Data Visualization (2)

Intermediate

Haohan Chen

POLI3148 Data Science in PPA (The University of Hong Kong)

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Objectives

Master data visualization methods with `ggplot`.

- Housekeeping
  - `ggplot` syntax
  - Variable types
- How to visualize everything

Reading Materials on Data Visualization

- [Kabacoff] Kabacoff, Rob. Data Visualization with R. 2020. E-book: rkabacoff.github.io/datavis
- [Healy] Healy, Kieran. Data visualization: a practical introduction. Princeton University Press, 2018. E-book: socviz.co

Housekeeping

Load Data

```
library(tidyverse)
theme_set(theme_bw()) # Set my default theme for the whole document

d <- readRDS("Lec_07/data/wealth_and_health.rds")
d |> print(n = 3)
```

```
## # A tibble: 23,593 x 10
##   country_text_id  year region life_expectancy gdppc population infant_mortality
##   <chr>           <dbl>  <dbl>           <dbl> <dbl>      <dbl>            <dbl>
## 1 MEX              1800     17            26.9  1.35       5100              487
## 2 MEX              1801     17            26.9  1.34       5174.             487
## 3 MEX              1802     17            26.9  1.32       5249.             487
## # i 23,590 more rows
## # i 3 more variables: democracy_binary <dbl>, democracy_lexical <dbl>,
## #   democracy_polity5 <dbl>
```

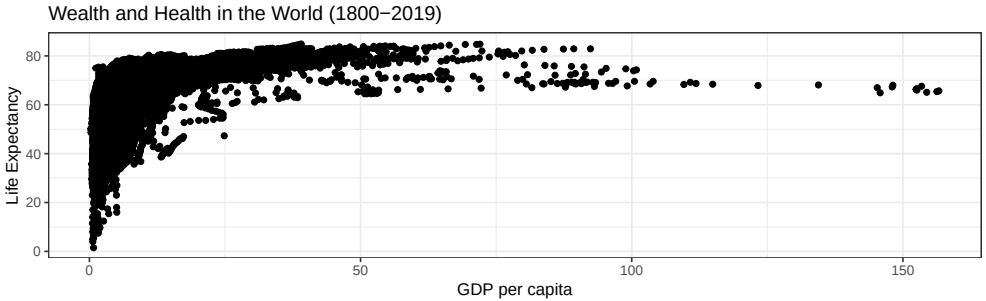
ggplot syntax

- Consider: "Painting" your data on a canvas, layer by layer
- Steps
  - Specify the data you want to viaulize
  - Specify the type(s) of visualization tools
  - Label the figure (titles of the figure, axes, and legends)
- Command: Use + to connect layers (ATTENTION: not |>)

Note: ***Always*** properly label your figures!

ggplot syntax: example

```
d |> # Specify the data frame to plot
  ggplot(aes(x = gdppc, y = life_expectancy)) + # Specify the variables to plot
  geom_point() + # Choose the visualization tool: point
  labs(x = "GDP per capita", y = "Life Expectancy", # set up the axes' titles
       title = "Wealth and Health in the World (1800-2019)", # set up the figure's title
       caption = "By Haohan Chen. Data source: V-Dem v.13") # set up footnote
```



Variable Types

Visualization tools to use largely depends on variable types

- "Quantitative" (Continuous, Count)
  - GDP per capita
  - Life expectancy
  - Population
  - Infant mortality
- Categorical
  - Binary: Binary "democracy" indicator
  - Nominal: Region
  - Ordinal: Lexical Index of Electoral Democracy

Quant. X 1

Viaulize One Quantitative Variable

- Summary Statistics
  - Min, max, median, mean, standard deviation, variance,
  - Quantiles, quintiles
- Visualization
  - Histogram
  - Density Plot
- Advanced
  - Skewed distribution
  - Annotate cases

Summary Statistics

```
summary(d$gdppc) # Quick summary
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##   0.286   1.599   2.774   7.194   7.606 156.628    4571
```

```
length(d$gdppc) # Number of observations
```

```
## [1] 23593
```

```
is.na(d$gdppc) |> sum() # Number of missing values
```

```
## [1] 4571
```

Summary Statistics (con'd)

```r
mean(d$gdppc, na.rm = TRUE) # Mean
```

```
## [1] 7.193588
```

```r
var(d$gdppc, na.rm = TRUE) # Variance
```

```
## [1] 131.029
```

```r
sd(d$gdppc, na.rm = TRUE) # Standard deviation
```

```
## [1] 11.44679
```

```r
quantile(d$gdppc, na.rm = TRUE) # Quantile
```

```
##       0%      25%      50%      75%     100%
##  0.28600  1.59900  2.77400  7.60575 156.62800
```

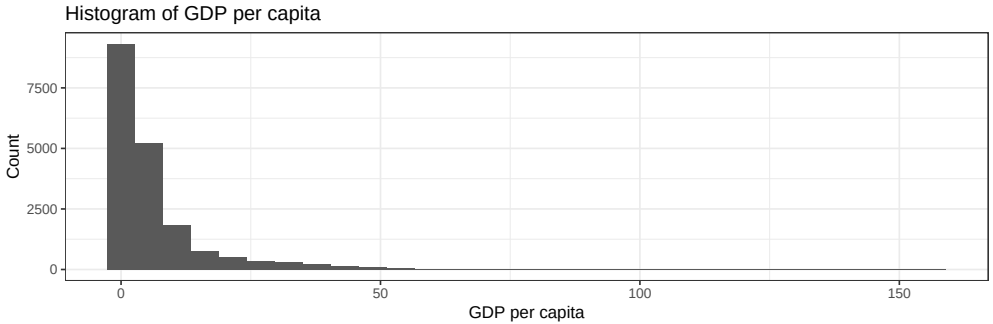
```r
quantile(d$gdppc, seq(0, 1, 0.1), na.rm = TRUE) # Quintile
```

```
##       0%      10%      20%      30%      40%      50%      60%      70%
##   0.2860   1.0451   1.4340   1.7760   2.1624   2.7740   4.0246   6.0687
##       80%      90%     100%
##   9.4364  18.7600 156.6280
```

Histogram

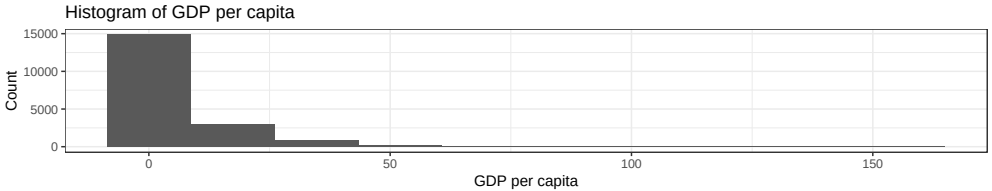
```
d |>
  ggplot(aes(x = gdppc)) +
  geom_histogram() + # Draw a histogram
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

## Warning: Removed 4571 rows containing non-finite values (stat_bin).
```

