Mastering ggplot2: From Novice to Data Viz Pro

Unleash Your Inner Data Scientist

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Before We Start

In December 2017, after completing my first year of statistics, I delved into learning R. Having a background in `Java`, `C`, and `C++` coding since high school, I enjoyed R but found its plots not so appealing and the code a bit tricky. On a quest for something beautiful and user-friendly, I stumbled upon a blog titled **Beautiful plotting in R: A ggplot2 cheatsheet** by Zev Ross, last updated in January 2016. Intrigued, I decided to follow the tutorial step by step, learning a great deal. As time passed, I tweaked and expanded the codes, adding new chart types and resources.

Realizing that Zev Ross's blog hadn't been updated for years, I took the initiative to create my own version, incorporating updates like the amazing `{patchwork}`, `{ggtext}`, and `{ggforce}` packages. I also shared insights on custom fonts, colors, and introduced a variety of R packages for interactive charts. The journey led to a unique tutorial, and now, I've decided to make it public, adding even more updates, such as Maps! because who doesn't love maps!!

I incorporated the following enhancements into my tutorial:

- Following the R style guide (e.g., by Hadley Wickham, Google, or the Coding Club style guides).
- Implementing changes to the style and aesthetics of plots, including axis titles, legends, and color schemes for all plots.
- Ensuring that the tutorial remains up-to-date with changes in `{ggplot2}` (current version: 3.4.0).
- Modifying data import methods to utilize GitHub as a data source.
- Offering additional tips on various topics such as chart selection, color palettes, title modifications, adding lines, adjusting legends, annotations with labels, arrows and boxes, multi-panel plots, Geospatial Visualizations and interactive visualizations. …

What you'll discover

- Tie Your Seatbelt: Setting the stage for your journey into advanced plotting techniques.
- The Dataset: Understanding the importance of data in crafting compelling visualizations.
- The {ggplot2} Package: Unleashing the power of {ggplot2} for elegant and customizable plots.
- A Default ggplot: Exploring the basics with a default {ggplot} and understanding its components.
- Working with Axes: Mastering the art of manipulating axes to convey meaningful insights.
- Working with Titles: Crafting informative and visually appealing titles to captivate your audience.
- Working with Legends: Enhancing clarity and interpretation by effectively managing legends.
- Working with Backgrounds & Grid Lines: Elevating aesthetics with stylish backgrounds and grid lines.
- Working with Margins: Fine-tuning margins to optimize plot presentation.
- Working with Multi-Panel Plots: Diving into the world of multi-panel plots for comprehensive data representation.

- Working with Colors: Harnessing the power of color to convey information and evoke emotions.
- Working with Themes: Creating cohesive visual narratives with carefully curated themes.
- Working with Lines: Adding emphasis and clarity through strategic use of lines.
- Working with Text: Utilizing text annotations to provide context and highlight key findings.
- Working with Coordinates: Manipulating coordinates to achieve desired plot layouts and perspectives.
- Working with Chart Types: Expanding your repertoire with diverse and impactful chart types.
- Working with Ribbons (AUC, CI, etc.): Enhancing visualizations with ribbons for confidence intervals and more.
- Working with Smoothings: Incorporating smoothings to reveal underlying trends and patterns.
- Working with Interactive Plots: Engaging your audience with interactive visualizations for dynamic exploration.
- Remarks, Tipps & Resources: Leveraging insights, tips, and resources to further refine your plotting skills.

1 Tie Your Seatbelt

To fully execute the tutorial, you'll need to install the following packages:

- `{ggplot2}`, a part of the `{tidyverse}` package collection
- `{tidyverse}` package collection, including:
  - `{dplyr}` for data wrangling
  - `{tibble}` for modern data frames
  - `{tidyr}` for data cleaning
  - `{forcats}` for handling factors
- `{corrr}` for calculating correlation matrices
- `{cowplot}` for composing ggplots
- `{ggforce}` for creating sina plots and other advanced visualizations
- `{ggrepel}` for enhancing text labeling in plots
- `{ggridges}` for creating ridge plots
- `{ggsci}` for accessing nice color palettes
- `{ggtext}` for advanced text rendering in plots
- `{ggthemes}` for additional plot themes
- `{grid}` for creating graphical objects
- `{gridExtra}` for additional functions for "grid" graphics
- `{patchwork}` for generating multi-panel plots
- `{prismatic}` for manipulating colors
- `{rcartocolor}` for accessing great color palettes
- `{scico}` for perceptional uniform color palettes
- `{showtext}` for utilizing custom fonts
- `{shiny}` for developing interactive apps
- Several packages for interactive visualizations, including:
  - `{charter}`
  - `{echarts4r}`
  - `{ggiraph}`
  - `{highcharter}`
  - `{plotly}`

1.1 Installing Packages

To install the necessary packages, run the following code:

```r
# install CRAN packages
install.packages(
  c("ggplot2", "tibble", "tidyr", "forcats", "purrr", "prismatic", "corrr",
    "cowplot", "ggforce", "ggrepel", "ggridges", "ggsci", "ggtext", "ggthemes",
    "grid", "gridExtra", "patchwork", "rcartocolor", "scico", "showtext",
    "shiny", "plotly", "highcharter", "echarts4r")
)

# install from GitHub since not on CRAN
install.packages(devtools)
devtools::install_github("JohnCoene/charter")
```

For instructional purposes, and to ensure smooth transitions for learners navigating directly to specific plots, I'll load the necessary package beside `{ggplot2}` in the corresponding section.

2 The Dataset

We are utilizing data from the *National Morbidity and Mortality Air Pollution Study* (NMMAPS), focusing specifically on data pertaining to Chicago and the years 1997 to 2000 to ensure manageability of the plots. For a more comprehensive understanding of this dataset, readers can refer to Roger Peng's book Statistical Methods in Environmental Epidemiology with R.

To import the data into our R session, we can employ `read_csv()` from the `{readr}` package. Subsequently, we'll store the data in a variable named `chic` using the *assignment arrow* `<-`. Just Copy and Paste the following code.

```
chic <- readr::read_csv("https://raw.githubusercontent.com/rana2hin/ggplot_guide/master/chicago_data.c
```

```
Rows: 1461 Columns: 10
-- Column specification --------------------------------------------------------
Delimiter: ","
chr  (3): city, season, month
dbl  (6): temp, o3, dewpoint, pm10, yday, year
date (1): date

i Use `spec()` to retrieve the full column specification for this data.
i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

Using namespace Directly

The `::` symbolizes *namespace* and enables accessing a function without loading the entire package. Alternatively, you could load the `readr` package first using `library(readr)` and then execute `chic <- read_csv(...)` subsequently.

```
tibble::glimpse(chic)
```

```
Rows: 1,461
Columns: 10
$ city     <chr> "chic", "chic", "chic", "chic", "chic", "chic", "chic", "chic~
$ date     <date> 1997-01-01, 1997-01-02, 1997-01-03, 1997-01-04, 1997-01-05, ~
$ temp     <dbl> 36.0, 45.0, 40.0, 51.5, 27.0, 17.0, 16.0, 19.0, 26.0, 16.0, 1~
$ o3       <dbl> 5.659256, 5.525417, 6.288548, 7.537758, 20.760798, 14.940874,~
```

```
$ dewpoint <dbl> 37.500, 47.250, 38.000, 45.500, 11.250, 5.750, 7.000, 17.750,~
$ pm10     <dbl> 13.052268, 41.948600, 27.041751, 25.072573, 15.343121, 9.3646~
$ season   <chr> "Winter", "Winter", "Winter", "Winter", "Winter", "Winter", "~
$ yday     <dbl> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18~
$ month    <chr> "Jan", "Jan", "Jan", "Jan", "Jan", "Jan", "Jan", "Jan", "Jan"~
$ year     <dbl> 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1~
```

```r
library(gt)
head(chic, 10) %>% gt()
```

city	date	temp	o3	dewpoint	pm10	season	yday	month	year
chic	9862	36.0	5.659256	37.500	13.052268	Winter	1	Jan	1997
chic	9863	45.0	5.525417	47.250	41.948600	Winter	2	Jan	1997
chic	9864	40.0	6.288548	38.000	27.041751	Winter	3	Jan	1997
chic	9865	51.5	7.537758	45.500	25.072573	Winter	4	Jan	1997
chic	9866	27.0	20.760798	11.250	15.343121	Winter	5	Jan	1997
chic	9867	17.0	14.940874	5.750	9.364655	Winter	6	Jan	1997
chic	9868	16.0	11.920985	7.000	20.228428	Winter	7	Jan	1997
chic	9869	19.0	8.678477	17.750	33.134819	Winter	8	Jan	1997
chic	9870	26.0	13.355892	24.000	12.118381	Winter	9	Jan	1997
chic	9871	16.0	10.448264	5.375	24.761534	Winter	10	Jan	1997

3 The `ggplot2` Package

`ggplot2` is a graphics system that facilitates the declarative creation of visualizations, founded on principles outlined in The Grammar of Graphics. With `ggplot2`, you furnish the data, specify how variables should be mapped to aesthetics, define graphical parameters to employ, and the system handles the rest.

A ggplot is made up several key elements:

1. **Data**: Your raw dataset that you want to visualize.
2. **Geometries** `geom_`: These are the shapes that represent your data, like points, lines, or bars.
3. **Aesthetics** `aes()`: This controls how your data is visually represented, including aspects like color, size, and shape.
4. **Scales** `scale_`: These map the data onto the aesthetic dimensions, like converting data values to plot dimensions or factor values to colors.
5. **Statistical transformations** `stat_`: These are statistical summaries of your data, such as calculating quantiles or fitting curves.
6. **Coordinate system** `coord_`: This defines how your data coordinates are mapped onto the plot's coordinate system.
7. **Facets** `facet_`: This organizes your data into a grid of plots based on specified variables.
8. **Visual themes** `theme()`: These set the overall appearance of your plot, covering things like background, grids, axes, default fonts, sizes, and colors.

> **The number of elements may vary depending on the situation you're working on.**

3.1 A Default ggplot

Before diving into the capabilities of `{ggplot2}`, we need to load the package. Alternatively, we can load it through the tidyverse package collection:

```
library(ggplot2)
# Or,
library(tidyverse)
```

```
-- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
v dplyr     1.1.4     v readr     2.1.5
v forcats   1.0.0     v stringr   1.5.1
v lubridate 1.9.3     v tibble    3.2.1
```

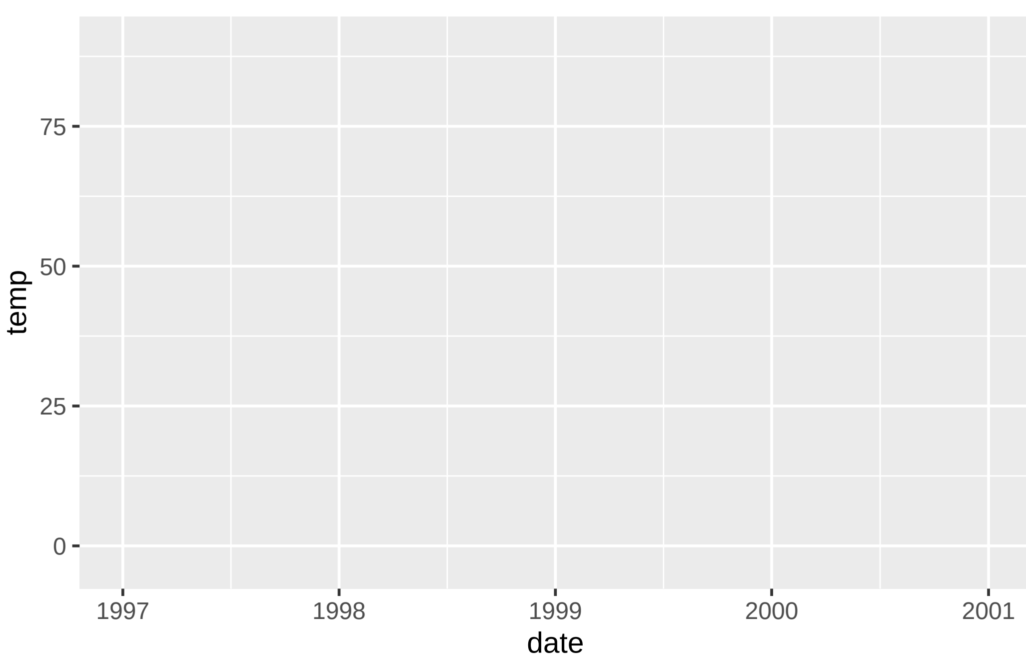
```
v purrr     1.0.2     v tidyr     1.3.1
-- Conflicts ------------------------------------------ tidyverse_conflicts() --
x dplyr::filter() masks stats::filter()
x dplyr::lag()    masks stats::lag()
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

The syntax of `{ggplot2}` differs from base R. Following the basic elements, a default ggplot requires specifying three things: the *data*, *aesthetics*, and a *geometry*. To begin defining a plotting object, we call `ggplot(data = df)`, indicating that we'll work with that dataset. Typically, we aim to plot two variables—one on the x-axis and one on the y-axis. These are *positional aesthetics*, so we add `aes(x = var1, y = var2)` to the `ggplot()` call (where `aes()` denotes aesthetics). However, there are cases where one may need to specify one, three, or more variables, which we'll address later.

> **! Pay Attention!**
>
> We indicate the data *outside* of `aes()` and include the variables that ggplot maps to the aesthetics *inside* of `aes()`.

In this instance, we assign the variable `date` to the x-position and the variable `temp` to the y-position. Subsequently, we'll also map variables to various other aesthetics such as color, size, and shape.

```
(g <- ggplot(chic, aes(x = date, y = temp)))
```



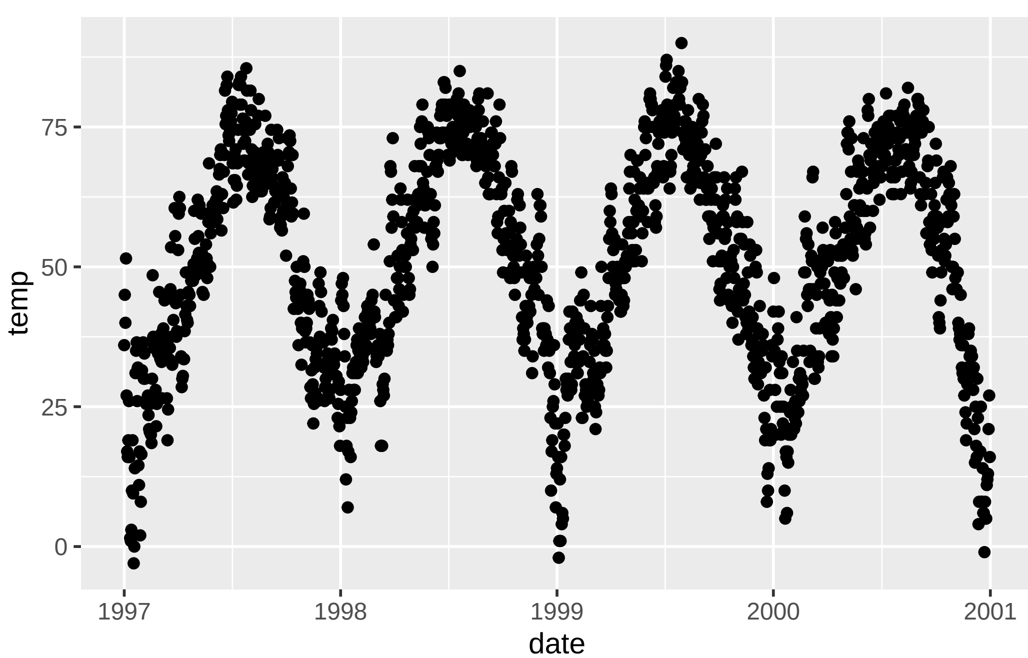
Ah, the reason only a panel is generated when executing this code is because `{ggplot2}` lacks information on how we want to visualize the data. We still need to specify a geometry!

In {ggplot2}, you can store the current ggobject in a variable of your choosing, such as g. This allows you to extend the ggobject later by adding additional layers, either all at once or by assigning it to the same or another variable.

> **A Quick Tip!**
>
> By using parentheses when assigning an object, the object will be printed immediately. Instead of writing g <- ggplot(...) followed by g, we can simply write (g <- ggplot(...)).

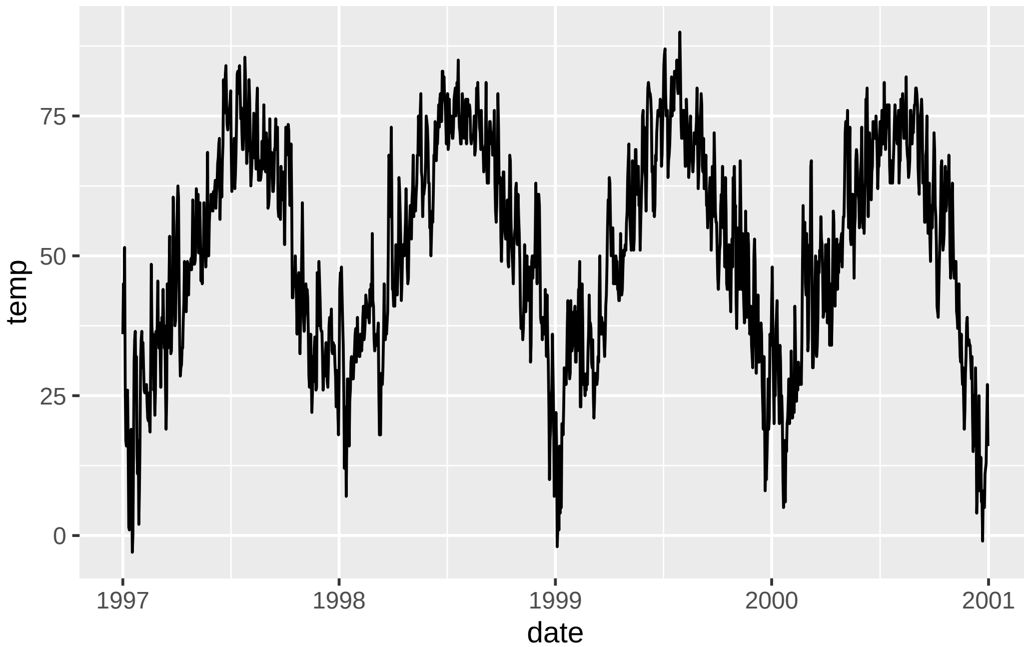
There's a wide array of geometries in {ggplot2}, often referred to as *geoms* because their function names typically start with geom_. You can find the full list of default geoms here, and there are even more options available through extension packages, which you can explore here. To instruct {ggplot2} on the style we want to use, we can, for example, add geom_point() to create a scatter plot:

```
g + geom_point()
```



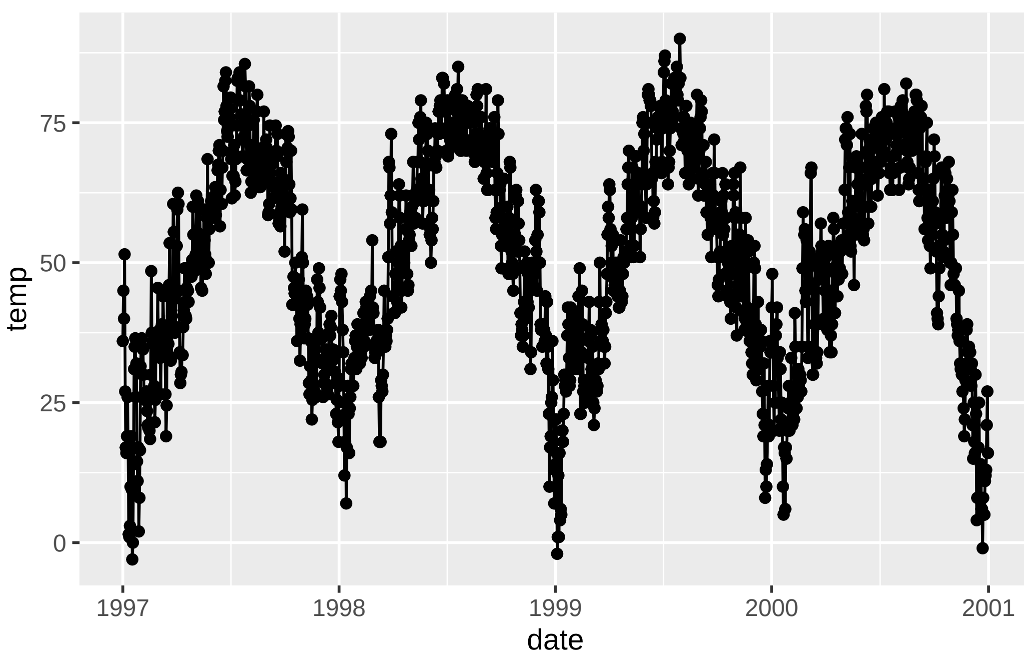
Great! However, this data could also be represented as a line plot (although it might not be the optimal choice, but it's a common practice). So, we can simply replace geom_point() with geom_line() and boom!

```
g + geom_line()
```



Indeed, one can combine multiple geometric layers, and this is where the magic and fun truly begin!

```
g + geom_line() + geom_point()
```

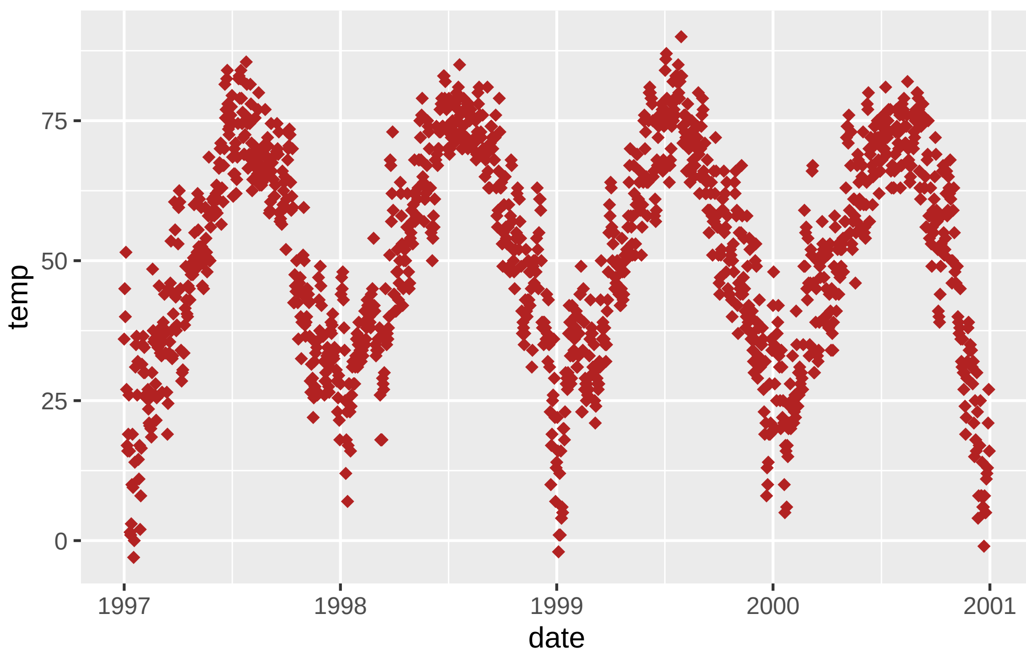


That's enough discussion on geometries for now. Don't worry, we'll dive into various plot types at a later point, as outlined here.

3.1.1 Change Properties of Geometries

Within the `geom_*` command, you can already manipulate visual aesthetics such as the color, shape, and size of your points. Let's transform all points into large fire-red diamonds!

```
g + geom_point(color = "firebrick", shape = "diamond", size = 2)
```



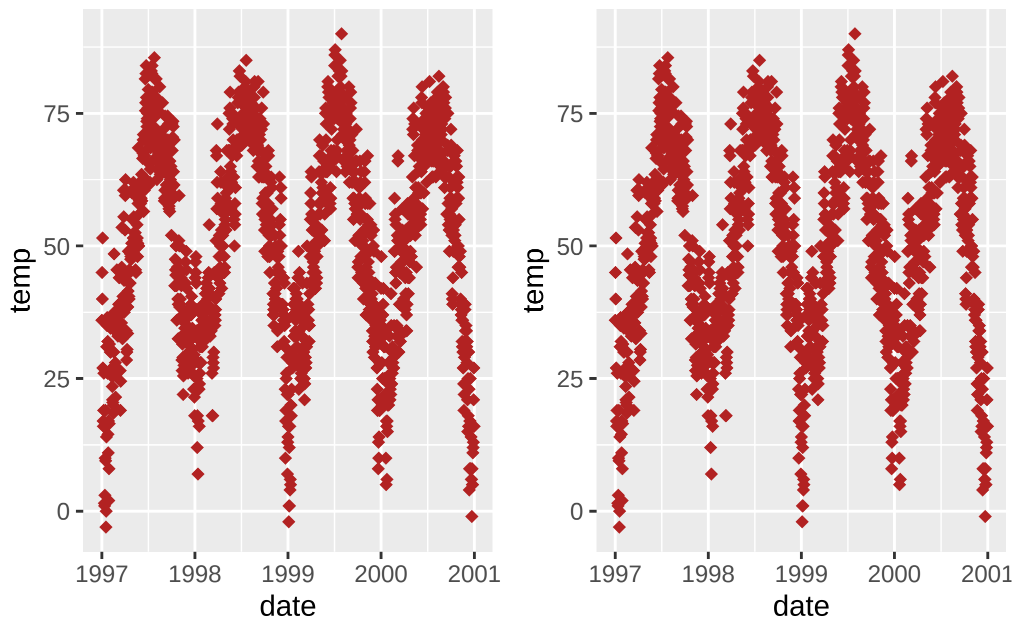
Color or Colour?

`{ggplot2}` understands both `color` and `colour` as well as the short version `col`.

Color Presets ⊠

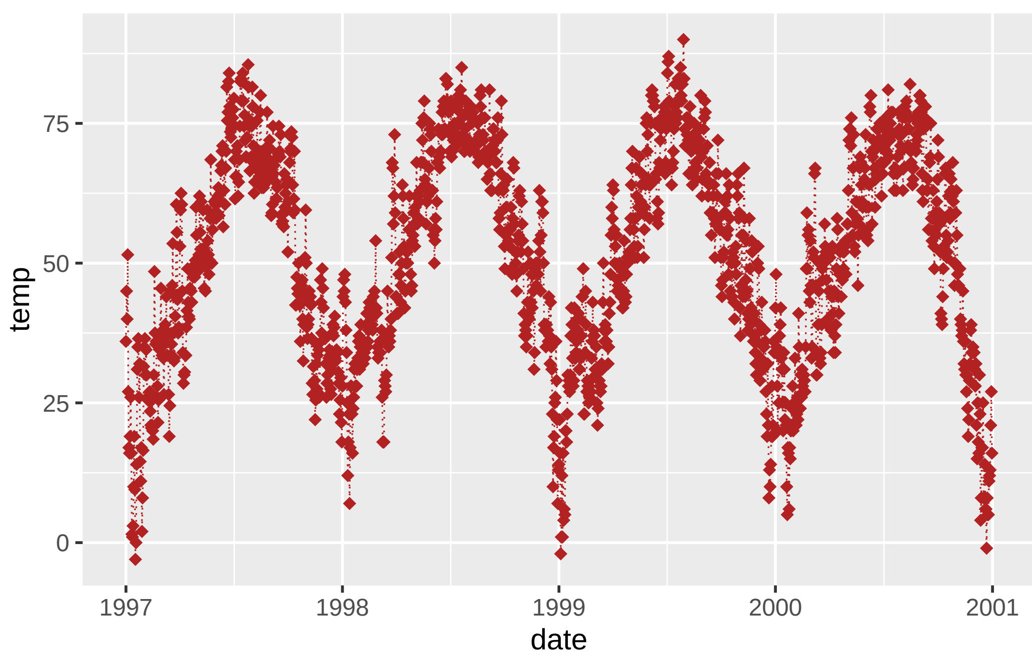
You can utilize preset colors (a full list can be found here) or hex color codes, both enclosed in quotes. Additionally, you can specify RGB/RGBA colors using the `rgb()` function. Click to expand:

```
g + geom_point(color = "#b22222", shape = "diamond", size = 2)
g + geom_point(color = rgb(178, 34, 34, maxColorValue = 255), shape = "diamond", size = 2)
```



Each geom has its unique properties, referred to as *arguments*, and the same argument might produce different effects depending on the geom you're employing.

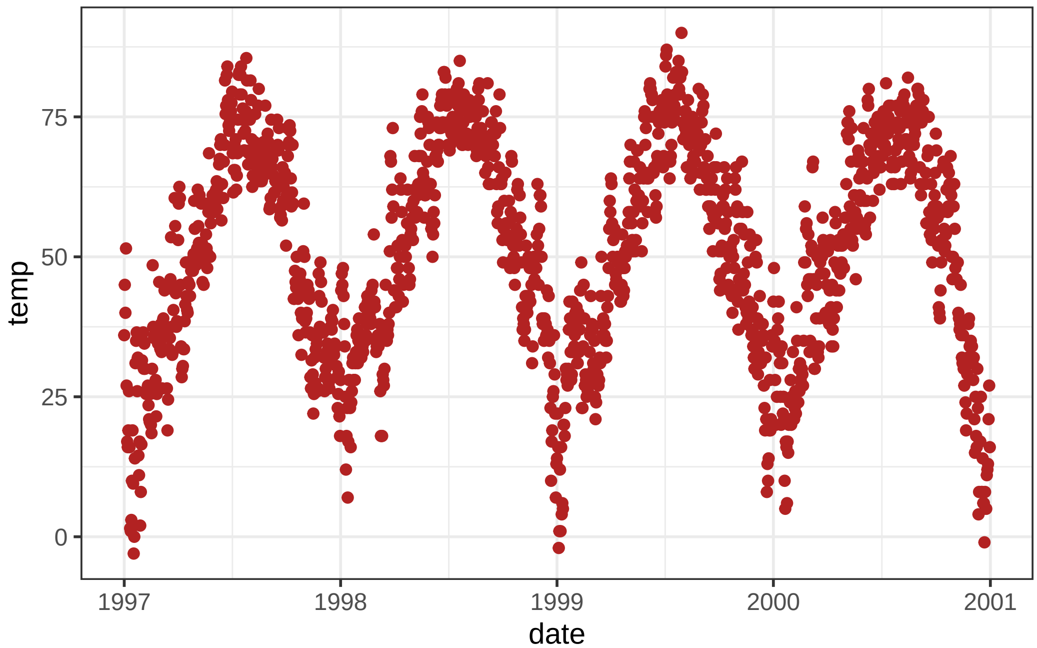
```
g + geom_point(color = "firebrick", shape = "diamond", size = 2) +
    geom_line(color = "firebrick", linetype = "dotted", lwd = .3)
```



3.1.2 Replace the default `ggplot2` theme

To further demonstrate ggplot's versatility, let's enhance the appearance by removing the default grayish `{ggplot2}` style and setting a different built-in theme, such as `theme_bw()`. By using `theme_set()`, all subsequent plots will adopt the same black-and-white theme. This adjustment will notably enhance the appearance of the red points!

```
theme_set(theme_bw())

g + geom_point(color = "firebrick")
```



For further details on using built-in themes and customizing themes, refer to the section "Working with Themes". Starting from the next chapter, we'll also utilize the `theme()` function to customize specific elements of the theme.

> **!** Remember!
>
> `theme()` is a crucial command for manually adjusting various theme elements such as texts, rectangles, and lines.

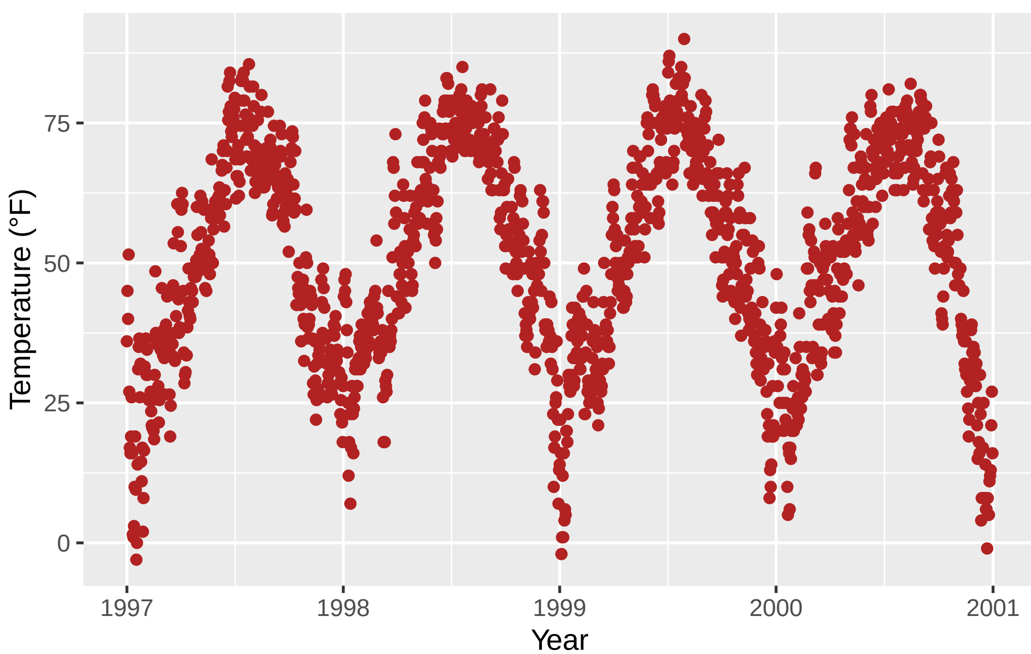
To explore the numerous details of a ggplot theme that can be modified, refer to the extensive list available here. Take your time, as it's a comprehensive list!

