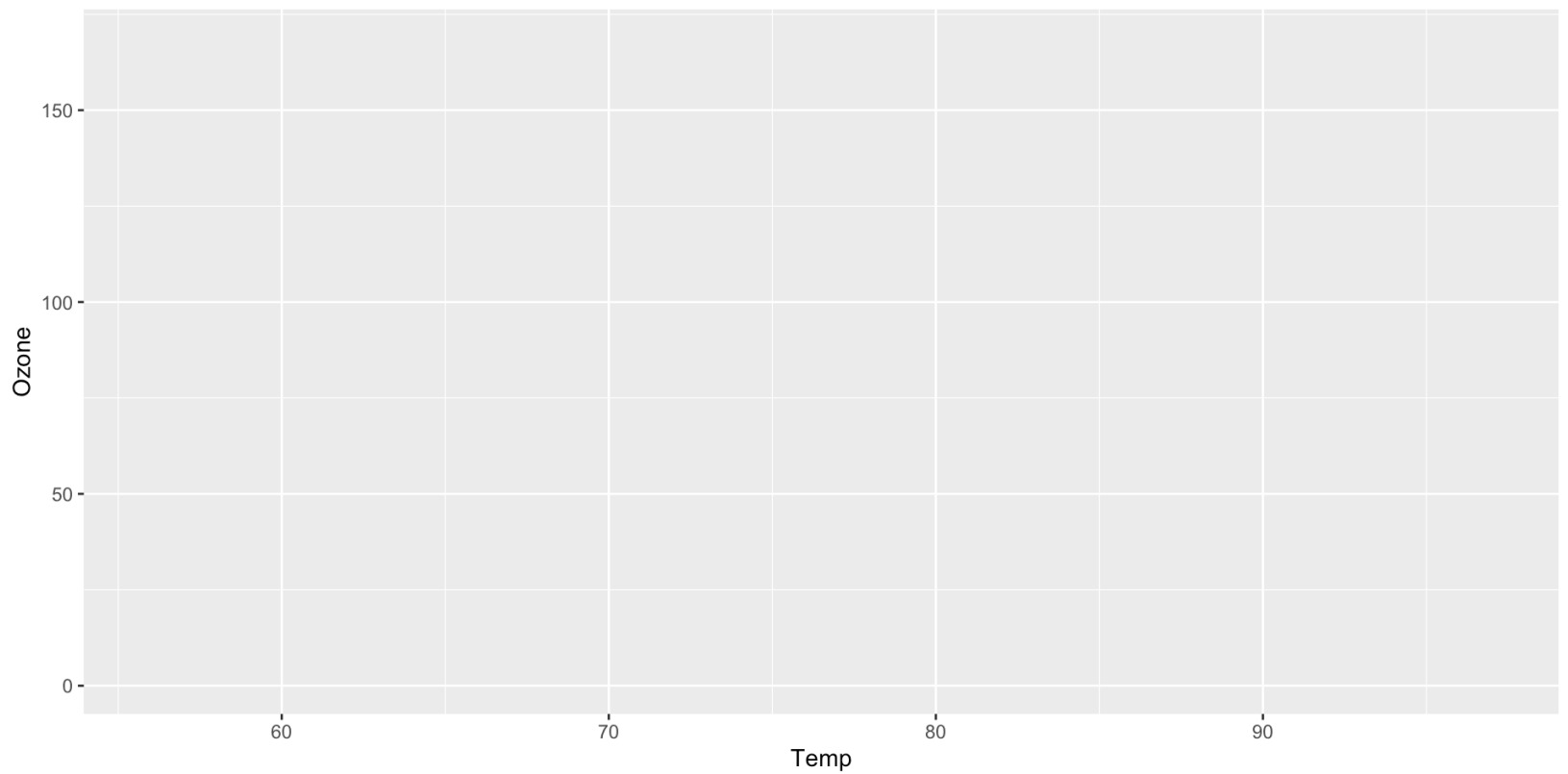
Initialize the plot using `ggplot()`. It is empty because we haven't told ggplot how to map the data to the plot yet.

```
1 library(tidyverse)
2 data(airquality)
3 ggplot(data = airquality)
```

Step 1: Map the variables

The `mapping` argument is used to specify how variables in the data are mapped to aesthetic attributes of the plot. The `aes()` function is used to define the mapping.

