Chapter 7 Data Visualization

Descriptive statistics summarize data numerically, but visualizations often reveal patterns, trends, and anomalies more quickly. This chapter introduces basic data visualization techniques in R. We begin with Base R graphics to understand core plotting concepts, then move to ggplot2, which provides a more flexible and powerful system for creating graphics.

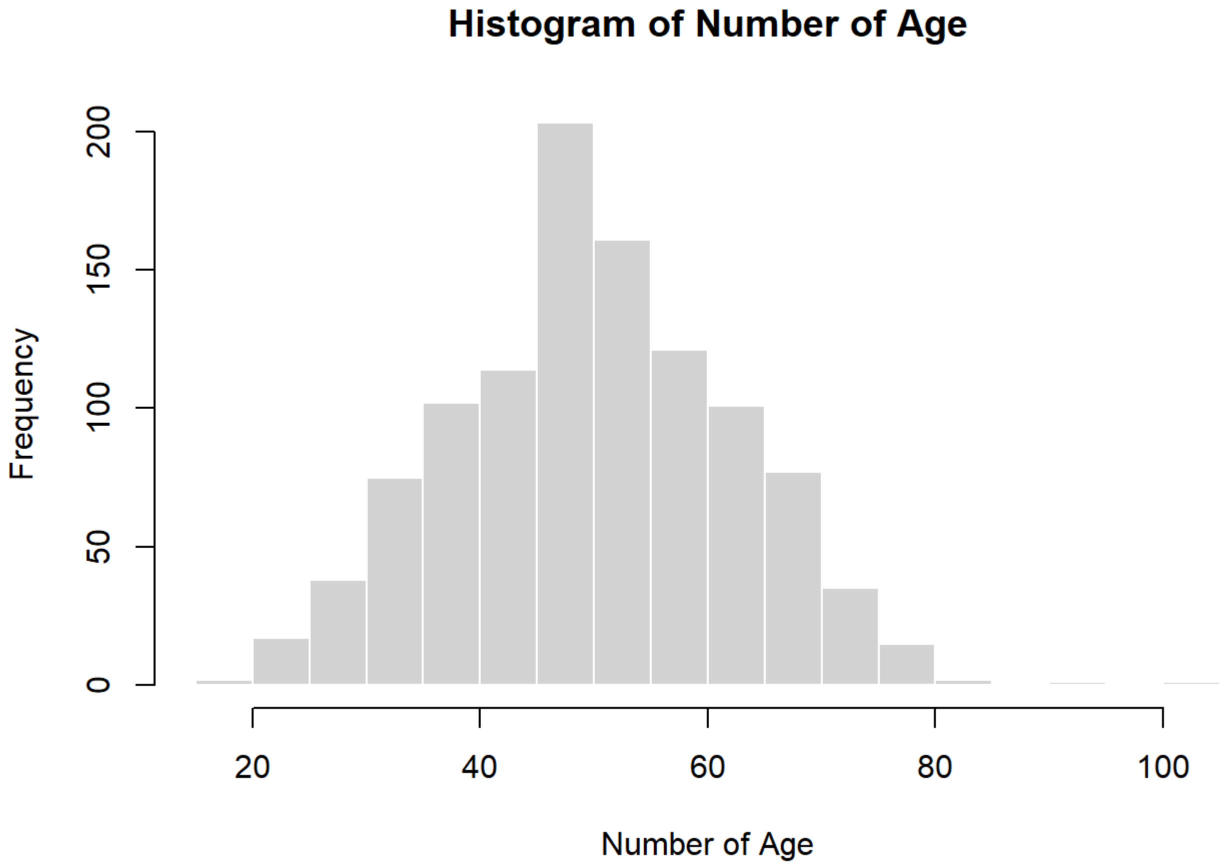
7.1 Base R Visualizations

Base R graphics are built into R and require no additional packages. They are useful for quick exploratory analysis and for understanding how plotting works at a fundamental level.

7.1.1 Histogram (Base R)

A histogram shows the distribution of a numeric variable. Histograms are useful for assessing the shape, spread, and potential outliers in a numeric variable.

```r
hist(airlinesat_small$age,
     main = "Histogram of Number of Age",
     xlab = "Number of Age",
     col = "lightgray",
     border = "white")
```



7.1.2 Box-and-Whisker Plot (Base R)

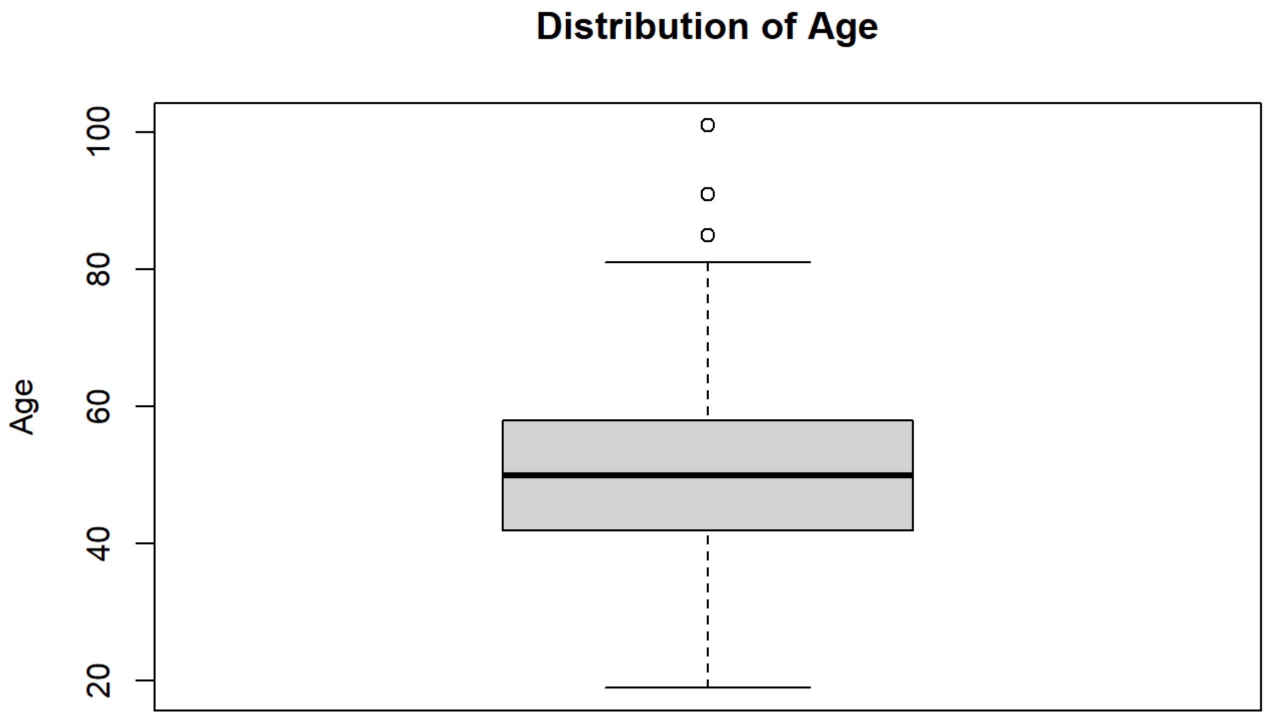
A box-and-whisker plot (often called a boxplot) summarizes the distribution of a numeric variable using five key values:

- Minimum
- First quartile (25th percentile)
- Median
- Third quartile (75th percentile)
- Maximum

Boxplots are especially useful for:

- Comparing distributions across groups
- Identifying skewness
- Detecting potential outliers

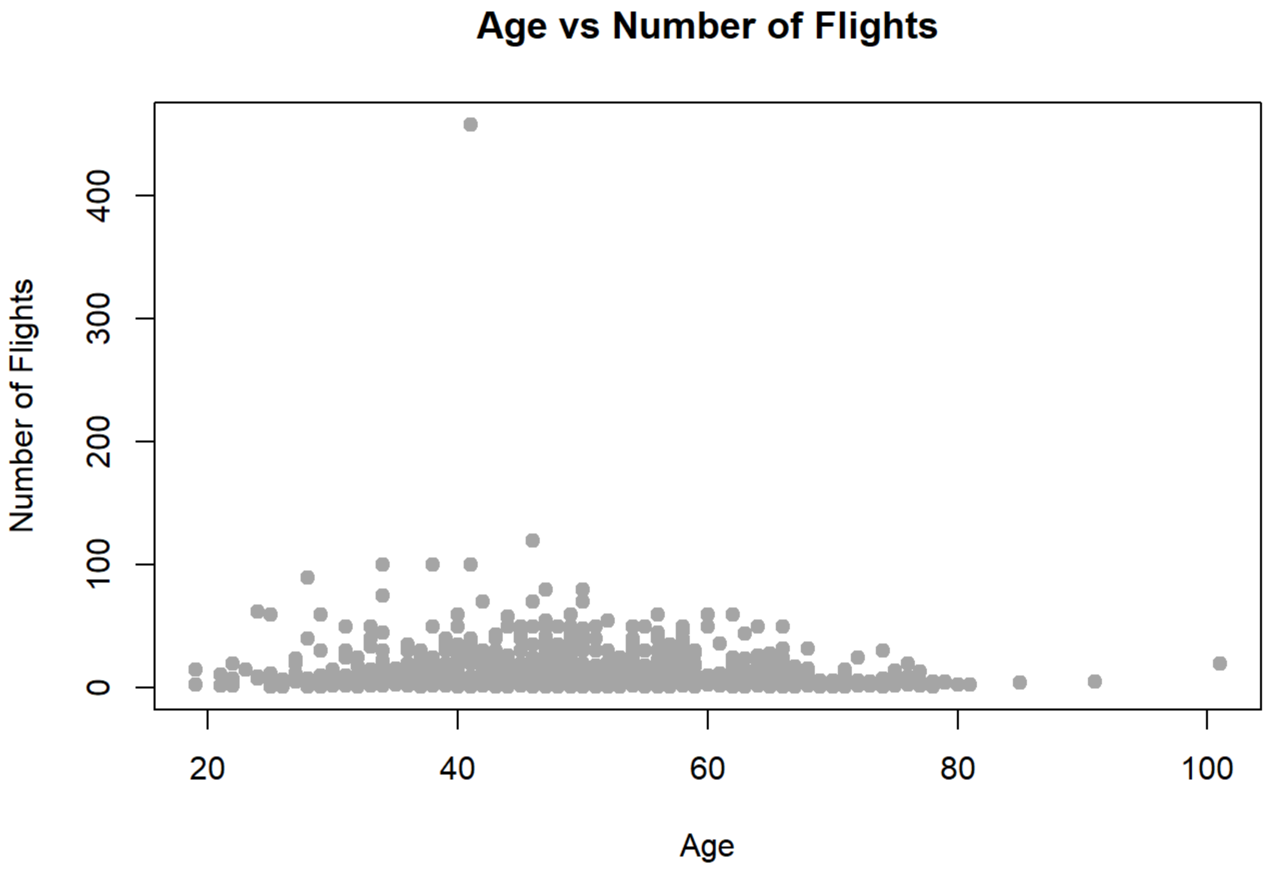
```r
boxplot(airlinesat_small$age,
        main = "Distribution of Age",
        ylab = "Age",
        col  = "lightgray")
```



7.1.3 Scatterplot (Base R)

A scatterplot displays the relationship between two numeric variables. Scatterplots are commonly used to detect relationships, nonlinear patterns, and outliers.

```
plot(airlinesat_small$age,
     airlinesat_small$nflights,
     main = "Age vs Number of Flights",
     xlab = "Age",
     ylab = "Number of Flights",
     pch = 19,
     col = "darkgray")
```