4 Working with Axes

4.1 Change Axis Titles

To add clear and descriptive labels to the axes, we can utilize the `labs()` function. This function allows us to provide a character string for each label we wish to modify, such as `x` and `y`:

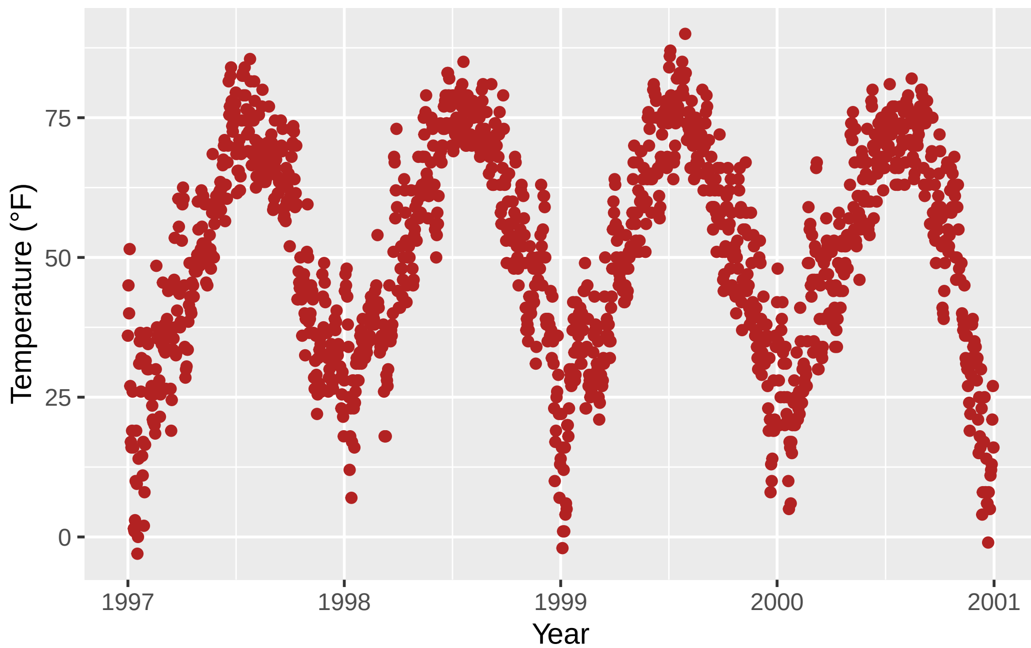
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)")
```



`xlab()` and `ylab()`

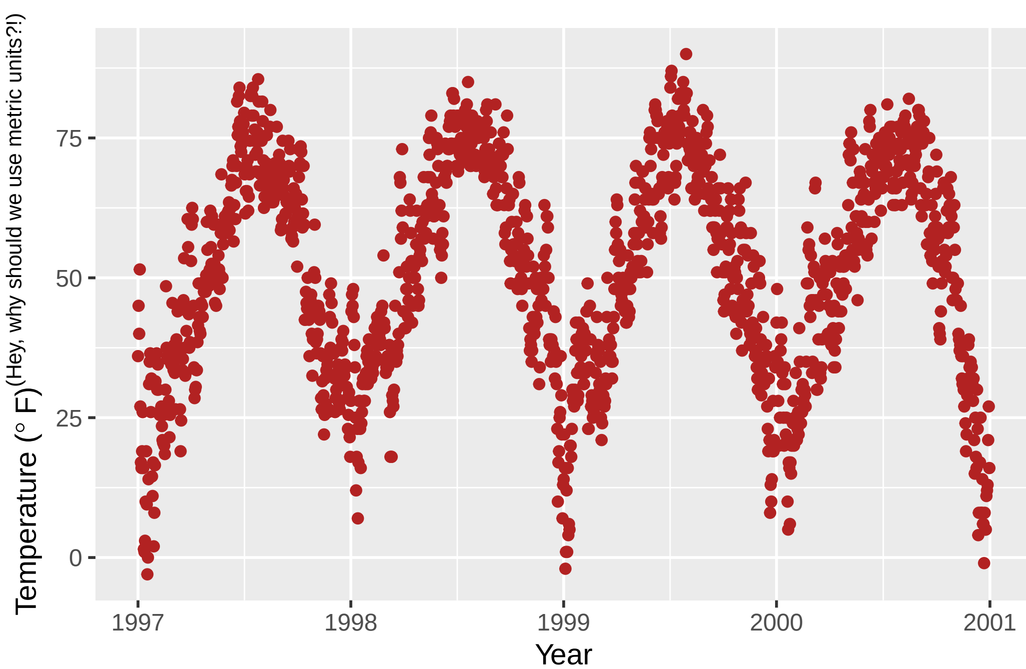
You also can add axis titles by using `xlab()` and `ylab()`. Click to see example.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  xlab("Year") +
  ylab("Temperature (°F)")
```



Typically, you can specify symbols by directly adding the symbol itself (e.g., "°"). However, the code below also enables the addition of not only symbols but also features like superscripts:

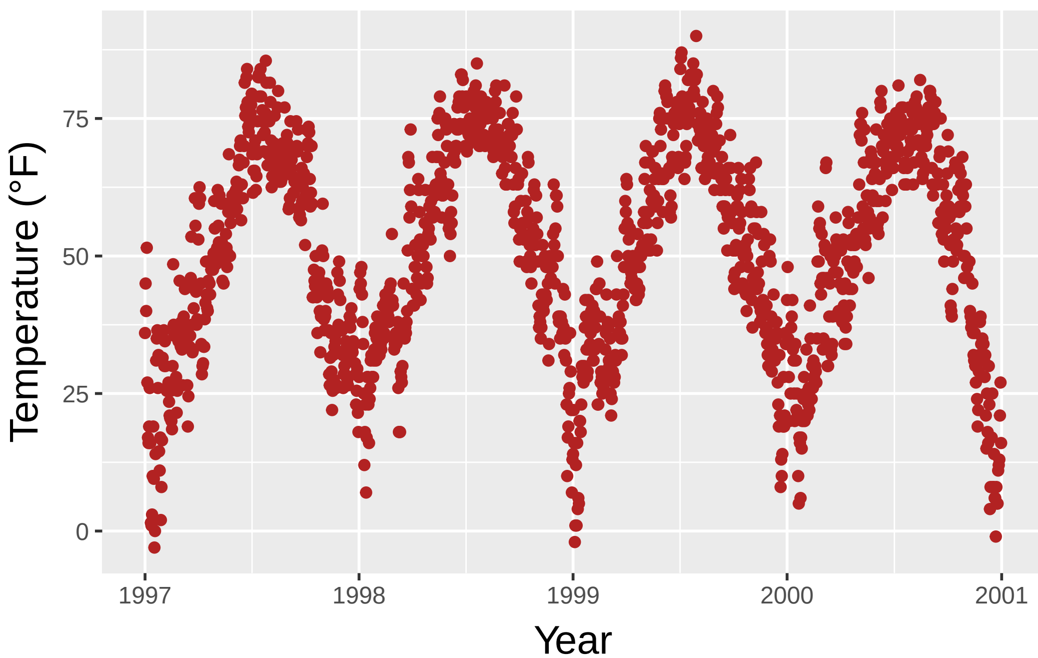
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = expression(paste("Temperature (", degree ~ F, ")"^"(Hey, why should we use m
```



4.2 Increase Space between Axis and Axis Titles

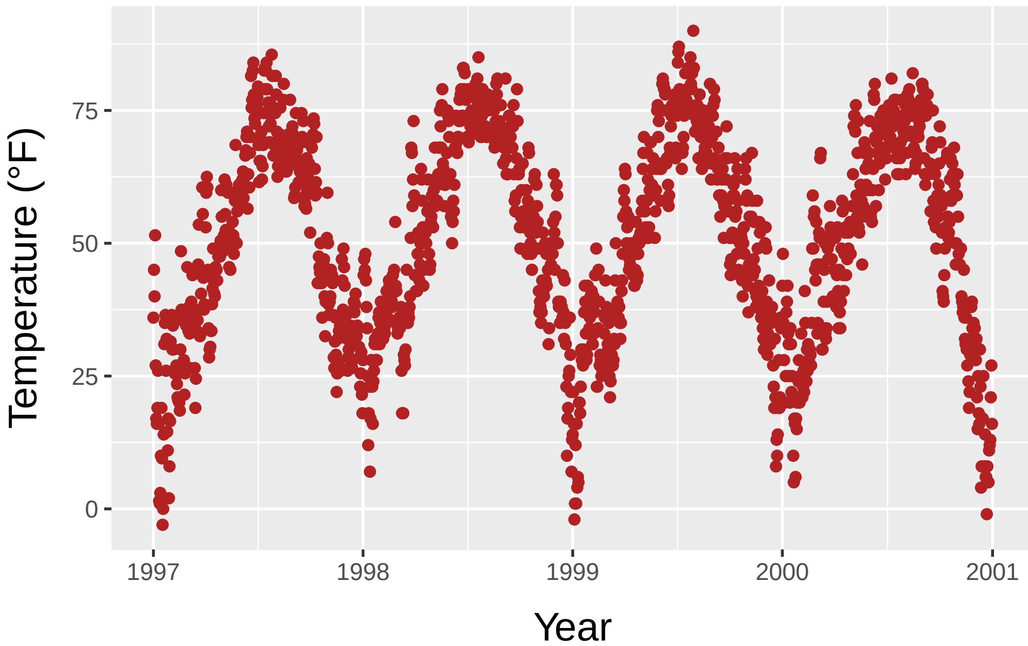
`theme()` is a crucial command for adjusting specific theme elements such as texts, titles, boxes, symbols, backgrounds, and more. We'll be utilizing this command extensively! Initially, we'll focus on modifying text elements. We can customize the properties of all text elements or specific ones, such as axis titles, by overriding the default `element_text()` within the `theme()` call:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title.x = element_text(vjust = 0, size = 15),
        axis.title.y = element_text(vjust = 2, size = 15))
```



The `vjust` parameter controls vertical alignment and typically ranges between 0 and 1, but you can also specify values outside that range. It's worth noting that even when adjusting the position of the axis title along the y-axis horizontally, we still need to specify `vjust` (which is correct from the perspective of the label's alignment). Additionally, you can modify the distance by specifying the margin for both text elements:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title.x = element_text(margin = margin(t = 10), size = 15),
        axis.title.y = element_text(margin = margin(r = 10), size = 15))
```



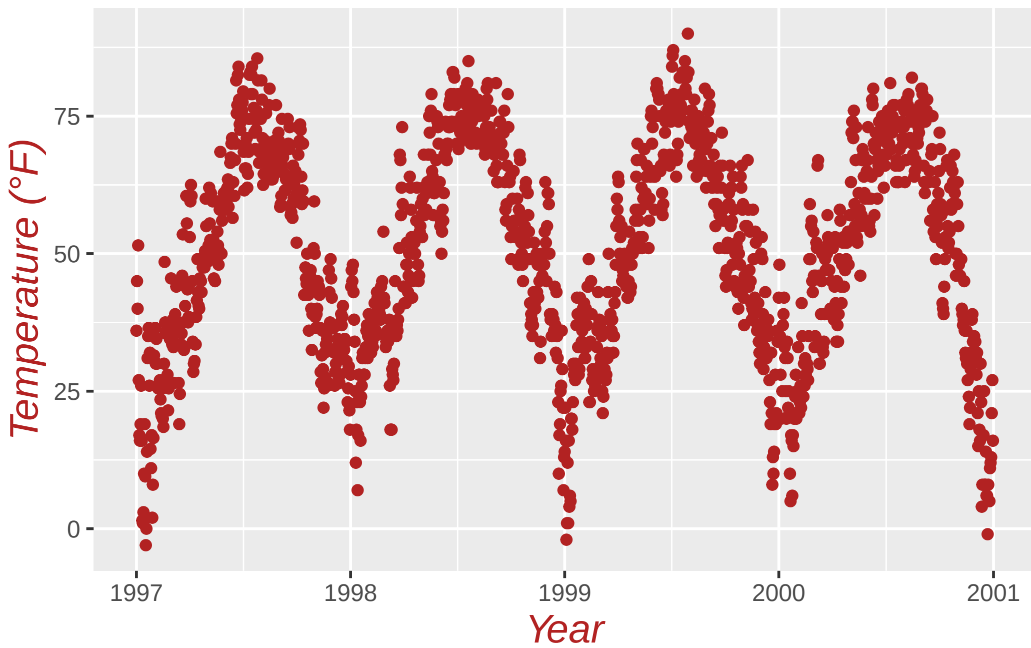
The labels `t` and `r` within the `margin()` object correspond to *top* and *right*, respectively. Alternatively, you can specify all four margins using `margin(t, r, b, l)`. It's important to note that we need to adjust the right margin to modify the space on the y-axis, not the bottom margin.

> Having trouble with Margins?
>
> A helpful mnemonic for remembering the order of the margin sides is "*t*-*r*-ou-*b*-*l*-e".

4.3 Change Aesthetics of Axis Titles

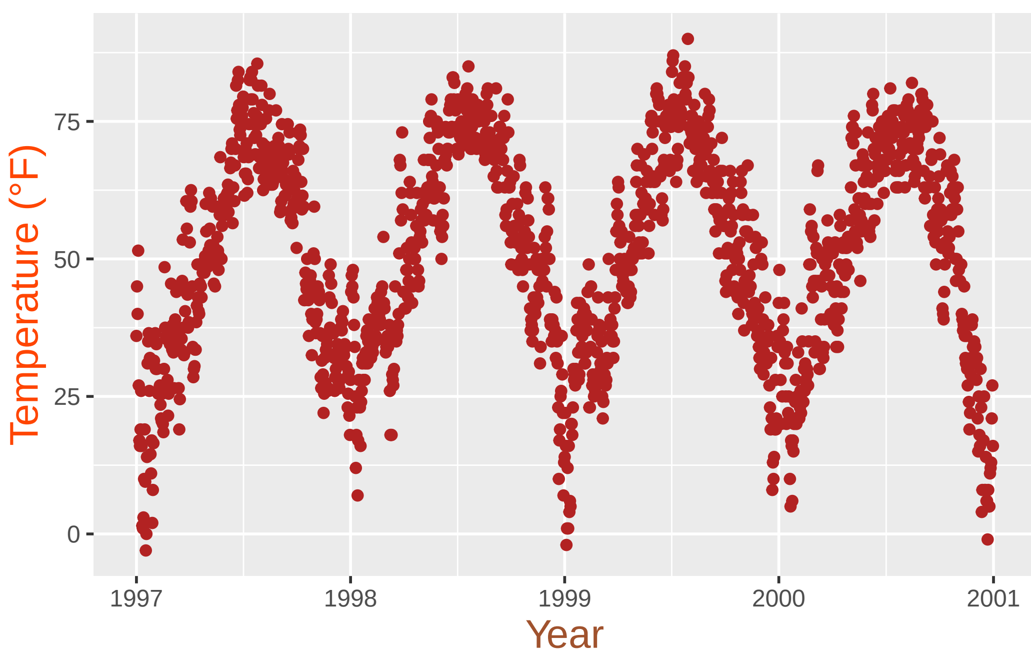
Once more, we utilize the `theme()` function to modify the `axis.title` element and/or its subordinated elements, `axis.title.x` and `axis.title.y`. Within the `element_text()` function, we can override defaults for properties such as `size`, `color`, and `face`:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title = element_text(size = 15, color = "firebrick",
                                  face = "italic"))
```



The face argument can be used to make the font bold or italic or even bold.italic.

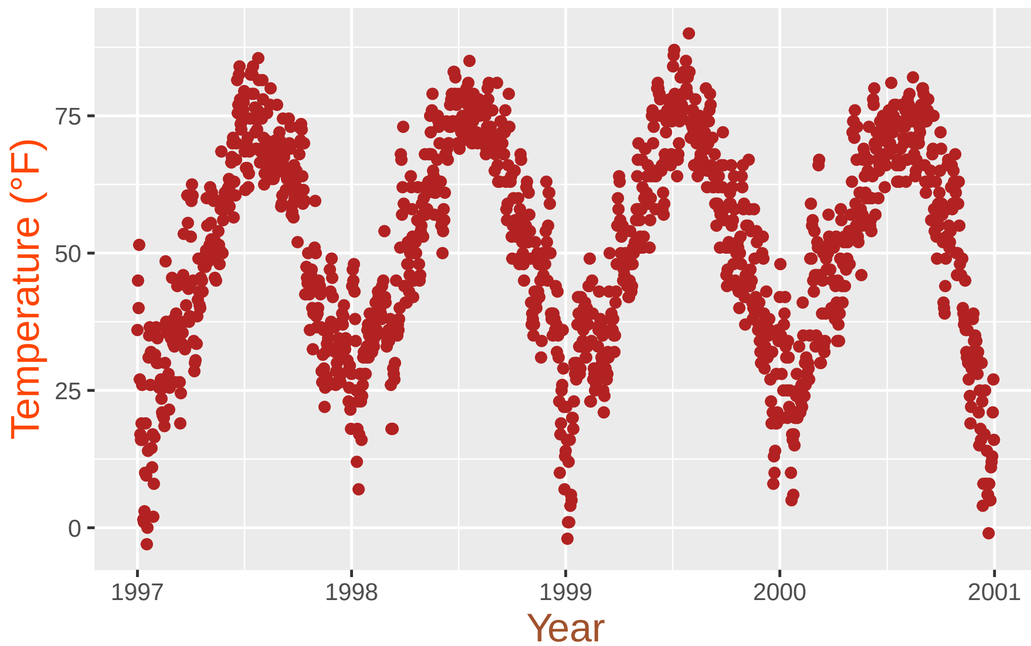
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title.x = element_text(color = "sienna", size = 15),
        axis.title.y = element_text(color = "orangered", size = 15))
```



Customising Invidual Axis

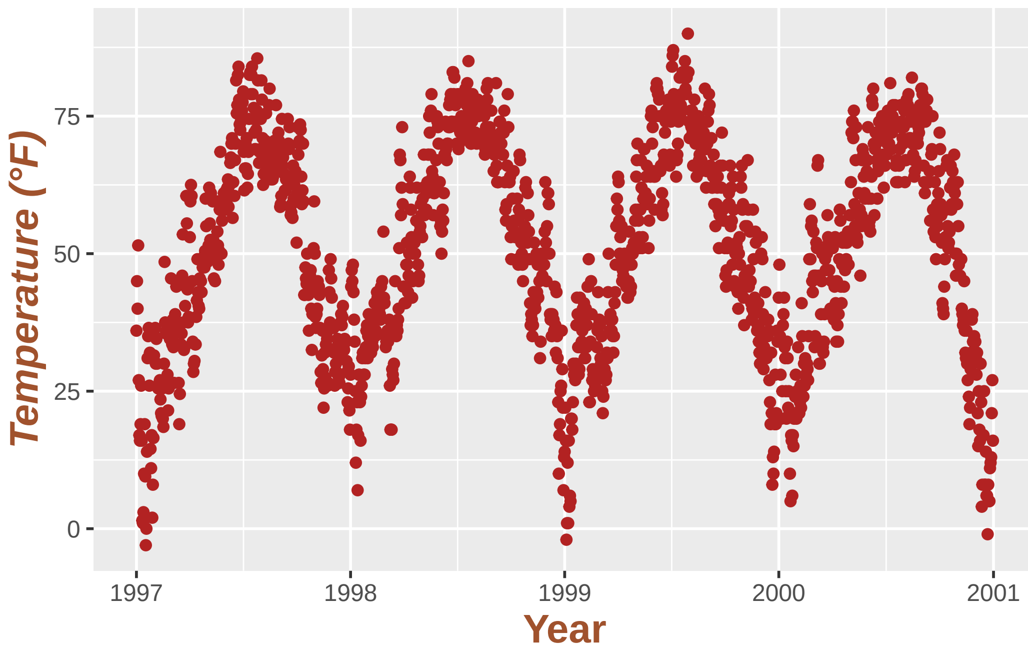
You could also employ a combination of `axis.title` and `axis.title.y`, as `axis.title.x` inherits values from `axis.title`. Expand to See the example below:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title = element_text(color = "sienna", size = 15),
        axis.title.y = element_text(color = "orangered", size = 15))
```



You can adjust some properties for both axis titles simultaneously, while modifying others exclusively for one axis or individual properties for each axis title:

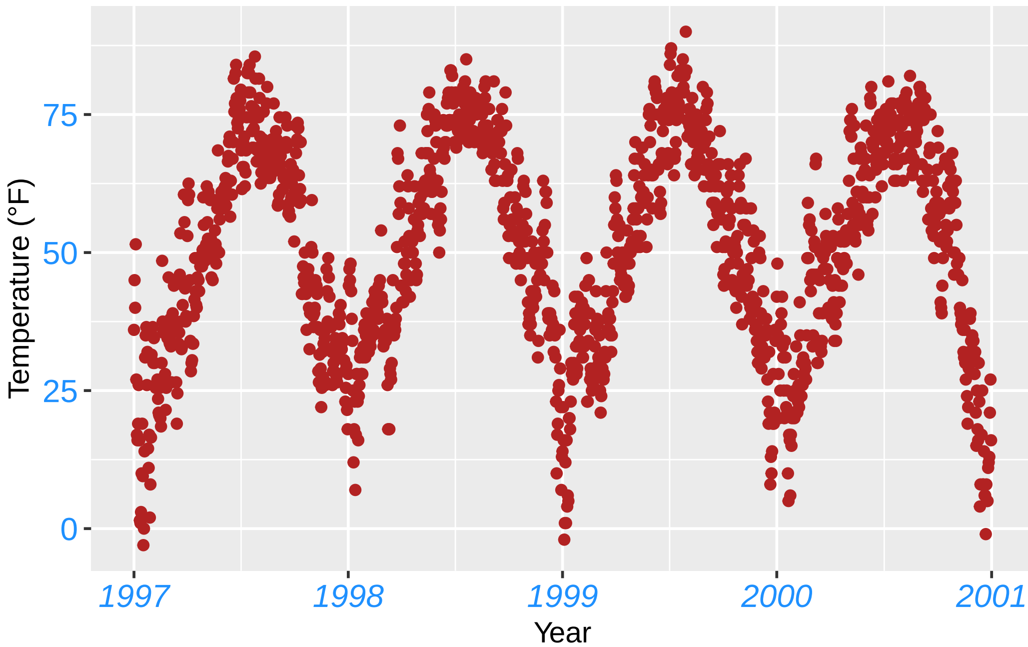
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.title = element_text(color = "sienna", size = 15, face = "bold"),
        axis.title.y = element_text(face = "bold.italic"))
```



4.4 Change Aesthetics of Axis Text

Likewise, you can alter the appearance of the axis text (i.e., the numbers) by utilizing `axis.text` and/or its subordinated elements, `axis.text.x` and `axis.text.y`:

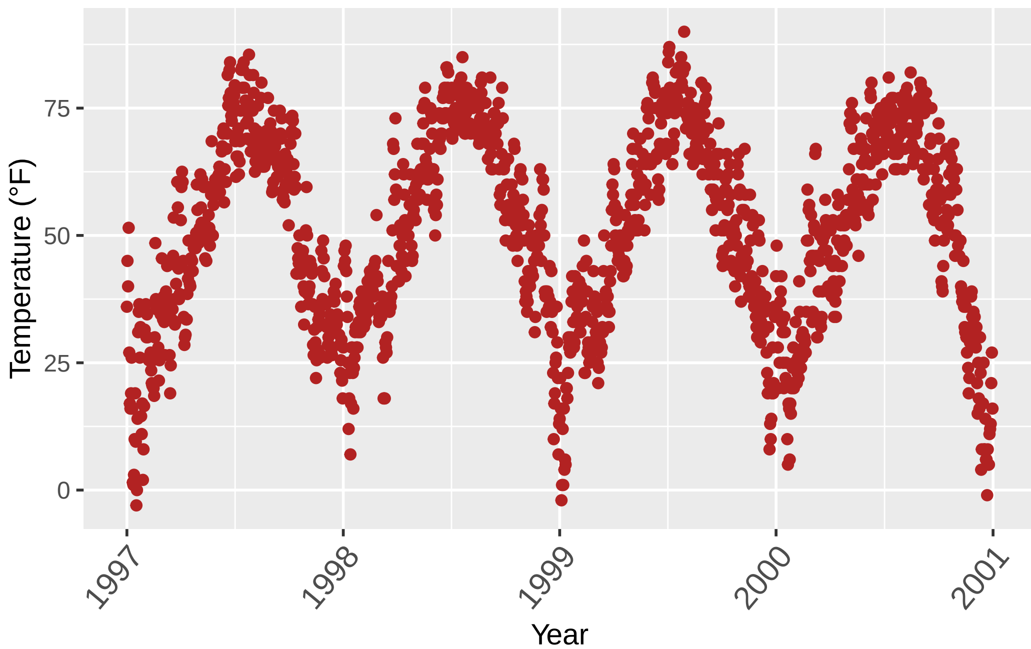
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.text = element_text(color = "dodgerblue", size = 12),
        axis.text.x = element_text(face = "italic"))
```



4.5 Rotate Axis Text

You can rotate any text elements by specifying an `angle`. Subsequently, you can adjust the position of the text horizontally (0 = left, 1 = right) and vertically (0 = top, 1 = bottom) using `hjust` and `vjust`:

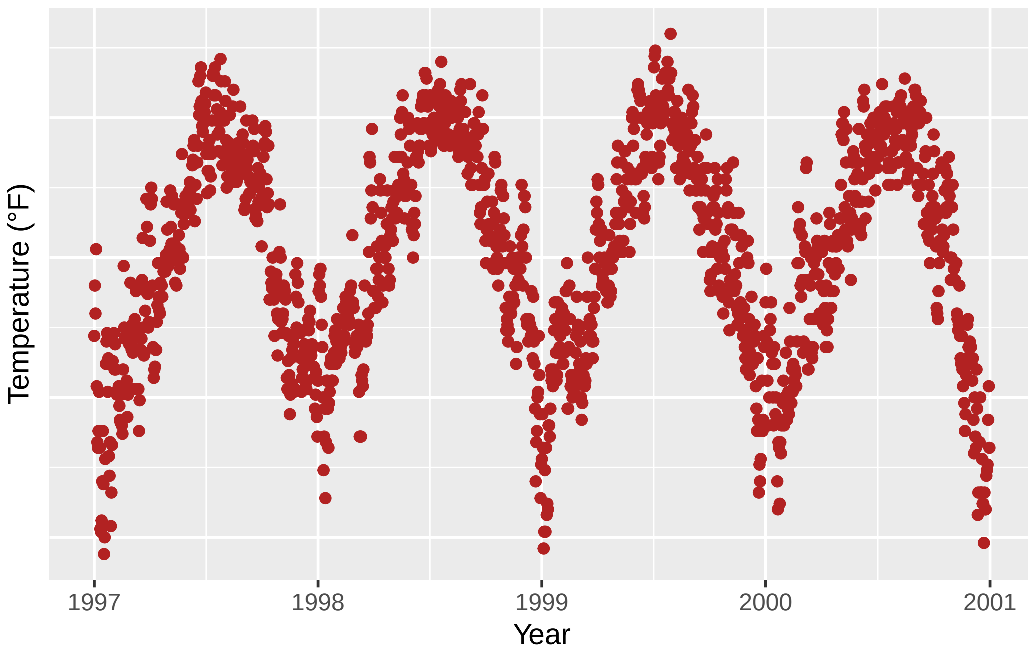
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.text.x = element_text(angle = 50, vjust = 1, hjust = 1, size = 12))
```



4.6 Removing Axis Text & Ticks

There might be rare occasions where you need to remove axis text and ticks. Here's how you can achieve it:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(axis.ticks.y = element_blank(),
        axis.text.y = element_blank())
```



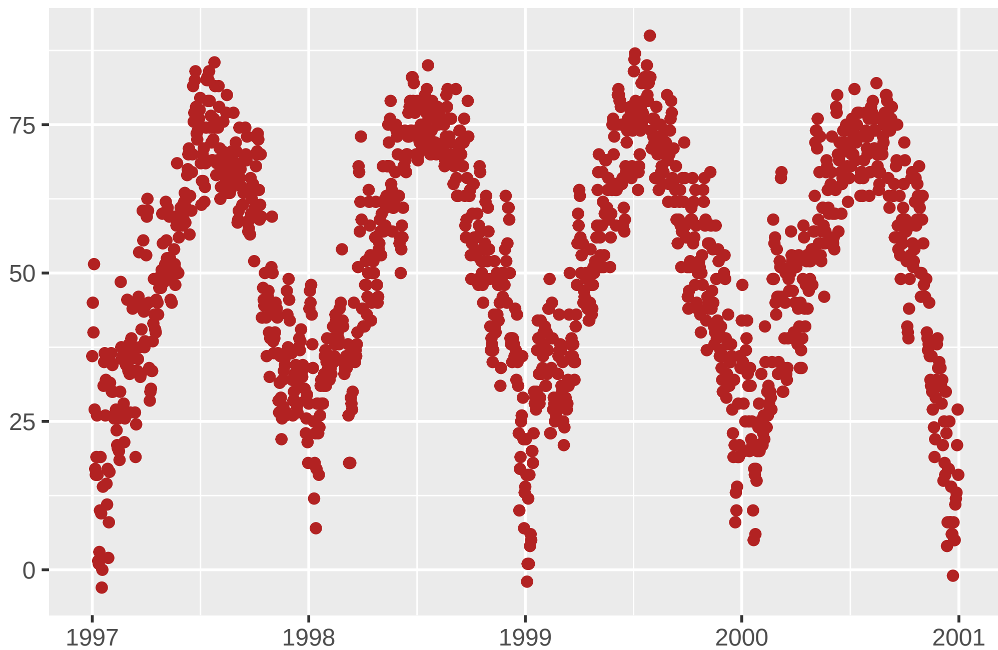
I've introduced three theme elements—text, lines, and rectangles—but there's actually one more: `element_blank()`, which removes the element entirely. However, it's not considered an official element like the others.

> **Removing Theme Element**
>
> If you wish to remove a theme element entirely, you can always use `element_blank()`.

4.7 Removing Axis Titles

We can use `theme_blank()`, but it's much simpler to just omit the label in the `labs()` (or `xlab()`) call:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = NULL, y = "")
```



RAnother Tip!

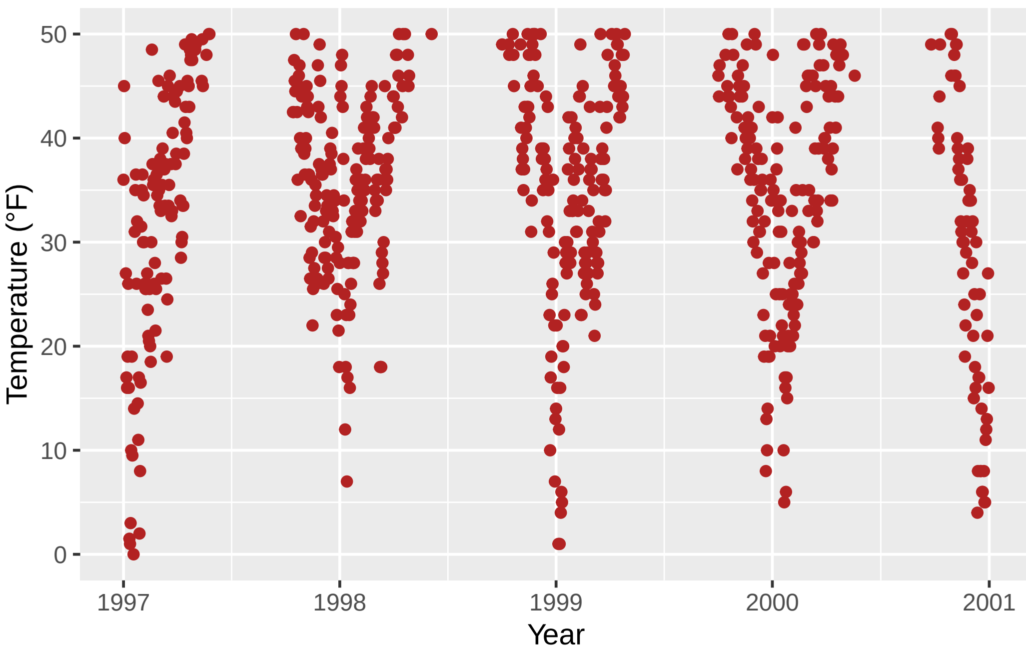
Note that `NULL` removes the element (similarly to `element_blank()`), while empty quotes `""` will keep the spacing for the axis title but print nothing.

4.8 Limiting Axis Range

Occasionally, you may want to focus on a specific range of your data without altering the dataset itself. You can accomplish this with ease:

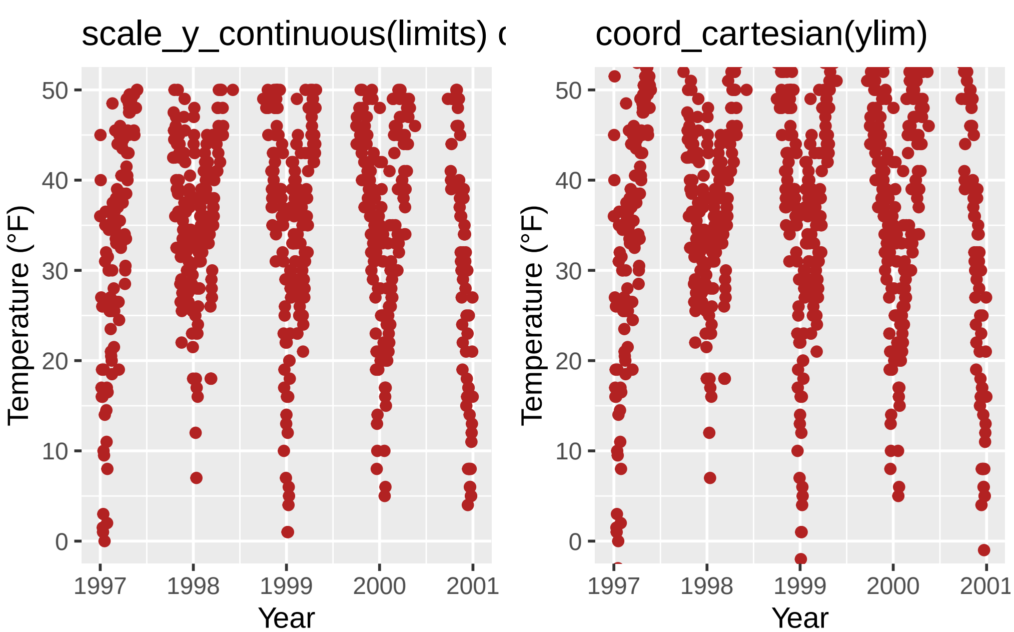
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  ylim(c(0, 50))
```

```
Warning: Removed 777 rows containing missing values or values outside the scale range
(`geom_point()`).
```



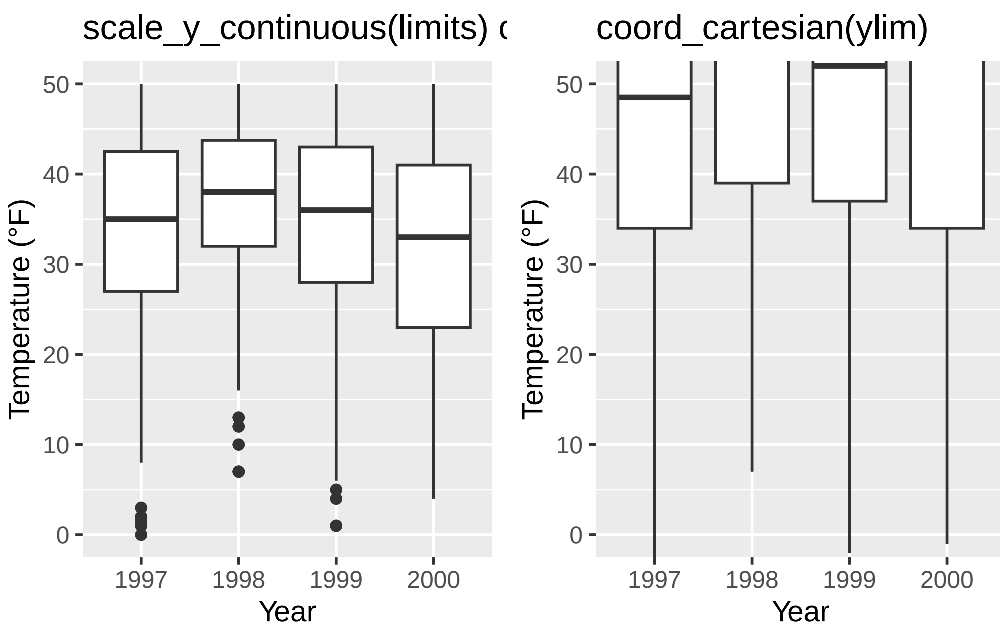
Alternatively, you can utilize `scale_y_continuous(limits = c(0, 50))` or `coord_cartesian(ylim = c(0, 50))`. The former removes all data points outside the specified range, while the latter adjusts the visible area, similar to `ylim(c(0, 50))`. At first glance, it may seem that both approaches yield the same result. However, there is an important distinction—compare the following two plots:

```
Warning: Removed 777 rows containing missing values or values outside the scale range
(`geom_point()`).
```



You may have noticed that on the left, there is some empty buffer around your y limits, while on the right, points are plotted right up to the border and even beyond. This effectively illustrates the concept of subsetting (left) versus zooming (right). To demonstrate why this distinction is significant, let's examine a different chart type: a box plot.

```
Warning: Removed 777 rows containing non-finite outside the scale range
(`stat_boxplot()`).
```

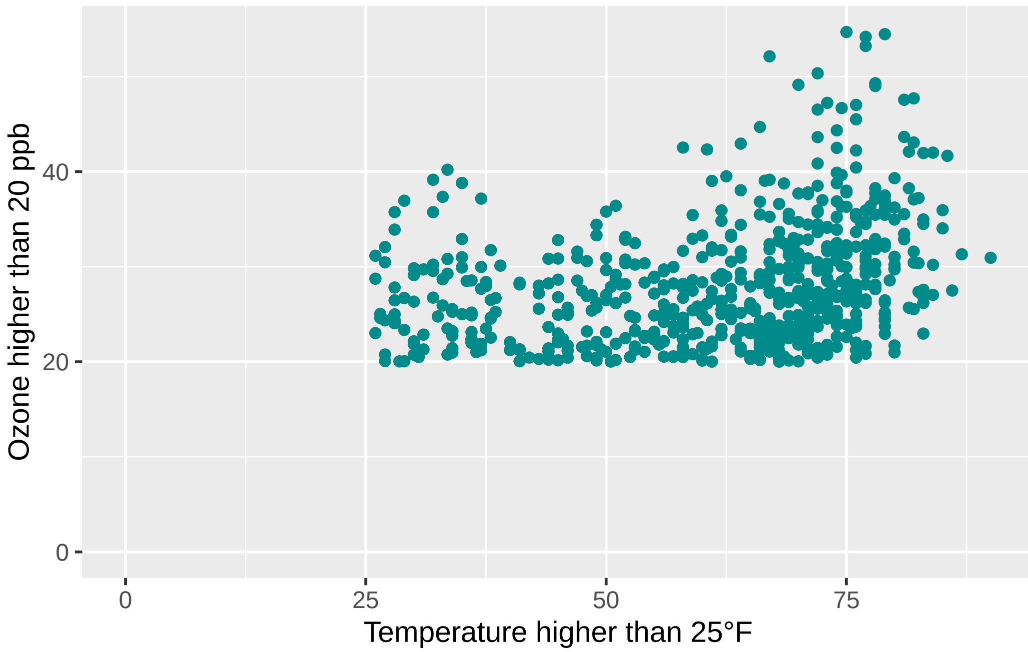


Indeed, because `scale_x|y_continuous()` subsets the data first, we obtain completely different (and potentially incorrect, especially if this was not our intention) estimates for the box plots! This realization highlights the importance of ensuring data integrity throughout the plotting process. It's crucial to avoid inadvertently manipulating the data while plotting, as it could lead to inaccurate summary statistics reported in your report, paper, or thesis.

4.9 Forcing Plot to Start at Origin

Related to that, you can instruct R to plot the graph starting at the origin:

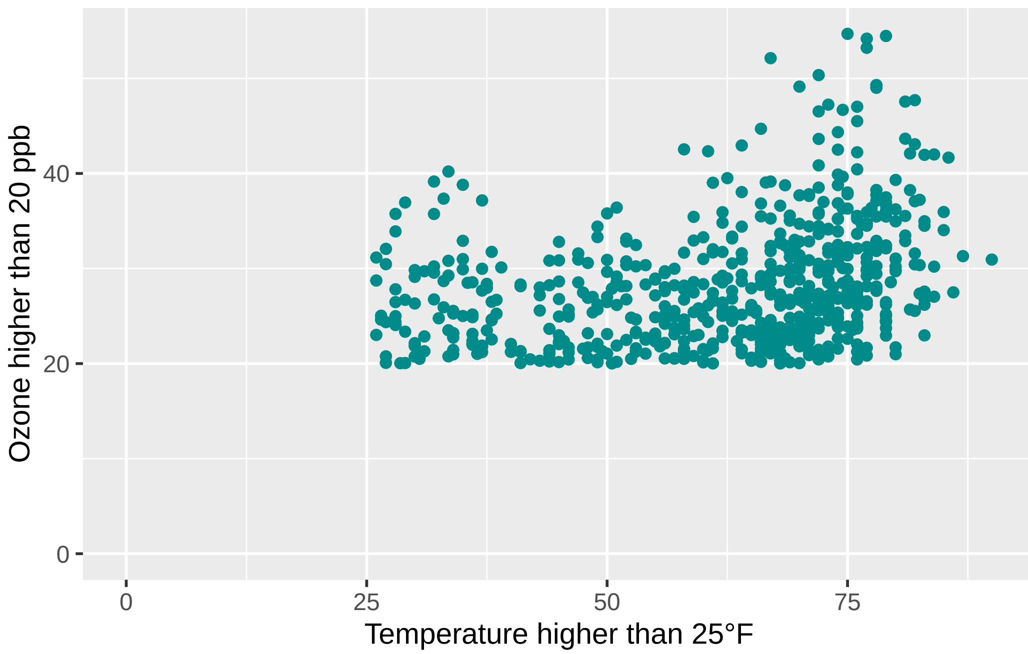
```
chic_high <- dplyr::filter(chic, temp > 25, o3 > 20)

ggplot(chic_high, aes(x = temp, y = o3)) +
  geom_point(color = "darkcyan") +
  labs(x = "Temperature higher than 25°F",
       y = "Ozone higher than 20 ppb") +
  expand_limits(x = 0, y = 0)
```



Another Way using `coord_cartesian(xlim = c(0, NA), ylim = c(0, NA))`

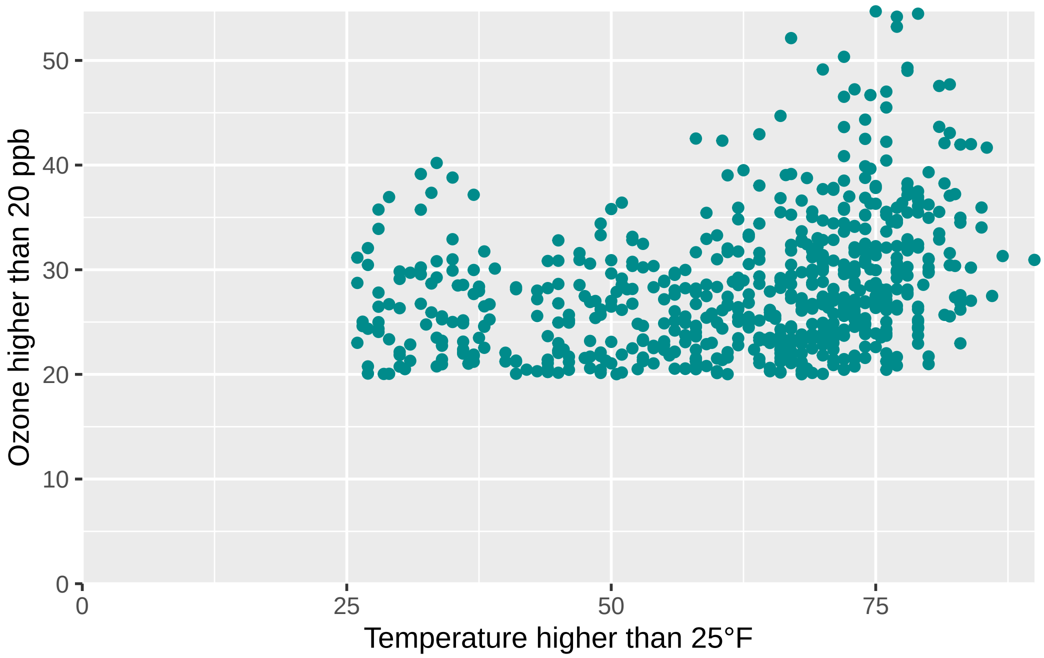
Using `coord_cartesian(xlim = c(0, NA), ylim = c(0, NA))` will produce the same result. CLICK to See the example below:

```
chic_high <- dplyr::filter(chic, temp > 25, o3 > 20)

ggplot(chic_high, aes(x = temp, y = o3)) +
  geom_point(color = "darkcyan") +
  labs(x = "Temperature higher than 25°F",
       y = "Ozone higher than 20 ppb") +
  coord_cartesian(xlim = c(0, NA), ylim = c(0, NA))
```



But we can also ensure that it *truly* starts at the origin!

```
ggplot(chic_high, aes(x = temp, y = o3)) +
  geom_point(color = "darkcyan") +
  labs(x = "Temperature higher than 25°F",
       y = "Ozone higher than 20 ppb") +
  expand_limits(x = 0, y = 0) +
  coord_cartesian(expand = FALSE, clip = "off")
```



> **Tip**
>
> The `clip = "off"` argument in any coordinate system, always starting with `coord_*`, enables drawing outside of the panel area.

