Business 4720 - Class 7

Data Visualization with R

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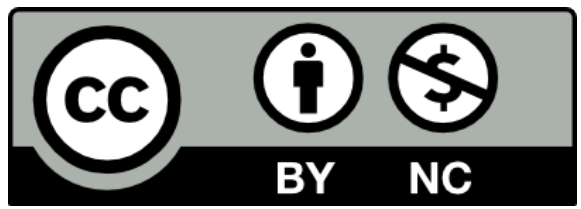

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This Class

What You Will Learn:

- Introduction to Visualization
- Visualizing data with R using the ggplot2 library

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Why Visualize?

"A Picture is Worth 1000 Words"

- Humans are good at visual pattern recognition, but
  - Humans also identify patterns where there are none!
  - It's easy to mislead or deceive with visualization (others and oneself!)

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Why Visualize?

Visual Discovery: Sense Making

- Exploration, confirmation, or verification
- Iterative, dynamic

Declarative Visualization: Storytelling

- Explanation
- Affirming, convincing
- Presenting, explaining
- Decision support
- Static

Operational Visualization: Monitoring

- Supervision, alarms
- Operational decision making

Purpose of Visualization

- Simplify, summarize & abstract
- Compare
- Identify trends, patterns & relationships
- Gain insights

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Quantitative Messages

1. Time-series (e.g. line chart)
2. Ranking (e.g. bar chart)
3. Part-whole (e.g. pie chart)
4. Deviation (e.g. bar chart)
5. Frequency distribution (e.g. histogram, boxplot)
6. Correlation (e.g. scatter plot)
7. Nominal comparison (e.g. bar chart)
8. Geographic distribution (e.g. cartogram)

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Honesty in Visualization

General Guidelines

- Do not deceive your target audience
- Do not diminish or hide relationships or trends
- Do not exaggerate relationships or trends
- Do not confuse or obfuscate

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Honesty in Visualization

Specific ”no-nos”

- Graph unrelated data to suggest non-existent relationships
- Scale multiple vertical axes to suggest correlations
- Truncate or scale axes to hide or exaggerate trend
- Scale in multiple dimensions
- Plot cumulative growth to hide trend
- Use maps for non-geographic data
- Use incomplete data (”cherry-picking”)
- Use invalid data

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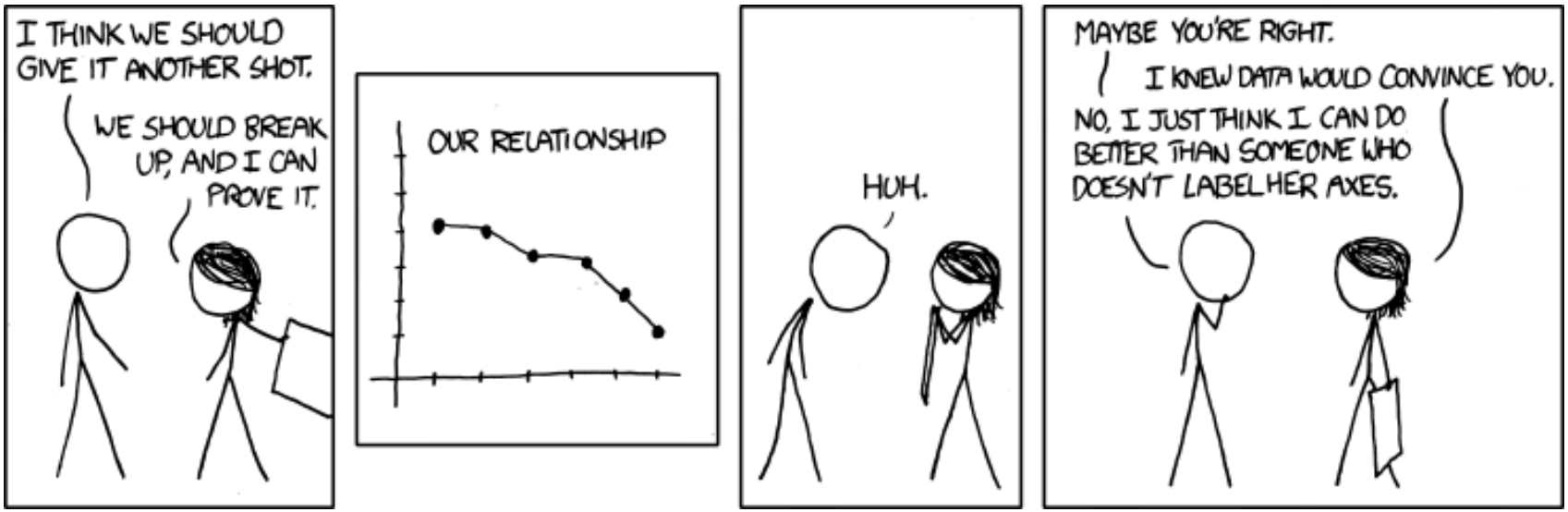
Label your Axes (XKCD)



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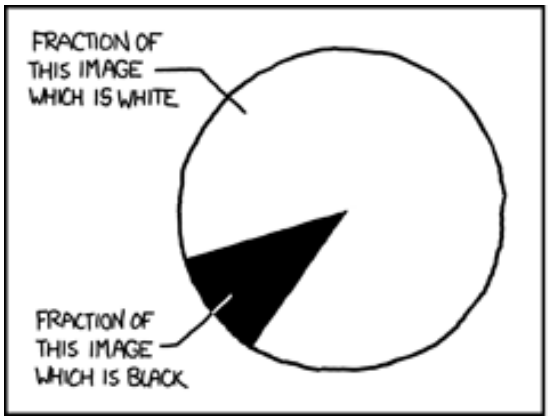
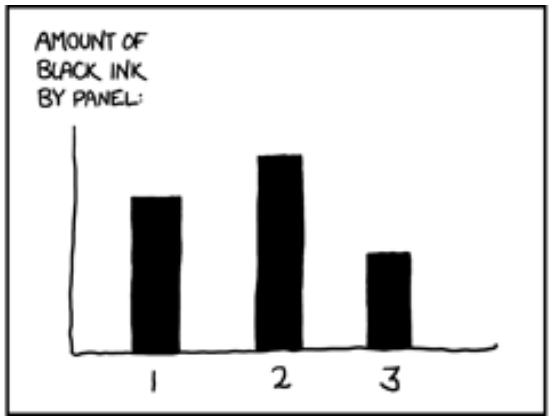
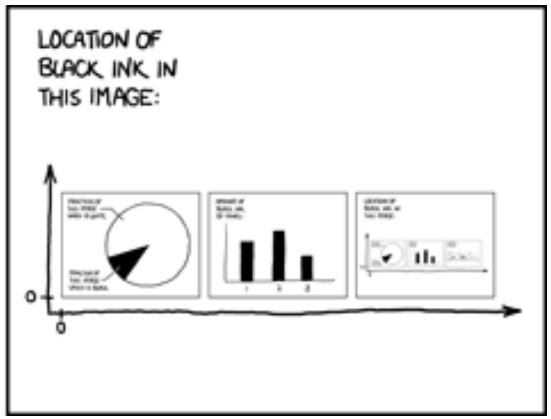
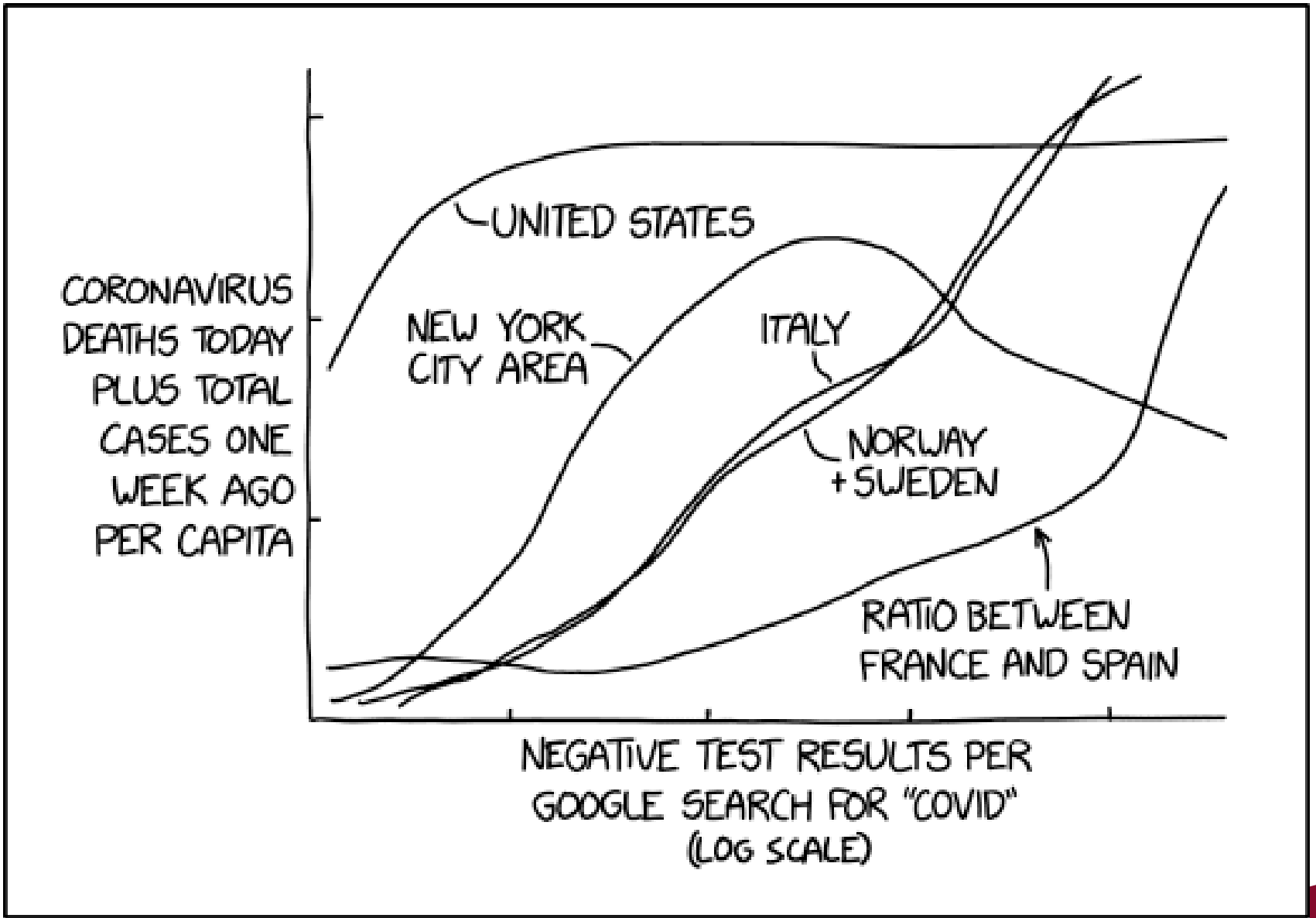
Use Meaningful Data (XKCD)



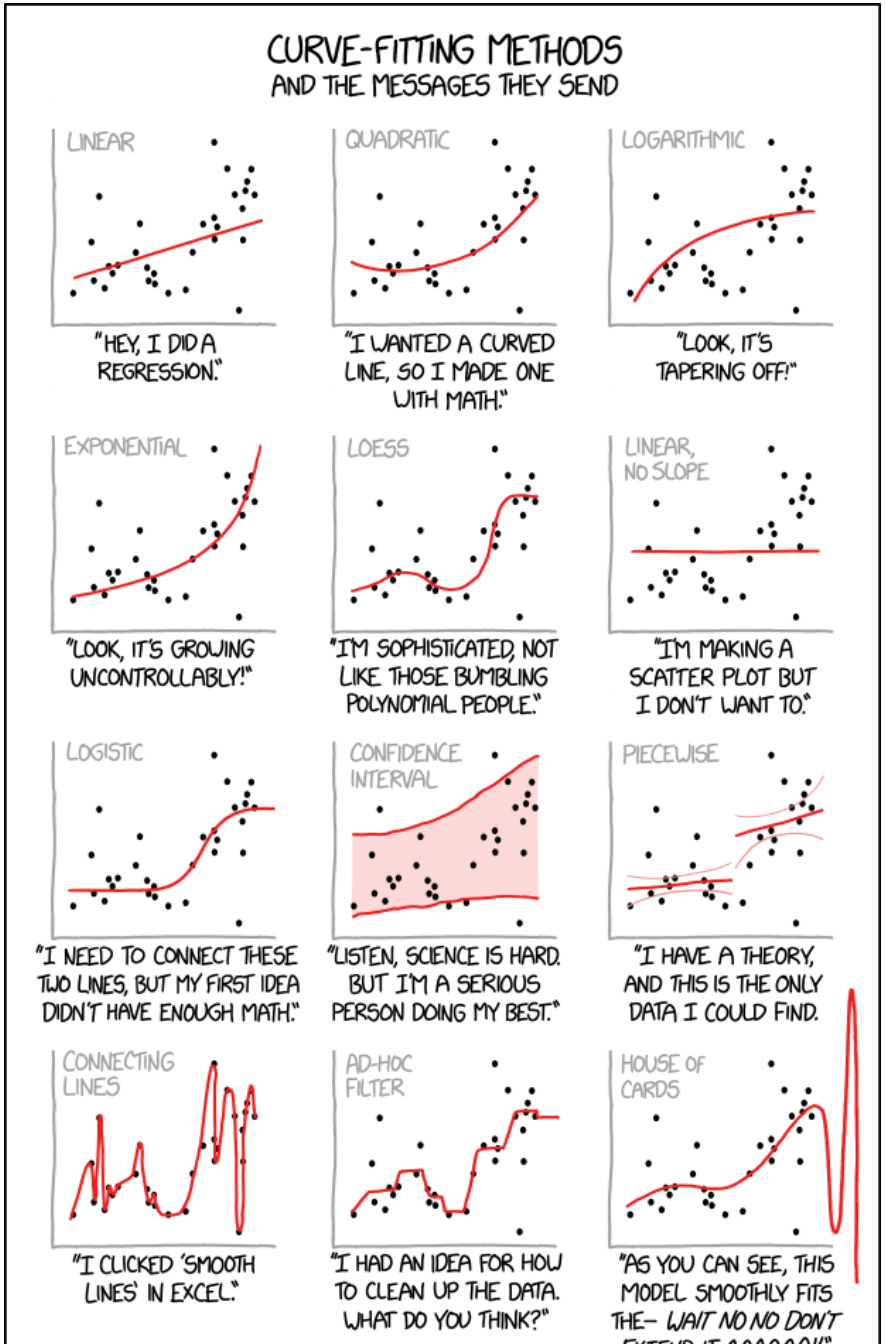




Use Related Data (XKCD)



Do Not Mislead (XKCD)



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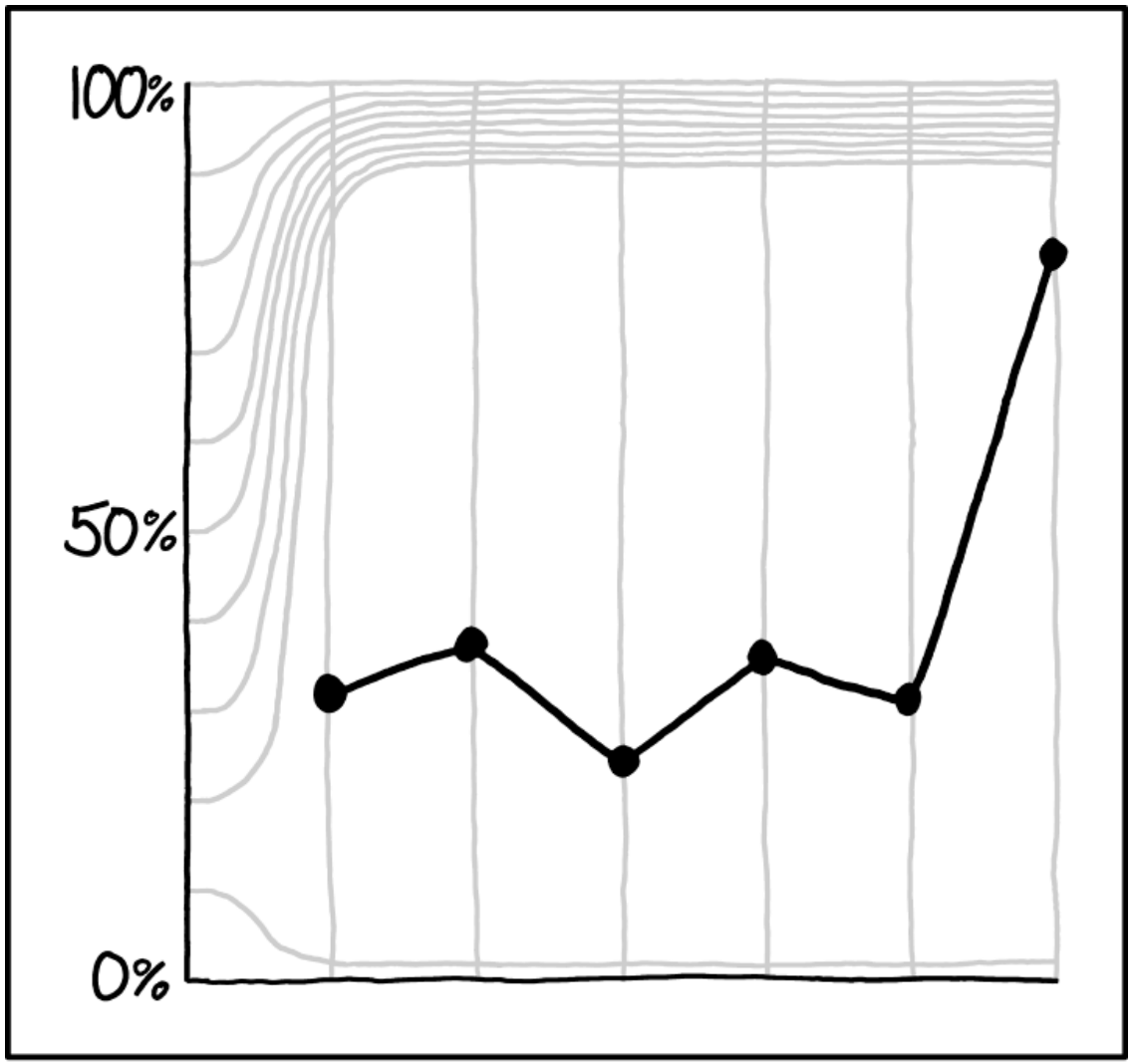
Choose Your Axes Meaningfully



PEOPLE HAVE WISED UP TO THE "CAREFULLY CHOSEN Y-AXIS RANGE" TRICK, SO WE MISLEADING GRAPH MAKERS HAVE HAD TO GET CREATIVE.