7.1.4 Line Chart (Base R)

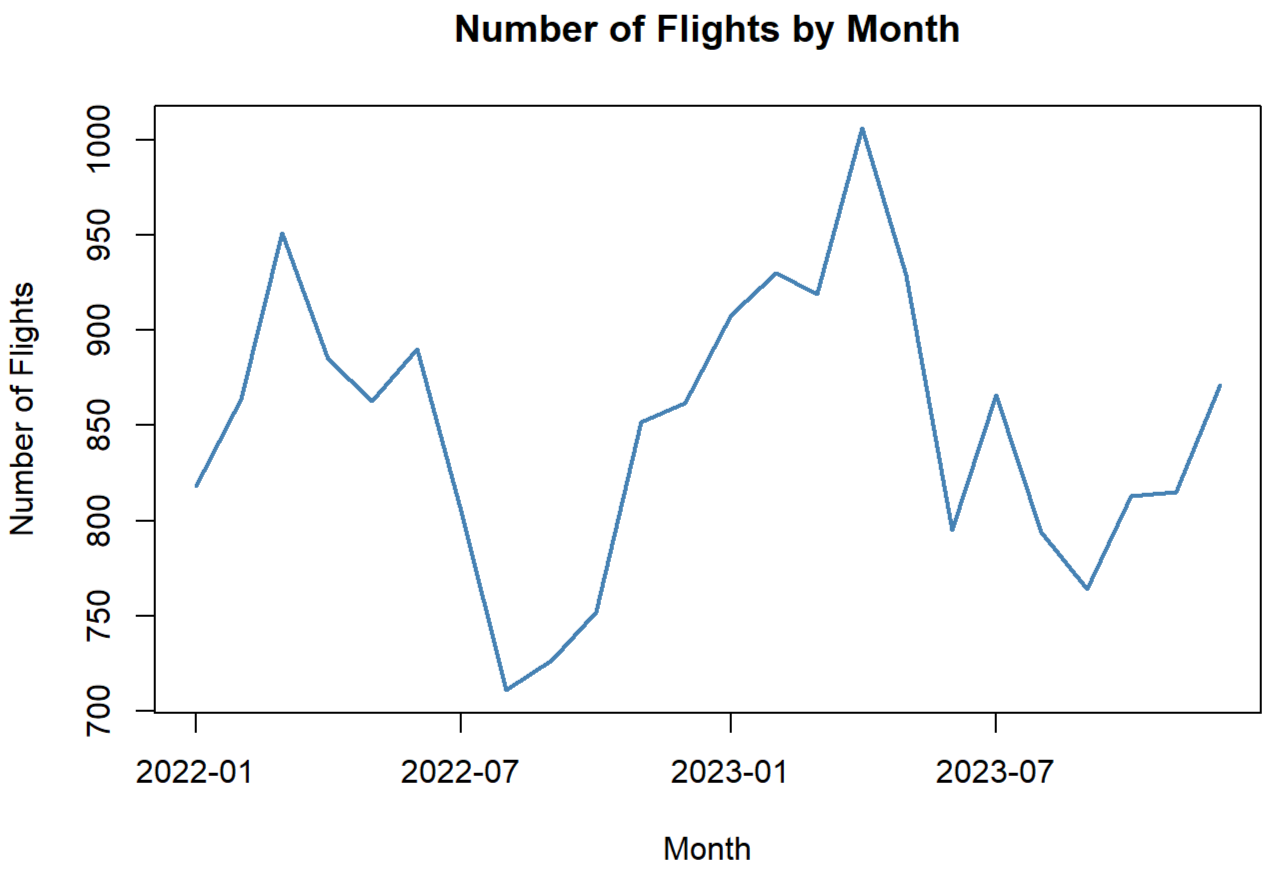
Line charts are typically used for ordered data, such as time series or values summarized across an ordered variable. Line charts emphasize change across an ordered dimension rather than individual observations.

First, we’ll simulate some time series data, and then we’ll create the line chart.

```r
# Simulate monthly flight data
set.seed(123)
months <- seq(from = as.Date("2022-01-01"), to = as.Date("2023-12-01"), by = "month")
n_months <- length(months)
flights <- round(800 +
    seq(0, 100, length.out = n_months) +          # upward trend
    80 * sin(2 * pi * (1:n_months) / 12) +         # seasonality
    rnorm(n_months, mean = 0, sd = 40))              # random noise

flight_ts <- data.frame(month = months, flights = flights)

# Line chart of flights by month
plot(flight_ts$month,
     flight_ts$flights,
     type = "l",
     main = "Number of Flights by Month",
     xlab = "Month",
     ylab = "Number of Flights",
     col  = "steelblue",
     lwd  = 2)
```

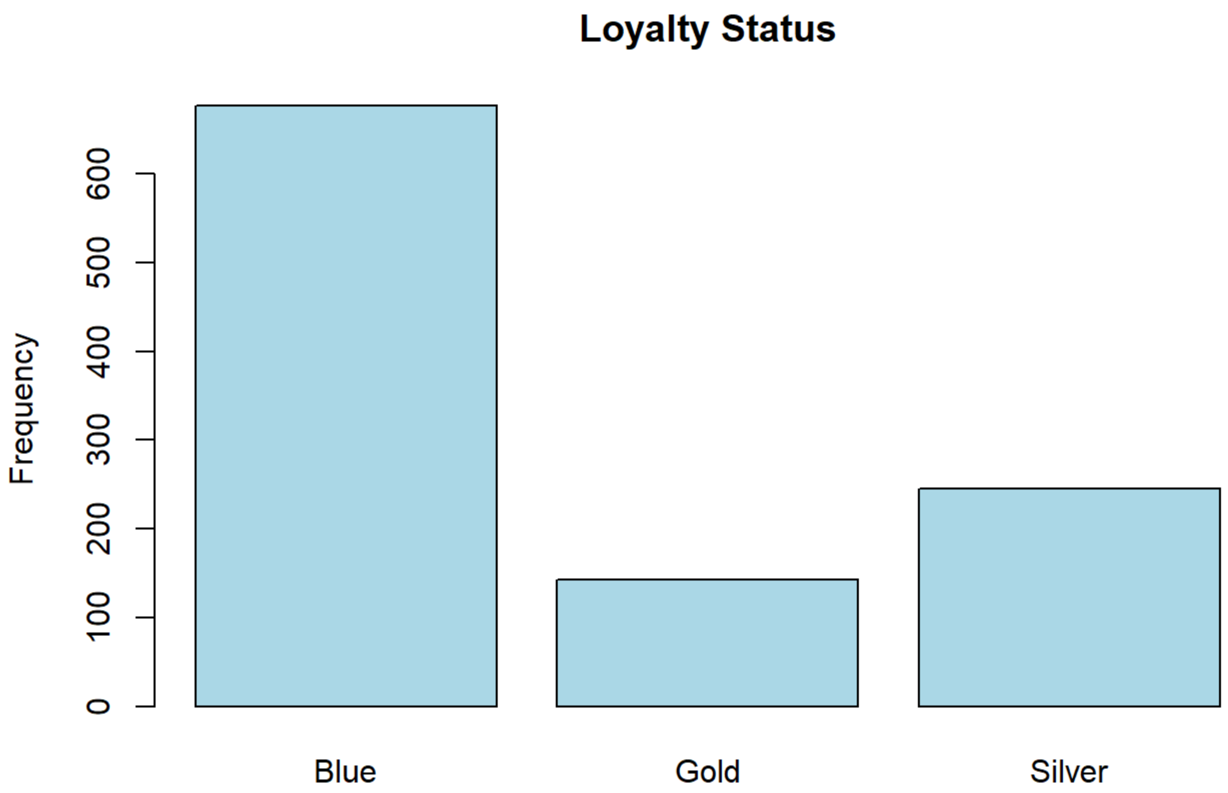


7.1.5 Bar Chart (Base R)

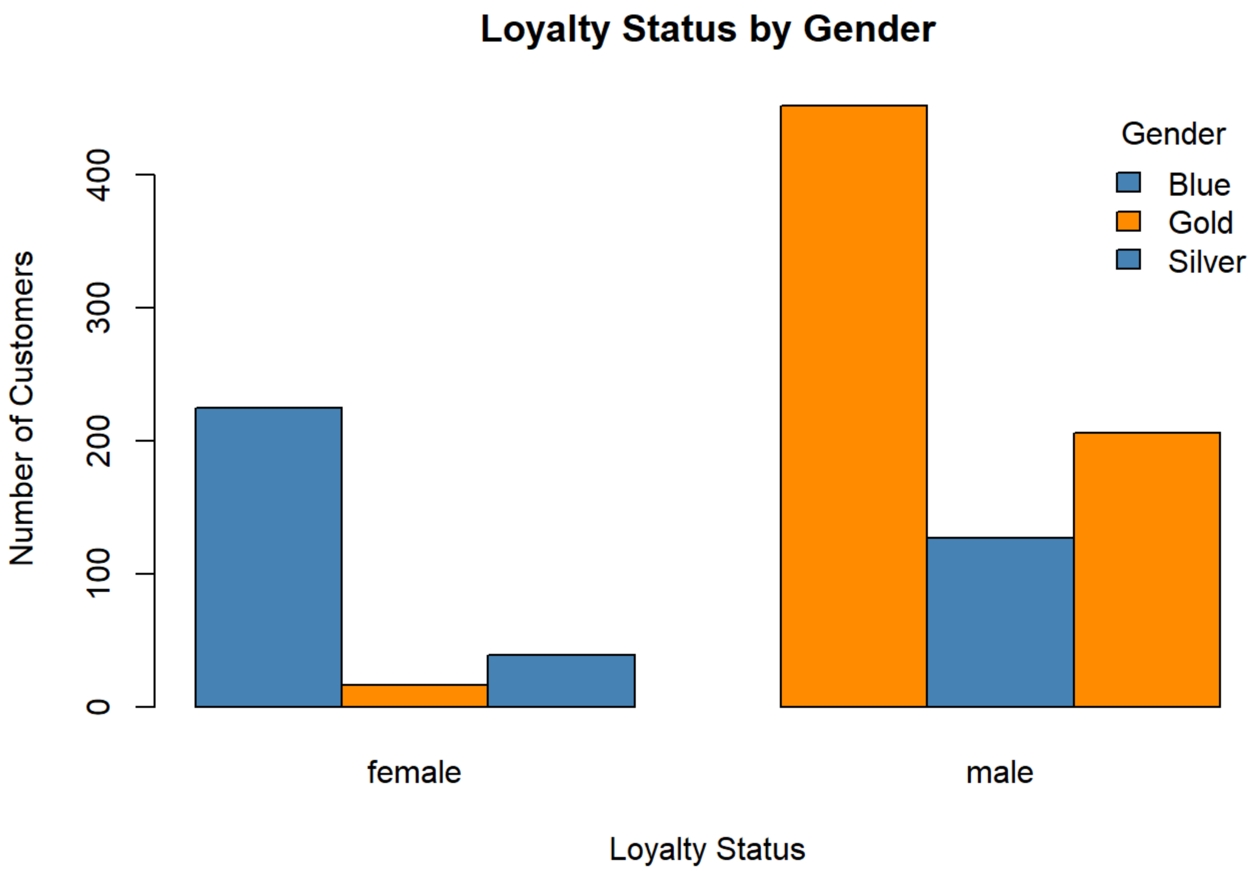
Bar charts are used for categorical variables. They are useful for comparing counts or proportions across categories. They can also show results for different categories of another variable (i.e., a side-by-side bar chart).

```r
status_counts <- table(airlinesat_small$status)

barplot(
  status_counts,
  main = "Loyalty Status",
  ylab = "Frequency",
  col = "lightblue"
)
```



```r
status_gender_tab <- table(airlinesat_small$status, airlinesat_small$gender)
barplot(status_gender_tab,
        beside = TRUE,
        col = c("steelblue", "darkorange"),
        main = "Loyalty Status by Gender",
        xlab = "Loyalty Status",
        ylab = "Number of Customers",
        legend.text = TRUE,
        args.legend = list(title = "Gender", x = "topright", bty = "n"))
```



7.2 Moving Beyond Base R

While Base R graphics are useful, they can become cumbersome when creating more complex plots or when consistent styling is needed. The `ggplot2` package provides a structured approach to visualization based on the **g**rammar of **g**raphics.