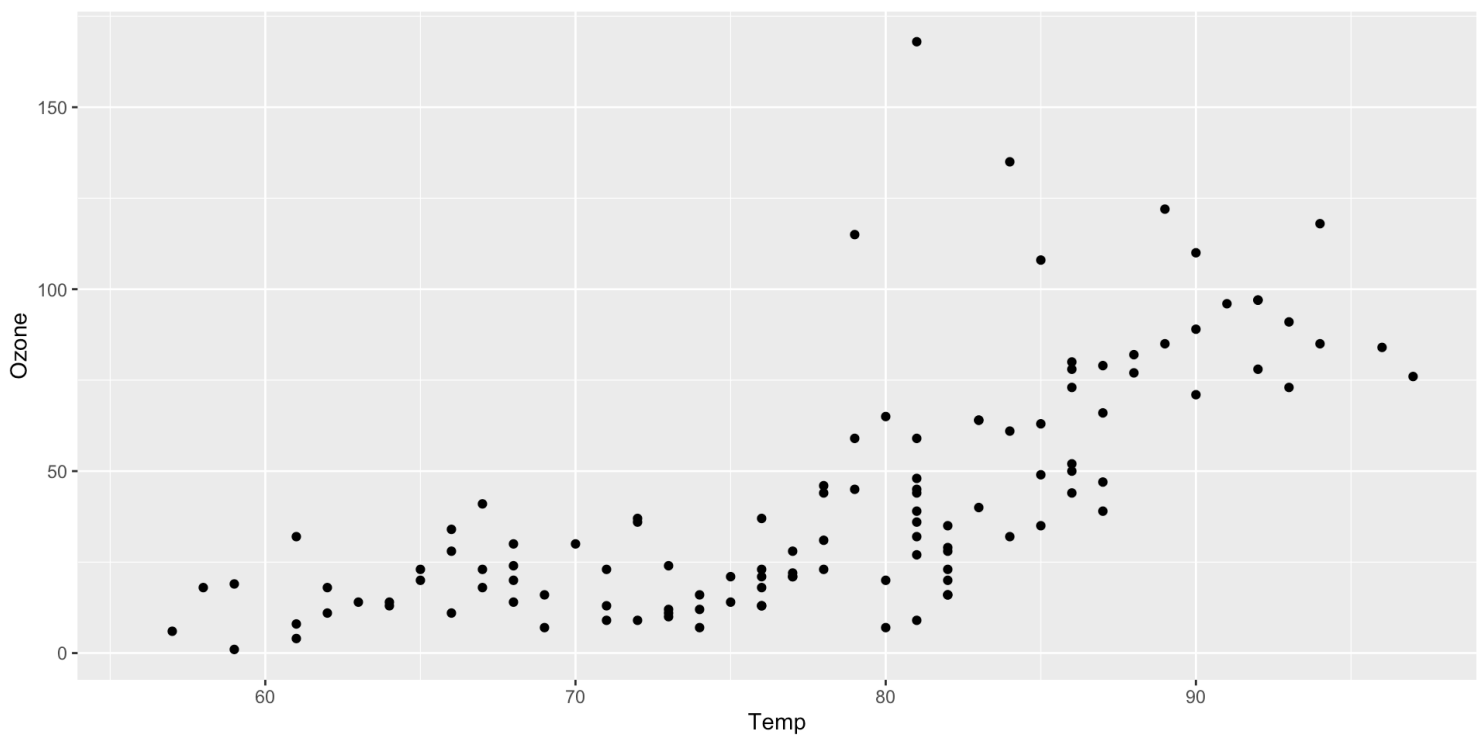
```
1 library(tidyverse)
2 data(airquality)
3 ggplot(data = airquality,
4        mapping = aes(x = Temp, y = Ozone)) # x-axis and y-axis
```



Step 2: Add points (`geom_point`)

Next, we add a geometric object (**geom**) that represents the data. In this case, we use `geom_point()` to add points to the plot. There are many more geoms (`geom_*()`) built into `{ggplot2}` and extension packages.

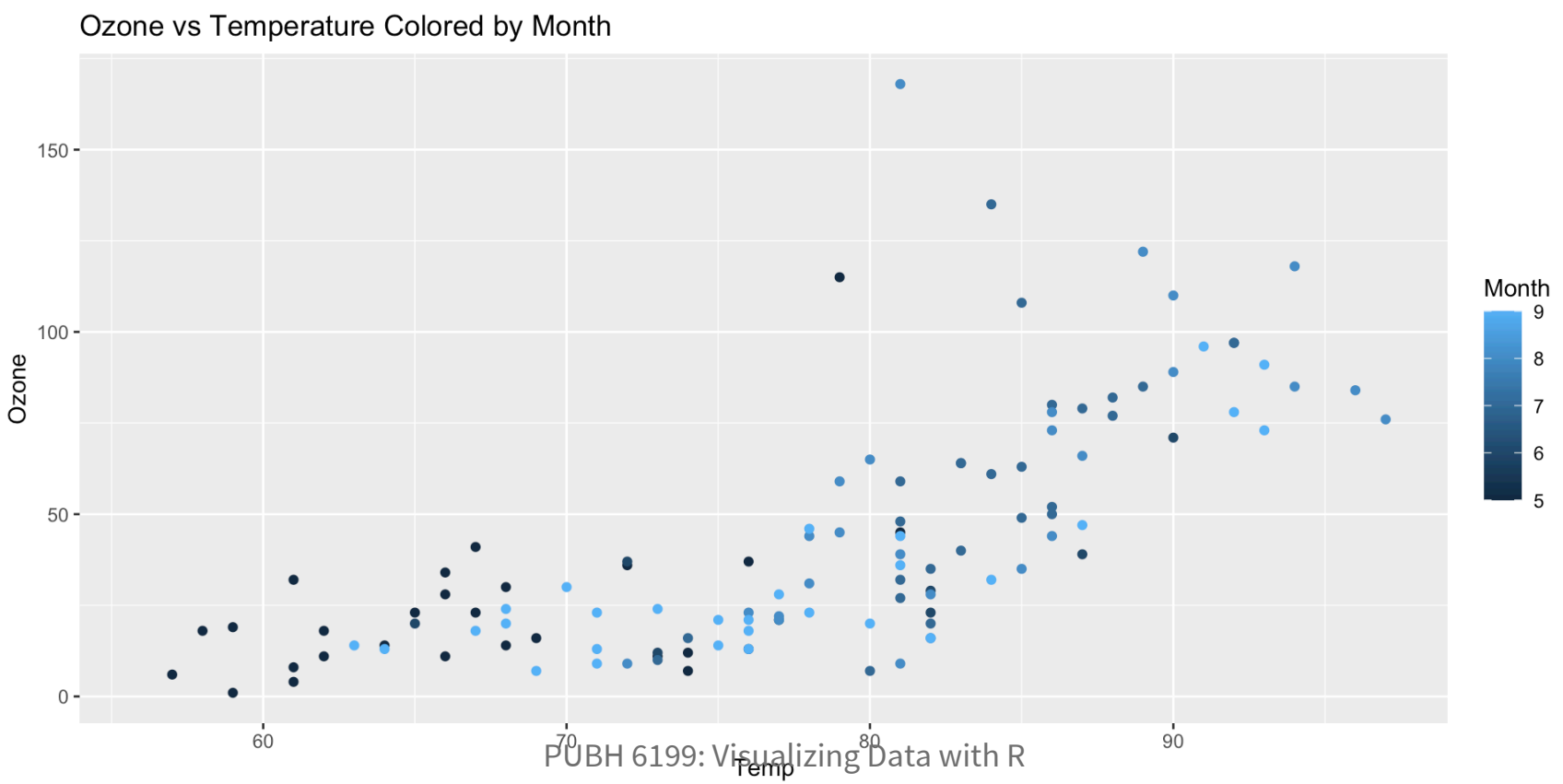
```
1 library(tidyverse)
2 data(airquality)
3 ggplot(data = airquality, mapping = aes(x = Temp, y = Ozone)) + # x-axis and y-axis
4   geom_point() # add points
```