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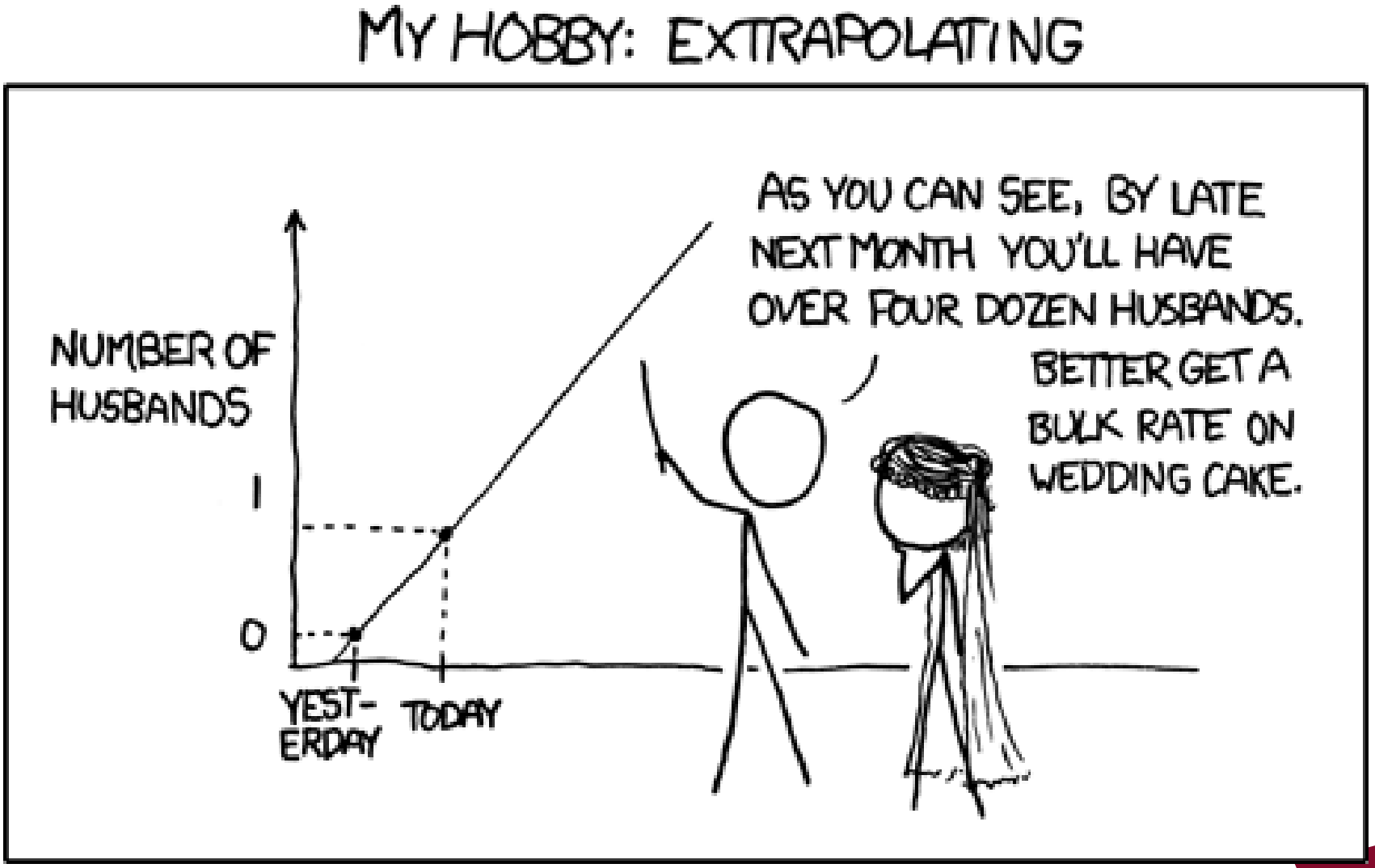
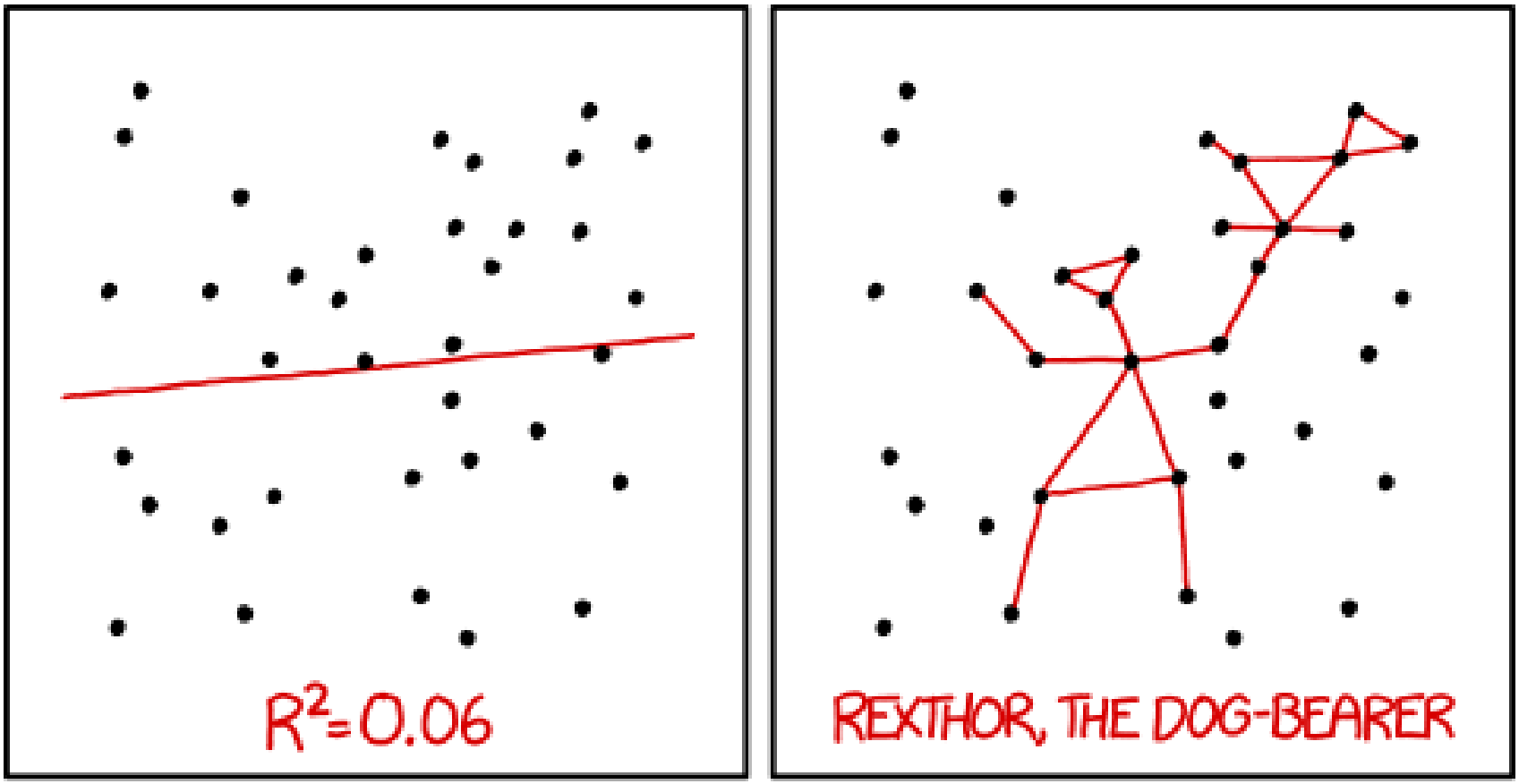
Be Careful When Extrapolating (XKCD)



Verify Trends (XKCD)



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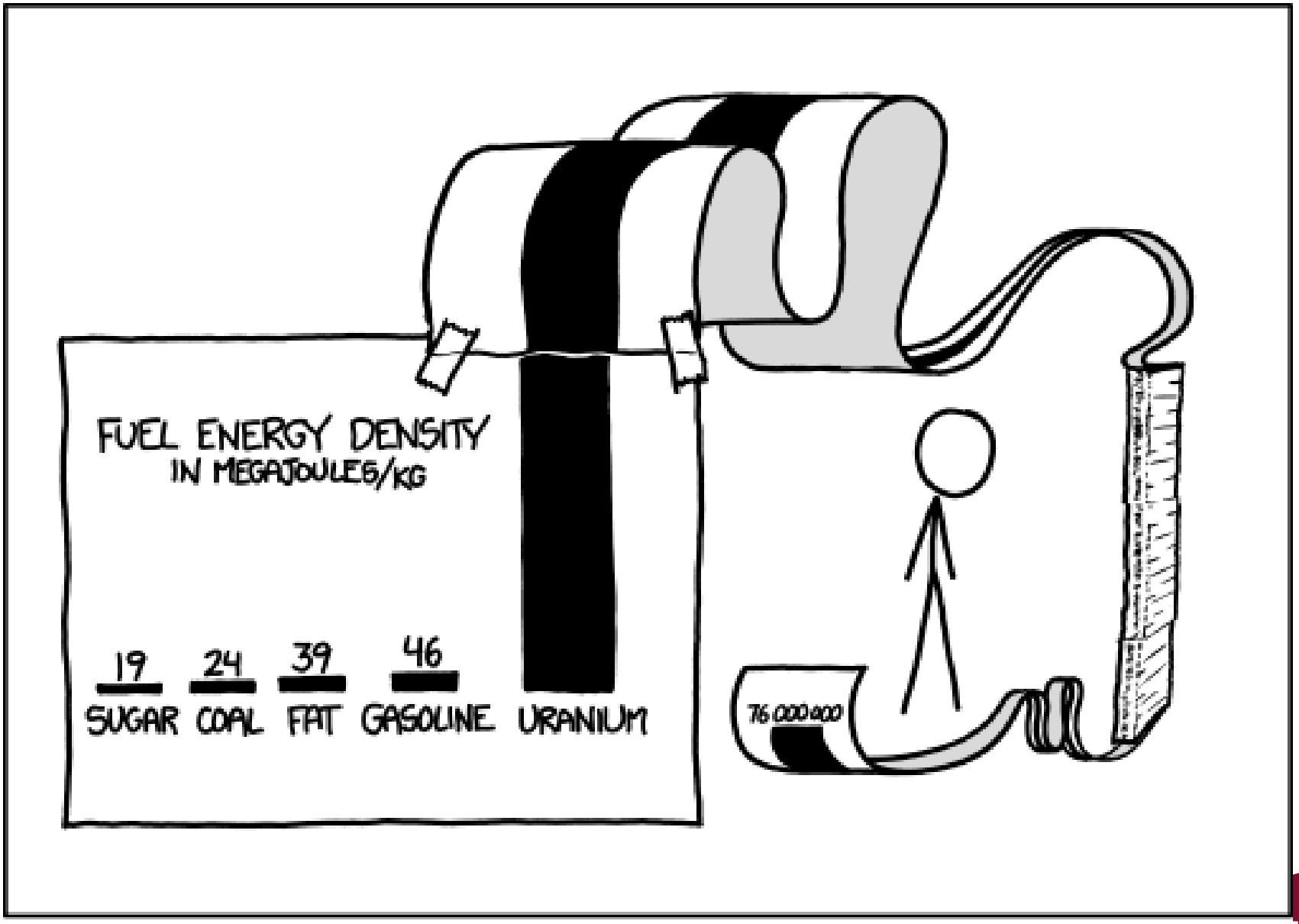
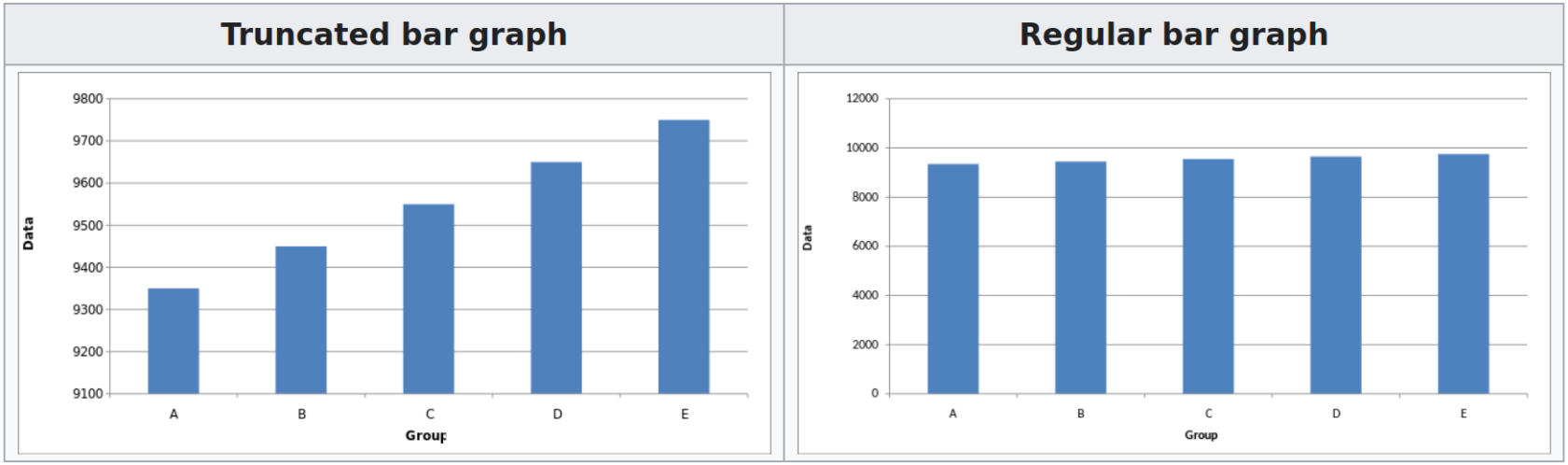
Use Appropriate Scales (XKCD)