7.3 Introduction to *ggplot2*

In `ggplot2`, plots are built in layers from three main components: data, aesthetic mappings (i.e., a coordinate system identifying `x` and `y` variables), and geometric objects (i.e., how the data should be displayed). In addition, the plot can be enhanced by adding additional layers using the

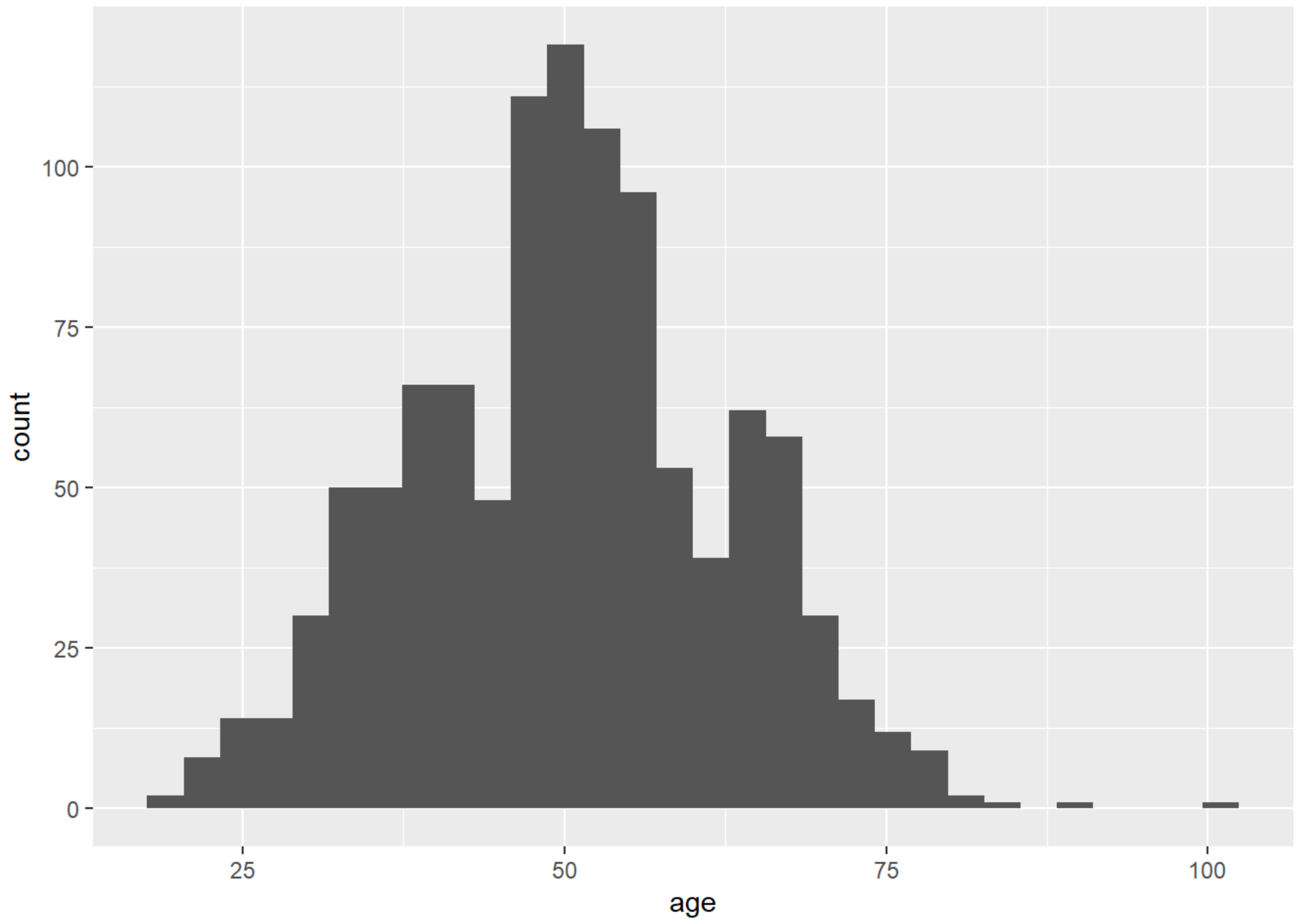
`+` operator. `ggplot2` also works very well with `dplyr` when data manipulation is needed prior to creating the plot.

7.3.1 Histogram

Histograms in `ggplot` use the `geom_histogram()` layer. As with many geoms in `ggplot2`, no options are *required* in the geom. Here is a basic histogram.

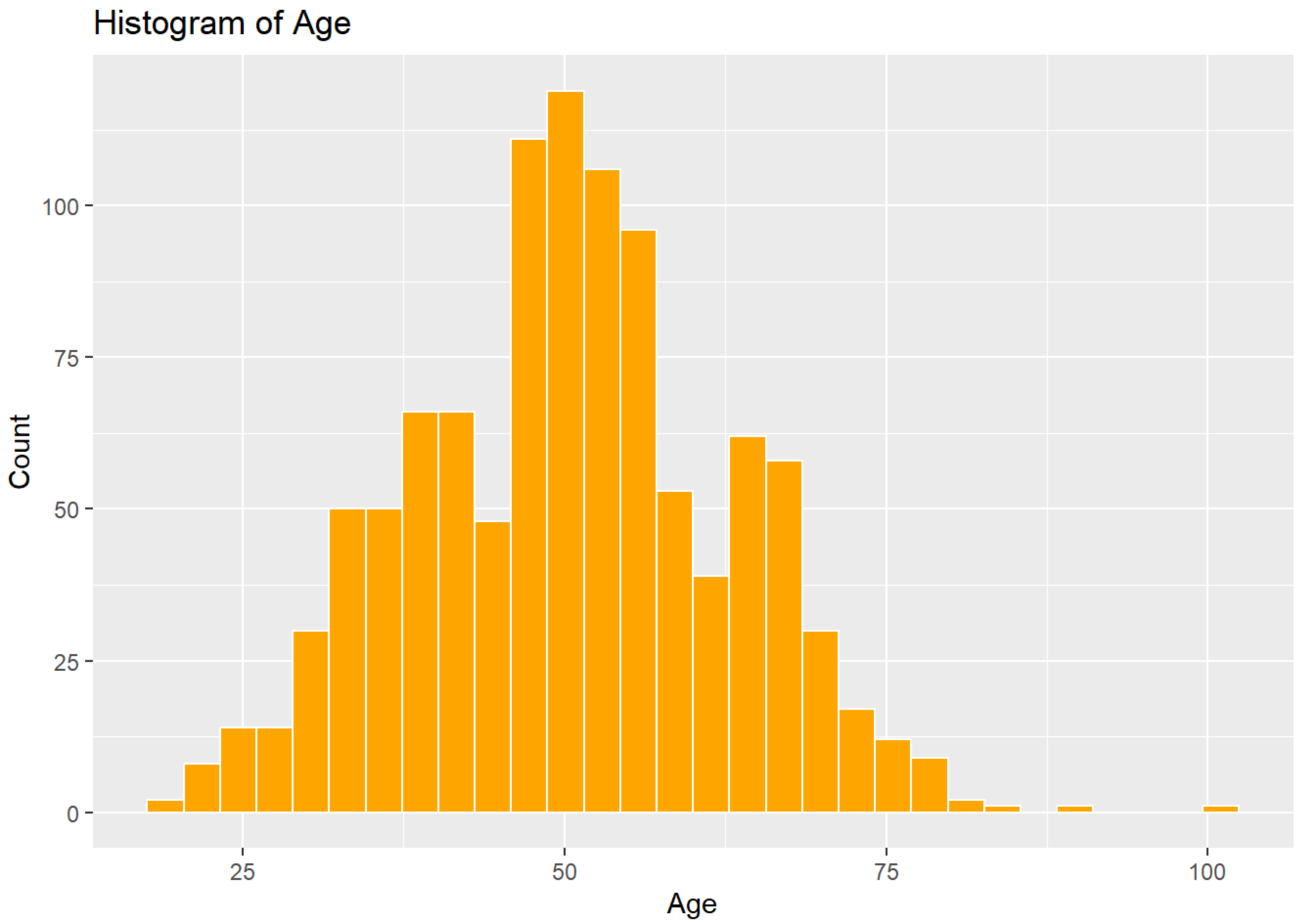
```
ggplot(airlinesat_small, aes(x = age)) +
  geom_histogram()
```

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



One of the benefits of `ggplot2` is the ease of making the plot look more visually appealing often more informative. Here is the histogram with additional options for `bins`, the `fill` color, and the outline `color`, along with labels using the `labs` layer.

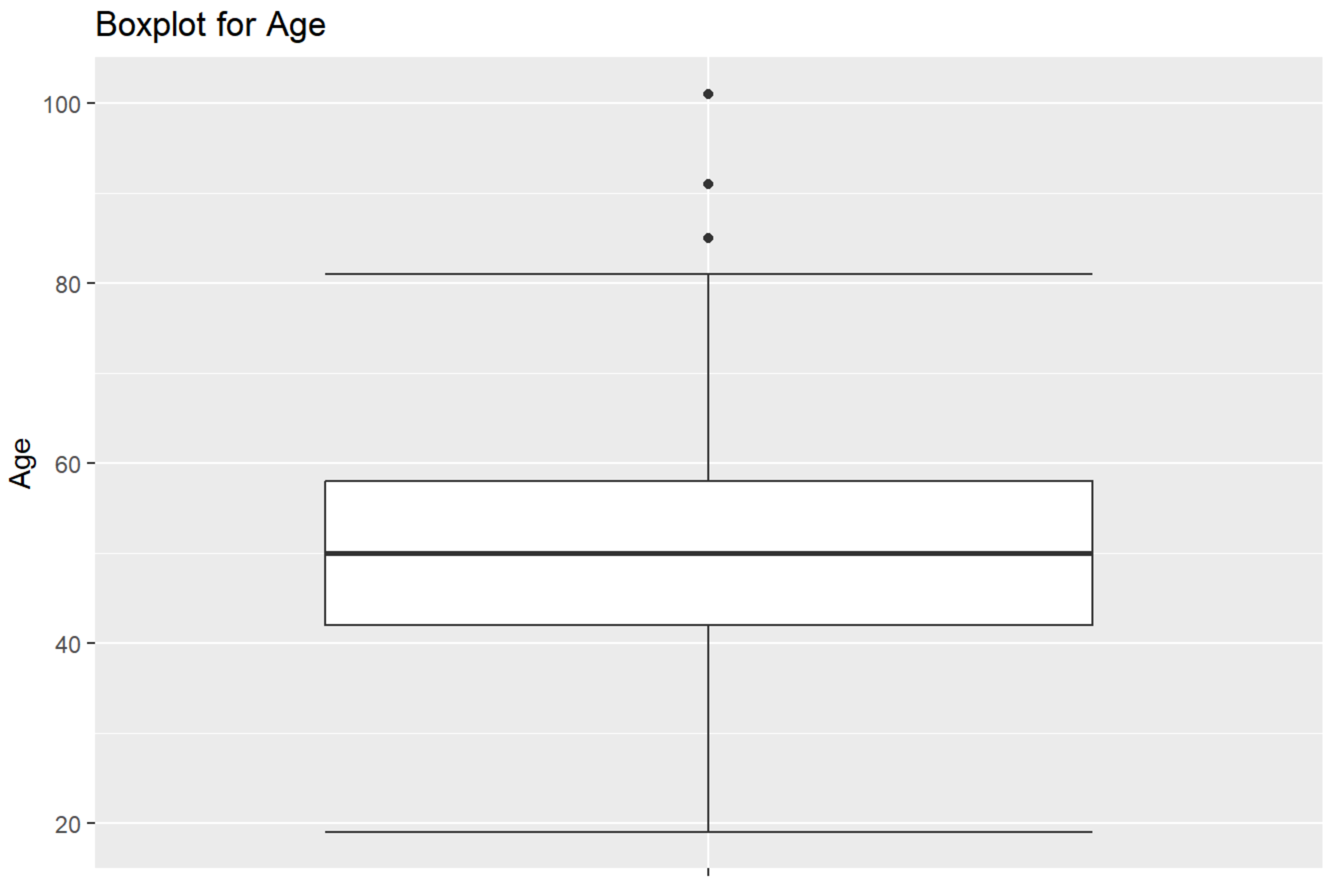
```
ggplot(airlinesat_small, aes(x = age)) +
  geom_histogram(bins = 30,
                 fill = "orange",
                 color = "white") +
  labs(title = "Histogram of Age",
       x = "Age",
       y= "Count")
```



7.3.2 Box-and-Whiskers Plot

Box Plots are drawn with the `geom_boxplot()` geom, which by default creates a box plot for a continuous `y` variable, but for each level of a discrete `x` variable. In addition, the standard box plot does not contain “whiskers”. To get a box plot for only the continuous `y` variable, use `x = ""` as the discrete `x` variable. To add whiskers, include a `staplewidth = 1` within the `geom_boxplot()`.