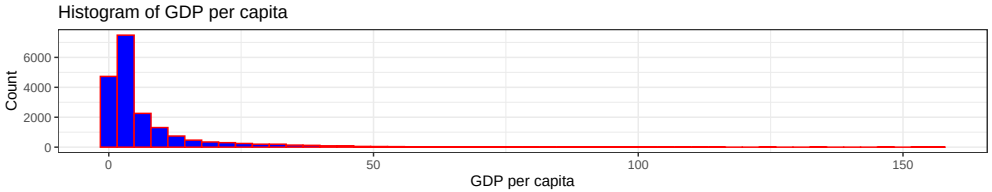


Histogram (customized)

```
d |> ggplot(aes(x = gdppc)) + geom_histogram(bins = 10) +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```

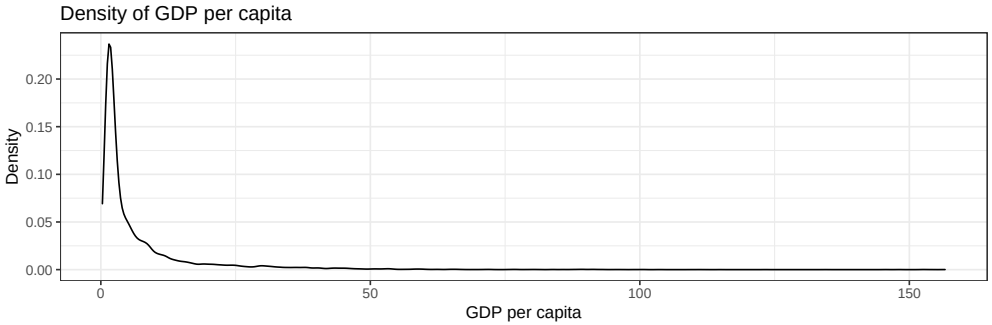



```
d |> ggplot(aes(x = gdppc)) + geom_histogram(bins = 50, fill = "blue", color = "red") +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```



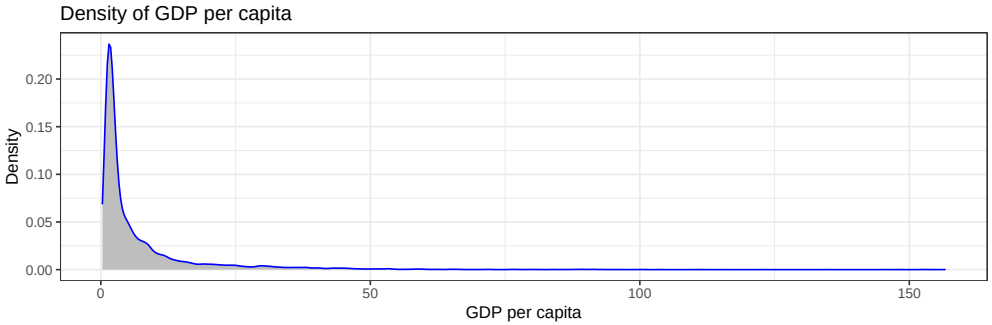
Density

```
d |>
  ggplot(aes(x = gdppc)) +
  geom_density() + # Draw a density plot
  labs(x = "GDP per capita", y = "Density", title = "Density of GDP per capita")
```



Density (customized)

```
d |>
  ggplot(aes(x = gdppc)) +
  geom_density(fill = "gray", color = "blue") + # Draw a density plot
  labs(x = "GDP per capita", y = "Density", title = "Density of GDP per capita")
```

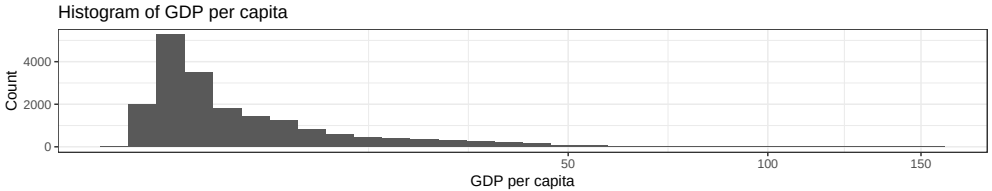


Skewed Distribution

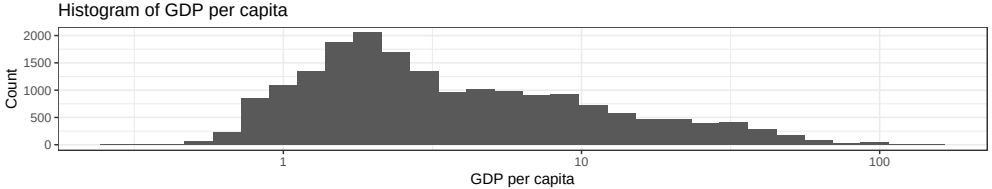
- **Challenge:** Quantitative data may have skewed distributions, which can make the visualization uninformative.
- **Solution:**
  - Re-scale the axes
  - Transform the variable(s)

Skewed Distribution: Re-scale Axes

```
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  scale_x_sqrt() + # Scale the x axis to make distribution easy to read
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```



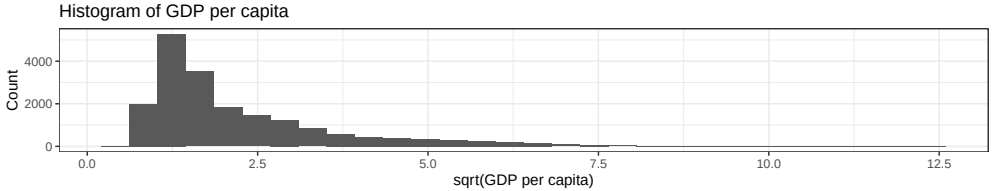

```
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  scale_x_log10() + # Scale the x axis to make distribution easy to read
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```



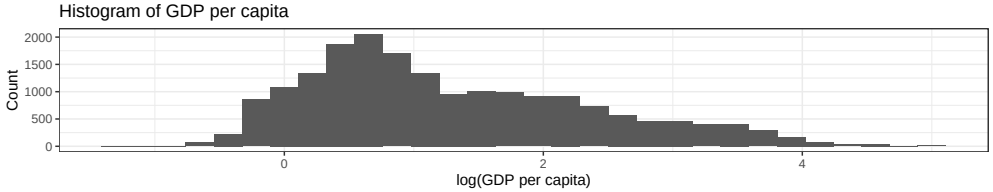
Skewed Distribution: Transform Variables

Alternatively you can first transform the variable before your visualization

```
d |> mutate(gdppc_sqrt = sqrt(gdppc)) |> # Transform the variable before visualization
  ggplot(aes(x = gdppc_sqrt)) + geom_histogram() +
  labs(x = "sqrt(GDP per capita)", y = "Count", title = "Histogram of GDP per capita")
```




```
d |> mutate(gdppc_log = log(gdppc)) |> # Transform the variable before visualization
  ggplot(aes(x = gdppc_log)) + geom_histogram() +
  labs(x = "log(GDP per capita)", y = "Count", title = "Histogram of GDP per capita")
```



Skewed Distribution: Note

```
summary(d$gdppc)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##   0.286   1.599   2.774   7.194   7.606 156.628    4571
```

The method only work when your variable contains NON-NEGATIVE values only.