SCIENCE TIP: LOG SCALES ARE FOR QUITTERS WHO CAN'T FIND ENOUGH PAPER TO MAKE THEIR POINT *PROPERLY.*

Don’t Lose Your Point

Dark Patterns – Truncated Axes



https://en.wikipedia.org/wiki/Misleading_graph

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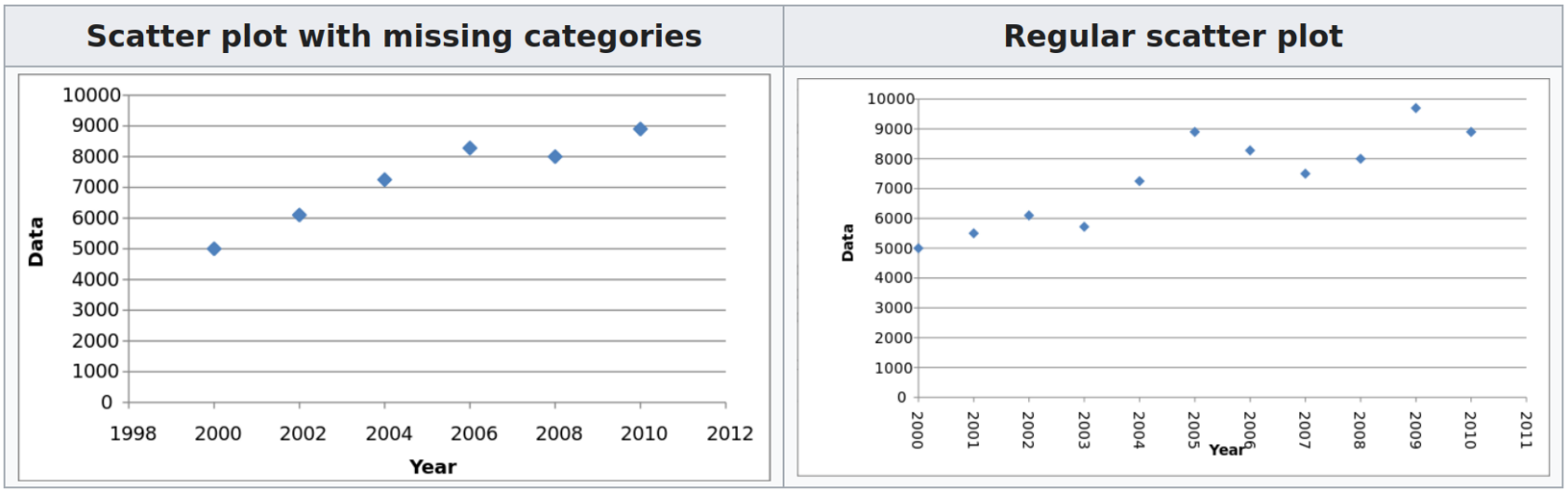
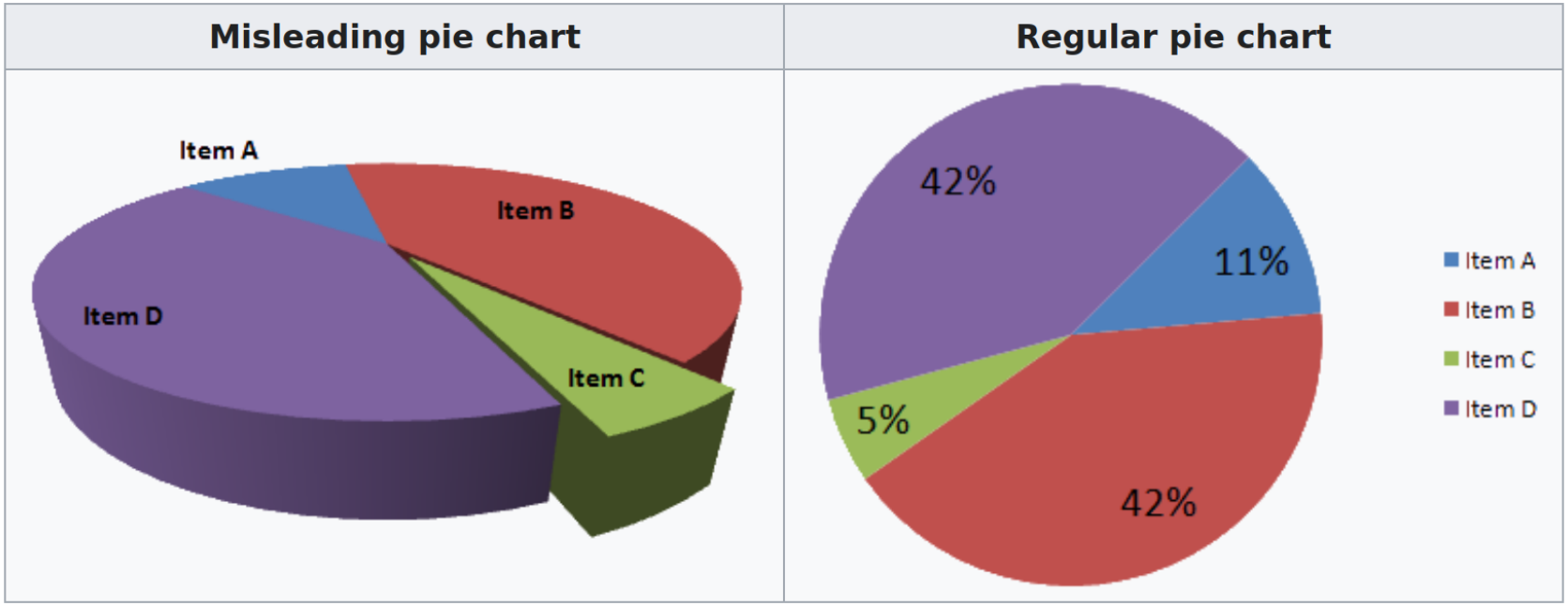
Dark Patterns – Omitted Data



https://en.wikipedia.org/wiki/Misleading_graph

Dark Patterns – 3D Pie Charts



https://en.wikipedia.org/wiki/Misleading_graph

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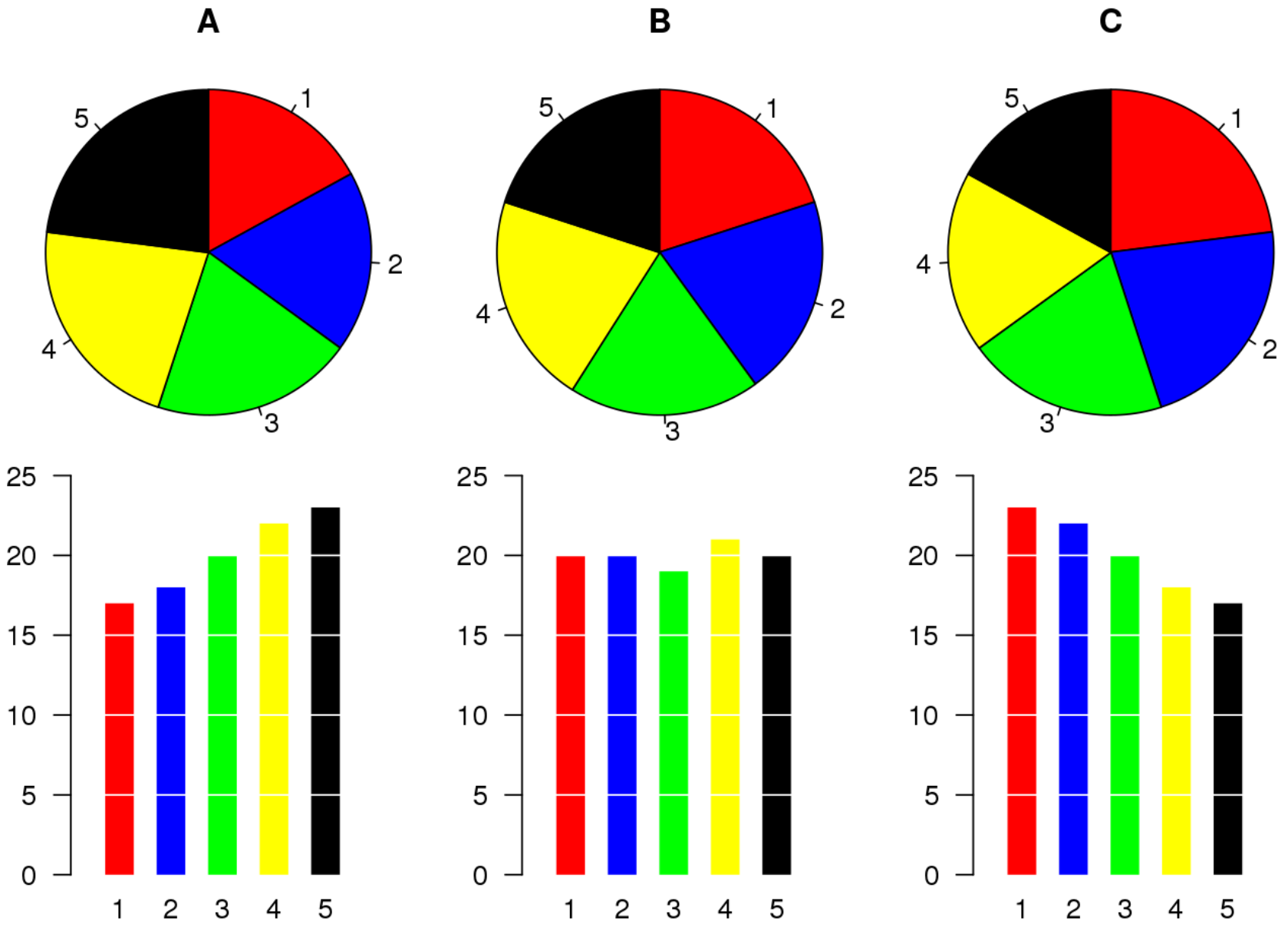
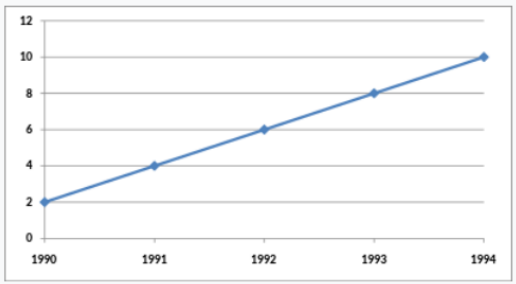
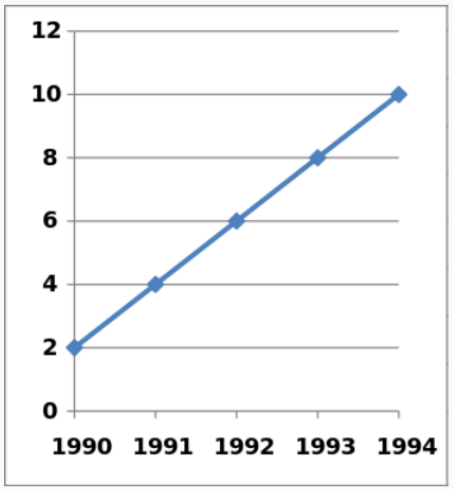
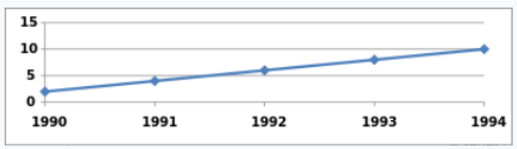
Dark Patterns – Comparing Pie Charts



https://en.wikipedia.org/wiki/Misleading_graph

Dark Patterns – Scaling Axes and Aspect Ratios

Original graph	Half-width, twice the height	Twice width, half-height
		

https://en.wikipedia.org/wiki/Misleading_graph

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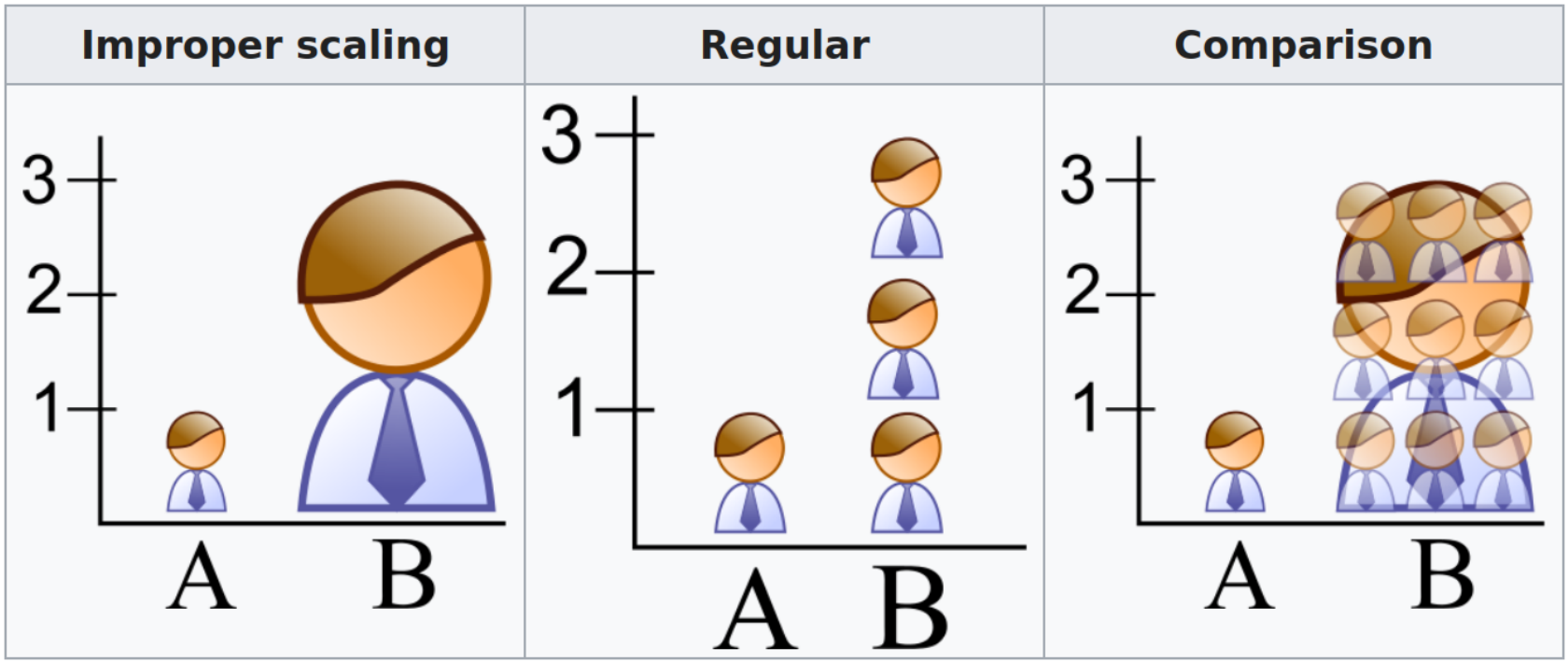
Dark Patterns – Scaling Multiple Dimensions



https://en.wikipedia.org/wiki/Misleading_graph

Colour Palettes

- Colour is an important visualization element
- A colour palette defines a set of colours for a graph/plot.

Desirable Characteristics

- Colourful (range of values)
- Perceptually uniform (even perceptual distances)
- Robust to colourblindness (CVD)
- Pretty

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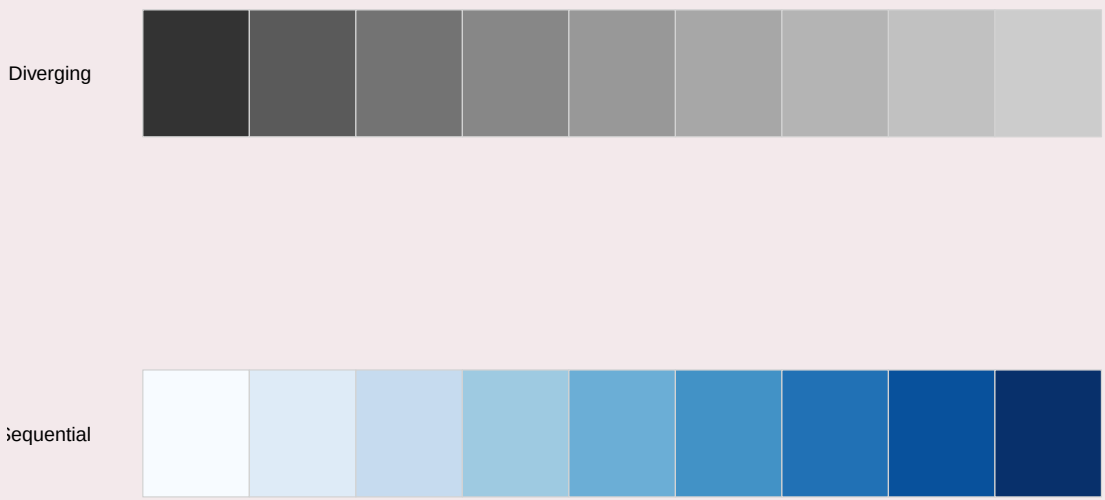
Types of Colour Palettes

Sequential/Monochrome

- Varying hue, light to dark/deep
- Discrete or continuous
- Show progression for data with inherent order



Types of Colour Palettes [cont'd]

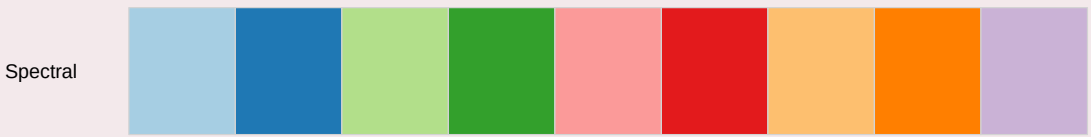
Divergent

- From one colour to another via white or black
- Discrete or continuous
- Useful for showing deviations or extremes on either size of midpoint
- Data with meaningful center

Types of Colour Palettes [cont'd]

Spectral

- Uses a number of different colours
- Discrete
- Data without inherent ordering
- Limited to few categories as colours become too similar



CVD (Colour Vision Deficiency)

