STAT 436 Exercises

Contents

1 Design Principles

1. [Formulating Questions] Pick a dataset from TidyTuesday, Data Is Plural, Kaggle Datasets, Google Dataset Search, AWS Data Registry, Wisconsin DNR, IPUMS, 538, Buzzfeed, Propublica, LILA BC, . . . , or your own personal studies that you would like to visualize this semester.

    a. What makes you interested in this dataset? What questions does it help to answer?
    b. Using any tools of your choice, make one example visualization from your dataset. What was your thought process behind the design of this visualization? This will not be evaluated except for effort – the purpose of the problem is to create a record your data visualization skills at the start of the course. Submit both your visualization and code used to create it.

2. [Data Types] For the following parts, specify whether the data field is Nominal, Ordinal, or Quantitative.

    a. `BuildingArea` in the Melbourne Homes dataset
    b. `Sport` in the 2012 Olympics dataset
    c. `age_group` in the Language Learning dataset

3. [Critique - Infographic] Figure 1 below is from the Information is Beautiful Infographic "Food Waste is a Big Climate Problem We Can Actually Solve." It shows the breakdown of sources of food waste in the UK. Give an example of a question that this visualization helps answer. How easy / difficult is it to answer based on the current design? What is one design choice that you like? What is one thing you would do differently if you were redesigning it?

4. [Critique - Science Paper] Figure 2 below is from the scientific article *Both consumptive and non-consumptive effects of predators impact mosquito populations and have implications for disease transmission* by Russell et al. (2022). It describes the predators of mosquitos at different points in their life cycles. Give an example of a question that this visualization helps answer. How easy / difficult is it to answer based on the current design? What is one design choice that you like? What is one thing you would do differently if you were redesigning it?

Figure 1: Sources of food waste, from Information is Beautiful infographic.

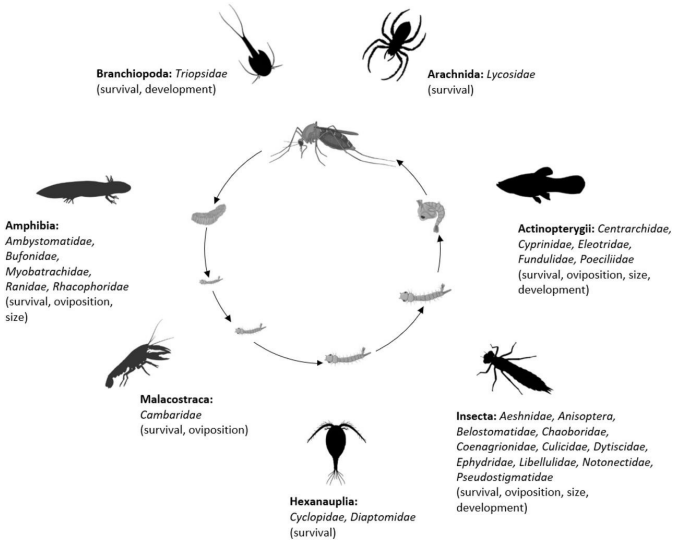


Figure 2: Animals that eat mosquitos, depending on the age of the mosquito, from Russell et al. (2022).

5. [Critique - Science Paper] Figure 3 below is from the scientific article *Genetic basis and dual adaptive role of floral pigmentation in sunflowers* by Todesco et al. (2022). While all sunflower petals look the same to us (they look yellow), they actually vary quite a bit in how they reflect ultraviolet light, which is visible to pollinators. The figure studies the variation in this ultraviolet proportion (LUVp) across populations of sunflowers. Give an example of a question that this visualization helps answer. How easy / difficult is it to answer based on the current design? What is one design choice that you like? What is one thing you would do differently if you were redesigning it?

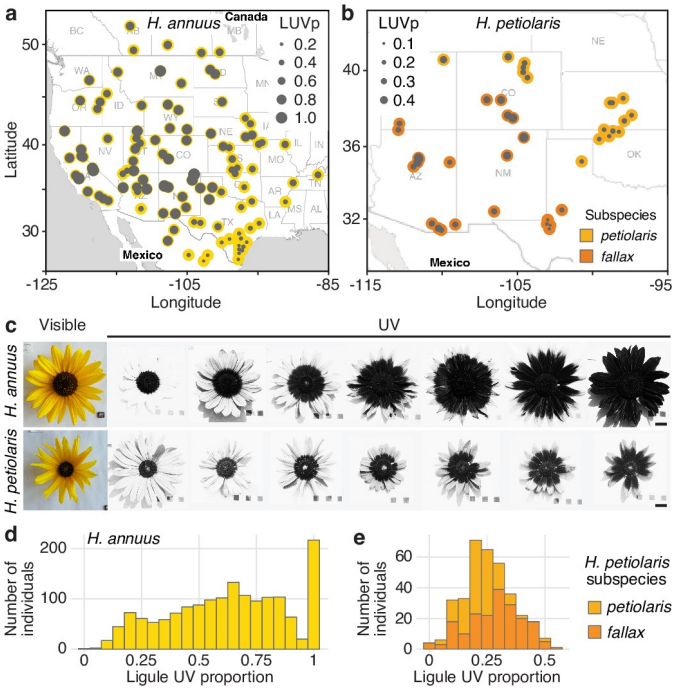


Figure 3: Variation in amount of ultraviolet proportion of sunflower petals, from Todesco et al. (2022).

6. [Critique - Personal Visualization] In this exercise, we will critically review the design for one of our own past visualizations. First, go through each part verbally with your partner, then summarize your discussion for each part in a short paragraph. Be respectful and make sure that all your comments are constructive.

    a. Find a partner for this exercise. Share an example of one visualization you have made before, either from a previous course or from an earlier lecture. Summarize the purpose of your visualizations.

    b. Critique one another's attention-to-detail. Is the plot legible – are all the graphical marks and text annotation easy to read? Are the colors easy to compare? Are there superfluous marks that could be removed to concentrate more of the reader's attention on the data?

    c. Critique's one another's designs. How does the choice of visual encodings prioritize some comparisons over others? How well does that prioritization match the goals of the visualization?

7. [`ggplot2` reflection] Compare and contrast the `ggplot2` package with an alternative interface for constructing visualizations with which you have past experience (e.g., base R's `plot`, the `lattice` package, `matplotlib` in python, Tableau, or Excel). What characteristics are common between the two interfaces, and what is unique to each? In which situations does it make more sense to use one approach vs. the other?

8. [Beauty and functionality] There are a surprising number of controversies in data visualization, but few can get as heated as the beautify vs. functionality debate. In each pair of articles below, we have one representative from each school of thinking.

- The Creative Pace of the 20th Century's Greatest Authors, Visualized vs. Redesigning Visualizations
- Poor op/ed data graphic in New York Times vs. The Power of Visualization's "Aha!" Moments

Respond to the positions taken by one of these pairs of articles (you are free to choose). Which of the arguments did you find most / least convincing? How might you evaluate the beauty or functionality of your own visualizations?

9. [Reading Response] This problem asks you to reflect on one of the readings from this week. Prepare a brief (1 paragraph) response. For example, you may discuss any of the following points,
   a. Are there points from the reading that you strongly agree or disagree with?
   b. Are there lessons from the reading that you think you might incorporate into your future projects or plans?
   c. How would you explain the main ideas of the reading to a friend who is not technically trained in visualization?
10. [Skimming a Paper] This problem asks you to analyze a paper (specified in lecture) from an area of active research in the visualization literature.
    a. Skim the abstract of the paper. What is the critical need that the paper seeks to address? What do they do to help address it (gather new data, propose new methods, etc.)?
    b. Review the figures from the paper. Pick two that you think are especially important, and summarize their takeaways.
    c. What is one way in which either the message or techniques of the paper might be releavnt to your own intellectual interests?
11. [Visual Redesign] In this exercise, you will find a visualization you have made in the past and redesign it using the skills you have learned in this course.
    a. Identify one of your past visualizations for which you still have data. Include a screenshot of this past visualization.
    b. Comment on the main takeaways from the visualization and the graphical relationships that lead to that conclusion. Is this takeaway consistent with the intended message? Are there important comparisons that you would like to highlight, but which are harder to make in the current design?
    c. Comment on the legibility of the original visualization. Are there aspects of the visualization that are cluttered or difficult to read?
    d. Propose and implement an alternative design. What visual tasks do you prioritize in the new design? Did you have to make any trade-offs? Did you make any changes specifically to improve legibility.
12. [Concept Map] Prepare a concept map to summarize the last week of reading material. An effective submission will include a thorough coverage of both abstract concepts and practical examples, summarized concisely into short phrases. It will also include well-justified links between nodes, with text explanations for edges whose interpretation might not be obvious at first.
13. [Mini-presentation] Prepare a short presentation to summarize the last week of reading material. Make sure to include coverage of both important concepts and practical implementation details. Prepare either a short set of slides or an original code notebook. When you present your material, make sure that all team members have an opportunity to speak.
14. [ggplot2 commands] Circle whether the following statements about ggplot2 are TRUE or FALSE.
    a. TRUE FALSE To use a custom color palette in a ggplot2 scatterplot, we can add a `scale_color_manual` layer.
    b. TRUE FALSE A `geom_boxplot()` layer can be used to simultaneously visualize a continuous variable against many levels of a categorical variable.
    c. TRUE FALSE A plot like the one shown in Figure 1 can be made using a `geom_area` layer.

d. TRUE FALSE The `aes()` function maps values stored in the columns of a dataset into properties of graphical marks.

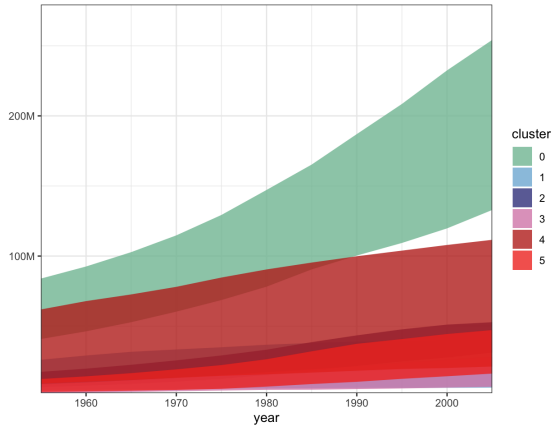


Figure 4: Plot for Q2c.

1. [Interactivity Discussion] This problem asks you to comment on variations of the Names App that we used to introduce Shiny.

   a. What is a reactive graph? What types of nodes can it contain and why is it relevant to interactive visualization?

   b. The code below is supposed to print "Hello {name}!" when the user enters their name into a textbox. It may or may not have a bug. If it has a bug, circle the line(s) and explain the issue. Otherwise, write "No Bug."

```
ui <- fluidPage(
  textInput("name", "Enter your name"),
  textOutput("printed_name")
)
server <- function(input, output) {
  input$name <- paste0("Hello ", input$name, "!")
  output$printed_name <- renderText({
    input$name
  })
}
```

   c. The code below is supposed to update a counter each time the user clicks on a button. It may or may not have a bug. If it has a bug, explain the issue. Otherwise write, "No Bug."

```
ui <- fluidPage(
  actionButton("increment", "Increment Counter"),
  verbatimTextOutput("counter_text")
)

server <- function(input, output) {
  counter <- reactiveVal(0)
  observe({
    counter <- counter + 1
  })
  output$counter_text <- renderPrint(counter)
```

```
}
```

2. [New Data Application] Create a version of a visualization included in this week's readings, lecture notes, or in-class exercises, but applied to new dataset of your choice.

    a. Provide a reference to the visualization that you will be adapting for your application.
    b. Identify a dataset that you will use. What makes this dataset interesting, and how was it gathered / generated?
    c. Generate a version of the visualization from (a) to the dataset from (b). Interpret the result in context.

3. [Transition Taxonomy] In "Animated Transitions in Statistical Graphics," Heer and Robertson introduce a taxonomy of visualizations transitions. These include,

    - View Transformation: We can move the "camera view" associated with a fixed visualization. This includes panning and zooming, for example.
    - Filtering: These transitions remove elements based on a user selection. For example, we may smoothly remove points in a scatterplot based on a dropdown menu selection.
    - Substrate Transformation: This changes the background context on which points lie. For example, we may choose to rescale the axis in a scatterplot to show a larger range.
    - Ordering: These transitions change the ordering of an ordinal variable. For example, we may transition between sorting rows of a heatmap alphabetically vs. by their row average.
    - Timestep: These transitions smoothly vary one plot to the corresponding plot at a different timestep. For example, we might show "slide" a time series to the left to introduce data for the most recent year.
    - Visualization Change: We may change the visual encoding used for a fixed dataset. For example, we may smoothly transition from a bar chart to a pie chart.
    - Data Scheme Change: This changes the features that are displayed. For example, we may smoothly turn a 1D point plot into a 2D scatterplot by introducing a new variable. In this problem, we will explore how these transitions arise in practice and explore how they may be implemented.

    a. Pick any visualization from the New York Times Upshot, Washington Post Visual Stories, the BBC Interactives and Graphics, or the Guardian Interactives pages. Describe two transitions that it implements. Of the 7 transition types given above, which is each one most similar to? Explain your choice.
    b. For any transition (which may or may not be one of those you chose in (a)), identify the types of graphical marks used to represent the data. How would you create this type of mark in SVG?
    c. To achieve the transition effect, how do you expect that the SVG elements would be modified / added / removed? Specifically, if elements are modified, what SVG `attrs` would be changed, and if elements are added or removed, how would the enter-exit-update pattern apply? You do not need to look at the code implementing the actual visualization, but you should give a plausible description of how the transition could be implemented in D3.

4. [Network Visualization Breakdown] In this problem, we will analyze a visualization hosted on either visualcomplexity or FlowingData using the language we've developed in class. Briefly respond to each of the queries below.

    a. What visual encodings does your selected example use (e.g., node-link vs. adjacency)? In its layout, does it use any additional structure (e.g., are any constraints present)?
    b. What types of queries does this visualization seemed designed to support? If the design includes any interactive elements, classify it into either view, encoding, or data interactivity.
    c. Propose one alternative layout or form of interactivity that could be used for this dataset. What are some of the trade-offs involved with using the original vs. your proposed layout?

5. [Dissecting a visualization] Pick two static views of visualizations from any of the following sites: 1, 2, 3. For each view, answer the questions below,

    a. What graphical marks are used in the display? What data attribute does each mark encode?

b. Are there visual queries that their design makes especially straightforward to answer? Are there queries that are more difficult relative to a simpler alternative?
c. Why do you think the authors chose the visual encodings that they did?

6. [Analyzing a Demo] Watch one of the following interactive demos, or choose a comparable one from your own visualization interests.

   a. Analyze the transitions or interactivity are shared in the demo. Specifically, list all transition or interactive elements of the visualization and summarize the designer's motivation for including them.
   b. For one of the transition or interactivity elements, imagine an alternative design that accomplishes a similar purpose. Compare and contrast your proposed implementation with that in the original display.

7. [Guided literature search] This exercise will help you search for references to support the literature review for your course project.

   a. Reflect on the problem your project is trying to solve. List 6 - 10 data visualization related keywords that should bring up literature relevant to that problem. These keywords can be related to the type of data you have or the visual tasks your work is supposed to support.

   b. Use these keywords to search for 10 - 15 papers relevant papers. You may find it useful to (i) search using Google Scholar, (ii) skim the bibliographies of the first few papers you find that seem relevant (especially if they are review papers), (iii) browse abstracts in major journals / conferences (like TVCG, PacificVis, IEEEVis, EuroVis or VAST, or (iv) go to the home pages of researchers chairing conference sessions related to your keywords.

   c. Skim the abstracts from the papers on your list. Based on your quick reading, group your identified papers into overall themes. Prepare a short description of each theme. How are the groups of papers similar / different from one another?

8. [The top ten worst graphs]. Prof. Broman has a delightful list of rogue data Visualizations: https://www.biostat.wisc.edu/~kbroman/topten_worstgraphs/

   a. Review 3 figures from the list *without* reading Prof. Broman's discussion of them. Summarize the essential issues with the underlying visualization.

   b. Again, without reading the discussion, propose an alternative way to communicate the main message of the graphic.

   c. Read the discussion. How does it complement your analysis? What shared data visualization principles are you drawing from?

   d. Bonus: Create your own list of top X worst data visualizations.

9. [Milestone Reflection] In this exercise, you will have a chance to reflect on your team's workflow for the upcoming project milestone. Please respond to the following prompts,

   a. How do you plan on organizing your team's writing and coding efforts? How can you ensure that relevant resources and preliminary progress can be easily reviewed?

   b. What do you anticipate will be the most significant challenge your team faces in preparing the project milestone? Which aspects of this challenge are within your team's control? How do you plan on overcoming (or sidestepping) this challenge?

   c. Do you have any questions for the teaching staff related to the upcoming project milestone?

10. [Brainstorming Exchange] This discussion shares an opportunity to describe technical challenges your team has encountered as well as brainstorm potential solutions.

    a. Describe the 1 - 2 most pressing technical challenges you encountered during your project's implementation (e.g., "Too many overlapping lines in a time series" or "Slow interactivity in

Shiny"). What is your ideal outcome and what is the gap with your current implementation? Provide concrete details.

b. Pair with another team and brainstorm solutions. Questions to consider are, Where might you find references from people who have encountered similar problems? Are there example visualizations from the course that might be a useful starting point? Are there ways to simplify the problem? Consider George Polya's advice: "If you cannot solve the proposed problem do not let this failure afflict you too much but try to find consolation with some easier success, try to solve first some related problem; then you may find courage to attack your original problem again."

c. Return to your original team and distill the most important takeaways. For a proposed approach, what would be the immediate next step? If you had 30 free minutes to work on it, how would you begin?

11. [Code Analysis] Pick one code example from this week's lecture notes. Provide a 3 - 4 sentence summary of the overall implementation strategy. Then, add comments every 10 - 15 lines describing what each section of code is doing. If there are parts that you do not understand, add a ??? next to it (we will review these in the next lecture).

2 Visualization with R

1. [Ikea Furniture] The dataset below shows prices of pieces of Ikea furniture. We will compare prices of different furniture categories and label the (relatively few) articles which cannot be bought online.

```
ikea <- read_csv("https://uwmadison.box.com/shared/static/iat31h1wjg7abhd2889cput7k264bdzd.csv")
```

   a. Make a plot that shows the relationship between the `category` of furniture and `price` (on a log-scale). Show each `item_id` as a point – do not aggregate to boxplots or ridgelines – but make sure to jitter and adjust the size the points to reduce the amount of overlap. *Hint: use the `geom_jitter` layer.*
   b. Modify the plot in (a) so that categories are sorted from those with highest to lowest average prices.
   c. Color points according to whether they can be purchased online. If they cannot be purchased online, add a text label giving the name of that item of furniture.

2. [City Temperatures] Let's create versions of Figure 2.3 and 2.4 from the reading this week. The command below reads in the data. We've filtered to a slightly different set of cities (Barrow is in Alaska, Honolulu is in Hawaii), but we should still be able to study changes in temperature over time.

```
temperature <- read_csv("https://go.wisc.edu/bo9m94")
```

   a. Make a version of Figure 2.3 using a line mark (`geom_line`). Make at least one customization of the theme to make the plot more similar to the version in Figure 2.3. *Hint: To group the lines by city, use the `group =` aesthetic mapping.*
   b. Using the `group_by` + `summarise` pattern, compute the mean temperature for each month in each city.
   c. Using the data generated in (b), Make a version of Figure 2.4 using a tile mark (`geom_tile`). Try either (i) adding the `scale_fill_viridis_c(option = "magma")` scale to match the color scheme from the reading or (ii) adding `coord_fixed()` to make sure the marks are squares, not rectangles.
   d. Compare and contrast the two displays. What types of comparisons are easier to make / what patterns are most readily visible using Figure 2.3 vs. Figure 2.4, and vice versa?

3. [Penguins] The data below measures properties of various Antarctic penguins.

```
penguins <- read_csv("https://uwmadison.box.com/shared/static/ijh7iipc9ect1jf0z8qa2n3j7dgem1gh.csv"
```

   Create a single plot that makes it easy to answer both of these questions, (i) How is bill length related to bill depth within and across species? (ii) On which islands are which species found?

Read about Simpson's paradox and summarize it in your own words. Then, explain how part (i) provides a real-world example of this paradox.

4. [Student Exercise Responses] The data here give an (anonymized) summary of responses to the [Formulating Questions] exercise, given by students in Stat 679 / 992 in Fall 2022. It describes the dataset topic, its source, the submitted visualization type, and the software used to create it.

    a. What types of topics seem to interest students in this class?
    b. What types of visualization techniques and software to students seem most familiar with? How should teaching be adapted to reflect this?
    c. When were submissions being made? Are the in-class exercises actually being solved in class?

5. [ggplot2 Flipbook] Gina Reynolds has prepared a ggplot2 flipbook that illustrates how ggplot2 figures are built up layer-by-layer, using the concept of "slow ggplotting." This helps to clarify what each step of a long ggplot2 command actually does, and it also lets you see how rough, initial plots can be gradually improved into refined, final versions.

    a. Pick one of the flipbook visualizations to study. Compare and contrast the initial vs. final versions of the plot. What do you think motivated these design choices?

    b. Did you learn any new ggplot2 tricks from reading the example? Explain.

    c. Create your own ggplot2 flipbook example. You may use a visualization of your own or any from the prior class notes.

6. [When2Meet Queries] In addition to being a scheduling tool, When2Meet polls provide a heatmap visualization of respondent availability. In this exercise, use the results from our office hour poll to evaluate the properties of this visualization.

    a. What are two concrete questions that the heatmap visualization is effective at answering? Why do you think this?
    b. What are two concrete questions that the heatmap visualization is *not* effective at answering? Why do you think this?
    c. Describe an alternative static or interactive visual design that is better suited to one of the questions you identified in (b).
    d. The dataset at this link include responses from our poll. Columns 1 - 35 represent students, and 1/0 denotes whether the student is or is not available. Implement a version of your proposed visual design from (c).

7. [London Olympics] The data at this link describes all participants in the London 2012 Olympics.

    a. Create a layered display that shows (i) the ages of athletes across sports and (ii) the average age within each sport.
    b. Sort the sports from lowest to highest average age.
    c. Develop one new question based on these data. What makes you interested in it? Provide a visualization that supports the comparisons needed to arrive at an answer.

```
olympics <- read_csv("https://uwmadison.box.com/shared/static/rzw8h2x6dp5693gdbpgxaf2koqijo12l.csv"
```

8. [Coffee Ratings] The data at this link comes from a 2018 report by the Coffee Quality Institute[1]. We'll be working with this lightly processed version of the data.

    a. Clean the `harvest_year` column. Specifically, if a year of the form 20XX appears in the name, keep it in a new column. For example, `23 July 2010` and `Abril - Julio /2011` should be converted into 2010 and 2011, respectively. Remove years that appear less than 10 times.
    b. Create a layered visualization of `aroma` against the year variable defined in (a).
    c. Develop a new question related to these data. Make sure that it refers to 3 or more variables. Provide a visualization that answers your question.

[1] Yes, it's a real thing.

d. Study a public analysis of any public dataset. For example, you can skim David Robinson's screencast or Benjamin Smith's blog about the coffee data discussed in this problem, or you could watch one of Julia Silge's screencast or read one of Danielle Navarro's blog posts on any data analysis. You can also choose your own public data analysis. Comment on either (i) one code technique you learned from the example or (ii) the visual design of one figures.

```
coffee_ratings <- read_csv("https://raw.githubusercontent.com/rfordatascience/tidytuesday/master/da
```

9. [Language Learning] This problem will look at a simplified version of the data from the study *A critical period for second language acquisition: Evidence from 2/3 million English speakers*, which measured the effect of the the age of initial language learning on performance in grammar quizzes. We have downloaded the data from the supplementary material and reduced it down to the average and standard deviations of test scores within (initial learning age, the `Eng_start` variable) $\times$ (current age-group, the `age_group` variable) combinations. We have kept a column `n` showing how many participants were used to compute the associated statistics. The resulting data are available here.

   a. Define two new fields, `low` and `high`, giving confidence intervals for the means in each row. That is, derive new variables according to $\hat{x} \pm 2 * \frac{1}{\sqrt{n}}\hat{\sigma}$.

   b. Design and implement a visualization that helps answer the following questions,

   - How does test score vary as a function of current age group?
   - How does test score vary as a function of initial learning age? Is this relationship the same across all age groups?
   - For which populations are we least certain about true language learning ability?

   c. Provide answers for each question from (b) within context.

10. [Homelessness] Take a static screenshot from any of the visualizations in this article, and deconstruct its associated visual encodings.

    a. What do you think was the underlying data behind the current view? What where the rows, and what were the columns?
    b. What were the data types of each of the columns?
    c. What encodings were used? How are properties of marks on the page derived from the underlying abstract data?
    d. Is multi-view composition being used? If so, how?