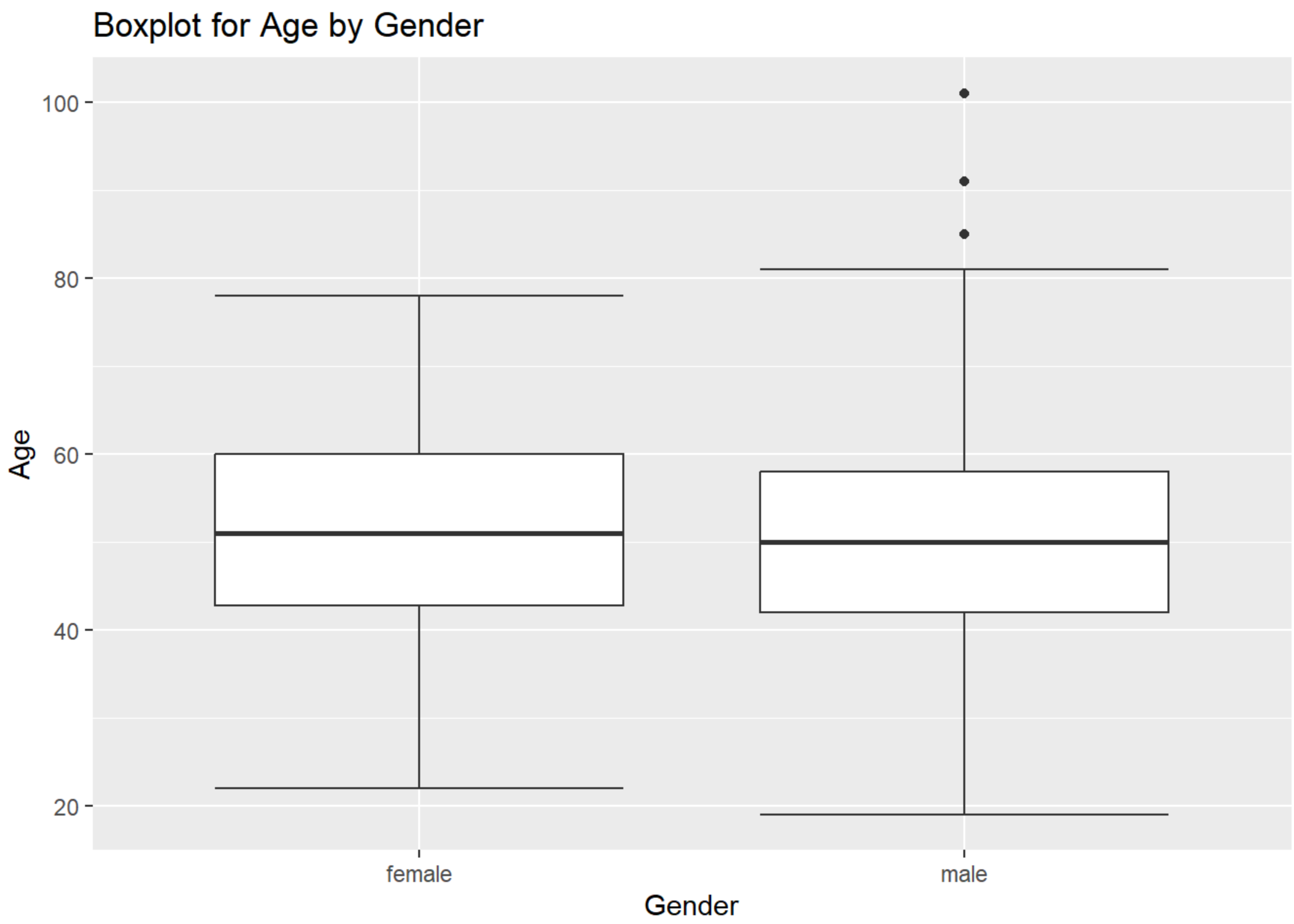
```
ggplot(airlinesat_small, aes(x = "", y=age)) +
  geom_boxplot(staplewidth = 1) +
  labs(title="Boxplot for Age",
       x = "",
       y = "Age")
```



7.3.2.1 Side-by-Side Boxplot

To create side-by-side boxplots for a discrete variable, simply repace the `x = ""` with a variable name.

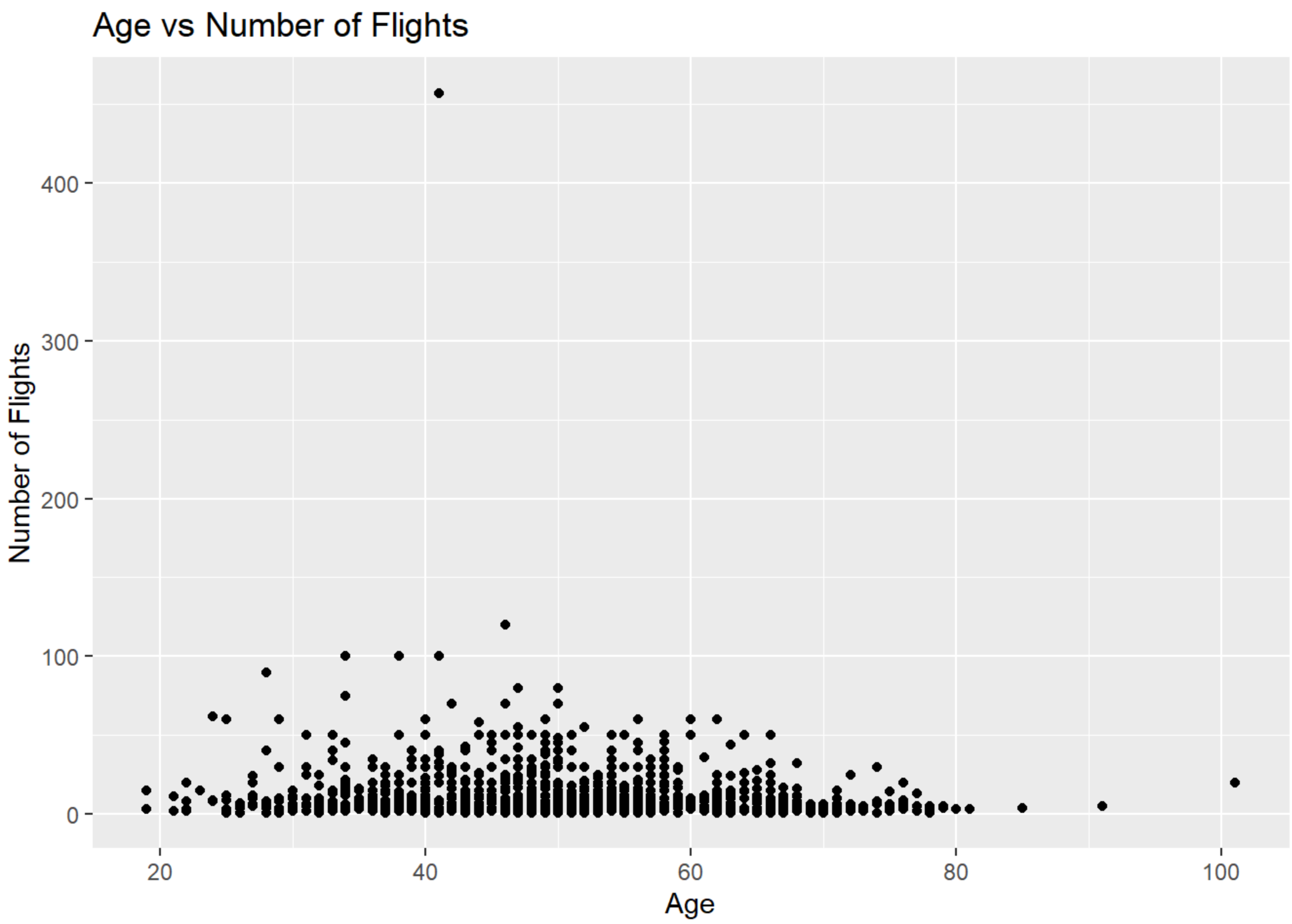
```
ggplot(airlinesat_small, aes(x = gender, y=age)) +
  geom_boxplot(staplewidth = 1) +
  labs(title="Boxplot for Age by Gender",
       x = "Gender",
       y = "Age")
```



7.3.3 Scatterplot

Scatterplots are drawn with the `geom_point()` geom and are used to show the relationship between two continuous variables.

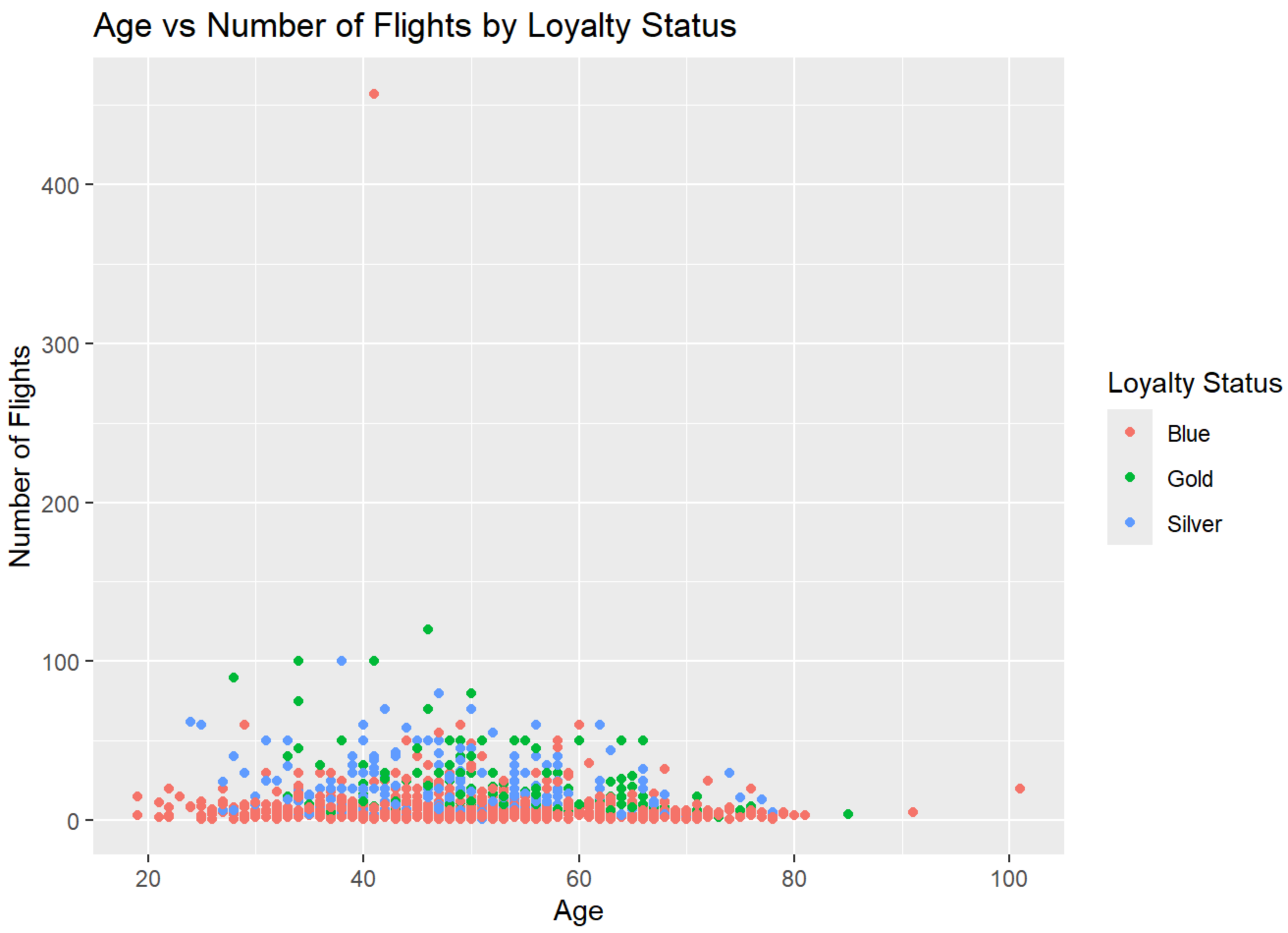
```
ggplot(airlinesat_small, aes(x = age, y = nflights)) +
  geom_point() +
  labs(title = "Age vs Number of Flights",
       x = "Age",
       y = "Number of Flights")
```



7.3.3.1 Scatterplot with a Categorical Variable

More interesting scatterplots can be created by changing the color of the points by a third, discrete variable. This means adding a new aesthetic in the `aes()` part.

```
ggplot(airlinesat_small, aes(x = age, y = nflights, color=status)) +
  geom_point() +
  labs(title = "Age vs Number of Flights by Loyalty Status",
       x = "Age",
       y = "Number of Flights",
       color = "Loyalty Status")
```