- Monochromatism
- Protanopia (missing ”S-cone”, blue)
- Deuteranopia (missing ”M-cone”, green)
- Tritanopia (missing ”L-cone”, red)

1 in 12 men have CVD
1 in 200 women have CVD
2.6 million Canadians are colour blind

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Original

MUN Faculty of Education Class Room

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Simulated Colour Vision Deficiencies

Monochromatism

Protanopia

Deuteranopia

Tritanopia

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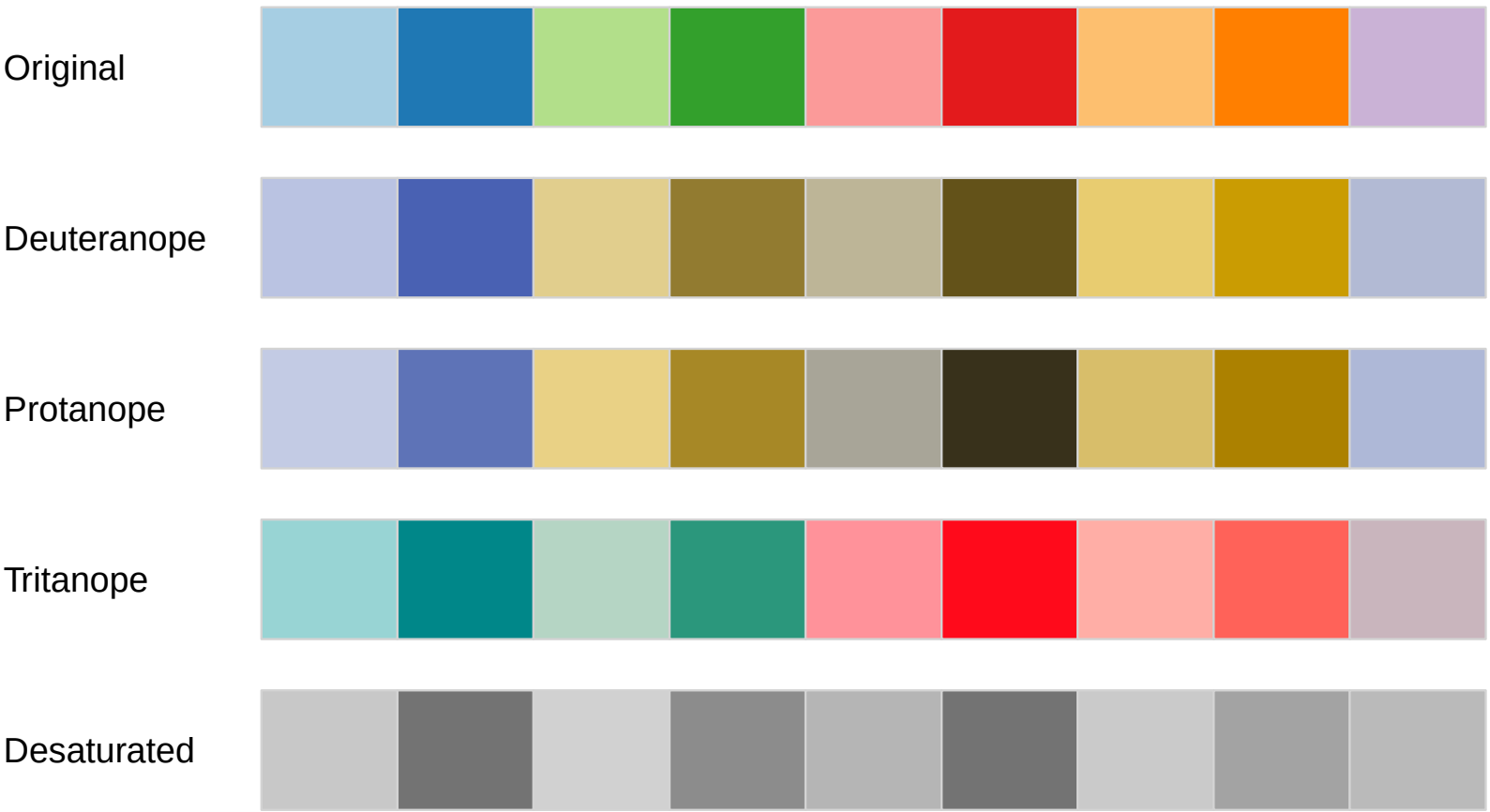
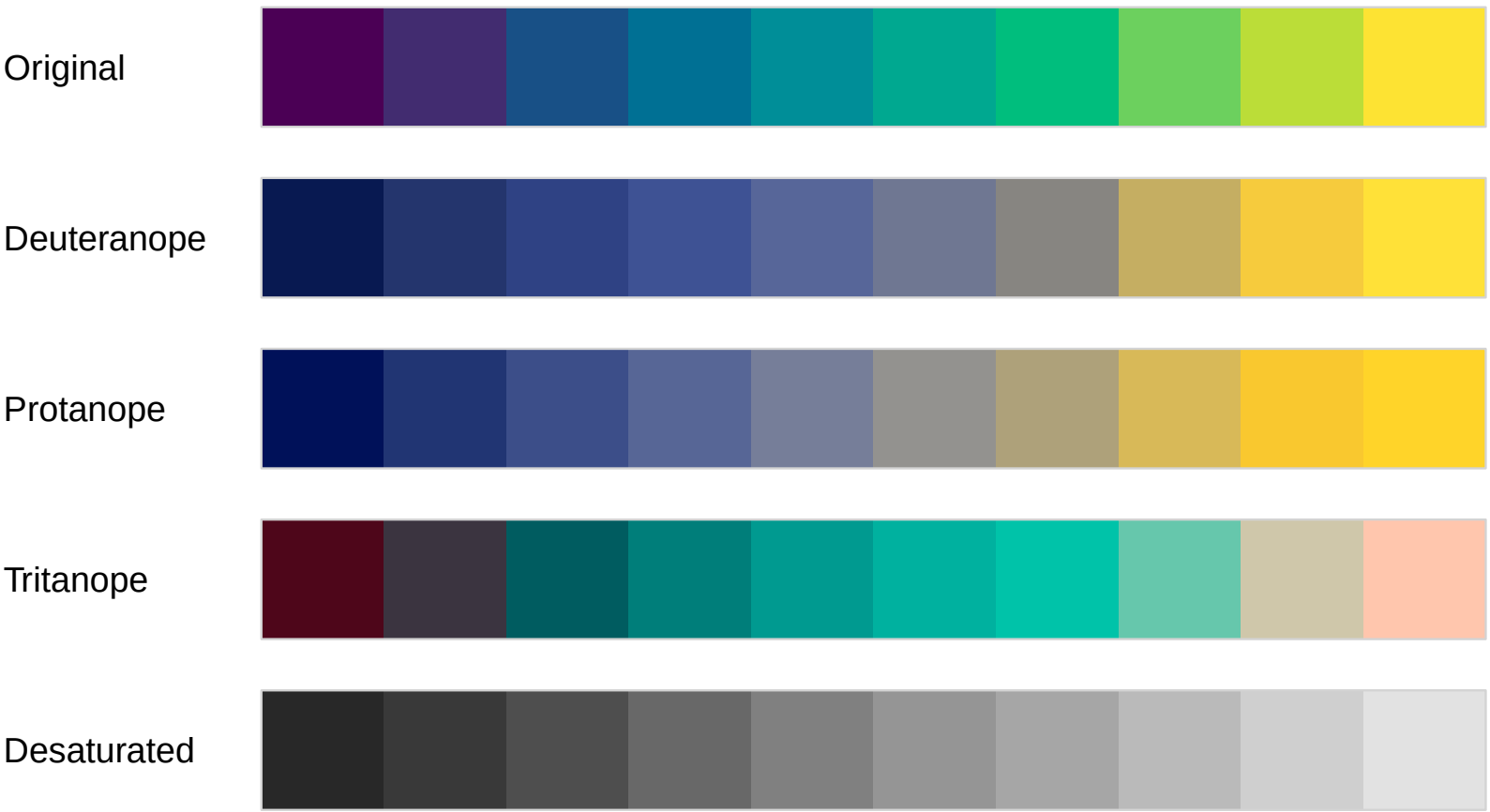
Example: Colourbrewer Palette ”Paired”

Brewer Paired



Viridis Colour Palette

Viridis Palette



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Popular Graphics Libraries and Frameworks

R

- GGPlot (and related libraries such as GGPattern)
- Plotly for R
- GGVis (for Dashboards)
- Shiny (for Dashboards)

Python

- Matplotlib
- Seaborn
- Plotly (Express, GO, Dash)
- Plotnine (”GGPlot for python”)
- Shiny (for Dashboards)

Web & JS

- D3, ChartJS, GoogleCharts

Plot Elements

Map Data to Plot Elements

- X, Y axis
- Colour (point, line, fill)
- Transparency (”alpha”)
  - Be aware of print versus screen or color vision deficiency
- Pattern (fill)
- Size, Weight/Width (point, line)
- Shape, Style (point, line)

Other Plot Elements

- Title, sub-title, captions
- Axis titles, axis labels and ”ticks”
- Legend(s)

Example Dataset

- Government of Canada, Open Government Portal
- Fuel Consumption Ratings – Battery-electric vehicles – 2012–2023; last updated Oct 10, 2023
- https://open.canada.ca/data/en/dataset/98f1a129-f628-4ce4-b24d-6f16bf24dd64

Column	Data Type
Make	Discrete
Model	Discrete
Year	Numeric
Category	Discrete
City	Numeric[1]
Hwy	Numeric
Comb	Numeric
Range	Numeric[2]

[1] Fuel consumption in l/100km equivalent

[2] Range in km

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Example Dataset – Read Data

```r
# Load tidyverse package
library(tidyverse)

# Read the data set to a Tibble
data <- read_csv('https://evermann.ca/busi4720/fuel.csv')

# Ensure vehicle category is a factor (categorical)
data$Fuel <- as.factor(data$Fuel)
```

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Load Graphics Libraries

```
library(ggplot2)
library(ggpattern)
library(ggstream)
library(ggsci)
library(scales)
library(ggrepel)
library(ggradar)
```

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Histogram

```
data |>
  ggplot(aes(x=Range)) +
    geom_histogram(bins=50)
```

- Aesthetic `aes()` determines mapping of data to plot elements
- Add ”geoms” that determine the type of plot
- Geoms can have their own additional aesthetics and other options

```
ggsave("histogram.pdf", height=5, width=7.5, units='in')
```

- Save plot in different formats (PDF, PNG, JPEG, . . .)

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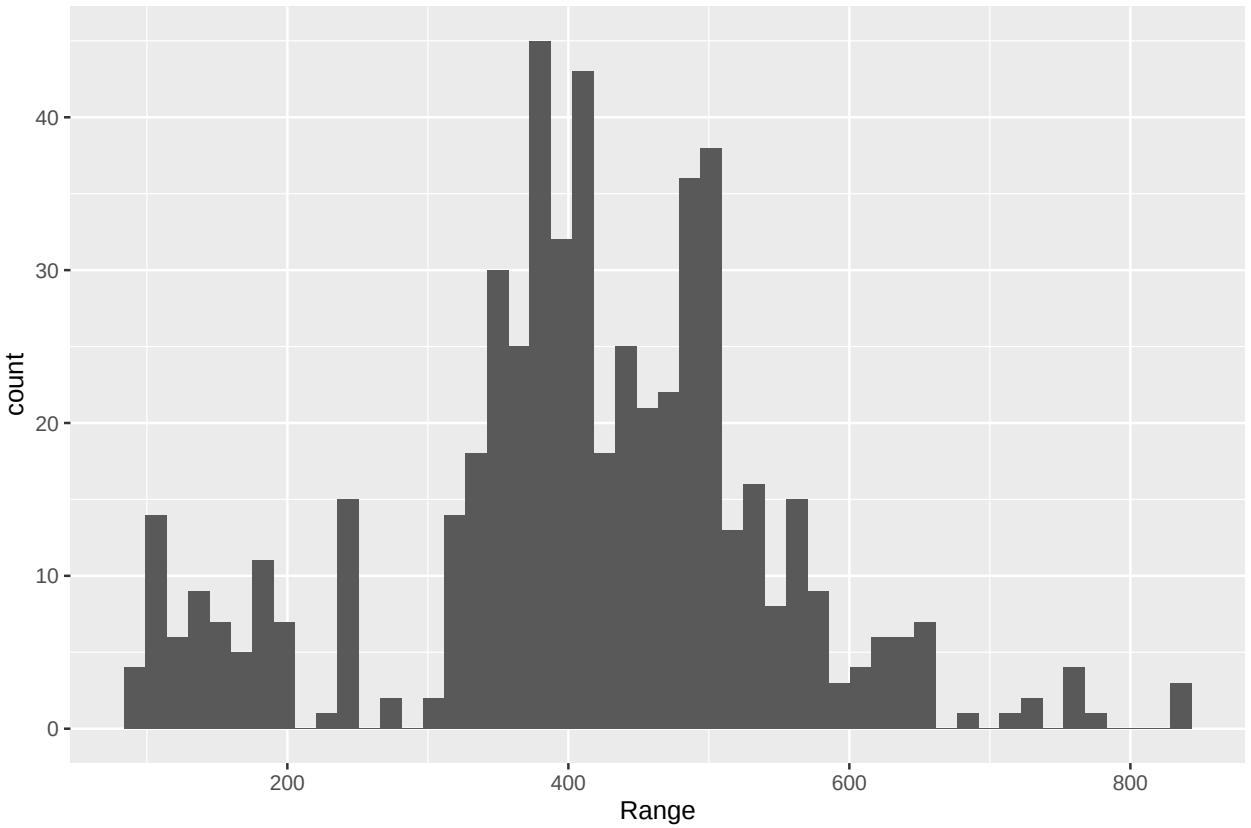
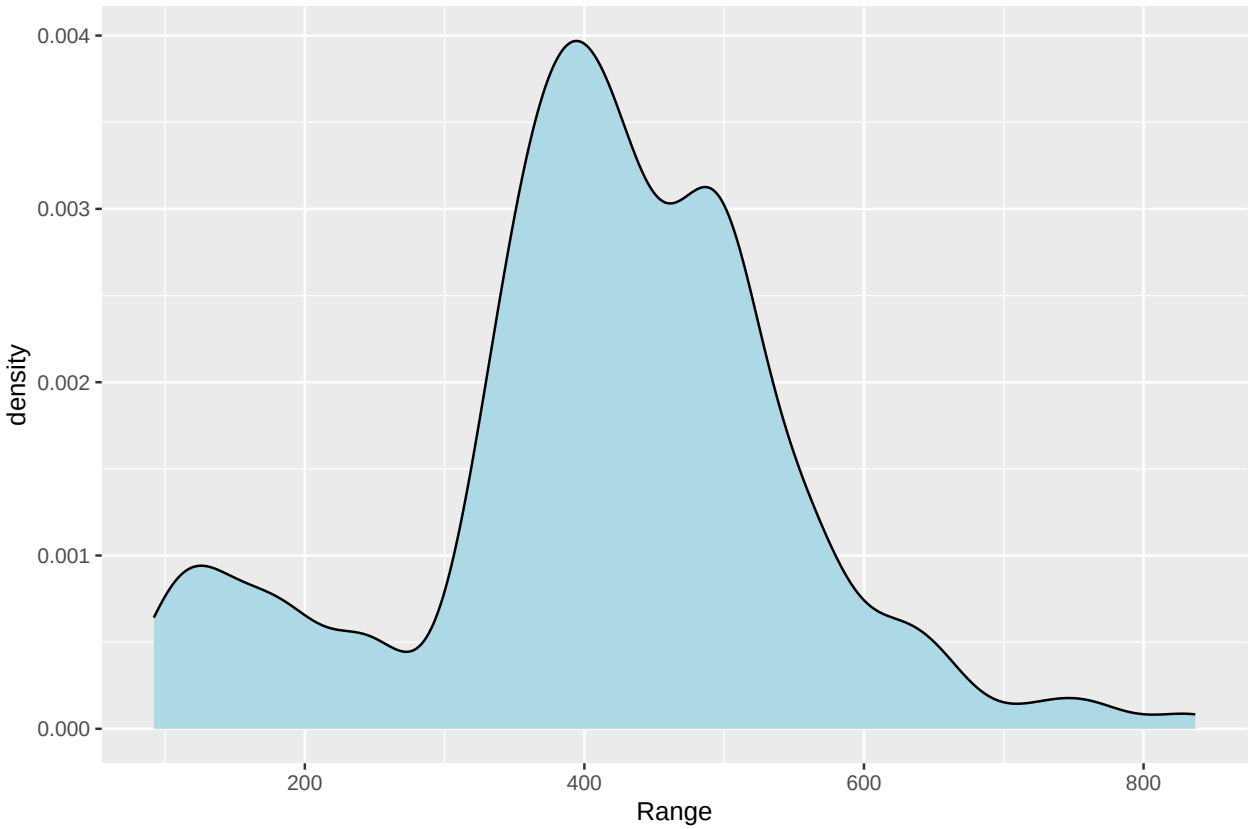
Histogram