11. [Plant Growth Experiment] This problem will give you practice with tidying a dataset so that it can be easily visualized. The data describe the height of several plants measured every 7 days. The plants have been treated with different amounts of a growth stimulant. The first few rows are printed below – `height.x` denotes the height of the plant on day `x`.

```
plants <- read_csv("https://uwmadison.box.com/shared/static/qg9gwk2ldjdtcmmmiropcunf34ddonya.csv")
```

    a. Propose an alternative arrangement of rows and columns that conforms to the tidy data principle.

    b. Implement your proposed arrangement from part (a).

    c. Using the dataset from (b), design and implement a visualization showing the growth of the plants over time according to different treatments.

12. [California Wildfires] In this problem, we will interactively visualize a dataset giving statistics of recent California wildfires. The steps below guide you through the process of building this visualization.

    a. (Static) Plot the day of the year that each fire started against the county within which it was located. Use the size of the mark to encode the number of acres burned in each fire.

    b. (Interactive) Provide a way for the viewer to interactively highlight or reveal details about subsets of fires. For example, introduce a slider to interactively highlight selected years, a tooltip to

highlight the name of a fire, or a select to search for counties, or a slider to filter by fire size.

c. Introduce at least one other UI output. For example, print a table of the selected fires, interactively print summary statistics, or show a histogram of fire sizes. Sketch the reactivity graph associated with your application.

13. [California Wildfire Alternatives] Below, we provide three approaches to visualizing wildfire severity in the California fires dataset.

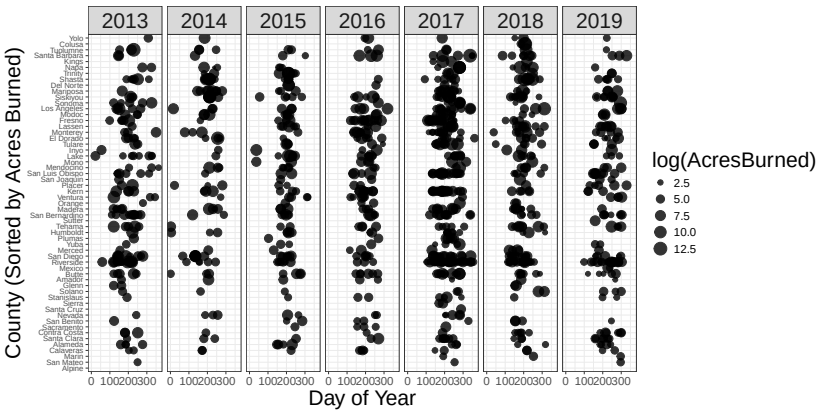
```
fires <- read_csv("https://uwmadison.box.com/shared/static/k5vvekf1bhh9e16qb9s66owygc70t7dm.csv") |
  select(Name, Counties, year, day_of_year, AcresBurned, MajorIncident)
head(fires, 3)
```

```
## # A tibble: 3 x 6
##   Name        Counties   year day_of_year AcresBurned MajorIncident
##   <chr>       <chr>     <dbl>       <dbl>       <dbl> <lgl>
## 1 Becks Fire  Lake       2013          22         296 FALSE
## 2 River Fire  Inyo       2013          55         406 TRUE
## 3 Jurupa Fire Riverside  2013          59         311 FALSE
```

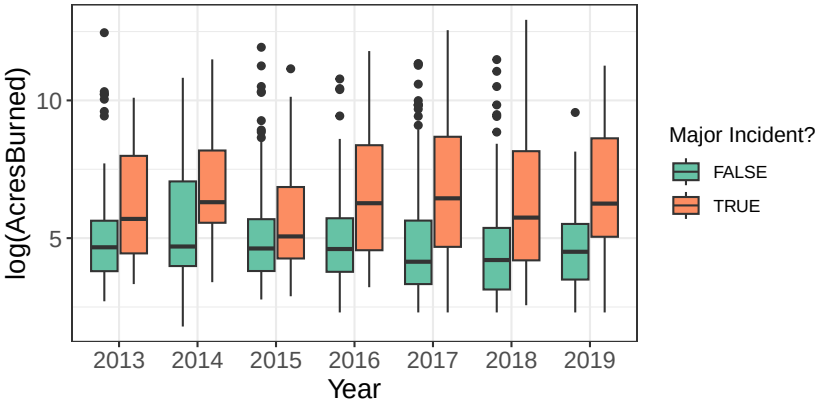
For each approach, describe,

- One type of visual comparison for which the visualization is well-suited.
- One type of visual comparison for which the visualization is poorly-suited. Make sure to explain your reasoning.

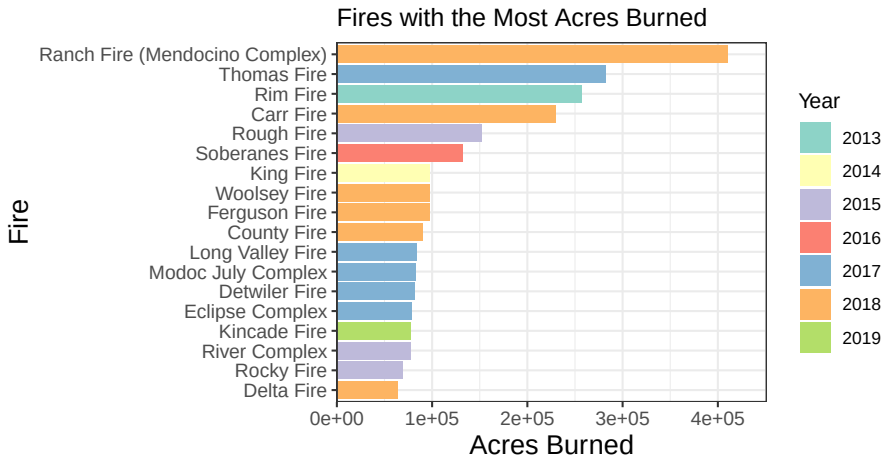
a. Approach 1



b. Approach 2



c. Approach 3



d. Provide the code that could be used to create one of the figures above. If the original data need to be transformed/reshaped, include code for this as well.

14. [NCAA Trends] This 538 article describes NCAA women's college basketball team performance over time. Each team was assigned a score representing how successfully it played during each year from 1982 to the present. This overall score is contained in the "points" column below.

```
ncaa <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/main/exercises/ps1/ncaa_filtered.cs
```

a. Derive new columns representing (i) the cumulative total number of points over time for each school (ii) the cumulative total number of points over time for a hypothetical team that earns 35 points a year.

b. Create a visualization that shows the running total number of points for each school over time. If you use faceting, ensure that facets are sorted in an informative way.

c. Design a visualization that that compares each school's performance with that of the hypothetical team that averages 35 points per year. See the figure below for an example approach. Explain the strengths and weaknesses of your design and comment on a finding from your visualization.

d. Note that the original data includes 250+ schools. Propose, but do not implement, a visualization of the full dataset that makes use of dynamic queries. What questions would the visualization answer? What would be the structure of interaction, and how would the display update when the user provides a cue?

15. [Pokemon] This problem gives practice in deriving new variables to improve a faceted plot. The data below give attack and defense statistics for Pokemon, along with their types. We will build a visualization to answer the question – how do the different types of Pokemon vary in their attack and defense potential?

```
pokemon <- read_csv("https://uwmadison.box.com/shared/static/hf5cmx3ew3ch0v6t0c2x56838er1lt2c.csv")
```

a. Derive a new column containing the attack-to-defense ratio, defined as $\frac{\text{Attack}}{\text{Defense}}$.

b. For each `type_1` group of Pokemon, compute the median attack-to-defense ratio.

c. Plot the attack vs. defense scores for each Pokemon, faceted by `type_1`. Use the result of (b) to ensure that the panels are sorted from types with highest to lowest attack-to-defense ratio.

d. Propose, but do not implement, a visualization of this dataset that makes use of dynamic queries. What questions would the visualization answer? What would be the structure of interaction, and how would the display update when the user provides a cue?

16. [Plot Annotation] This StorytellingWithData post highlights 88 community examples of plots that use annotation to call attention to specific aspects of the data. In this problem, we will discuss a few

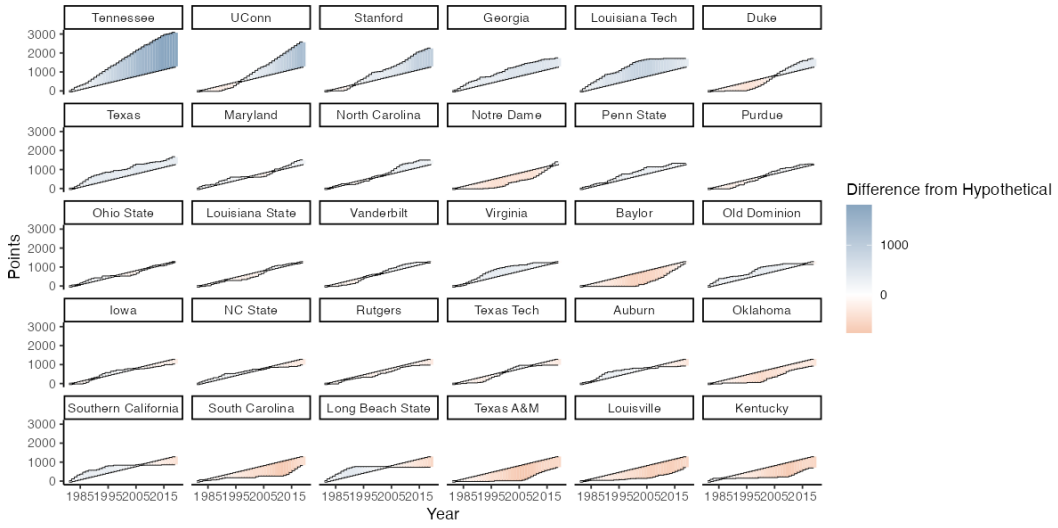


Figure 5: An example figure for [NCAA Trends] part (c).

examples.

a. Pick one of the examples and discuss its use of annotation. How does it change the way that you read the visualization, compared to if it had no annotation at all?

b. Are there other stylistic decisions the author made that stood out to you? What do you think was the intent of that decision? Do you think it was effective? Explain your reasoning.

c. Briefly review the ggtext package. Could it be used to recreate the annotation in your example? Why or why not?

17. [Melbourne Missingness] Consider the plot of missingness in the Melbourne Homes dataset in Figure 4. Select all the true conclusions.

- The `Landsize` variable is always missing.
- The variable with the highest number of missing values is `BuildingArea`.
- There are 560 rows where exactly one of `CouncilArea`, `YearBuilt`, or `BuildingArea` are missing.
- In more than 2/3 of the rows where `BuildingArea` is missing, `YearBuilt` is also missing.

18. Study the visualization at this link. Its design reflects which of the following visualization techniques? (select all that apply).

- Faceting
- Details-on-demand
- Ridgelines
- Overview + detail
- Tidy data

19. [Yu-Gi-Oh!] This question asks you to tidy a Yi-Gi-Oh! dataset.

a. Write code that provides more meaningful attribute and type columns. The result of your transformation should look like this.

b. Count the number of attribute and type combinations. Derive new features that count the fraction of each combination that are on the trading and official card game banlists (Banned trading and official cards have non-NA values in the tcg_ban and ocg_ban columns, respectively). The result of your transformation should look like this.

c. Reshape the dataset so that the trading and official card game proportions are listed in a single column and the Spell and Trap cards are at the top. The result of your transformation should

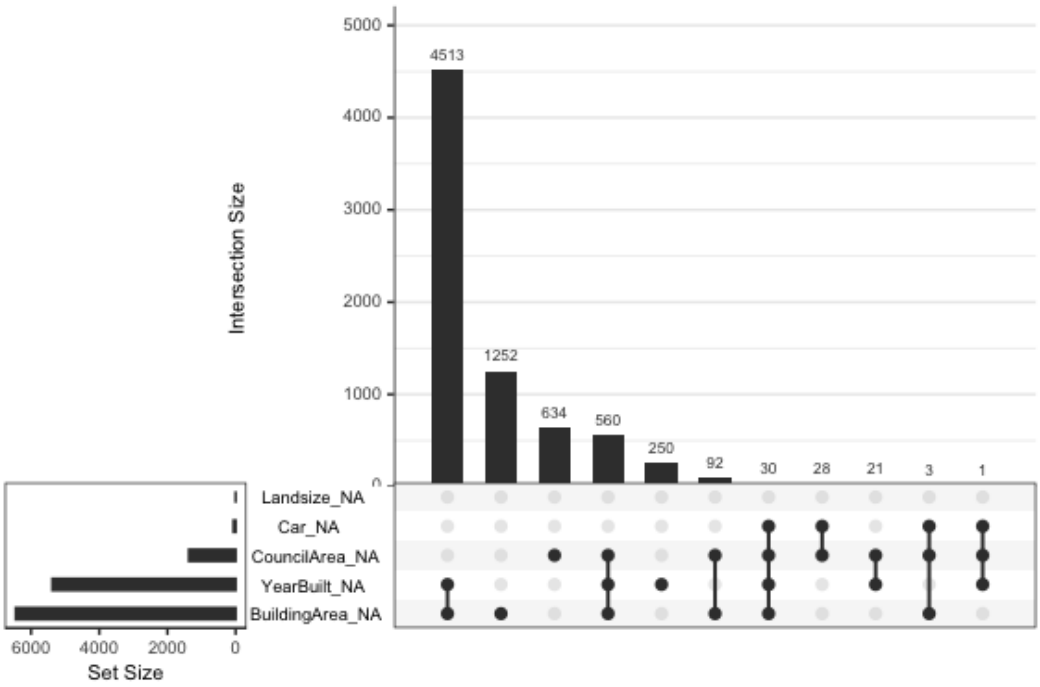


Figure 6: Upset plot of missingness in the Melbourne Homes dataset.

look like this.

20. [Reshaping practice] The following parts ask you to provide R code that transforms one dataset (I) into another (II).

    a. Regional murder rates: Turn I into II.
    b. Antiobitics and bacteria. Turn I into II

21. [Sales summaries] Consider the sales data below.

```
##   region quarter sales
## 1      A      Q1     6
## 2      A      Q2     5
## 3      A      Q3     3
## 4      A      Q4     2
## 5      B      Q1     4
## 6      B      Q2     8
## 7      B      Q3     2
## 8      B      Q4     6
```

    a. Provide code to compute the total sales for each quarter, across both regions. The result should look like the table below.

```
## # A tibble: 4 x 2
##   quarter total
##   <chr>   <dbl>
## 1 Q1         10
## 2 Q2         13
## 3 Q3          5
## 4 Q4          8
```

b. Provide code to compute the proportion of each quarter's sales that came from each region. The result should look like the table below.

```
## # A tibble: 8 x 4
##   region quarter sales  prop
##   <chr>  <chr>   <dbl> <dbl>
## 1 A      Q1          6 0.6
## 2 A      Q2          5 0.385
## 3 A      Q3          3 0.6
## 4 A      Q4          2 0.25
## 5 B      Q1          4 0.4
## 6 B      Q2          8 0.615
## 7 B      Q3          2 0.4
## 8 B      Q4          6 0.75
```

22. [Interactive Penguins] This problem visualizes the Penguins dataset interactively.

    a. Create two static scatterplots: one of of bill length vs. depth and another of flipper length vs. body mass.
    b. Create selection menus that can be used to highlight the island that the penguin came from, along with its gender.
    c. Create selection brushes that can be used to link the two plots together. That is, highlighting points in a brush for one view should highlight the corresponding penguins in the other.
    d. Provide one takeaway from the interactive visualization that is not possible to make using the original static version.

23. [Olympics Derivations] This problem gives some practice with deriving and visualizing new variables.

    a. Create new columns for the city and country of birth for each athlete in the London 2012 Olympics dataset.
    b. Compute the standard deviation of athlete age within each sport. Which sport has widest SD in age?
    c. Make a visualization of sports against participant age. Sort sports by age variance.

```
olympics <- read_csv("https://uwmadison.box.com/shared/static/rzw8h2x6dp5693gdbpgxaf2koqijo12l.csv'
```

24. [NYC Flights] The following questions refer to the NYC flights dataset. The first few lines are printed below.

```
library(nycflights13)
flights |> select(carrier, air_time, distance)
```

```
## # A tibble: 336,776 x 3
##    carrier air_time distance
##    <chr>      <dbl>    <dbl>
##  1 UA           227     1400
##  2 UA           227     1416
##  3 AA           160     1089
##  4 B6           183     1576
##  5 DL           116      762
##  6 UA           150      719
##  7 B6           158     1065
##  8 EV            53      229
##  9 B6           140      944
## 10 AA           138      733
## # i 336,766 more rows
```

    a. Provide code to create a new column giving the average speed of the flight: `speed` $:= \frac{\texttt{distance}}{\texttt{air\_time}}$.

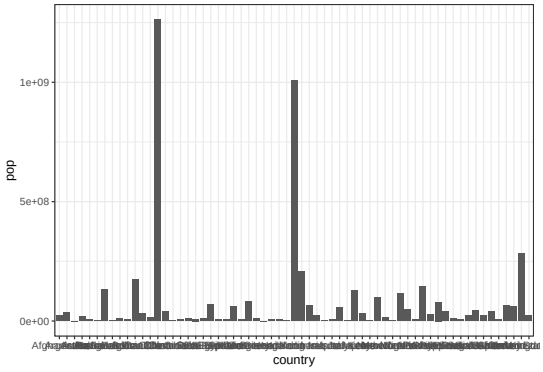
b. Is there a large variation in flight speed across carriers? Design and a visualization to answer this question and comment on your findings.

25. [Gapminder Queries] The example visualization below comes from the course notes. It is supposed to help readers compare country populations.

```
gapminder <- read_csv("https://uwmadison.box.com/shared/static/dyz0qohqvgake2ghm4ngupbltkzpqb7t.csv
  mutate(cluster = as.factor(cluster))

print(head(gapminder, 3))
```

```
## # A tibble: 3 x 6
##    year country     cluster      pop life_expect fertility
##   <dbl> <chr>       <fct>      <dbl>       <dbl>     <dbl>
## 1  1955 Afghanistan 0        8891209        30.3       7.7
## 2  1960 Afghanistan 0        9829450        32.0       7.7
## 3  1965 Afghanistan 0       10997885        34.0       7.7
```

```
ggplot(filter(gapminder, year == 2000)) +
 geom_col(aes(country, pop))
```



a. Give two distinct examples of specific user queries related to the overall `gapminder` dataset printed above that are difficult (or impossible) to make with the current display.

b. Implement an alternative visualization that addresses the issues you raised in part (a). Why does it help?

26. [Code Diary] In this exercise, you will write a reflection on your experience of writing code over the next 48 hours. Prepare brief answers to the following questions:

a. What was your programming environment/workflow? For example, were you running code in an Rmarkdown notebook with Rstudio, or switching between a terminal and a code editor, . . . ?
b. What techniques did you use to plan your code? For example, did you write pseudocode, brainstorm ideas with a partner, or draw any guiding diagrams?
c. What kinds of bugs did you encounter? What steps did you take to resolve them?
d. If you were starting the programming task again, would you do anything differently?

We encourage you to share some problem solving techniques with others in the class and see whether others have approaches you might be able to borrow.

27. [Birds Code Review] This exercise asks you to conduct an imaginary code review. These are often used in data science teams to,

- Catch potential bugs
- Make sure code is transparent to others
- Create a shared knowledge base

It is important to be perceptive but friendly.

- Can the code be made more compact?
- Are there visual design choices / encodings that could be refined?
- If your colleague did something well, say so!

They can also be a great way to learn new functions and programming patterns. Unlike standard code-reviews, I ask you to give an example implementing your recommendations.

Specifically, in this review, suppose you are working with a scientific colleague on your study of bird egg properties and their evolutionary implications. They have written the code below. Provide your code review as a set of bullet points, and include code giving an example implementation of your ideas. The original data are from this study.

```
library(ggrepel)

birds <- read_csv("https://raw.githubusercontent.com/krisrs1128/stat479_s22/main/exercises/data/bir
  separate(Species, c("genus", "species2"))

bird_summaries <- birds |>
  group_by(genus) |>
  summarise(
    across(
      c("Asymmetry", "Ellipticity", "AvgLength (cm)",
        "Number of images", "Number of eggs"),
      list(MEAN = mean, STANDARD_DEVIATION = sd))) |>
  arrange(-Ellipticity_MEAN)

ggplot(bird_summaries) +
  geom_point(aes(Asymmetry_MEAN, Ellipticity_MEAN)) +
  geom_text_repel(aes(Asymmetry_MEAN, Ellipticity_MEAN, label = genus))
```

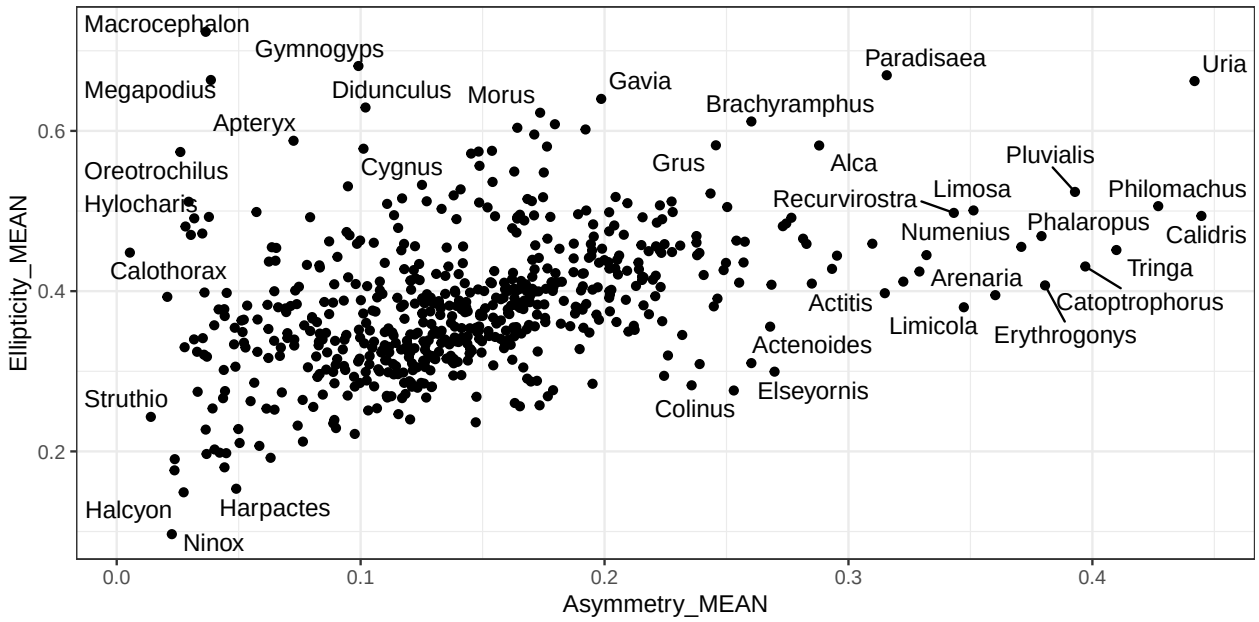


Figure 7: An example figure for code review.

28. [Soccer Code Review] This exercise asks you to conduct an imaginary code review. These are often used in data science teams to,

- Catch potential bugs
- Make sure code is transparent to others
- Create a shared knowledge base

It is important to be perceptive but friendly.

- Can the code be made more compact?
- Are there visual design choices / encodings that could be refined?
- If your colleague did something well, say so!

They can also be a great way to learn new functions and programming patterns. Unlike standard code-reviews, I ask you to give an example implementing your recommendations.