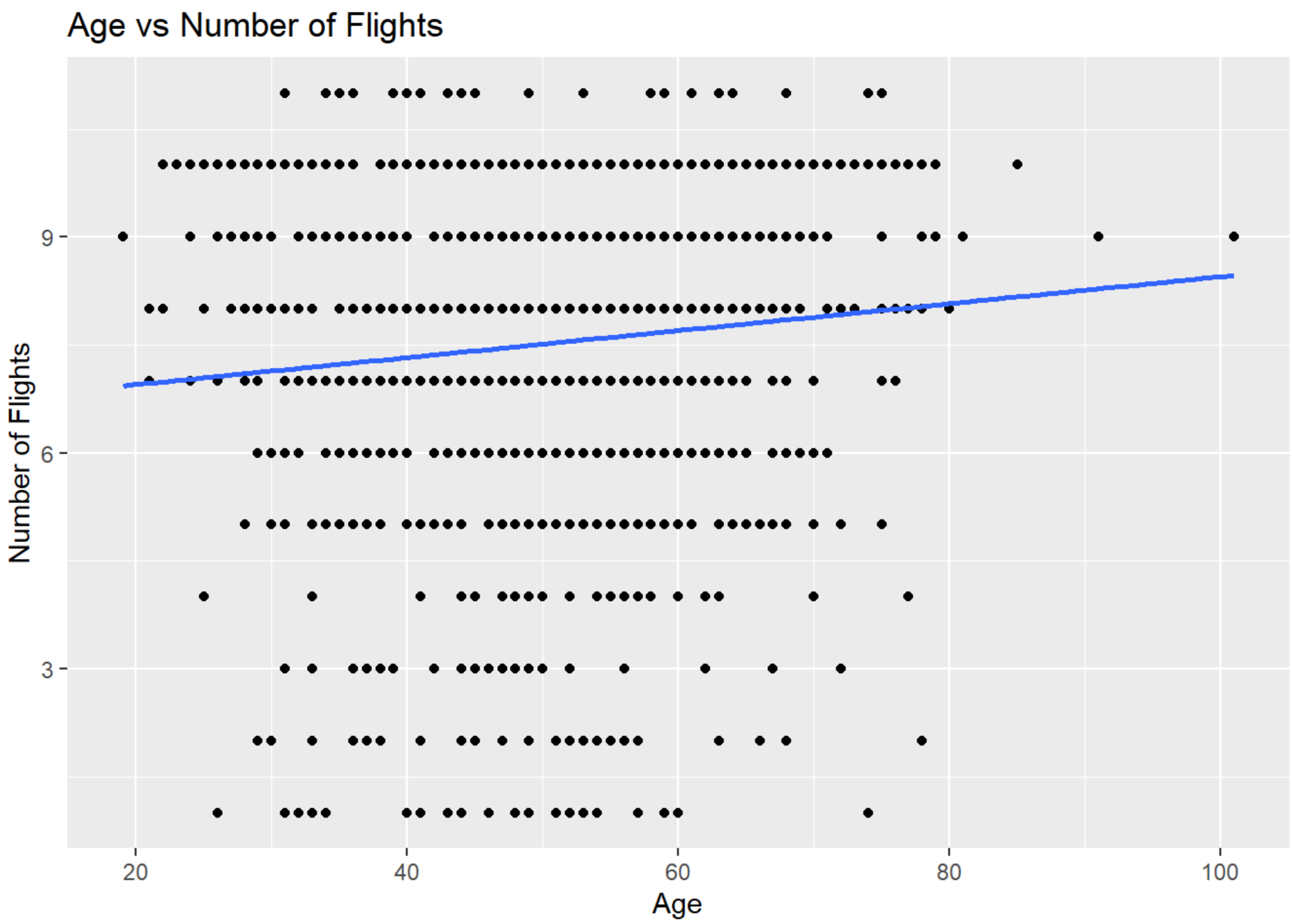


7.3.3.2 Scatterplot with a Trendline

Scatterplots become more helpful when we add a trend line. The most common trend line is a simple regression line, although others can be used. Use `geom_smooth(method = "lm", se = FALSE)` to add a linear trend line.

```
ggplot(airlinesat_small, aes(x = age, y = nps)) +
  geom_point() +
  geom_smooth(method = "lm", se = FALSE) +
  labs(title = "Age vs Number of Flights",
       x = "Age",
       y = "Number of Flights")
```

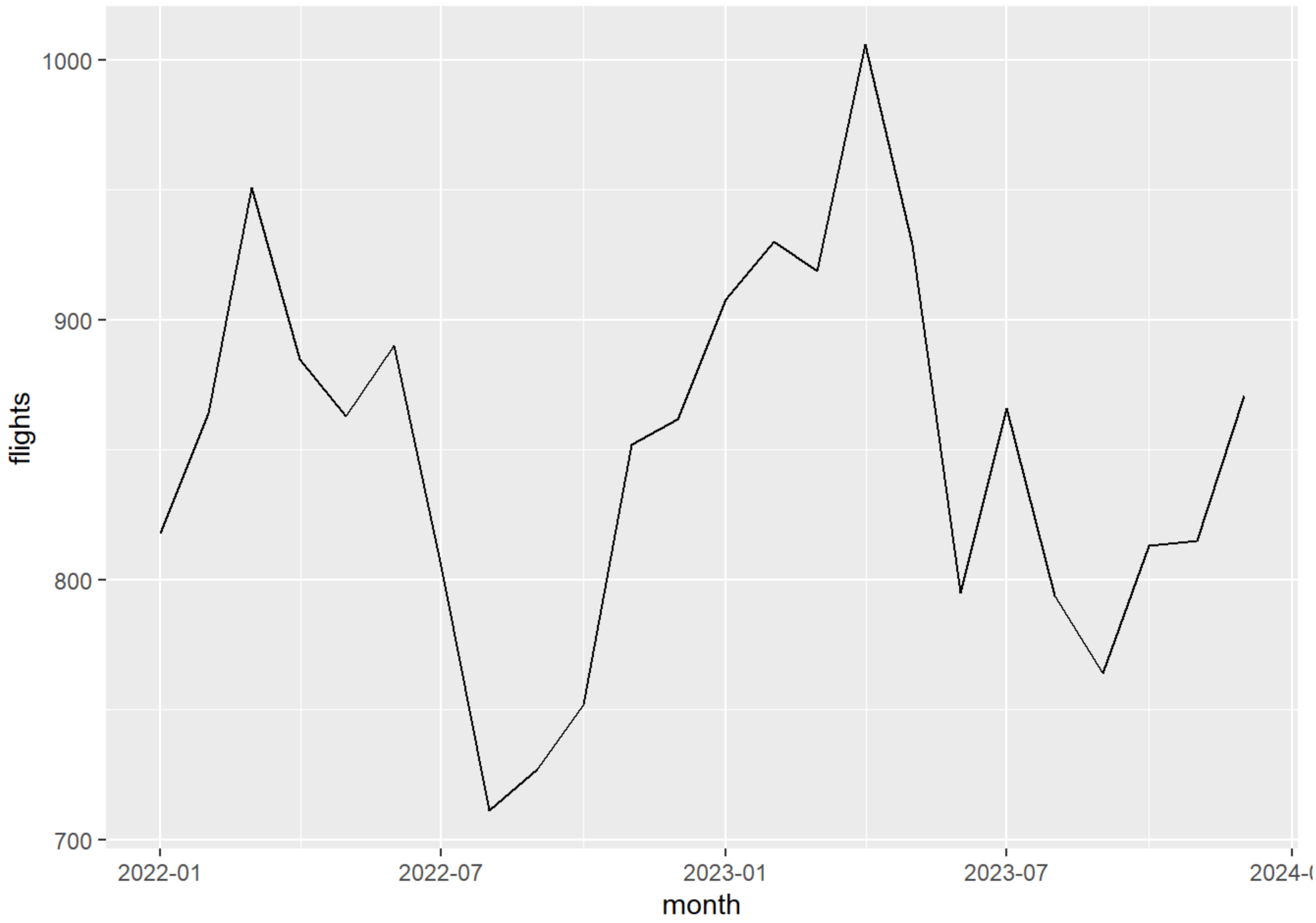
```
`geom_smooth()` using formula = 'y ~ x'
```



7.3.4 Line Chart

Line charts are drawn with the `geom_line()` geom and are used to emphasize change across an ordered dimension rather than individual observations. We'll use the simulated data from the line chart in base R created above.

```
ggplot(flight_ts, aes(x = month, y = flights)) +
  geom_line()
```