- Shows frequencies or counts

Density Plot

```
data |>
  ggplot(aes(Range)) +
    geom_density(kernel='gaussian', fill='lightblue')
```



- Shows probability density functions
- Kernel is used to smooth the curve (how to weight points)

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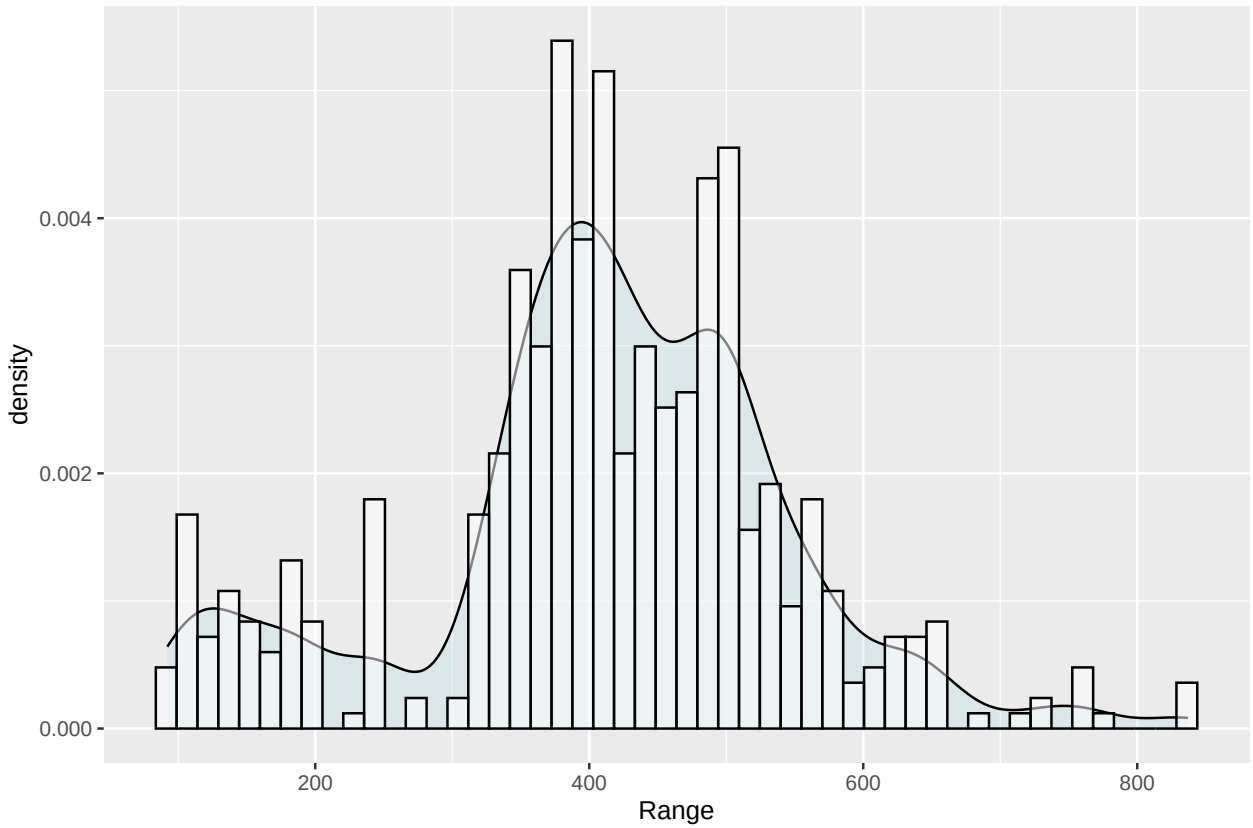
Combining Geoms

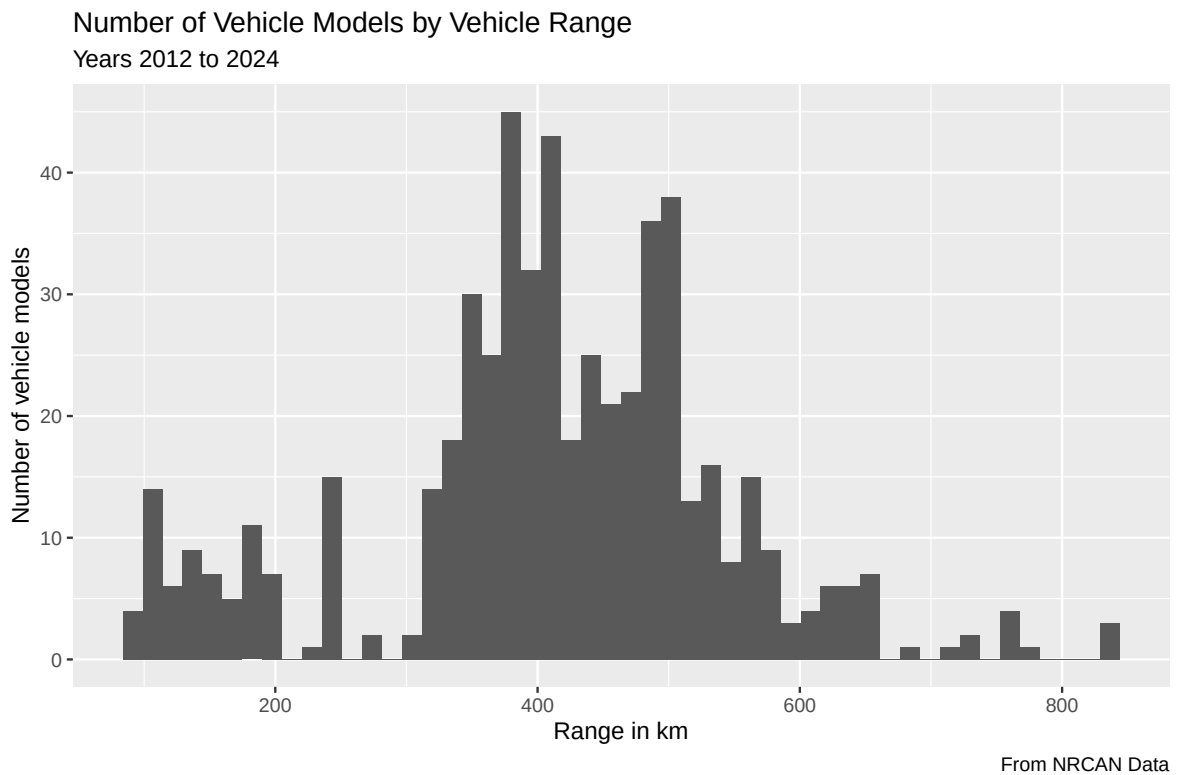
```
data |> ggplot(aes(Range)) +
    geom_density(kernel='gaussian',
        alpha=0.25, fill='lightblue') +
    geom_histogram(aes(y=after_stat(density)), bins=50,
        alpha=0.5, fill='white', color='black')
```



- The `alpha` option controls transparency

Labelling

```
data |>  ggplot(aes(x=Range)) +
    geom_histogram(bins=50) +
    labs(x = 'Range in km',
         y = 'Number of vehicle models',
         title='Number of Vehicle Models by Vehicle Range',
         subtitle='Years 2012 to 2024',
         caption='From NRCAN Data')
```



Hands-On Exercises

1. Read the EV fuel efficiency data set into R .
2. Create a blue histogram of highway efficiency with 25 bins.
3. Add labels for the axes, and add a title.

Tips

- Use the `read_csv()` function from the tidyverse library
- The column name is `Hwy`
- Use the `geom_histogram` geom
- Use the `bins=...` option
- Use the `fill='...'` option
- Use the `labs` geom for labels

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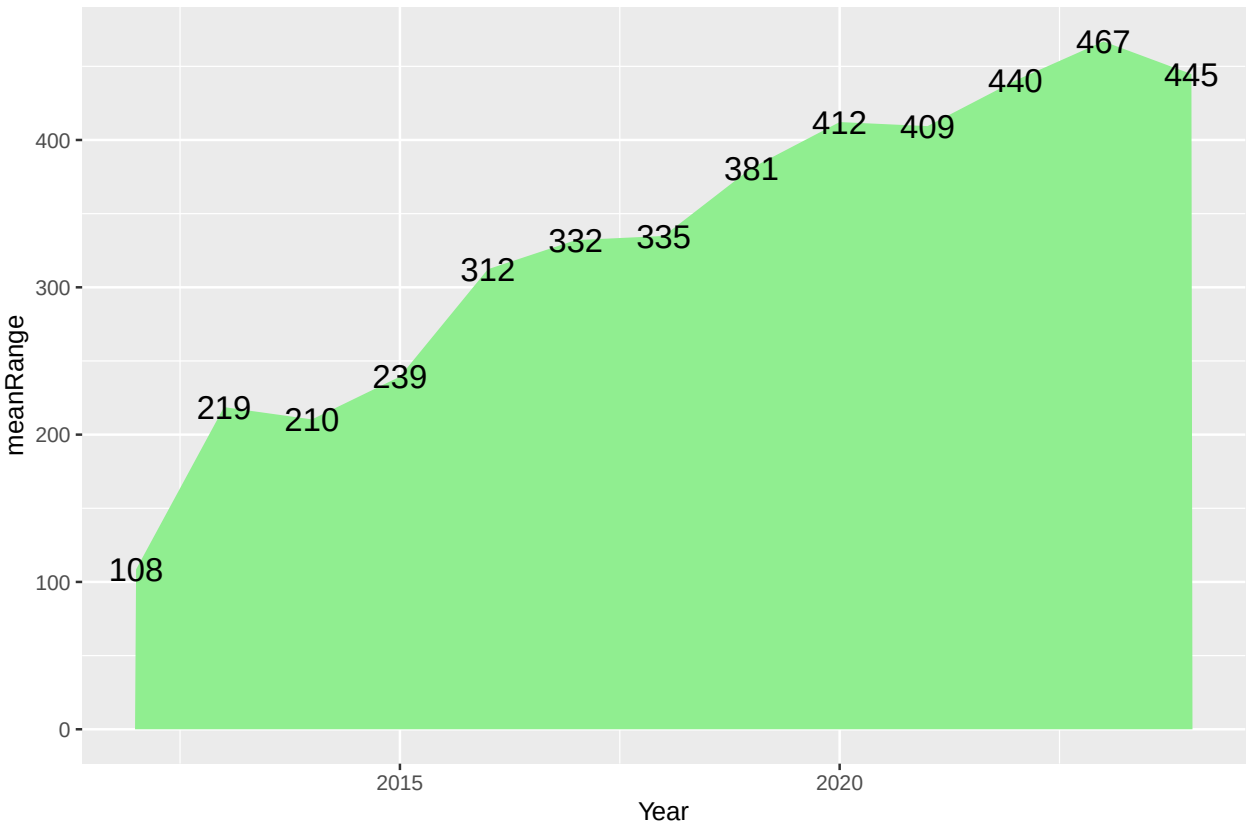
Area Plot

```
data %>% group_by(Year) %>%
  summarize(meanRange = mean(Range)) %>% ungroup() %>%
  ggplot(aes(Year, meanRange)) +
    geom_area(fill='lightgreen') +
    geom_text(aes(label=round(meanRange)), size=5)
```



- The `ggplot()` function is the last in a data processing pipeline

Column Chart

- Data must have one variable mapped to Y axis
- Data must have one variable mapped to fill colour

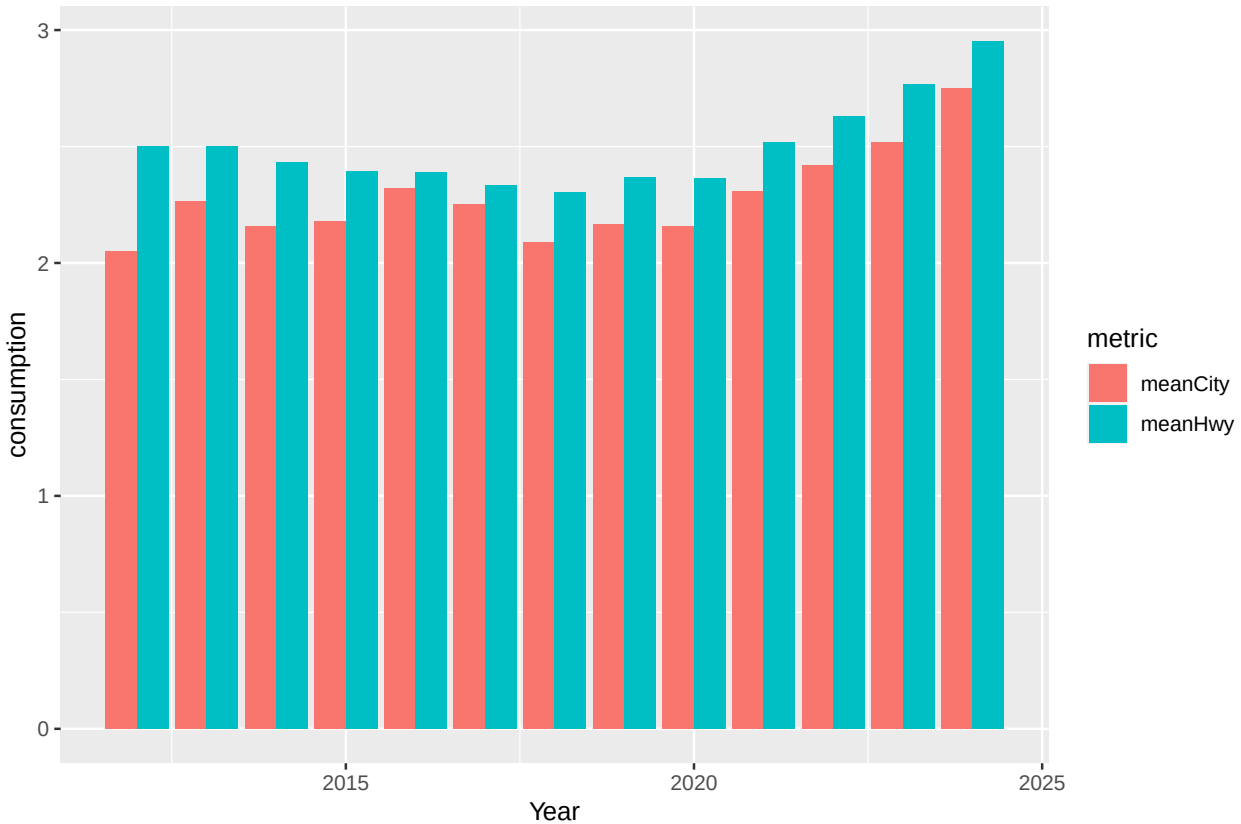
```
col.data <- data %>%
   group_by(Year) %>%
   summarize(
     meanCity = mean(City),
     meanHwy = mean(Hwy)) %>%
   ungroup() %>%
   pivot_longer(
     cols=c('meanCity', 'meanHwy'),
     names_to='metric',
     values_to='consumption')
```

	Year	meanCity	meanHwy
	<dbl>	<dbl>	<dbl>
1	2012	2.05	2.5
2	2013	2.27	2.5
3	2014	2.16	2.43

	Year	metric	consumption
	<dbl>	<chr>	<dbl>
1	2012	meanCity	2.05
2	2012	meanHwy	2.5
3	2013	meanCity	2.27
4	2013	meanHwy	2.5
5	2014	meanCity	2.16
6	2014	meanHwy	2.43

Column Chart [cont'd]

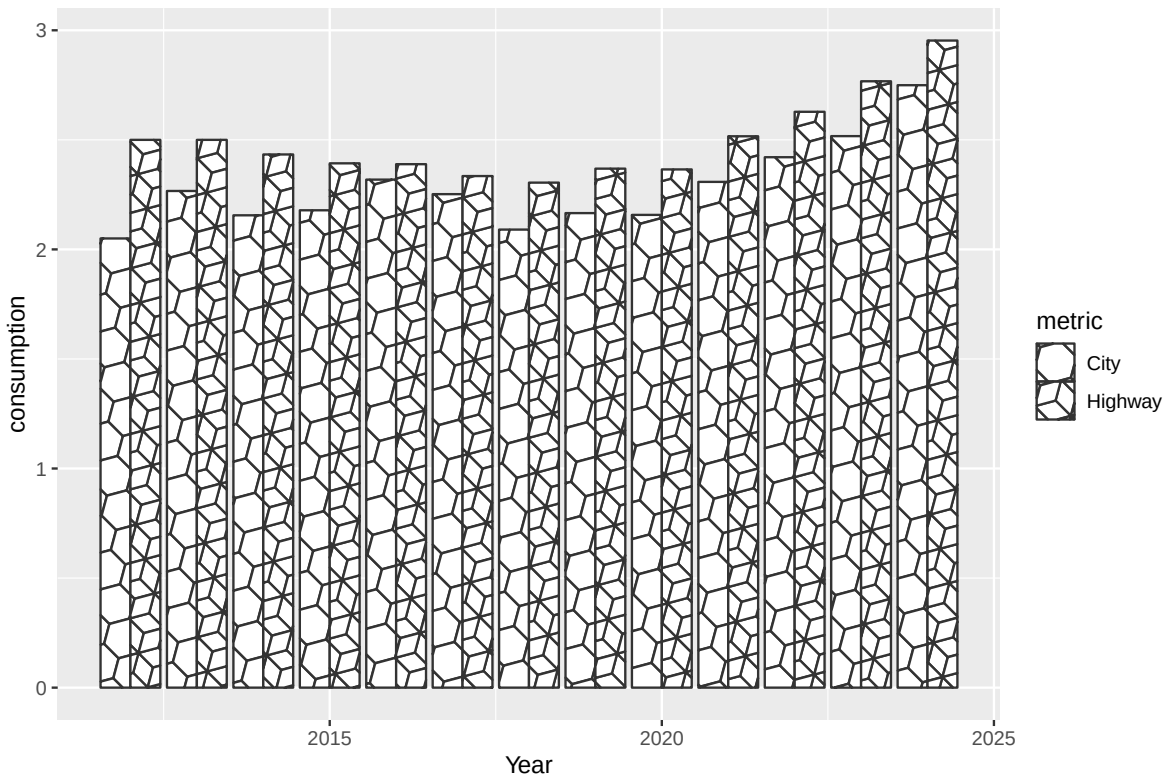
```
col.data |>
   ggplot(aes(x=Year, y=consumption, fill=metric)) +
      geom_col(position='dodge')
```



- The option `position = 'dodge'` places the columns next to each other, instead of on top of each other.