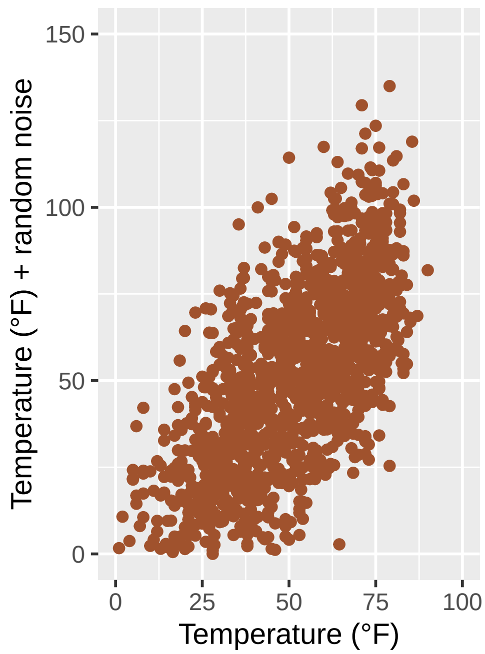
Here, I invoke it to ensure that the tick marks at `c(0, 0)` remain intact and are not truncated. For further insights, refer to the Twitter thread by Claus Wilke.

4.10 Axes with Same Scaling

For demonstration purposes, let's plot temperature against temperature with some random noise. The `coord_equal()` function provides a coordinate system with a specified ratio, representing the number of units on the y-axis equivalent to one unit on the x-axis. By default, `ratio = 1` ensures that one unit on the x-axis is the same length as one unit on the y-axis:

```
ggplot(chic, aes(x = temp, y = temp + rnorm(nrow(chic), sd = 20))) +
  geom_point(color = "sienna") +
  labs(x = "Temperature (°F)", y = "Temperature (°F) + random noise") +
  xlim(c(0, 100)) + ylim(c(0, 150)) +
  coord_fixed()
```

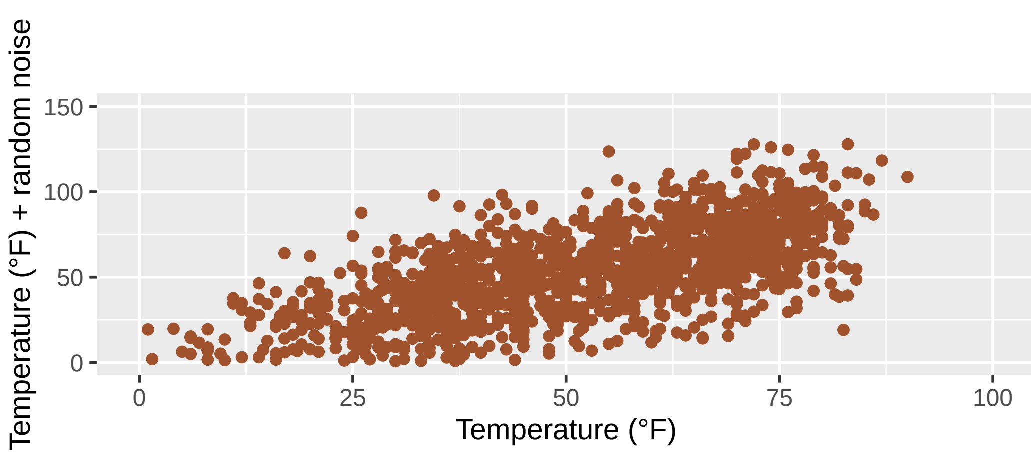
```
Warning: Removed 46 rows containing missing values or values outside the scale range
(`geom_point()`).
```



Ratios higher than one result in units on the y-axis being longer than units on the x-axis, while ratios lower than one have the opposite effect:

```
ggplot(chic, aes(x = temp, y = temp + rnorm(nrow(chic), sd = 20))) +
  geom_point(color = "sienna") +
  labs(x = "Temperature (°F)", y = "Temperature (°F) + random noise") +
  xlim(c(0, 100)) + ylim(c(0, 150)) +
  coord_fixed(ratio = 1/5)
```

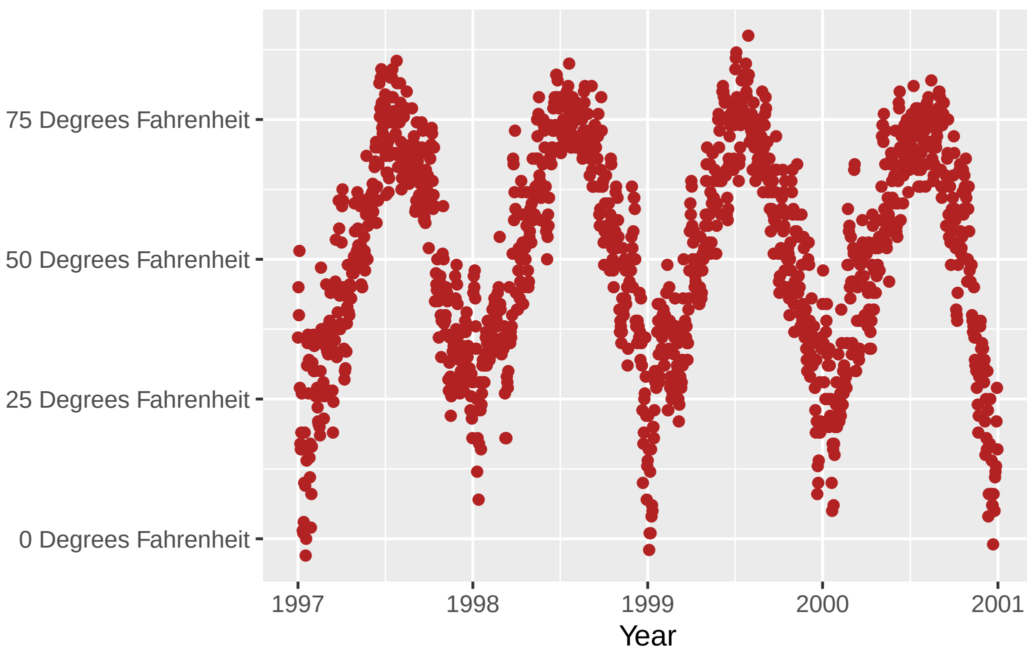
```
Warning: Removed 62 rows containing missing values or values outside the scale range
(`geom_point()`).
```



4.11 Using a Function to Alter Labels

Occasionally, it's useful to slightly modify your labels, such as adding units or percent signs, without altering your underlying data. You can achieve this using a function:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = NULL) +
  scale_y_continuous(label = function(x) {return(paste(x, "Degrees Fahrenheit"))})
```

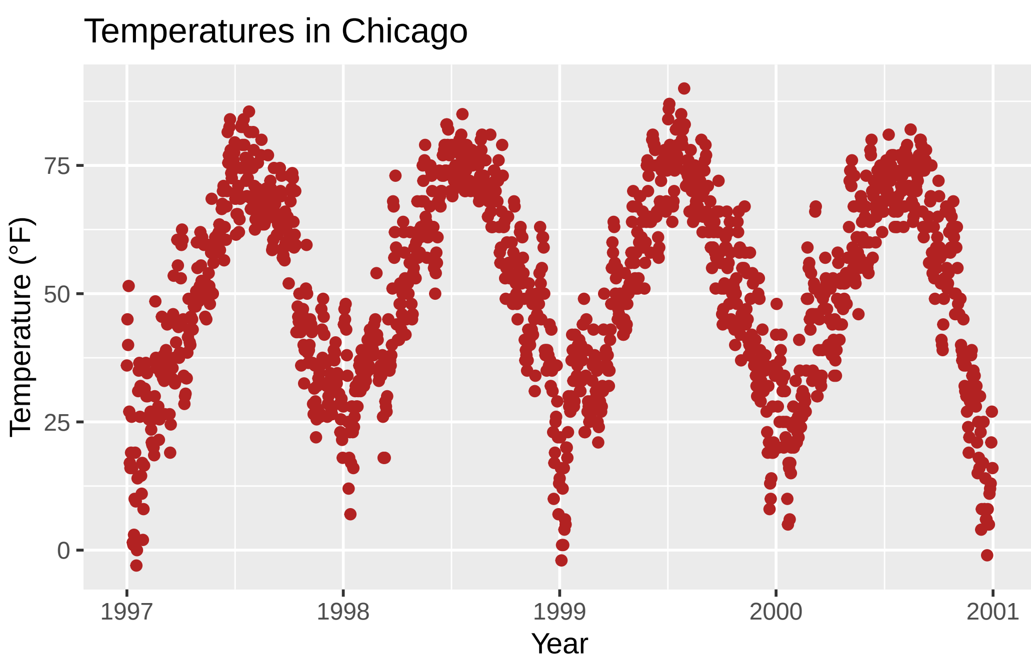


5 Working with Titles

5.1 Add a Title

We can add a title by using the `ggtitle()` function:

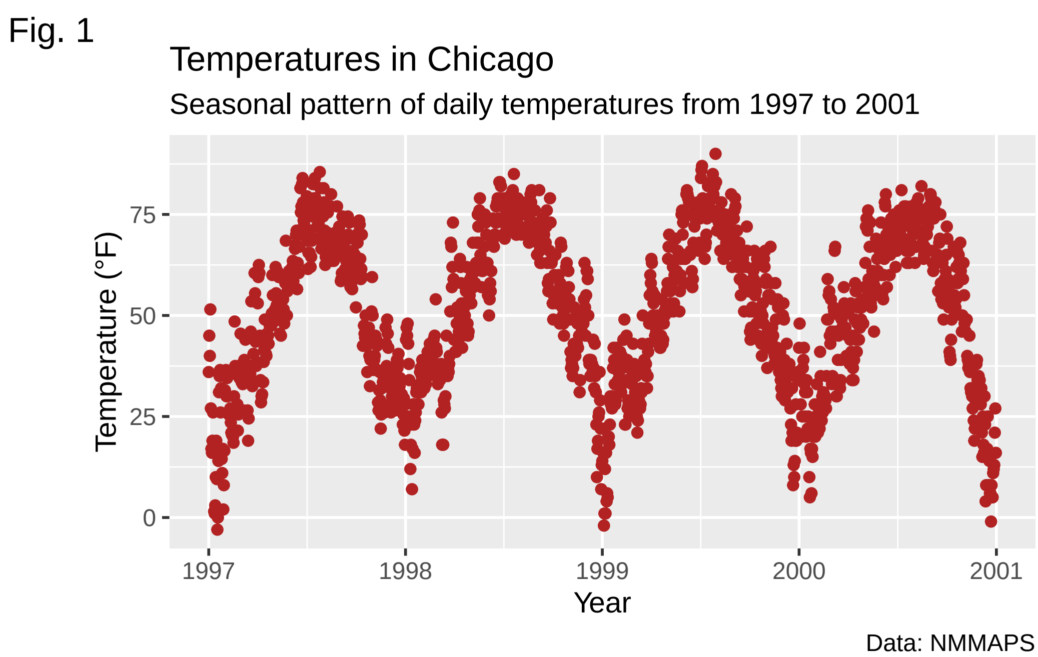
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  ggtitle("Temperatures in Chicago")
```



Alternatively, you can utilize `labs()`. Here, you can include multiple arguments, such as a subtitle, a caption, and a tag, in addition to axis titles as demonstrated earlier:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)",
       title = "Temperatures in Chicago",
       subtitle = "Seasonal pattern of daily temperatures from 1997 to 2001",
```

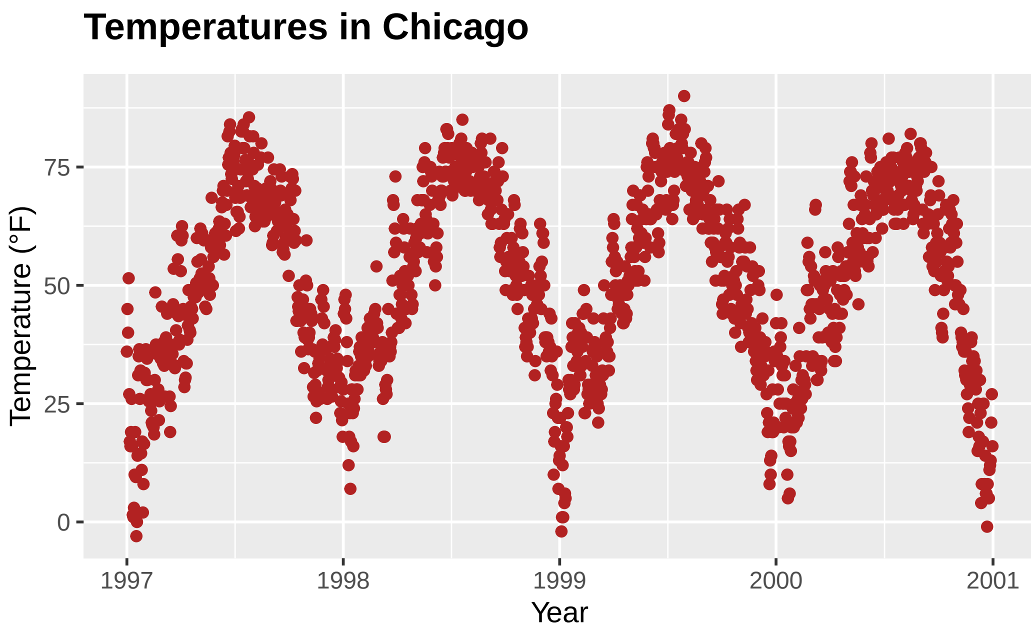
```
      caption = "Data: NMMAPS",
      tag = "Fig. 1")
```



5.2 Making Title Bold & Adding a Space at the Baseline

Once again, to adjust the properties of a theme element, we employ the `theme()` function. Similar to modifying text elements like `axis.title` and `axis.text`, we can alter the font face and margin for the title. These modifications apply not only to the title but also to other labels such as `plot.subtitle`, `plot.caption`, `plot.tag`, `legend.title`, `legend.text`, `axis.title`, and `axis.text`.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)",
       title = "Temperatures in Chicago") +
  theme(plot.title = element_text(face = "bold",
                                  margin = margin(10, 0, 10, 0),
                                  size = 14))
```



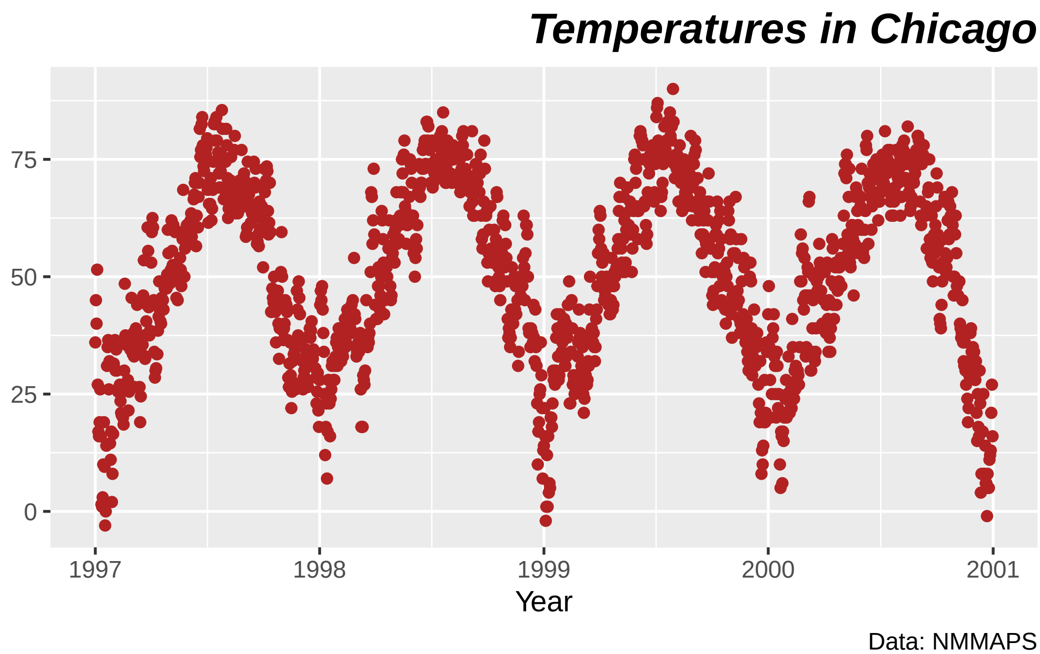
Having trouble with Margins?

A helpful mnemonic for remembering the order of the margin sides is "*t*-*r*-ou-*b*-*l*-e".

5.3 Adjusting Position of Titles

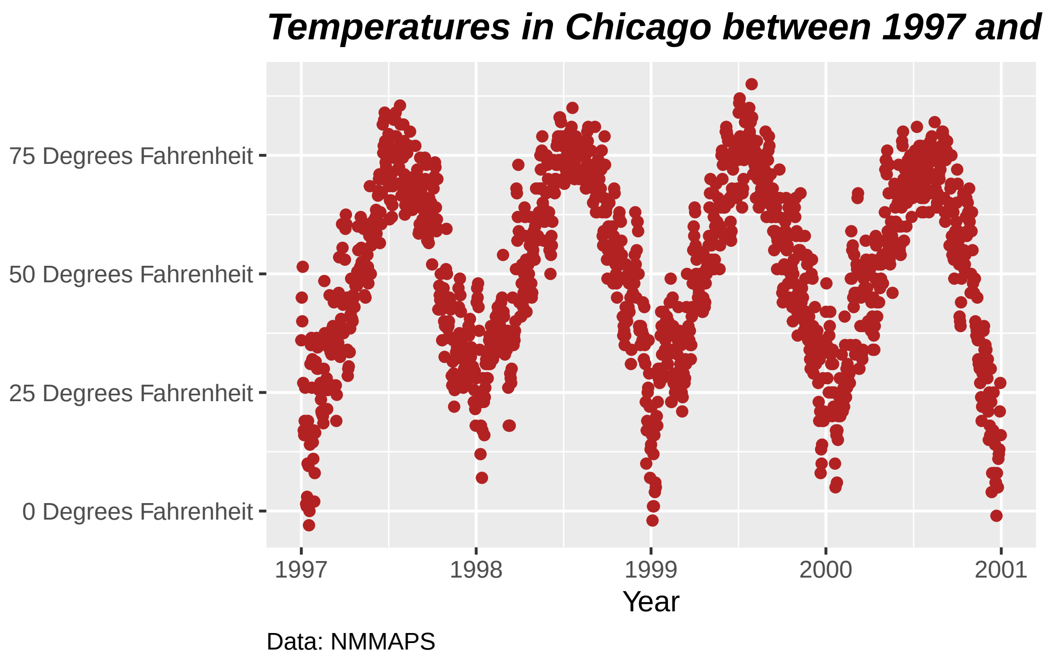
The general alignment (left, center, right) is controlled by `hjust` (horizontal adjustment):

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = NULL,
       title = "Temperatures in Chicago",
       caption = "Data: NMMAPS") +
  theme(plot.title = element_text(hjust = 1, size = 16, face = "bold.italic"))
```

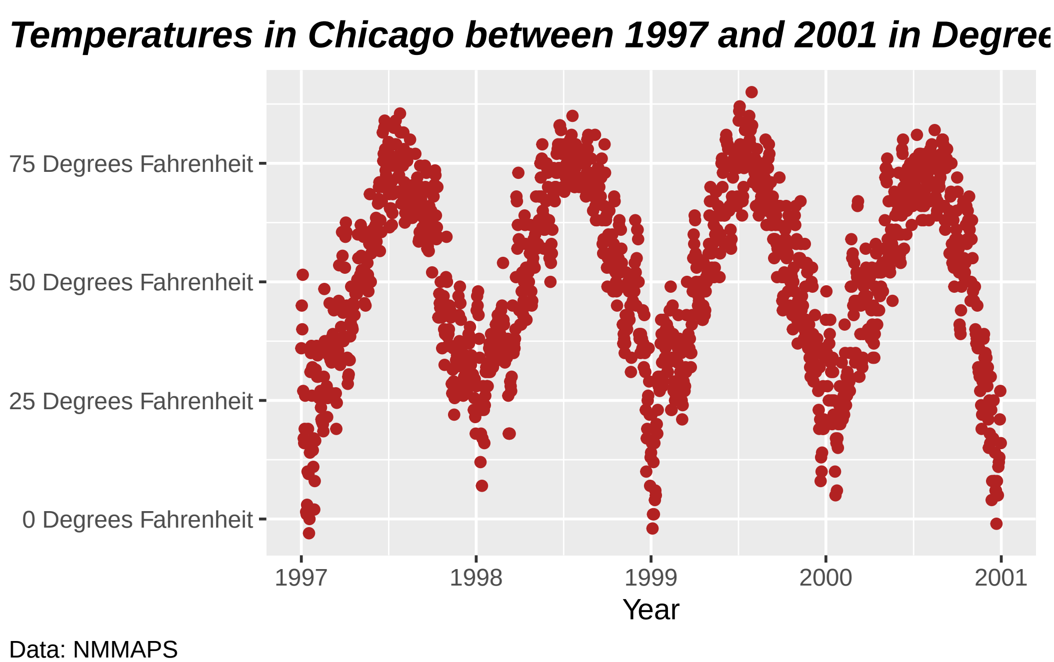


Certainly, it's also possible to adjust the vertical alignment, which is controlled by `vjust`. Since 2019, users have been able to specify the alignment of the title, subtitle, and caption either based on the panel area (the default) or the plot margin via `plot.title.position` and `plot.caption.position`. The latter is often the preferred choice from a design perspective, as it yields better results in most cases. Many users have expressed satisfaction with this new feature, particularly as it addresses issues with alignment, especially when dealing with very long y-axis labels:

```
(g <- ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  scale_y_continuous(label = function(x) {return(paste(x, "Degrees Fahrenheit"))}) +
  labs(x = "Year", y = NULL,
       title = "Temperatures in Chicago between 1997 and 2001 in Degrees Fahrenheit",
       caption = "Data: NMMAPS") +
  theme(plot.title = element_text(size = 14, face = "bold.italic"),
        plot.caption = element_text(hjust = 0)))
```




```
g + theme(plot.title.position = "plot",
          plot.caption.position = "plot")
```



5.4 Using a Non-Traditional Font in Your Title

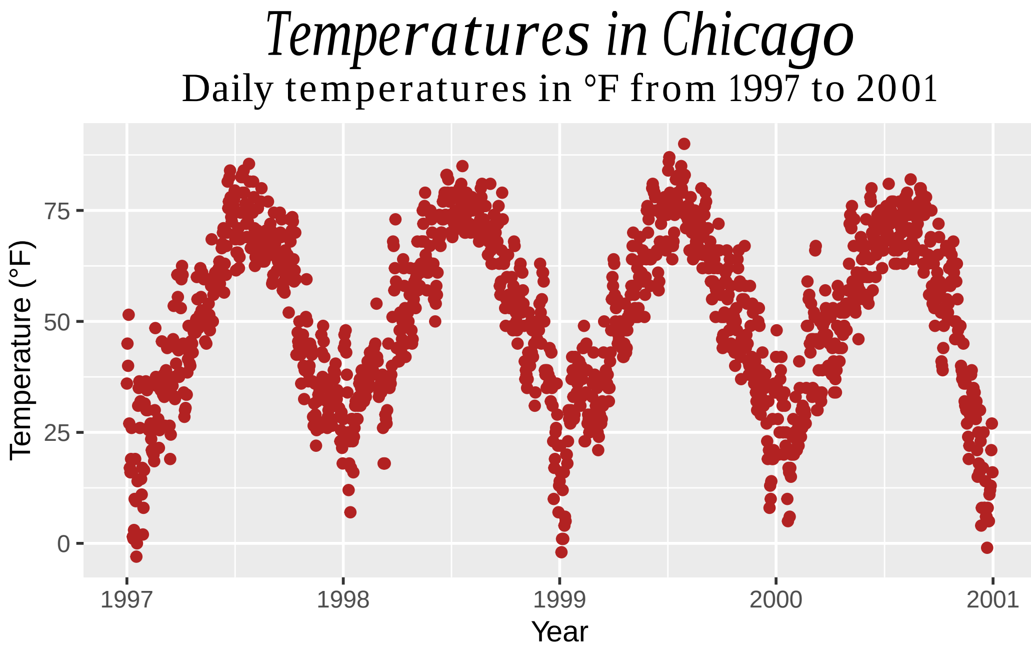
You can incorporate different fonts, not just the default one provided by ggplot (which can vary between operating systems). Several packages facilitate the usage of fonts installed on your machine, such as the showtext package, which simplifies the utilization of various font types (TrueType, OpenType, Type 1, web fonts, etc.) in R plots.

Once the package is loaded, you'll need to import the desired font, which must also be installed on your device. I often utilize Google fonts, which can be imported using the `font_add_google()` function. However, you can add other fonts using `font_add()` as well. It's important to note that even when using Google fonts, you must install the font and restart RStudio to apply it. if you found any warnings after doing all the steps, or the fonts aren't working. Just install `extrafont` package and run `font_import()` function to import all the fonts in your system. and then `loadfonts(device = "win", quiet = TRUE)` to load the fonts. It'll work like a charm. You can also check the available fonts in your system by running `fonts()`.

```
library(showtext)
library(extrafont)
font_add_google("Playfair Display", ## name of Google font
                "Playfair Display")  ## name that will be used in R
font_add_google("Bangers", "Bangers")
loadfonts(device = "win", quiet = TRUE)
```

Now, we can use those font families by `theme()` function:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)",
       title = "Temperatures in Chicago",
       subtitle = "Daily temperatures in °F from 1997 to 2001") +
  theme(plot.title = element_text(family = "Bangers", hjust = .5, size = 25),
        plot.subtitle = element_text(family = "Playfair Display", hjust = .5, size = 15))
```



You can also establish a non-default font for all text elements of your plots. For more details, refer to the section "Working with Themes". In this case, I'll use *Roboto Condensed* as the new font for all subsequent plots.

```
font_add_google("Roboto Condensed", "Roboto Condensed")
theme_set(theme_bw(base_size = 12, base_family = "Roboto Condensed"))
```

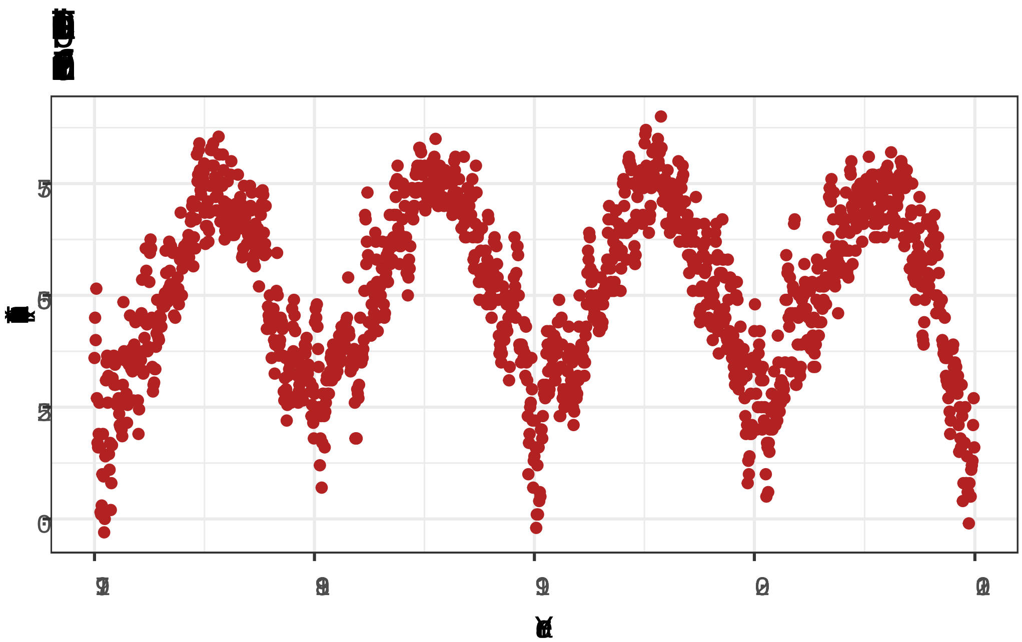
(Previously, this tutorial utilized the `{extrafont}` package, which performed admirably until last year. However, suddenly I encountered issues where I couldn't add any new fonts, and even after acquiring a new laptop, the package failed to detect any fonts altogether. As an alternative, I typically recommend the `{ragg}` package now. However, I encountered difficulties in making it work for my homepage. Therefore, I'm utilizing the `{showtext}` package, which is also excellent, albeit with a key distinction: you need to explicitly import the font you wish to use with `{showtext}`. Nonetheless, it appears that there are some technical challenges that are not optimally resolved by `{showtext}` (as mentioned in this Twitter thread), so you may want to consider using the package only as a last resort.)

5.5 Adjusting Spacing in Multi-Line Text

To modify the spacing between lines, you can utilize the `lineheight` argument. In the following example, I've compressed the lines together (lineheight < 1).

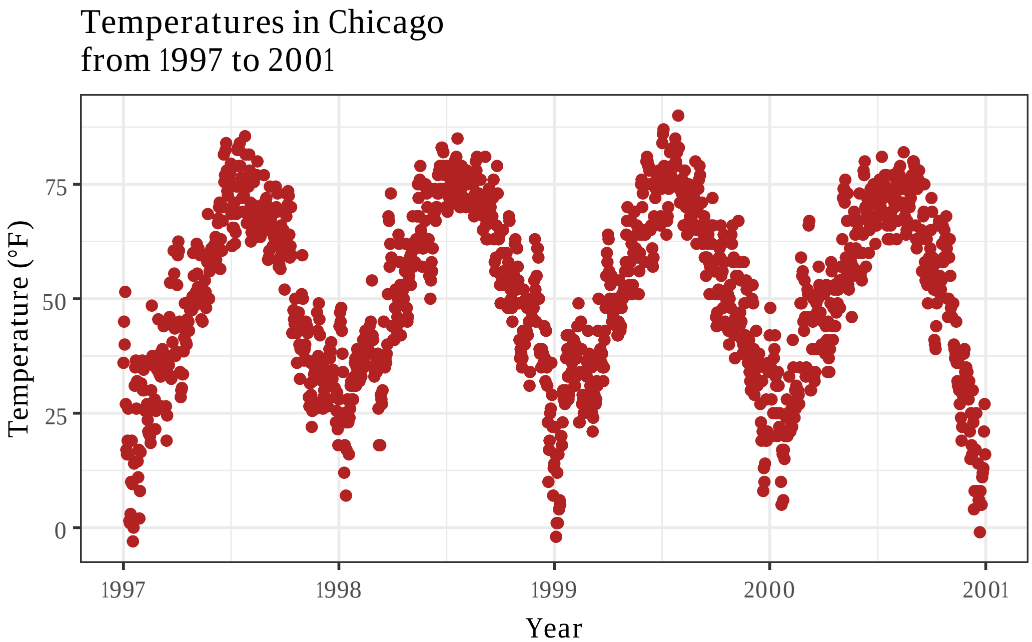
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
```

```
  ggtitle("Temperatures in Chicago\nfrom 1997 to 2001") +
  theme(plot.title = element_text(lineheight = .8, size = 16))
```



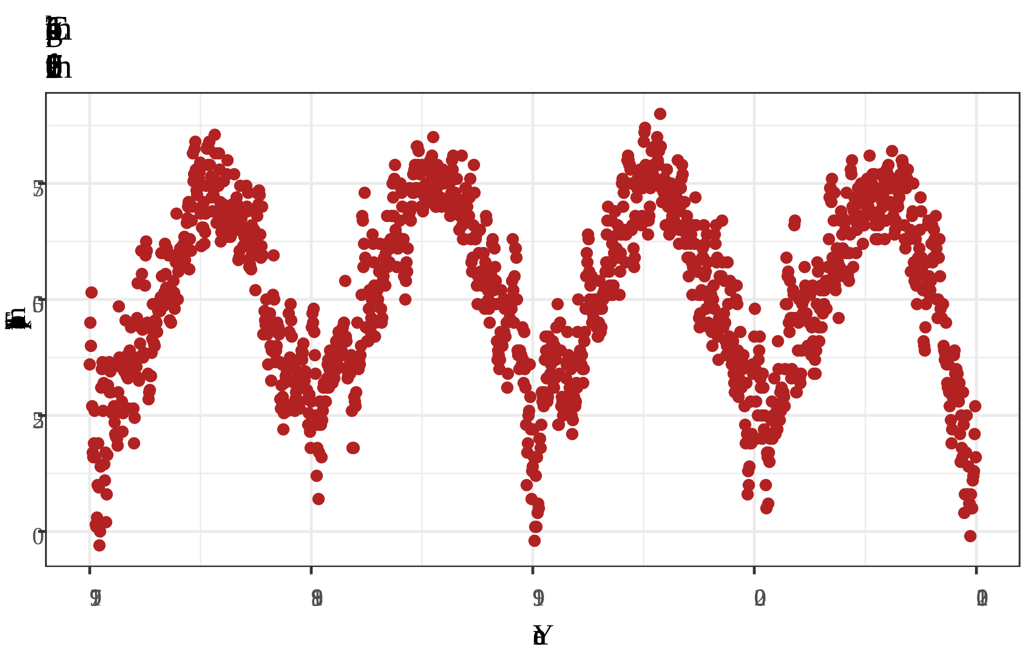
Now You can Change fonts on the fly!