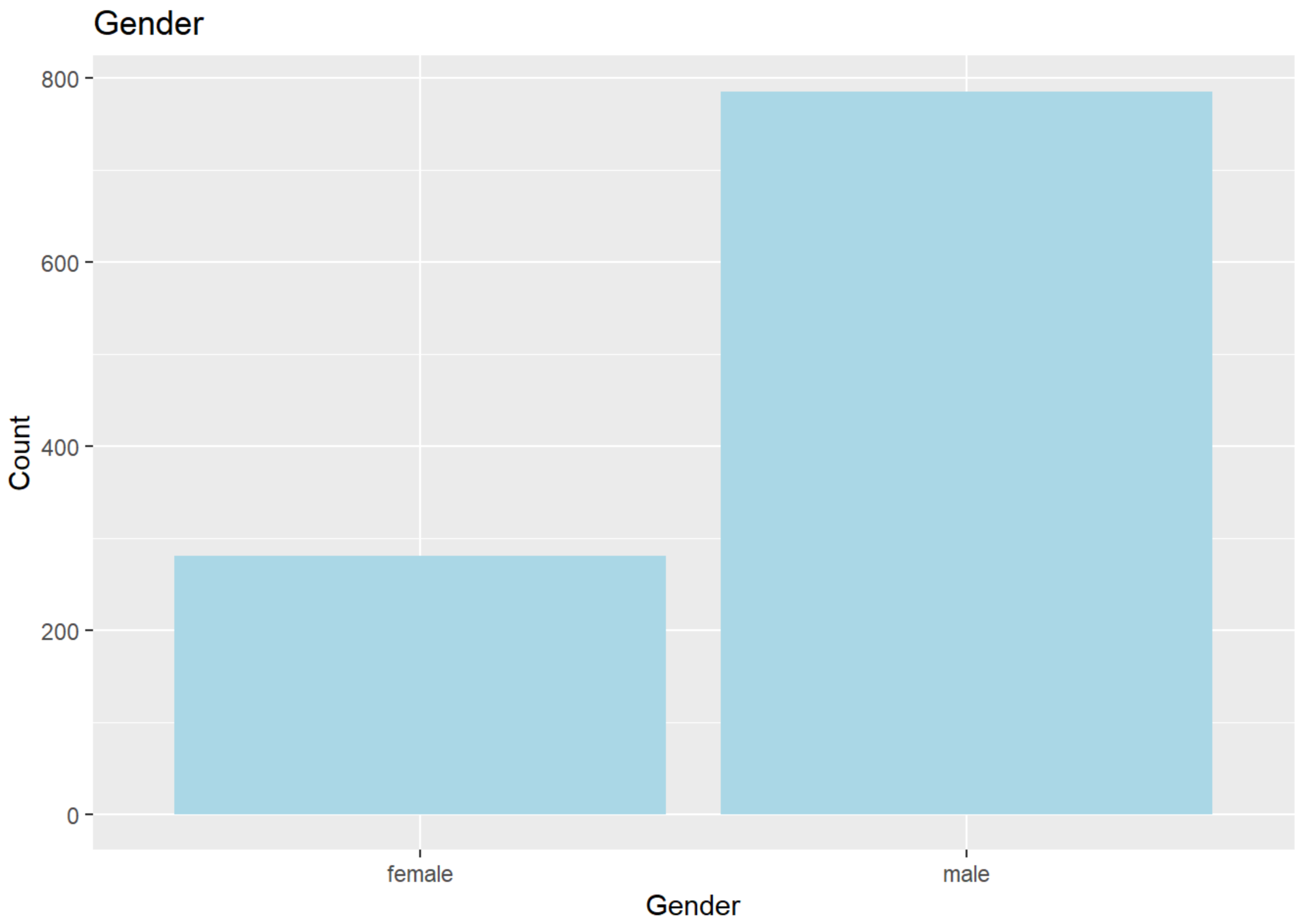


7.3.5 Bar Chart

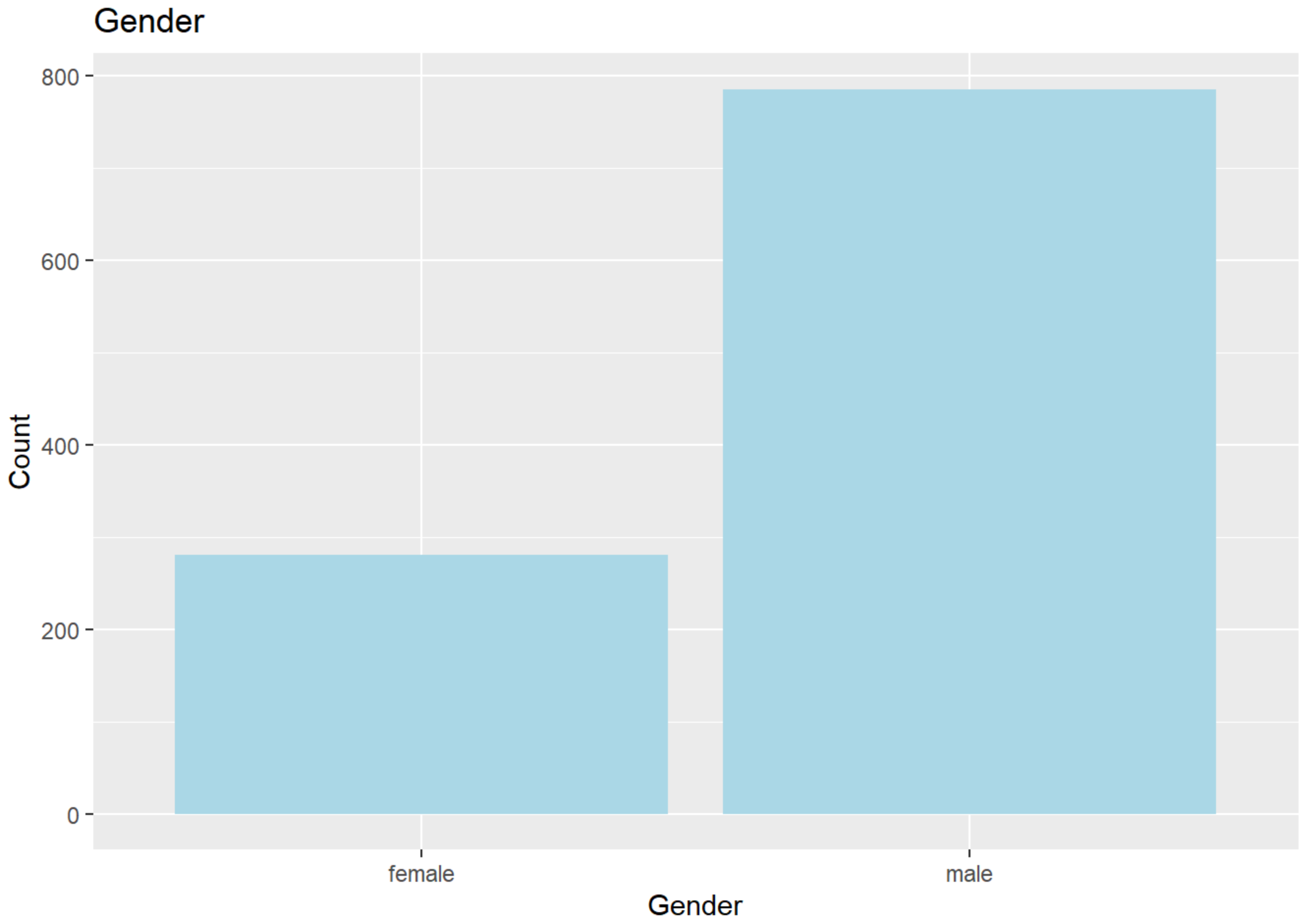
In `ggplot2` , bar charts, `geom_bar()` , are often used for plotting a single discrete variable, while column charts, `geom_col()` , are used for plotting a discrete variable on the x axis and a continuous variable on the y axis. However, `geom_col()` can be used for both if the data is "preformatted", which is easy with `dplyr` . Other than the first example below, all other examples use `geom_col()` as it tends to be more flexible when combined with `dplyr` .

The second example below first organizes the data using `dplyr` and then passes that result to `ggplot` .

```
ggplot(airlinesat_small, aes(x = gender)) +
  geom_bar(fill = "lightblue") +
  labs(title = "Gender",
       x = "Gender",
       y = "Count")
```



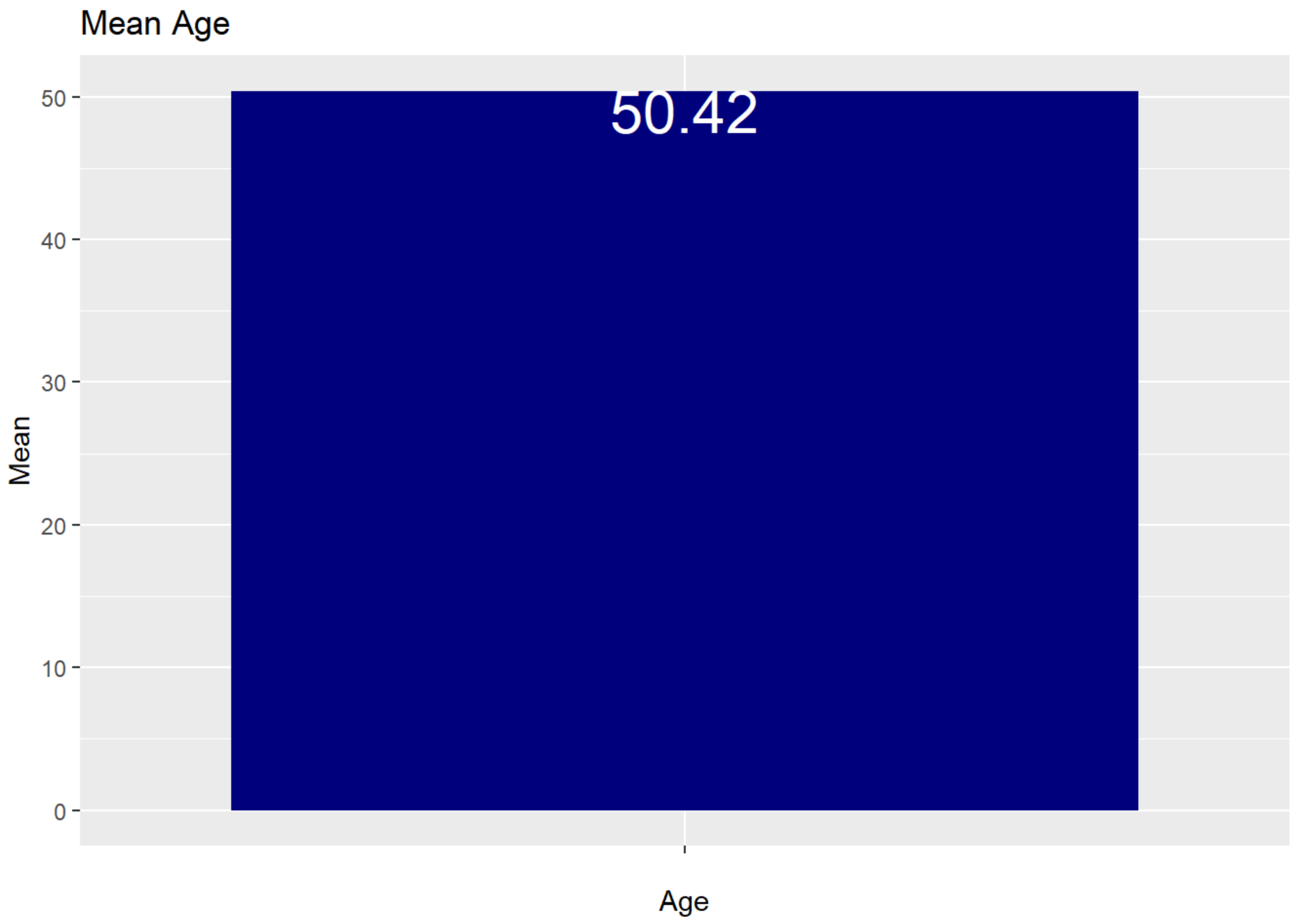
```
airlinesat_small %>%
  group_by(gender) %>%
  summarise(n=n()) %>%
  ggplot(aes(x = gender, y = n)) +
  geom_col(fill = "lightblue") +
  labs(title = "Gender",
       x = "Gender",
       y = "Count")
```



7.3.5.1 Bar Charts for Continuous Variables

Bar charts can be used to show a summary statistic (e.g., mean, median, etc.) of a continuous variable. This is easily done with `dplyr` . We can also add labels using the `geom_text()` or `geom_label()` geoms. `geom_text()` tends to be more flexible. By default, `ggplot` places the label at the exact height of the value, but that will overlap with the bar itself. Use the `vjust =` option to change the position of the label vertically. Usually `vjust = 0.95` puts the label just inside the top of the bar, while `vjust = -.05` puts the label just outside the top of the bar. You can also change the color of the label with `color =` , the size of the label with `size =` , and you can round the label to a specific number of digits with `round()` .

```
airlinesat_small %>%
  summarise(mean_age=mean(age)) %>%
  ggplot(aes(x = "", y = mean_age)) +
  geom_col(fill = "navyblue") +
  geom_text(aes(label = round(mean_age,2)),
            vjust = .95,
            color="white",
            size=8) +
  labs(title = "Mean Age",
       x = "Age",
       y = "Mean")
```



7.3.6 Grouped Bar Chart

When used with `dplyr`, it is easy to create side-by-side or stacked bar charts. In the code below, first a table is created and displayed using `dplyr`. Ultimately, we want to take those results pass them to a `ggplot` to create the chart.

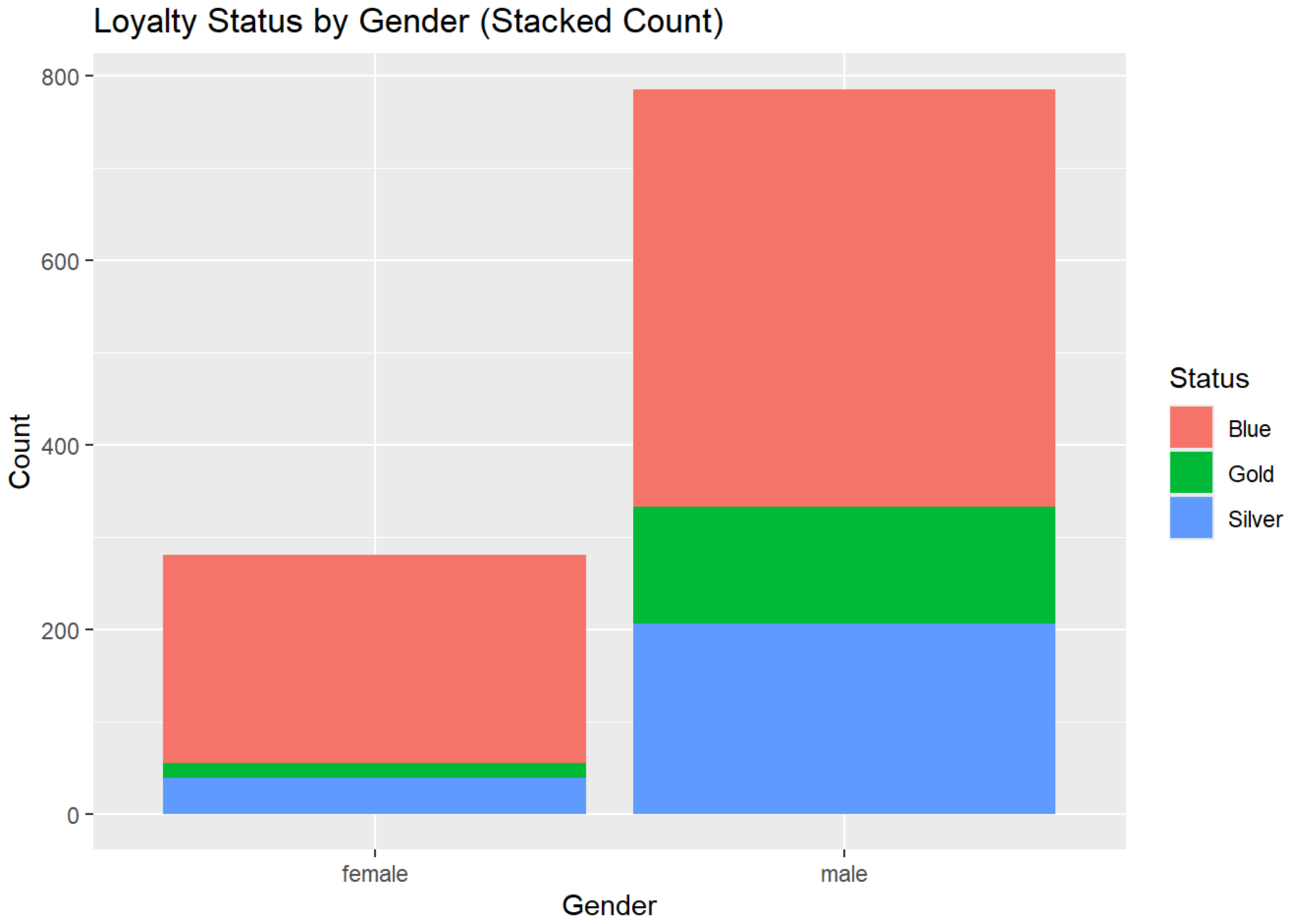
7.3.6.1 Stacked Bar Chart with Counts

The default is to “stack” the counts.

```
airlinesat_small %>%
  group_by(gender, status) %>%
  summarise(n=n())
```

```
# A tibble: 6 × 3
# Groups:   gender [2]
  gender status     n
  <fct>  <fct>  <int>
1 female Blue     225
2 female Gold      16
3 female Silver    39
4 male   Blue     452
5 male   Gold     127
6 male   Silver   206
```

```
airlinesat_small %>%
  group_by(gender, status) %>%
  summarise(n=n()) %>%
  ggplot(aes(x = gender, y = n, fill = status)) +
  geom_col() +
  labs(title = "Loyalty Status by Gender (Stacked Count)",
       x = "Gender",
       y = "Count",
       fill = "Status")
```