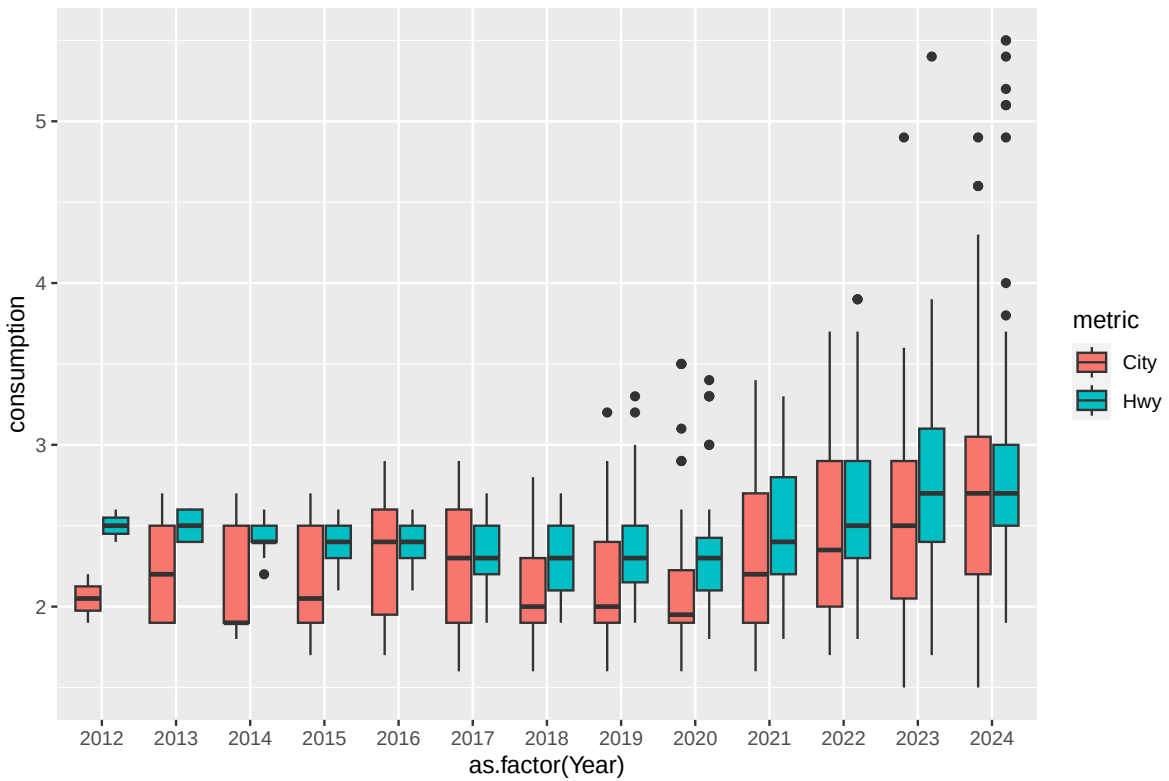
Column Chart with Patterns

```
col.data |> ggplot(aes(x=Year, y=consumption)) +
    geom_col_pattern(aes(pattern_type=metric),
          pattern='polygon_tiling', pattern_angle=45,
          pattern_fill='white', position='dodge') +
    scale_pattern_type_manual(
       values = c('hexagonal', 'rhombille'),
       labels=c("City", "Highway"))
```



Box Plot

```
data |>
  pivot_longer(cols=c('City', 'Hwy'),
               names_to='metric', values_to='consumption') |>
ggplot(aes(x=as.factor(Year), y=consumption, fill=metric)) +
  geom_boxplot()
```



- Shows distribution
- Median
- 1st quartile Q_1
- 3rd quartile Q_3
- "Inter-quartile range"
- $IQR = Q_3 - Q_1$
- "Whiskers"
- $Q_3 + 1.5 \times IQR$
- $Q_1 - 1.5 \times IQR$
- "Outliers"

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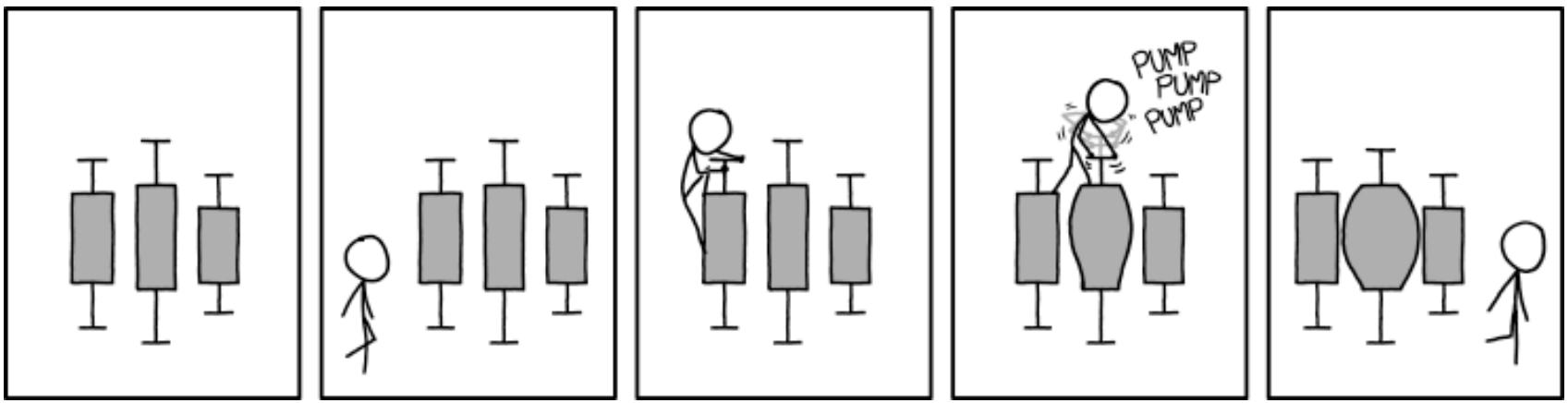
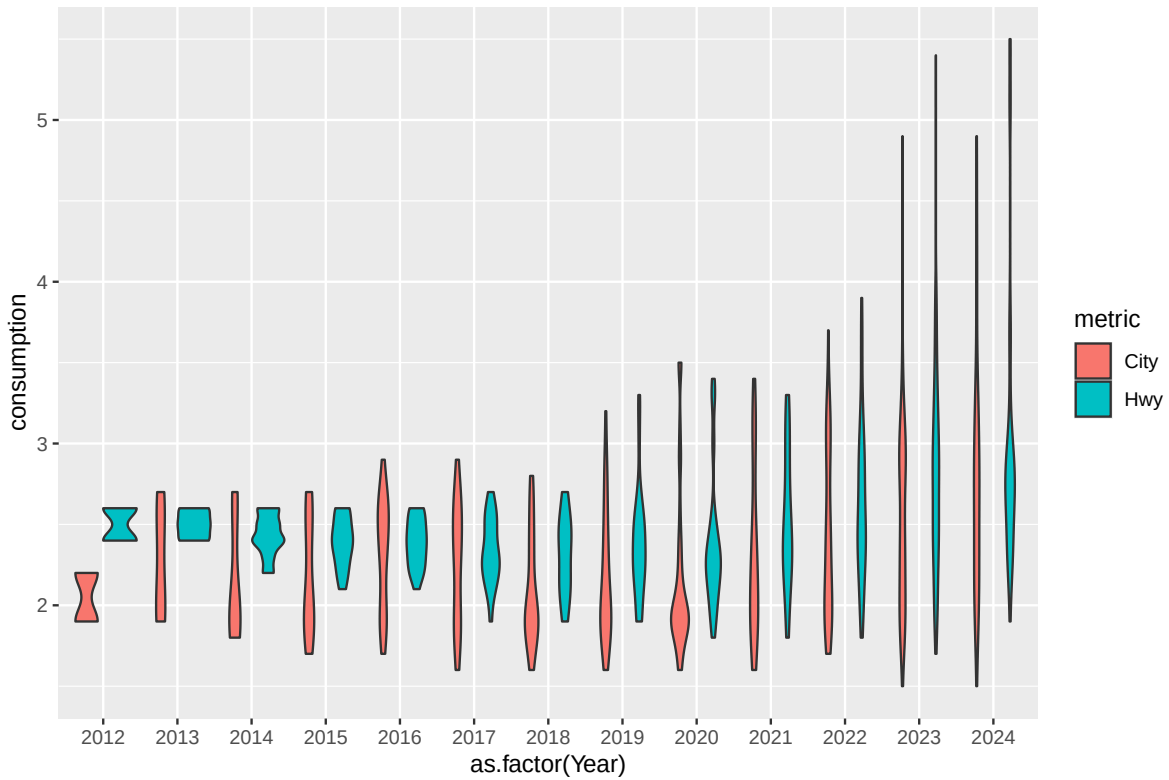
Boxplot (XKCD)



Violin Plot

```
data |>
  pivot_longer(cols=c('City', 'Hwy'),
               names_to='metric',
               values_to='consumption') |>
  ggplot(aes(x=as.factor(Year), y=consumption, fill=metric)) +
    geom_violin()
```



- Shows detailed density
- But no summary statistics

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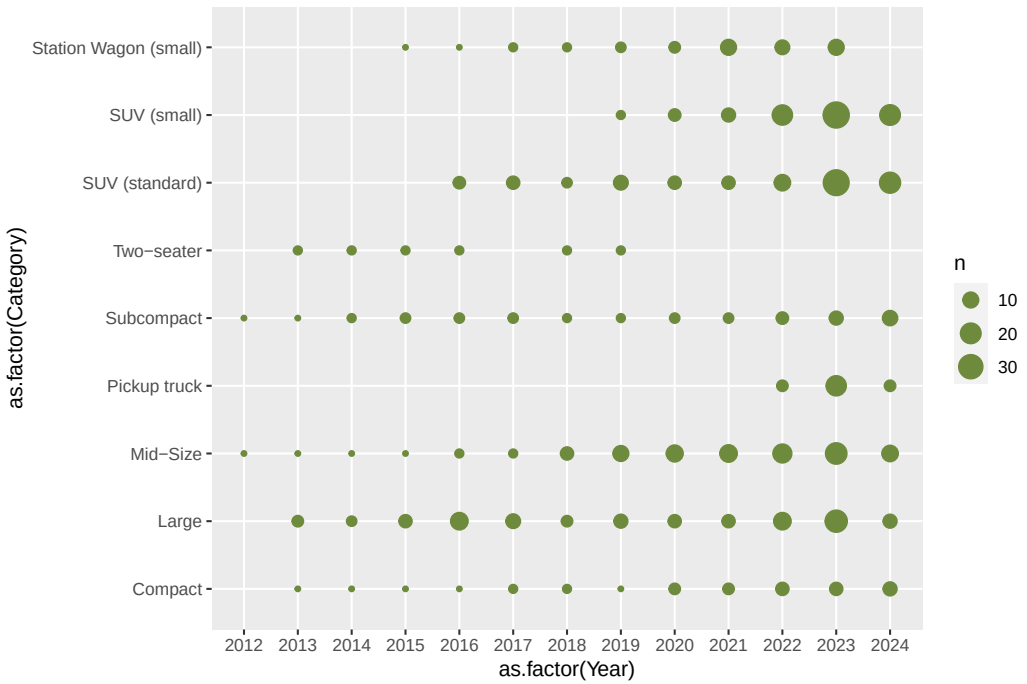
Count Plot

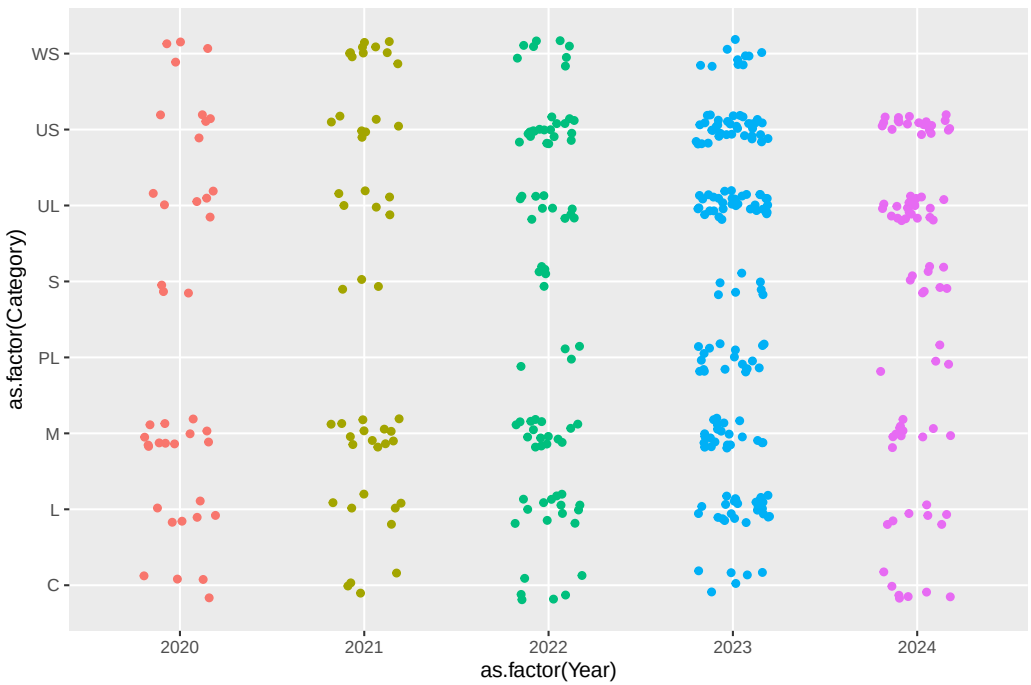
```
data %>%
ggplot(aes(as.factor(Year), as.factor(Category))) +
    geom_count(color='darkolivegreen4') +
    scale_y_discrete(
      labels=c('Compact', 'Large', 'Mid-Size', 'Pickup truck',
               'Subcompact', 'Two-seater', 'SUV (standard)',
               'SUV (small)', 'Station Wagon (small)'))
```



- Explicit labels for discrete y axis

Jitter Plot

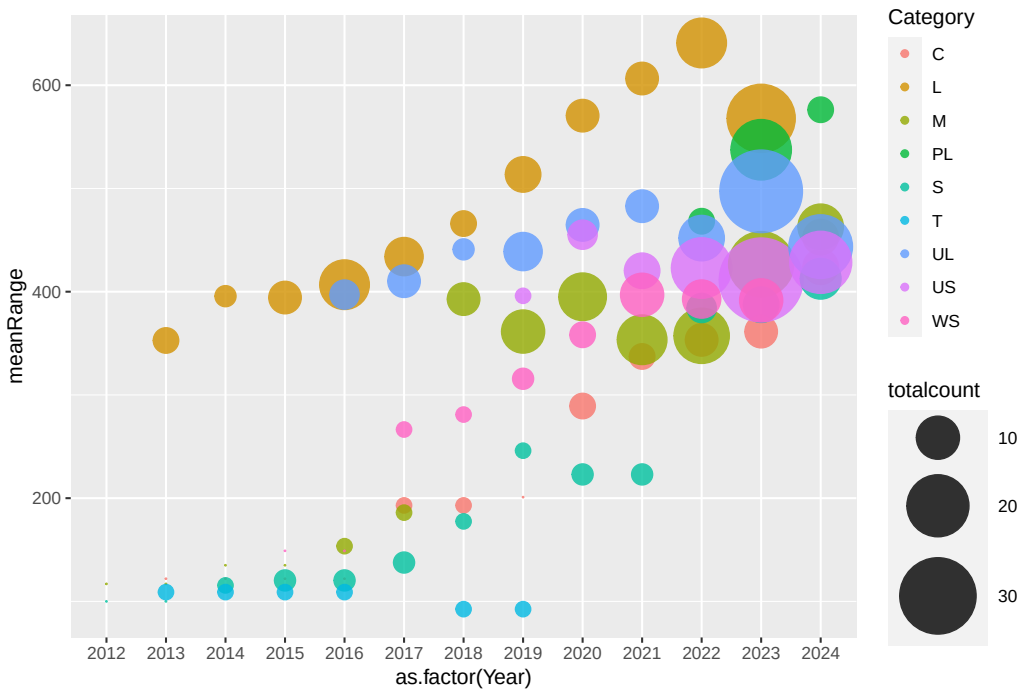
```
data |>
  filter(Year >= 2020) |>
  ggplot(aes(x=as.factor(Year), y=as.factor(Category),
             color=as.factor(Year))) +
    geom_jitter(width=0.2, height=0.2) +
    guides(color='none')
```