```
ggplot(chic, aes(x = date, y = temp)) +
    geom_point(color = "firebrick") +
    labs(x = "Year", y = "Temperature (°F)") +
    ggtitle("Temperatures in Chicago\nfrom 1997 to 2001") +
    theme_bw(base_family = "Berkshire Swash")
```



Or, Change it to Traditional `Times New Roman`:

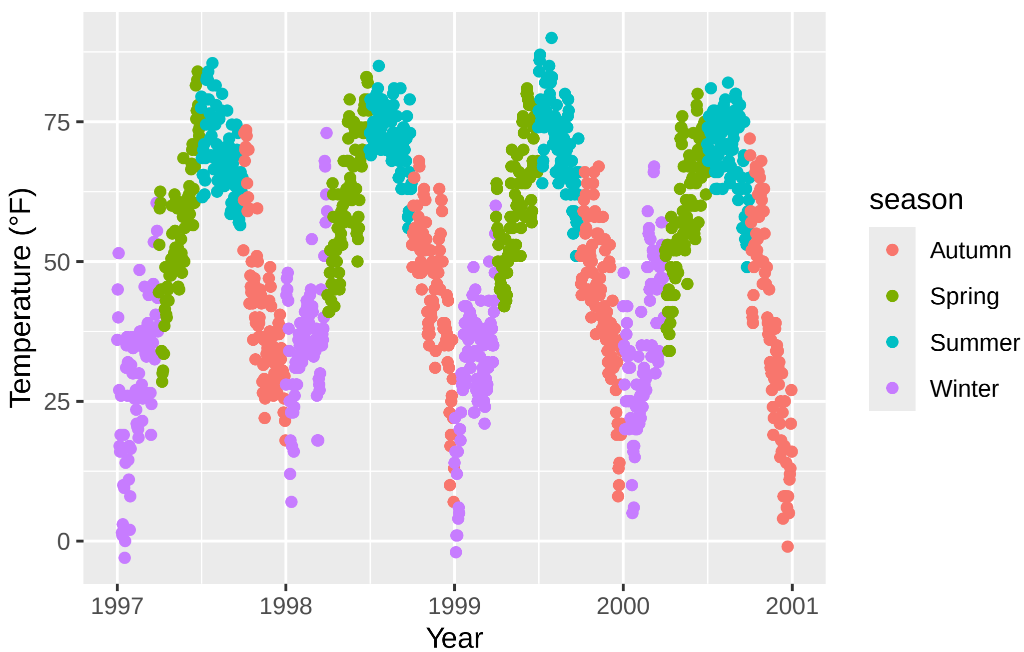
```
ggplot(chic, aes(x = date, y = temp)) +
    geom_point(color = "firebrick") +
    labs(x = "Year", y = "Temperature (°F)") +
    ggtitle("Temperatures in Chicago\nfrom 1997 to 2001") +
    theme_bw(base_family = "Times New Roman")
```



6 Working with Legends

In this section, we will color code the plot based on the season. Or, to phrase it more in the style of ggplot: we'll map the variable `season` to the aesthetic `color`. One of the advantages of `{ggplot2}` is that it automatically adds a legend when mapping a variable to an aesthetic. As a result, the legend title defaults to what we specified in the color argument:

```
ggplot(chic,
       aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)")
```

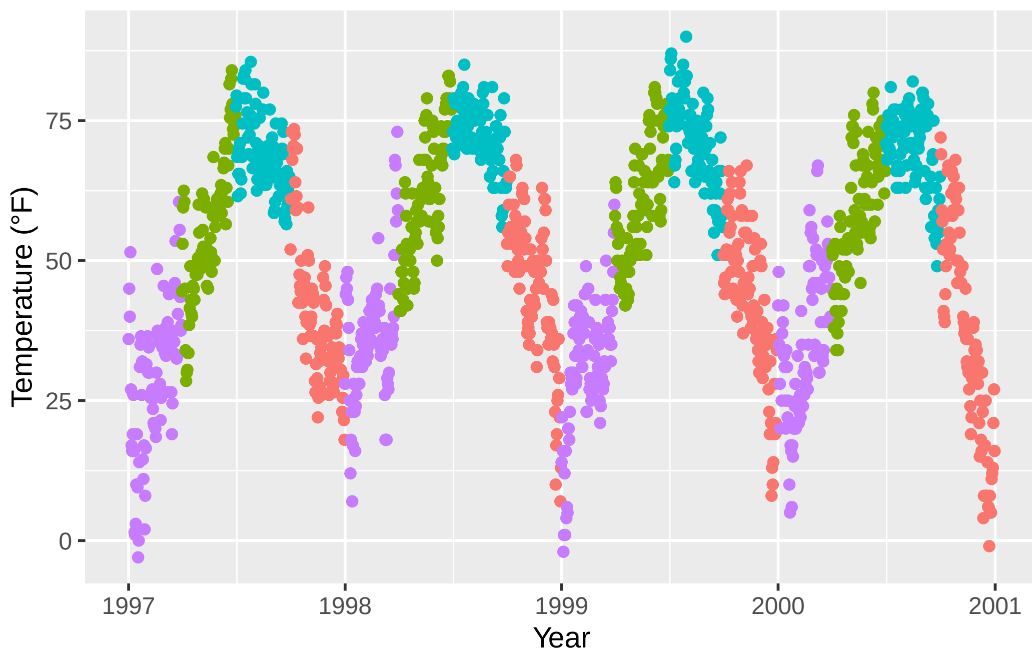


6.1 Disabling the Legend

One of the most common questions is: "How do I remove the legend?"

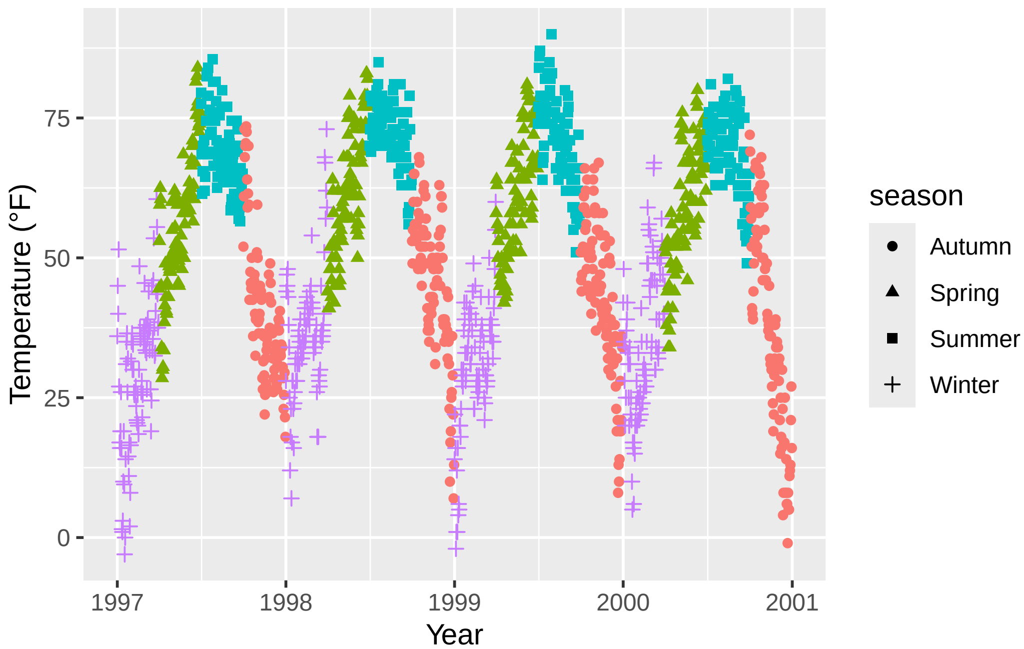
It's quite straightforward and always effective with `theme(legend.position = "none")`:

```
ggplot(chic,
       aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.position = "none")
```



You can also utilize `guides(color = "none")` or `scale_color_discrete(guide = "none")`, depending on the specific case. While altering the theme element removes all legends at once, you can selectively remove specific legends using the latter options while keeping others:

```
ggplot(chic,
       aes(x = date, y = temp,
           color = season, shape = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  guides(color = "none")
```

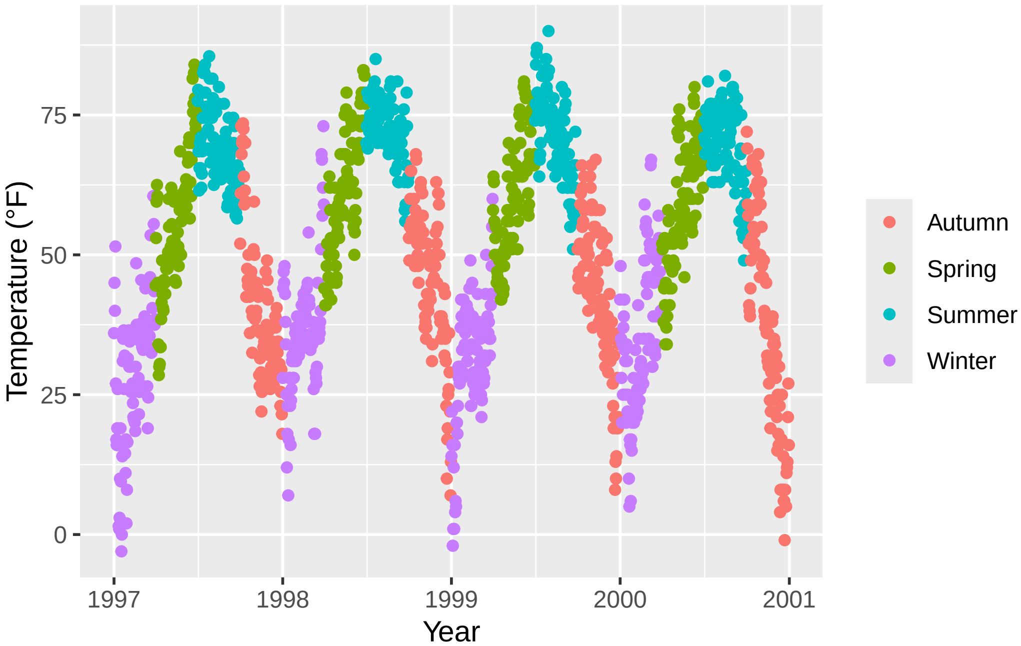


Here, for example, we retain the legend for the shapes while discarding the one for the colors.

6.2 Eliminating Legend Titles

As we've previously learned, utilize `element_blank()` to render *nothing*:

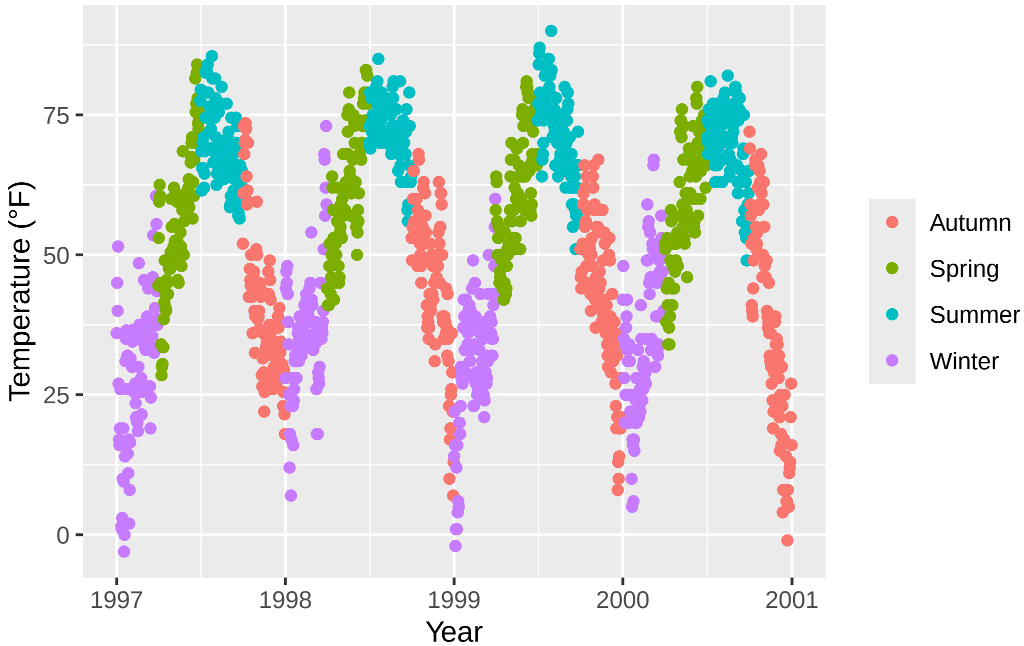
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.title = element_blank())
```



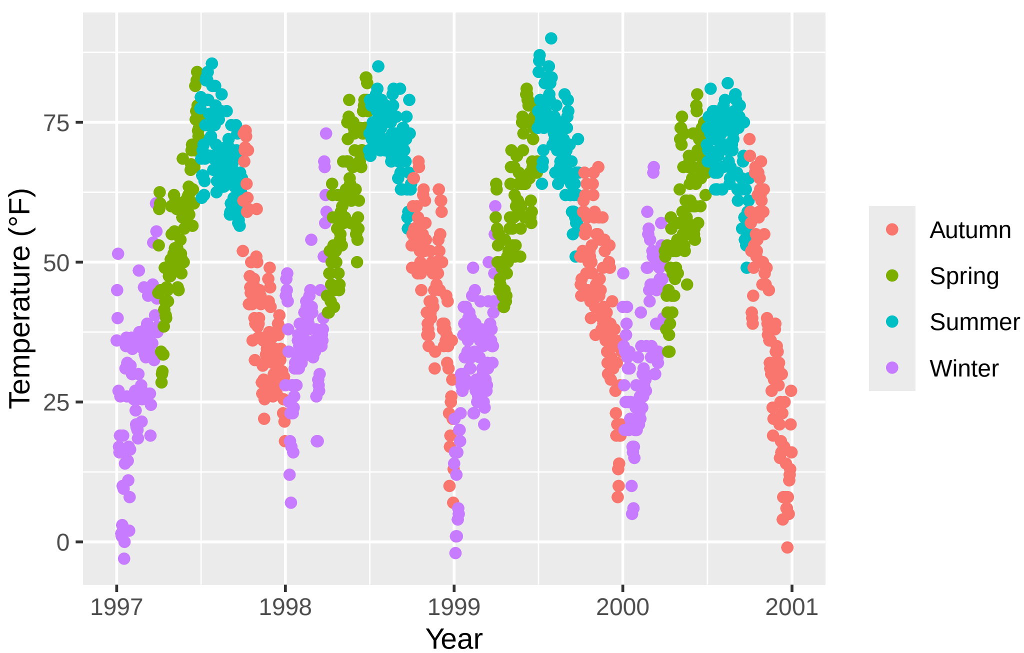
Other Ways to remove Legend Titles

You can achieve the same outcome by setting the legend name to `NULL`, either through `scale_color_discrete(name = NULL)` or `labs(color = NULL)`. Expand to see examples.

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  scale_color_discrete(name = NULL)
```



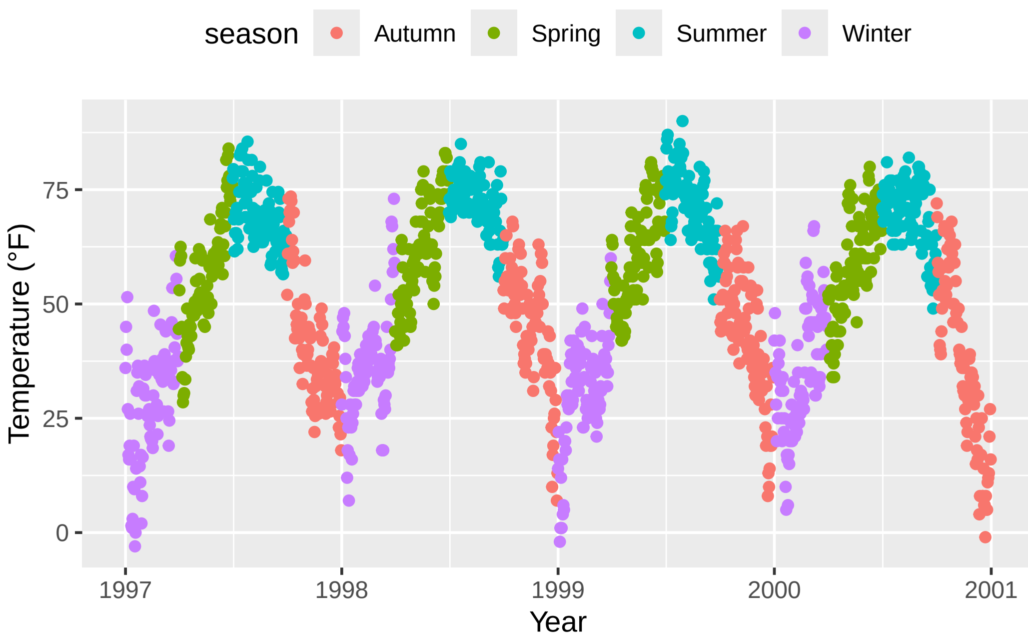

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  labs(color = NULL)
```



6.3 Adjusting Legend Position

To relocate the legend from its default position on the right side, you can use the `legend.position` argument within `theme`. Available positions include "top", "right" (the default), "bottom", and "left".

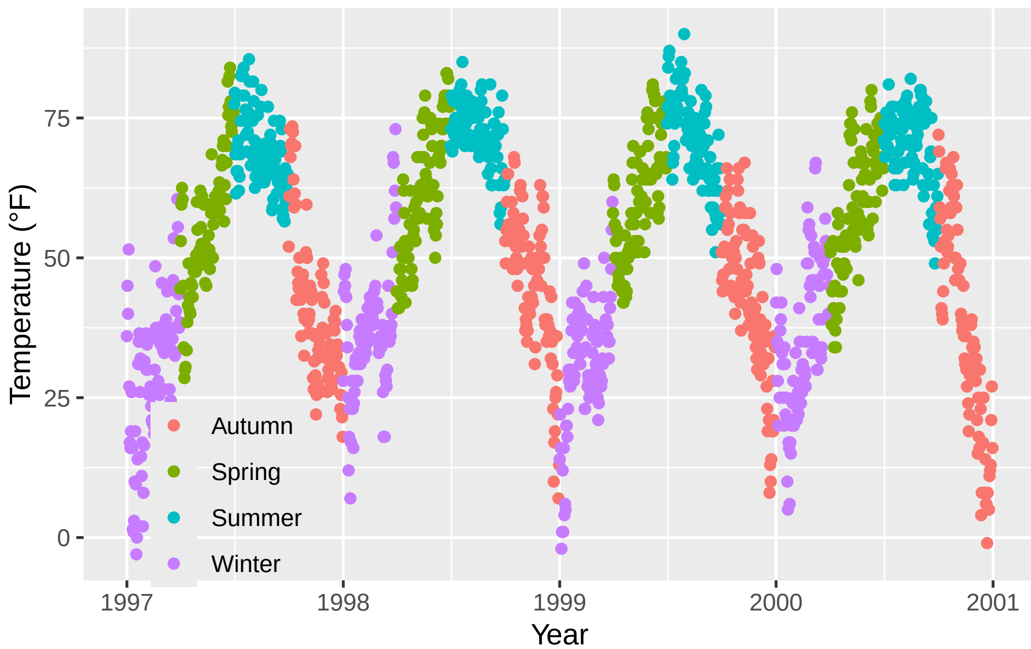
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.position = "top")
```



You can also position the legend inside the panel by specifying a vector with relative x and y coordinates ranging from 0 (left or bottom) to 1 (right or top):

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)",
       color = NULL) +
  theme(legend.position = c(.15, .15),
        legend.background = element_rect(fill = "transparent"))
```

```
Warning: A numeric `legend.position` argument in `theme()` was deprecated in ggplot2
3.5.0.
i Please use the `legend.position.inside` argument of `theme()` instead.
```

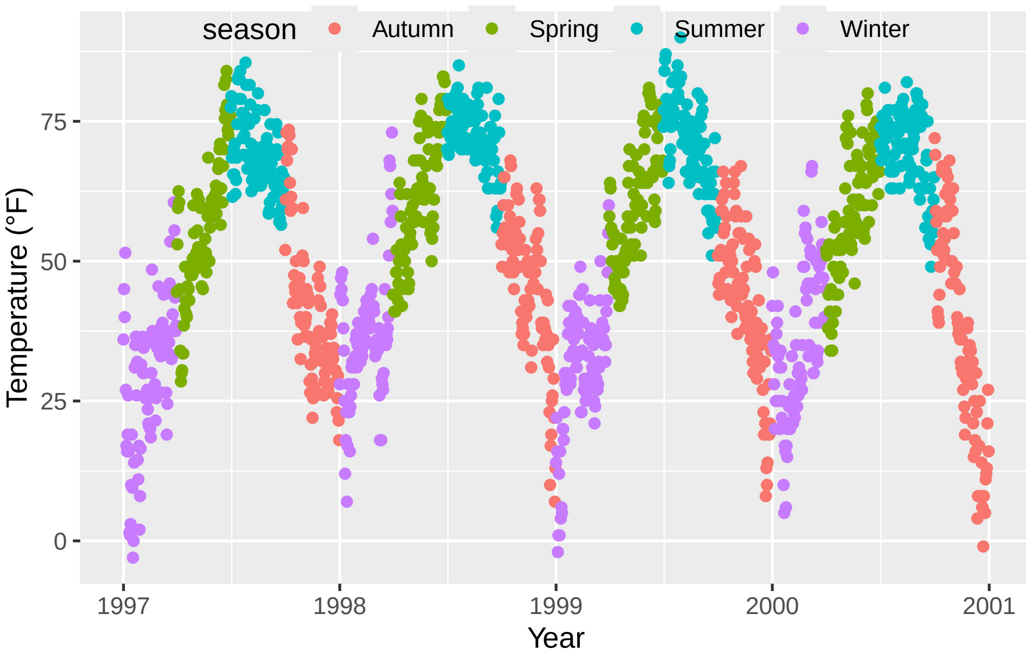


Here, I also override the default white legend background with a transparent fill to ensure the legend doesn't obscure any data points.

6.4 Modifying Legend Direction

By default, the legend direction is vertical. However, when you select either the "top" or "bottom" position, it becomes horizontal. Nevertheless, you can freely switch the direction as desired:

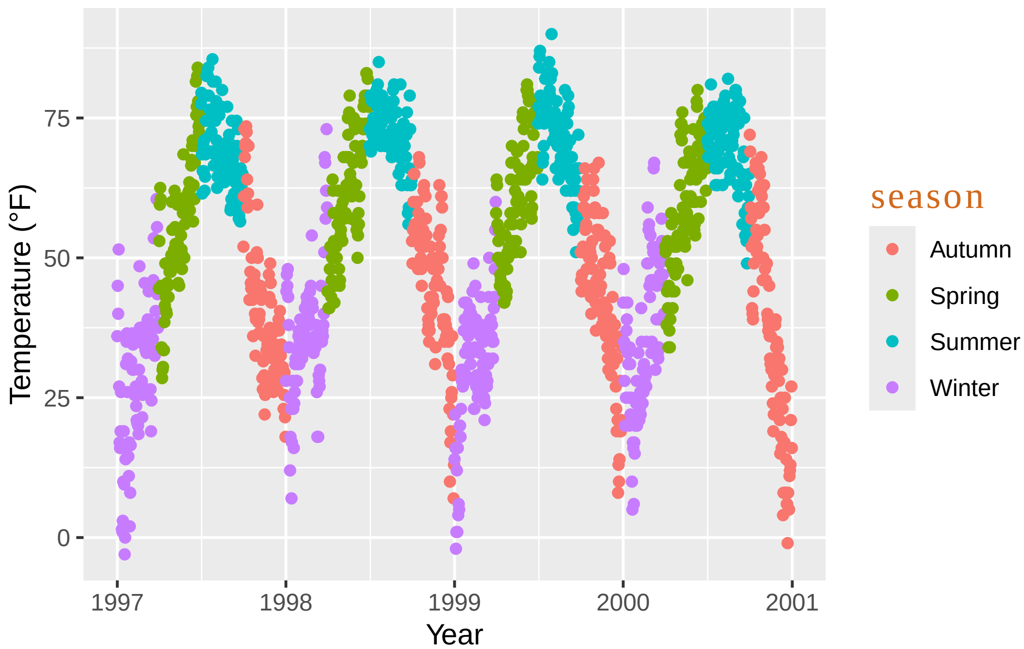
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.position = c(.5, .97),
        legend.background = element_rect(fill = "transparent")) +
  guides(color = guide_legend(direction = "horizontal"))
```



6.5 Change Style of the Legend Title

You can customize the appearance of the legend title by adjusting the theme element `legend.title`:

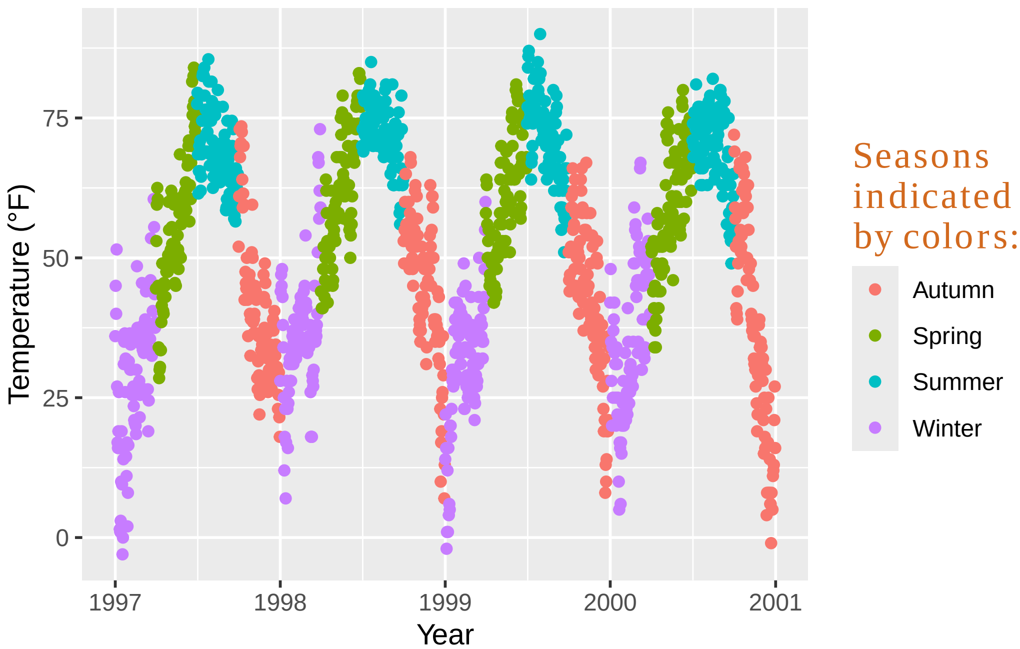
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.title = element_text(family = "Playfair Display",
                                    color = "chocolate",
                                    size = 14, face = "bold"))
```



6.6 Modifying Legend Title

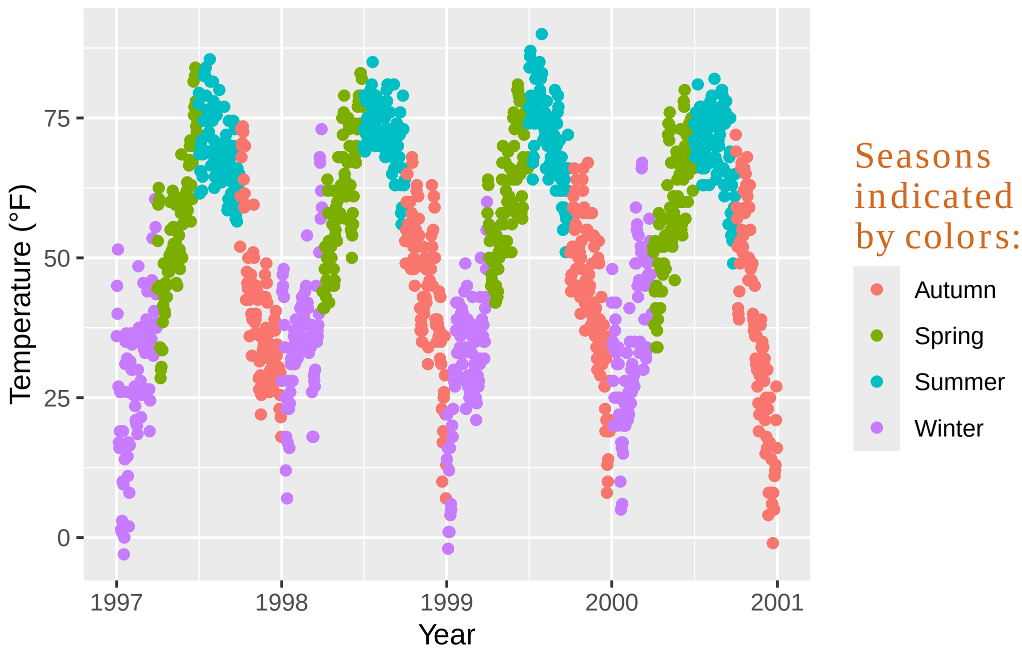
The simplest method to change the title of the legend is through the `labs()` layer:

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)",
       color = "Seasons\nindicated\nby colors:") +
  theme(legend.title = element_text(family = "Playfair Display",
                                    color = "chocolate",
                                    size = 14, face = "bold"))
```



You can adjust the legend details using `scale_color_discrete(name = "title")` or `guides(color = guide_legend("title"))`:

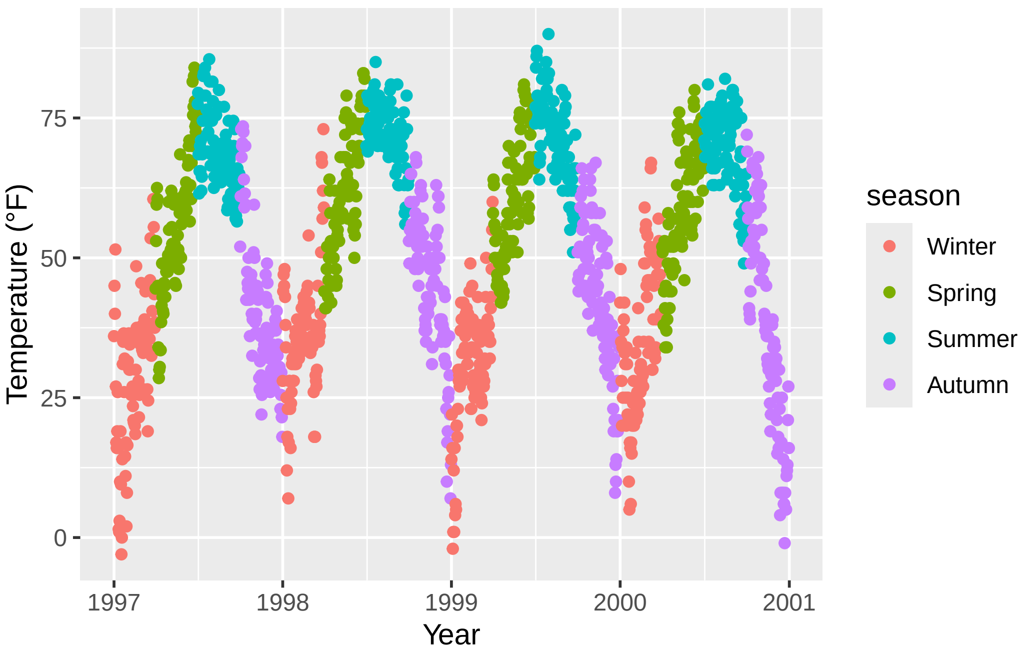
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.title = element_text(family = "Playfair Display",
                                    color = "chocolate",
                                    size = 14, face = "bold")) +
  scale_color_discrete(name = "Seasons\nindicated\nby colors:")
```



6.7 Rearrange Order of Legend Keys

This can be accomplished by changing the levels of `season`:

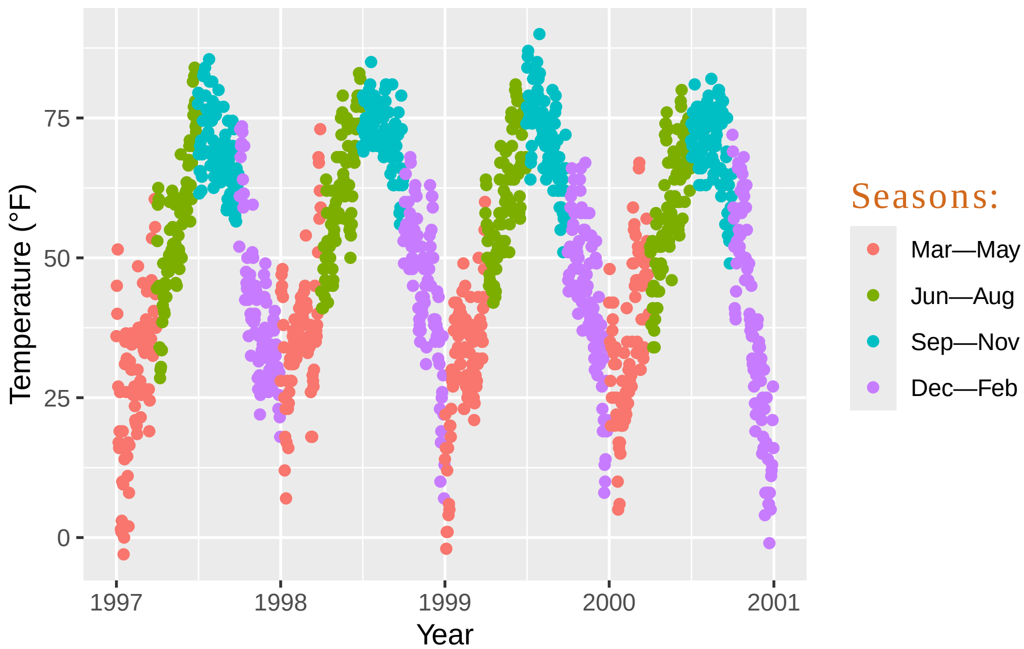
```
chic$season <-
  factor(chic$season,
         levels = c("Winter", "Spring", "Summer", "Autumn"))

ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)")
```



6.8 Modify Legend Labels

To replace the seasons with the months they represent, provide a vector of names in the `scale_color_discrete()` call:

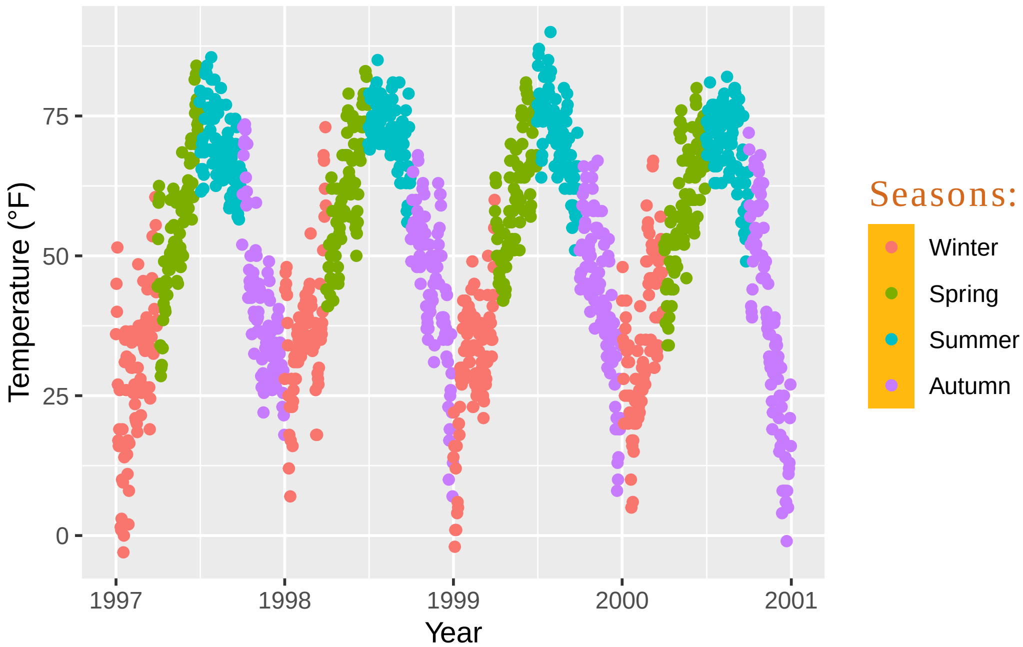
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  scale_color_discrete(
    name = "Seasons:",
    labels = c("Mar—May", "Jun—Aug", "Sep—Nov", "Dec—Feb")
  ) +
  theme(legend.title = element_text(
    family = "Playfair Display", color = "chocolate", size = 14, face = 2
  ))
```



6.9 Adjust Background Boxes in the Legend

To alter the background color (fill) of the legend keys, we modify the setting for the theme element `legend.key`:

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.key = element_rect(fill = "darkgoldenrod1"),
        legend.title = element_text(family = "Playfair Display",
                                    color = "chocolate",
                                    size = 14, face = 2)) +
  scale_color_discrete("Seasons:")
```

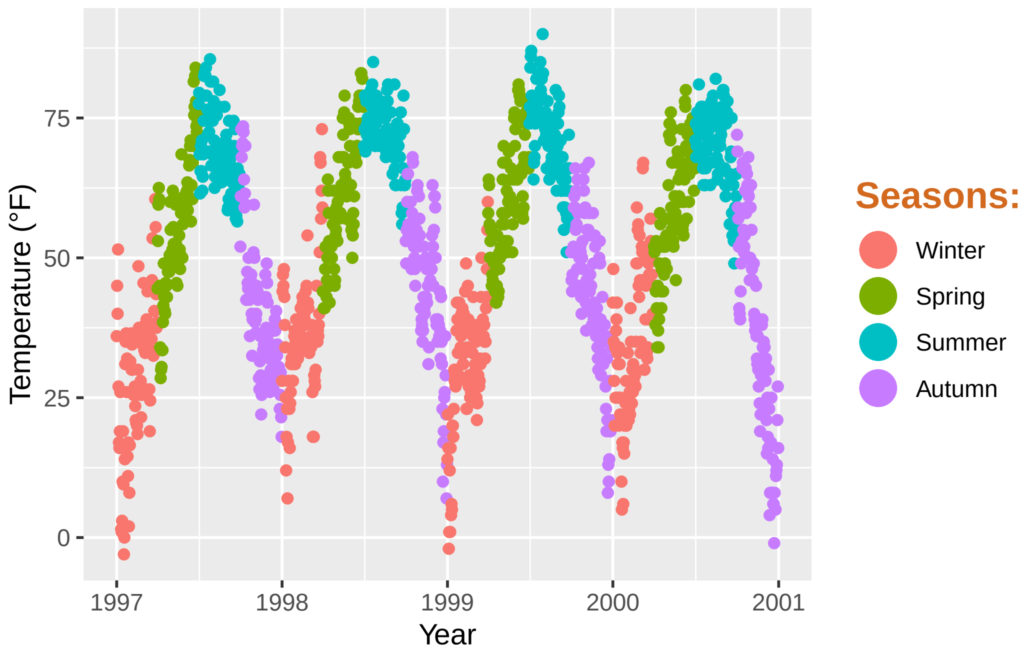


If you wish to remove them entirely, use `fill = NA` or `fill = "transparent"`.

6.10 Adjust Size of Legend Symbols

The default size of points in the legend may cause them to appear too small, especially without boxes. To modify this, you can again use the `guides` layer as follows:

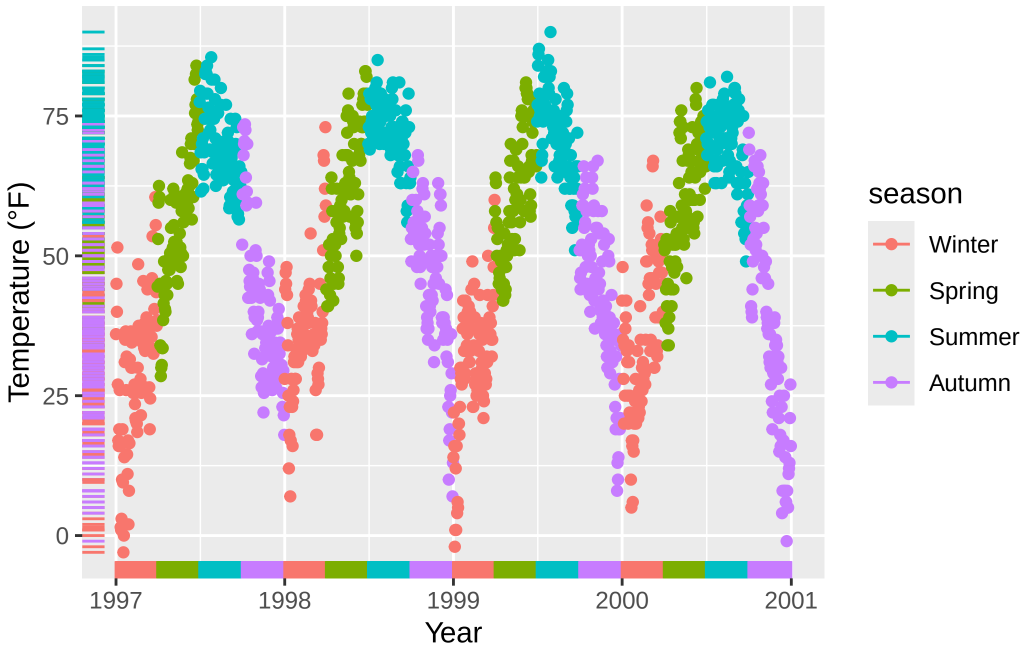
```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.key = element_rect(fill = NA),
        legend.title = element_text(color = "chocolate",
                                    size = 14, face = 2)) +
  scale_color_discrete("Seasons:") +
  guides(color = guide_legend(override.aes = list(size = 6)))
```



6.11 Exclude a Layer from the Legend

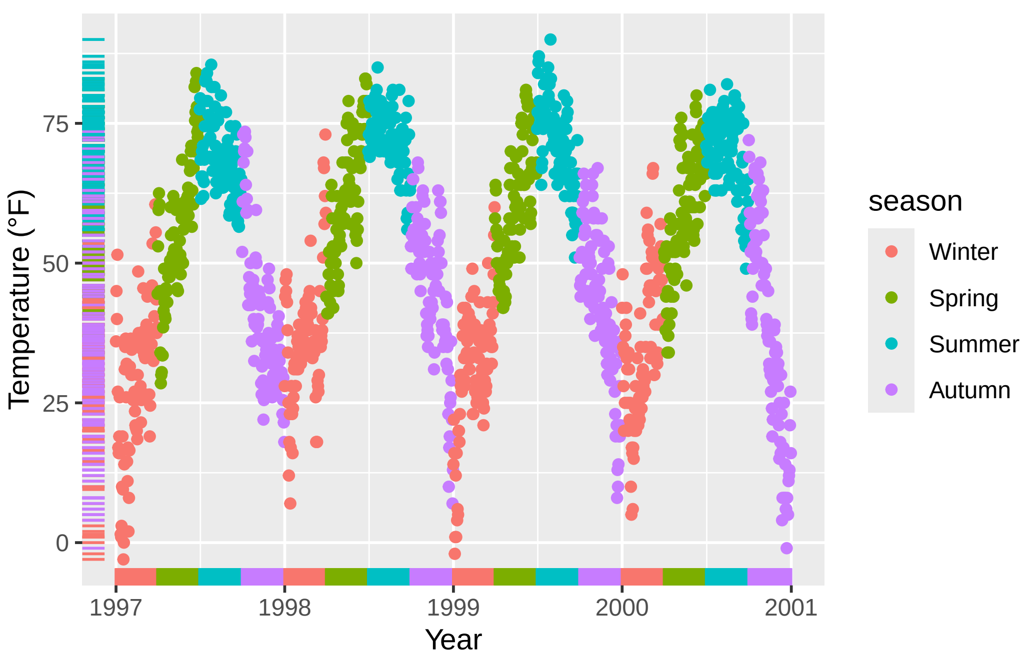
Suppose you have two different geometric layers mapped to the same variable, such as color being used as an aesthetic for both a point layer and a rug layer of the same data. By default, both the points and the "line" end up in the legend like this:

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  geom_rug()
```



You can utilize `show.legend = FALSE` to exclude a layer from the legend:

```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  geom_rug(show.legend = FALSE)
```

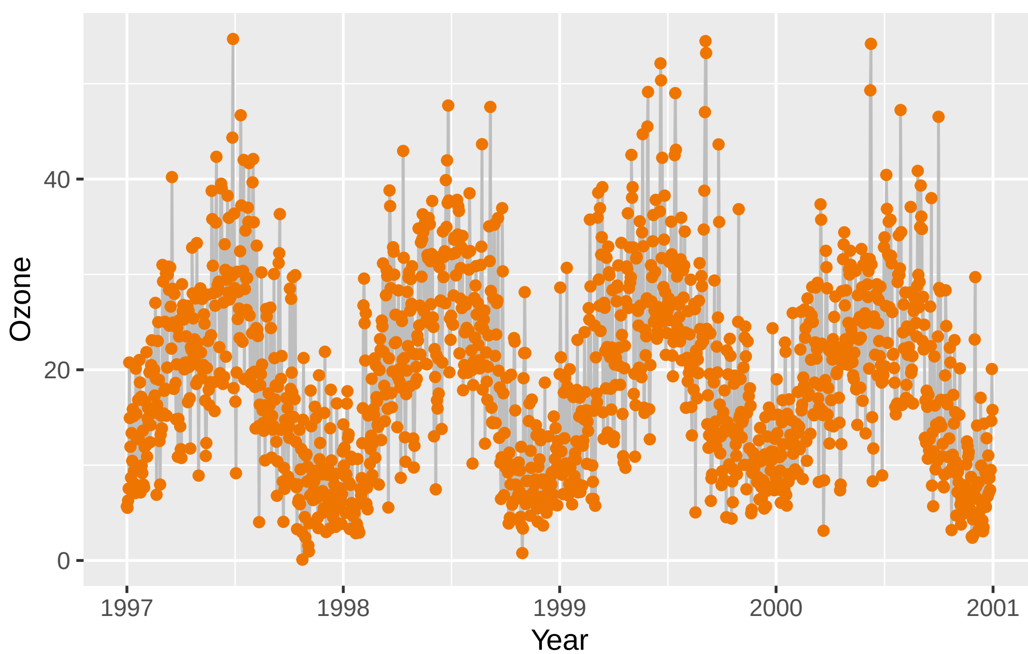


6.12 Manually Adding Legend Items

By default, `{ggplot2}` won't add a legend unless you map aesthetics (color, size, etc.) to a variable. However, there are occasions where you may want to include a legend for clarity.

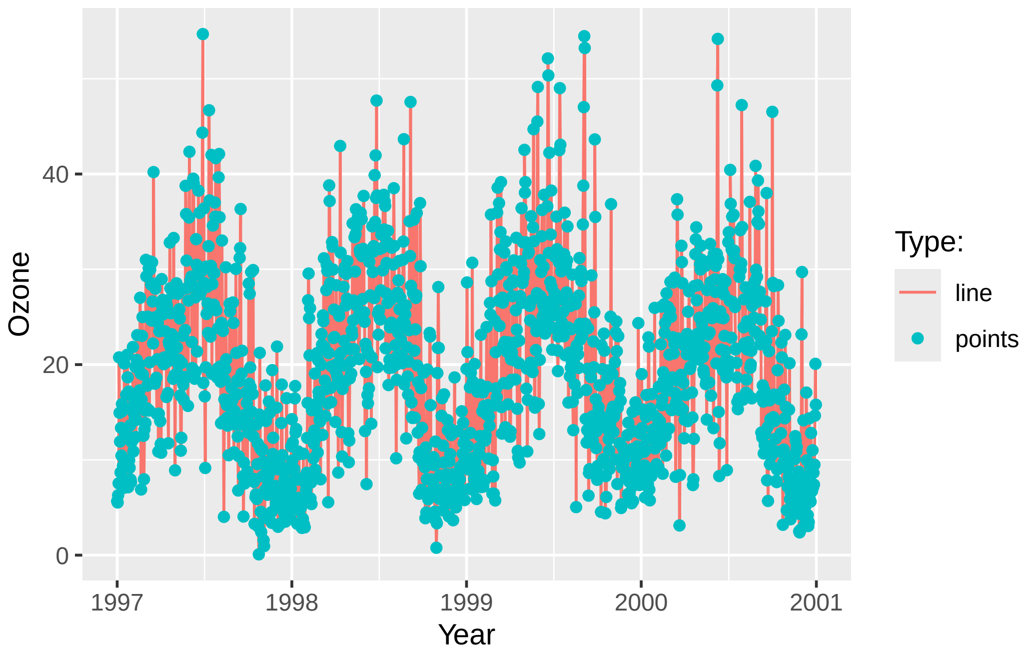
Here's the default behavior:

```
ggplot(chic, aes(x = date, y = o3)) +
  geom_line(color = "gray") +
  geom_point(color = "darkorange2") +
  labs(x = "Year", y = "Ozone")
```



To force a legend, we can map a guide to a *variable*. Here, we're mapping the lines and the points using `aes()`, but we're not mapping to a variable in our dataset. Instead, we're using a single string for each, ensuring we get just one color for each.

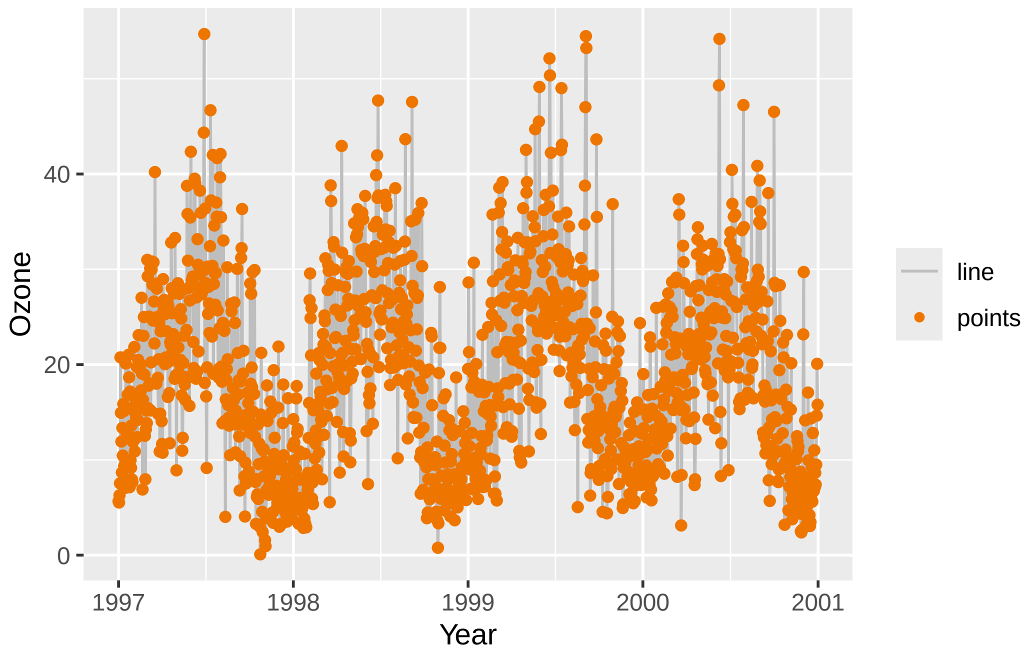
```
ggplot(chic, aes(x = date, y = o3)) +
  geom_line(aes(color = "line")) +
  geom_point(aes(color = "points")) +
  labs(x = "Year", y = "Ozone") +
  scale_color_discrete("Type:")
```



We're getting close, but this is not what we want. We desire gray lines and red points. To change the colors, we use `scale_color_manual()`. Additionally, we override the legend aesthetics using the `guide()` function.

Now, we have a plot with gray lines and red points, as well as a single gray line and a single red point as legend symbols.

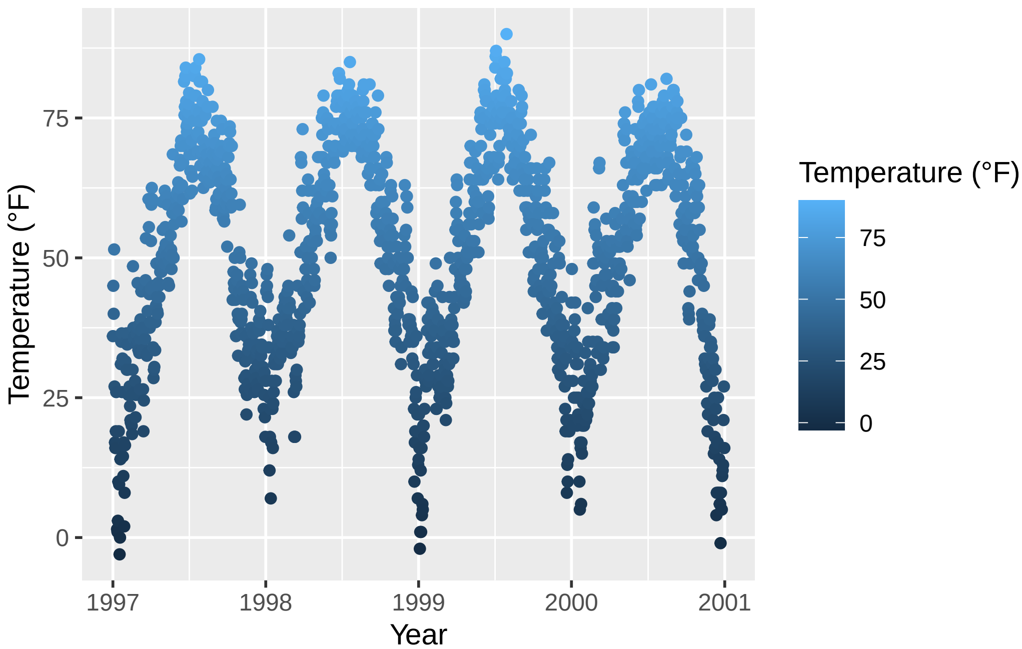
```
ggplot(chic, aes(x = date, y = o3)) +
  geom_line(aes(color = "line")) +
  geom_point(aes(color = "points")) +
  labs(x = "Year", y = "Ozone") +
  scale_color_manual(name = NULL,
                     guide = "legend",
                     values = c("points" = "darkorange2",
                                "line" = "gray")) +
  guides(color = guide_legend(override.aes = list(linetype = c(1, 0),
                                                  shape = c(NA, 16))))
```



6.13 Use Other Legend Styles

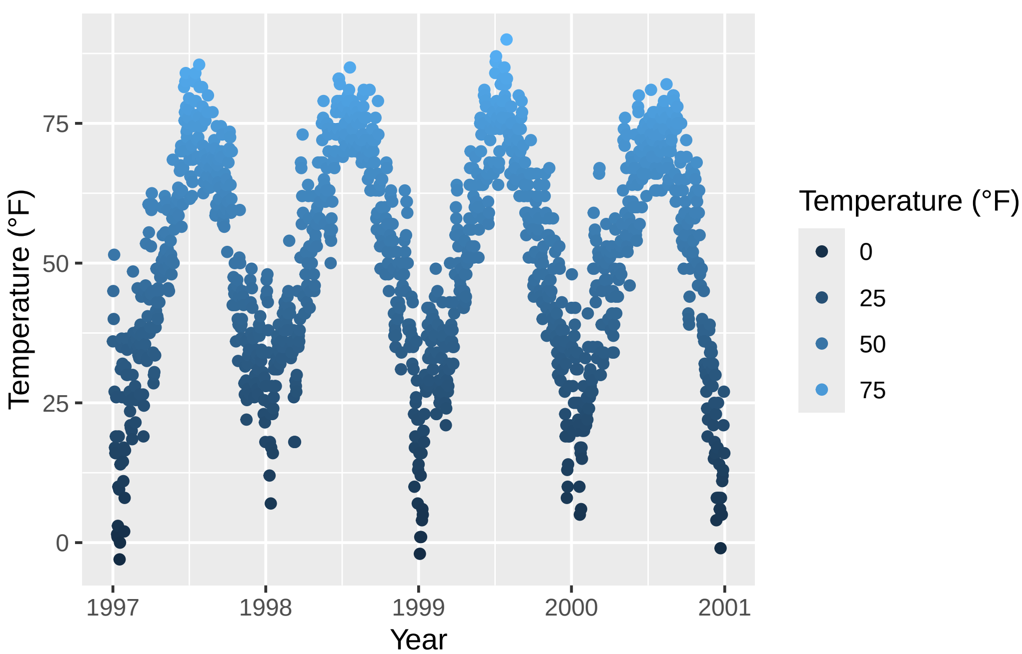
The default legend for categorical variables such as `season` is a `guide_legend()`, as you have seen in several previous examples. However, if you map a continuous variable to an aesthetic, `{ggplot2}` will by default not use `guide_legend()` but `guide_colorbar()` (or `guide_colourbar()`).

```
ggplot(chic,
       aes(x = date, y = temp, color = temp)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = "Temperature (°F)")
```



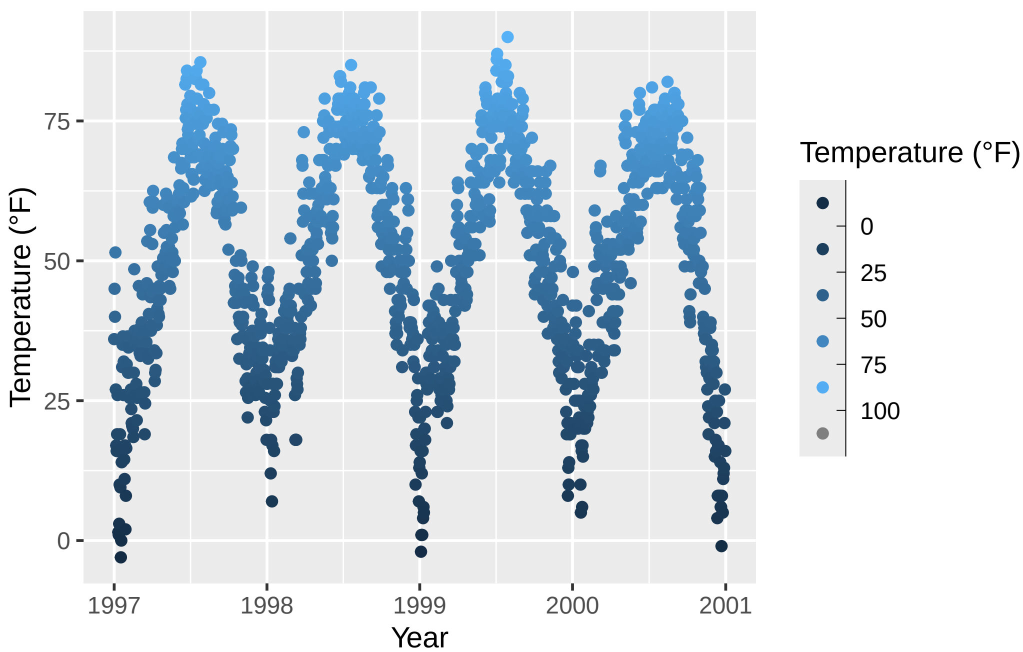
However, by using `guide_legend()`, you can force the legend to display discrete colors for a given number of breaks as in the case of a categorical variable:

```
ggplot(chic,
       aes(x = date, y = temp, color = temp)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = "Temperature (°F)") +
  guides(color = guide_legend())
```



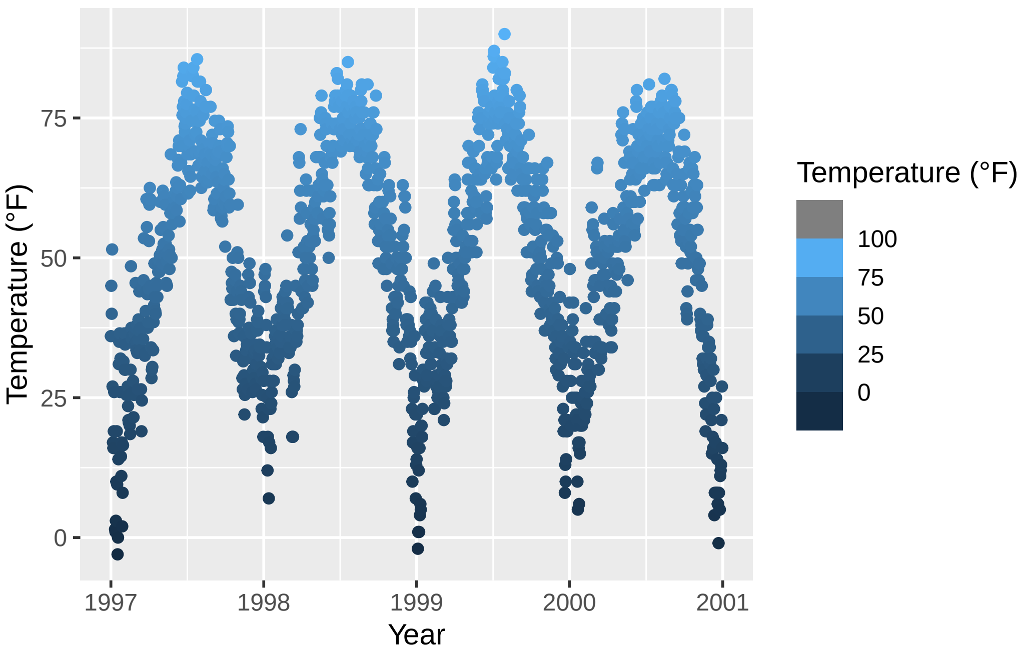
You can also utilize binned scales:

```
ggplot(chic,
       aes(x = date, y = temp, color = temp)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = "Temperature (°F)") +
  guides(color = guide_bins())
```



... or binned scales as discrete colorbars:

```
ggplot(chic,
       aes(x = date, y = temp, color = temp)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = "Temperature (°F)") +
  guides(color = guide_colorsteps())
```


Temperature (°F)
75
50
25
0
1997
1998
1999
2000
2001
Year
Temperature (°F)
100
75
50
25
0

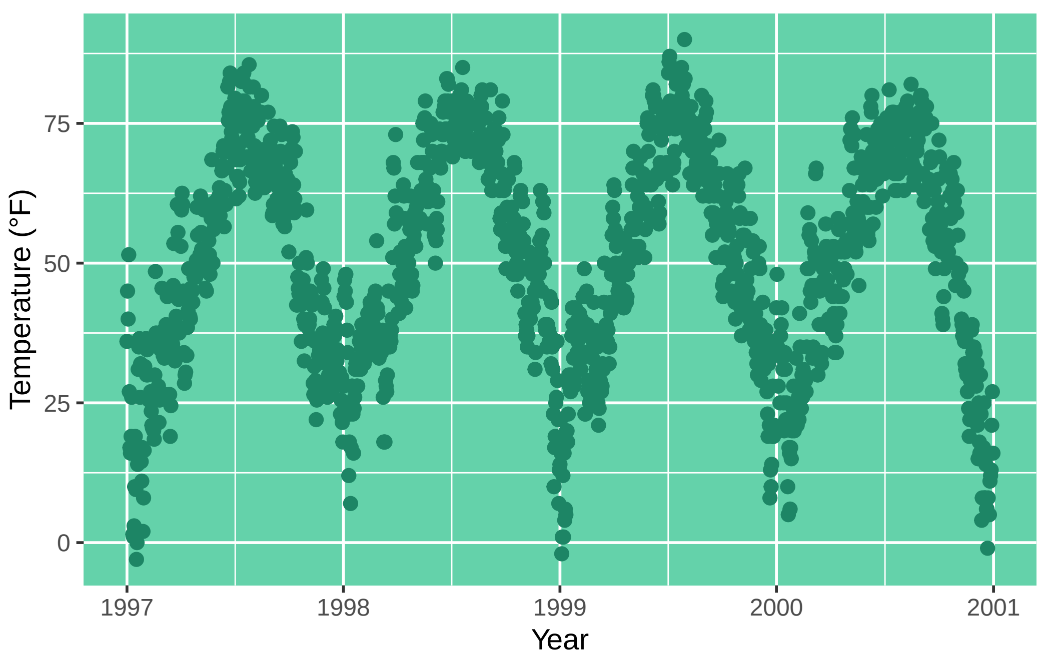
7 Working with Backgrounds & Grid Lines

To modify the overall appearance of your plot, you can use various functions. While altering the entire theme of your plot is one option (covered in detail in the "Working with Themes" section below), you can also make specific changes to individual elements such as backgrounds and grid lines.

7.1 Change the Panel Background Color

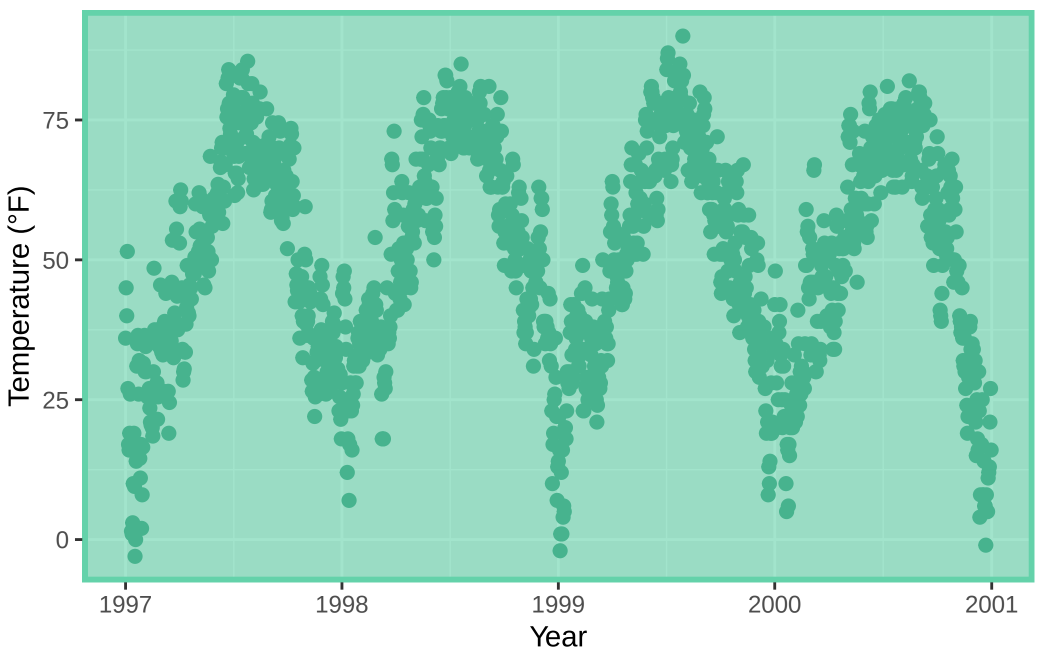
You can adjust the background color (fill) of the panel area (where the data is plotted) by modifying the theme element `panel.background`:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "#1D8565", size = 2) +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.background = element_rect(
    fill = "#64D2AA", color = "#64D2AA", linewidth = 2)
  )
```



Keep in mind that the true color — the outline of the panel background — didn't change despite our specification. This is because there's a layer on top of `panel.background`, namely `panel.border`. However, it's important to use a transparent fill here; otherwise, your data will be hidden behind this layer. In the following example, I illustrate this by using a semitransparent hex color for the `fill` argument in `element_rect`:

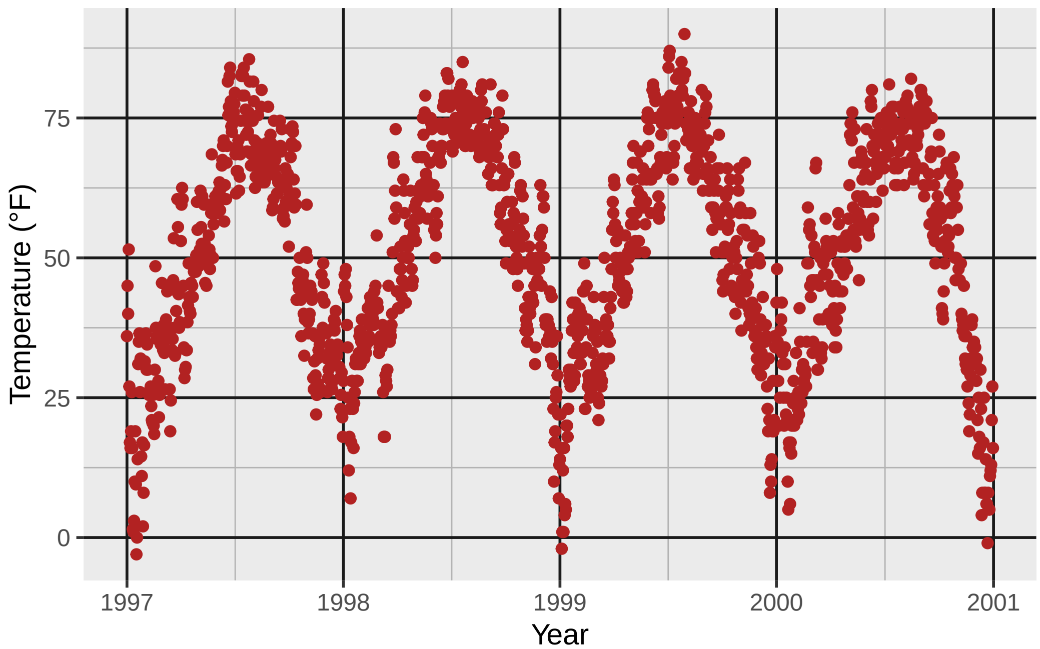
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "#1D8565", size = 2) +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.border = element_rect(
    fill = "#64D2AA99", color = "#64D2AA", linewidth = 2)
  )
```



7.2 Change Grid Lines

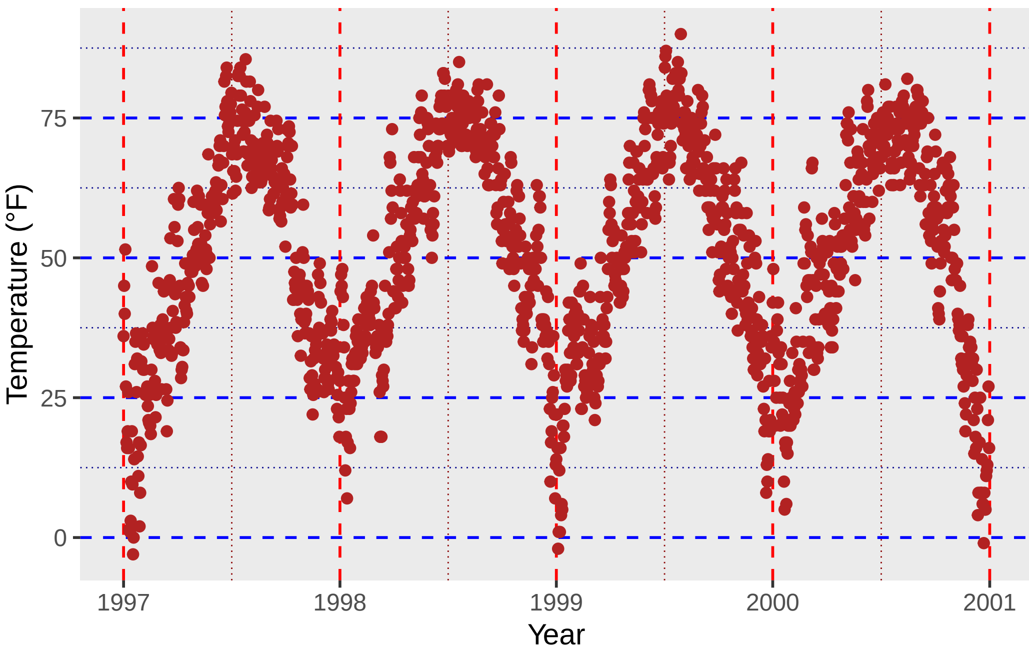
There are two types of grid lines: major grid lines indicating the ticks and minor grid lines between the major ones. You can customize both by overwriting the defaults for `panel.grid` or for each set of gridlines separately, `panel.grid.major` and `panel.grid.minor`.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.grid.major = element_line(color = "gray10", linewidth = .5),
        panel.grid.minor = element_line(color = "gray70", linewidth = .25))
```



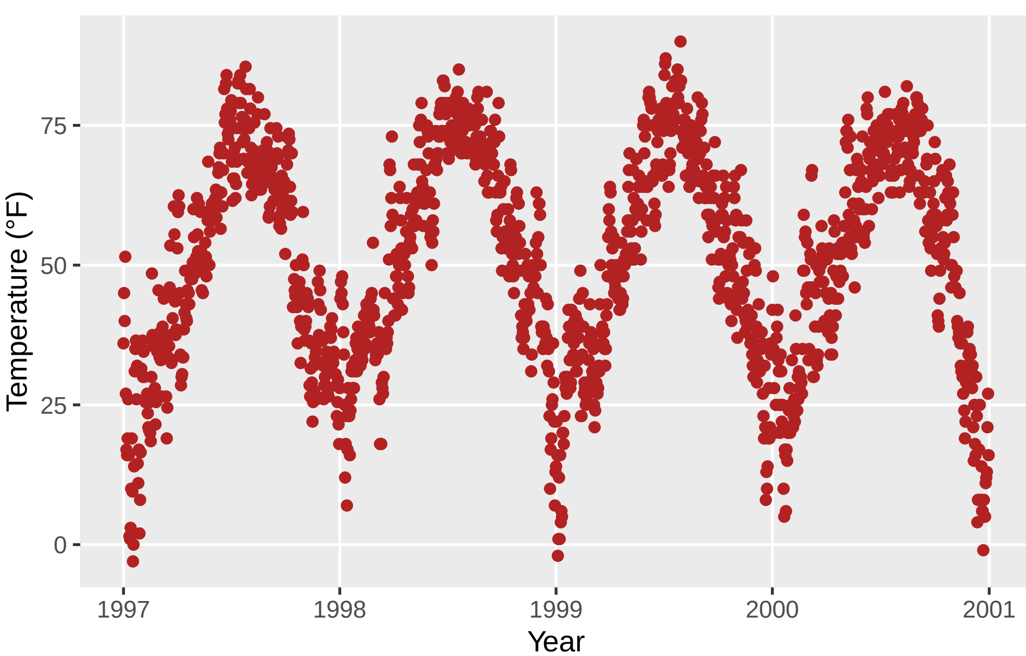
You can even specify settings for all four different levels of grid lines: major horizontal, major vertical, minor horizontal, and minor vertical.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.grid.major = element_line(linewidth = .5, linetype = "dashed"),
        panel.grid.minor = element_line(linewidth = .25, linetype = "dotted"),
        panel.grid.major.x = element_line(color = "red1"),
        panel.grid.major.y = element_line(color = "blue1"),
        panel.grid.minor.x = element_line(color = "red4"),
        panel.grid.minor.y = element_line(color = "blue4"))
```

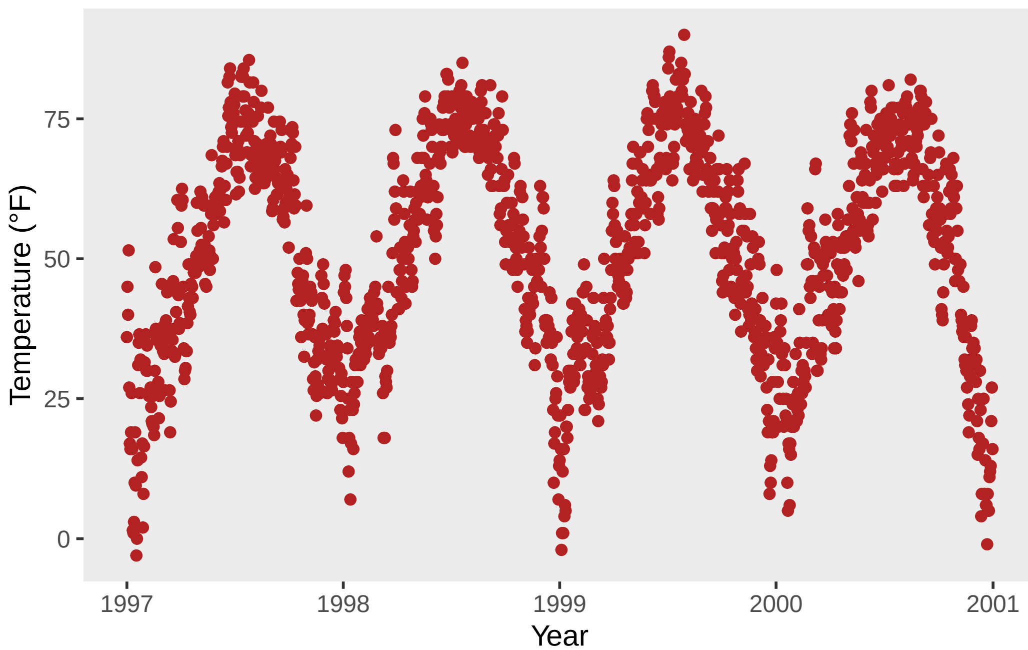


And, of course, you can remove some or all grid lines if you like. For instance, to remove all grid lines, you can set `panel.grid = element_blank()`. Alternatively, you can remove only major or minor grid lines by specifying `panel.grid.major` or `panel.grid.minor` accordingly and setting them to `element_blank()`.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.grid.minor = element_blank())
```



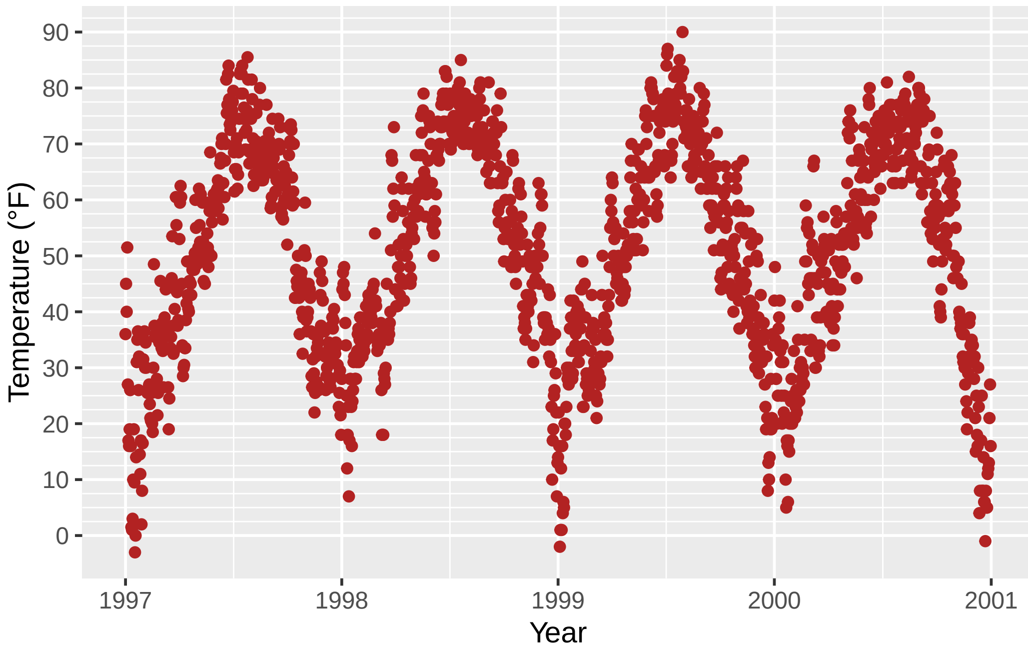
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.grid = element_blank())
```



7.3 Change Spacing of Gridlines

Furthermore, you can also define the breaks between both major and minor grid lines by specifying the `breaks` argument.

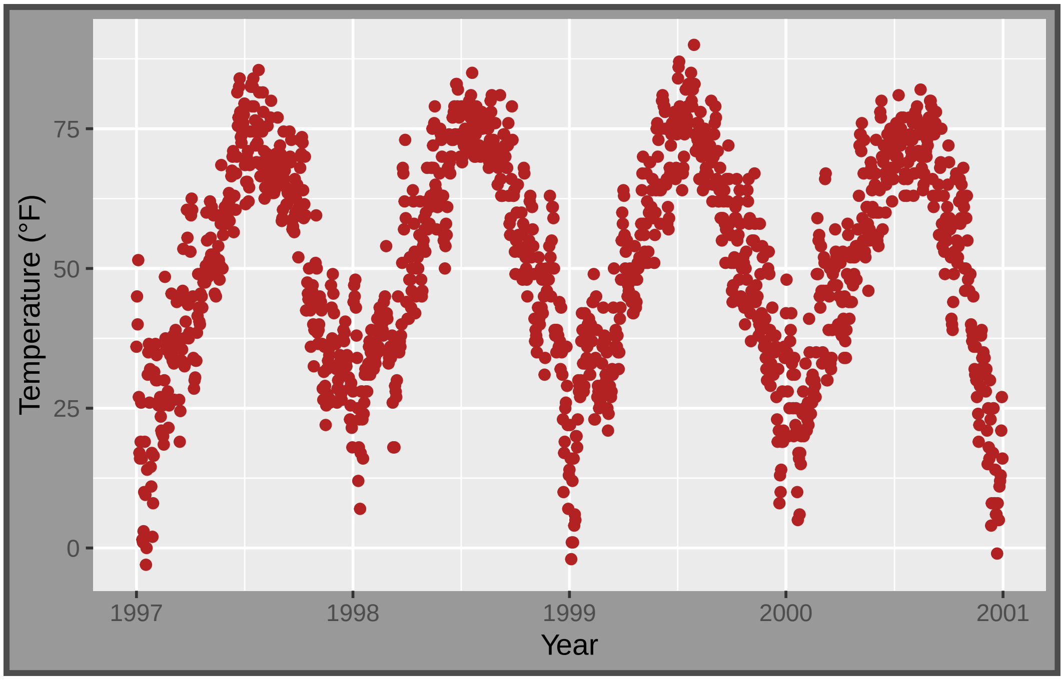
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  scale_y_continuous(breaks = seq(0, 100, 10),
                     minor_breaks = seq(0, 100, 2.5))
```



7.4 Change the Plot Background Color

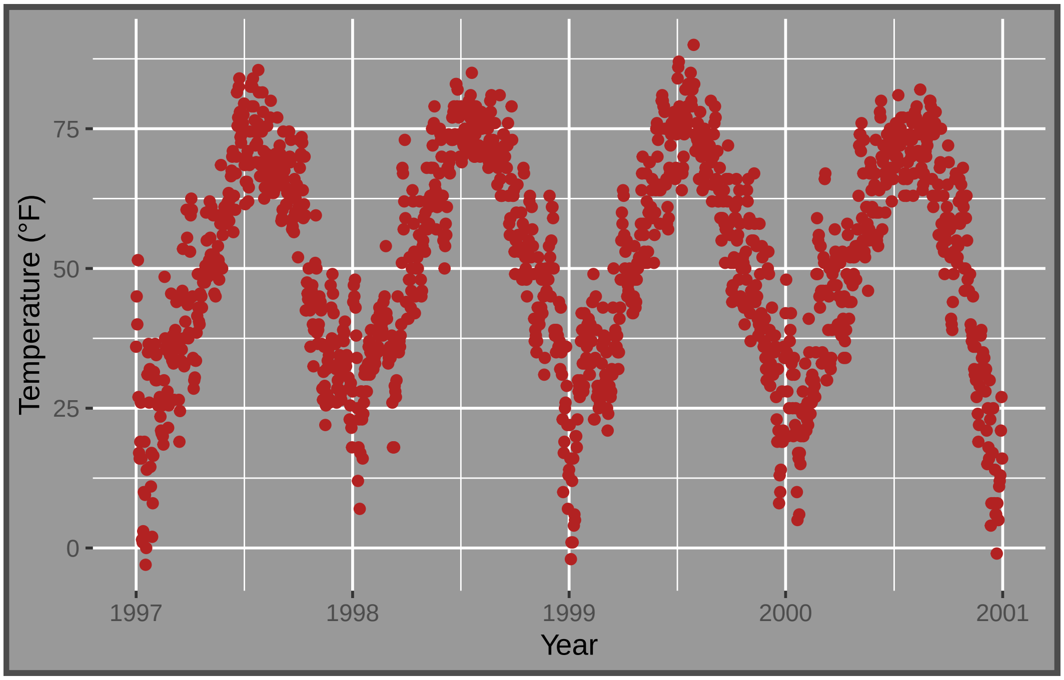
Similarly, to change the background color (fill) of the plot area, you can modify the theme element `plot.background` using the `theme()` function. This allows you to customize the appearance of the entire plot area according to your preferences.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(plot.background = element_rect(fill = "gray60",
                                       color = "gray30", linewidth = 2))
```



You can achieve a unique background color by either setting the same colors in both `panel.background` and `plot.background` or by setting the background filling of the panel to `"transparent"` or `NA`. This customization can help you create visually appealing plots that match your design preferences.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(panel.background = element_rect(fill = NA),
        plot.background = element_rect(fill = "gray60",
                                       color = "gray30", linewidth = 2))
```

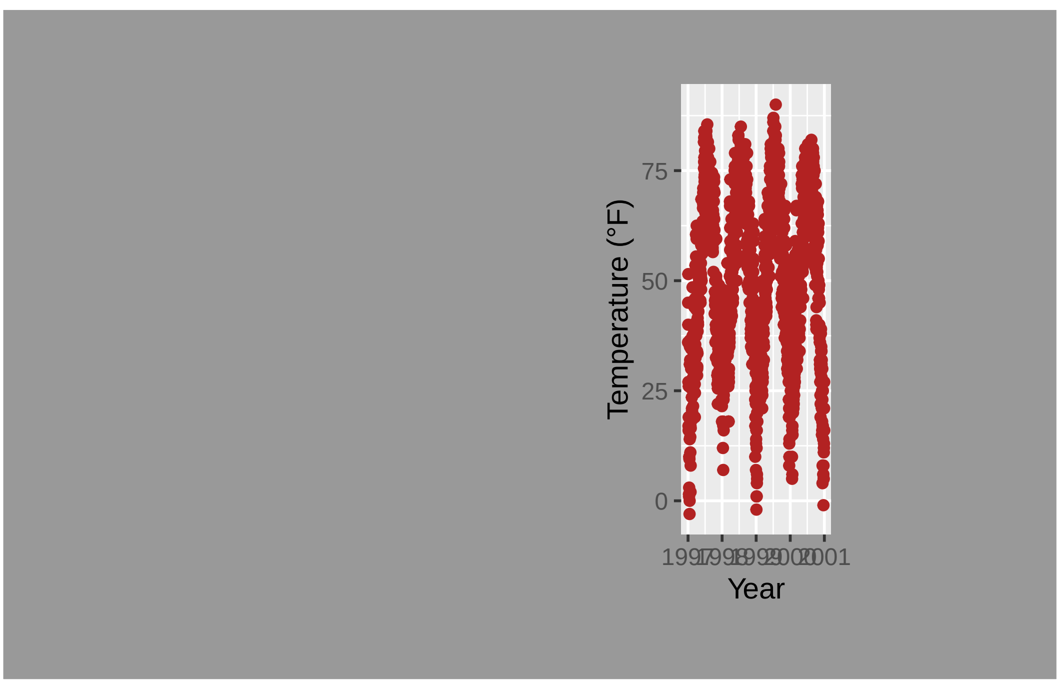

Temperature (°F)
75
50
25
0
1997
1998
1999
2000
2001
Year

8 Working with Margins

Sometimes it is useful to add a little space to the plot margin. Similar to the previous examples, we can use an argument to the `theme()` function. In this case, the argument is `plot.margin`. As illustrated in the previous example where we changed the background color using `plot.background`, we can now add extra space to both the left and right.