Specifically, in this review, suppose you are working on a sports blog, and your colleague is soccer interested in which teams won the most games in a few European leagues over the last few years. They have written the code below. Provide your code review as a set of bullet points, and include code giving an example implementation of your ideas. The original data are from this link.

```
win_props <- read_csv("https://raw.githubusercontent.com/krisrs1128/stat479_s22/main/exercises/data
  group_by(team, year) |>
  summarise(n_games = n(), wins = sum(wins) / n_games)

best_teams <- win_props |>
  ungroup() |>
  slice_max(wins, prop = 0.2) |>
  pull(team)

win_props |>
  filter(team %in% best_teams) |>
  ggplot() +
  geom_point(aes(year, team, size = n_games, alpha = wins))
```

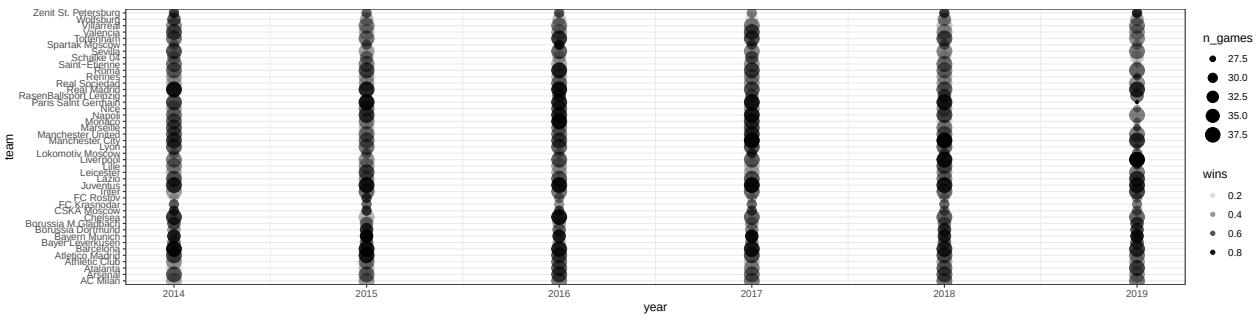


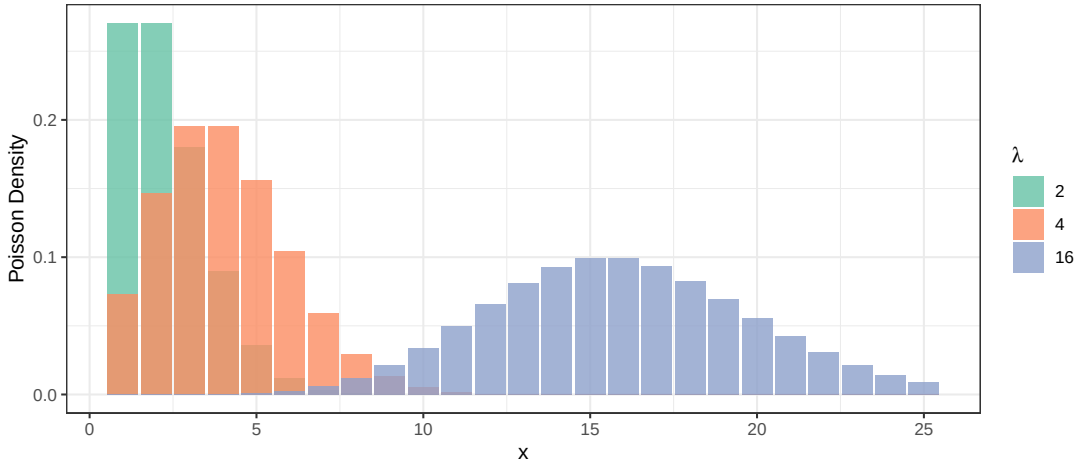
Figure 8: An example figure for code review.

29. [Poisson Guidance] This exercises asks you to imagine working with a student who is just beginning to learn ggplot2 and needs help constructing a plot. Specifically, the student would like to create a barplot of Poisson distribution mass functions for a few choices of λ, like the figure displayed below. The following code is their initial attempt.

```
mylambda1 <- function(x) dpois(x, lambda = 2)
mylambda2 <- function(x) dpois(x, lambda = 4)
mylambda3 <- function(x) dpois(x, lambda = 16)

ranges1 <- data.frame(x=c(0,25), PMF = factor(1))
ranges2 <- data.frame(x=c(0,25), PMF = factor(2))
range3 <- data.frame(x=c(0,25), PMF = factor(3))
```

```r
ggplot(NULL, aes(x=x, colour=PMF)) +
   stat_function(data = ranges1, fun = mylambda1, size = 1.5) +
   stat_function(data = ranges2, fun = mylambda2, size = 1.5) +
   stat_function(data = range3, fun = mylambda3, size = 1.5) +

  geom_bar()+

  theme_bw(base_size = 14) +
   scale_colour_manual("Parameters", guide="legend",
                  labels = c("2", "4", "16"),
                  values= c("red", "green"))
```

a. Provide code implementing the figure that the student is interested in.
b. From the attempted solution, what conceptual difficulties do you think the student encountered?
c. How might you have helped the student resolve the challenges evident in part(b)? Briefly explain at least one concept that would improve their knowledge of either ggplot2 or effective code style.



30. [Pair Code Review] In this exercise, we will share a code review with a partner in the class. Reading others' code is a great way to learn new programming or documentation techniques. This exercise also gives practice in code review, which is ubiquitous in software engineering industry.

a. Pick a partner who you will work through this exercise with, and find an example of code that you wrote for this course that you would like your partner to review.
b. Individually, review one another's code. Are there alternative ways of writing the program and documentation that might make it more efficient or readable? Were there elements of the approach that you thought were especially clear or creative?
c. If a visualization is generated, critique the figure. How easy is it to make the comparisons of interest? Are there details that could be refined?
d. Once you are both done, exchange comments and submit a one paragraph summary of your discussion.

31. [Multiple Weather Variables] In this problem, we will construct a compound figure to simultaneously visualize several weather variables in one display. The block below reads a dataset that includes temperature, precipitation, and wind measurements for New York City and Seattle over the course of several years. It then then averages each variable for each day (1 - 365) in the year.

```r
weather <- read_csv("https://raw.githubusercontent.com/krisrs1128/stat479_s22/main/exercises/data/w
  mutate(day_in_year = lubridate::yday(date)) |>
  group_by(location, day_in_year) |>
  summarise(across(precipitation:wind, mean))
```

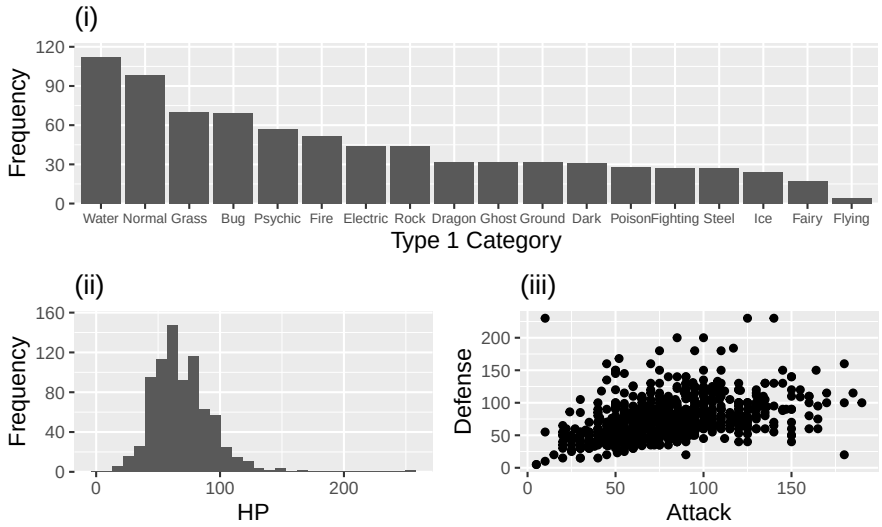
a. Construct three base `ggplot2` plots based on the variables that are provided. For example, you may construct a line plot (`geom_line`) of average precipitation, a histogram (`geom_histogram`) of per-city windspeeds, or a ribbon plot (`geom_ribbon`) of temperature ranges over time. Make sure to display at least two weather variables from among the four that are provided.
b. Design a compound figure based on the base plots in part (a). Why did you lay out the subplots in the locations that you did? Ensure that consistent visual encodings are used throughout, that legends are collected, and that clear but unobtrusive annotation is provided.
c. Discuss, but do not implement, an alternative compound figure for the same data, with either different base plots or overall layout (or both). For which visual comparisons are either designs best suited?

32. [Pokemon View Composition] This problem revisits the pokemon dataset and asks you to combine complementary visualizations into a single display.

```
a. What is the difference between faceting and compound figures?

b. The figure below shows three views of the pokemon dataset.  Provide code
to recreate it. You do not need to customize the axis titles or themes but
should include the panel titles (i), (ii), and (iii).
```

```
pokemon <- read_csv("https://uwmadison.box.com/shared/static/hf5cmx3ew3ch0v6t0c2x56838er1lt2c.csv")
head(pokemon, 3)
```

```
## # A tibble: 3 x 12
##   Name      type_1 type_2 Total    HP Attack Defense speed_attack speed_defense Speed Generation
##   <chr>     <chr>  <chr>  <dbl> <dbl>  <dbl>   <dbl>        <dbl>         <dbl> <dbl>      <dbl>
## 1 Bulbasaur Grass  Poison   318    45     49      49           65            65    45          1
## 2 Ivysaur   Grass  Poison   405    60     62      63           80            80    60          1
## 3 Venusaur  Grass  Poison   525    80     82      83          100           100    80          1
```




```
c. List one consideration that can (in general) improve readability
for either compound or faceted figures.
```

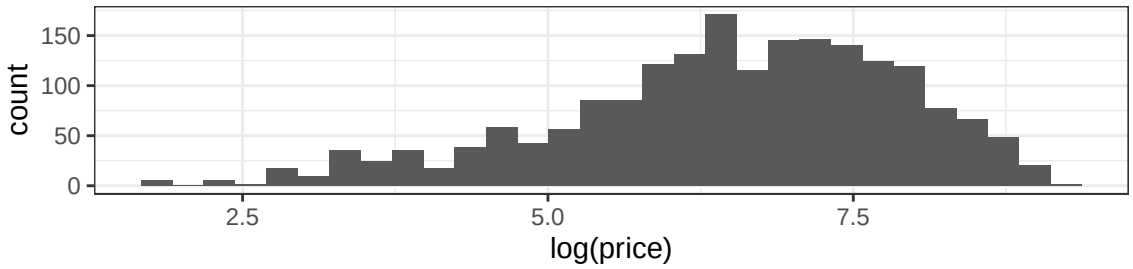
33. [Faceting rules-of-thumb] Circle all the true statements for compound and faceted figures.

a. Whenever possible, each panel in a faceted plot should be made to have its own y-axis scale.
b. When using the `patchwork` package, two plots `p1` and `p2` can be placed side-by-side using `p1 / p2`.
c. When using the `patchwork` package, the `plot_layout` function can be used to collect legends.

d. Relative to interactively filtered displays, faceted plots are less taxing on the reader's memory.

34. [Ikea Faceting] The code below generates a histogram of prices for a subset of items sold at Ikea, a furniture outlet.

```
ikea <- read_csv("https://uwmadison.box.com/shared/static/iat31h1wjg7abhd2889cput7k264bdzd.csv") |>
  filter(category %in% c("Tables", "Bookcases", "Beds", "Cabinets", "Sofas", "Wardrobes"))
ggplot(ikea) +
  geom_histogram(aes(log(price)))
```



The four plots (i - iv) are generated by faceting this base plot by furniture category (the variable `category`). On the blank lines below, put the number of the plot that matches the corresponding faceting command, or leave the line empty if the corresponding plot does not appear.

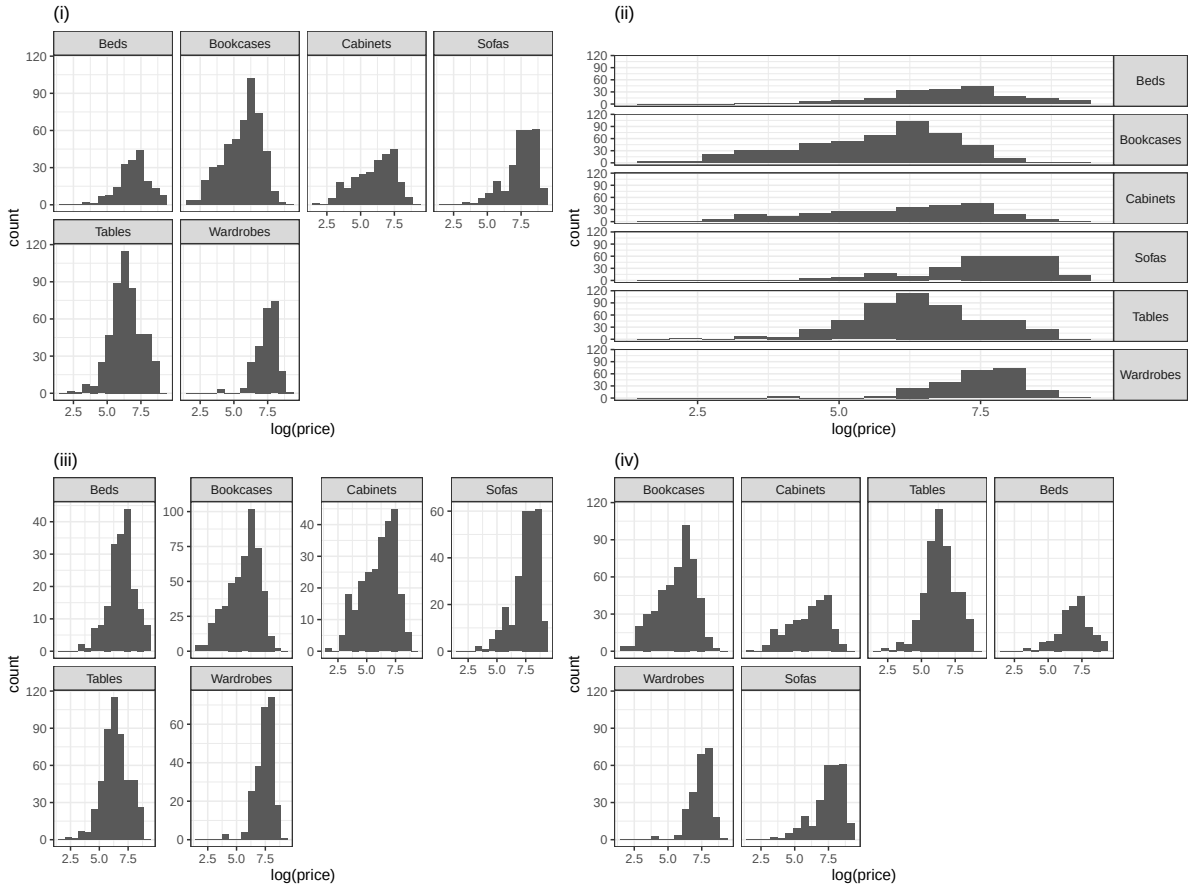
___ a. `facet_grid(category ~ .)`

___ b. `facet_wrap(~ category)`

___ c. `facet_wrap(~ category, scales = "free_y")`

___ d. `facet_wrap(~ category, axes = "separate")`

___ e. `facet_wrap(~ reorder(category, price))`

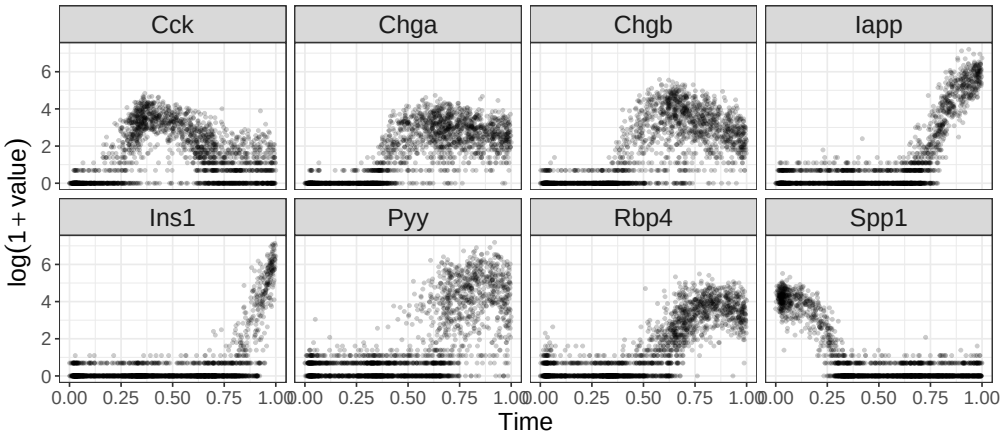


35. [Gene Expression Faceting] In this problem, we will experiment with several approaches to visualizing a dataset of gene expression over time. Each row below contains the expression level for one gene in one sample at a single timepoint.

```
genes <- read_csv("https://uwmadison.box.com/shared/static/dwzchdtfca33r0f6i055k2d0939onnlv.csv")
head(genes, 3)
```

```
## # A tibble: 3 x 4
##   sample gene   time value
##    <dbl> <chr> <dbl> <dbl>
## 1      1 Pyy   0.677   103
## 2      1 Iapp  0.677     0
## 3      1 Chgb  0.677    86
```

a. Provide code to create the small multiples plot below. Note that the points have been made semi-transparent and that the y-axis is a transformation of the original `value` column.

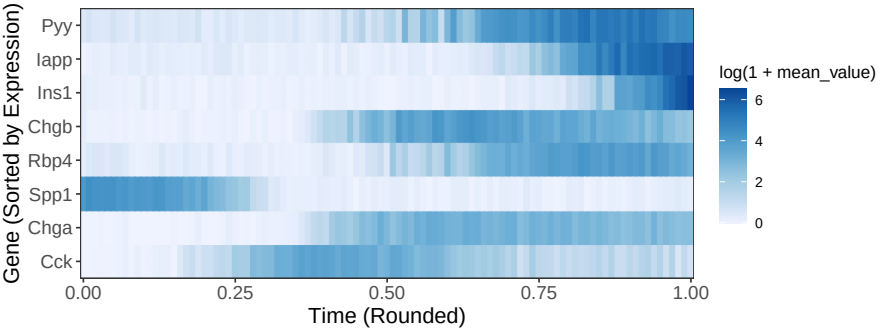


b. In your own words, describe one strength and one weakness of using small multiples.

c. Suppose we instead wanted a heatmap of expression values with genes along rows and timepoint along columns. Provide code to draw this, starting from the `gene_groups` dataset defined below. Ensure that genes are sorted from most to least abundant, and also that expression values are shown on a $\log(1+x)$ scale.

```
gene_groups <- genes |>
  group_by(gene, rounded_time = round(time, 2)) |>
  summarise(mean_value = mean(value))
head(gene_groups, 3)
```

```
## # A tibble: 3 x 3
## # Groups:   gene [1]
##   gene  rounded_time mean_value
##   <chr>        <dbl>      <dbl>
## 1 Cck            0        0
## 2 Cck            0.01     0
## 3 Cck            0.02     0.0652
```

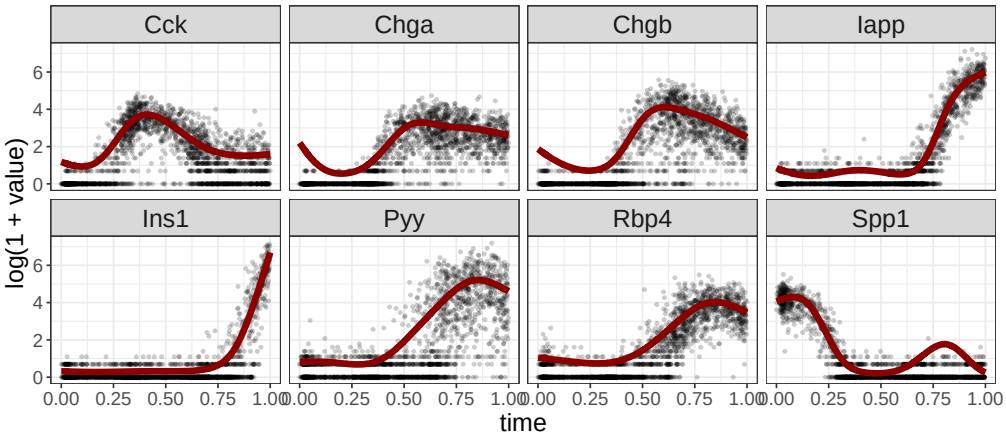


d. Imagine that we trained a model that generates a smooth curve over time for each gene. It is stored in the `fitted_values` data below. How can you modify your solution to (a) to overlay this? Provide example code and discuss how this relates to the concept of a "grammar of graphics."

```
fitted_values <- read_csv("https://go.wisc.edu/x678hu")
head(fitted_values, 3)
```

```
## # A tibble: 3 x 4
##   gene   time     mu sigma
##   <chr> <dbl>  <dbl> <dbl>
## 1 Pyy   0.677  52.8   3.17
## 2 Pyy   0.432   2.47  1.23
```

```
## 3 Pyy   0.749 112.    1.95
```



36. [Antibiotics Comparison] Below, we provide three approaches to visualizing species abundance over time in an antibiotics dataset.

```
antibiotic <- read_csv("https://uwmadison.box.com/shared/static/5jmd9pku62291ek20lioevsw1c588ahx.cs
antibiotic
```

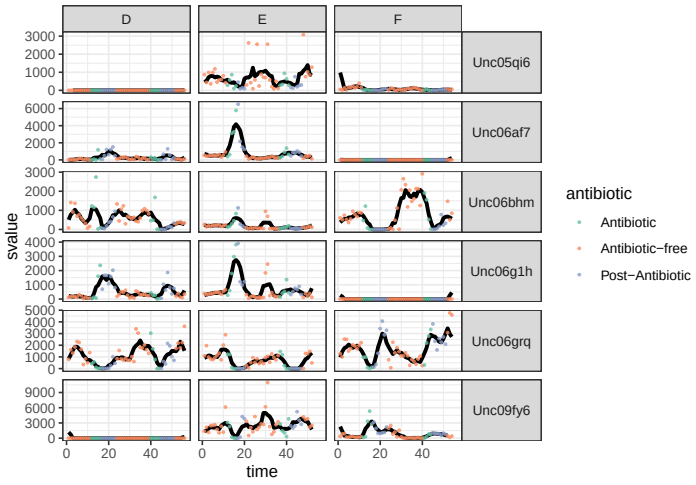
```
## # A tibble: 972 x 7
##    species  sample value ind    time svalue antibiotic
##    <chr>    <chr>  <dbl> <chr> <dbl>  <dbl> <chr>
##  1 Unc05qi6 D1         0 D         1   NA   Antibiotic-free
##  2 Unc05qi6 D2         0 D         2   NA   Antibiotic-free
##  3 Unc05qi6 D3         0 D         3    0   Antibiotic-free
##  4 Unc05qi6 D4         0 D         4    0   Antibiotic-free
##  5 Unc05qi6 D5         0 D         5    0   Antibiotic-free
##  6 Unc05qi6 D6         0 D         6    0.2 Antibiotic-free
##  7 Unc05qi6 D7         0 D         7    0.2 Antibiotic-free
##  8 Unc05qi6 D8         1 D         8    0.2 Antibiotic-free
##  9 Unc05qi6 D9         0 D         9    0.2 Antibiotic-free
## 10 Unc05qi6 D10        0 D        10    0.2 Antibiotic-free
## # i 962 more rows
```

For each approach, describe,

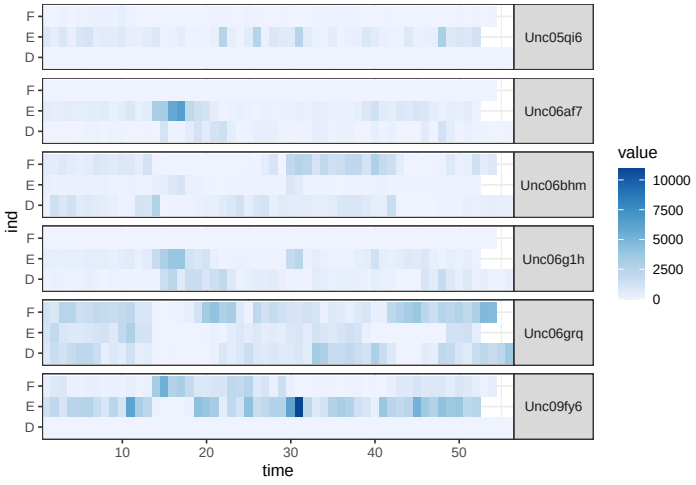
- One type of visual comparison for which the visualization is well-suited.
- One type of visual comparison for which the visualization is poorly-suited.

Make sure to explain your reasoning.

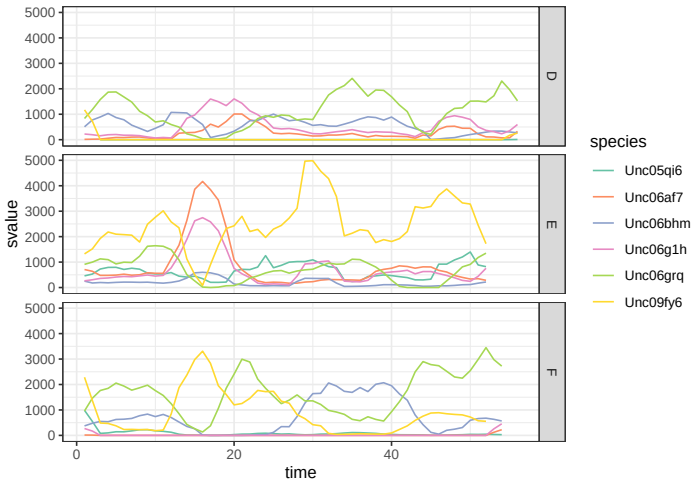
a. Approach 1



b. Approach 2



c. Approach 3



d. Sketch code that could be used to make one of the three visualizations above.