Annotate Case(s) of Interest

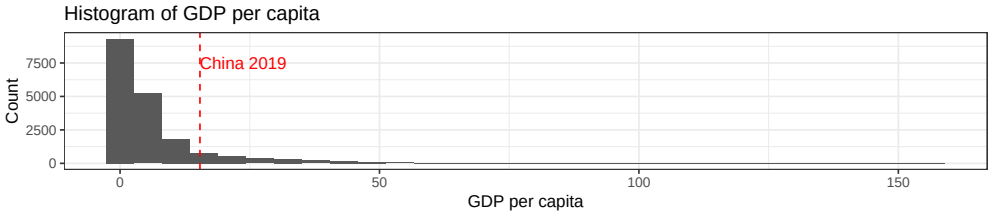
```
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```

Annotate Case(s) of Interest (con'd)

```
d_anno <- d |> filter(country_text_id == "CHN", year == 2019) |> mutate(anno = paste(country_text_id, year), .after = year)
print(d_anno)
```

```
## # A tibble: 1 x 11
##   country_text_id  year anno     region life_expectancy gdppc population
##   <chr>           <dbl> <chr>     <dbl>           <dbl> <dbl>      <dbl>
## 1 CHN              2019 CHN 2019     12            77.6  15.4    1407745
## # i 4 more variables: infant_mortality <dbl>, democracy_binary <dbl>,
## #   democracy_lexical <dbl>, democracy_polity5 <dbl>
```

```
# A "manual" approach
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  geom_vline(aes(xintercept = 15.4), linetype = "dashed", color = "red") +
  annotate("text", x = 15.4, y = 7500, hjust = 0, label = "China 2019", color = "red") +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```




```
# How do I get y = 7500? Observe the y-axis in the previous figure.
```

Annotate Case(s) of Interest (con'd)

```r
# An automated approach
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  geom_vline(data = d_anno, aes(xintercept = gdppc), linetype = "dashed", color = "red") +
  geom_text(data = d_anno, aes(x = gdppc, y = 7500, label = anno), hjust = 0, color = "red") +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```

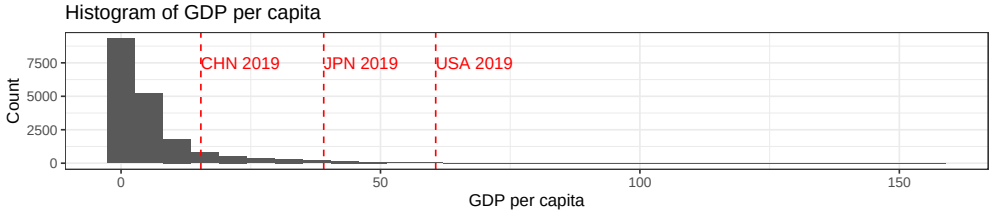
Why bother with the automated approach? It helps when you want to annotate multiple cases.

Annotate Case(s) of Interest (con'd)

```
d_anno <- d |> filter(country_text_id %in% c("CHN", "JPN", "USA"), year == 2019) |>
  mutate(anno = paste(country_text_id, year), .after = year)
print(d_anno)
```

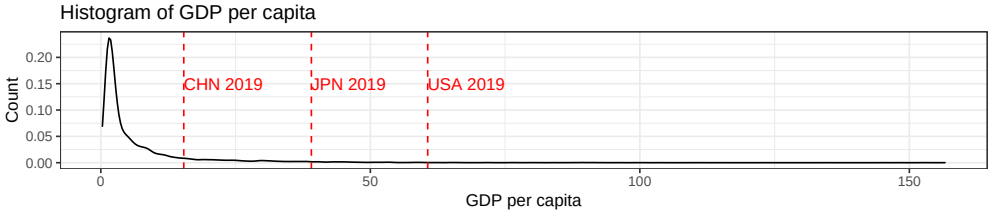
```
## # A tibble: 3 x 11
##   country_text_id  year anno     region life_expectancy gdppc population
##   <chr>           <dbl> <chr>     <dbl>           <dbl> <dbl>      <dbl>
## 1 JPN              2019 JPN 2019     12            84.8  39.1     126633
## 2 USA              2019 USA 2019     16            78.9  60.6     328330.
## 3 CHN              2019 CHN 2019     12            77.6  15.4    1407745
## # i 4 more variables: infant_mortality <dbl>, democracy_binary <dbl>,
## #   democracy_lexical <dbl>, democracy_polity5 <dbl>
```

```
d |> ggplot(aes(x = gdppc)) + geom_histogram() +
  geom_vline(data = d_anno, aes(xintercept = gdppc), linetype = "dashed", color = "red") +
  geom_text(data = d_anno, aes(x = gdppc, y = 7500, label = anno), hjust = 0, color = "red") +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```



Annotate Case(s) of Interest (con'd)

```
d |> ggplot(aes(x = gdppc)) +
  geom_density() +
  geom_vline(data = d_anno, aes(xintercept = gdppc), linetype = "dashed", color = "red") +
  geom_text(data = d_anno, aes(x = gdppc, y = 0.15, label = anno), hjust = 0, color = "red") +
  labs(x = "GDP per capita", y = "Count", title = "Histogram of GDP per capita")
```




```
# Why do I change y to 0.15? Through observation again...
```

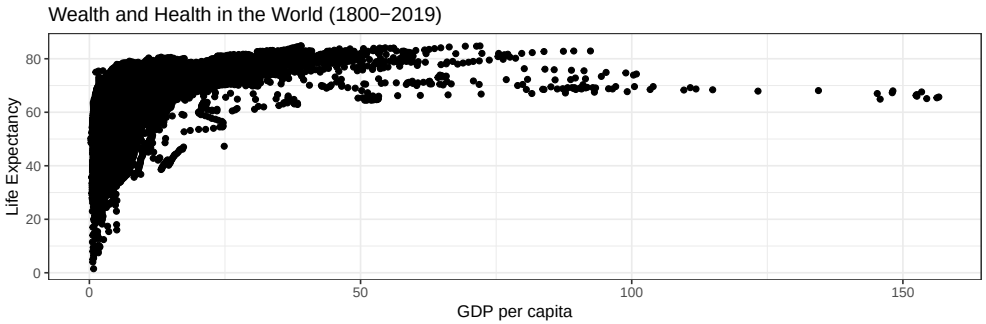
Quant. X 2

Visualize Two Quantitative Variables

- Plots
  - Scatter plot
  - Scatter plot with a trend line
- Advanced
  - Skewed distribution
  - Annotate data points
  - 2D “Histogram”
- Summary Statistics: Correlation