The `plot.margin` argument can handle a variety of different units (cm, inches, etc.), but it requires the use of the `unit` function from the package `grid` to specify the units. You can either provide the same value for all sides (easiest via `rep(x, 4)`) or particular distances for each. Here, I am using a 1cm margin on the top and bottom, 3 cm margin on the right, and an 8 cm margin on the left.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(plot.background = element_rect(fill = "gray60"),
        plot.margin = margin(t = 1, r = 3, b = 1, l = 8, unit = "cm"))
```



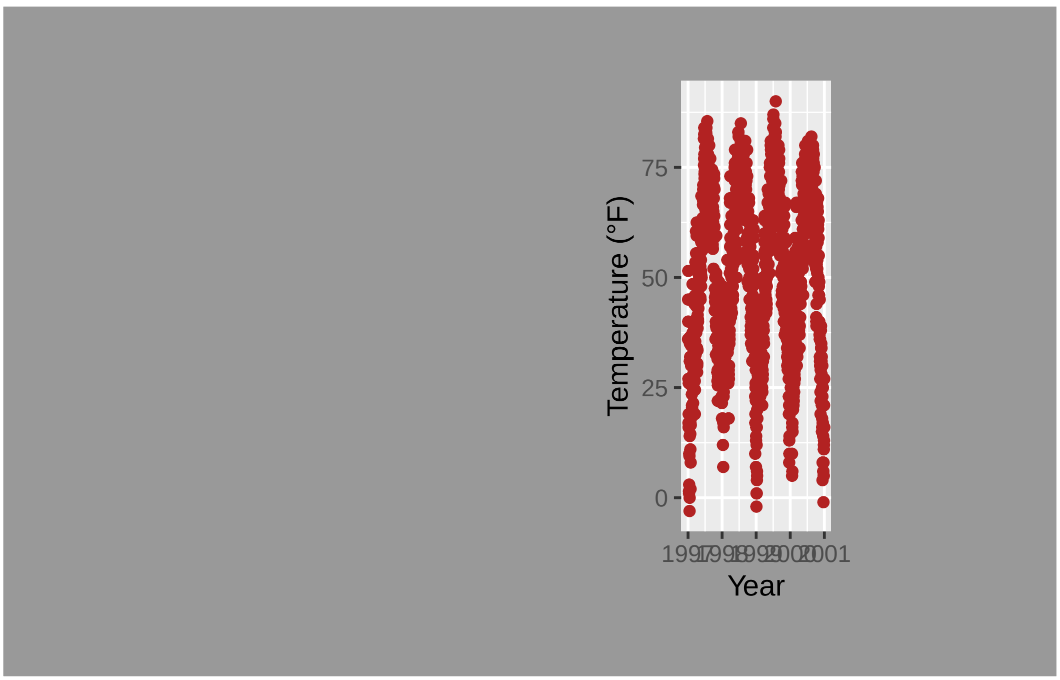
! Having trouble with Margins?

A helpful mnemonic for remembering the order of the margin sides is "*t*-*r*-ou-*b*-*l*-e".

`unit()` instead of `margin()`

You can also use `unit()` instead of `margin()`.

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(plot.background = element_rect(fill = "gray60"),
        plot.margin = unit(c(1, 3, 1, 8), "cm"))
```



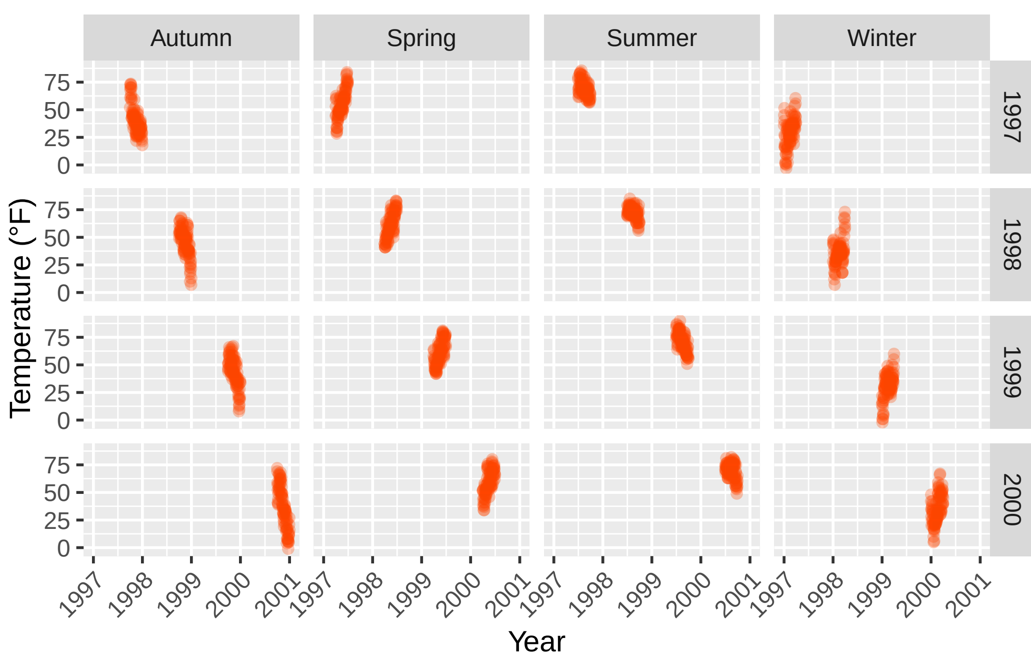
9 Working with Multi-Panel Plots

The {ggplot2} package offers two handy functions for creating multi-panel plots, called *facets*. They are related but have slight differences: facet_wrap creates a ribbon of plots based on a single variable, while facet_grid spans a grid of plots based on two variables.

9.1 Create a Grid of Small Multiples Based on Two Variables

When dealing with two variables, facet_grid is the appropriate choice. In this function, the order of the variables determines the number of rows and columns in the grid:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "orangered", alpha = .3) +
  theme(axis.text.x = element_text(angle = 45, vjust = 1, hjust = 1)) +
  labs(x = "Year", y = "Temperature (°F)") +
  facet_grid(year ~ season)
```

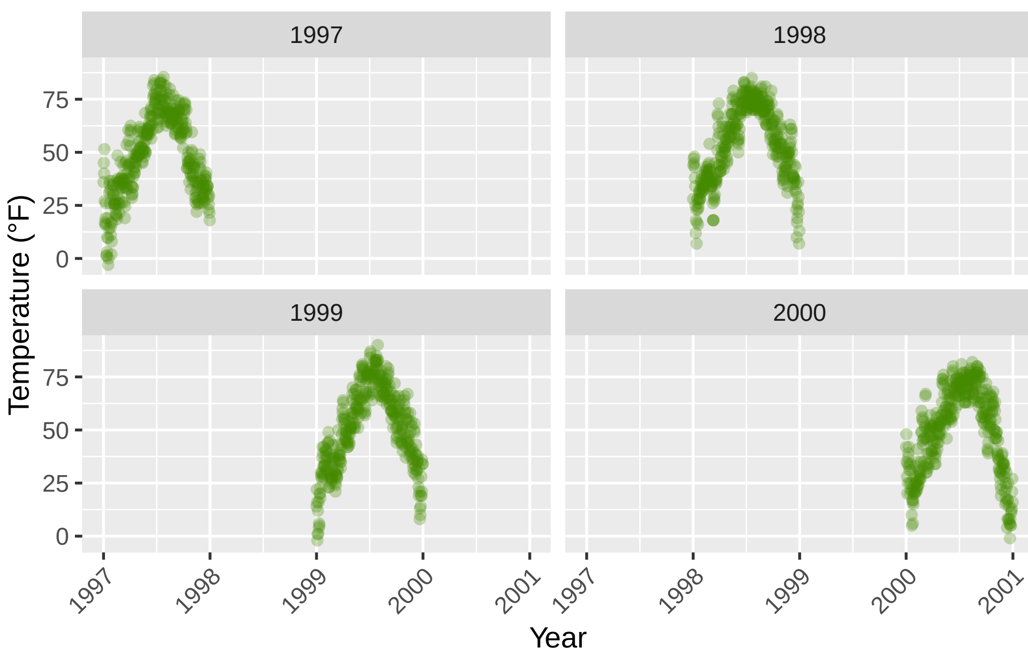


To switch from a row-based arrangement to a column-based one, you can modify facet_grid(year ~ season) to facet_grid(season ~ year).

9.2 Create Small Multiples Based on One Variable

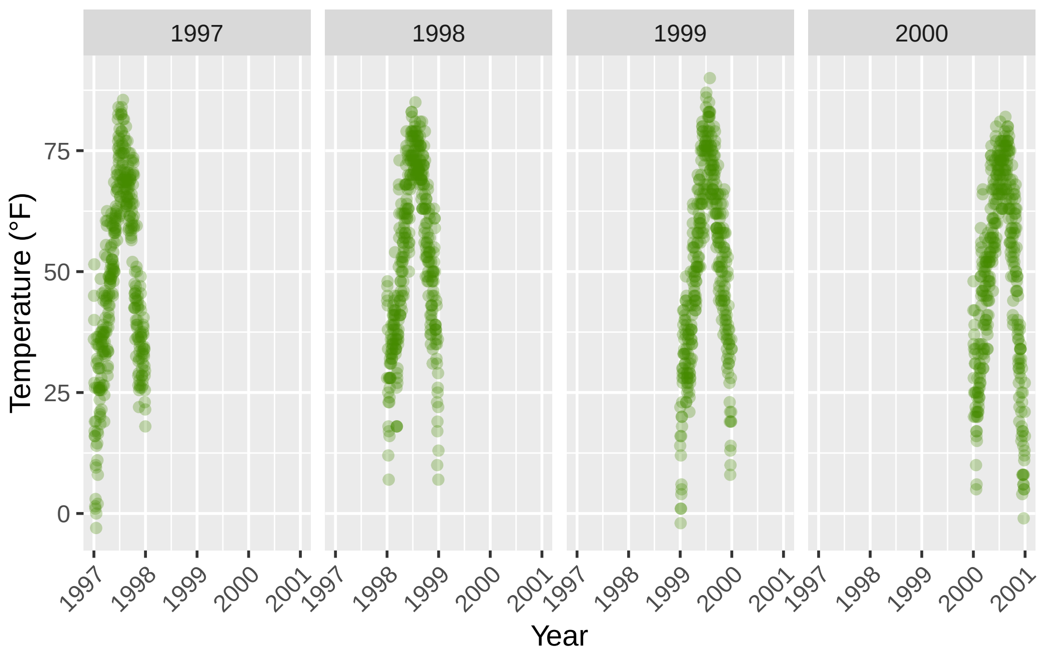
`facet_wrap` creates a facet of a single variable, specified with a tilde in front: `facet_wrap(~ variable)`. The appearance of these subplots is determined by the arguments `ncol` and `nrow`:

```
g <-
  ggplot(chic, aes(x = date, y = temp)) +
    geom_point(color = "chartreuse4", alpha = .3) +
    labs(x = "Year", y = "Temperature (°F)") +
    theme(axis.text.x = element_text(angle = 45, vjust = 1, hjust = 1))

g + facet_wrap(~ year)
```



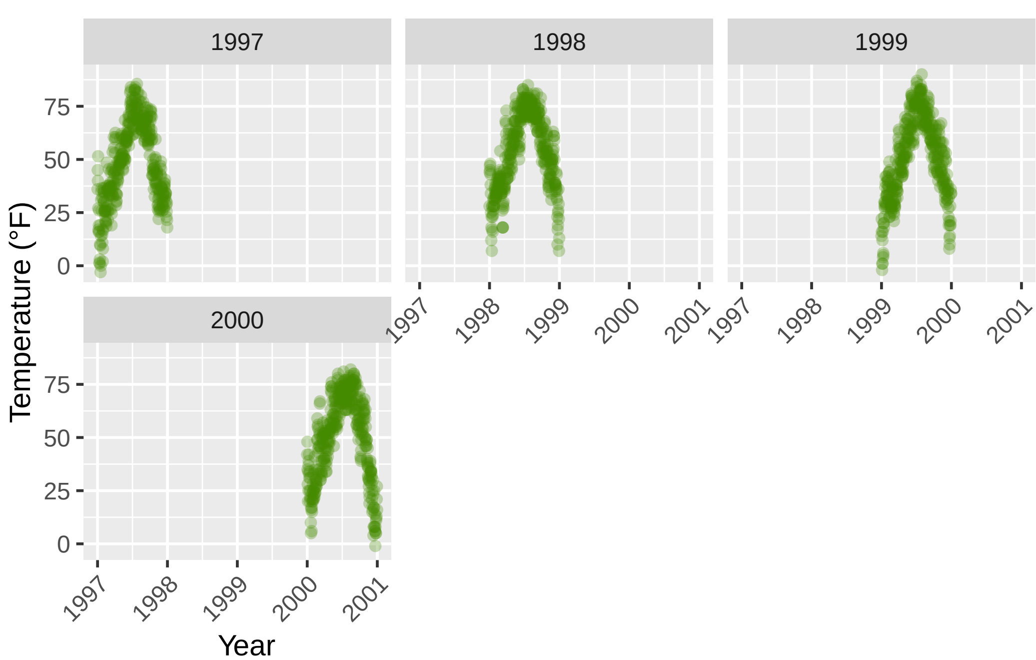
Accordingly, you can arrange the plots as you like, instead as a matrix in one row…

```r
g + facet_wrap(~ year, nrow = 1)
```



... or even as a asymmetric grid of plots:

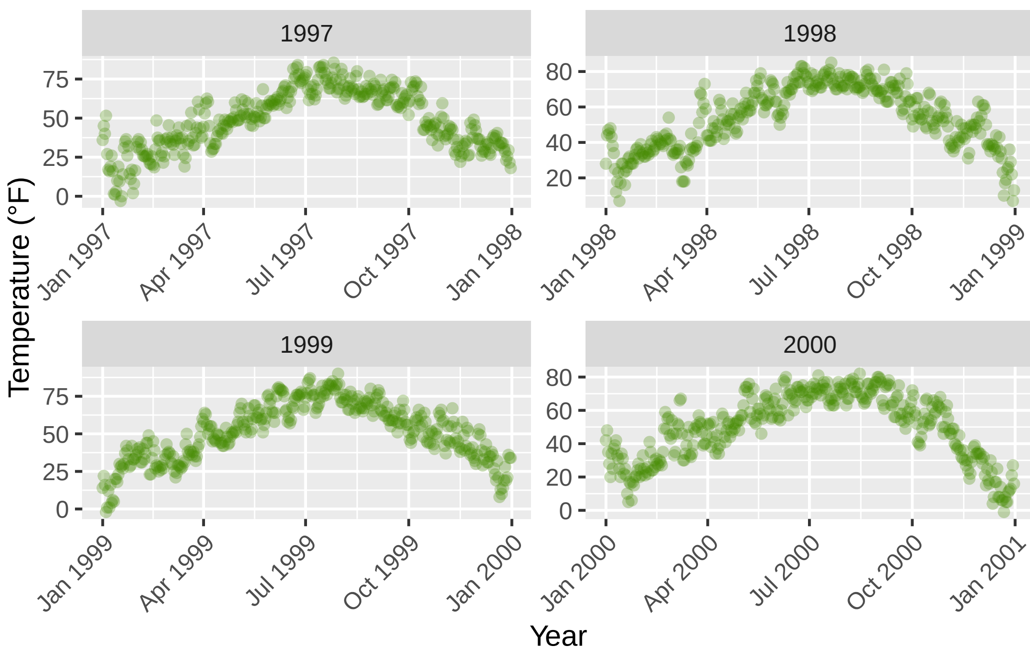
```r
g + facet_wrap(~ year, ncol = 3) + theme(axis.title.x = element_text(hjust = .15))
```



9.3 Allow Axes to Roam Free

The default for multi-panel plots in {ggplot2} is to use equivalent scales in each panel. But sometimes you want to allow a panels own data to determine the scale. This is often not a good idea since it may give your user the wrong impression about the data. But sometimes it is indeed useful and to do this you can set `scales = "free"`:

```
g + facet_wrap(~ year, nrow = 2, scales = "free")
```

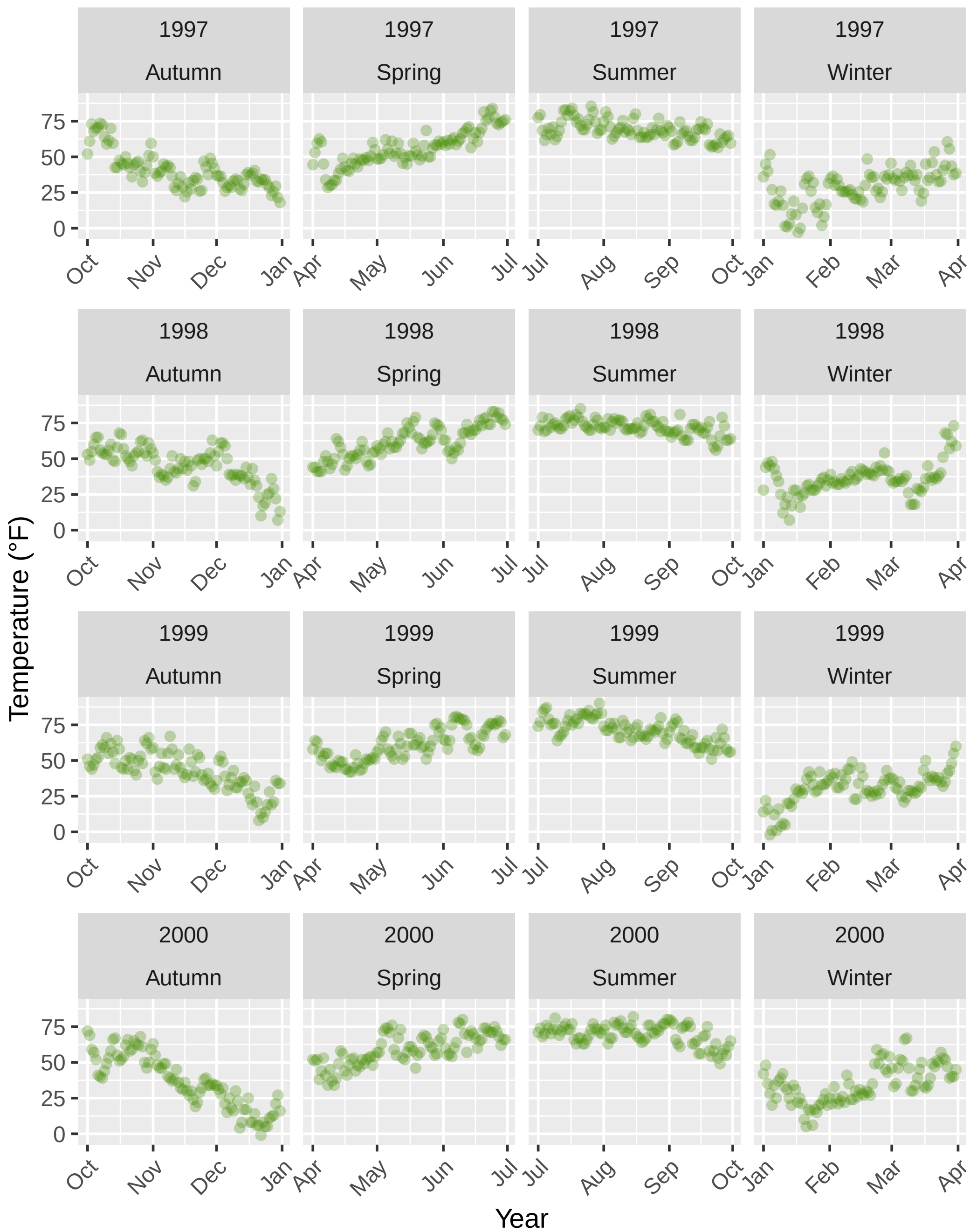


Note that both, x and y axes differ in their range!

9.3.0.1 Use `facet_wrap` with Two Variables

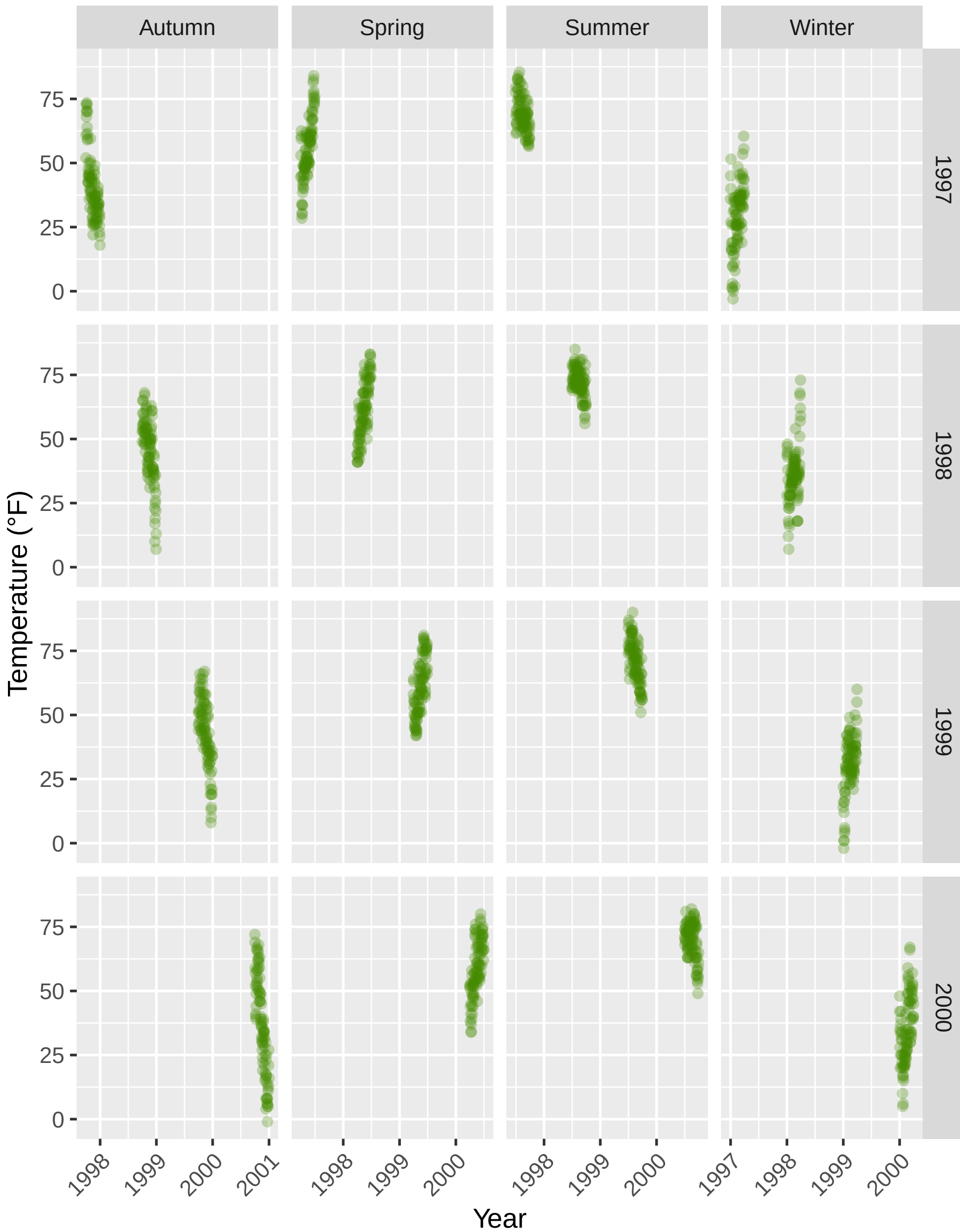
The function `facet_wrap` can also take two variables:

```
g + facet_wrap(year ~ season, nrow = 4, scales = "free_x")
```



When using `facet_wrap` you are still able to control the grid design: you can rearrange the number of plots per row and column and you can also let all axes roam free. In contrast, `facet_grid` will also take a `free` argument but will only let it roam free per column or row:

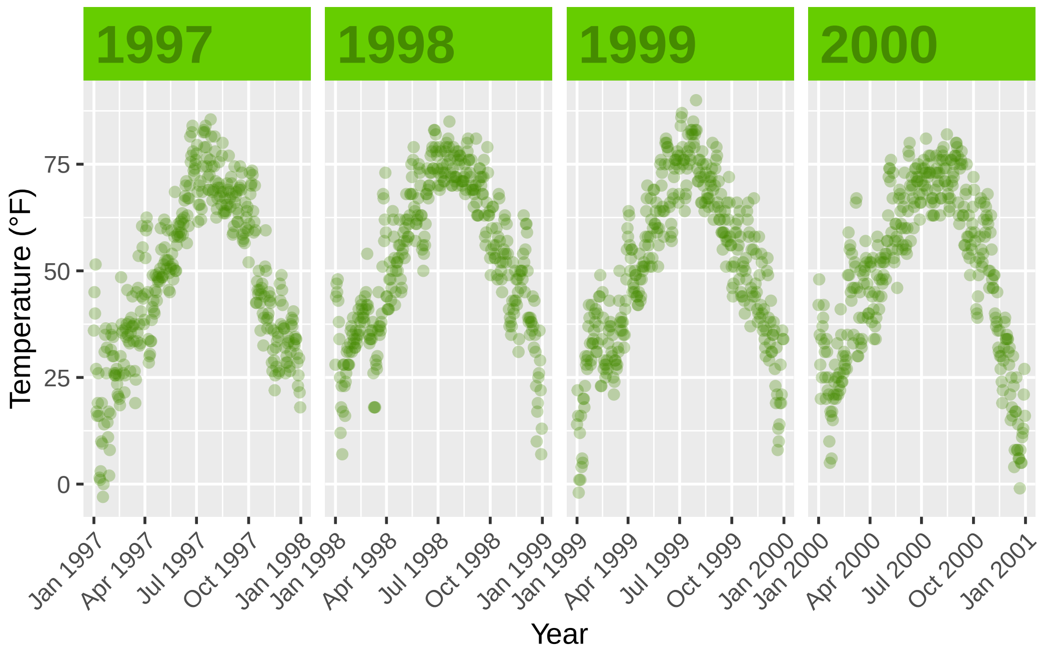
```
g + facet_grid(year ~ season, scales = "free_x")
```



9.4 Modify Style of Strip Texts

By using `theme`, you can modify the appearance of the strip text (i.e. the title for each facet) and the strip text boxes:

```
g + facet_wrap(~ year, nrow = 1, scales = "free_x") +
  theme(strip.text = element_text(face = "bold", color = "chartreuse4",
                                  hjust = 0, size = 20),
        strip.background = element_rect(fill = "chartreuse3", linetype = "dotted"))
```



The following two functions adapted from this answer by Claus Wilke, the author of the {ggtext} package, allow to highlight specific labels in combination with `element_textbox()` that is provided by {ggtext}.

```
library(ggtext)
library(purrr) ## for %||%

element_textbox_highlight <- function(..., hi.labels = NULL, hi.fill = NULL,
                                      hi.col = NULL, hi.box.col = NULL, hi.family = NULL) {
  structure(
    c(element_textbox(...),
      list(hi.labels = hi.labels, hi.fill = hi.fill, hi.col = hi.col, hi.box.col = hi.box.col, hi.fami
    ),
    class = c("element_textbox_highlight", "element_textbox", "element_text", "element")
  )
}

element_grob.element_textbox_highlight <- function(element, label = "", ...) {
  if (label %in% element$hi.labels) {
    element$fill <- element$hi.fill %||% element$fill
    element$colour <- element$hi.col %||% element$colour
    element$box.colour <- element$hi.box.col %||% element$box.colour
```

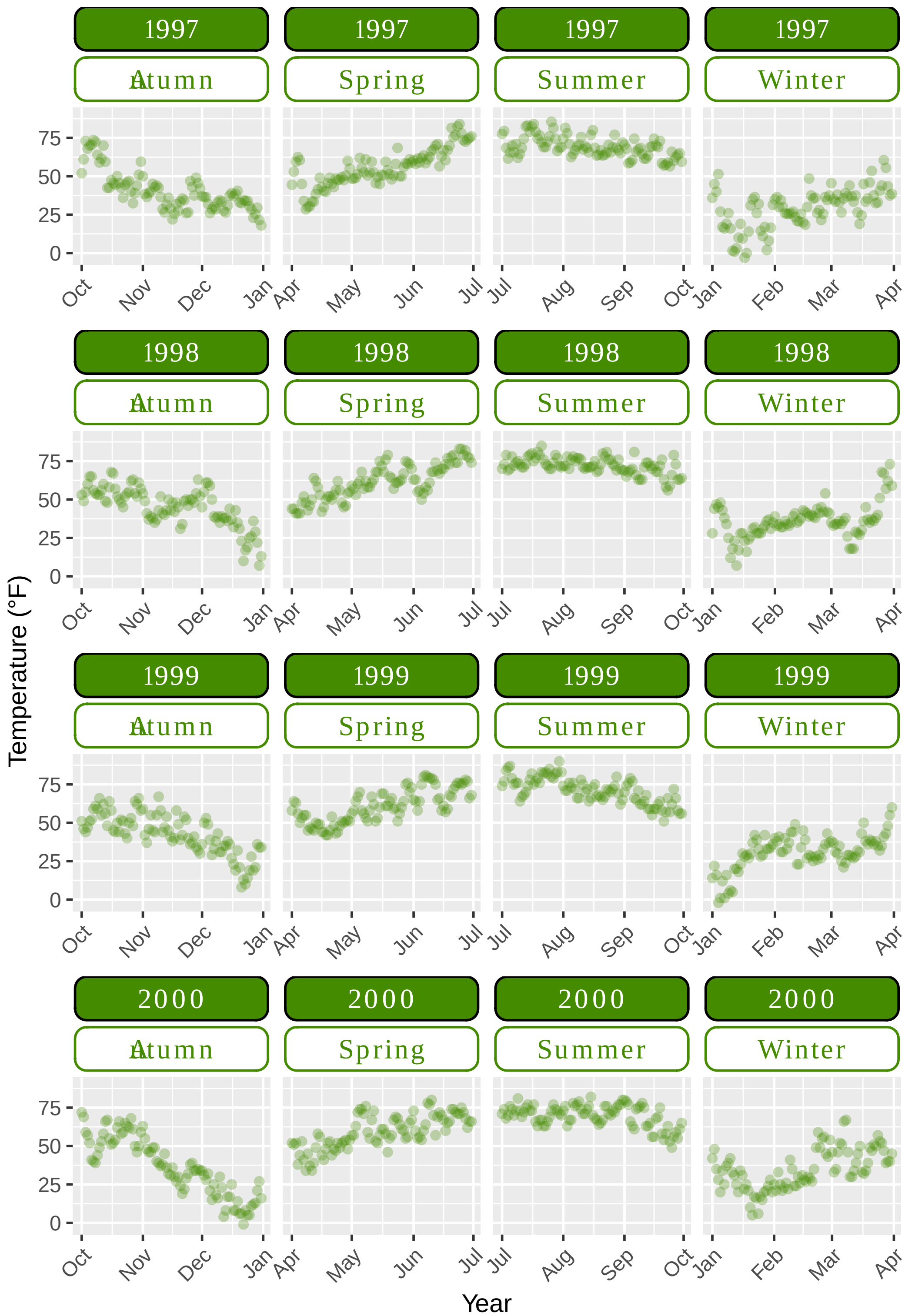
```
    element$family <- element$hi.family %||% element$family
  }
  NextMethod()
}
```

Now you can use it and specify for example all striptexts:

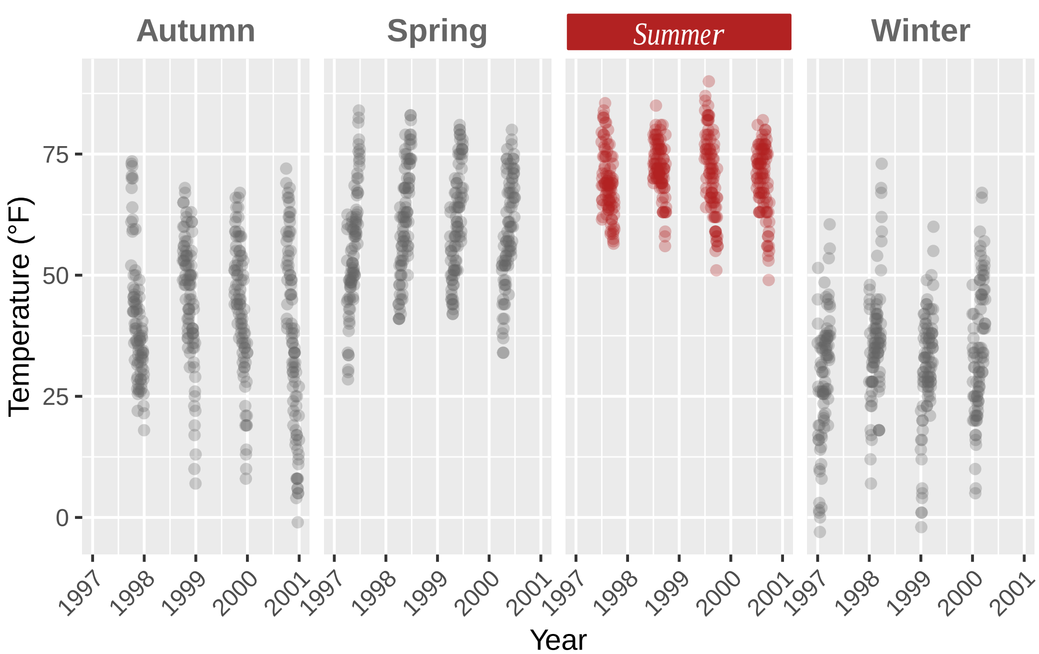
```
g + facet_wrap(year ~ season, nrow = 4, scales = "free_x") +
  theme(
    strip.background = element_blank(),
    strip.text = element_textbox_highlight(
      family = "Playfair Display", size = 12, face = "bold",
      fill = "white", box.color = "chartreuse4", color = "chartreuse4",
      halign = .5, linetype = 1, r = unit(5, "pt"), width = unit(1, "npc"),
      padding = margin(5, 0, 3, 0), margin = margin(0, 1, 3, 1),
      hi.labels = c("1997", "1998", "1999", "2000"),
      hi.fill = "chartreuse4", hi.box.col = "black", hi.col = "white"
    )
  )
```

```
Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font
width unknown for character 0x41
Warning in grid.Call(C_textBounds, as.graphicsAnnot(x$label), x$x, x$y, : font
width unknown for character 0x41
```