Step 3: Color aesthetic (Month)

If we like to add more information to the plot, we can use the `color` aesthetic to map another variable to the color of the points. In this case, we will use `Month` as the color aesthetic.

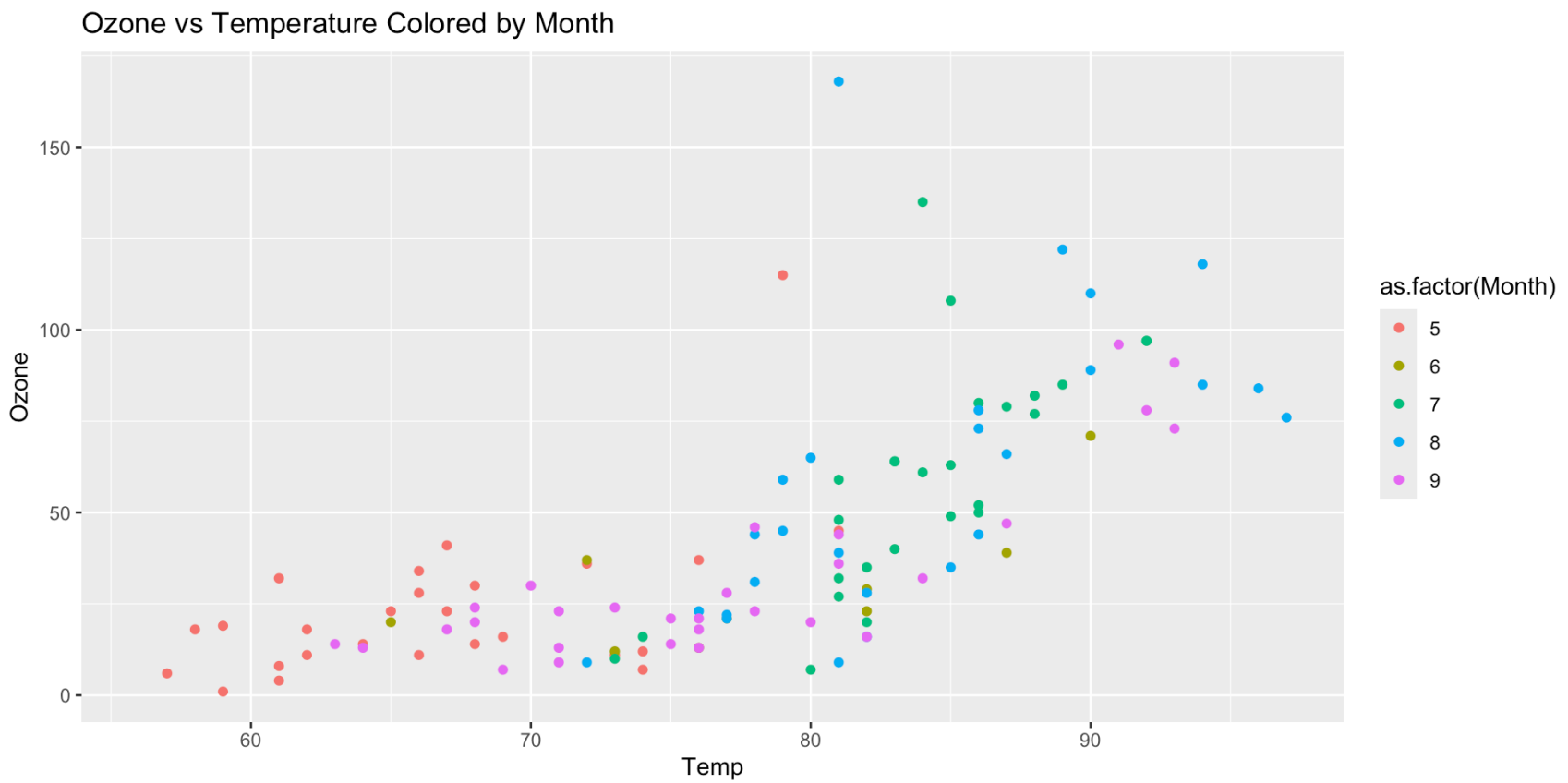
```
1 ggplot(airquality, aes(x = Temp, y = Ozone, color = Month)) +
2   geom_point() +
3   labs(title = "Ozone vs Temperature Colored by Month")
```



Step 3: Color aesthetic (Month)

Instead of treating `Month` as a continuous variable, maybe we want to treat `Month` like a categorical variable.