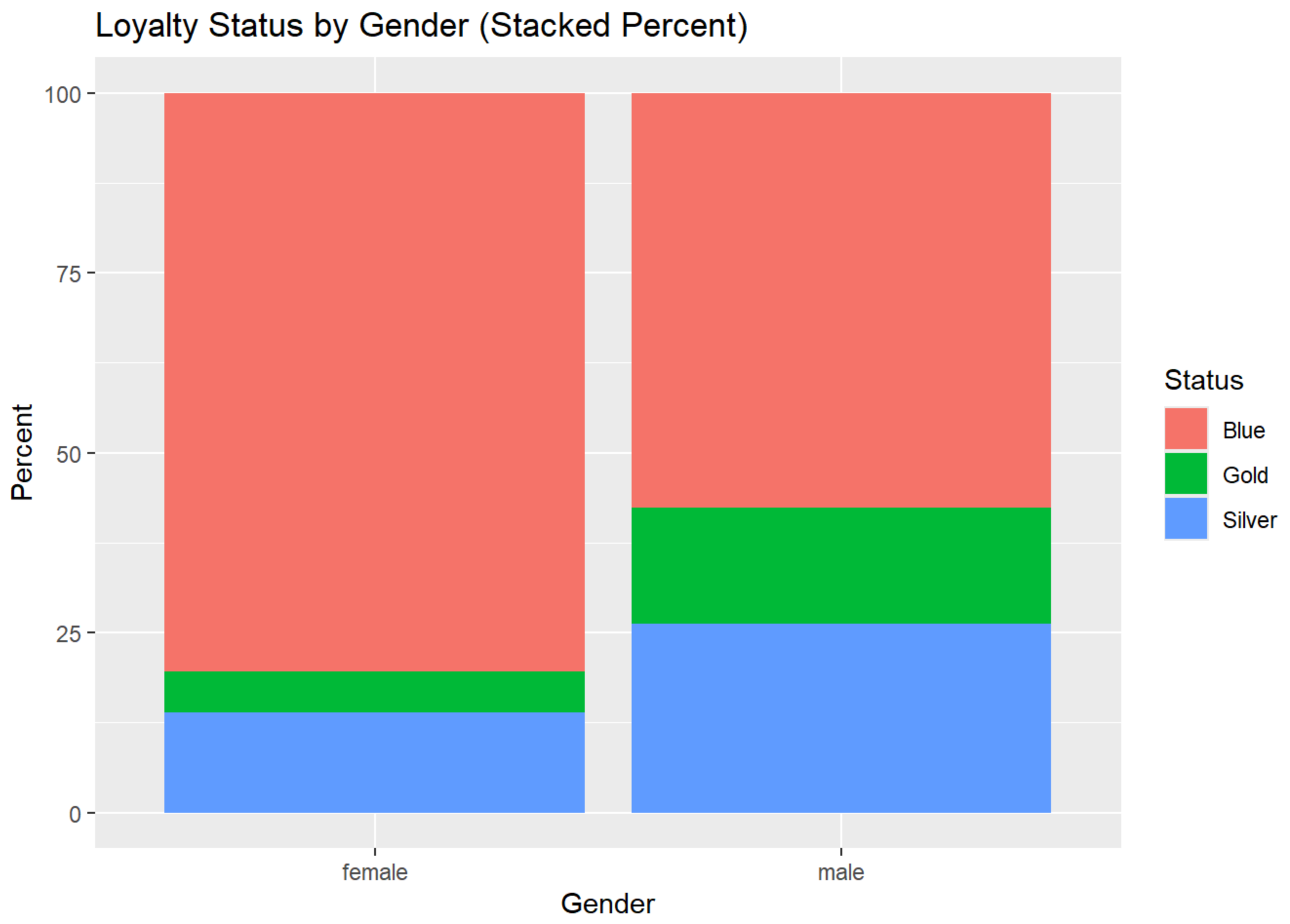
7.3.6.2 Stacked Bar Chart with Percentages

We can create “100%” stacked bar charts by calculating the percentages in the `dplyr` code. With the code below, the percentages will add up to 100% for the first `group_by` variable.

```
airlinesat_small %>%
  group_by(gender, status) %>%
  summarise(n=n()) %>%
  mutate(perc = 100 * n/sum(n))
```

```
# A tibble: 6 × 4
# Groups:   gender [2]
  gender status     n  perc
  <fct>  <fct>  <int> <dbl>
1 female Blue     225 80.4
2 female Gold      16  5.71
3 female Silver    39 13.9
4 male   Blue     452 57.6
5 male   Gold     127 16.2
6 male   Silver   206 26.2
```

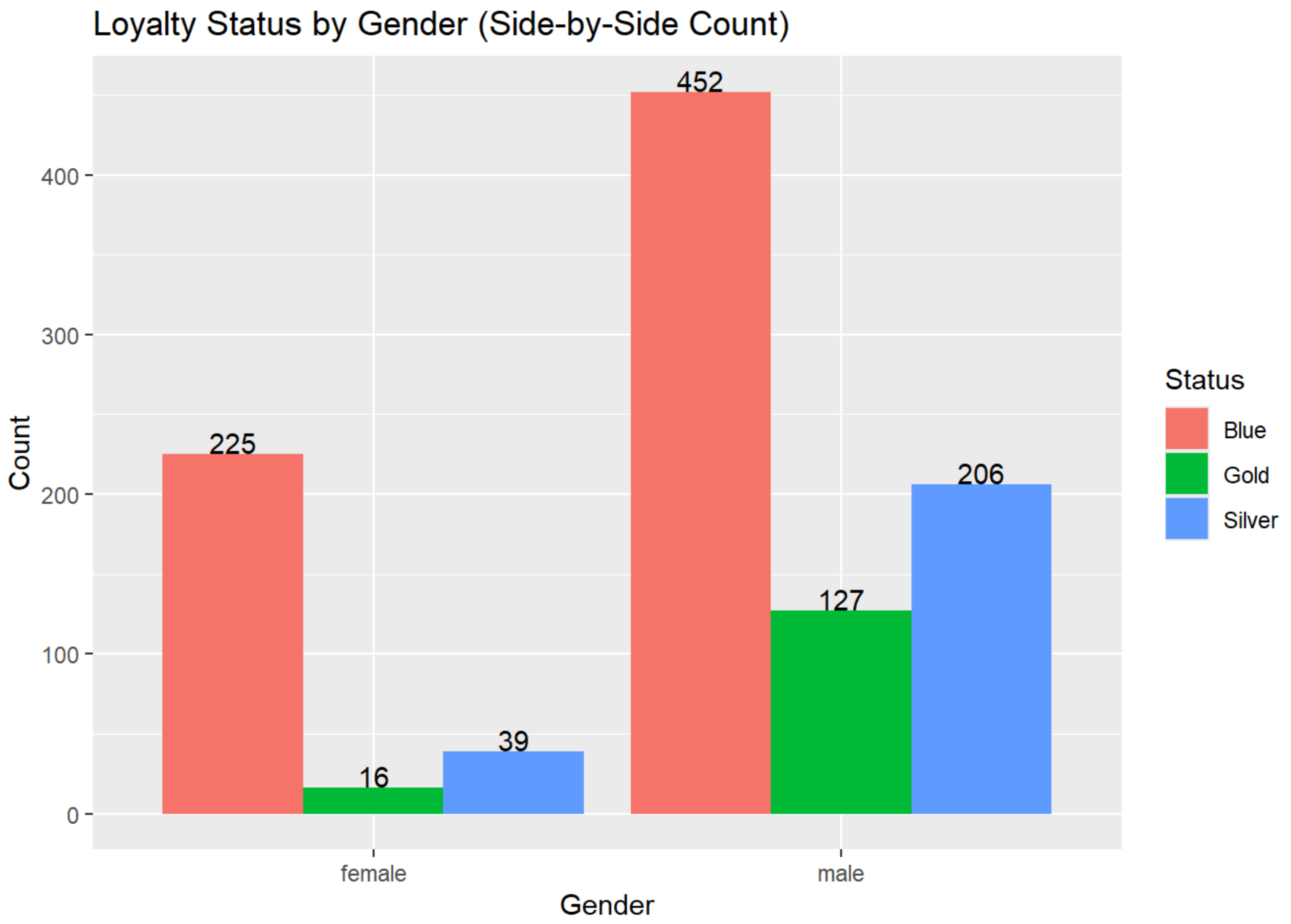
```r
airlinesat_small %>%
  group_by(gender, status) %>%
  summarise(n=n()) %>%
  mutate(perc = 100 * n/sum(n)) %>%
  ggplot(aes(x = gender, y = perc, fill = status)) +
  geom_col() +
  labs(title = "Loyalty Status by Gender (Stacked Percent)",
       x = "Gender",
       y = "Percent",
       fill = "Status")
```



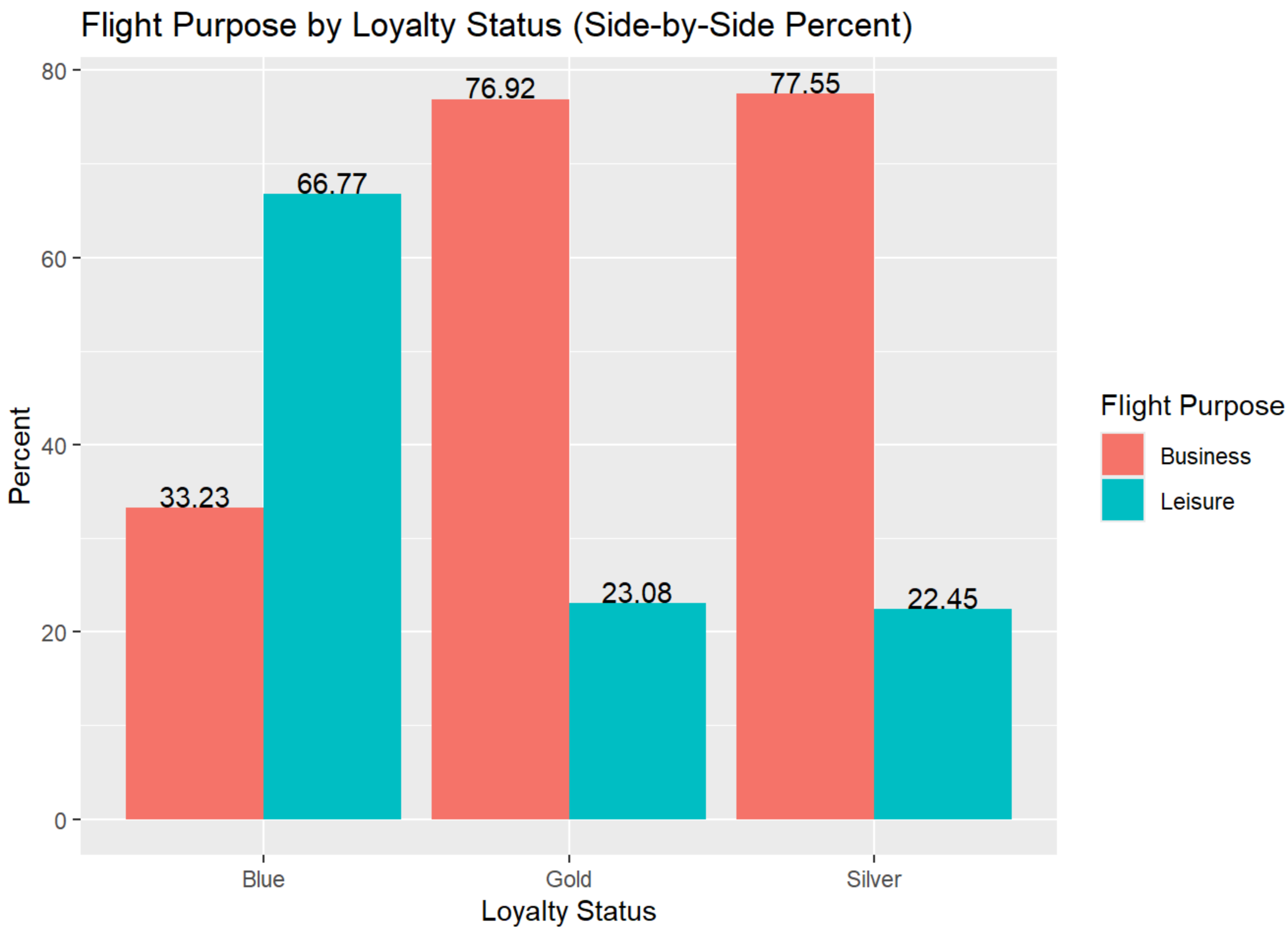
7.3.6.3 Side-by-Side Bar Chart with Counts/Percentages