- Shows all data points (observations)
- No legend (”guide”) for different colours
- Because colour is also mapped to Year, same as x axis

Points Plot

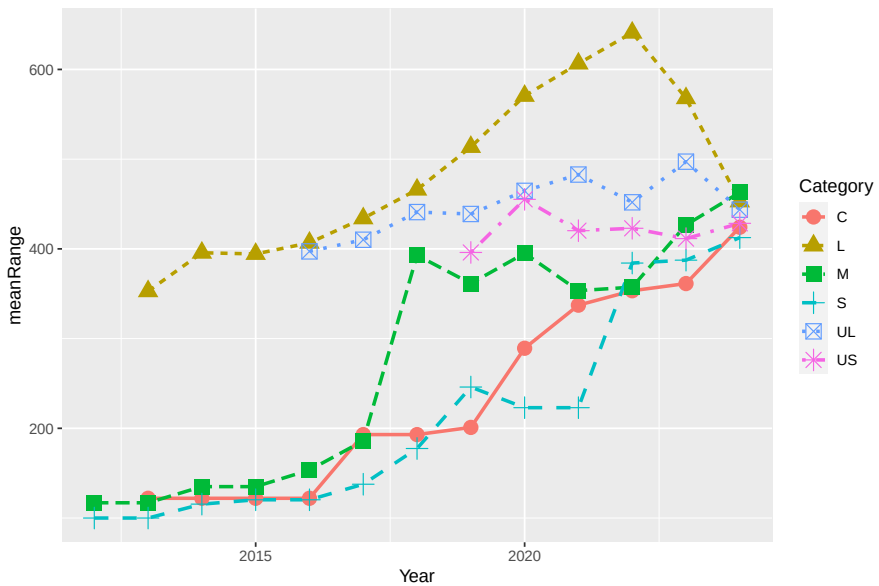
```
data |>
  group_by(Year, Category) |>
  summarize(totalcount=n(), meanRange=mean(Range)) |>
  ungroup () |>
ggplot(aes(x=as.factor(Year), y=meanRange,
           size=totalcount, color=Category)) +
  geom_point(alpha=0.8) +
  scale_size_continuous(range=c(0, 20))
```



- Shows 4 variables
- Custom scale for point size

Lines and Points Plot

```
data |>
  filter(Category %in% c('C','L','M','S','US','UL')) |>
  group_by(Year, Category) |>
  summarize(meanRange = mean(Range)) |>
  ungroup() |>
ggplot(aes(x=Year, y=meanRange,
       color=Category, shape=Category, linetype=Category)) +
  geom_line(size=1) +
  geom_point(size=4)
```



- 2 Geoms, line and point
- Category mapped to 3 plot elements

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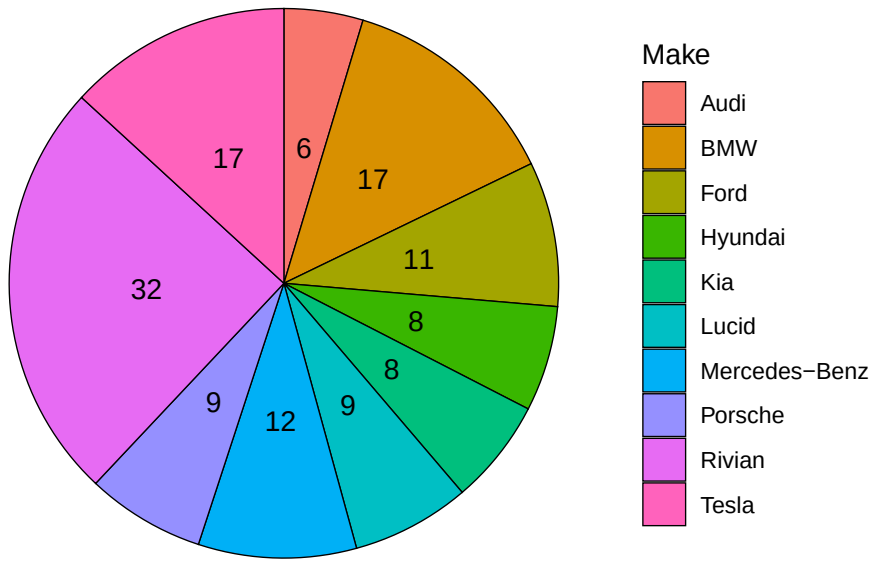
Pie Chart

```
data |>
  filter(Year==2023) |>
  group_by(Make) |>
  summarize(totalcount = n()) |>
  filter(totalcount >= 5) |>
  ungroup() |>
ggplot(aes(x='', y=totalcount,
           fill=Make)) +
  geom_bar(stat='identity',
           color='black',
           size=0.25, width=1) +
  coord_polar('y',
              direction=-1,
              start=0) +
  geom_text(aes(
    label=ifelse(totalcount >= 5,
                 totalcount,'')),
    position = position_stack(
                 vjust=0.5)) +
  theme_void()
```



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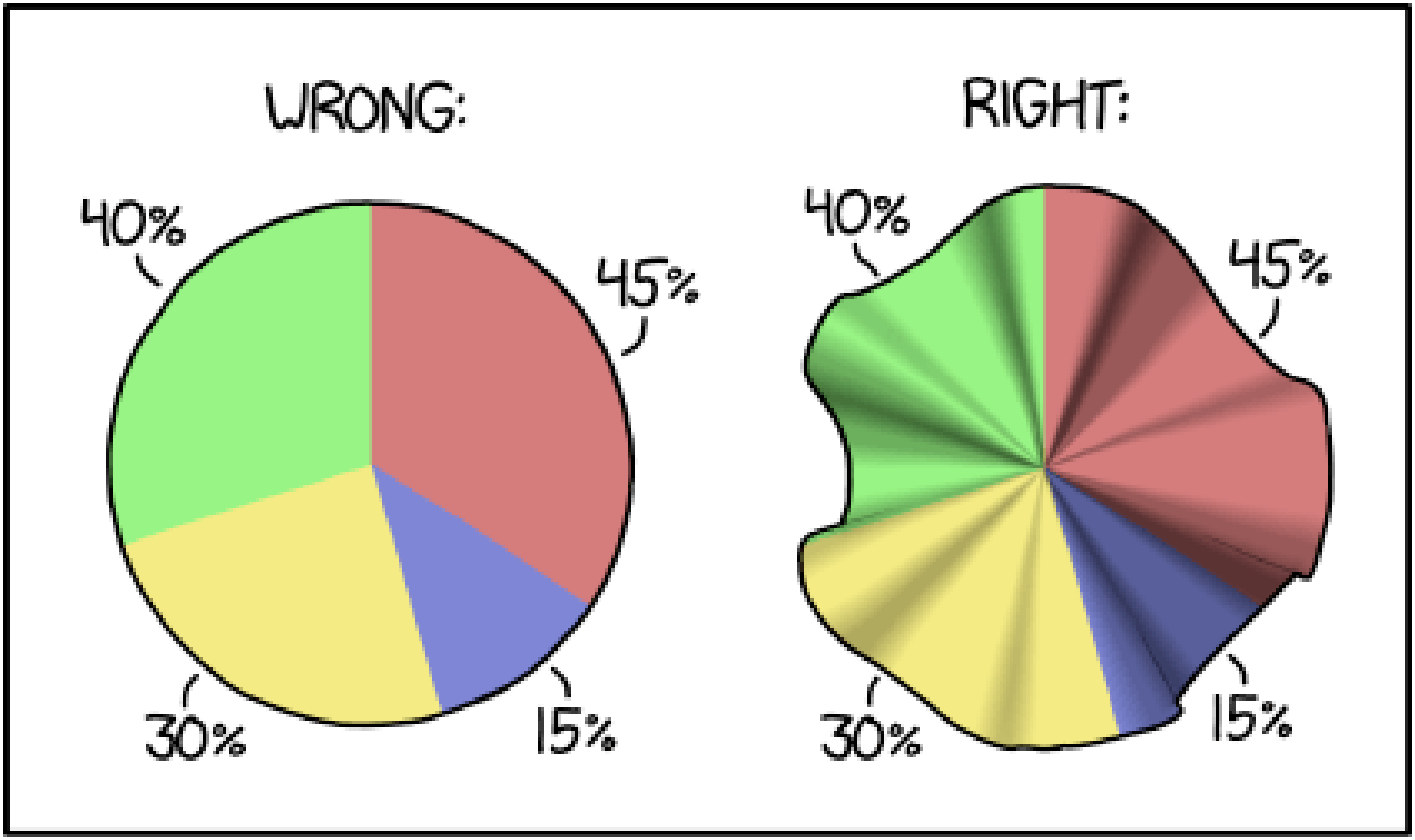
Pie Charts (XKCD)



HOW TO MAKE A PIE CHART IF YOUR PERCENTAGES DON'T ADD UP TO 100

Radar Plot

Prepare data:

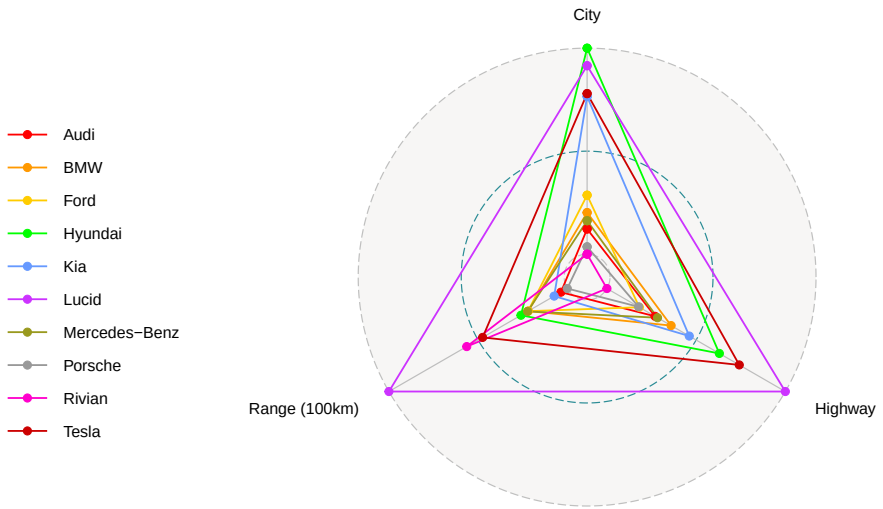
```
radardata <- data |>
  filter(Year == 2023) |> group_by(Make) |>
  summarize(meanCity = 1/mean(City),
            meanHwy = 1/mean(Hwy),
            meanRange = mean(Range)/100,
            nModels = n()) |>
  filter(nModels >= 5) |> ungroup() |>
  select(-nModels) |>
  mutate(across(-Make, rescale))
```

- The line `mutate(across(-Make, rescale))` rescales all columns except `Make` so values are between $[0, 1]$

```
# A tibble: 10 x 4
   Make           meanCity meanHwy meanRange
   <chr>             <dbl>   <dbl>     <dbl>
 1 Audi              0.122   0.270    0.0357
 2 BMW               0.202   0.360    0.219
 3 Ford              0.287   0.182    0.220
 4 Hyundai           1       0.630    0.260
```

Radar Plot

```
radardata |>
  ggradar(
    axis.labels=c(
        'City',
        'Highway',
        'Range'),
    values.radar='',
    group.line.width=0.75,
    group.point.size=3) +
  scale_color_ucscgb()
```



- Shows a comparison of different objects on a number of dimensions/aspects.
- Changed the colour palette to UCS CGB colours.

Lines with Multiple Axes

```
data |>
   group_by(Year) |>
   summarize(meanCity = mean(City),
             meanHwy = mean(Hwy),
             meanRange = mean(Range)/100) |>
   ungroup() |>
ggplot(aes(x=Year)) +
  geom_line(aes(y=meanCity, color='Mean City')) +
  geom_line(aes(y=meanHwy, color='Mean Hwy')) +
  geom_line(aes(y=meanRange, color='Mean Range')) +
  scale_color_manual(name='Data Series',
     values=c('Mean City' = 'red',
              'Mean Hwy' = 'blue',
              'Mean Range' = 'green')) +
  scale_y_continuous(labels=scales::comma,
      name="Fuel Consumption\n(l/100km equiv)",
      sec.axis=sec_axis(~ .*100,
                        labels=scales::comma,
                        name="Mean Range (km)")) +
  scale_x_continuous(breaks=seq(from=2012,to=2024,by=1))
```

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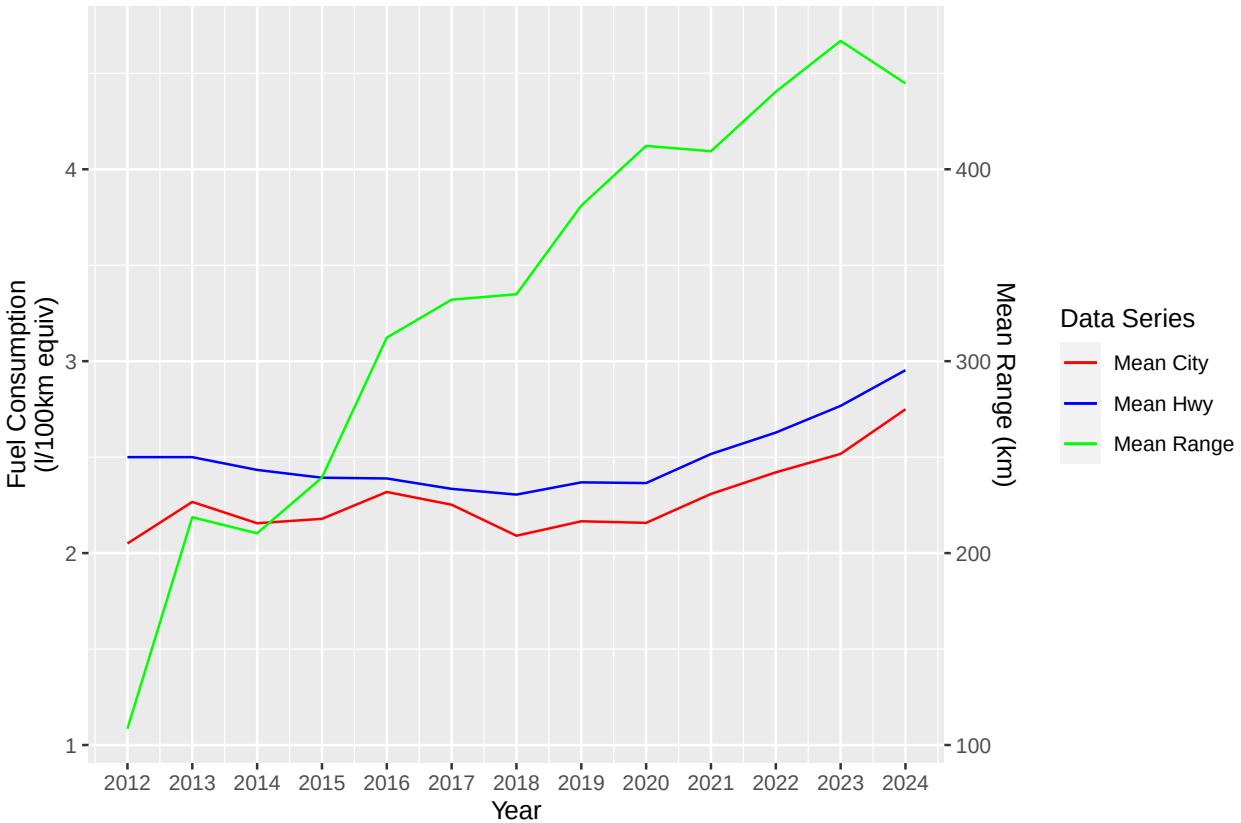
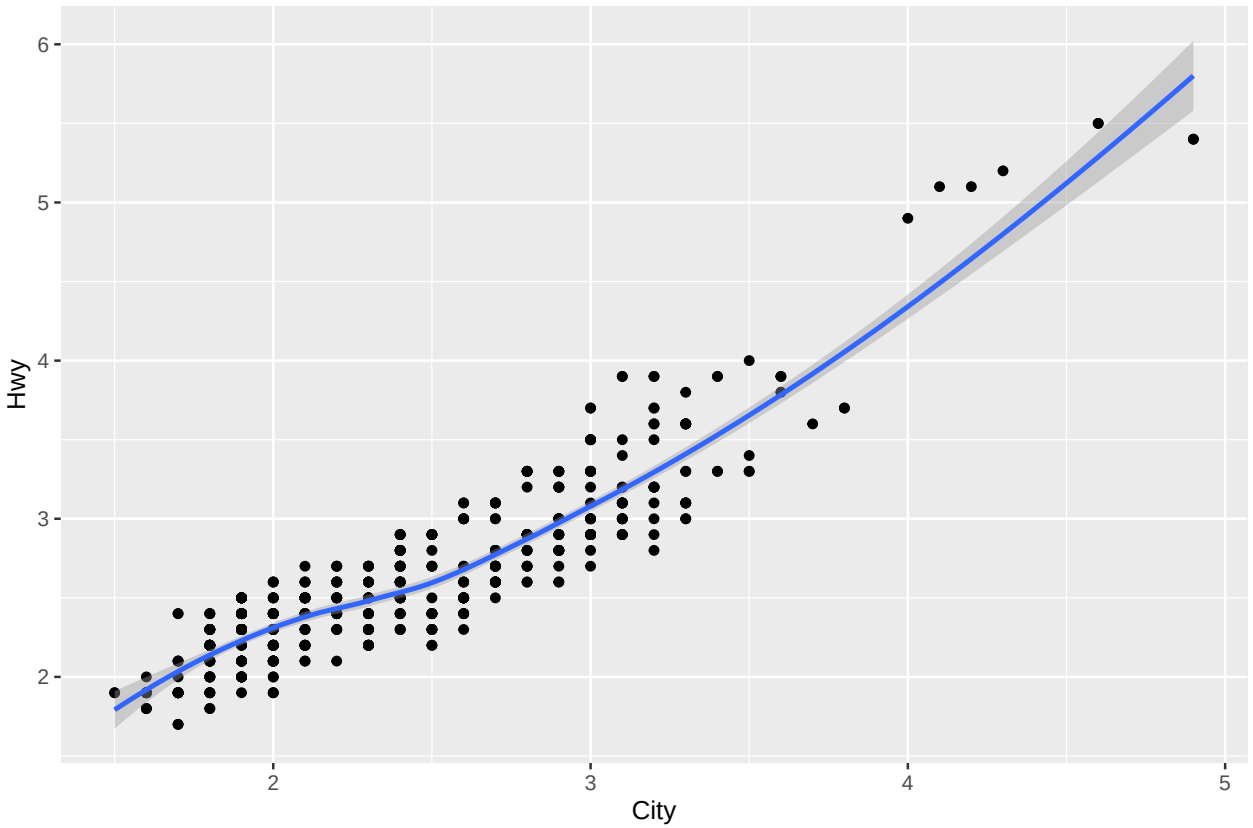
Lines with Multiple Axes