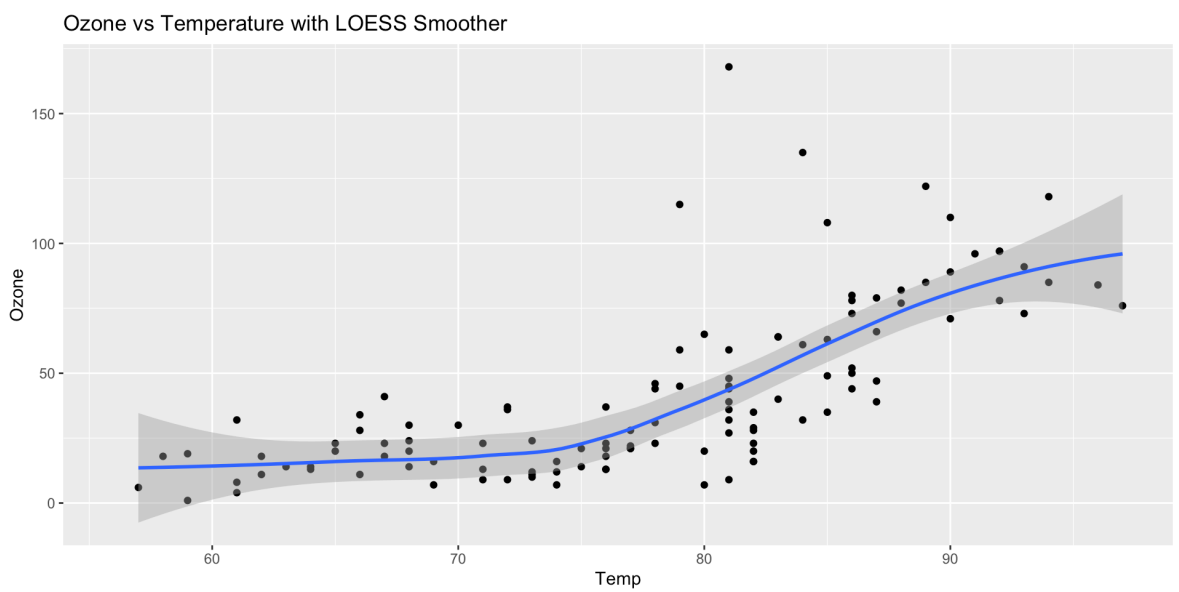
```
1 ggplot(airquality, aes(x = Temp, y = Ozone, color = as.factor(Month))) +
2   geom_point() +
3   labs(title = "Ozone vs Temperature Colored by Month")
```



Step 4: Add layers (smoother lines with `geom_smooth`)

We can add a smoother line to the plot using `geom_smooth()`. The default method is linear regression, but we can also use other methods like LOESS (locally weighted scatterplot smoothing).

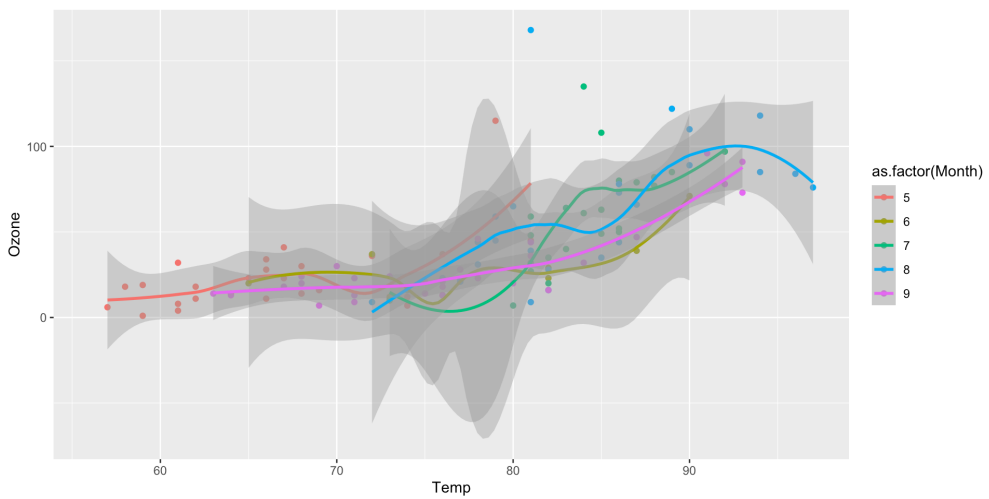
```
ggplot(airquality, aes(x = Temp, y = Ozone)) +
  geom_point() +
  geom_smooth(method = "loess") +
  labs(title = "Ozone vs Temperature with LOESS Smoother")
```