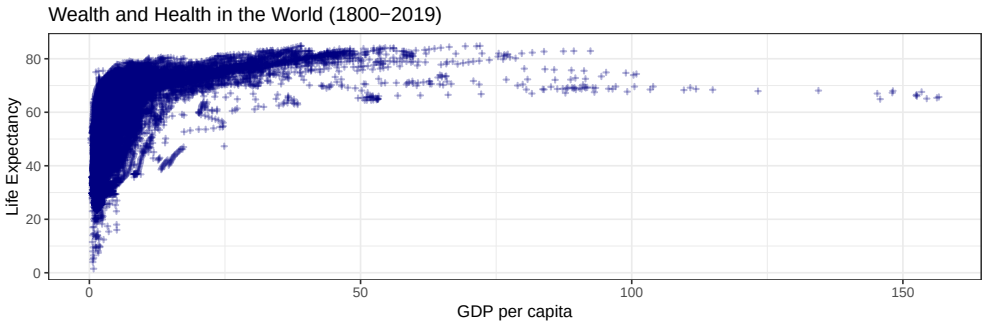
Scatter Plot

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



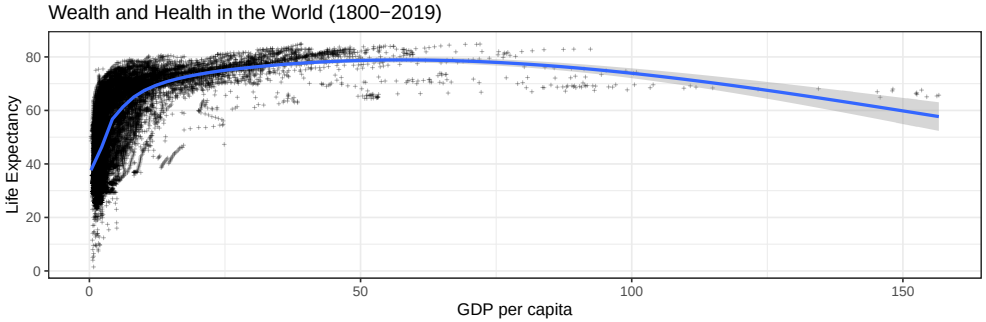
Scatter Plot (customized)

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, color = "navy", shape = 3, size = 0.5, stroke = 1) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



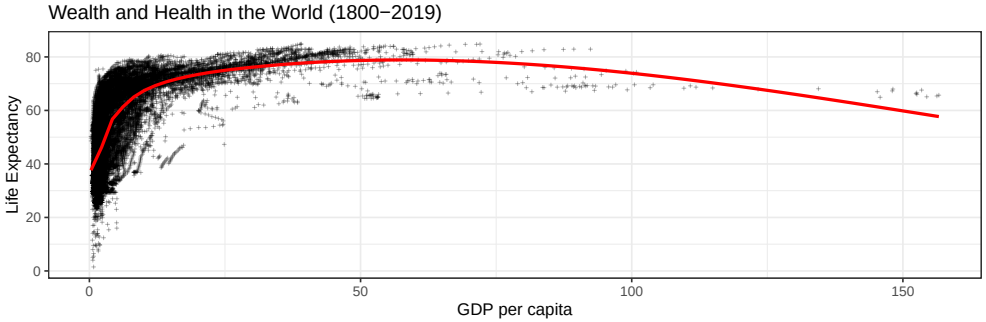
Scatter Plot with a Trend Line

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  geom_smooth() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



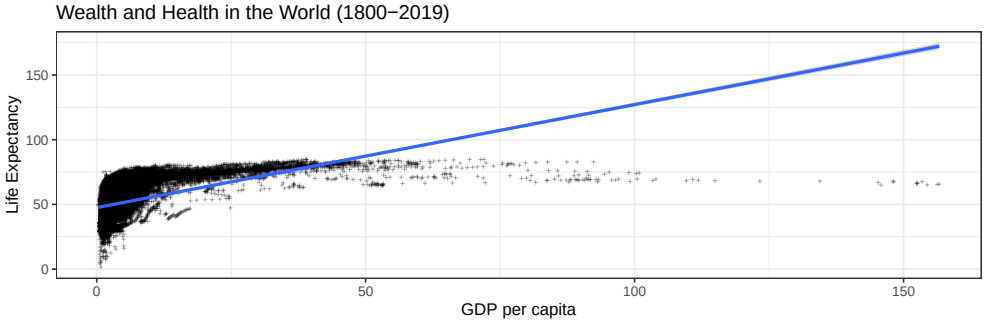
Scatter Plot with a Trend Line (customized aesthetic)

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  geom_smooth(se = FALSE, color = "red") +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



Scatter Plot with a Trend Line (customized model)

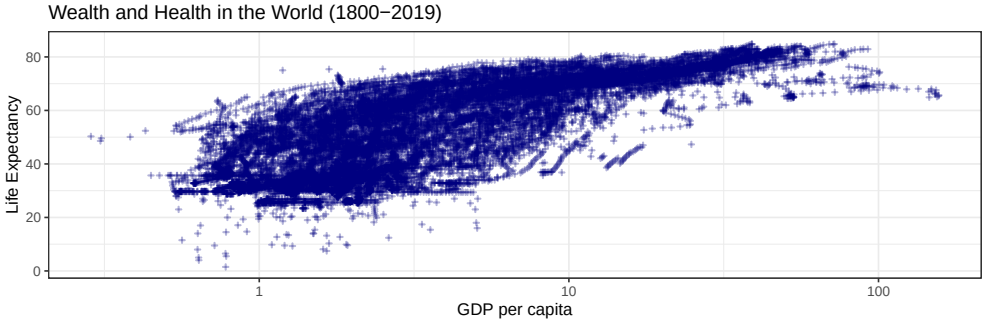
```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  geom_smooth(method = "lm") +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



This is a BAD example, because the relationship between the two variables is clearly not linear!

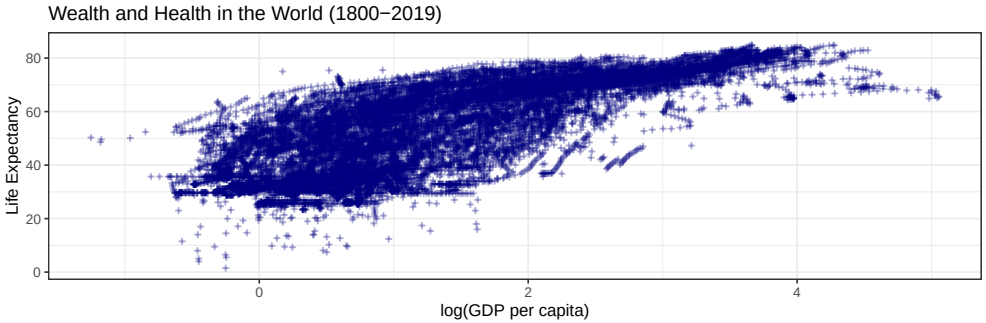
Skewed Distribution: Re-scale Axes

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, color = "navy", shape = 3, size = 0.5, stroke = 1) +
  scale_x_log10() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



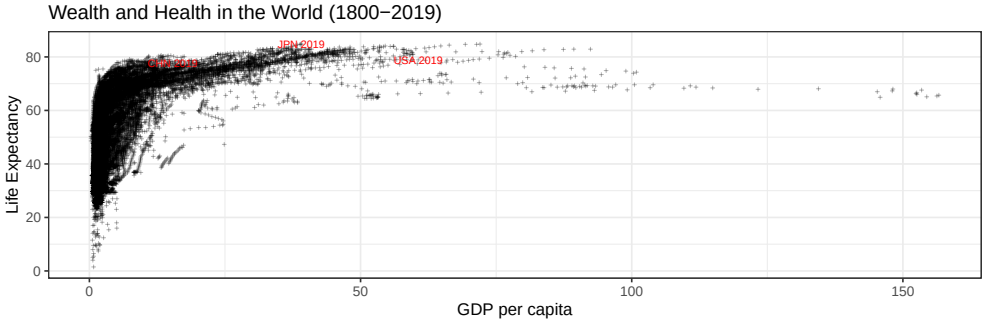
Skewed Distribution: Transform variables