```
Warning in grid.Call.graphics(C_text, as.graphicsAnnot(x$label), x$x, x$y, :
font width unknown for character 0x41
Warning in grid.Call.graphics(C_text, as.graphicsAnnot(x$label), x$x, x$y, :
font width unknown for character 0x41
Warning in grid.Call.graphics(C_text, as.graphicsAnnot(x$label), x$x, x$y, :
font width unknown for character 0x41
Warning in grid.Call.graphics(C_text, as.graphicsAnnot(x$label), x$x, x$y, :
font width unknown for character 0x41
```


1997
Atumn
Spring
Summer
Winter
1998
1999
2000
75
50
25
0
Oct
Nov
Dec
Jan
Apr
May
Jun
Jul
Aug
Sep
Feb
Mar
Temperature (°F)
Year

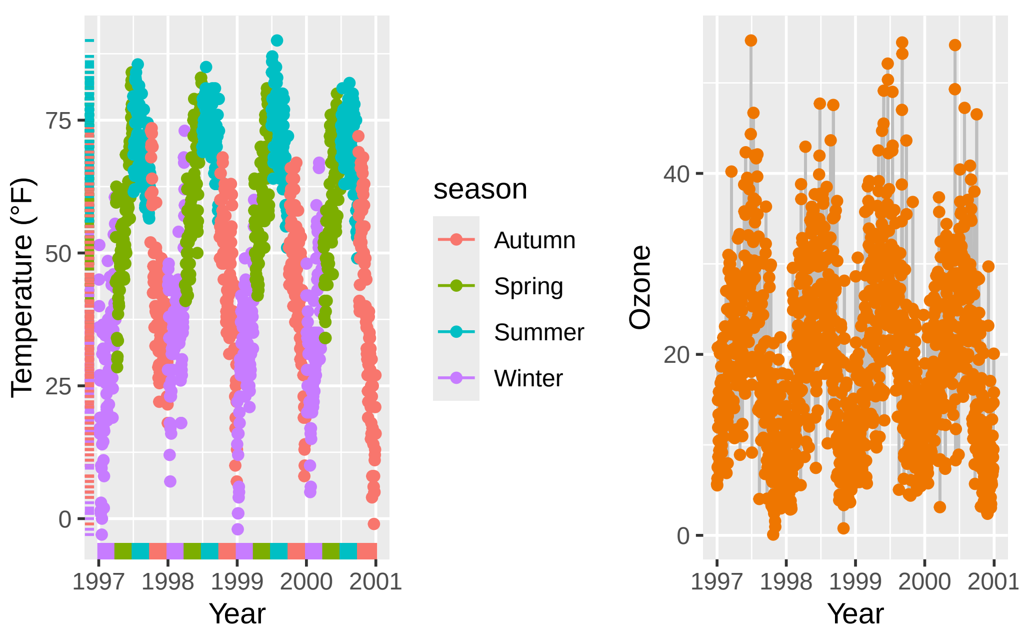
```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(aes(color = season == "Summer"), alpha = .3) +
  labs(x = "Year", y = "Temperature (°F)") +
  facet_wrap(~ season, nrow = 1) +
  scale_color_manual(values = c("gray40", "firebrick"), guide = "none") +
  theme(
    axis.text.x = element_text(angle = 45, vjust = 1, hjust = 1),
    strip.background = element_blank(),
    strip.text = element_textbox_highlight(
      size = 12, face = "bold",
      fill = "white", box.color = "white", color = "gray40",
      halign = .5, linetype = 1, r = unit(0, "pt"), width = unit(1, "npc"),
      padding = margin(2, 0, 1, 0), margin = margin(0, 1, 3, 1),
      hi.labels = "Summer", hi.family = "Bangers",
      hi.fill = "firebrick", hi.box.col = "firebrick", hi.col = "white"
    )
  )
```



9.5 Create a Panel of Different Plots

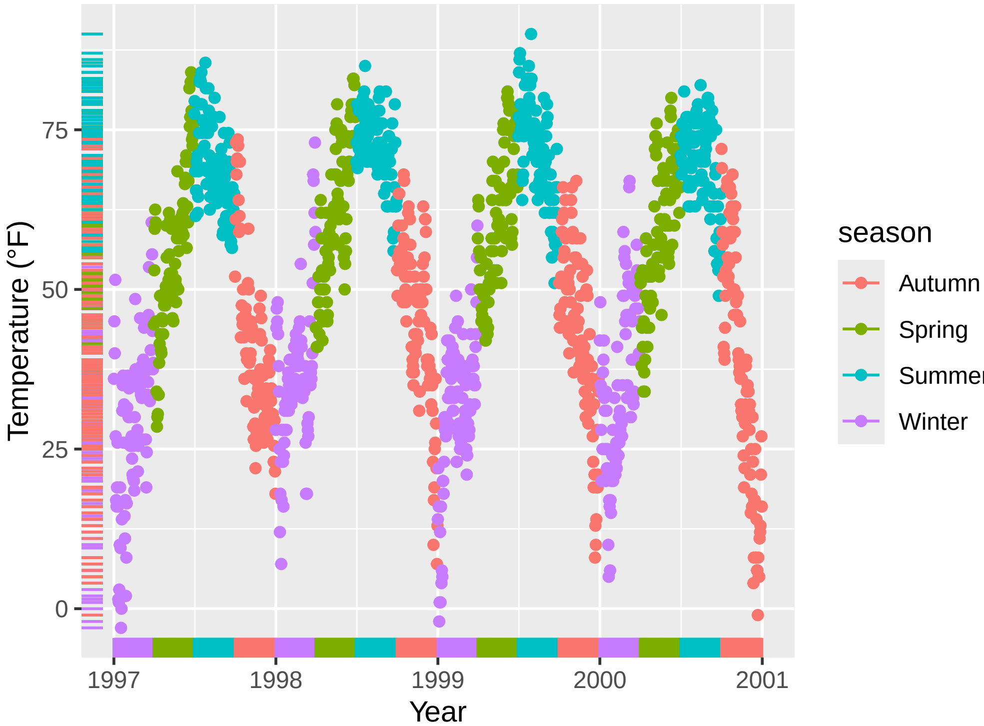
There are several ways how plots can be combined. The easiest approach in my opinion is the {patchwork} package by Thomas Lin Pedersen:

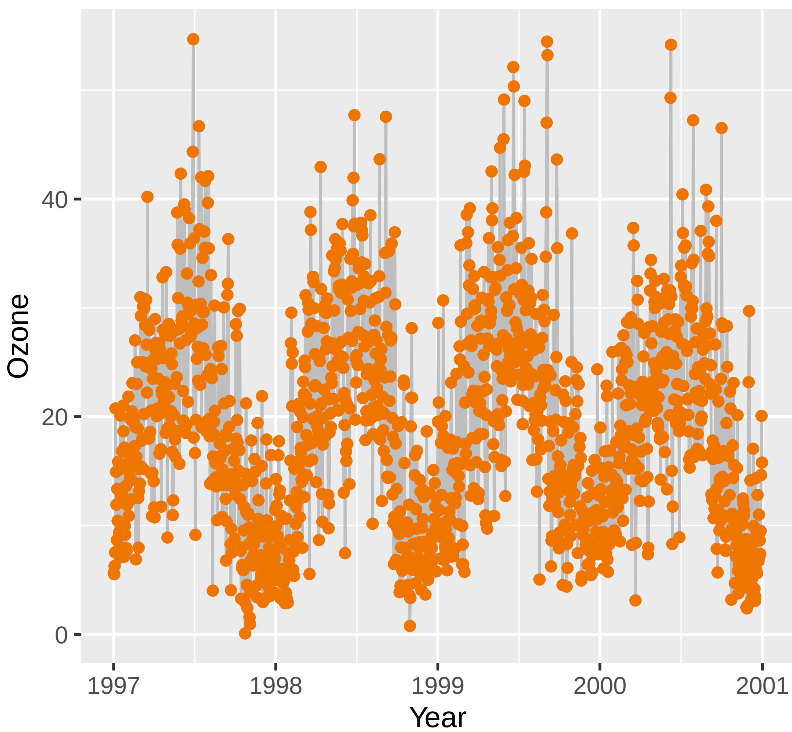
```
p1 <- ggplot(chic, aes(x = date, y = temp,
                       color = season)) +
        geom_point() +
        geom_rug() +
        labs(x = "Year", y = "Temperature (°F)")

p2 <- ggplot(chic, aes(x = date, y = o3)) +
        geom_line(color = "gray") +
        geom_point(color = "darkorange2") +
        labs(x = "Year", y = "Ozone")

library(patchwork)
p1 + p2
```



We can change the order by "dividing" both plots (and note the alignment even though one has a legend and one doesn't!):

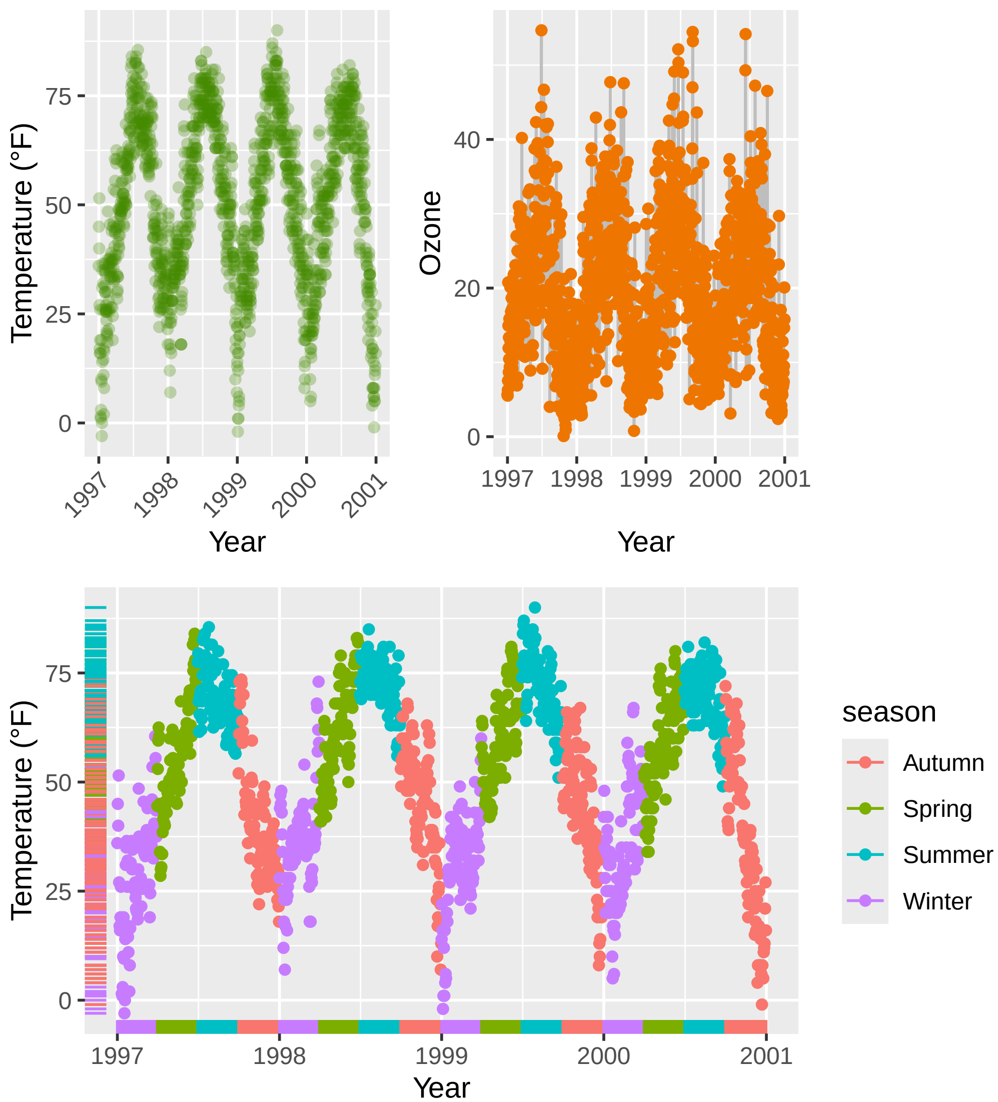
```
p1 / p2
```





And also nested plots are possible!

```
(g + p2) / p1
```



(Note the alignment of the plots even though only one plot includes a legend.)

Alternatively, the `{cowplot}` package by Claus Wilke provides the functionality to combine multiple plots (and lots of other good utilities):

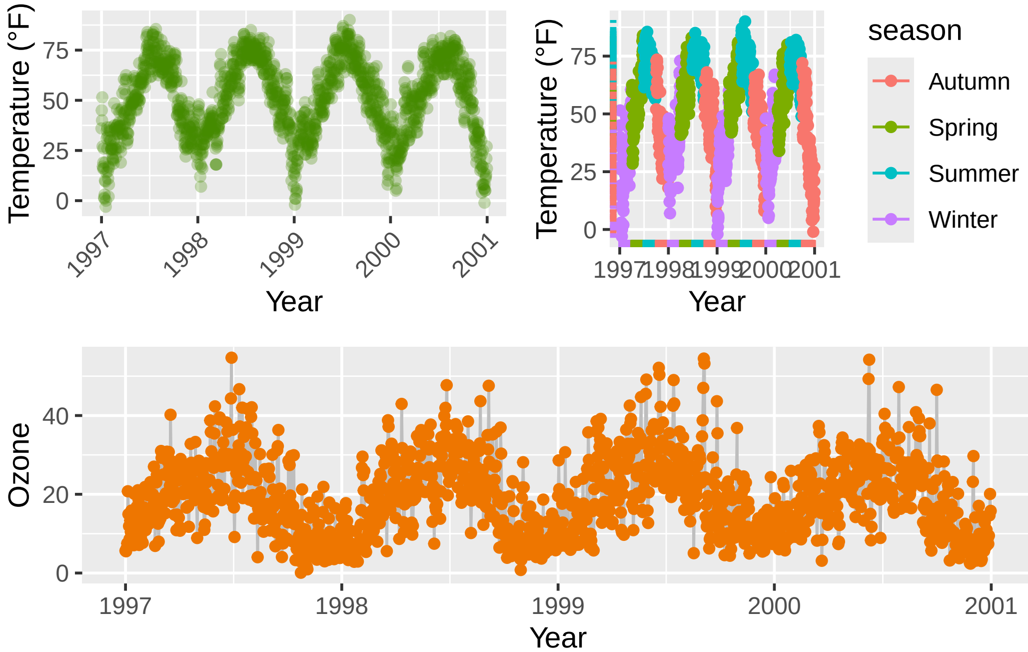
```
library(cowplot)
```

```
Attaching package: 'cowplot'
```

```
The following object is masked from 'package:patchwork':
```

```
    align_plots

The following object is masked from 'package:lubridate':

    stamp
```

```
plot_grid(plot_grid(g, p1), p2, ncol = 1)
```

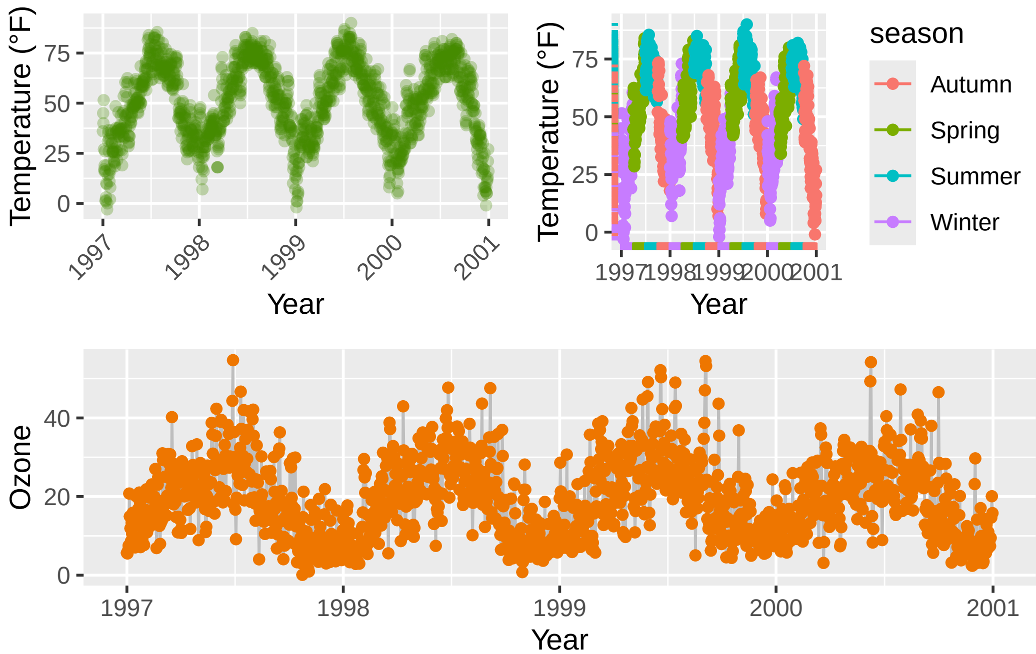


… and so does the {gridExtra} package as well:

```
library(gridExtra)
```

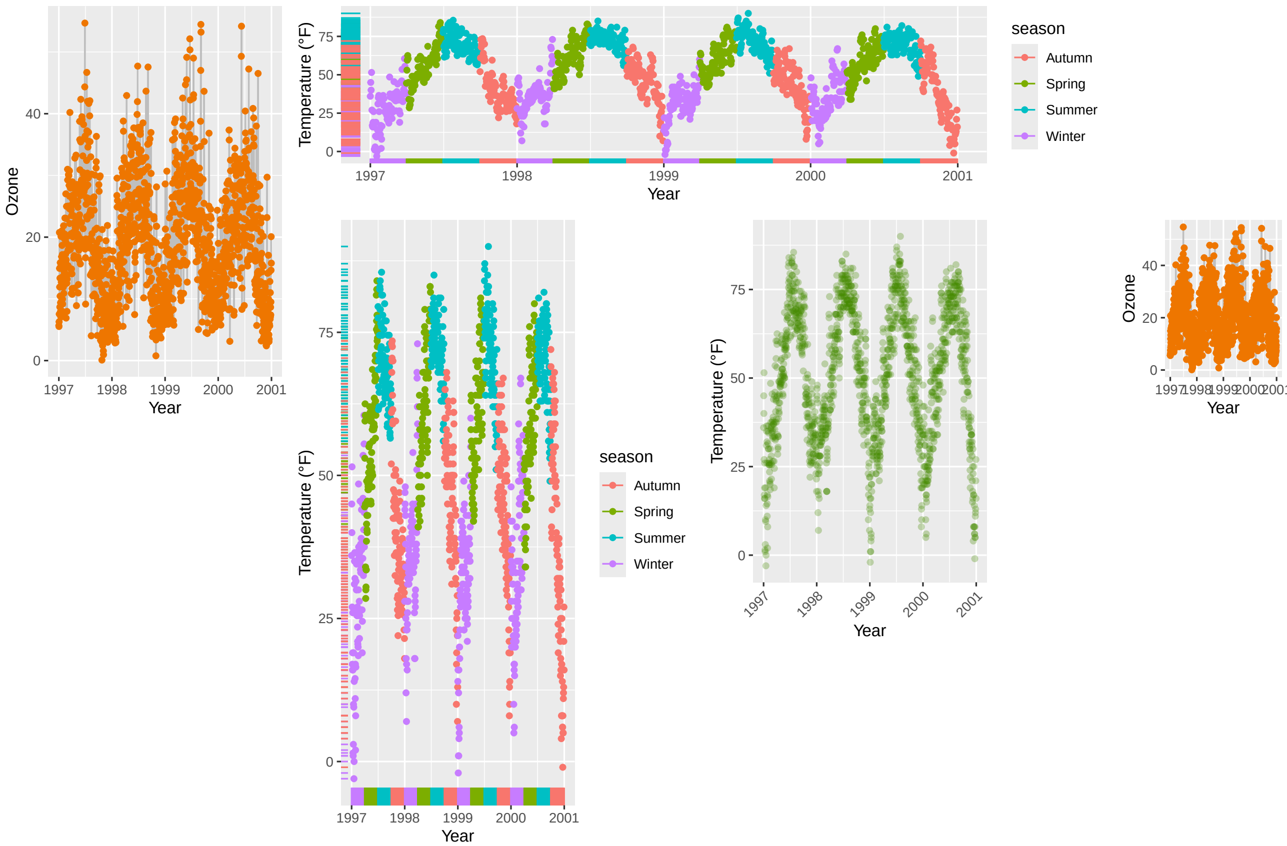
```
Attaching package: 'gridExtra'

The following object is masked from 'package:dplyr':

    combine
```

```
grid.arrange(g, p1, p2,
             layout_matrix = rbind(c(1, 2), c(3, 3)))
```



The same idea of defining a layout can be used with {patchwork} which allows creating complex compositions:

```
layout <- "
AABBBB#
AACCDDE
##CCDD#
##CC###
"

p2 + p1 + p1 + g + p2 +
  plot_layout(design = layout)
```


Ozone
Year
Temperature (°F)
season
Autumn
Spring
Summer
Winter
1997
1998
1999
2000
2001

10 Working with Colors

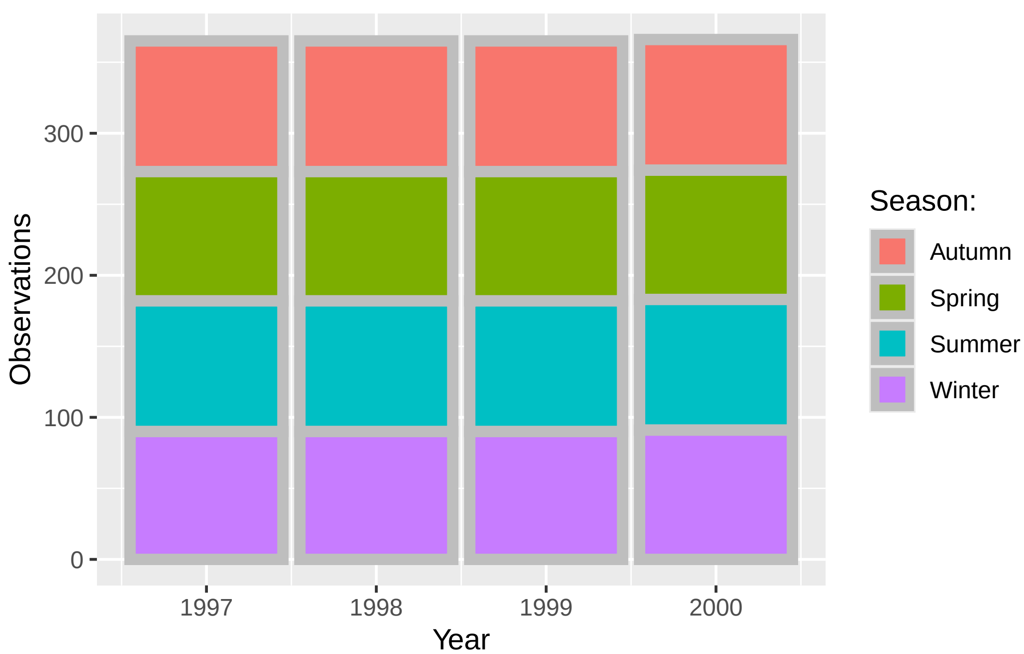
For simple applications working with colors is straightforward in {ggplot2}. For a more advanced treatment of the topic you should probably get your hands on Hadley's book which has nice coverage. Other good sources are the R Cookbook and the ‘color section in the R Graph Gallery by Yan Holtz.

There are two main differences when it comes to colors in {ggplot2}. Both arguments, color and fill, can be

1. specified as single color or
2. assigned to variables.

As you have already seen in the beginning of this tutorial, variables that are *inside* the aesthetics are encoded by variables and those that are *outside* are properties that are unrelated to the variables. This complete nonsense plot showing the number of records per year and season illustrates that fact:

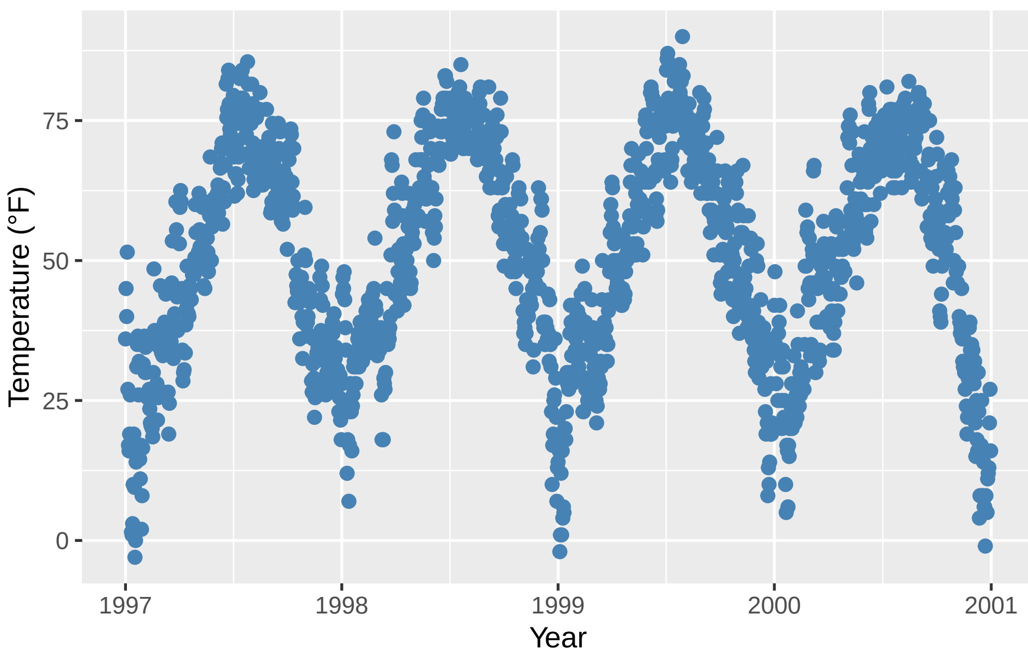
```
ggplot(chic, aes(year)) +
  geom_bar(aes(fill = season), color = "grey", linewidth = 2) +
  labs(x = "Year", y = "Observations", fill = "Season:")
```



10.1 Specify Single Colors

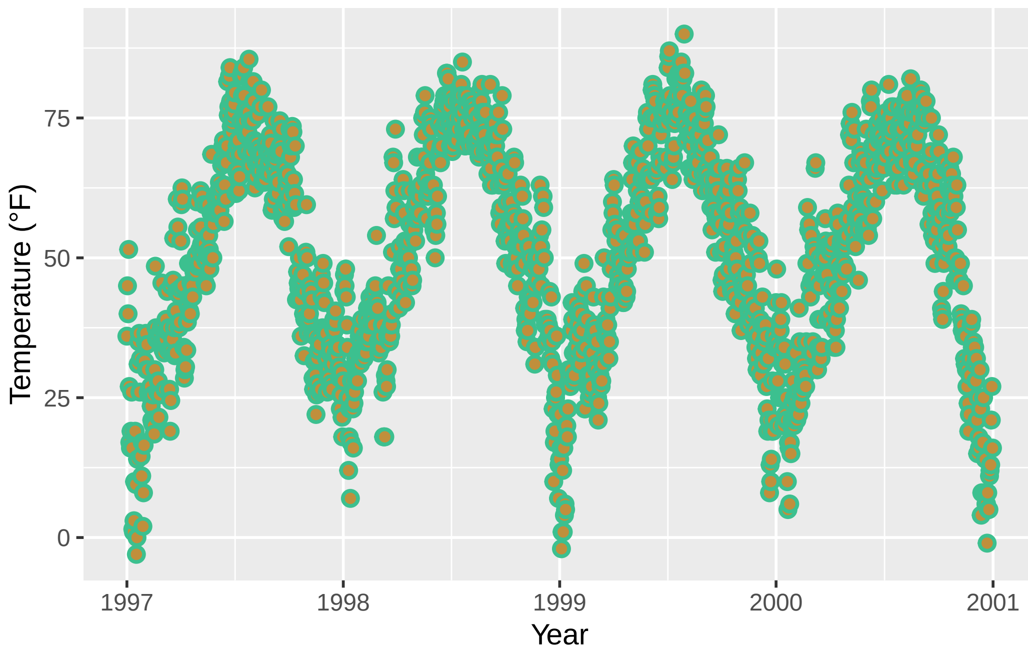
Static, single colors are simple to use. We can specify a single color for a geom:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "steelblue", size = 2) +
  labs(x = "Year", y = "Temperature (°F)")
```



… and in case it provides both, a `color` (outline color) and a `fill` (filling color):

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(shape = 21, size = 2, stroke = 1,
             color = "#3cc08f", fill = "#c08f3c") +
  labs(x = "Year", y = "Temperature (°F)")
```



Tian Zheng at Columbia has created a useful PDF of R colors. Of course, you can also specify hex color codes (simply as strings as in the example above) as well as RGB or RGBA values (via the `rgb()` function: `rgb(red, green, blue, alpha)`).

10.2 Assign Colors to Variables

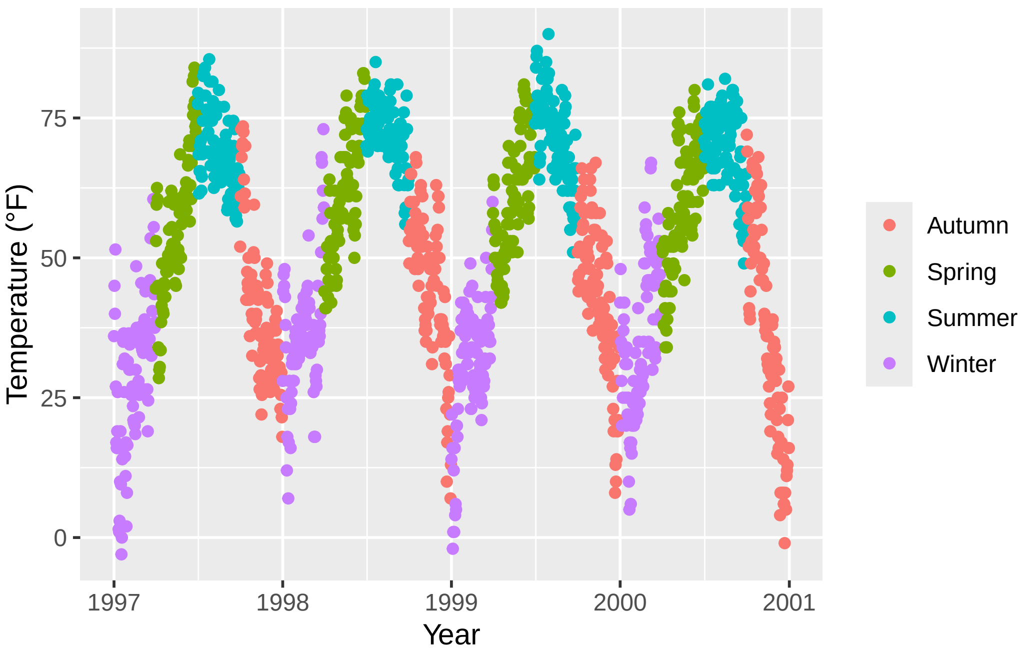
In `{ggplot2}`, colors that are assigned to variables are modified via the `scale_color_*` and the `scale_fill_*` functions. In order to use color with your data, most importantly you need to know if you are dealing with a categorical or continuous variable. The color palette should be chosen depending on type of the variable, with sequential or diverging color palettes being used for continuous variables and qualitative color palettes for categorical variables:

10.3 Qualitative Variables

Qualitative or categorical variables represent types of data which can be divided into groups (*categories*). The variable can be further specified as nominal, ordinal, and binary (dichotomous). Examples of qualitative/categorical variables are:

The default categorical color palette looks like this:

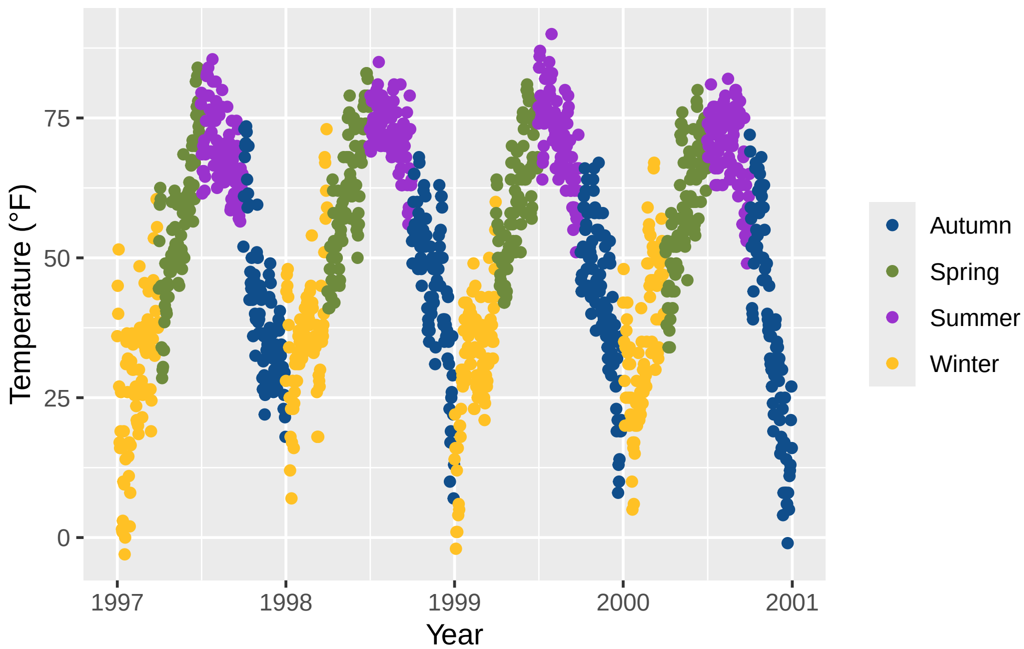
```
(ga <- ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = NULL))
```



10.3.1 Manually Select Qualitative Colors

You can pick your own set of colors and assign them to a categorical variables via the function `scale_*_manual()` (the `*` can be either `color`, `colour`, or `fill`). The number of specified colors has to match the number of categories:

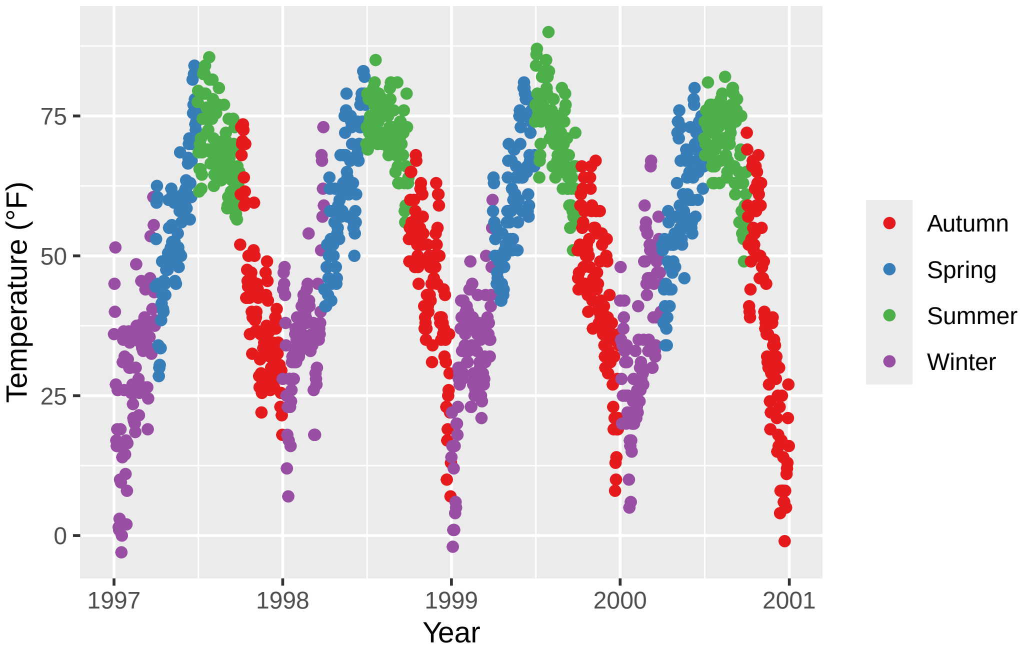
```
ga + scale_color_manual(values = c("dodgerblue4",
                                   "darkolivegreen4",
                                   "darkorchid3",
                                   "goldenrod1"))
```



10.3.2 Use Built-In Qualitative Color Palettes

The ColorBrewer palettes is a popular online tool for selecting color schemes for maps. The different sets of colors have been designed to produce attractive color schemes of similar appearance ranging from three to twelve. Those palettes are available as built-in functions in the `{ggplot2}` package and can be applied by calling `scale_*_brewer()`:

```
ga + scale_color_brewer(palette = "Set1")
```



> **Note**
>
> You can explore all schemes available via `RColorBrewer::display.brewer.all()`.

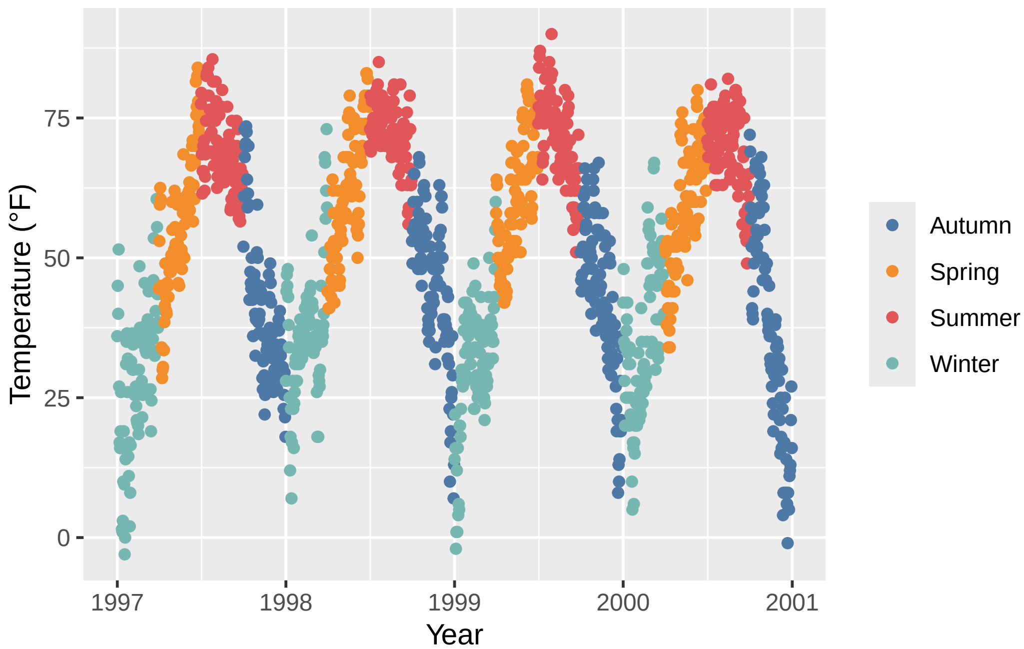
10.3.3 Use Qualitative Color Palettes from Extension Packages

There are many extension packages that provide additional color palettes. Their use differs depending on the way the package is designed. For an extensive overview of color palettes available in R, check the collection provided by Emil Hvitfeldt. One can also use his `{paletteer}` package, a comprehensive collection of color palettes in R that uses a consistent syntax.

Examples:

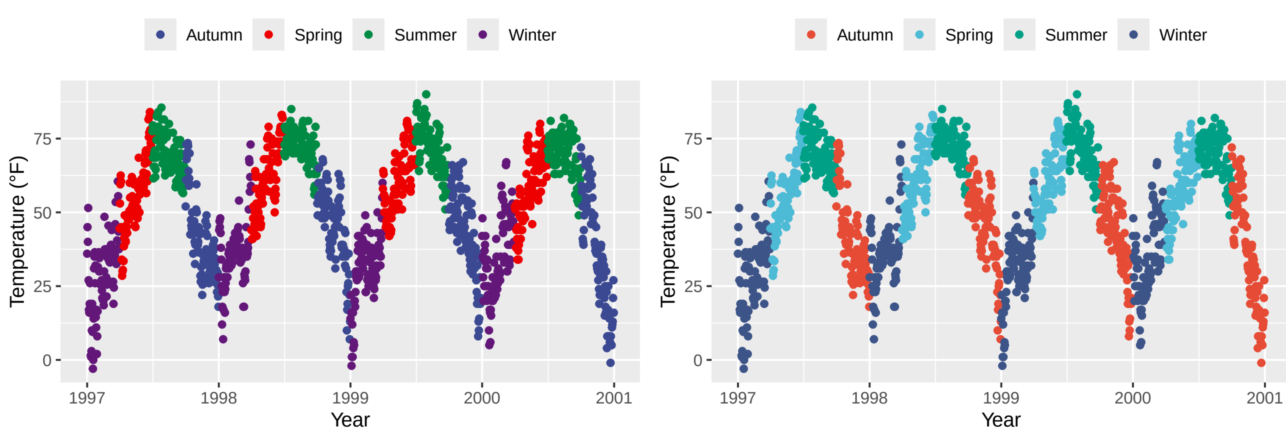
The `{ggthemes}` package for example lets R users access the Tableau colors. Tableau is a famous visualiztion software with a well-known color palette.

```
library(ggthemes)
ga + scale_color_tableau()
```



The {ggsci} package provides scientific journal and sci-fi themed color palettes. Want to have a plot with colors that look like being published in *Science* or *Nature*? Here you go!