Global mapping v.s. Local mapping

Global mapping are passed down to each subsequent layer

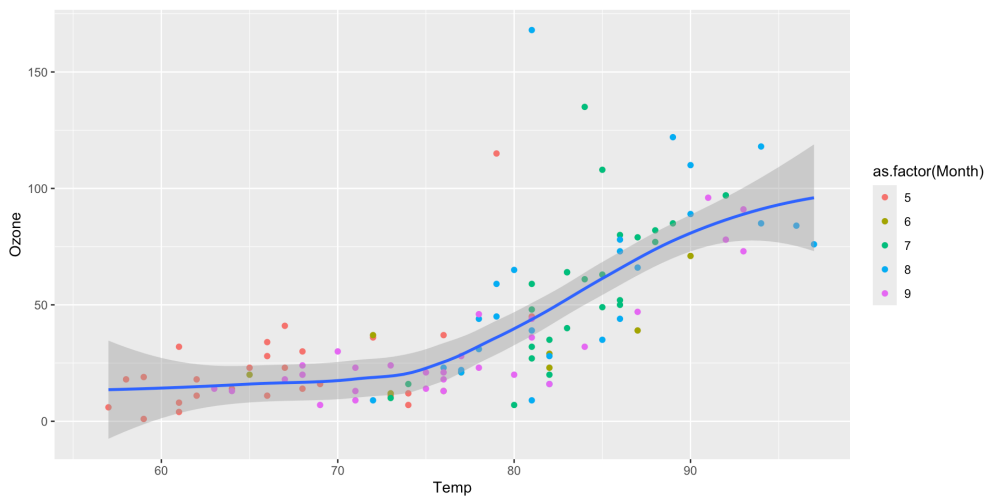
```
1 ggplot(airquality, aes(x = Temp, y = Ozone, color =
2   geom_point() +
3   geom_smooth(method = "loess")
```



`color = as.factor(Month)` is passed to both `geom_point()` and `geom_smooth()`, so the points and the line are colored by month.

Local mapping are only used in that layer and don't affect other layers

```
1 ggplot(airquality, aes(x = Temp, y = Ozone)) +
2   geom_point(aes(color = as.factor(Month))) +
3   geom_smooth(method = "loess")
```

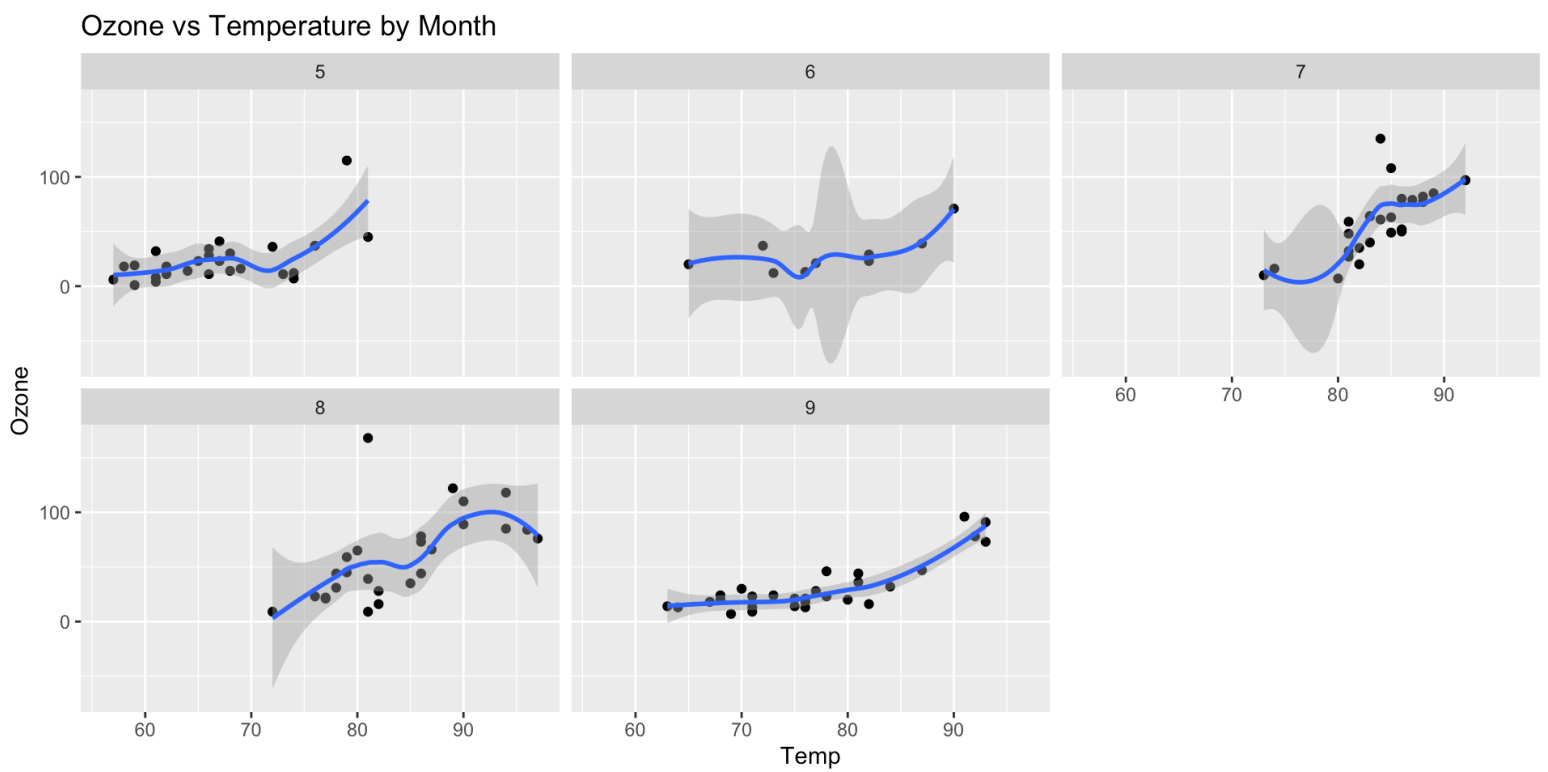


`color = as.factor(Month)` is only passed to `geom_point()`, so the points are colored by month, but the line is not colored by month.