```
d |>
  mutate(gdppc_log = log(gdppc)) |>
  ggplot(aes(x = gdppc_log, y = life_expectancy)) +
  geom_point(alpha = 0.3, color = "navy", shape = 3, size = 0.5, stroke = 1) +
  labs(x = "log(GDP per capita)", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



Annotate Data Points: geom_text

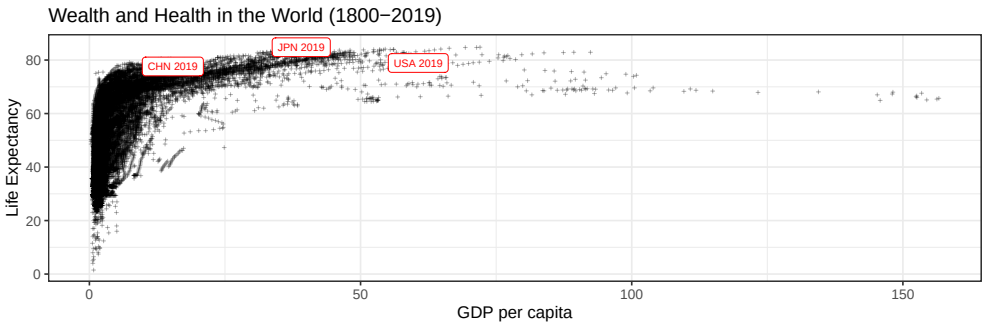
```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  geom_text(data = d_anno, aes(x = gdppc, y = life_expectancy, label = anno), color = "red", size = 2.5) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



Annotate Data Points: geom_label

geom_text might not be able to highlight your data points enough (especially when your scatter plot has a lot of data points). geom_label may help.

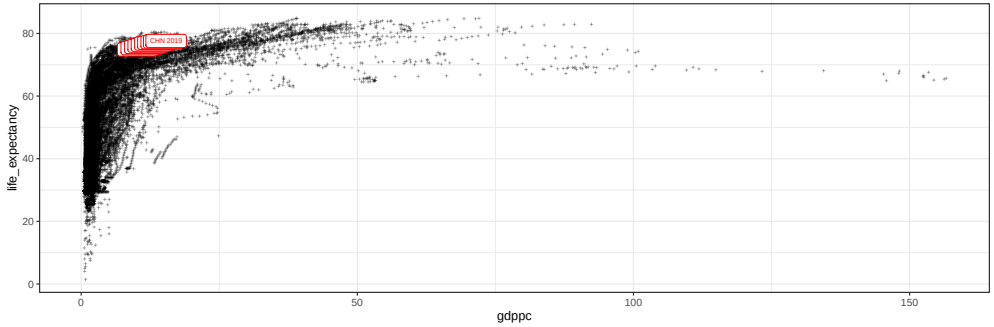
```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  geom_label(data = d_anno, aes(x = gdppc, y = life_expectancy, label = anno), color = "red", size = 2.5) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



Annotate MANY Data Points: Problem

`geom_label` and `geom_text` may get you uninformative annotation if the points you want to annotate cluster in a small area of your figure.

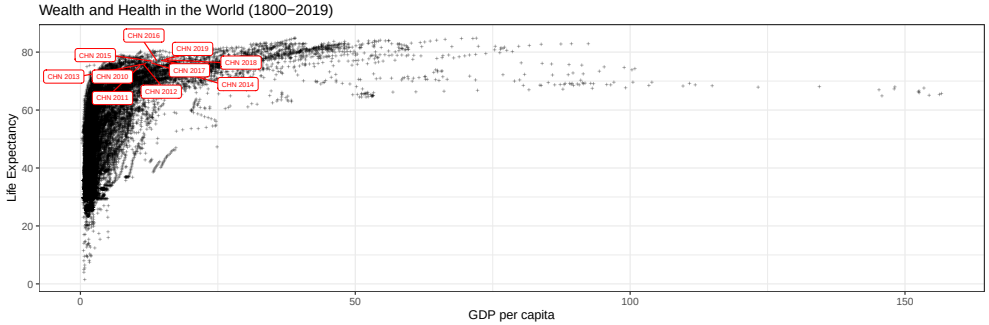
```
d_anno_2 <- d |> filter(year >= 2010, country_text_id == "CHN") |>
  mutate(anno = paste(country_text_id, year), .after = year)

d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  # geom_point(data = d_anno_2, aes(x = gdppc, y = life_expectancy), color = "red", size = 0.5) +
  geom_label(data = d_anno_2, aes(x = gdppc, y = life_expectancy, label = anno), color = "red", size = 2)
```



Annotate MANY Data Points: `geom_label_repel`

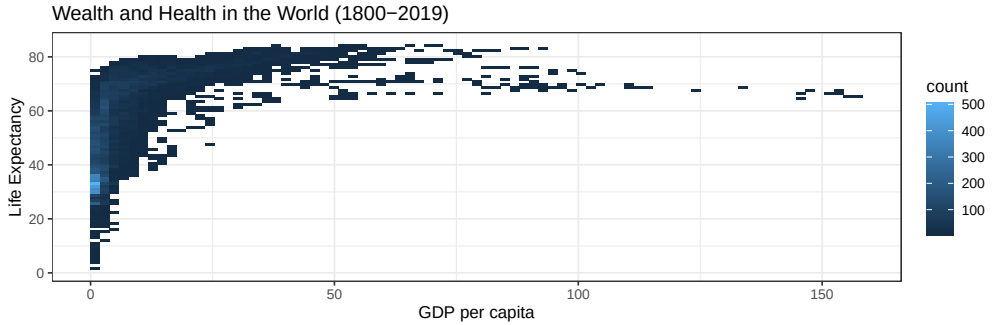
When you need to annotate a few points that may cluster in a small area of your figure, `geom_label_repel` can adjust the labels' locations to avoid overlaps.

```
library(ggrepel)
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(alpha = 0.3, shape = 3, size = 0.5) +
  # geom_point(data = d_anno_2, aes(x = gdppc, y = life_expectancy), color = "red", size = 0.5) +
  geom_label_repel(data = d_anno_2, aes(x = gdppc, y = life_expectancy, label = anno),
                   color = "red", size = 2, max.overlaps = 20) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



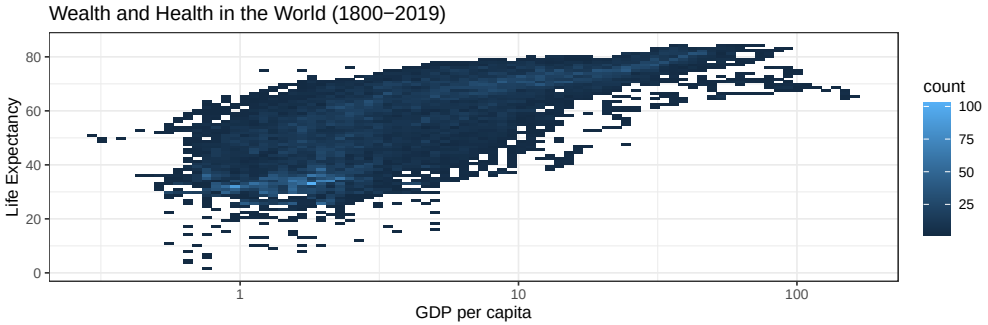
2D “Histogram”

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_bin_2d(bins = 80) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



2D “Histogram”

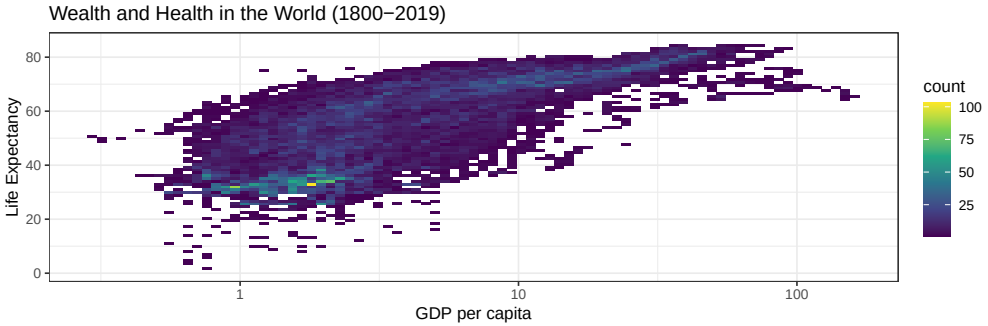
```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_bin_2d(bins = 80) + scale_x_log10() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