37. [Visualization and LLMs] This course generally avoids using large language models (LLMs) when teaching new material, because they can sometimes be a distraction (e.g., hallucinating incorrect answers). In practice, though, these models can help improve programming efficiency. They have also

been the source of concern for many engineers, who wonder whether the models will replace them. This exercise asks you to reflect on ways to use LLMs when designing and implementing visualizations.

a. Try solving any past course demo using an LLM. Reflect on the experience.
b. How do you think you might use language models when making visualizations? Or, if you already use them, what have you found to be best practices?
c. If programming is not just about writing code, then what is it about?

1. [Name app bugs] The following versions of the Name app all have errors that will raise an error if you try running them in R. For each part, isolate the line(s) that contain the bug. Provide a conceptual explanation for why the error occurred and how they could be prevented more generally.

   a. Program (a).

```
library(shiny)

ui <- fluidPage(
  titlePanel("Hello!"),
  textInput("name", "Enter your name"),
  textOutput("printed_name")
)

server <- function(input, output) {
  input$name <- paste0("Welcome to shiny, ", input$name, "!")
  output$printed_names <- renderText({ input$name })
}

app <- shinyApp(ui, server)
```

   b. Program (b).

```
library(shiny)

ui <- fluidPage(
  titlePanel("Hello!"),
  textInput("name", "Enter your name"),
  textOutput("printed_name")
)

server <- function(input, output) {
  output$printed_names <- renderText({
    paste0("Welcome to shiny, ", input$name, "!")
  })
}

app <- shinyApp(ui, server)
```

   c. Program (c).

```
library(shiny)

ui <- fluidPage(
  titlePanel("Hello!"),
  textInput("name", "Enter your name"),
  textOutput("printed_name")
)
```

```
server <- function(input, output) {
  output$printed_name <- renderDataTable({
    paste0("Welcome to shiny, ", input$name, "!")
  })
}

app <- shinyApp(ui, server)
```

d. Program (d).

```
library(shiny)

ui <- fluidPage(
  titlePanel("Hello!")
  textInput("name", "Enter your name")
  textOutput("printed_name")
)

server <- function(input, output) {
  output$printed_name <- renderText({
    paste0("Welcome to shiny, ", input$name, "!")
  })
}

app <- shinyApp(ui, server)
```

2. [More Shiny Bugs] None of the Shiny apps below work in the way that their authors intended. For each part, isolate the line(s) that contain the bug. Provide an alternative working implementation together with a conceptual explanation for why the error occurred.

   a. Program (a). Goal: When the user inputs a number, the program reports whether or not that number is larger than 10.

```
ui <- fluidPage(
  numericInput("input_num", "Enter a number:", value = 5),
  textOutput("output_text")
)

server <- function(input, output) {
  output$output_text <- renderText({
    ifelse(input_num > 10, "Number is greater than 10", "Number is less than or equal to 10")
  })
}

shinyApp(ui, server)
```

   b. Program (b). Goal: When the user clicks a button labeled "Increment Counter", then the text next to the button should increase by one.

```
ui <- fluidPage(
  actionButton("increment", "Increment Counter"),
  verbatimTextOutput("counter_text")
)

server <- function(input, output) {
  counter <- reactiveVal(0)
```

```
  observe({
    counter <- counter + 1
  })

  output$counter_text <- renderPrint(counter)
}

shinyApp(ui, server)
```

c. Program (c). Goal: When the user selects a variable from the selection menu, we will show a scatterplot of `mpg` against the selected variable in the `mtcars` dataset.

```
library(ggplot2)

ui <- fluidPage(
  selectInput("plot_type", "Select plot type:", choices = c("cyl", "disp", "hp", "wt")),
  plotOutput("plot")
)

server <- function(input, output) {
  cur_data <- mtcars[, c("mpg", input$plot_type)]
  output$plot <- renderPlot({
    ggplot(cur_data, aes(mpg, .data[[y_var]])) +
      geom_point()
  })
}

shinyApp(ui, server)
```

d. Program (d). Goal: When the user enters numbers x and y, the program will print $f(x,y)^2$ and $f(x,y)^3$. We wanted to implement this without computing $f(x,y)$ twice, because this operation is time consuming.

```
ui <- fluidPage(
  numericInput("x", "Enter x", value = 0),
  numericInput("y", "Enter y", value = 0),
  textOutput("output1"),
  textOutput("output2")
)

f <- function(x, y) {
  Sys.sleep(4)
  sqrt(x ^ 2 + y ^ 2)
}

server <- function(input, output) {
  f_xy <- f(input$x, input$y)

  output$output1 <- renderText({
    paste("f(x, y) ^ 2:", total ^ 2)
  })

  output$output2 <- renderText({
    paste("f(x, y) ^ 3:", total ^ 3)
```

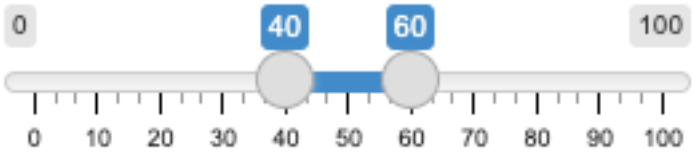
```
  })
}

shinyApp(ui, server)
```

3. [UI Options] Look into the Shiny and shinyWidgets documentation to determine which UI functions can be used to generate the types of inputs described below. Example figures are also shown. Provide a minimal app with similar input functionality (just leave the server empty).

   a. An input to select a date range.

   b. A yes / no toggle that uses an icon for the options.

   c. A slider that can be used to select a range of values.



4. [Improving an app] Make the following apps more concise, modular, and readable by using reactive expressions to capture duplicated computation and / or externalizing complex computations into functions which are defined outside of the server.

   a. Program (a)

```
library(shiny)

ui <- fluidPage(
  titlePanel("Calculator"),
  numericInput("x", "Enter the value of x", 0),
  textOutput("f1"),
  textOutput("f2"),
  textOutput("f3")
)

server <- function(input, output) {
  output$f1 <- renderText({ 3 * input$x ^ 2 + 3})
  output$f2 <- renderText({ sqrt(3 * input$x ^ 2 + 3) - 5})
  output$f3 <- renderText({ 30 * input$x ^ 2 + 30})
}

shinyApp(ui, server)
```

   b. Program (b)

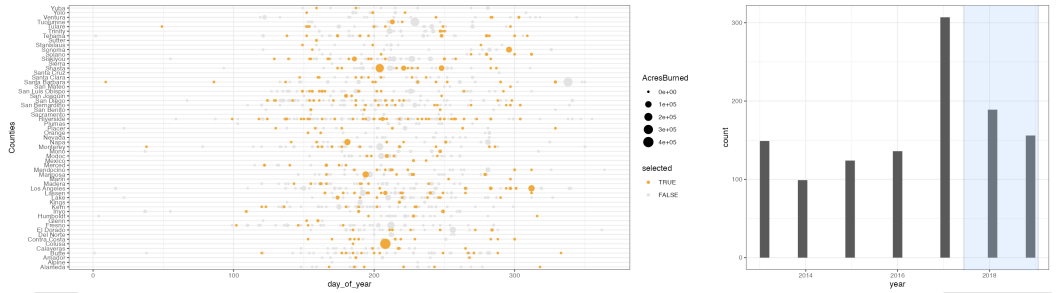
```r
penguins <- read_csv("https://uwmadison.box.com/shared/static/ijh7iipc9ect1jf0z8qa2n3j7dgem1gh.csv"
islands <- unique(penguins$island)
species <- unique(penguins$species)

ui <- fluidPage(
  titlePanel("Penguins Plot"),
  selectInput("species", "Species", species, multiple = TRUE),
  selectInput("island", "Island", islands, multiple = TRUE),
  selectInput("var1", "First Variable", colnames(penguins)[3:6]),
  selectInput("var2", "Second Variable", colnames(penguins)[3:6]),
  plotOutput("scatterplot"),
  plotOutput("histogram1"),
  plotOutput("histogram2"),
)

server <- function(input, output) {
  output$scatterplot <- renderPlot({
    current_data <- penguins |>
      filter(
        island %in% input$island,
        species %in% input$species
      )
    ggplot(current_data) +
      geom_point(aes(.data[[input$var1]], .data[[input$var2]]))
  })

  output$histogram1 <- renderPlot({
    current_data <- penguins |>
      filter(
        island %in% input$island,
        species %in% input$species
      )
    ggplot(current_data) +
      geom_histogram(aes(.data[[input$var1]]))
  })

  output$histogram2 <- renderPlot({
    current_data <- penguins |>
      filter(
        island %in% input$island,
        species %in% input$species
      )
    ggplot(current_data) +
      geom_histogram(aes(.data[[input$var2]]))
  })

}

shinyApp(ui, server)
```

5. [Reactivity Graphs] Manually sketch out the reactivity graph associated with any of the "Shiny Demos" in the official Shiny Gallery. Make sure to distinguish between input, output, observe, and reactive nodes. For a challenge, try the same exercise for one of the apps in the Shiny User Showcase. *Note: In many cases, the UI and server functions have been split into two files,* `ui.R` *and* `server.R`*. The code*

can nonetheless be read as if the functions were in a single `app.R` *file.*

6. [Wildfires Interactive II] The following code creates an interactive Shiny app that provides a histogram that can be brushed to zoom into selected years in the California fires dataset. A screenshot of the final visualization is shown below. Brushing over certain years in the histogram highlights the corresponding fires in the dotplot. The first few rows of the dataset are also shown.

   a. In your own words, explain the concept of a graphical query. Give an example of when it would be useful.



Name	Counties	year	day_of_year	AcresBurned	MajorIncident
Montecito Flooding / Mudflows	Santa Barbara	2018	9	0	TRUE
Haycamp Fire	Monterey	2018	38	50	FALSE
Wilcox Fire	Tulare	2018	49	33	FALSE

```
fires <- read_csv("https://uwmadison.box.com/shared/static/k5vvekf1bhh9e16qb9s66owygc70t7dm.csv") |
select(Name, Counties, year, day_of_year, AcresBurned, MajorIncident)
head(fires, 3)
```

```
## # A tibble: 3 x 6
##   Name        Counties   year day_of_year AcresBurned MajorIncident
##   <chr>       <chr>     <dbl>       <dbl>       <dbl> <lgl>
## 1 Becks Fire  Lake       2013          22         296 FALSE
## 2 River Fire  Inyo       2013          55         406 TRUE
## 3 Jurupa Fire Riverside  2013          59         311 FALSE
```

   b. The starter code below sets up the UI, but doesn't support brushing. Modify the UI so that years can be brushed as shown in the screenshot.

```
ui <- fluidPage(
fluidRow(
    column(8, plotOutput("dotplot")),
    column(4, plotOutput("histogram"))
),
dataTableOutput("table")
)
```

   c. The starter code below sets up the server. Describe how to modify the code so that it updates both the dotplot and the table to reflect the currently brushed years. Be as specific as possible. The second argument of `dotplot` is a vector of `TRUE` or `FALSE` specifying whether a given row of fires should be highlighted. For reference, the function is given at the end of the exam.

```
server <- function(input, output) {
output$dotplot <- renderPlot(dotplot(fires, # ??
output$histogram <- renderPlot(year_histogram(fires))
output$table <- renderDataTable( # ??
}
```

   d. Sketch the reactivity graph of your final application. Make sure to distinguish node types.

7. [Olympics Interactive App] The code below sets up a Shiny app for interactively visualizing athlete weight and heights in the 2012 London Olympics. We would like to have an interactive scatterplot of `Weight` vs. `Height, cm` that updates which points (athletes) are highlighted depending on which sports have been selected by a dropdown menu. Code for generating the scatterplot is provided in the function `scatterplot`.

```
library(shiny)
library(tidyverse)
olympics <- read_csv("https://uwmadison.box.com/shared/static/rzw8h2x6dp5693gdbpgxaf2koqijo12l.csv"

#' Scatterplot with highlighted points
#'
#' Assumes a column in df called "selected" saying whether points should be
#' larger / darker
scatterplot <- function(df) {
  ggplot(df) +
    geom_point(
      aes(Weight, `Height, cm`,
          alpha = as.numeric(selected),
          size = as.numeric(selected))
      ) +
    scale_alpha(range = c(0.05, .8)) +
    scale_size(range = c(0.1, 1))
}

ui <- fluidPage(
  selectInput("dropdown", "Select a Sport", choices = unique(olympics$Sport), multiple = TRUE),
  plotOutput("scatterplot")
)

server <- function(input, output) {
  # fill this in...
}
```

   a. Provide server code which would allow the scatterplot to update the highlighted athletes depending on the currently selected sports.

   b. We have been asked to also print a table of the selected athletes. Assume the UI has the form,

```
ui <- fluidPage(
  selectInput("dropdown", "Select a Sport", choices = unique(olympics$Sport), multiple = TRUE),
  plotOutput("scatterplot"),
  dataTableOutput("table")
)
```

   Describe changes to your solution to (a) to meet the new requirements. How would you minimize code duplication? Be as specific as possible.

8. [NYC Rentals] In this problem, we'll create a visualization to dynamically query a dataset of Airbnb rentals in Manhattan in 2019. The steps below guide you through the process of building this visualization.

   a. Make a scatterplot of locations (Longitude vs. Latitude) for all the rentals, colored in by `room_type`.

   b. Design a plot and a dynamic query so that clicking or brushing on the plot updates the points that are highlighted in the scatterplot in (a). For example, you may query a histogram of prices to focus on neighborhoods that are more or less affordable.

c. Implement the reverse graphical query. That is, allow the user to update the plot in (b) by brushing over the scatterplot in (a).

d. Comment on the resulting visualization(s). If you had a friend who was interested in renting an Airbnb in NYC, what would you tell them?

9. [NYC Rentals Alternative] In this problem, we will use Shiny to visualize the NYC AirBnB Rental Prices dataset. Each row in this dataset is one rental.

```
rentals <- read_csv("https://uwmadison.box.com/shared/static/zi72ugnpku714rbqo2og9tv2yib5xped.csv")
  select(id, room_type, price, latitude, longitude) |>
  mutate(log_price = log(price, 10))
head(rentals, 3)
```

```
## # A tibble: 3 x 6
##         id room_type       price latitude longitude log_price
##      <dbl> <chr>           <dbl>    <dbl>     <dbl>     <dbl>
## 1  2619549 Entire home/apt   140     40.8     -74.0      2.15
## 2 34291583 Entire home/apt   100     40.7     -74.0      2
## 3 16427854 Entire home/apt   180     40.7     -74.0      2.26
```

Our Shiny app is defined in the code below.

```
scatterplot <- function(df) {
  ggplot(df) +
    geom_point(aes(longitude, latitude, col = room_type)) +
    scale_color_brewer(palette = "Set2") +
    coord_fixed()
}

ui <- fluidPage(
  sliderInput("log_price", "Log(Price)", min = 1, max = 4, value = c(1, 4), step = 0.01),
  selectInput("room_type", "Room Type", choices = unique(rentals$room_type), multiple = TRUE),
  plotOutput("scatterplot"),
  dataTableOutput("table")
)

server <- function(input, output) {
  current_data <- reactive({
    rentals |>
      filter(
        log_price >= input$log_price[1],
        log_price <= input$log_price[2],
        room_type %in% input$room_type
      )
  })

  output$scatterplot <- renderPlot(scatterplot(current_data()))
  output$table <- renderDataTable(current_data())
}

shinyApp(ui, server)
```

a. What interactions does this app respond to? How does it respond to them?

b. Sketch this app's reactive graph.

c. Propose a variation on the interface that uses a graphical query. How would it respond to user

interactions? What is an advantage of this approach?

d. How would you approach an implementation to (c)? You do not need to provide all the code, but break your approach into a precise steps.

10. [Midwestern Power Plants] Where does our electricity come from? The World Resources Institute compiles a database of power plants to help answer this question. We'll read in a small, preprocessed subset focused on the upper midwest. Note that the data can be read in using the following code.

```
library(sf)
power_plants <- read_sf("https://raw.githubusercontent.com/krisrs1128/stat992_f23/main/exercises/ps
  mutate(
    coords = st_coordinates(geometry),
    longitude = coords[, 1],
    latitude = coords[, 2]
  )
```

a. Create a map of power plants that shows where plants are located, how they generate electricy (`primary_fuel`), and how much generation capacity they have (`capacity_mw`).

b. Create an interactive version of the map from version (a) that allows users to brush a histogram to highlight plants with generation capacity within a certain range. One potential solution is shown here.

c. Describe one strength and one limitation of the visualization generated in part (b). Consider one visual query for which it is poorly suited, and discuss (but do not implement) and alternative.

11. [Graphical Queries Discussion] This problem asks you to share your understanding of the concept of graphical queries in data visualization.

a. Provide a one sentence summary of the concept of graphical queries.
b. Describe an example application that uses a graphical query. Give details of the interactivity patterns associated with your example.
c. Why is a graphical query appropriate in your example from part (b)? Contrast the graphical query approach with a non-graphical alternative.

12. [Birds Brushed Scatterplot]. The `birds` and `bird_summaries` datasets defined below give characteristics of the eggs laid by different species of birds. In this problem, you will build an interactive app to compare egg `Asymmetry` and `Ellipticity` across species and genera.

```
birds <- read_csv("https://raw.githubusercontent.com/krisrs1128/stat479_s22/main/exercises/data/bir
  separate(Species, c("genus", "species2"))

bird_summaries <- birds |>
  group_by(genus) |>
  summarise(
    across(
      c("Asymmetry", "Ellipticity",
        "AvgLength (cm)", "Number of images",
        "Number of eggs"),
      list(
        MEAN = mean,
        STANDARD_DEVIATION = sd)
      )
    ) |>
  arrange(-Ellipticity_MEAN)
```

a. Create a scatterplot of `Asymmetry` vs. `Ellipticity` which supports brushing. Specifically, whenever the user brushes over a set of points in the scatterplot, they should be shown a table of the selected

species. Also, change the color of the currently brushed points, so that they stand out more clearly.

b. Design and implement an additional genus-level graphical input using the `bird_summaries` data. For example, you could allow the user to highlight species belonging to taxa with high average egg asymmetry.

13. [Shiny free exploration] Pick one of the following datasets, or propose one of your own interest: London Olympics, Pokemon, Chicago Traffic Accidents, Australian Pharmaceuticals.

    a. Based on your understanding of how the data were collected and what they represent, prepare four questions that you are interested in. Choose questions that reflect different aspects of the data and whose answers will require more nuanced analysis.

    b. Design and implement a Shiny app whose interactivity helps to answer the questions you identified in (a).

    c. Sketch the reactivity graph of your app's final implementation.

14. [Shiny True/False] Circle whether the following statements about interactive visualization with Shiny are TRUE or FALSE.

    a. TRUE FALSE The `bs_theme()` function from the `bslib` library can be used to both customize the overall UI theme and modify fonts in a Shiny application.

    b. TRUE FALSE In order to implement a brush graphical query that only moves in the `x` direction, a version of the following code will have to appear at some point within the application's server function,

    ```
    plotOutput("output_id", brush = brushOpts("plot_brush", direction = "x")))
    ```

    c. TRUE FALSE By using a `reactive({...})` expression within a server function, it is possible to reduce the number of edges appearing in an application's reactive graph.

    d. TRUE FALSE If the code

    ```
    output$scatterplot <- renderPlot({
      ggplot(filter(df, group %in% input$groups)) +
        geom_point(aes(x, y))
    })
    ```

    appeared in an application's server, then we would expect to see `plotOutput(input$scatterplot)` in the UI.

15. [Reactivity Discussion] Consider the `reactive()` and `observeEvent()` functions implemented by the `shiny` package. What are common use cases for the two functions? Be as specific as possible.

3 Visualization with D3

1. [Javascript Array Manipulation] These are some exercises to prepare you for more complex array and object manipulation that you may need in more advanced D3 visualizations. You will likely find the following resources useful: [1, 2, 3, 4].

    a. Find the minimum, maximum, and mean of the following array.

    ```
    let generator = d3.randomUniform()
    let x = d3.range(100).map(generator)
    ```

    b. Extract the first 5 elements of `x` and then concatenate them to the last 5 elements of `y`. Your result should look like `[0, 1, 2, 3, 4, 15, 16, 17, 18, 19]`.

    ```
    let x = d3.arrange(100),
          y = d3.arrange(20);
    ```

c. Given the object below, how would you create the array `['apple', 'orange', 'banana']` of just the object's keys?

```
let fruits = {apple: 32, orange: 14, banana: 10}
```

d. Repeat (c), but to create the array [32, 14, 10] of just the object's values.
e. Given an array, how would you create a new array of just its unique values? For example, given an array `[1, 3, 3, 3, 4, 1, 2, 1]`, how would you create `[1, 3, 4, 2]`. Your solution doesn't need to preserve the order of appearance in the original array.

2. [Penguins Array Manipulation] We will use the `penguins` dataset to practice common types of javascript array operations. The javascript file here defines two objects, `penguins` and `penguins2`, each storing the first 10 rows of the penguins dataset, but in slightly different formats.

   a. For each of `penguins` and `penguins2`, describe whether the data structure is (i) an object of arrays, (ii) an array of objects, or (iii) neither. In case (iii), specify the structure.
   b. Using `penguins2`, compute the mean flipper length.
   c. Using `penguins`, define a new array whose elements are `true` or `false` depending on whether flipper length is larger than 187.
   d. Create a new array containing all information from just two penguins: The ones with the smallest and largest flipper lengths.

3. [Draw a Smiley Face] This exercise gives practice in drawing SVG elements from scratch and styling them.

   a. Using only SVG elements, draw a black-and-white smiley face.
   b. Associate each of your SVG elements with either a class or an ID. Use these newly defined classes / IDs together with a CSS file to style your SVG elements.
   c. Using d3's `clone` function, create 50 copies of your smiley face, located at random locations on the SVG canvas.

4. [Modifying Selections] This exercise gives practice making selections on an HTML page and applying changes using either CSS or D3. We will work with this HTML page, which contains a variety of SVG elements grouped and labeled according to different classes and IDs.

   a. Draw the HTML tree structure of the provided page.
   b. Using a CSS rule, change all circles to blue.
   c. Using D3, move the circle with the ID `part_c` to location (100, 100)
   d. Using D3, change all the squares of class `part_d` to red.
   e. Using CSS or D3, change all circles of class `part_e` to red, but only if they are contained within the group with label `group_part_e`.

5. [Practicing Selections] Circle whether the statements about the D3 selections below are TRUE or FALSE.

```
<svg width="900" height="500">
  <circle id="part_c" r="50" cx="800" cy="100"></circle>
  <g id="group_part_e">
    <circle cx="134.05" cy="219.08" r="10" class="part_e"></circle>
    <circle cx="25.92" cy="150.64" r="10" class="part_e"></circle>
    <circle cx="40.86" cy="186.98" r="10" class="part_e"></circle>
    <circle cx="99.38" cy="217.51" r="10"></circle>
  </g>
  <g id="other_circles">
    <circle cx="132.12" cy="238.44" r="3" class="part_e"></circle>
    <circle cx="14.11" cy="279.48" r="3"></circle>
    <circle cx="109.64" cy="80.25" r="3"></circle>
```

```
  </g>
  <h1>Change me!</h1>
  <g id="squares">
    <rect x="496.15" y="283.39" width="3.19" height="10.87" class="part_d"></rect>
    <rect x="527.82" y="302.35" width="4.67" height="22.71" class="other"></rect>
  </g>
</svg>
```

a. TRUE FALSE To change the colors of circles on lines 4 - 6 (and only these circles) to red, we could use

```
d3.select("#group_part_e")
  .selectAll(".part_e")
  .attrs({"fill": "red"})
```

b. TRUE FALSE To change the colors of circles on lines 4 - 6 (and only these circles) to red, we could use

```
d3.selectAll("#group_part_e .part_e")
  .attrs({"fill": "red"})
```

c. TRUE FALSE To change the radius of the circle on line 10 to 20 pixels, we could use

```
d3.select("#other_circles")
  .attrs({"r": 20})
```

d. TRUE FALSE To switch the text `Change me!` to `You are changed!` after a 2 second delay, we could use

```
d3.select("h1")
  .transition()
  .delay(2000)
  .text("you are changed!!")
```

6. [Debugging JS Code] Imagine that you are helping your colleagues debug their javascript programs. They have explained their implementation goals and the difficulties they have encountered. Your job is to both help them resolve their specific bug and to briefly explain the concepts that will help them avoid these issues in the future. Specifically, for each part, explain propose a solution to your colleague's problem and briefly explain the concept that will help avoid similar bugs.

   a. Goal: I want to try to get the average of the "temp_max" array in "forecast" below.