Step 5: Facet by month (`facet_wrap`)

We can use `facet_wrap()` to create small multiples of the plot, one for each month. This allows us to see how the relationship between temperature and ozone varies by month.

```
ggplot(airquality, aes(x = Temp, y = Ozone)) +
  geom_point() +
  facet_wrap(~ Month) +
  geom_smooth(method = "loess") +
  labs(title = "Ozone vs Temperature by Month")
```

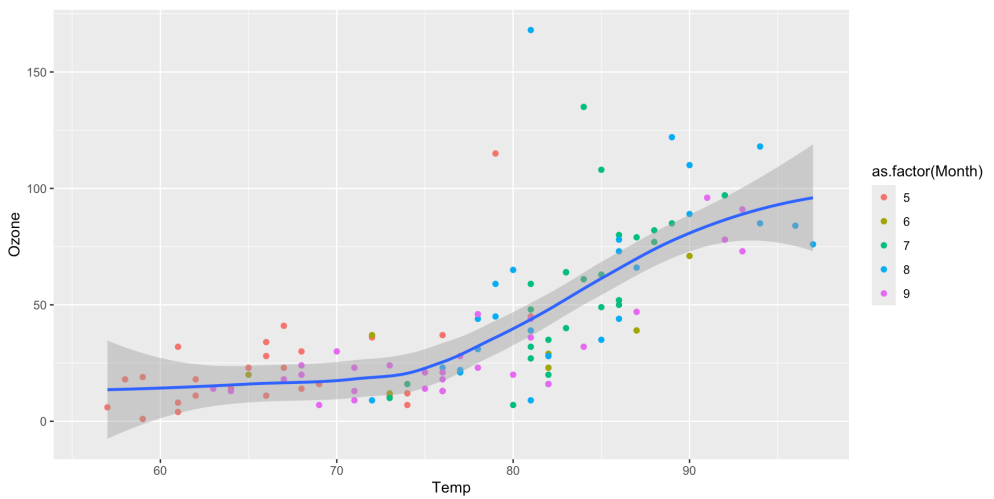


Step 6: Customize the appearance

{ggplot2} has a number of built-in themes, which control all non-data display.

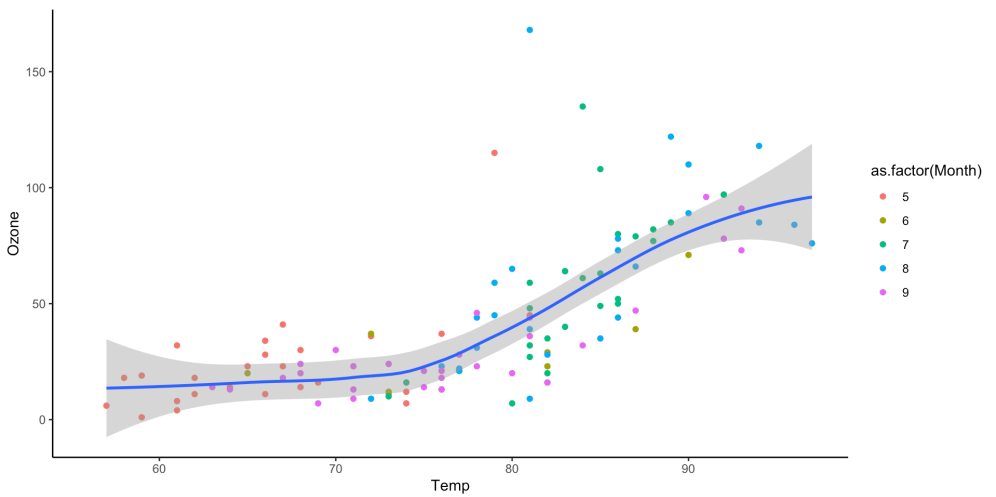
Never use the default theme

```
1 ggplot(airquality, aes(x = Temp, y = Ozone)) +
2   geom_point(aes(color = as.factor(Month))) +
3   geom_smooth(method = "loess")
```



`theme_classic()` is a good starting point

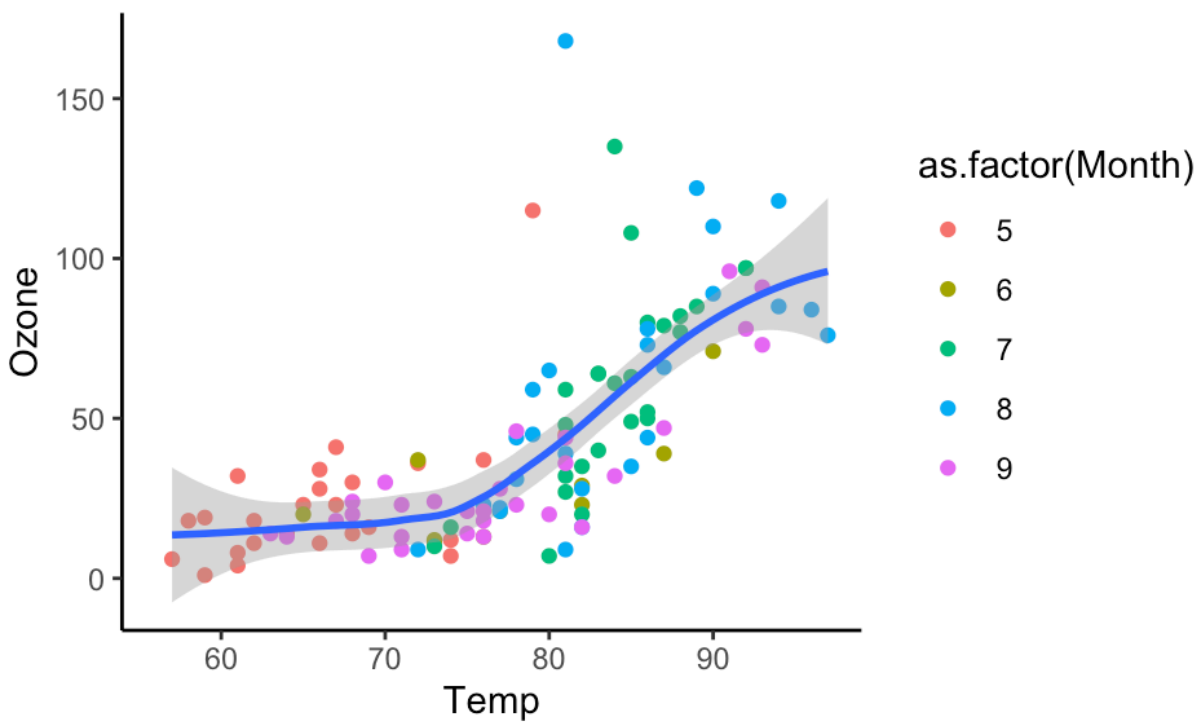
```
1 ggplot(airquality, aes(x = Temp, y = Ozone)) +
2   geom_point(aes(color = as.factor(Month))) +
3   geom_smooth(method = "loess") +
4   theme_classic()
```