2D "Histogram"

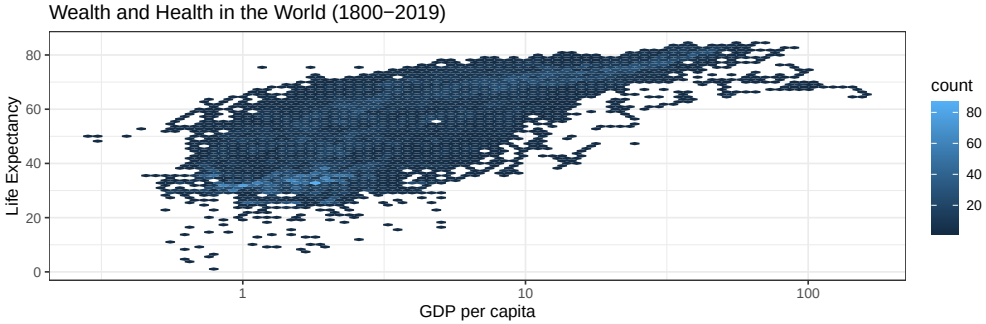
If you find the default color scheme (dark to light blue) to no adequately visualize the different frequencies, you may use a different scheme that offers higher "contrast" between low and high values. `scale_fill_viridis_c` is one of my favorite.

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_bin_2d(bins = 80) + scale_x_log10() +
  scale_fill_viridis_c() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



2D “Histogram”

```
d |> ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_hex(bins = 80) + scale_x_log10() +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (1800-2019)")
```



Summary Statistics: Pearson Correlation

Pearson correlation (aka. Pearson's *r*), ranging from -1 to 1, is our typical indicator of the correlation between two quantitative variables.

```
cor(d$life_expectancy, d$gdppc, use = "complete.obs", method = "pearson")
```

```
## [1] 0.5600421
```

```
cor.test(d$life_expectancy, d$gdppc, use = "complete.obs", method = "pearson")
```

```
##
##  Pearson's product-moment correlation
##
## data:  d$life_expectancy and d$gdppc
## t = 92.412, df = 18688, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.5501224 0.5698037
## sample estimates:
##       cor
## 0.5600421
```

Summary Statistics: Pearson Correlation

To use Pearson correlation, the two variables should meet the following assumptions:

- Continuous
- Linear relationship
- No outlier
- Normally distributed

Summary Statistics: Spearman Correlation

If the data seem to break at least one of the assumptions for Pearson correlation, you may use Spearman correlation (aka. Spearman's ρ).

```
cor(d$life_expectancy, d$gdppc, use = "complete.obs", method = "spearman")
```

```
## [1] 0.767604
```

```
cor.test(d$life_expectancy, d$gdppc, use = "complete.obs", method = "spearman")
```

```
## Warning in cor.test.default(d$life_expectancy, d$gdppc, use = "complete.obs", :
## Cannot compute exact p-value with ties
```

```
##
##  Spearman's rank correlation rho
##
## data:  d$life_expectancy and d$gdppc
## S = 2.5287e+11, p-value < 2.2e-16
## alternative hypothesis: true rho is not equal to 0
## sample estimates:
##      rho
## 0.767604
```

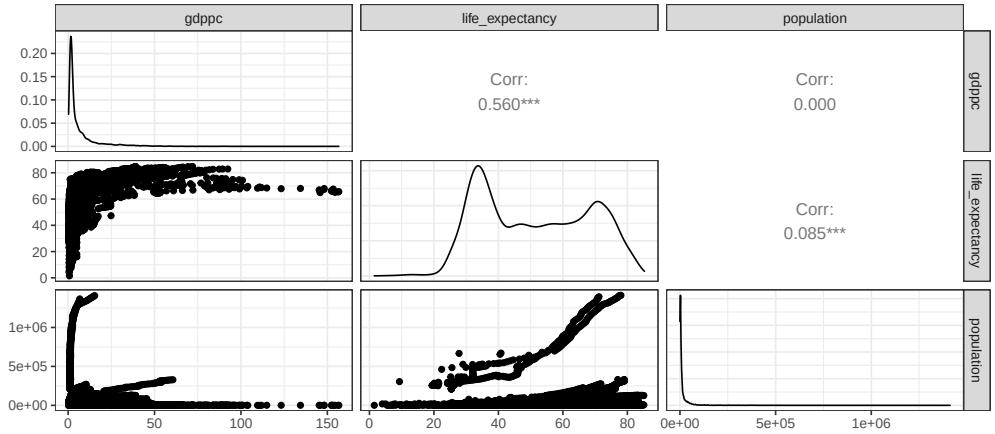
Quant. X 3

Visualize 3 Quantitative Variables

- Correlation Matrix
- Bubble Plot: 3rd variable visualized with size
- Make it colorful: 3rd variable visualized with color