- Three geoms
- Manual colour scale
- Y axis scale with primary label
- Secondary axis with `sec.axis` option, scale factor to primary axis, and secondary label

Local Regression Smoothing Plot

```
data |>
  ggplot(aes(City, Hwy)) +
    geom_point() +
    geom_smooth()
```



- Two geoms
- Local regression line
- Uncertainty interval around regression line

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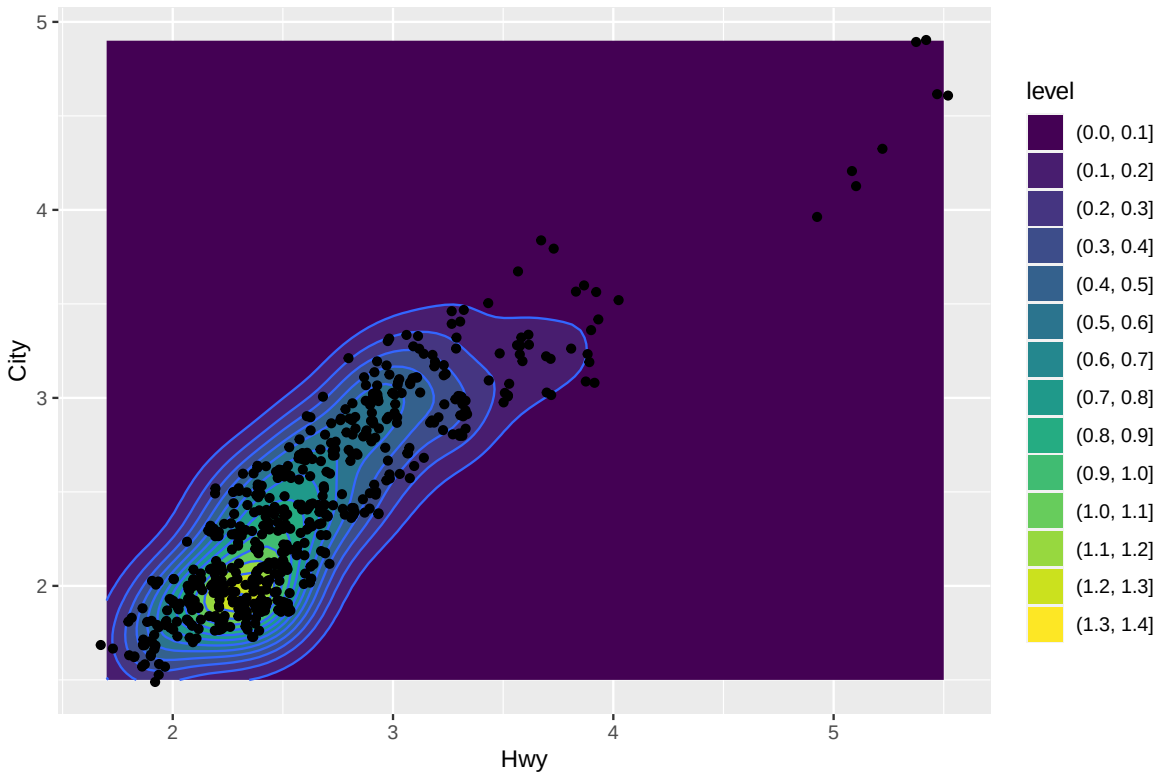
2D Density Plot

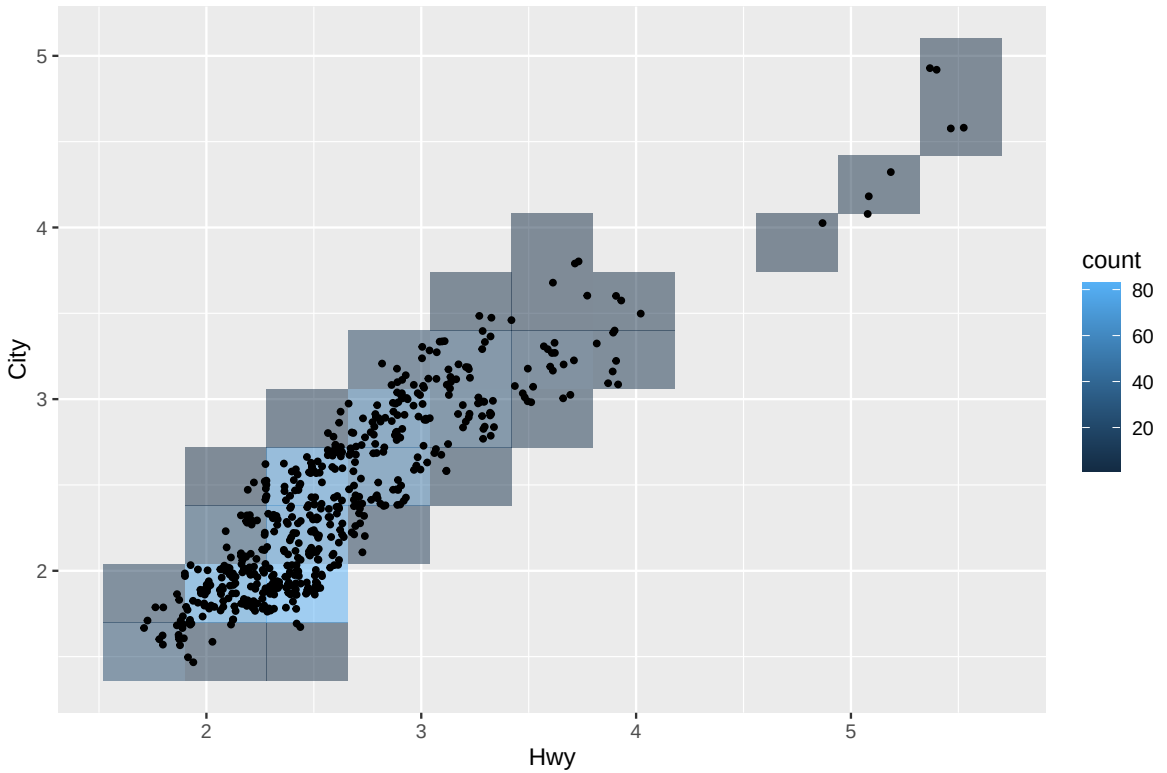
```
data |>
  ggplot(aes(x=Hwy, y=City)) +
    geom_density_2d_filled() +
    geom_density_2d() +
    geom_point(position='jitter')
```



- Shows (co-)distribution of observations
- Generalization of (1D) density plot
- Three geoms
- One for outline, one for fill, one for points

2D Bin Plot

```
data %>%
  ggplot(aes(x=Hwy, y=City)) +
    geom_bin2d(alpha=0.5, bins=10) +
    geom_point(color="black", size=1, position='jitter')
```



- Shows (co-)distribution of observations
- Generalization of (1D) histogram plot

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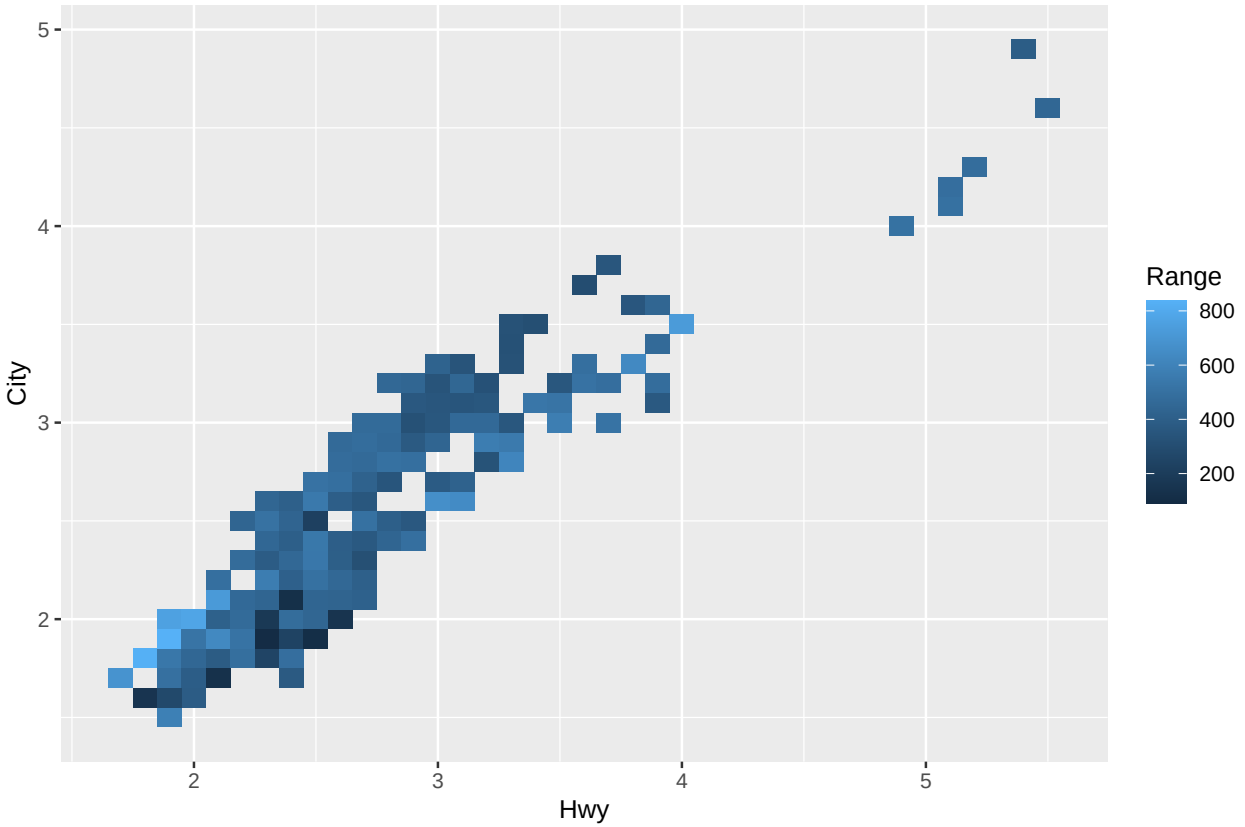
3D Raster/Tile Plot

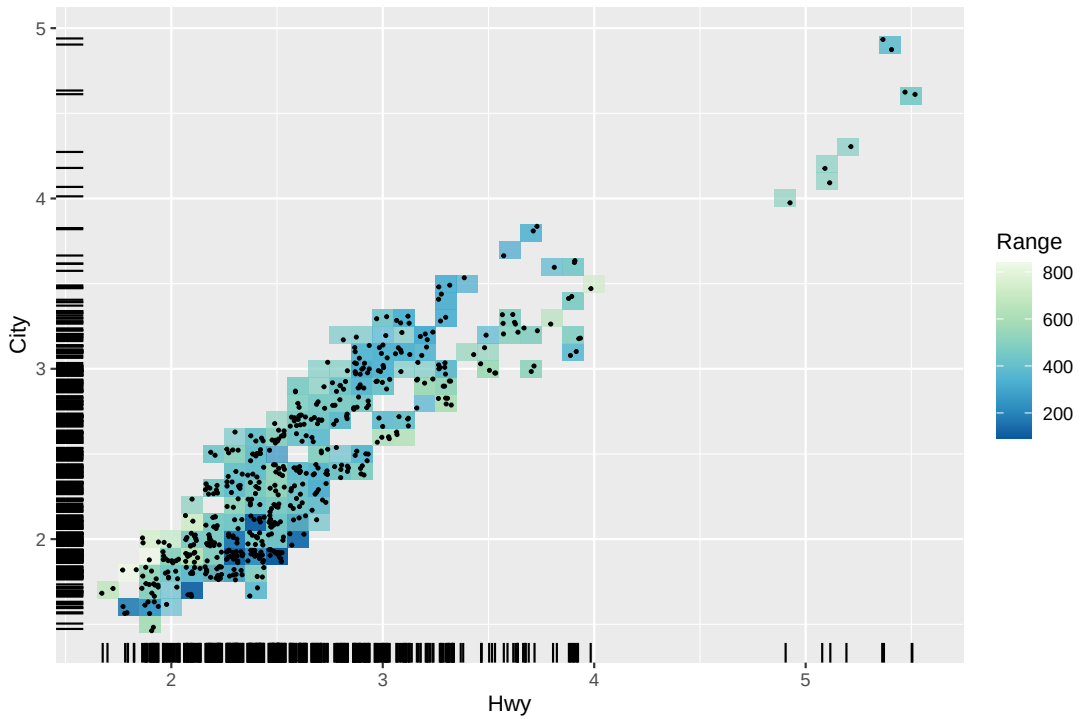
```
data |>
  ggplot(aes(x=Hwy, y=City, fill=Range)) +
    geom_tile()
```



- Plot of three variables

Complex Example – 3D Raster Plot with Rug

```
data |>
  ggplot(aes(x=Hwy, y=City, fill=Range)) +
    geom_tile() +
    geom_point(size=0.5, position='jitter') +
    geom_rug(position='jitter') +
    scale_fill_distiller(palette=4, direction=-1)
```



- Geom for tiling
- Geom for points/observations
- Geom for ”rugs”
- Custom colour scale

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Hands-On Exercises

Using the Pagila database data from `https://evermann.ca/busi4720/rentals.csv`, create

1. A histogram and/or density chart of film length by film category
2. A column chart of the mean rental payments for films by film category
3. A scatter plot of total rental payments by year and week
   - Add a local regression line to this plot
4. A pie or donut chart of rental counts by film rating

Tips:

- Use the `read_csv()` function to read from a URL
- The data is de-normalized, use the `unique()` function to get accurate film counts
- Use the `year()` and `week()` functions from the `lubridate` package (another package of the Tidyverse set)

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