Step 6: Customize the appearance

Almost always the default font size in `ggplot2` are too small. This is because the font size is set to 11 by default, but the size of the figure is set to 10 inches by 5 inches, so when you insert the figure to a Word or Powerpoint, it ends up being too small

```
ggplot(airquality, aes(x = Temp, y = Ozone)) +
  geom_point(aes(color = as.factor(Month))) +
  geom_smooth(method = "loess") +
  theme_classic(base_size = 11) # I set the output figure size to be 5 inches by 3 inches
```

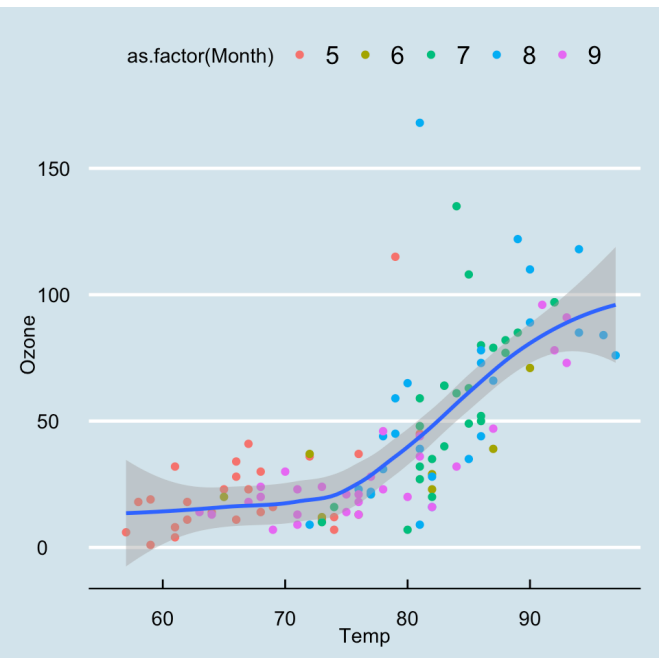


Step 6: Customize the appearance

You can explore other pre-built themes in the {ggthemes}.

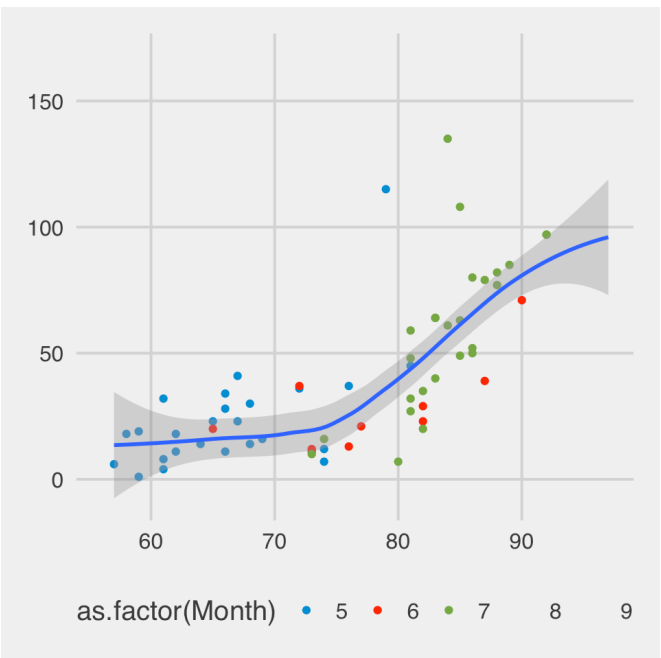
Theme economist

```
library(ggthemes)
ggplot(airquality, aes(x = Temp,
  geom_point(aes(color = as.fact
  geom_smooth(method = "loess")
  theme_economist()
```