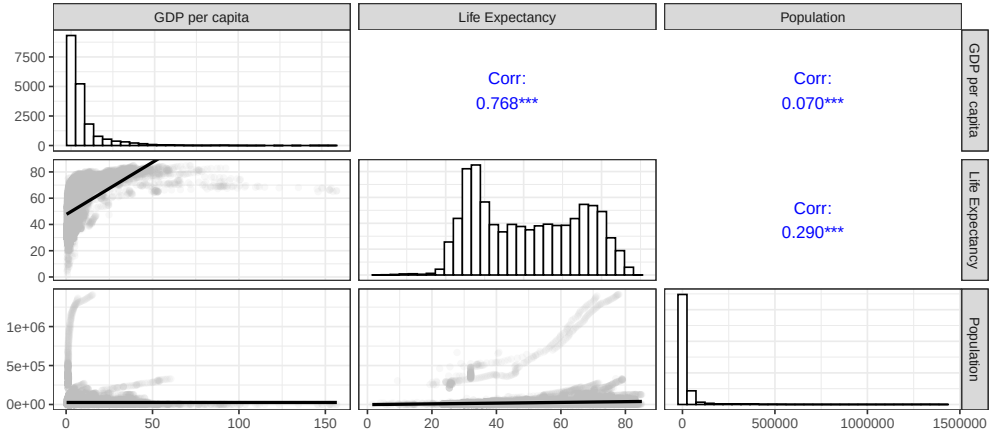
Correlation Matrix

```
# install.packages("GGally")
library(GGally)
d |>
  select(gdppc, life_expectancy, population) |>
  ggpairs()
```



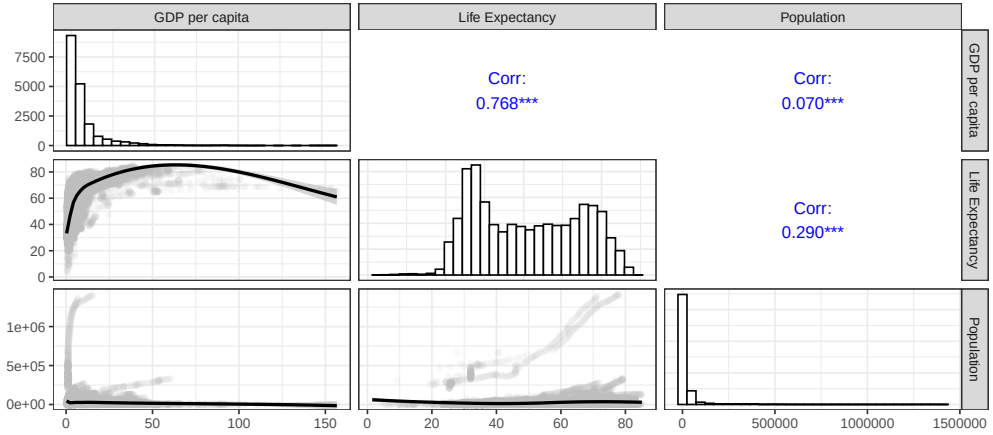
Correlation Matrix

```
d |> select(gdppc, life_expectancy, population) |>
  ggpairs(
    columnLabels = c("GDP per capita", "Life Expectancy", "Population"), # Label variables
    upper = list(continuous = wrap("cor", method = "spearman", color = "blue")), # Upper triangle: Spearman correlation
    diag = list(continuous = wrap("barDiag", bins = 30, fill = "white", color = "black")), # Diagnal: histogram
    lower = list(continuous = wrap("smooth", alpha = 0.1, color = "gray"))) # Lower triag: + linear trend line
```



Correlation Matrix

```
d |> select(gdppc, life_expectancy, population) |>
  ggpairs(
    columnLabels = c("GDP per capita", "Life Expectancy", "Population"), # Label variables
    upper = list(continuous = wrap("cor", method = "spearman", color = "blue")), # Upper triangle: Spearman correlation
    diag = list(continuous = wrap("barDiag", bins = 30, fill = "white", color = "black")), # Diagnal: histogram
    lower = list(continuous = wrap("smooth_loess", alpha = 0.1, color = "gray"))) # Lower triag: + loess trend line
```

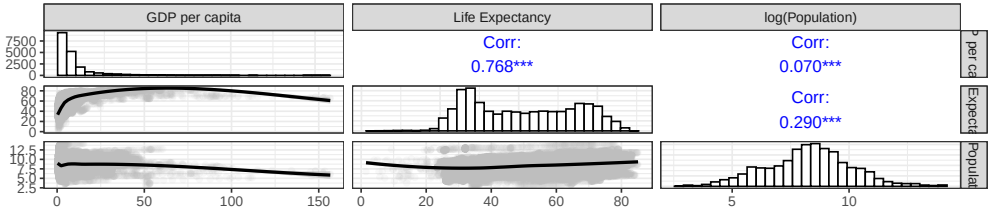


Correlation Matrix

```r
summary(d$population) # The population variable is skewed. Consider transofmration
```

```
##      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.      NA's
##      17.9    1246.3    4234.3   23083.3   11914.2 1412360.0      2981
```

```r
d |> select(gdppc, life_expectancy, population) |>
  mutate(population = log(population)) |> # log transformation
  ggpairs(
    columnLabels = c("GDP per capita", "Life Expectancy", "log(Population)"), # Label variables
    upper = list(continuous = wrap("cor", method = "spearman", color = "blue")), # Upper triangle: Spearman correlation
    diag = list(continuous = wrap("barDiag", bins = 30, fill = "white", color = "black")), # Diagnal: histogram
    lower = list(continuous = wrap("smooth_loess", alpha = 0.1, color = "gray"))) # Lower triag: + loess trend line
```



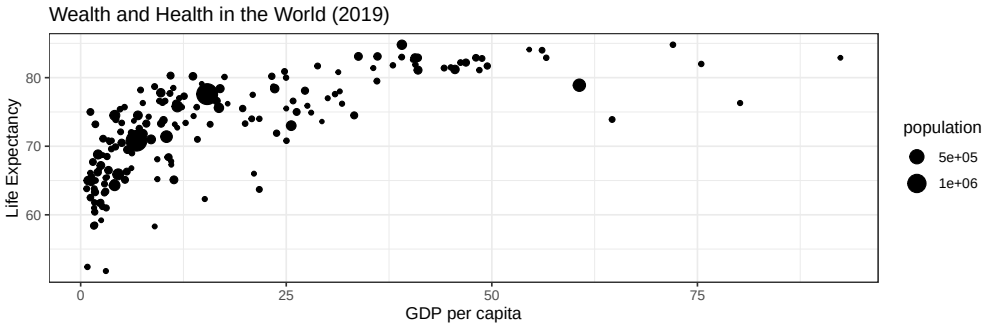
Play with ggpairs

Check out its documentation: https://www.rdocumentation.org/packages/GGally/versions/1.5.0/topics/ggpairs

Bubble Plot

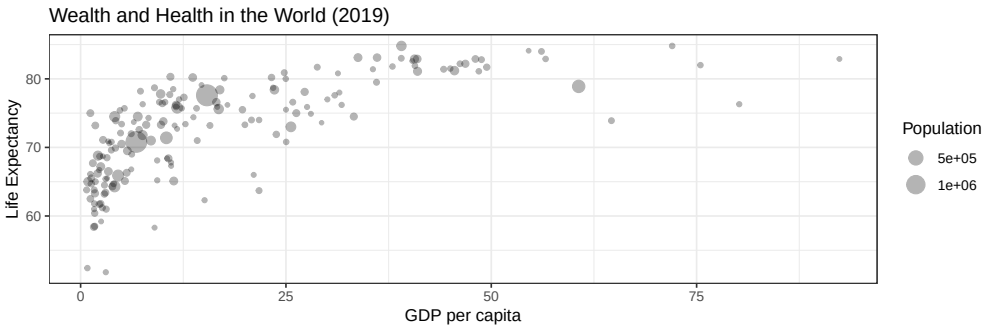
```
d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population)) +
  labs(x = "GDP per capita", y = "Life Expectancy", title = "Wealth and Health in the World (2019)")
```

```
## Warning: Removed 8 rows containing missing values (geom_point).
```