   Attempt: Here is my HTML and JS file. This is the part that I think is relevant,

```
let forecast = {temp_max: [22, 24, 28, 21], temp_min: [15, 14, 21, 24]}
d3.mean(forecast[0])
```

   Problem: The console prints the error message, `Uncaught TypeError: t is not iterable at t.mean (d3-array@3:2:13861) at in_class4-2a.js:3:4`

   b. Goal: I want to change the color of all the circles on my HTML page to blue.

   Attempt: Here is my HTML and JS file. This is the part that I think is relevant,

```
d3.select("circle")
  .attr("fill", "blue")
```

   Problem: Only the color of the one circle is changing.

   c. Goal: I want to change the color of all the class "highlighted" squares.

   Attempt: Here is my HTML and JS file. This is the part that I think is relevant,

```
d3.selectAll("highlighted")
  .attr("fill", "red")
```

Problem: Nothing is changing.

d. Goal: I want to move the circle to location 100, 200 on the SVG canvas.

Attempt: Here is my HTML and JS file. This is the part that I think is relevant,

```
d3.select("#my_circle")
  .attrs({ x: 100, y: 200 })
```

Problem: It is not moving.

7. [Random Point Transitions] This exercise will give practice implementing transitions on simulated data. The code below generates a random set of 10 numbers,

```
let generator = d3.randomUniform();
let x = d3.range(10).map(generator);
```

   a. Encode the data in `x` using the x-coordinate positions of 10 circles.
   b. Animate the circles. Specifically, at fixed time intervals, generate a new set of 10 numbers, and smoothly transition the original set of circles to locations corresponding to these new numbers.
   c. Extend your animation so that at least one other attribute is changed at each time step. For example, you may consider changing the color or the size of the circles. Make sure that transitions remain smooth (e.g., if transitioning size, gradually increase or decrease the circles' radii).

8. [Simple Bar Chart] Consider the following list of numbers,

```
let generator = d3.randomUniform();
let x = d3.range(10).map(generator);
```

   a. Create a bar chart that has one bar per number, with the height of that bar determined by the value in the array. There is no need to add labels or axes.

   b. Turn the bar chart from (a) on its side. The horizontal length of each bar should now encode each of the original numbers.

9. [Bar Chart Transitions] This problem continues [Simple Bar Chart] above. We will create a bar chart that adds and removes one bar each time a button is clicked. Specifically, the function below takes an initial array `x` and creates a new array that removes the first element and adds a new one to the end. Using D3's generate update pattern, write a function that updates the visualization from [Simple bar chart] every time that `update_data()` is called. New bars should be entered from the left, exited from the right, and transitioned after each click. Your solution should look (roughly) like this example.

```
let bar_ages = [],
generator = d3.randomUniform(0, 500),
id = 0;

function update() {
  bar_ages = bar_ages.map(d => { return {id: d.id, age: d.age + 1, height: d.height }})
  bar_ages.push({age: 0, height: generator(), id: id});
  bar_ages = bar_ages.filter(d => d.age < 5)
  id += 1;
}
```

10. [Marching Circles] This problem gives practice using D3's general update pattern. The code at this link updates an array of objects each time a button is clicked. You will build a visualization that draws circles whose positions are updated each time the underlying data changes.

a. What does the `update` function do? Give a brief explanation of each line.
b. Using the general update pattern, create a drawing of circles where the x-coordinate position encodes the age (in terms of button clicks) of each circle. Older circles should be on the right.
c. Exit all circles whose age is larger than 5.
d. Modify your implementation so that circles enter from the top left corner and exit to the bottom right.
e. Modify your implementation so that (i) circles are only exited after their age exceeds 10 and (ii) the y-coordinate positions of the circles move along a sine curve.

11. [Colorful squares] The code below draws a square on an otherwise blank canvas.

a. Modify the code so that, every time the square is clicked, it changes to a new, randomly chosen color from the `d3.schemeCategory10` color palette.

b. Introduce at least one new transition or interactive element. Be creative! For example, you can let the user create new squares, have the squares fall off of the canvas, change in size, or automatically change color.

12. [Scales subtleties] Circle whether the following statements about reshaping data and scales are TRUE or FALSE.

a. TRUE FALSE According to the definition below, calling `x_scale(0)` will return 0.

```
x_scale = d3.scaleLinear()
  .domain([0, 15000])
  .range([0, 700])
```

Then calling `x_scale(0)` will return 0.

b. TRUE FALSE In the `plants` data below, each row represents the growth of one plant over 4 consecutive weeks.

```
## # A tibble: 3 x 6
##   treatment plantid height.0 height.7 height.14 height.21
##   <chr>     <chr>      <dbl>    <dbl>     <dbl>     <dbl>
## 1 control   plant_1      235      525       810      1090
## 2 control   plant_2      182      391       615       810
## 3 control   plant_3      253      452       620       880
```

If we want to reshape the data into the format

```
## # A tibble: 3 x 4
##   treatment plantid day       value
##   <chr>     <chr>   <chr>     <dbl>
## 1 control   plant_1 height.0    235
## 2 control   plant_1 height.7    525
## 3 control   plant_1 height.14   810
```

then it is sufficient to use the following code,

```
plants |>
  pivot_longer(starts_with("height"), names_to = "day", values_to = "value")
```

c. TRUE FALSE Suppose we have a ggplot2 `geom_line` layer that encodes line color into discrete colors according to a categorical variable. If we want to customize the line colors, we would have to add the layer `scale_line_color_discrete(manual = ...)`
d. TRUE FALSE. Suppose we have data stored in a javascript array `data = [{species: "Adelie", flipper_length: 142}, {species: ...}, ]`. To replace the flipper lengths with the square root of flipper length, we can use `data.map(d => Math.sqrt(d))`

13. [General Update Pattern Summary] This problem asks you to share your understanding of the "General Update" (also called the enter, update, exit) pattern in D3.

    a. Provide a one sentence summary of the purpose of the General Update pattern for building interactive visualizations.

    b. Provide a concrete example where the General Update pattern could be used. What aspects of the example (if any) correspond to the enter, update, and exit steps?

    c. Describe and annotate pseudocode that could be used to implement the pattern in the example you proposed for (b). Make sure to include the relevant D3 selection, `.attr`, `.append`, and `.remove` commands, and summarize the data structures you use.

14. [A revised "general update pattern"] When D3 was introduced, it recommended creating, modifying, and deleting elements using a "general update pattern", and this is still found in most introductions to D3, e.g., 1, 2, or 3. However, recent versions of D3 support a new `selection.join()` pattern to streamline updates. This exercise provides practice with this new pattern, following the documentation available here.

    a. Consider the join pattern in the second block in the documentation,

```
svg.selectAll("text")
  .data(randomLetters())
  .join("text")
    .attr("x", (d, i) => i * 16)
    .text(d => d);

yield svg.node();
await Promises.tick(2500);
```

    What would happen if instead of `.join("text")`, we had used `.append("text")`? What can you conclude about the behavior of `.join()`?

    b. Consider the join pattern in the third block in the documentation,

```
svg.selectAll("text")
 .data(randomLetters(), d => d)
 .join(
   enter => enter.append("text")
            .attr("fill", "green")
            .text(d => d),
   update => update
            .attr("fill", "gray")
 )
```

    Every time new random letters are generated using `randomLetters()`, there is a chance that some letters are removed, others are added, and some overlap between the two calls. In each of the three cases above, how does the letter appear in the visualization after the update? Does it depend on the original location of that letter within the array?

    c. Rewrite one example either from the D3 for R users book or from our own course lecture notes so that, instead of using the earlier general update pattern (based on `.enter()`, `.exit()`, `.merge()`, or `.update()`) it uses only `.join()`.

15. [Interactive Penguins II] The code at this link creates a scatterplot of body mass against flipper length in the penguins dataset. Your goal in this exercise is to provide a version that responds to user queries.

    a. Skim through `penguins.csv`, which can be downloaded by clicking the small paperclip symbol on the right hand side of the interface. Based on the data available, discuss a potential user query that might be worth supporting. What makes the query interesting?

b. Describe two types of interactivity available in D3 that could be used to support this query. For each, explain (i) the types of input the user provides to specify the query and (ii) the changes in the appearance of graphical marks that is initiated by the query.
c. Implement one of the two interactivity possibilities that you described in the previous part. You may extend the current online implementation. In your submission, include a short video of the interactivity, the code you used, and a brief explanation of the logic behind your implementation.

16. [General Update Pattern Reflection] The general update pattern is one of the central, but also most complex, concepts relevant to D3 programming. This exercise asks you to reflect on your understanding of this concept.

    a. Explain one situation where the general update pattern might be used. Your application may be to an animation or interactive visualization, for example. Be as specific as possible.
    b. Sketch the pseudocode that implements a version of the general update pattern that could potentially be used in the example you outlined in part (a). Give an explanation of the main parts of your pseudocode.
    c. What is one aspect of D3's general update pattern that you think might be most confusing to your peers?

17. [Random Walk with Links] This problem gives practice with the general update pattern in an animation inspired by this example. The code at this link creates a data structure that stores the locations and velocities of all the circles. You will add SVG circle and line elements that reflect updates to this data structure.

    a. What does the `update()` function do? Be specific.
    b. Append the circles in their initial state. The result should be a static plot of circles at the `x` and `y` coordinate positions specified by `circles`.
    c. Animate the circles by calling the `update` function repeatedly. Their locations should reflect the changes in the underlying `x` and `y` property values.
    d. Create links between pairs of circles that are within a prespecified distance of one another. Make sure to enter, exit, and update the paths to reflect the motion of the circles. Hint: For paths with only two endpoints, you may use the `line` SVG element.
    e. What would happen if you did not exit the lines when the circles drifted too far apart? Try this in your visualization and explain what you see.

18. [Urbanization Linked Plots I] In this problem, we will create a static version of the linked bar chart + slope graph visualization from Nadieh Bremer's Urbanization in East Asia visualization. Starter HTML, CSS, and JS code is available at these links [1, 2, 3]. Note that the group elements for the slope graph and barchart have already been translated, so each individual component can assume that the x-axis starts at pixel 0.

    a. Describe the structure of the data that are available for the visualization. How will be able to create a set of bars for both 2000 and 2010?
    b. What types of scales can be used to create the bar chart? Note that the country-level population densities vary from 0 to 10000. Create these scales.
    c. Append the rectangles in the bar chart. The colors from the original visualization are #858483 and #da6761 for 2000 and 2010, respectively. d Annotate the bar chart with country names.
    d. What types of scales should be used for the slope graph? Note that the city-level population densities vary from 0 to 35000. Create these scales.
    e. Draw the circles and lines needed for the slope graph. Provide labels for the cities whose 2010 population density is above 19600.

19. [Urbanization Linked Plots II] This problem continues [Urbanization Linked Plots I], adding interactivity to the scaffolding from the previous version. Starter HTML, CSS, and JS code is available at these links [1, 2, 3]. This provides a static visualization over which we will add our interactivity.

    a. Add an event listener to the rectangles in the bar chart. Print the name of the currently hovered country every time a new bar is hovered.

b. Update the slope graph based on bar chart interaction. Specifically, show only cities within the currently hovered country. You do not need to return to displaying all cities when the mouse moves off of a country.
c. Add an event listener to the lines and circles in the slope graph. Print the name of the currently hovered city every time a new slope is hovered.
d. Update the appearance of the slope graph depending on user interactions. Specifically, if the user has hovered over either the line or the circle associated with a city, highlight that city and make the rest more transparent.

20. [Interactive Census] The code below creates a bar chart of US female population by age groups from the 1900 census. The x-axis is age group, and the y-axis is number of people. We will create an interactive version of this display that allows us to see how the age structure changes over time. [This exercise is adapted from a visualization by Tongshuang (Sherry) Wu at the University of Washington.]

    a. Create an interactive version of the original display that allows you to toggle between age groups in 1900 and 1910. New bars should be introduced for people born between 1900 and 1910. The remaining bars should be shifted to the right by 10 years, and their heights should be adjusted to reflect the new size of that age group.

    b. Generalize your solution in (a) to allow the user to click forward or backward across all the decades in the original dataset.

    c. Allow the user to switch between the genders available in the dataset. When a selection is made, apply a smooth transition to the heights of the bars.

21. [Icelandic Population Analysis] In this problem, we will analyze the design and implementation of this interactive visualization of Iceland's population.

    a. Explain how to read this visualization. What are two potential insights a reader could takeaway from this visualization?
    b. The implementation uses the following data join,

```
rect = rect
  .data(data.filter(d => d.year === year), d => `${d.sex}:${d.year - d.age}`)
```

    What does this code do? What purpose does it serve within the larger visualization?

    c. When the bars are entered at `Age = 0`, they seem to "pop up," rather than simply being appended to the end of the bar chart. How is this effect implemented?
    d. Suppose that you had comparable population-by-age data for two countries. What queries would be interesting to support? How would you generalize the current visualization's design to support those queries?

22. [D3 free exploration] Pick one of the following datasets, or propose one of your own interest: London Olympics, Pokemon, Chicago Traffic Accidents, Australian Pharmaceuticals.

    a. Based on your understanding of how the data were collected and what they represent, prepare four questions that you are interested in. Choose questions that reflect different aspects of the data and whose answers will require more nuanced analysis.

    b. Design and implement a D3 visualization whose interactivity helps to answer the questions you identified in (a). Make sure to include the general update pattern in some part of your implementation.

    c. Explain the way the general update pattern is used in your visualization. Describe why you do or do not use transitions within your implementation.

4 Spatial and Temporal Data

1. [Matching Autocorrelation Functions] The purpose of this problem is to build further intuition about

auto-correlation. We'll simulate data with known structure and then see what happens to the associated autocorrelation functions.

a. The code below simulates a sinusoidal pattern over the course of 2020. Extend the code so that `date` and `y` are contained in a tsibble object.

```
library(lubridate)
date <- seq(from = as_date("2020-01-01"), to = as_date("2020-12-31"), by = 1)
x <- seq(0, 12 * 2 * pi, length.out = length(date))
y <- sin(x) + rnorm(length(x), 0, .4)
```

b. Using the tsibble object, calculate and visualize the induced autocorrelation function. Use a maximum lag of 50, and interpret the resulting plot.

c. Write a function to simulate a version of the tsibble above, but with a linear trend from 0 to `z`, where `z` is an argument to the function.

d. Using the function from (c), generate 5 datasets with linear trends of varying magnitudes. Plot the associated autocorrelation functions and comment on the relationship between the strength of the trend and the shape of the function.

2. [American Time Use Survey] The data here come from the American Time Use Survey (source). Each row gives the typical proportion of Americans engaged in different activities during a given time of the day. The `time` column gives the time of day in five-minute intervals[2]. The `prop` column gives the raw proportion of people engaged in the activity, `prop_relative` gives that proportion normalized to the peak proportion for that activity, and `prop_smooth` is a moving-average smooth of `prop_relative`. We'll use this data to see variation in activities across different times of day.

```
activity <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/main/exercises/ps2/activity.csv
```

a. Skim the data without visualizing it. Write three questions for follow-up analysis. Among these, at least one should compare multiple activities with one another, and at least one should compare timepoints within a single activity.

b. Make a plot of `prop_smooth` over time for each activity. Justify your choice of visual encoding – what questions does it help answer efficiently?

c. Create an alternative visualization using a different encoding. For example, you may (but do not have to) use a heatmap, horizon [notes, package] or ridgeline [notes, package] plot. Compare the trade-offs involved between the two encodings. What questions are easier to answer using your visualization from (b), and which are easier to visualize using your visualization from (c)?

3. [German Traffic] We will use compare and contrast two encodings to visualize traffic volumes across a set of cities. The data are read in below,

```
traffic <- read_csv("https://uwmadison.box.com/shared/static/x0mp3rhhic78vufsxtgrwencchmghbdf.csv")
```

Each row is a timepoint of traffic within a city in Germany.

a. Make a plot of traffic over time, within each of the cities.
b. Describe two takeaways from the resulting figure.
c. Propose an alternative encoding of the same data. What are the strengths of the second approach? What are the strengths of the original approach?

4. [Interactive German Traffic] This problem will revisit the previous problem from an interactive point of view. We will build a visualization that helps users explore daily traffic patterns across multiple German cities, using interactivity to help users navigate the collection. We will need additional features related to the day of the week for each timepoint, created by the `wday` function below,

[2]The date component is an irrelevant placeholder. We included it to simplify the time-of-day formatting in axis labels.

```
library(lubridate)
traffic <- read_csv("https://uwmadison.box.com/shared/static/x0mp3rhhic78vufsxtgrwencchmghbdf.csv")
 mutate(day_of_week = wday(date))
```

   a. Design and implement a Shiny app that allows users to visualize traffic over time across selected subsets of cities. Make sure that it is possible to view data from more than one city at a time. It is not necessary to label the cities within the associated figure.
   b. Introduce new inputs to allow users to select a contiguous range of days of the week. For example, the user should have a way of zooming into the samples taken within the Monday - Wednesday range.
   c. Propose, but do not implement, at least one alternative strategy for supporting user queries from either part (a) or (b). What are the tradeoffs between the different approaches in terms of visual effectiveness and implementation complexity?

5. [Spotify Time Series I] In this problem, we will study music streaming on Spotify in 2017. We'll start by looking at some characteristics of the most streamed song, and then will practice how to extract features from across the collection of most streamed songs.

   a. Let's look at the most streamed song of 2017, which was "Shape of You." The dataset here contains the number of streams for this song across regions, for each day in which it was in the Spotify 100 most streamed songs for that region. Create a `tsibble` object from this dataset, keying by `region` and indexing by `date`.

   b. Filter to `region == "global"`, and make a `gg_season` plot by month. Comment on the what you see.

   c. Provide a scatterplot showing the relationship between the number of streams of this song in the US and in Canada. Do the same between the US and Japan. Briefly comment. **Hint**: Use `pivot_wider` to spread the time series for each region across columns of a reshaped dataset.

   d. The dataset here contains similar data, but for all songs that appeared in the Spotify 100 for at least 200 days in 2017. We have filtered to only the global totals. Read these data into a tsibble, keyed by `artist:track_name` and extract features of the `streams` time series using the `features` function in the feasts library. It is normal to see a few errors reported by this function, it just means that some of the statistics could not be calculated.

   e. Which tracks had the highest and lowest `trend_strength`'s? Visualize their streams over the course of the year.

   f. Discuss one other feature that would be interesting to extract from these time series. Provide a non-technical explanation about what songs with high values of this feature would potentially look like.

6. [Spotify Time Series II] The code below provides the number of Spotify streams for the 40 tracks with the highest stream count in the Spotify 100 dataset for 2017. This problem will ask you to explore a few different strategies that can be used to visualize this time series collection.

```
spotify_full <- read_csv("https://uwmadison.box.com/shared/static/xj4vupjbicw6c8tbhuynw0pll6yh1w0d.
top_songs <- spotify_full |>
  group_by(track_name) |>
  summarise(total = sum(streams)) |>
  slice_max(total, n = 40) |>
  pull(track_name)

spotify <- spotify_full |>
  filter(region == "global", track_name %in% top_songs)
```

   a. Design and implement a line-based visualization of these data.

b. Design and implement a horizon plot visualization of these data.

c. Building from the static views from (a - b), propose, but do not implement, a visualization of this dataset that makes use of dynamic queries. What would be the structure of interaction, and how would the display update when the user provides a cue? Explain how you would use one type of D3 selection or mouse event to implement this hypothetical interactivity.

7. [Global Carbon Footprint Network I] This problem studies a dataset of global carbon emissions collected by the Global Carbon Footprint Network. It was the subject of a previous course project. We will first quality check and structure the raw data. Then, we'll try answering some time series questions visually.

```
carbon <- read_csv("https://go.wisc.edu/7qx7u1")
head(carbon)
```

```
## # A tibble: 6 x 56
##   country  `Country Code` `1992` `1993` `1994` `1995` `1996` `1997` `1998` `1999` `2000` `2001`
##   <chr>    <chr>           <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>
## 1 Afghani~ AFG              0      0      0      0      0      0      0      0      0      0
## 2 Albania  ALB              0.41   0.39   0.4    0.39   0.42   0.35   0.48   0.66   0.68   0.77
## 3 Algeria  DZA              0      0      0      0      0      0      0      0      0      0
## 4 Angola   AGO              0.14   0.14   0.14   0.13   0.13   0.12   0.11   0.11   0.11   0.11
## 5 Argenti~ ARG              0.99   1.01   1.09   1.03   1.09   1.15   1.12   1.06   1.07   0.92
## 6 Armenia  ARM              1.11   0.54   0.32   0.42   0.33   0.41   0.43   0.52   0.48   0.5
## # i 29 more variables: `1982` <dbl>, `1983` <dbl>, `1984` <dbl>, `1985` <dbl>, `1986` <dbl>, `19
## #   `1963` <dbl>, `1964` <dbl>, `1965` <dbl>, `1966` <dbl>, `1967` <dbl>, `1968` <dbl>, `1969` <
## #   `1977` <dbl>, `1978` <dbl>, `1979` <dbl>
```

a. The first few rows of the dataset are printed above. Write down two interesting questions that you think the dataset could help to answer. Refer to at least one of the following vocabulary terms: trend, seasonality, autocorrelation, cross-correlation, cyclic behavior.

b. Build a `tsibble` object from the data above. Discuss why it can be useful to convert the original `data.frame` object to this new `tsibble` class.

c. Create either a line or heatmap visualization of the time series across all countries. What have you learned from your visualization?

d. Create a lag plot of the series for the United States. How do you interpret this figure?

This plots each timepoint against the time series' value n steps in the past. Each facet corresponds to a different n. Notice that there is stronger correlation with the immediate past (lag 1) compared to the long-run past.

e. Create a lineplot across all countries after taking a moving aver neighboring years. What are the advantages and disadvantages of smoothing the original line plot?

8. [Global Carbon Footprint Network II] This problem creates interactive versions of the carbon emissions dataset introduced in the previous problem.

a. Using `ggplotly`, create a line plot where country names can be revelaed on hover.

b. Propose an interactive time series visualization that graphically queries a time series feature (or several features) that can be generated using the `feasts` package. What questions is your visualization particularly well-suited to? What questions is it not appropriate for?

c. Implement your proposal from part (b).

9. [Bike Demand] This problem asks you to visualize a dataset of hourly bikeshare demand. Provide your code and make sure it is readable.

a. Make a line plot of bike demand (`count`) by hour, faceted out across the 7 days of the week (`weekday`).

b. Create a new summary data.frame giving the 25 and 75 percent quantiles of demand (`count`) for each hour (`hr`) by day of the week (`weekday`) combination, separately within each year (`yr`) that the data was collected.
c. Using a ribbon plot, overlay the quantities from (b) onto your plot from part (a). Use color to distinguish between the ribbons for the first and second year that the data were collected.
d. Provide a brief description of some takeaways from the final visualization.

10. [Australian Pharmaceuticals I] The PBS dataset contains the number of orders filed every month for different classes of pharmaceutical drugs, as tracked by the Australian Pharmaceutical Benefits Scheme. It is read in below,

```
pbs <- read_csv("https://uwmadison.box.com/shared/static/fcy9q1uleqru7gcs287q903y0rcnw2a2.csv") |>
  mutate(Month = as.Date(Month))
```

a. In the text box below, provide code that will transform the data into a tsibble object, with month as the index and ATC2_desc as the key.
b. Using the feasts package, extract features for this time series collection. The series with the largest trend_strength is...
c. Perform a PCA on the following subset of extracted features (these are just trend_strength, features that start with "seasonal", or features containing the string "acf"), Make sure to normalize all features first.

```
"trend_strength", "seasonal_strength_week", "seasonal_peak_week", "seasonal_trough_week",
"stl_e_acf1", "stl_e_acf10", "acf1", "acf10", "diff1_acf1",
"diff1_acf10", "diff2_acf1", "diff2_acf10", "season_acf1",
"pacf5", "diff1_pacf5", "diff2_pacf5", "season_pacf"
```

d. Make a plot of the top two principal components. Show the 17 features for each component, and order the features according to the magnitude of their contribution. Provide a brief interpretation of the second principal component direction.

11. [Australian Pharmaceuticals II] The code below takes the full PBS dataset from the previous problem and filters down to the 10 most commonly prescribed pharmaceutical types. This problem will ask you to implement and compare two approaches to visualizing this dataset.

```
pbs_full <- read_csv("https://uwmadison.box.com/shared/static/fcy9q1uleqru7gcs287q903y0rcnw2a2.csv"
    mutate(Month = as.Date(Month))

top_atcs <- pbs_full |>
  group_by(ATC2_desc) |>
  summarise(total = sum(Scripts)) |>
  slice_max(total, n = 10) |>
  pull(ATC2_desc)

pbs <- pbs_full |>
  filter(ATC2_desc %in% top_atcs, Month > "2007-01-01")
```

a. Implement a stacked area visualization of these data.
b. Implement an alluvial visualization of these data.
c. Compare and contrast the strengths and weaknesses of these two visualization strategies. Which user queries are easier to answer using one approach vs. the other?