To create side-by-side bar charts (vs. stacked), use the `position = position_dodge(width=.9)` option within the `geom_col()`. If you add labels, you need to use `position = position_dodge(width=.9)` in the `geom_text`, otherwise the labels will be on top of each other.

```r
airlinesat_small %>%
  group_by(gender, status) %>%
  summarise(n=n()) %>%
  ggplot(aes(x = gender, y = n, fill = status)) +
  geom_col(position = position_dodge(width=.9)) +
  geom_text(aes(label = n),
            position = position_dodge(width=.9),
            vjust = -.05) +
  labs(title = "Loyalty Status by Gender (Side-by-Side Count)",
       x = "Gender",
       y = "Count",
       fill = "Status")
```



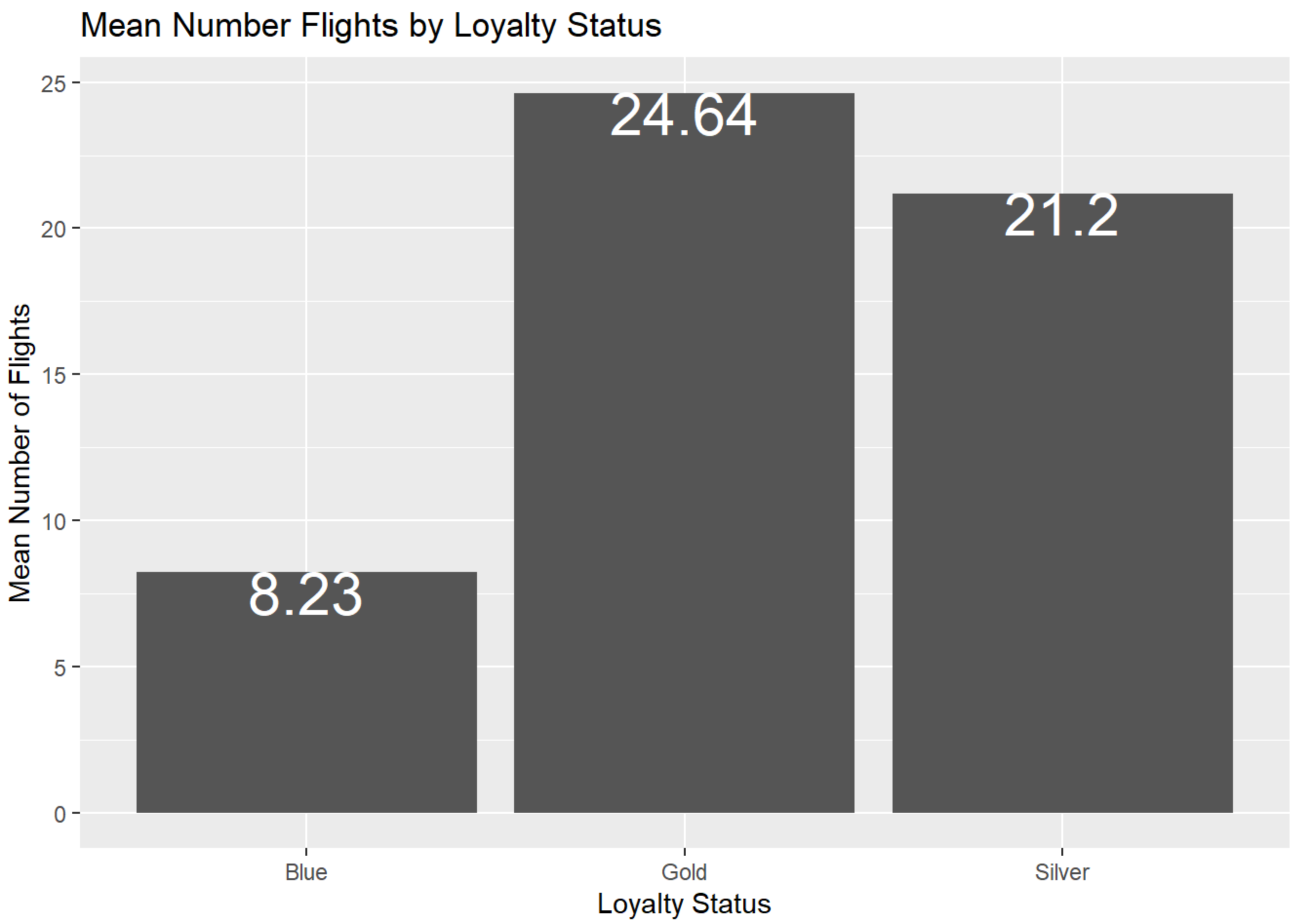
```
airlinesat_small %>%
  group_by(status, flight_purpose) %>%
  summarise(n = n()) %>%
  mutate(perc = 100*n/sum(n)) %>%
  ggplot(aes(x = status, y = perc, fill = flight_purpose)) +
  geom_col(position = position_dodge(width=.9)) +
  geom_text(aes(label = round(perc, 2)),
            position = position_dodge(width=.9),
            vjust = -.05) +
  labs(title = "Flight Purpose by Loyalty Status (Side-by-Side Percent)",
       x = "Loyalty Status",
       y = "Percent",
       fill = "Flight Purpose")
```



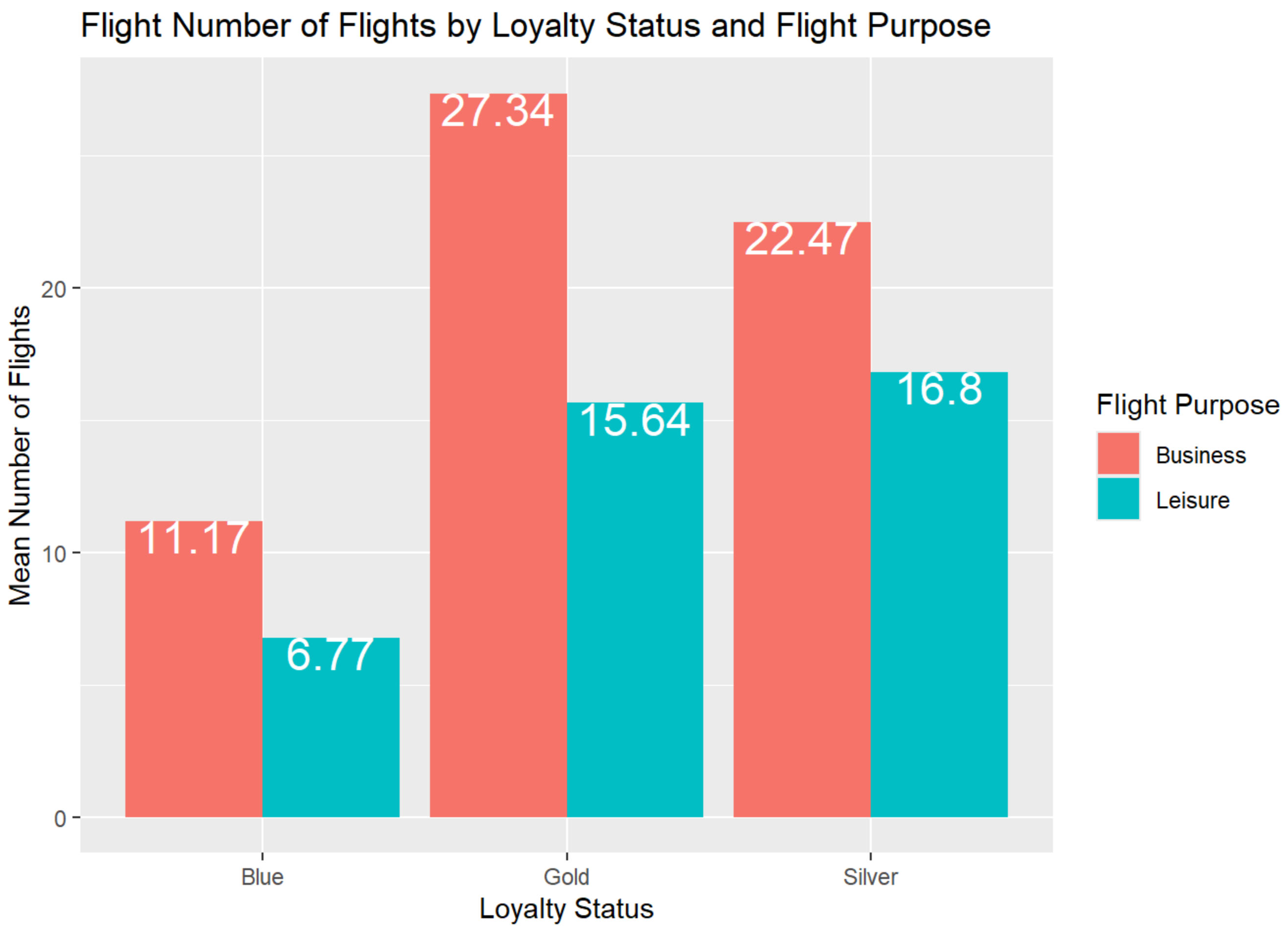
7.3.6.4 Side-by-Side Bar Chart with Continuous Variable

We can also calculate a summary statistic (e.g., mean, median, etc.) for a continuous variable and use that to create a side-by-side bar chart of a discrete variable or two discrete variables.

```r
airlinesat_small %>%
  group_by(status) %>%
  summarise(mean=mean(nflights)) %>%
  ggplot(aes(x = status, y = mean)) +
  geom_col(position = position_dodge(width=.9)) +
  geom_text(aes(label = round(mean, 2)),
            position = position_dodge(width=.9),
            vjust = .95,
            color="white",
            size=8) +
  labs(title = "Mean Number Flights by Loyalty Status",
       x = "Loyalty Status",
       y = "Mean Number of Flights")
```



```
airlinesat_small %>%
  group_by(status, flight_purpose) %>%
  summarise(mean = mean(nflights)) %>%
  ggplot(aes(x = status, y = mean, fill = flight_purpose)) +
  geom_col(position = position_dodge(width=.9)) +
  geom_text(aes(label = round(mean, 2)),
            position = position_dodge(width=.9),
            vjust = .95,
            color="white",
            size=6) +
  labs(title = "Flight Number of Flights by Loyalty Status and Flight Purpose",
       x = "Loyalty Status",
       y = "Mean Number of Flights",
       fill = "Flight Purpose")
```



7.4 Summary

Base R graphics provide a simple way to create quick plots, while `ggplot2` offers a more flexible and extensible framework for data visualization. In practice, Base R is useful for fast checks, and `ggplot2` is preferred for exploratory analysis and communication.

7.5 What’s Next

In the next chapter, we move from visual summaries to formal modeling. You will learn how to use linear regression to quantify relationships between variables, estimate marginal effects, and make predictions while holding other factors constant.