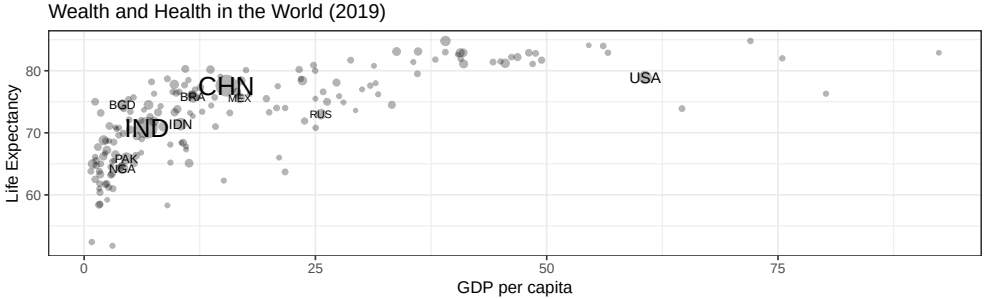
Bubble Plot (customized)

```
d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population), alpha = 0.3) +
  labs(x = "GDP per capita", y = "Life Expectancy", size = "Population",
       title = "Wealth and Health in the World (2019)")
```



Bubble Plot (annotated)

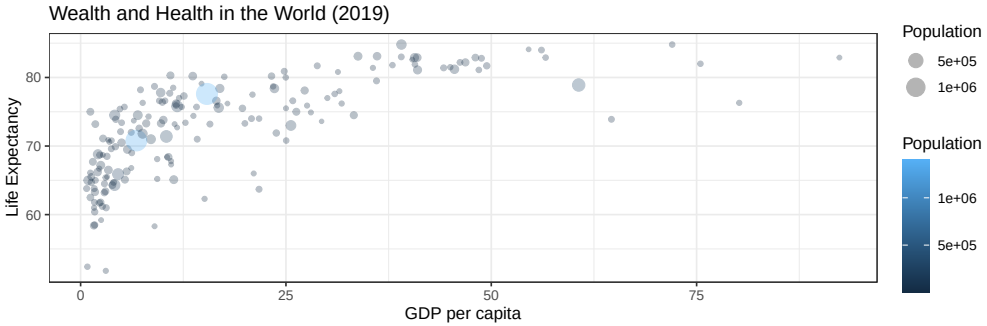
```
d_anno_pop <- d |> filter(year == 2019) |> slice_max(order_by = population, n = 10)

d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population), alpha = 0.3) +
  geom_text(data = d_anno_pop, aes(x = gdppc, y = life_expectancy, label = country_text_id, size = population)) +
  labs(x = "GDP per capita", y = "Life Expectancy", size = "Population",
       title = "Wealth and Health in the World (2019)",
       caption = "Note: World's top 10 most populated countries are annotated.") +
  theme(legend.position = "none") # Remove the legend
```



Make it Colorful

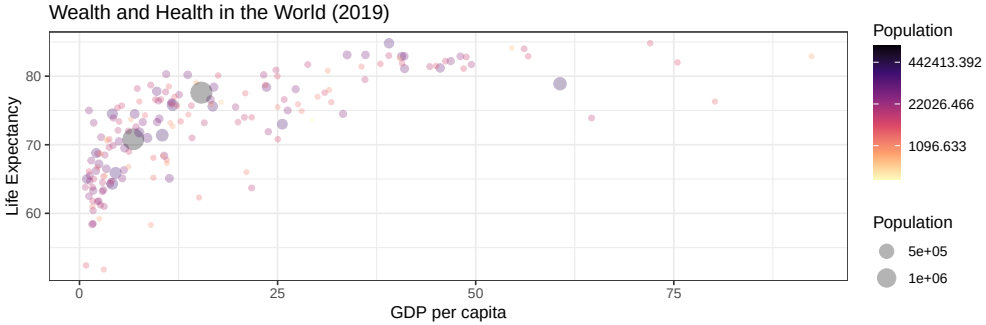
Strengthen the visual message from the third variable

```
d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population, color = population), alpha = 0.3) +
  labs(x = "GDP per capita", y = "Life Expectancy",
       size = "Population", color = "Population", fill = "Population",
       title = "Wealth and Health in the World (2019)")
```



Make it Colorful (customized)

```
d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population, color = population), alpha = 0.3) +
  scale_color_viridis_c(option = "A", trans = "log", direction = -1) +
  labs(x = "GDP per capita", y = "Life Expectancy",
       size = "Population", color = "Population", fill = "Population",
       title = "Wealth and Health in the World (2019)")
```



Quant. X 4+?

Warning

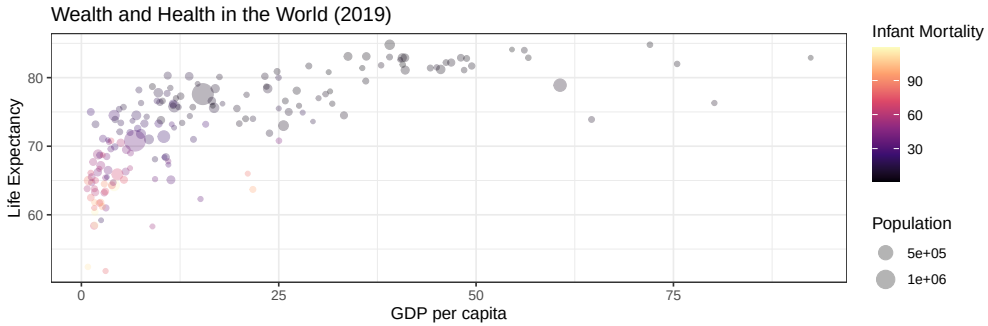
It is *technically* feasible to plot more than 3 variables in the same figure, but...

- You don't want your figure to be too "busy"
- "Less is more"

Add infant mortality to the visualization

In this case, using color to visualize infant mortality is reasonable.

```
d |>
  filter(year == 2019) |>
  ggplot(aes(x = gdppc, y = life_expectancy)) +
  geom_point(aes(size = population, color = infant_mortality), alpha = 0.3) +
  scale_color_viridis_c(option = "A") +
  labs(x = "GDP per capita", y = "Life Expectancy",
       size = "Population", color = "Infant Mortality",
       title = "Wealth and Health in the World (2019)")
```



Correlation Matrix

```
d |> filter(year == 2019) |>select(gdppc, life_expectancy, population, infant_mortality) |>
  mutate(population = log(population)) |>
  ggpairs(
    columnLabels = c("GDP per capita", "Life Expectancy", "log(Population)", "Infant Mortality"), # Label variables
    upper = list(continuous = wrap("cor", method = "spearman", color = "blue")),
    diag = list(continuous = wrap("barDiag", bins = 30, fill = "white", color = "black")),
    lower = list(continuous = wrap("smooth_loess", alpha = 0.3, color = "gray")))
```