12. [Polio incidence] In this problem, we will use a heatmap to visualize a large collection of time series. The data, prepared by the Tycho Project, contain weekly counts of new polio cases in the United States, starting as early as 1912 (for some states).

a. Pivot the raw dataset so that states appear along rows and weeks appear along columns. Fill

weeks that don't have any cases with 0's.

```
polio <- read_csv("https://uwmadison.box.com/shared/static/nm7yku4y9q7ylvz5kbxya3ouj2njd0x6.csv")
```

b. Use the `superheat` package to make a heatmap of the data from (a). Have the color of each tile represent `log(1 + cases)`, rather than the raw counts. Reorder the states using a hierarchical clustering by setting `pretty.order.rows = TRUE`.

c. Supplement the view from part (b) with a barchart showing the US total incidence during every given week. Interpret the resulting visualization. *Hint: use the* `yt` *argument of superheat.*

d. Describe types of annotation would improve the informativeness of the plot made in part (c). Also, describe one advantage and one disadvantage of visualizing a collection of time series as a heatmap, instead of as a collection of line plots.

13. [Chicago Traffic Accidents] The dataset here is a preprocessed version of a dataset downloaded from Chicago's official traffic accidents database. In this problem, we will use a heatmap to understand what times during the week and over the year are associated with the highest number of traffic accidents.

    a. Use a heatmap to visualize the accident counts over time. Specifically, one dimension of the heatmap should index the 168 hours in the week, and the other should index every week from 2013-03-03 to 2022-03-27.

    b. Enrich your visualization with information about the total number of accidents in each of the 168 hours in the week. *Hint: Use the* `yt` *or* `yr` *arguments to* `superheat`*.*

    c. Provide a brief interpretion of your final visualization.

14. [Air Pollution Time Searcher] The dataset at this link measures hourly PM2.5 concentration in Beijing for one year (2014). We will implement a simplified version of a TimeSearcher visualization to help us discover patterns in daily pollution trends. We will start by creating a line plot before implementing brush interactivity.

    a. We will visualize the year's worth of data as a collection fo 365 separate lines. How do the data need to be restructured in order support this visualization? Implement a function that reshapes the data. You may use either R or javascript.

    b. Build a static lineplot visualization of these data. Make sure to provide x and y-axes.

    c. Introduce a brush so that all series that pass through the brush are highlighted.

    d. Following the discussion on this page, modify your solution to part (c) so that multiple brushes can be drawn simultaneously. Filter down to series that pass simultaneously through all brushes.

    e. Comment on the shapes of the series that you can discover with your multi-brush visualization. What are the most common trends? Did you discover any outlying shapes?

    f. Bonus: Link your time searcher visualization with a table. Consider using an existing javascript tables library, like one of those discussed on this page.

15. [Women, Business and the Law] The World Bank's Women, Business, and the Law program has curated a dataset about gender equality across countries since 1971. Since there are more than 30 variables summarizing each country for each year, we will use clustering to observe the general trends across all measures.

    a. The code below reads in the data, simplifies column names (saving the original names in the `question_mapping` data.frame), and converts text Yes / No responses to numerical 0 / 1. Widen the dataset so that each row corresponds to a single country × year combination.

```
# read in and create a codebook
survey <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/main/exercises/data/Viz5-July-202
question_mapping <- survey |>
  select(Question, `Question Category`) |>
```

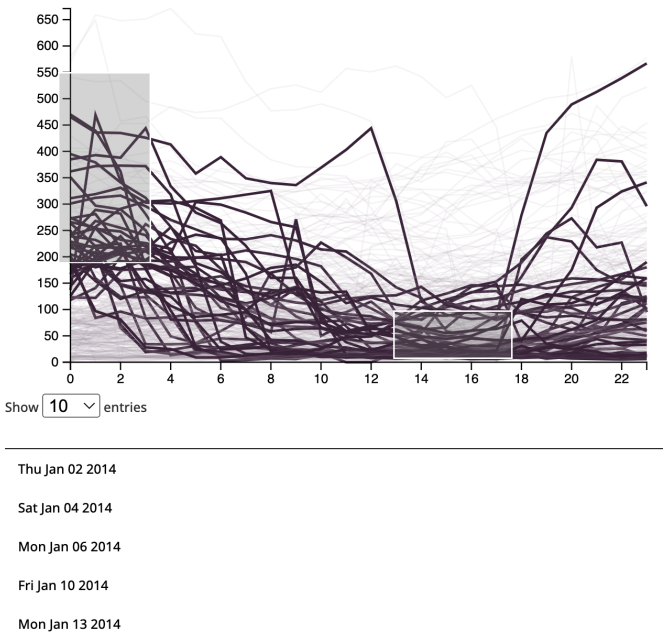


Figure 9: An example solution to [Air Pollution Time Searcher].

```
  distinct() |>
  mutate(q_id = str_c("Q", row_number()))

recode_vector <- setNames(question_mapping$Question, question_mapping$q_id)
survey <- survey |>
  mutate(
    Question = fct_recode(Question, !!!recode_vector),
    answer = as.numeric(ifelse(`Text Answer` == "Yes", 1, 0))
  ) |>
  select(Country, `WBL Report Year`, Question, answer)

survey
```

```
## # A tibble: 332,500 x 4
##    Country     `WBL Report Year` Question answer
##    <chr>                   <dbl> <fct>     <dbl>
##  1 Afghanistan              1971 Q1            0
##  2 Afghanistan              1971 Q2            1
##  3 Afghanistan              1971 Q3            0
##  4 Afghanistan              1971 Q4            1
##  5 Afghanistan              1971 Q5            0
##  6 Afghanistan              1971 Q6            1
##  7 Afghanistan              1971 Q7            1
##  8 Afghanistan              1971 Q8            1
##  9 Afghanistan              1971 Q9            0
## 10 Afghanistan              1971 Q10           1
## # i 332,490 more rows
```

b. Apply K-means to the question responses (you may choose K). Visualize the centroids and briefly in-

terpret each cluster in context, using the original text of the questions stored in `question_mapping`.

c. Visualize change in cluster sizes over time. Provide a brief interpretation (for example, in which types of questions is there the most / least progress towards equality?).

16. [NYC Trees] In this problem, we'll use vector data to enrich a visualization of trees in New York City. In the process, we'll practice reading in and generating summaries of geospatial data.

    a. The data at this link include a subset of data from the New York City Tree Census. Make a scatterplot of the locations of all trees in the data, coloring in by tree species group and faceting by health.

    b. Suppose we wanted to relate these data to characteristics of the built environment. We have curated public data on roads and buildings within the same neighborhood. Read these data into `sf` objects using `read_sf`. For both datasets, report (i) the associated CRS and (ii) the geometry type (i.e., one of point, linestring, polygon, multipoint, multilinestring, multipolygon, geometry collection).

    c. Generate a version of the plot in (a) that has the roads and buildings in the background.

17. [Himalayan Glaciers] In this problem, we'll apply the reading's discussion of raster data to understand a dataset containing Landsat 7 satellite imagery of a Himalayan glacier system.

    a. Read the data into a `brick` object. What is the spatial extent of the file (that is, within what geographic coordinates do we have data)? How many layers of sensor measurements are available?

    b. Generate an RGB image of this area. In Landsat 7, the first three layers (B1, B2, and B3) provide the red, green, and blue channels.

    c. Make a plot of the slopes associated with each pixel within this region.

18. [CalFresh Enrollment I] In this problem, we will investigate spatial and temporal aspects of enrollment in CalFresh, a nutritional assistance program in California.

    a. The code below reads in the CalFresh data. We've filtered out February 2019, since benefits were distributed differently in this month, leading to outliers for most counties. Extract features of the `calfresh` time series using the `features` function in the feasts library.

```
library(tsibble)
calfresh <- read_csv("https://uwmadison.box.com/shared/static/rduej9hsc4w3mdethxnx9ccv752f22yr.csv"
  filter(date != "2019 Feb") |>
  mutate(date = yearmonth(date)) |>
  as_tsibble(key = county, index = date)
```

    b. Visualize CalFresh enrollment over time for the counties with the highest and lowest `seasonal_strength_year`.

    c. The code below reads in a vector dataset demarcating the county boundaries in California. Join in the features dataset from (a) with this these vector data. Use this to produce a map with each county shaded in by its `seasonal_strength_year`.

```
library(sf)
counties <- read_sf("https://uwmadison.box.com/shared/static/gropucqxgqm82yhq13do1ws9k16dnxq7.geojs
```

    d. Propose, but do not implement, a visualization of this dataset that makes use of dynamic queries. What questions would the visualization answer? What would be the structure of interaction, and how would the display update when the user provides a cue?

19. [CalFresh Enrollment II] In this problem, we will develop an interactively linked spatial and temporal visualization of enrollment data from CalFresh, a nutritional assistance program in California. We will work off of the pre-filtered dataset from the previous problem. We will use D3 in this problem, and a recording of an example solution can be found here.

a. Using a line generator, create a static line plot that visualizes change in enrollment for every county in California.
b. On the same page as part (a), create a choropleth map of California, shaded in by the average enrollment for that county over the full time window of the dataset.
c. Propose one interactive, graphical query the links the combined spatial + temporal view from (a - b). For example, you may consider highlighting time series when a county is hovered, highlighting counties when specific series are brushed, or updating choropleth colors when a subsetted time range is selected.
d. Implement your proposal from part (c).

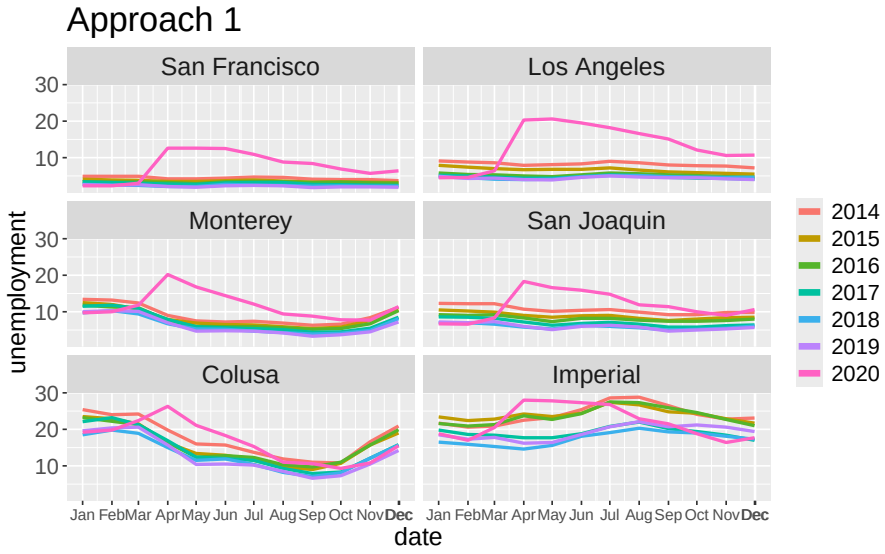
20. [CalFresh Comparison] In this problem, we will compare several approaches to visualizing the CalFresh enrollment dataset.

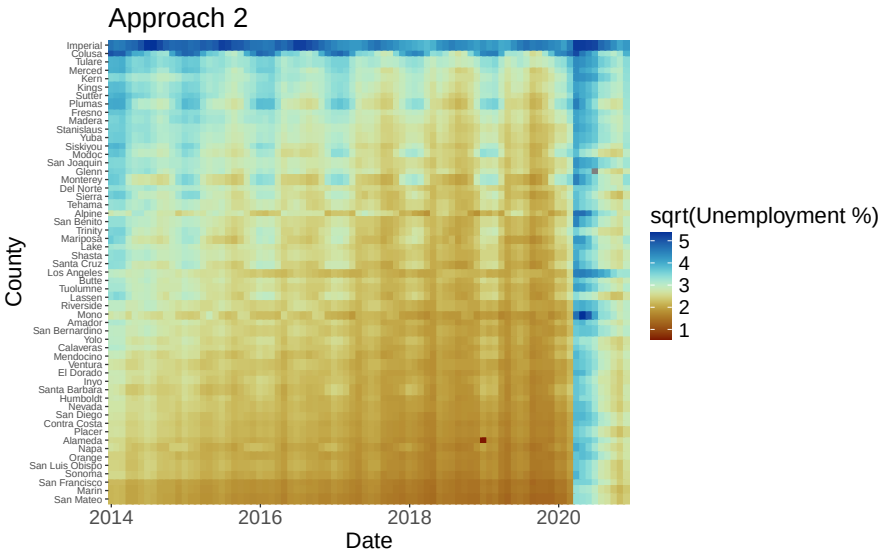
a. In your own words, define the term, "graphical encoding" and give an example.

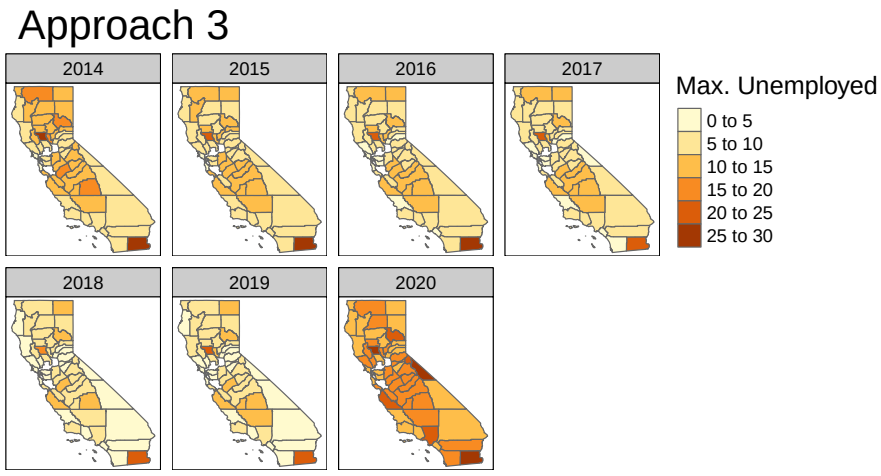
b. The code below reads in a dataset of monthly unemployment rates in California from 2014 through 2020. These data are visualized using three different techniques below. Describe the relative strengths and weaknesses of *two of these views* with respect to the tasks that they support.

```
unemployment <- read_sf("data/unemployment.geojson") |>
  mutate(date = yearmonth(date))
focus <- c("Colusa", "Monterey", "San Francisco", "Imperial", "Los Angeles", "San Joaquin")
head(unemployment, 3)
```

```
## Simple feature collection with 3 features and 4 fields
## Geometry type: MULTIPOLYGON
## Dimension:     XY
## Bounding box:  xmin: -122.3316 ymin: 37.45444 xmax: -121.4693 ymax: 37.90502
## Geodetic CRS:  WGS 84
## # A tibble: 3 x 5
##   county      date  year unemployment
##   <chr>      <mth> <dbl>        <dbl>
## 1 Alameda 2014 Jan  2014          6.5 (((-122.3129 37.89733, -122.2885 37.89793, -122.2742 37.90
## 2 Alameda 2014 Feb  2014          6.4 (((-122.3129 37.89733, -122.2885 37.89793, -122.2742 37.90
## 3 Alameda 2014 Mar  2014          6.4 (((-122.3129 37.89733, -122.2885 37.89793, -122.2742 37.90
```







c. Provide code to answer: For each county and year, what was the maximum unemployment rate across all months?

d. Provide code to implement one of the figures above. You may assume the result from part (c) and do not need to match color or text themes.

21. [Geospatial Datasets] For each of the datasets below, specify whether it is in a vector or raster data format. If it is in a vector data format, explain which types of geometries it contains (e.g., a point or linestring). Explain your reasoning.

    a. NYC Building Footprints

    b. Africa Population 2020

    c. Himalayan Glacial Lakes

    d. Wisconsin EV Charging

    e. Zion Elevation

    f. Visualize *one* of these datasets.

22. [Geospatial Commands] For each of the commands below, explain (i) whether it can be applied to vector data, raster data, or both and (ii) discuss a typical use case for the function.

    a. `read_sf`

b. `raster`

c. `as.data.frame(img, xy = TRUE)`

d. `geom_sf`

e. `coord_sf`

23. [Temporal and Geospatial Commands] For each of the commands below, explain what role it serves in temporal or spatial data visualization. Describe a specific (if hypothetical) situation within which you could imagine using the function.

    a. `geom_stream`
    b. `tm_lines`
    c. `rast`
    d. `geom_horizon`

24. [`tmap` Exploration] There are many example maps on the `tmap` package's homepage – see the vignettes, tutorials, or presentations, for example. In this problem, you will recreate and deconstruct one example visualization from this webpage.

    a. Pick one figure from the page linked above. Describe the data used to generate this figure. Is the data in a vector or raster format?
    b. Regenerate the figure and write comments in the code that describe the purpose for each layer (or related groups of layers).
    c. Have you ever worked with a dataset where the type of visualization you just created might have been helpful? If so, describe how. If not, imagine a hypothetical data analysis project where you might use this code.

25. [Glacial Lakes]. The data at this link contain labels of glacial lakes the Hindu Kush Himalaya, created during an ecological survey in 2015 by the International Centre for Integrated Mountain Development.

    a. How many lakes are in this dataset? What are the latitude / longitude coordinates of the largest lakes in each Sub-basin?

    b. Plot the polygons associated with each of the lakes identified in step (a). _Hint: You may find it useful to split lakes across panels using the `tmap_facets` function. If you use this approach, make sure to include a scale with `tm_scale_bar()`, so that it is clear that lakes have different sizes.

    c. Visualize all lakes with latitude between 28.2 and 28.4 and with longitude between 85.8 and 86. Optionally, add a basemap associated with each lake.

26. [Population Density] The problem below visualizes population data from the `afrilearndata` package.

    a. What are the dimensions (in pixels) of the population dataset? What is its coordinate reference system?

    b. Convert the raster data to a `data.frame`. Omit rows without any population data.

    c. Visualize the data. What are some regions with the lowest and highest population densities?

27. [Masking Temperature Data] This problem will visualize the temperature data downloaded from this site from the Australian Bureau of Meteorology. It presents some new ideas related to raster masking.

    a. Read in the raster data, directly convert it to a data.frame, and use a `geom_raster` layer to visualize raw temperature data.

    b. The data includes temperature over the ocean! We really only want to visualize the temperatures over land. Using the `mask` function from the `raster` package, clip the original raster data to a polygon containing the Australia country boundaries. These boundaries are read in the code block below,

```
library(rnaturalearth)
australia <- ne_countries(country = "australia")
# mask(... fill this in...)
```

c. Regenerate the plot from (a), but using the masked raster from (b). Ensure that the masked NA values are left out of the visualization. Bonus: Use a binned color scale (e.g., `scale_fill_viridis_b`) to make the temperature variations even clearer.

28. [Interactive NYC Trees] This problem walks through the creation of an interactive map of the NYC Trees Dataset.

    a. Filter down to only those trees whose diameter at breast height (`tree_dbh`) is larger than 10. This will help reduce overplotting.

    b. Use `leaflet` and the `addCircles` command to create a map with the trees kept in part (a). Have the size of the circles reflect the `tree_dbh` value.

    c. Add a basemap that highlights features of the city without being too busy. For example, you can use `addProviderTiles(providers$CartoDB.Positron)`.

    d. Color each tree's circle according to its species group. *Hint: Create a mapping from species groups to colors using the `colorFactor` function in Leaflet. For example, `pal <- colorFactor(brewer, filtered_trees$species_group)` creates an objet `pal` that can be called in the `color` argument to `addCircles`.*

29. [Job Interview] Imagine that you are interviewing job candidates for a data science position that involves visualizing {This Part Filled in Class}. Prepare an interview question that test candidates' knowledge of / experience with these topics. Also prepare examples of strong responses. An good question will either (i) ask the interviewee to describe a specific time in the past where they used the concept or (ii) present the interviewee with a type of challenge related to what is commonly encountered and see how they would address it.

30. [Social Data Vis] Perhaps the best way to learn data visualization is to (a) study the work of those who are more experienced and (b) practice. One neat way to go about this is to participate in social data visualization activities, like TidyTuesday or the 30DayChartChallenge. This exercise will ask you to study examples of/prepare your own submission to one of these activities.

    a. Pick any prompt from either TidyTuesday or 30DayChartChallenge that interests you. Without writing any code or searching online, briefly brainstorm some submission ideas (no more than 15 minutes). Summarize your thoughts.

    b. Search for some publicly posted submissions for your prompt. Pick two and comment their designs. Compare and contrast their choices of graphical encodings. What effective design decisions did the authors make that you could potential imitate? What might you have done differently?

    c. Prepare your own response to the prompt. Your visualization and commentary should be complete enough that you could hypothetically use it as a blog post/social media thread if you were participating in the challenge publicly.

31. [Visualization for Everyday Decisions] We routinely encounter spatial and temporal data in everyday life, from the from the dates on a concert calendar to the layout of buttons in an elevator. This problem asks you to critically reflect on the way these data are represented.

    a. Describe one type of spatial or temporal dataset (loosely defined) that you encounter in a nonacademic context. What visual encodings are used? Does it implement any interactivity?

    b. What questions does the visualization help you answer? How easily can you arrive at an accurate answer?

c. In the spirit of the re-imagined parking sign project, propose an alternative representation of these data (or an alternative way of interacting with the same representation). Why did you propose the design that you did? What advantages do you think it has?

5 Network and Hierarchical Data

1. [Political Book Recommendations] In this problem, we'll study a network dataset of Amazon bestselling US Politics books. Books are linked by an edge if they appeared together in the recommendations ("customers who bought this book also bought these other books").

   a. The code below reads in the edges and nodes associated with the network. The edges dataset only contains IDs of co-recommended books, while the nodes data includes attributes associated with each book. Build a `tbl_graph` object to store the graph.

```
edge_data_path <- "https://raw.githubusercontent.com/krisrs1128/stat992_f23/6c4130bddbdfc9ef90537c7
node_data_path <- "https://github.com/krisrs1128/stat992_f23/raw/6c4130bddbdfc9ef90537c794cdca47773
edges <- read_csv(edge_data_path, col_types = "cci")
nodes <- read_csv(node_data_path, col_types = "ccc")
```

   b. Use the result from part (a) to visualize the network as a node-link diagram. Include the book's title in the node label, and shade in the node according to political ideology.

   c. Create the analogous adjacency matrix visualization. Provide examples of visual queries that are easy to answer using one encoding but not the other (i.e., what is easy to see in the node-link view vs. what is easy to see in the adjacency matrix).

2. [Interactive Political Books] In this problem, we'll study a network dataset of Amazon bestselling US Politics books. Books are linked by an edge if they appeared together in the recommendations ("customers who bought this book also bought these other books"). Since including all the book titles in a single static view can be overwhelming, we will design an interactive view that selectively reveals titles depending on user interest.

   a. Represent the network using a node-link diagram. Layout the nodes using a force-directed layout. Color nodes in by their political affiliation.

   b. Implement a tooltip that reveals the title of a book whenever the user places their mouse near (but not necessarily on) its node. Use a transition to gradually increase the size of the associated node.

   c. Extend the interactivity in (b) so that the titles of all neighboring books of the currently hovered node are also displayed. Ensure that the title of the central book appears larger than the rest.

3. [Network Vis T/F] Select all the true statements about network visualization.

   - For large, dense networks, node-link diagrams are preferable to adjacency matrix visualizations.
   - For tasks related to local topology, node-link diagrams are preferable to adjacency matrix visualizations.
   - It is possible to visually encode edge weight in either node-link or adjacency matrix visualizations.
   - It is possible to visually encode node category in either node-link or adjacency matrix visualizations.

4. [More Network T/F] Circle whether the following statements about network and tree visualization are TRUE or FALSE.

   a. TRUE FALSE In treemap visualizations, each tree node is allocated an area, and all of its children are contained within that area.

   b. TRUE FALSE For large, dense networks, node-link diagrams are preferable to adjacency matrix visualizations.

   c. TRUE FALSE For topological queries, both node-link diagrams and adjacency network visualizations are equally effective.

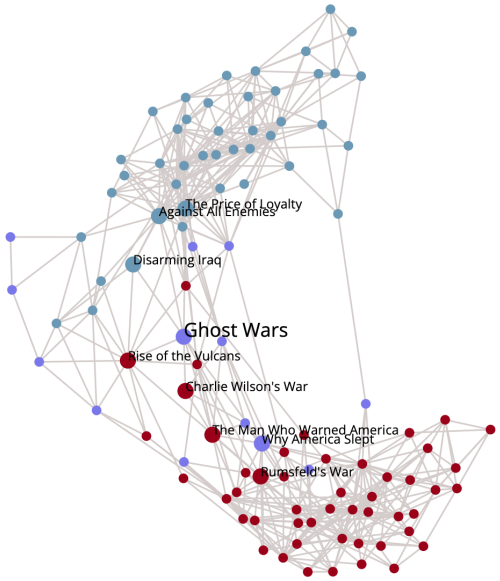


Figure 10: An example solution to [Interactive Political Books] part (c). The currently selected book is Ghost Wars. All its neighbors are also labeled, but in a smaller font.

d. TRUE FALSE Adjacency matrix views are only appropriate when all edges are undirected.