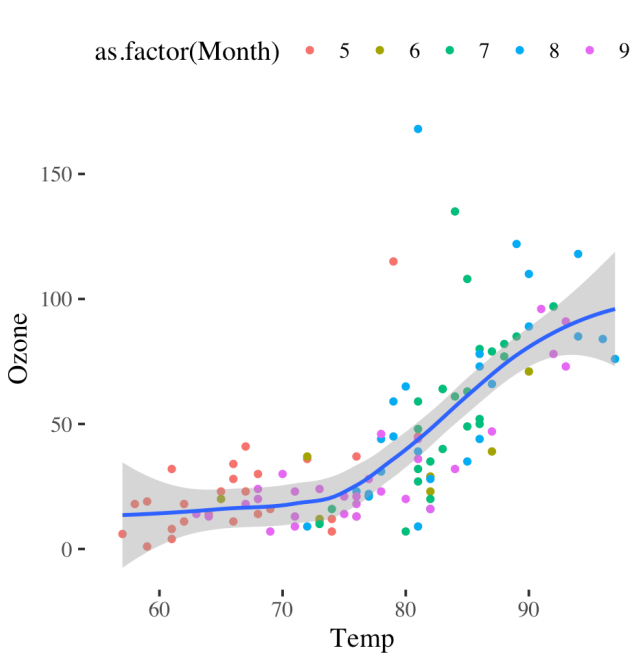
Theme 538

```
ggplot(airquality, aes(x = Temp,
  geom_point(aes(color = as.fact
  geom_smooth(method = "loess")
  scale_color_fivethirtyeight()
  theme_fivethirtyeight(base_siz
```

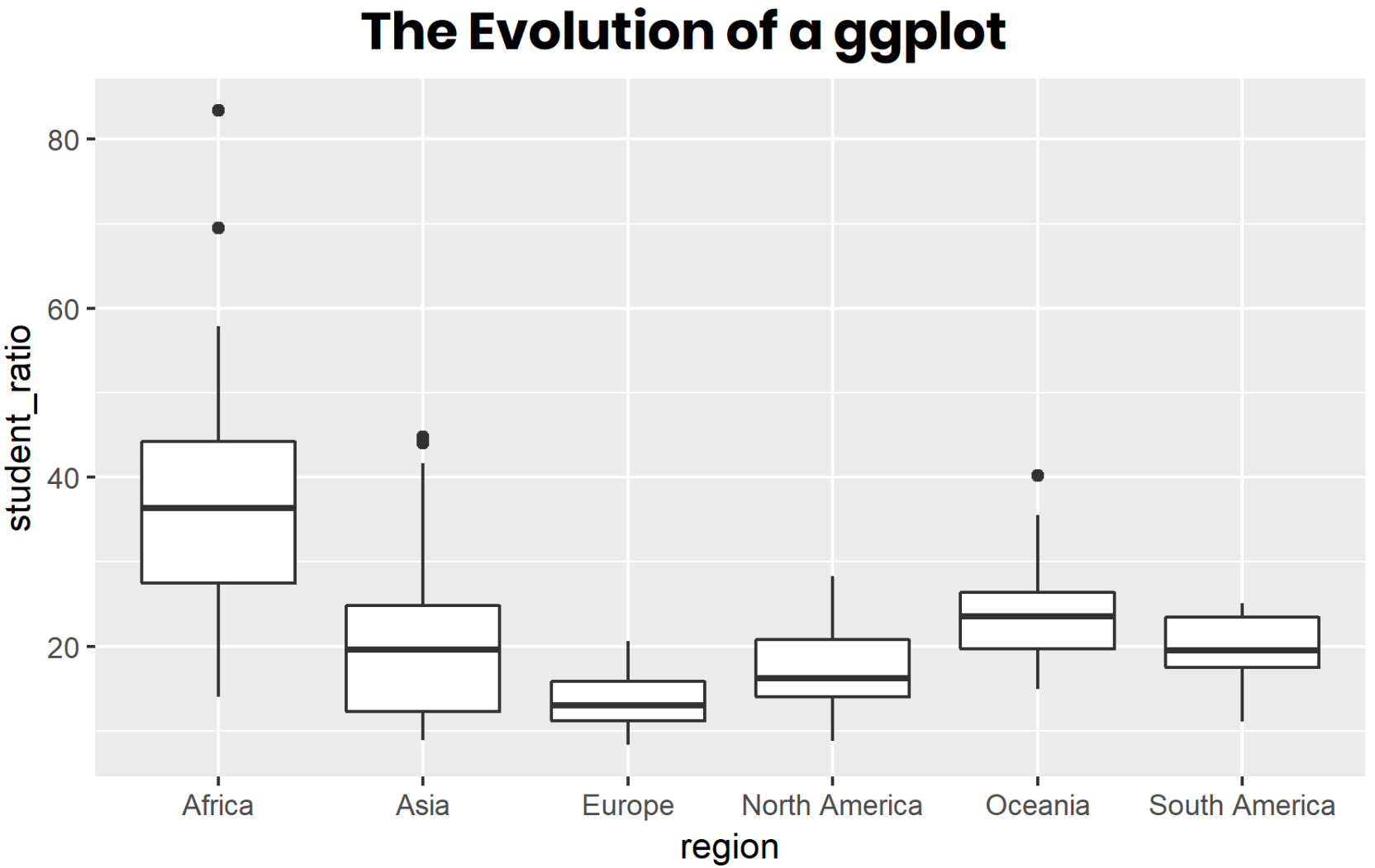


Theme Tufte

```
ggplot(airquality, aes(x = Temp,
  geom_point(aes(color = as.fact
  geom_smooth(method = "loess")
  theme_tufte(base_size = 15) +
  theme(legend.position = "top")
```



Building a data viz is an interative process!



Make your own ggplot evolution using the `{camcorder}` package

End-of-Class Survey

Fill out the end-of-class survey

~ This is the end of Lecture 1 ~

10:00