5. [Movie Genres] How do movie genres relate to one another? Is romance + comedy a more common combination than fantasy + adventure? We will use the dataset here to answer these questions, using a node-link diagram inspired by (but much simpler than) the film flowers project by Shirley Wu.

   a. Build a `tbl_graph` containing the movies and their links.

   b. Create a node-link diagram to represent the connections between movies and their genres.

   c. A list of all the genres in this network is available here. Design a strategy to distinguish between genres and movies, and justify your choice of visual encodings. *Hint: Mutate the nodes in the `tbl_graph`.*

6. [COVID-19 Phylogeny] We will visualize a phylogenetic tree of SARS-CoV-2 genetic sequences. Each sequence has been annotated with the date and location it was found, and we will try to see how genetic variation covaries with these measurements.

   a. Build a `tbl_graph` using the links and nodes associated with the phylogenetic tree. Note that many nodes do not have variables associated with them. This is because annotations are only available for the leaves of the tree, and nodes are unobserved common ancestor viruses.

   b. Visualize the phylogenetic tree using the data from (a).

   c. Visually encode the date or location at which each sequence was found (for a challenge, try encoding both). Justify your choice of encodings – what are some advantages / downsides of the approach you decided on?

   d. Discuss the resulting visualization. For example, how much genetic diversity do different countries have? Where are different waves located genetically?

7. [Interactive Phylogeny] We will build an interactive phylogenetic tree of SARS-CoV-2 genetic sequences. Each sequence has been annotated with a date and location of its discovery. We will use D3 to allow readers to explore the way genetic changes unfold over time and space. You can find the raw data here: nodes, edges. We have provided starter code to build a `d3.stratify()` object from the edge data and

to define an object, `node_lookup`, which can be used to look up the country and date associated with the `from` and `to` fields in the edges.

a. Create a static tree visualization that shows how the different COVID variants evolved from one another. Use color to encode the location of the variant's discovery. You may group rare countries into "Other," and draw variants with unknown origins using either white or grey.
b. Implement *one* of the following forms of interactivity,
   i. Provide a selection menu that highlights countries that the user selects.
   ii. As the user hovers near to a node, highlight all of its ancestors. Blend the rest of the nodes into the background.
   iii. As the user brushes a collection of nodes, highlight only those nodes under the brush. Blend the rest of the nodes into the background.
c. Propose, but do not implement, an extend version of part (b) that is linked with an additional table or visualization. How would the second graphic be updated in response to user interactions? What additional queries become possible in your proposed visualization?

8. [Climate Crisis Youtube recommendations] We will study a dataset giving links between Youtube videos related to the climate crisis. The data were gathered by simulating a user browsing through recommendations, after having initially searched using a set of climate-related seed terms. Each node is a video, which includes features like the number of views and the channel it belongs to. Each edge provides an algorithmically generated recommendation.

   a. Build a `tbl_graph` from the provided node and edge data.

   b. Visualize the connections between videos as a node-link diagram. Color nodes in by the simulated browser session.

   c. Visualize the connections between videos as an adjacency matrix.

   d. Compare and contrast the visualizations in parts (b) and (c). What are some of the trade-offs associated with using one view vs. the other?

   e. Select a small number of channels of interest (e.g., "The Daily Show with Trevor Noah") For either parts (b) or (c), find a way to visually distinguish nodes belonging to these channels from the rest.

9. [UK Energy Flow] We will visualize how energy is produced and consumed in the United States, using a dataset from the UK's Department of Energy and Climate Change. Nodes and edges are used to classify types of activity that produce or consume energy. For example, the edge

   ```
   Wind    Electricity grid    289
   ```

   means that 289 KwH produced by wind power were sent to the country's electricity grid.

   a. Build a `tbl_graph` from the provided edges. Ensure that the resulting graph object has directed edges.

   b. Use `ggraph` to visualize the flow of energy across nodes in this network. Ensure nodes are annotated.

   c. Experiment with several layouts. Which do you find most useful? Is there an alternative layout you would prefer? Explain your reasoning.

10. [Stack Overflow Tag Network] Questions on Stack Overflow are given tags. This makes it easy to search through all the questions on a certain topic. The co-occurrence of tags appearing on certain questions also makes it natural to build a network between these tags – we draw a weighted edge between co-occurring tag, with weights representing the number of questions within which the pair appears. We will look at only a small subset of tags, originally presented in this post. In the process, we will practice creating network visualizations and encoding detected cluster memberships.

    a. Build a `tbl_graph` object based on node and link data that were generated using a web scraper.

    b. Create a node-link visualization associated with the network.

c. Cluster nodes and encode modify your visualization from (b) to encode cluster membership. *Hint: Mutate the graph using the* ***group_louvain()*** *or* ***group_infomap()*** *functions from* ***tidygraph****.*

d. Comment on the visualization from (c). What do the clusters seem to correspond to?

11. [Coltrane Network] We will visualize the network of musicians who share a recording with John Coltrane, obtained from this source. Two musicians are linked with one another if they appeared on an album together, at least as recorded in the MusicBrainz database. To visualize these data, we will practice creating network visualizations and encoding detected cluster memberships.

    a. Build a `tbl_graph` object based on the node and link data.

    b. Create a node-link visualization associated with the network.

    c. Cluster nodes and modify your visualization from (b) to encode cluster membership. *Hint: Mutate the graph using the* ***group_louvain()*** *or* ***group_infomap()*** *functions from* ***tidygraph****.*

    d. Comment on the visualization from (c). How would you interpret the resulting clustering?

12. [Hierarchical Edge Bundling] In this problem, we will study a D3 hierarchical edge bundling implementation available at this link. The display shows how different files in a software package import from one another. Unlike a naive radial node-link layout, this layout "bundles" together edges if their source and target nodes have common ancestors in the package's directory tree (which is why the resulting layout is called a "Hierarchical Edge Bundling").

    a. Use `console.log()` to inspect the `root` object. Describe its structure.

    b. What does this line do?

    ```
    .attr("d", ([i, o]) => line(i.path(o)))
    ```

    Provide one example of an edge in the original visualization (e.g., for example `xor <--> or`, though this is not a correct answer) where you believe `i.path(o)` contains more than two elements, and explain your reasoning. You may find it useful to `console.log()` the result from `i.path(o)`.

    c. Imagine that you are working for a biotechnology firm that is interested in visualizing a protein network. You have data on the co-occurrence frequency for all pairs of proteins (high-co-occurrence can be interpreted as the proteins lying on a shared regulatory pathway). What, if any, additional information would you need before you could implement a hierarchical edge bundling visualization of the network? Explain your reasoning.

6 High-Dimensional and Text Data

1. [Colony Collapse] In this problem, we will study a dataset describing factors that might be leading to colony collapse disorder among bees. Since there are multiple stressors for each state × timepoint combination, we will use clustering to create a summarized "ecological stress" profile.

    a. The code below reads in data from its original Tidy Tuesday source and replaces NAs with 0's. We will summarize each state × timepoint combination by its profile of `stress_pct` across each stressor. Reshape the data so that `stressor` appears along columns, with the associated percentage contained within the table. Each row is therefore a profile of the amount of different stressors at a particular location and time.

    ```
    stressor <- read_csv('https://raw.githubusercontent.com/rfordatascience/tidytuesday/master/data/202
      mutate(stress_pct = replace_na(stress_pct, 0))
    ```

    b. Apply K-means to the profiles constructed in part (a). You may choose K. Visualize and briefly interpret the resulting centroids.

    c. Design and implement a visualization to show the change in cluster memberships over time. Briefly interpret your results in context.

d. [Bonus] The code below reads in spatial data associated with each state. Design and implement a visualization that encodes spatial variation across clusters, either at a single timepoint or over all time. An example result is shown in Figure 11.

```
library(rnaturalearth)
library(sf)
states <- ne_states("United States of America") |>
  st_as_sf() |>
  rmapshaper::ms_simplify() |> # reduce size for easy plotting
  filter(!(name %in% c("Alaska", "Hawaii"))) |>
  select(name, geometry) |>
  rename(state = name)
```

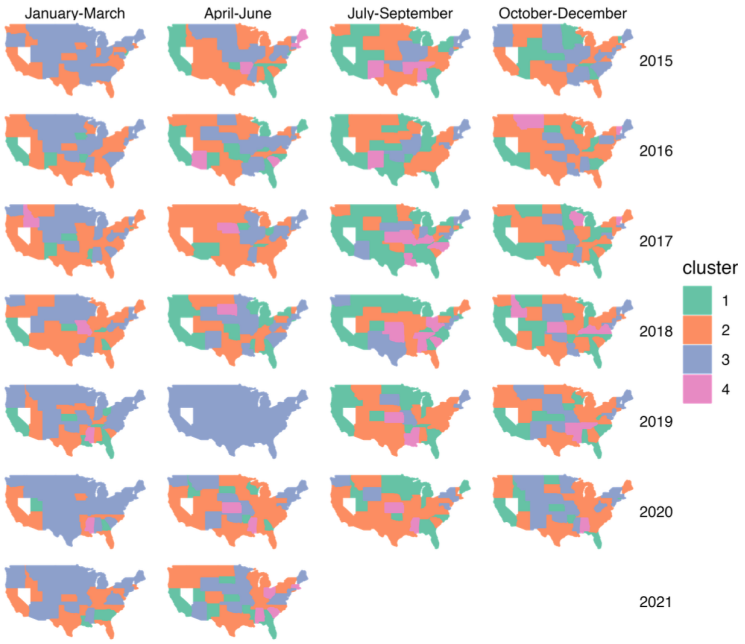


Figure 11: Spatial distribution of colony collapse clusters over time.

2. [Hierarchical Clustering T/F] Figure **??** shows a subset of a large hierarchical clustering tree. Select all the true statements below.

   - Samples C and D are more similar to one another than A and B.
   - If this subtree were cut to form K = 5 clusters, then C and D would belong to the same cluster.
   - A and B are more similar to each other than B and C.
   - If this subtree were cut to form K = 2 clusters, then A and B would belong to the same cluster.

3. [Taxi Trips] In this problem, we will use hierarchical clustering to find typical taxi trip trajectories in Porto, Portugal. The data are a subset from the the ECML / PKDD 2015 Challenge – the link provides a complete data dictionary. We have preprocessed it into two formats. The first (`wide`) includes each taxi trip on its own row, with latitude and longitude coordinates along the journey given as separate columns (`x_0, y_0` is the origin of the trip and `x_15, y_15` is the destination). The second (`long`) format spreads each point of the journey into a separate row.

   a. Filter the `long` form of the data down to trip `1389986517620000047` and plot its trajectory as a sequence of points.

```
trips <- read_csv("https://uwmadison.box.com/shared/static/098cjaetm8vy0mufq21mc8i9nue2rr2b.csv", c
trips_wide <- read_csv("https://uwmadison.box.com/shared/static/cv0lij4d9gn3s8m2k98t2ue34oz6sbj5.cs
```

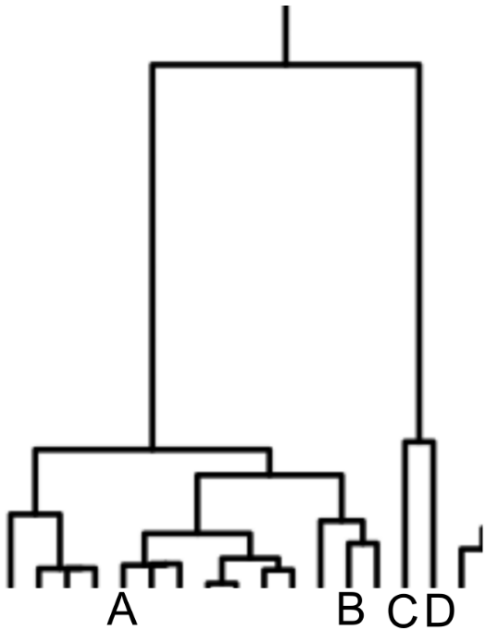


Figure 12: A subset of a large hierarchical clustering tree

b. We could hierarchically cluster rows in either the `wide` or the `long` format datasets. How would the interpretation of the results differ between the two approaches?

c. Compute a hierarchical clustering of the `wide` format data, using only the columns starting with `x` or `y` as features.

d. Cut the hierarchical clustering tree so that 8 clusters are produced. Visualize the trajectories of the taxi trips either colored or faceted by their cluster.

4. [Support for Animal Research] This problem utilizes response data from a survey of UW–Madison students and faculty by Sandgren and Streiffer (2019). The survey assessed respondents' support for the use of non-human animals in scientific research. Questions were categorized into various groups. The heatmap in figure **??** shows each respondent's average response by question type. Higher-valued responses indicate more support for the use of non-human animals in scientific research.

   a. The definition of "strong support" is not given. However, one cluster seems to correspond to the strong support group. Which one, and why?
   b. True or False: There appears to be a weak relationship between support for non-human animal research across question types.
   c. Cluster 3 contains the fewest respondents. Discuss potential reasons why this may have been the case.

5. [Interpreting Clustering] Imagine that you are a statistical consultant working with a scientist / sports team / journalist / sales division head (pick your favorite or make up your own example). At one point in your study, you found it useful to apply various types of clustering methods. In this problem, you are asked to provide a non-technical explanation of how to interpret your clustering output, assuming that your audience is familiar with their data but not statistical methodology.

   a. You have run K-means with $K = 5$ clusters across their dataset, which includes 50 different measurements for each row. Explain to your audience what each centroid represents.

   b. At another point, you applied hierarchical clustering to the same dataset. You include a visualization of the hierarchical clustering tree in your report. Provide a brief, non-technical explanation of how

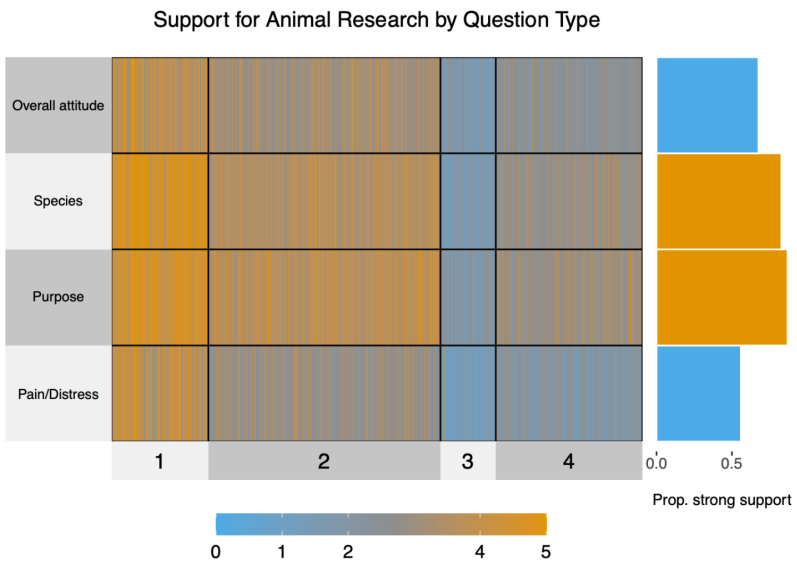


Figure 13: Responses from Sandgren and Streiffer (2022).

to interpret the tree.

c. Your audience finds the hierarchical clustering tree, but wonders why you needed a new algorithm to produce it. They think that you would have gotten similar results if you had simply run K-means with different values of K. Respond to their observations.

6. [Beijing Air Pollution] This problem studies daily air pollution and weather patterns in Beijing from 2010 to 2014. Each row in this dataset gives measurements for three variables, `pollution`, `temp`, and `wndspd` over time for a single day, indexed by `date`. For example the `temp_13` column gives the temperature at 1pm. Note that both `pollution` and `wndspd` have been $\log(1+x)$ transformed.

   a. Cluster all the days using a hierarchical clustering. Be sure to scale the columns in advance, so that no single variable has undue influence on the result. Cut the tree so that we are left with 10 clusters, and provide a ribbon plot to visualize several quantiles associated with each cluster's typical pollution, temperature, and windspeed trajectories. visualization to understand the centroids of each cluster. Briefly interpret the main patterns you observe.

   b. Visualize the hierarchical clustering tree associated with your clustering from part (a). Bonus: For a single time of day, encode the average pollution level for all descendant nodes within your tree representation. To summarize a the pollution level of all descendants leaves in a tree, you may use the `map_local_dbl` function from `tidygraph`.

```
mean_fun <- function(neighborhood, ...) {
  cur_pollution <- neighborhood |>
    filter(leaf) |>
    pull(pollution_10) # average the 10am pollutions
  mean(cur_pollution, na.rm = TRUE)
}

G |>
  mutate(avg_pollution = map_local_dbl(order = graph_order(), mode = "out", .f = mean_fun))
```

7. [Living wages] This problem will study a dataset from MIT's living wage calculator. Each row in this dataset gives living wages for state capitals within the continental US. Since living wages depend on a personal situation (e.g., number of children), this dataset is high-dimensional. The interpretation of

each column is given here.

a. Define a tidymodels `recipe` that normalizes all city features and specifies that PCA should be performed.

b. Visualize the top 4 principal components. Based on the interpretation of each columns, what seems to distinguish capital cities with low vs. high values of PC2?

c. Visualize the scores of each capital city with respect to the first two principal components. Make sure to annotate cities with their names. Pick a city on the graph and interpret its relative wage profile based on the principal components.

8. [Food nutrients] This problem will use PCA to provide a low-dimensional view of a 14-dimensional nutritional facts dataset. The data were originally curated by the USDA and are regularly used in visualization studies.

```
nutrients <- read_csv("https://uwmadison.box.com/shared/static/nmgouzobq5367aex45pnbzgkhm7sur63.csv
```

a. Define a tidymodels `recipe` that normalizes all nutrient features and specifies that PCA should be performed.

b. Visualize the top 6 principal components. What types of food do you expect to have low or high values for PC1 or PC2?

c. Compute the average value of PC2 within each category of the `group` column. Give the names of the groups sorted by this average.

d. Visualize the scores of each food item with respect to the first two principal components. Facet the visualization according to the `group` column, and sort the facets according to the results of part (c). How does the result compare with your guess from part (b)?

9. [Topics in *Pride and Prejudice*] This problem uses LDA to analyze the full text of *Pride and Prejudice*. The object `paragraph` is a data.frame whose rows are paragraphs from the book. We've filtered very short paragraphs; e.g., from dialogue. We're interested in how the topics appearing in the book vary from the start to the end of the book, for example.

```
library(tidytext)
paragraphs <- read_csv("https://uwmadison.box.com/shared/static/pz1lz301ufhbedzsj9iioee77r95xz4v.cs
paragraphs
```

```
## # A tibble: 1,092 x 2
##    text
##    <chr>
##  1 "however little known the feelings or views of such a man may be on his first entering a neig
##  2 "\"why, my dear, you must know, mrs. long says that netherfield is taken by a young man of la
##  3 "\"i see no occasion for that. you and the girls may go, or you may send them by themselves,
##  4 "\"my dear, you flatter me. i certainly _have_ had my share of beauty, but i do not pretend t
##  5 "\"but consider your daughters. only think what an establishment it would be for one of them.
##  6 "\"you are over-scrupulous, surely. i dare say mr. bingley will be very glad to see you; and
##  7 "\"i desire you will do no such thing. lizzy is not a bit better than the others; and i am su
##  8 "mr. bennet was so odd a mixture of quick parts, sarcastic humour, reserve, and caprice, that
##  9 "mr. bennet was among the earliest of those who waited on mr. bingley. he had always intended
## 10 "\"i honour your circumspection. a fortnight's acquaintance is certainly very little. one can
## # i 1,082 more rows
```

a. Create a Document-Term Matrix containing word counts from across the same paragraphs. That is, the i^{th} row of `dtm` should correspond to the i^{th} row of `paragraph`. Make sure to remove all stopwords.

b. Fit an LDA model to `dtm` using 6 topics. Set the seed by using the argument `control = list(seed = 479)` to remove any randomness in the result.

c. Visualize the top 30 words within each of the fitted topics. Specifically, create a faceted bar chart where the lengths of the bars correspond to word probabilities and the facets correspond to topics. Reorder the bars so that each topic's top words are displayed in order of decreasing probability.

d. Find the paragraph that is the purest representative of Topic 2. That is, if γ_{ik} denotes the weight of topic k in paragraph i, then print out paragraph i^* where $i^* = \arg\max_i \gamma_{i2}$. Verify that the at least a few of the words with high probability for this topic appear. Only copy the first sentence into your solution.

10. [Personality Types] This dataset contains a sample of posts from the Personality Cafe forum, together with labels giving the poster's (self-reported) Meyer-Briggs type (e.g., types starting with "I" are introverted, those with "E" are extroverted). It is time-consuming to go through all the posts manually, but to get a quick overview of the main topics that are discussed, we can use a Latent Dirichlet Allocation (LDA) model. This problem walks through the steps for (1) preparing a Document-Term matrix for LDA, (2) fitting the LDA model, and (3) interpreting the estimated topics and memberships.

    a. Transform the raw posts into a collection of per-post word counts. Remove stopwords from across all lexicons in `tidytext::stopwords`.

    b. Convert the `data.frame` from (a) into a topic models Document-Term matrix (i.e., an object of class `DocumentTermMatrix`). Fit an LDA model with 8 topics to the prepared object.

    c. Visualize the top 30 words within each of the fitted topics. Specifically, create a faceted bar chart where the lengths of the bars correspond to word probabilities and the facets correspond to topics. Reorder the bars so that each topic's top words are displayed in order of decreasing probability.

    d. Create a Structure plot displaying the topic memberships for each document. Sort documents according to their order on a hierarchical clustering tree, and facet documents according to personality type. Are there certain topics that appear to be more common in some personality types than others?

11. [Hotel Reviews] In this problem, we will practice using Latent Dirichlet Allocation to understand the topics that come up across hotel reviews from an online database. We will also study whether there are certain topics that are more common in positive vs. negative reviews.

    a. Transform the raw reviews into a collection of per-review word counts. Remove stopwords from across all lexicons in `tidytext::stopwords`.

    b. Convert the `data.frame` from (a) into a topic models Document-Term matrix (i.e., an object of class `DocumentTermMatrix`). Fit an LDA model with 8 topics to the prepared object.

    c. Create a Structure plot displaying the topic memberships for each review. Sort reviews according to their order on a hierarchical clustering tree, and facet documents according to hotel rating. Are there certain topics that appear to be more common in negative vs. positive reviews? Manually inspect a few reviews with high membership in these topics.

    d. Using either a heatmap or faceted barplot, visualize the content of the topics. Which terms distinguish the topics that are associated with more negative vs. positive reviews?

12. [Interpreting UMAP] Imagine that you are a statistical consultant working with a scientist / sports team / journalist / sales division head (pick your favorite or make up your own example). At one point in your study, you found it useful to apply nonlinear dimensionality reduction with UMAP. In this problem, you are asked to provide a non-technical explanation of how to interpret the dimensionality reduction output, assuming that your audience is familiar with their data but not statistical methodology.

    a. You have run UMAP on the dataset, which includes 50 different measurements for each row. You plot the first two dimensions as a scatterplot. Explain to your audience what the embedding represents.

b. Though they have not heard of UMAP, your audience has previously encountered principal components analysis for dimensionality reduction. Help your audience understand UMAP by comparing and contrasting it with PCA.

13. [Single-Cell Genomics] In this problem, we will apply UMAP to a dataset of Peripheral Blood Mononuclear Cells (PBMC) released by 10X Genomics. The first column, `cell_tag`, gives an identifier for each cell in the dataset. All other columns are molecules that were detected in that cell. For example, CD74 is a molecule often found on the surface of T-cells.

    a. Define a tidymodels `recipe` that specifies that UMAP should be performed with the parameters `learn_rate = 0.1` and `neighbors = 5`. There is no need to normalize these data, as they have been normalized in advance using methods tailored to single-cell genomics data.

```
pbmc <- read_csv("https://uwmadison.box.com/shared/static/ai539s30rjsw5ke4vxbjrxjaiihq7edk.csv")
```

    b. Compute the UMAP embeddings across cells. Color points in by their value of the GNLY molecule.

14. [Interactive Single-Cell Genomics] The cell-level UMAP embeddings from the previous problem give an overview of the landscape of PBMC cells. However, on their own, the embeddings do not provide details for why cells are grouped in the way that they are. In this problem, we will build an interactive view that allows users to investigate these details.

    a. Sketch an interactive visualization that supports the following queries,

    - For a subset of cells of interest, which gene expression patterns set it apart? Does the subset seem to have elevated levels of any specific genes?
    - For a given gene (or genes) of interest, which groups of cells show elevated (or suppressed) expression levels for this gene?

    b. Implement the design you proposed in part (a). Give an example conclusion that you derived interactively that would have been more difficult to discover using static views alone.

15. [How to (Mis)Read UMAP] This article includes a section titled "How to (Mis)Read UMAP," which provides five practical takeaways for reading UMAP visualizations. In this problem, you will study one of these takeaways (e.g., "Hyperparameters really Matter") in detail.

    a. Provide relevant screenshots from the interactive displays that illustrate the point you have chosen. Explain how the screenshot communicates the main takeaway.

    b. Imagine one real-world data analysis problem where failing to follow these recommendations could have serious consequences. Justify your claim.

16. [Phoneme Identification] The data read in below are a subset of about 4500 audio signals from the TIMIT speaker database. Each row is a processed version of an audio file describing how a single speaker said one of 5 sounds (e.g., "ao" is like the first vowel in "water" and "aa" is like the first vowel in "dark"). These 5 classes are stored in the column `g`. This dataset played a historically important role in sparking progress in the field of speech recognition.

```
phoneme <- read_csv("https://hastie.su.domains/ElemStatLearn/datasets/phoneme.data") |>
  separate(speaker, c("split", "dialect_region", "speaker_id", "sentence_id"))
```

    a. Create a plot that shows each speaker's series (colnames `x.1` to `x.256`), faceted by phoneme. What features of these audio signals might you consider using if your goal were to distinguish between phonemes? *Hint: use `pivot_longer(x.1:x.256)` to reshape the data into tidy format.*

    b. Prepare a UMAP recipe that could be used to reduce the 256 sound dimensions to only two. Since all 256 audio features have the same interpretation, there is no need to normalize them. Extract the embeddings from the prepared recipe.

    c. Create a visualization of your UMAP embeddings from (b). Which phonemes seem the most similar to one another in the high-dimensional audio space?

17. [UMAP Image Collection] We will analyze the visualization available at this link, which supports exploration of artworks in the Staatliche Museen zu Berlin. The visualization shows the results of applying UMAP to the high-dimensional image features extracted using a pretrained deep learning model (if you are curious, this notebook gives details). It is implemented using a combination of D3 and a graphics library called PIXI (which we won't be covering).

    a. This visualization supports panning and zooming. Which lines of code support this?
    b. This visualization applies a "fisheye" lens in addition to more standard pan and zoom. Why do you think this was included? Do you think it is effective? Why or why not?

18. [Political Blogs] In this problem, we will use topic modeling to see how the topics discussed across the political blogsphere evolved over course of 2008. We have fitted a model to a subsample of The CMU 2008 Political Blog Corpus, and the resulting topicmodels object is here.

    a. Use the discrepancy formula described in lecture,

    $$D(k,l) := \beta_{kw} \log\left(\frac{\beta_{kw}}{\beta_{lw}}\right) + (\beta_{lw} - \beta_{kw})$$

    to identify 50 words that can be used to discriminate between the fitted topics.

    b. Make a heatmap that displays the β_{kw} probabilities of the words in part (b).

    c. Using the document metadata file, design and implement a visualization that shows variation in the memberships γ_{dk} either over time, across blogs, or in relation to political leaning. Suggest some interpretations for patterns that you see.

19. [Interpreting Topic Models] Imagine that you are a statistical consultant working with a scientist / sports team / journalist / sales division head (pick your favorite or make up your own example). At one point in your study, you found it useful to apply LDA for visualizing a document collection. In this problem, you are asked to provide a non-technical explanation of how to interpret the topic model output, assuming that your audience is familiar with their data but not statistical methodology.

    a. You have run LDA on the dataset. There were originally 10,000 documents, and you used $K = 15$ topics. You have shared a Structure plot for the memberships and a faceted bar plot for the top terms in each topic. Explain to your audience what these visualizations represent.

    b. Though they have not heard of LDA, your audience has previously encountered principal components analysis for dimensionality reduction. Help your audience understand LDA by comparing and contrasting it with PCA.

7 Model Visualization

1. [Silhouette Statistics Simulation] This problem uses simulation to build intuition about silhouette statistics. The function below simulates a mixture of three Gaussians, with means evenly spaced out between `(start, 0)` and `(end, 0)`. We will investigate what happens to the silhouette statistics for each point as the three clusters are made to gradually overlap.

```
library(tibble)
library(purrr)
library(ggplot2)

mixture_data <- function(start = 0, end = 10, K = 3, n = 100) {
  mu <- cbind(seq(start, end, length.out = K), 0)
  map_dfr(1:K, ~ MASS::mvrnorm(n, mu[., ], diag(2)) |> as_tibble())
}

ggplot(mixture_data()) +
```

```
  geom_point(aes(V1, V2)) +
  coord_fixed() +
  labs(x = "x", y = "y")
```

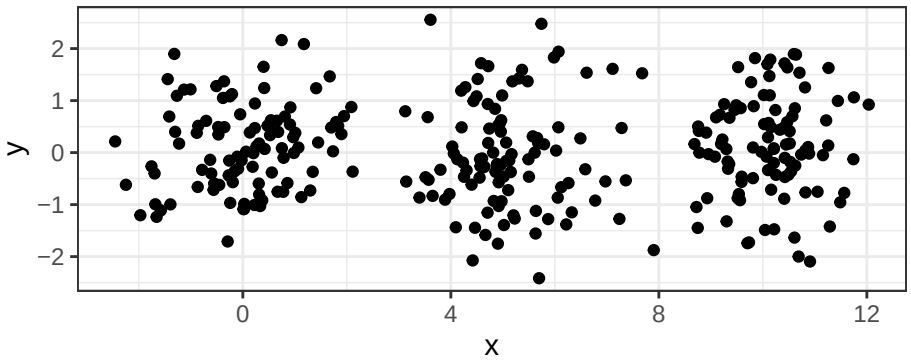


Figure 14: An example simulated dataset from problem 2.

a. Simulate versions of these data where the `end` argument is decreased from 10 to 0.

b. Write a function that performs K-means and computes the silhouette statistic given any one of the datasets generated in part (a). Use this function to compute the silhouette statistics for each point in the simulated datasets.

c. Visualize the silhouette statistics from part (b) overlaid onto the simulated data. Discuss the results.

2. [A Bikesharing Model] In this and the next problem, we will visualize models fitted to predict bikesharing demand in a subset of the Capitol Bikesharing dataset. We will see what types of features are learned by different types of models, whether there are any interactions between features, and whether linear and nonlinear approaches are substantively different.

   a. The code below fits a gradient boosting machine (GBM) to predict bikesharing demand (count) using all features available, except day of the year. Visualize the Ceteris Paribus profiles for the temperature and humidity variables, and provide a brief interpretation.

```
library(caret)
bike <- read_csv("https://uwmadison.box.com/shared/static/aa91qdqehagag8wg8mqsm4z5b4g2hu0x.csv")
x <- dplyr::select(bike, -count, -dteday)
hyper <- data.frame(n.trees = 100, interaction.depth = 4, shrinkage = 0.1, n.minobsinnode = 10)
fit <- train(x = x, y = bike$count, method = "gbm", tuneGrid = hyper, verbose = FALSE)
```

   b. Has the GBM learned an interaction effect between the hour of day (`hr`) and weekend (`weekend`) features? Briefly justify your answer using a grouped CP plot.

3. [Contrastive Profiles for Bikesharing] This problem continues the exploration in the previous one. Here, we study whether the choice of GBM was critical, or whether any other model would have learned the same relationship between the predictors and bikesharing demand.

   a. The code below fits a lasso model to the same input and output dataset. Provide contrastive partial dependence profiles between the lasso and the GBM from above, focusing on the hour (`hr`), humidity (`hum`), and temperature (`temp`) features. Comment on the result.

```
hyper <- data.frame(lambda = 0.001, alpha = 0)
fit_lm <- train(x = x, y = bike$count, method = "glmnet", tuneGrid = hyper)
```

   b. Repeat part (a), but comparing the GBM with the CART model fitted below. Comment on the result.

```
library(caret)
hyper <- data.frame(cp = 0.01)
fit_cart <- train(x = x, y = bike$count, method = "rpart", tuneGrid = hyper)
```

4. [Gender Pay Gap] This problem uses CP profiles to investigate the gender gap in a Glassdoor dataset of employee salaries. It is helpful to use a model, because it allows us to control for multiple other factors – a direct plot of salary vs. gender could be criticized as not accounting for confounding variables. The code below trains a gradient boosting machine model on `BasePay` variable (yearly salary in USD), using all potential predictors in the dataset.

```
salary <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/main/exercises/data/Glassdoor%20
library(caret)

x <- salary |>
  select(Gender:Seniority) |>
  mutate(across(where(is.character), as.factor)) # gbm needs chr -> factor
y <- salary$BasePay
fit <- train(x, y, method = "gbm", verbose = FALSE)
```

   a. Before attempting to explain the model, it is helpful to consider its accuracy. Make a plot of the truth (`y`) against model predictions (`y_hat <- predict(fit)`) and comment on model performance.

   b. Compute aggregate CP profiles grouped by gender and comment on the extent of the gender pay gap. According to the fitted prediction surface, is there more or less of a pay gap at certain ages or levels of seniority?

   c. Show the analogous display without aggregating (i.e., `geom = "profiles"`). What is the interpretation of each line in this plot?

5. [Overfitting `sin(x)`] We can use contrastive PD plots to visually evaluate model over / underfitting. To illustrate, we will fit two K-nearest neighbors models on a simple dataset, simulated below.

```
N <- 100
df <- data.frame(x = runif(N, -pi, pi)) |>
  mutate(y = sin(x) + rnorm(N, 0, 0.2))

ggplot(df) +
  geom_point(aes(x, y))
```

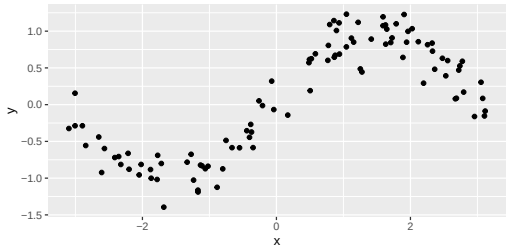


Figure 15: A simulated sine wave dataset, used to evaluate overfitting.

Below, we train three models to fit this curve, averaging over the 2, 10, and 50 nearest neighbors before making a prediction at a new location.

```
library(caret)
library(tidyverse)
```

```
hyper <- map(c(2, 10, 50), ~ data.frame(k = .))
fits <- map(
  hyper,
  ~ train(x = df |> select(x), y = df$y, method = "knn", tuneGrid = .)
)
```

a. Create an `explainer` object for each of the fits above. Use these to create contrastive PD profiles between the three models. *Hint: It will be important to label each of the derived profile objects.*

b. Interpret the result from (a). Which models seem over / underfit? Which would you use in practice, and how did you draw this conclusion?

c. Repeat the same analysis with a random forest model (`method = "rf"` in caret). Instead of varying the `k` parameter, try several values of `mtry`. Is this class of models more or less sensitive to overfitting than K-nearest neighbors?

6. [Deep Learning as a Mixture of Separating Planes] In this exercise, we will visualize the predictions and hidden layer activations in a simple, but nonlinear, classification problem. The goal is to illustrate how nonlinear decision boundaries can be learned by deeper layers of a neural network, even though each neuron is a linear combination of the previous layer's units.

a. The block below simulates a toy dataset with predictors `x` and response `y`. Provide a visualization for the dataset and comment on why a one-layer deep learning model would not be sufficient to achieve good performance.

```
x <- matrix(rt(N * 2, 12), N, 2)
y <- rowSums(x ^ 2) < 1
flip_ix <- sample(N, N / 20) # 5% unavoidable error
y[flip_ix] <- !y[flip_ix]
simulation <- data.frame(x = x, y = y)
```

b. The block below defines and fits a deep learning model with three hidden layers. Design and implement a visualization that shows the predicted probabilities for each sample after the model has converged.

```
library(keras)
model <- keras_model_sequential() |>
  layer_dense(units = 20, activation = "relu", input_shape = c(2)) |>
  layer_dense(units = 20, activation = "relu", input_shape = c(20)) |>
  layer_dense(units = 20, activation = "relu", input_shape = c(20)) |>
  layer_dense(2, activation = "softmax")

model |>
  compile(optimizer = "adam", loss = "categorical_crossentropy") |>
  fit(
    x = simulation |> select(starts_with("x")) |> as.matrix(),
    y = to_categorical(simulation$y),
    metric = "accuracy",
    epochs = 60,
    verbose = 0
  )
```

c. The block below defines a `keras` model that can be used to extract activations from the first hidden layer of the trained deep learning model. Design and implement a visualization to characterize how activations for a single neuron behave, as a function of the input x coordinates. Make the analogous visualization for a deeper layer.

```
submodel <- keras_model(model$input, model$layers[[1]]$output)
```

d. Generate a heatmap of activations across all neurons from some layer of the model. Comment on the structure of the learned features.

7. [Tensorflow Playground] This website provides an interactive visualization of a deep learning model trained on several toy datasets. This problem invites you to explore the visualization and reflect on its interpretation and design.

   a. Experiment with several datasets, input features, layer sizes, or network depths. For which setups does the model seem to converge to a solution most easily? When does the model struggle to converge? Describe how you drew your conclusions.

   b. Comment on the design of this visualization and the visualization concepts that it uses. What do you think are some of its more effective design decisions?

   c. Pose a question motivated by your experimentation with the interface. For example, this can be something you found confusing about the interface, a question it raised about neural networks more generally, or a thought about visual design.

8. [Histopathology Embeddings] This problem investigates the features learned by a residual network model trained trained to classify histopathology slides. Specifically, the script at this link was used to train a model to images from the Pcam benchmark dataset. Each image is a tissue slide. The class labels describe whether the center 32×32 patch within the image contains any cancerous cells.

   In the process, we will also practice using the `reticulate` package to read in numpy arrays produced by the python training script linked above. This language interoperability makes it possible to use the packages best suited to both modeling (`pytorch`) and visualization (`ggplot2`).

   a. We have hosted a subsample of the training images at this link. Their corresponding labels are stored as numpy arrays. Visualize the raw images corresponding to 10 images from each class. *Hint: To unzip these files from the command line, you can use* `tar -zxvf subset.tar.gz`

   b. For the subsample in part (a), we have saved the residual network features from the final pre-classification layer. They are available at this link. Generate UMAP embeddings for the images based on these features, and shade in each sample according to its class.

   c. Using `annotation_raster` layers from `ggplot2`, display the original images from (a) at the locations of the UMAP coordinates from (b). The correspondence between image filenames and features is given by this array. In particular, the i^{th} element of this array is the source image for the i^{th} row of the features matrix.

9. [Representation Analysis for CIFAR10] This problem asks you to investigate the features learned by a deep learning model trained to the CIFAR10 dataset. We will study the structure of the dataset and develop some intuition for what representations different neurons are learning.

   a. The code below loads the CIFAR training dataset. Training images and labels can be accessed using `cifar$x` and `cifar$y`, respectively. Plot the first 15 examples from this dataset and print out their class labels. What does class 7 seem to correspond to?

```
library(keras)
cifar <- dataset_cifar10()$train
```

   b. We have trained a small model to this dataset, available at this link. Extract and visualize the feature activations associated with the first five features in layer 1 (`conv2d_8`) for the first image in the dataset.

```
f <- tempfile()
download.file("https://uwmadison.box.com/shared/static/c9kkxyrjb9myfj5knj5vnx0j8gn1uh0s.h5", f)
model <- load_model_hdf5(f)
```

c. The block below extracts feature activations associated with layer 7, for the first 10% of the dataset. Specifically, the ij^{th} element of `features` gives the activation of neuron j (in layer 7) on image i. Visualize the 10 images that have the highest activation for neuron 1. What does this neuron seem to be responsive to?

```
activation_model <- keras_model(inputs = model$input, outputs = model$layers[[7]]$output)
features <- activation_model(cifar$x[1:5000,,, ]) |>
  as.matrix()
```

10. [Model Visualization Use Cases] The exercise below describes a few hypothetical situations where model visualization can be used. Discuss how you might approach them.

    a. Your colleagues have trained a random forest model to predict whether activity observed on a corporate network might be the early signs of a cyberattack. The model is based on features like the average network data rate, the average packet size, and the port numbers of source traffic. Describe visualizations that could help your colleagues understand and improve their trained model.

    b. You working with a client to analyze data from a crisis text helpline. They are interested in the topics that often arise during these support sessions. They are also curious whether some topics are are more easily resolved than others, as measured by a follow-up survey. Propose an analysis strategy and the types of visualizations you expect to be helpful.

    c. You have built a deep learning model to detect changes in satellite imagery (e.g., before and after a natural disaster). Describe visualization techniques that can help you understand the latent image characteristics that may be learned by your model.

8 Uncertainty Visualization

1. [Evolutionary Ecology] This problem visualizes the uncertainty of estimates derived from an evolutionary ecology model. Vonesh and Bolker (2005) ran an experiment to see how three factors – size, initial population density, and presence of predators – influenced tadpole survival. There were several replicate tanks for each combination of factors. As an initial analysis strategy, it is natural to quantify the uncertainty in per-tank survival probability using a multilevel model. This is discussed in full detail in Chapter 12 of McElreath's Statistical Rethinking[3]. This model implements a kind of partial pooling: Each tank is allowed to have its own survival probability, but information is shared across all the tanks.

    a. Each row in the raw dataset below describes a single tank. Visualize variation in tank-level survival, as well as the potential influence of initial density and tadpole size.

```
x <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/e9b55299b9c4d4140665eadf1d4268ed2d940b
  mutate(tank = as.factor(tank))
x
```

```
## # A tibble: 48 x 6
##    density pred  size   surv propsurv tank
##      <dbl> <chr> <chr> <dbl>    <dbl> <fct>
##  1      10 no    big       9      0.9 1
##  2      10 no    big      10      1   2
##  3      10 no    big       7      0.7 3
##  4      10 no    big      10      1   4
##  5      10 no    small     9      0.9 5
##  6      10 no    small     9      0.9 6
##  7      10 no    small    10      1   7
##  8      10 no    small     9      0.9 8
##  9      10 pred  big       4      0.4 9
```

[3]This book is accompanied by a fantastic set of free lectures.

```
## 10      10 pred  big       9      0.9 10
## # i 38 more rows
```

b. The code below fits the following model, where y_i represents the number of tadpoles that survive in tank i, N_i is the initial tadpole density, and p_i is the (unknown) survival probability.

$$
\begin{aligned}
y_i &\sim \text{Bin}\left(N_i, p_i\right) \\
p_i &= \text{logit}^{-1}\left(\alpha_i\right) \\
\alpha_i &\sim \mathcal{N}\left(0, 2\right)
\end{aligned}
$$

```
library(brms)
fit <- brm(
  data = x, family = binomial,
  surv | trials(density) ~ 0 + factor(tank),
  prior(normal(0, 2)),
  silent = 2, refresh = 0,
  chains = 1
)

posterior <- as_draws_df(fit)
```

Make a graded confidence plot of the posterior p_i associated with each tank. Overlay the tank's original survival probability, and comment on how uncertainty varies across experimental settings.

c. Create a version of the same figure that shows the full posterior densities, rather than simply their quantiles.

d. In assessment of more complex models, it is often interesting to visualize samples simulated from the fitted model. If the simulation captures the most salient aspects of the original data without simply memorizing it, then we can have more faith in our model. Conversely, if important features are not reflected, then we may need to refine the model. The code below samples 4000 survival counts for each tank in the fitted model.

```
y_sim <- posterior_predict(fit)
```

Create a static visualization that shows the variation associated with 10 of these 4000 hypothetical datasets.

e. Create an animated hypothetical outcome plot of the same data used in the previous part.

2. [Household Radon Levels] This problem analyzes a dataset of household radon levels in Minnesota. The data were gathered by the EPA in an effort to understand which factors lead to increased exposure to this carcinogenic gas; e.g., it is known that radon levels are higher in basements than on the ground floor. A secondary goal of this problem is to illustrate the use of the `rstanarm` and `tidybayes` packages to extract prior and posterior predictive distributions. While these packages cannot be applied as generally as the methods discussed in lecture, they provide an elegant interface for specific types of Bayesian models. You will not need to write any code using these packages – we only ask that you visualize their outputs.

a. Design and implement a visualization that describes the variation in `log_radon` levels from county to county.

```
radon <- read_csv("https://uwmadison.box.com/shared/static/3yn994tc1ft73z3br4ys18uri700gvik.csv")
```

b. The code below simulates prior predictive data from two potential Bayesian models of `log_radon`. Both models have the form `log_radon ~ (1 | county) + floor`, which means each county -

floor level combination gets its own mean. In the first model, a vague $\mathcal{N}(0, 1000)$ prior is used, while in the second, a somewhat more informative $\mathcal{N}(0, 10)$ is used instead.

```
library(rstanarm)
priors <- list(
  "vague" = stan_lmer(log_radon ~ (1 | county) + floor, prior = normal(0, 1000), data = radon, pric
  "informative" = stan_lmer(log_radon ~ (1 | county) + floor, prior = normal(0, 10), data = radon,
)
```

The code below extracts 5 simulated datasets from the prior predictive. Each row is a simulated house; the simulation number is denoted by `.draw`. The index to the original dataset is given by `.row`. The simulated `log_radon` levels are given in the `.prediction` column. The `prior` column describes which type of prior was used for that simulation.

```
library(tidybayes)
prior_preds <- map_dfr(priors, ~ add_predicted_draws(radon, .), .id = "prior") |>
  filter(.draw > 3995)

head(prior_preds)
```

```
## # A tibble: 6 x 10
## # Groups:   floor, county, log_radon, log_uranium, .row [2]
##   prior floor county log_radon log_uranium  .row .chain .iteration .draw .prediction
##   <chr> <dbl> <chr>      <dbl>       <dbl> <int>  <int>      <int> <int>       <dbl>
## 1 vague     1 Aitkin     0.833      -0.689     1     NA         NA  3996       300.
## 2 vague     1 Aitkin     0.833      -0.689     1     NA         NA  3997       483.
## 3 vague     1 Aitkin     0.833      -0.689     1     NA         NA  3998     -1186.
## 4 vague     1 Aitkin     0.833      -0.689     1     NA         NA  3999      -674.
## 5 vague     1 Aitkin     0.833      -0.689     1     NA         NA  4000      -512.
## 6 vague     0 Aitkin     0.833      -0.689     2     NA         NA  3996       -67.3
```

Design and implement a visualization to compare the two types of priors. Which prior seems more plausible?

c. The code below draws posterior predictive samples from two new models, which either ignore or model variation from county to county (`lm` and `hierarchical` respectively). Both use information about whether the measurement came from a basement. Only the last 10 simulated runs are kept. Using these data, make boxplots of posterior predictive samples across counties, for each of the two models. What are the main differences between the two models? In what ways are the county level effects (as you studied in part (a)) accurately or inaccurately modeled?

```
library(tidybayes)
posterior_preds <- list(
  "lm" = stan_glm(log_radon ~ floor, prior = normal(0, 10), data = radon, chains = 1, refresh = 0),
  "hierarchical" = stan_lmer(log_radon ~ (1 | county) + floor, prior = normal(0, 10), data = radon,
) |>
  map_dfr(~ add_predicted_draws(radon, .), .id = "model") |>
  filter(.draw > 990)
```

3. [South African Heart Disease GAM] In this problem, we will visualize the prediction uncertainty in a generalized additive model (GAM) of the South African Heart Disease dataset. This data were used to evaluate risk factors for heart disease in a sample of 462 South African men in a region with high coronary heart disease (CHD) prevalence. We will use a GAM to fit a type of logistic regression to the binary CHD response using LDL cholesterol level as the predictor. Unlike standard logistic regression, a GAM's logistic regression does not constrain the predicted probability to follow a logistic function[4].

[4]This is achieved by applying the logistic link to a nonlinear transformation of LDL.

a. Make a jittered scatterplot showing how CHD risk varies as a function of LDL.

```
heart <- read_csv("https://github.com/krisrs1128/stat992_f23/raw/e9b55299b9c4d4140665eadf1d4268ed2c
```

b. The code below fits a GAM between LDL and CHD. Visualize 20 predicted probability curves obtained by bootstrapping the original dataset.

```
library(mgcv)
fit <- gam(chd ~ s(ldl), data = heart, family = "binomial")
new_data <- tibble(ldl = seq(min(heart$ldl), max(heart$ldl), length.out = 100))
```

c. Overlay a 95% pointwise confidence band onto the 20 hypothetical outcomes from (b).

d. Instead of showing all the predicted probability curves simultaneously, create an animated hypothetical outcome plot. Each frame should highlight both the a hypothetical predicted probability curve and the samples used to generate that bootstrap sample.