```
library(ggsci)
g1 <- ga + scale_color_aaas()
g2 <- ga + scale_color_npg()

library(patchwork)
(g1 + g2) * theme(legend.position = "top")
```



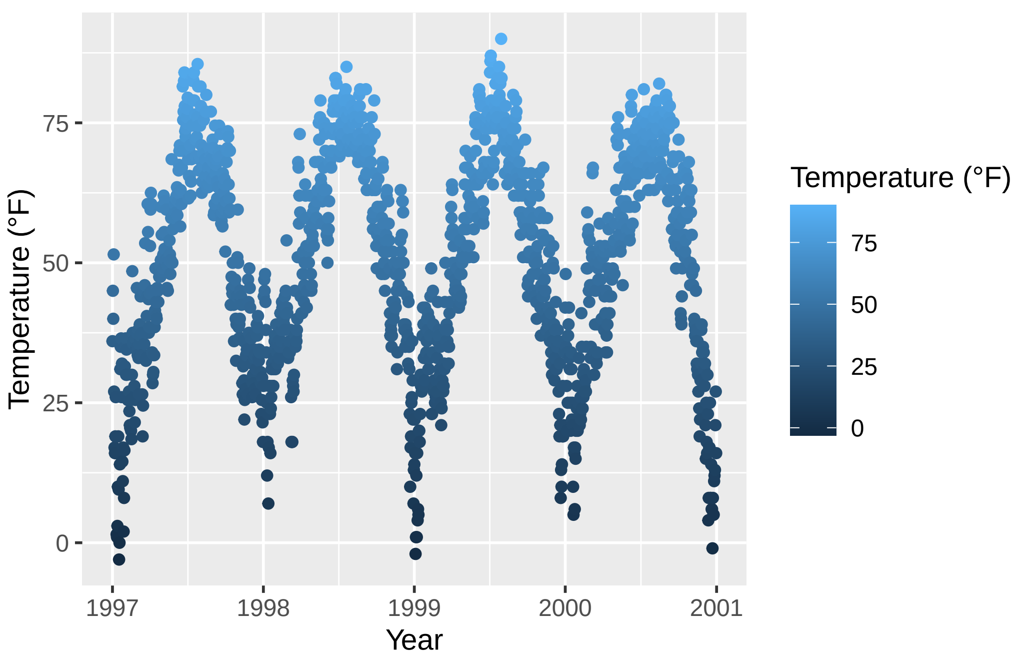
10.4 Quantitative Variables

Quantitative variables represent a measurable quantity and are thus numerical. Quantitative data can be further classified as being either continuous (floating numbers possible) or discrete (integers only):

In our example we will change the variable we want to color to ozone, a continuous variable that is strongly related to temperature (higher temperature = higher ozone). The function `scale_*_gradient()` is a sequential gradient while `scale_*_gradient2()` is diverging.

Here is the default `{ggplot2}` sequential color scheme for continuous variables:

```
gb <- ggplot(chic, aes(x = date, y = temp, color = temp)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)", color = "Temperature (°F):")

gb + scale_color_continuous()
```

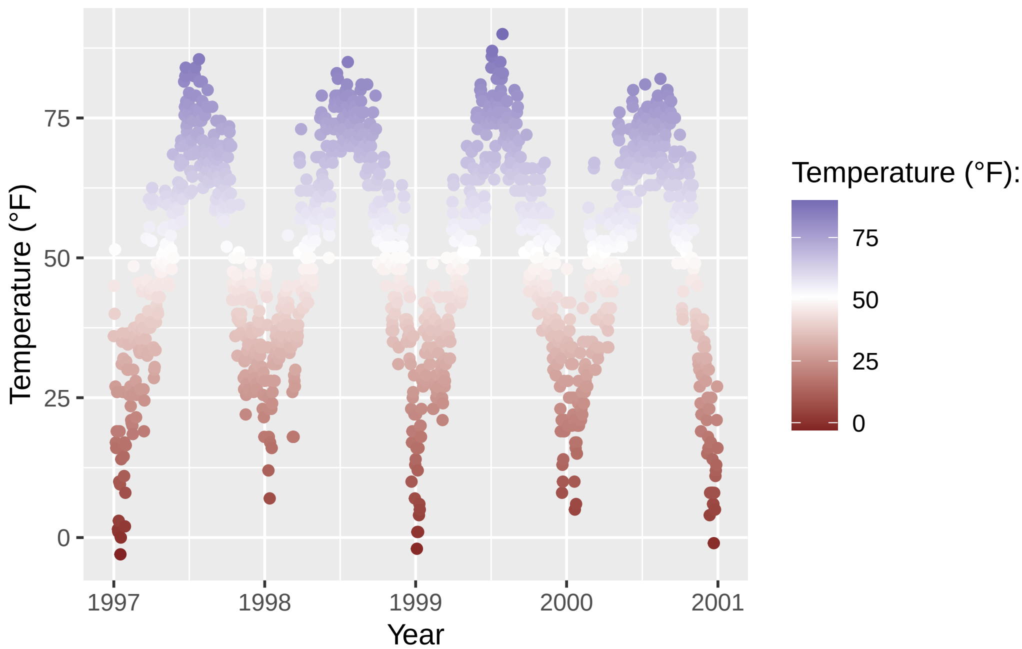


This code produces the same plot:

```
gb + scale_color_gradient()
```

And here is the diverging default color scheme:

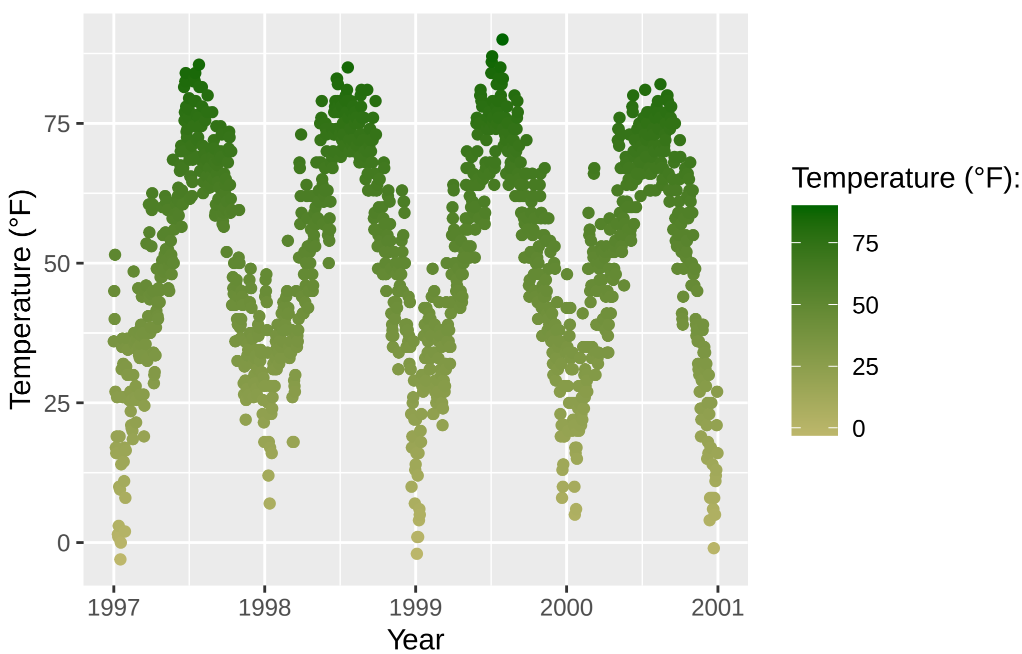
```
mid <- mean(chic$temp)  ## midpoint

gb + scale_color_gradient2(midpoint = mid)
```



10.4.1 Manually Set a Sequential Color Scheme

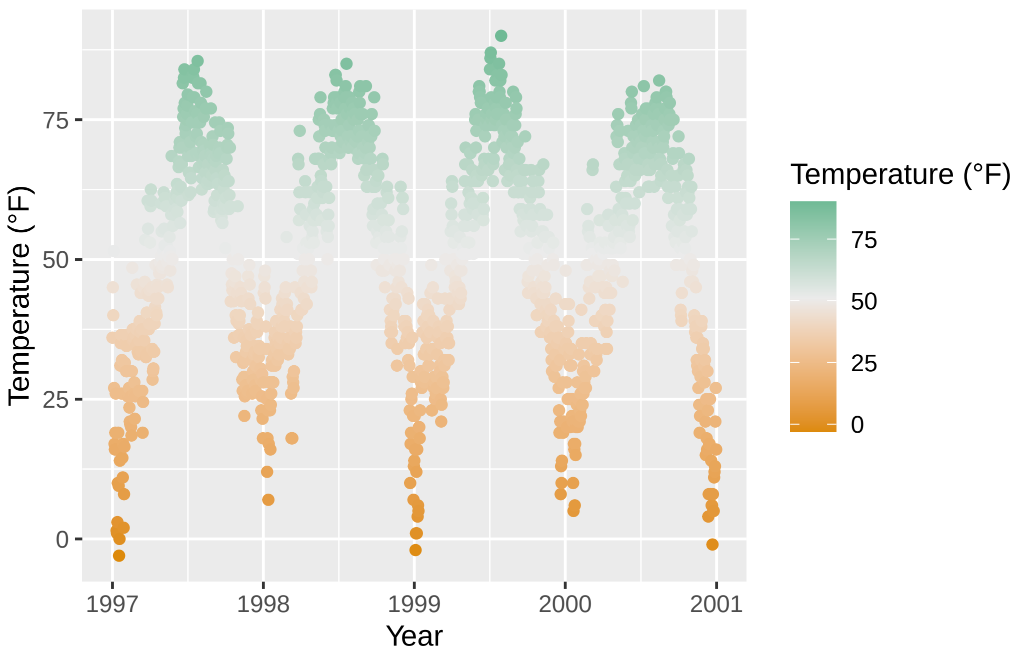
You can manually set gradually changing color palettes for continuous variables via `scale_*_gradient()`:

```
gb + scale_color_gradient(low = "darkkhaki",
                          high = "darkgreen")
```



Temperature data is normally distributed so how about a diverging color scheme (rather than sequential)... For diverging color you can use the `scale_*_gradient2()` function:

```
gb + scale_color_gradient2(midpoint = mid, low = "#dd8a0b",
                           mid = "grey92", high = "#32a676")
```

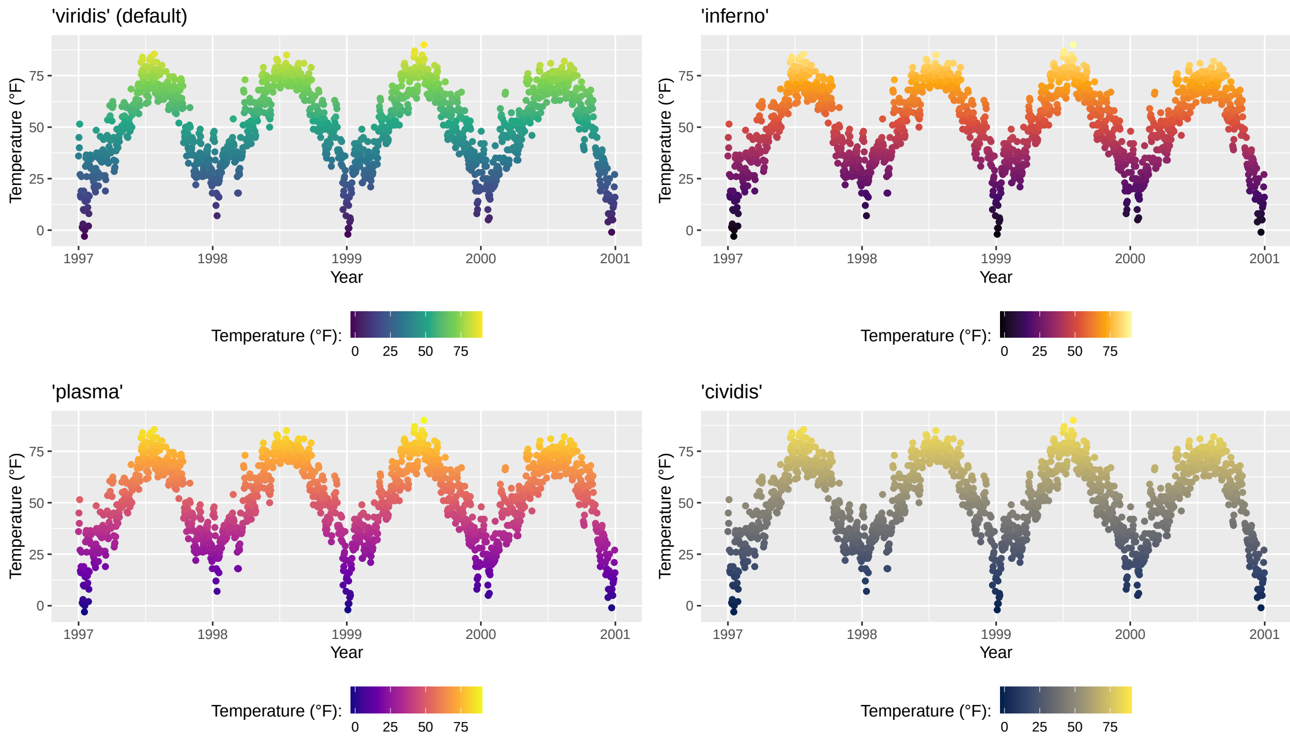


10.4.2 The Beautiful Viridis Color Palette

The **viridis** color palettes do not only make your plots look pretty and good to perceive but also easier to read by those with colorblindness and print well in gray scale. You can test how your plots might appear under various form of colorblindness using `{dichromat}` package.

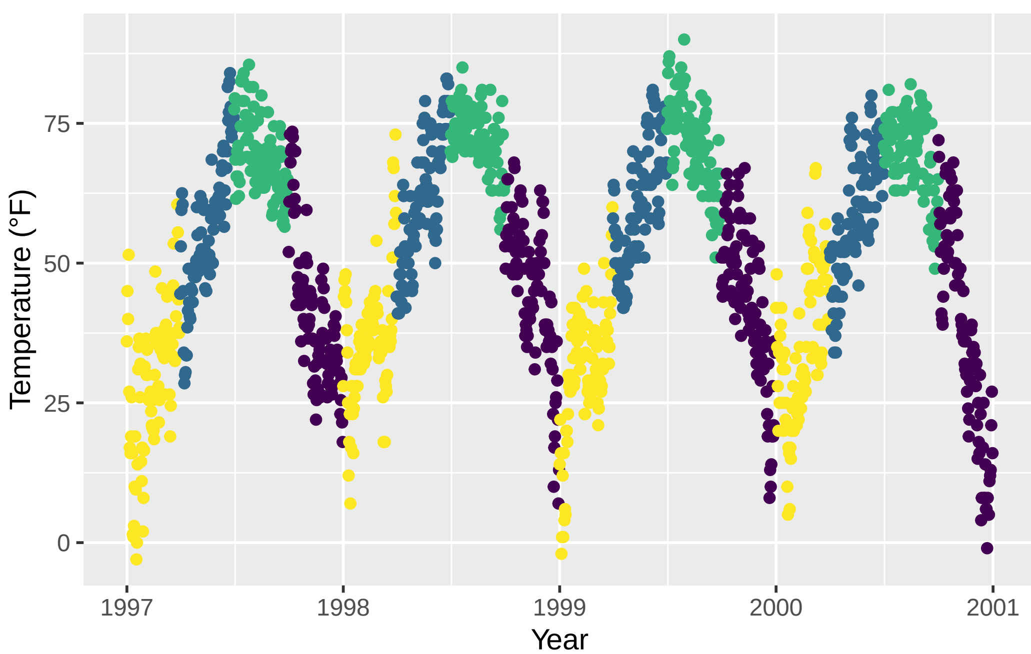
And they also come now shipped with `{ggplot2}`! The following multi-panel plot illustrates three out of the four viridis palettes:

```
p1 <- gb + scale_color_viridis_c() + ggtitle("'viridis' (default)")
p2 <- gb + scale_color_viridis_c(option = "inferno") + ggtitle("'inferno'")
p3 <- gb + scale_color_viridis_c(option = "plasma") + ggtitle("'plasma'")
p4 <- gb + scale_color_viridis_c(option = "cividis") + ggtitle("'cividis'")

library(patchwork)
(p1 + p2 + p3 + p4) * theme(legend.position = "bottom")
```



It is also possible to use the viridis color palettes for discrete variables:

```
ga + scale_color_viridis_d(guide = "none")
```



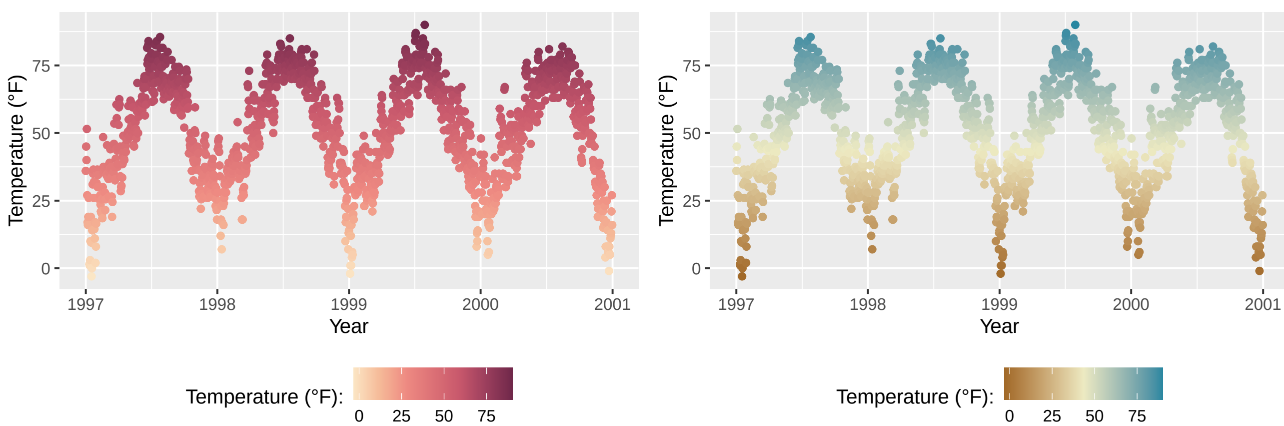
10.4.3 Use Quantitative Color Palettes from Extension Packages

The many extension packages provide not only additional categorical color palettes but also sequential, diverging and even cyclical palettes. Again, I point you to the great collection provided by Emil Hvitfeldt for an overview.

Examples:

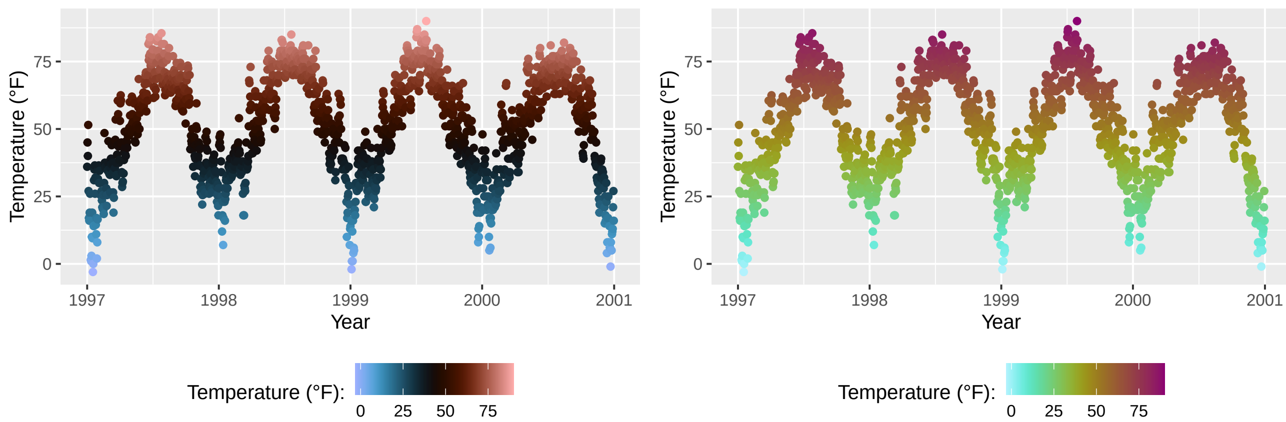
The `{rcartocolors}` packages ports the beautiful CARTOcolors to `{ggplot2}` and contains several of my most-used palettes:

```
library(rcartocolor)
g1 <- gb + scale_color_carto_c(palette = "BurgYl")
g2 <- gb + scale_color_carto_c(palette = "Earth")

(g1 + g2) * theme(legend.position = "bottom")
```



The `{scico}` package provides access to the color palettes developed by Fabio Crameri. These color palettes are not only beautiful and often unusual but also a good choice since they have been developed to be perceptually uniform and ordered. In addition, they work for people with color vision deficiency and in grayscale:

```
library(scico)
g1 <- gb + scale_color_scico(palette = "berlin")
g2 <- gb + scale_color_scico(palette = "hawaii", direction = -1)

(g1 + g2) * theme(legend.position = "bottom")
```



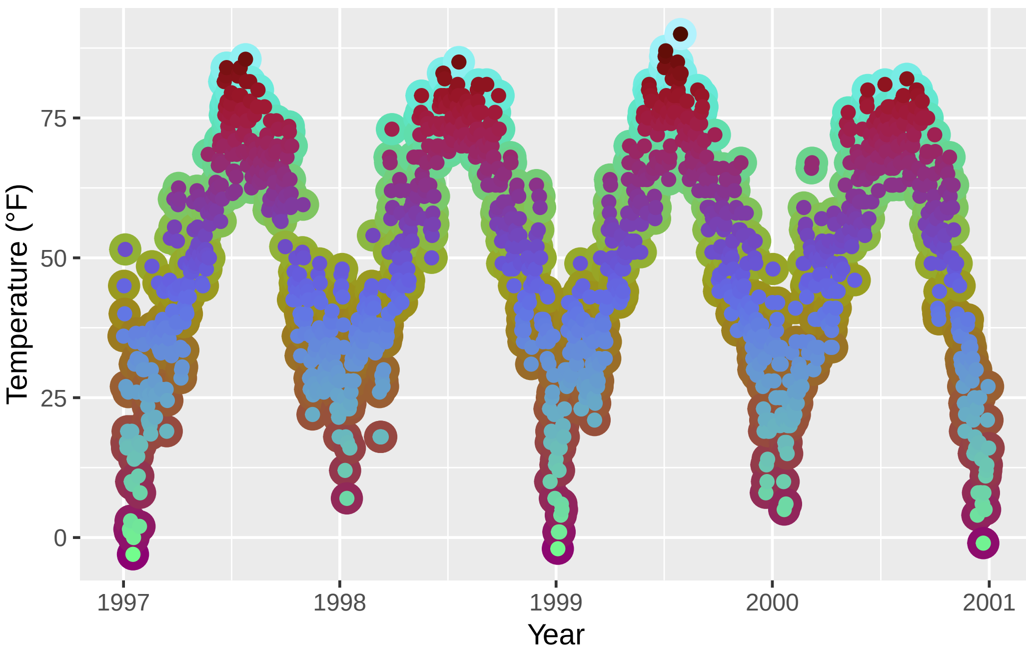
10.4.3.1 Modify Color Palettes Afterwards

Since the release of `ggplot2 3.0.0`, one can modify layer aesthetics after they have been mapped to the data. Or as the `{ggplot2}` phrases it: "Use `after_scale()` to flag evaluation of mapping for after data has been scaled."

So why not use the modified colors in the first place? Since `{ggplot2}` can only handle one `color` and one `fill` scale, this is an interesting functionality. Look closer at the following example where we use `clr_negate()` from the `{prismatic}` package:

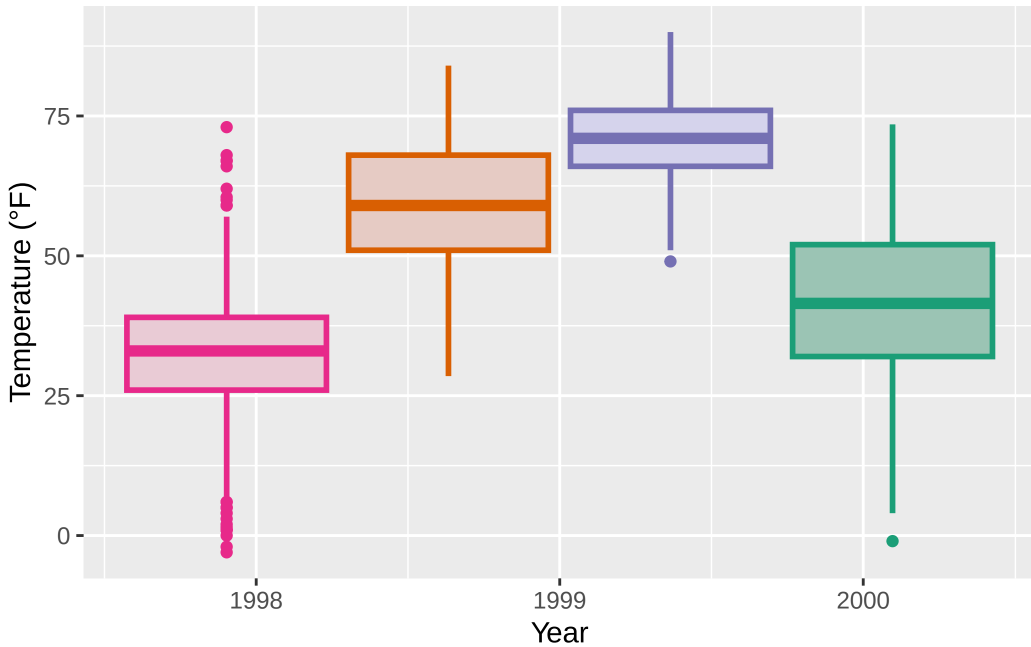
```
library(prismatic)

ggplot(chic, aes(date, temp, color = temp)) +
  geom_point(size = 5) +
  geom_point(aes(color = temp,
                 color = after_scale(clr_negate(color))),
             size = 2) +
  scale_color_scico(palette = "hawaii", guide = "none") +
  labs(x = "Year", y = "Temperature (°F)")
```

```
Warning: Duplicated aesthetics after name standardisation: colour
```



Changing the color scheme afterwards is especially fun with functions from the `{prismatic}` packages, namely `clr_negate()`, `clr_lighten()`, `clr_darken()` and `clr_desaturate()`. You can even combine those functions. Here, we plot a box plot that has both arguments, `color` and `fill`:

```
library(prismatic)

ggplot(chic, aes(date, temp)) +
  geom_boxplot(
    aes(color = season,
        fill = after_scale(clr_desaturate(clr_lighten(color, .6), .6))),
    linewidth = 1
  ) +
  scale_color_brewer(palette = "Dark2", guide = "none") +
  labs(x = "Year", y = "Temperature (°F)")
```



Note that you need to specify the `color` and/or `fill` in the `aes()` of the respective `geom_*()` or `stat_*()` to make `after_scale()` work.

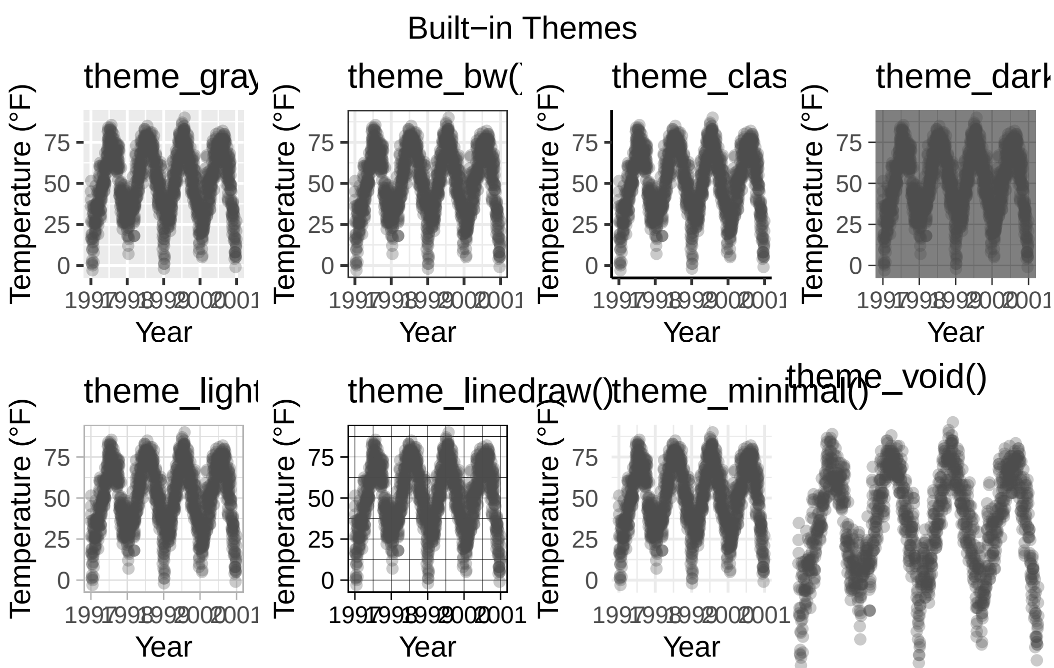
> **!** Important
>
> This seems a bit complicated for now—one could simply use the `color` and `fill` scales for both. Yes, that is true but think about use cases where you need several `color` and/or `fill` scales. In such a case, it would be senseless to occupy the `fill` scale with a slightly darker version of the palette used for `color`.

11 Working with Themes

11.1 Change the Overall Plotting Style

You can change the entire look of the plots by using themes. {ggplot2} comes with eight built-in themes:

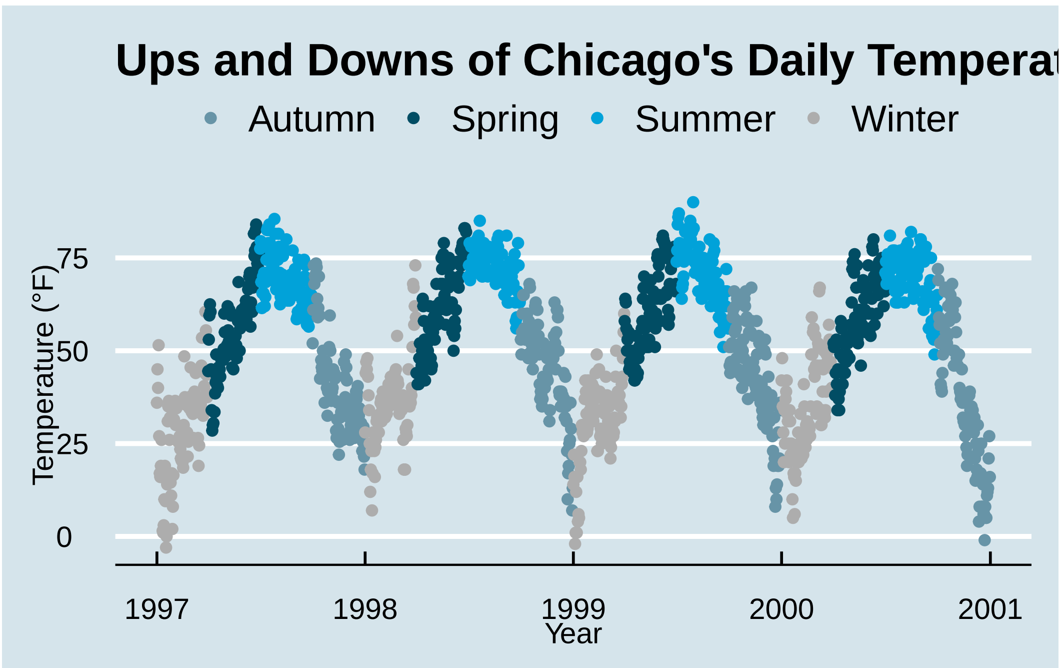
```
Attaching package: 'gridExtra'


The following object is masked from 'package:dplyr':

    combine
```



There are several packages that provide additional themes, some even with different default color palettes. As an example, Jeffrey Arnold has put together the library {ggthemes} with several custom themes imitating popular designs. For a list you can visit the {ggthemes} package site. Without any coding you can just adapt several styles, some of them well known for their style and aesthetics.

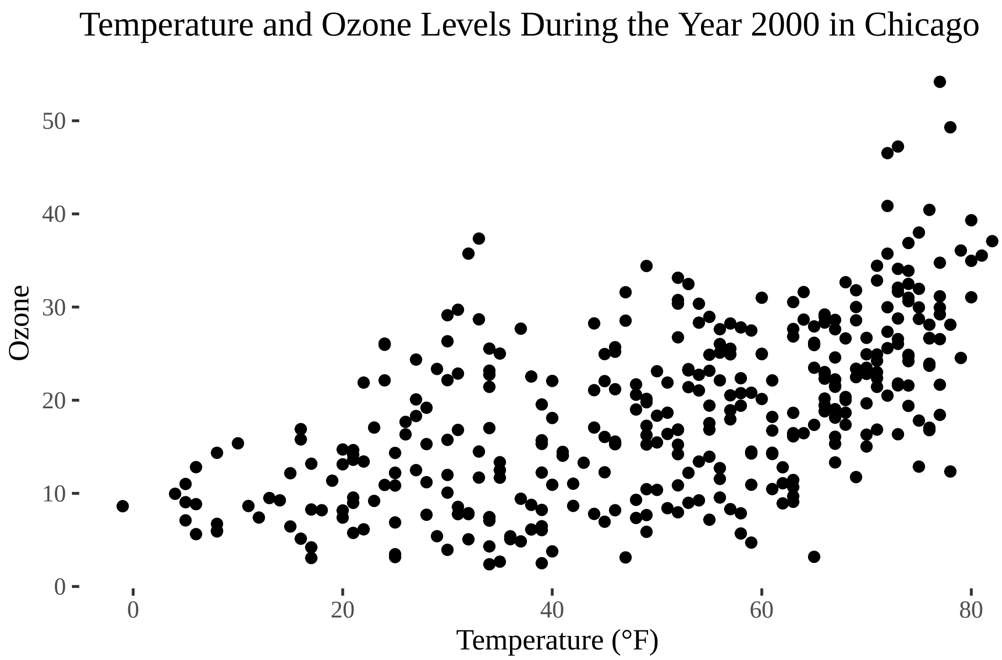
Here is an example copying the plotting style in the The Economist magazine by using `theme_economist()` and `scale_color_economist()`:

```
library(ggthemes)

ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  ggtitle("Ups and Downs of Chicago's Daily Temperatures") +
  theme_economist() +
  scale_color_economist(name = NULL)
```



Another example is the plotting style of Tufte, a minimal ink theme based on Edward Tufte's book The Visual Display of Quantitative Information. This is the book that popularized Minard's chart depicting Napoleon's march on Russia as one of the **best statistical drawings ever created**. Tufte's plots became famous due to the purism in their style. But see yourself:

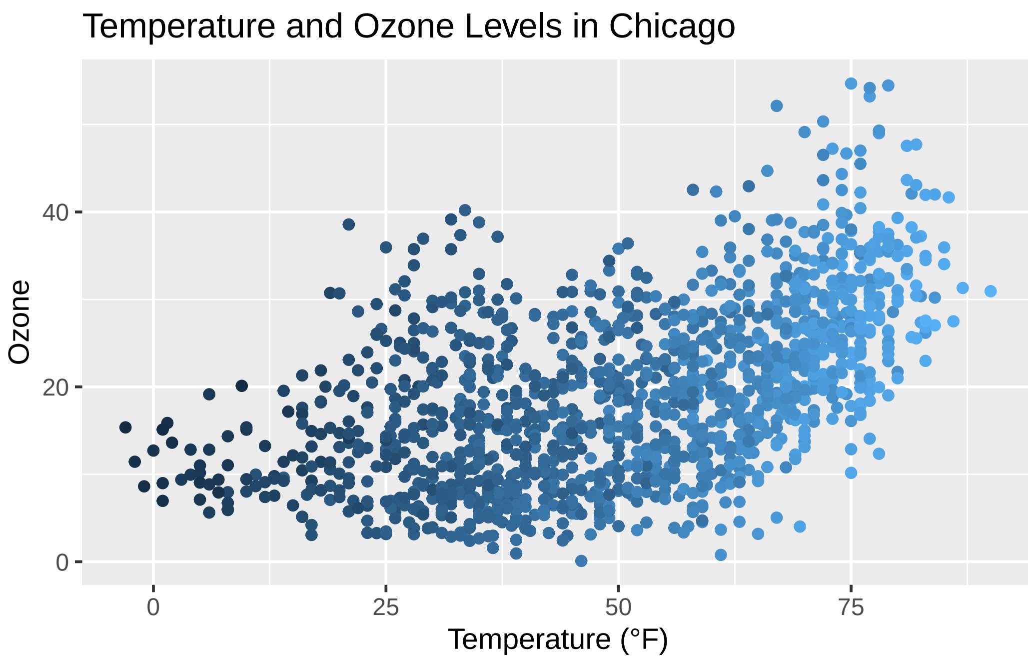
```
library(dplyr)
chic_2000 <- filter(chic, year == 2000)

ggplot(chic_2000, aes(x = temp, y = o3)) +
  geom_point() +
  labs(x = "Temperature (°F)", y = "Ozone") +
  ggtitle("Temperature and Ozone Levels During the Year 2000 in Chicago") +
  theme_tufte()
```



I reduced the number of data points here simply to fit it Tufte's minimalism style. If you like the way of plotting have a look on this blog entry creating several Tufte plots in R.

Another neat packages with modern themes and a preset of non-default fonts is the `{hrbrthemes}` package by Bob Rudis with several light but also dark themes:

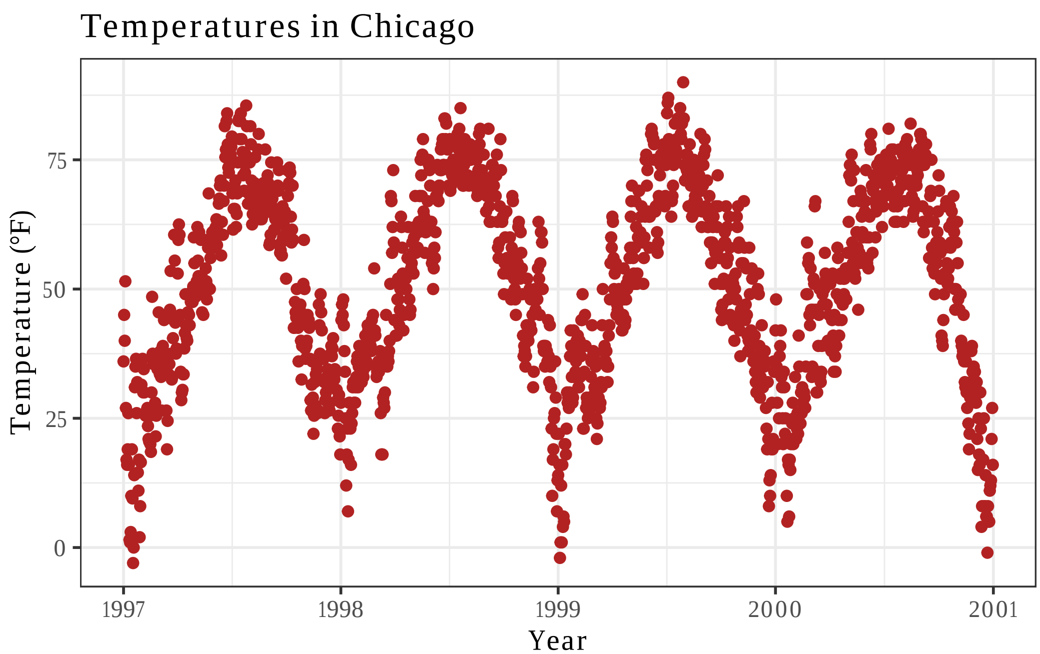
```
library(hrbrthemes)

ggplot(chic, aes(x = temp, y = o3)) +
  geom_point(aes(color = dewpoint), show.legend = FALSE) +
  labs(x = "Temperature (°F)", y = "Ozone") +
  ggtitle("Temperature and Ozone Levels in Chicago")
```



11.2 Change the Font of All Text Elements

It is incredibly easy to change the settings of all the text elements at once. All themes come with an argument called `base_family`:

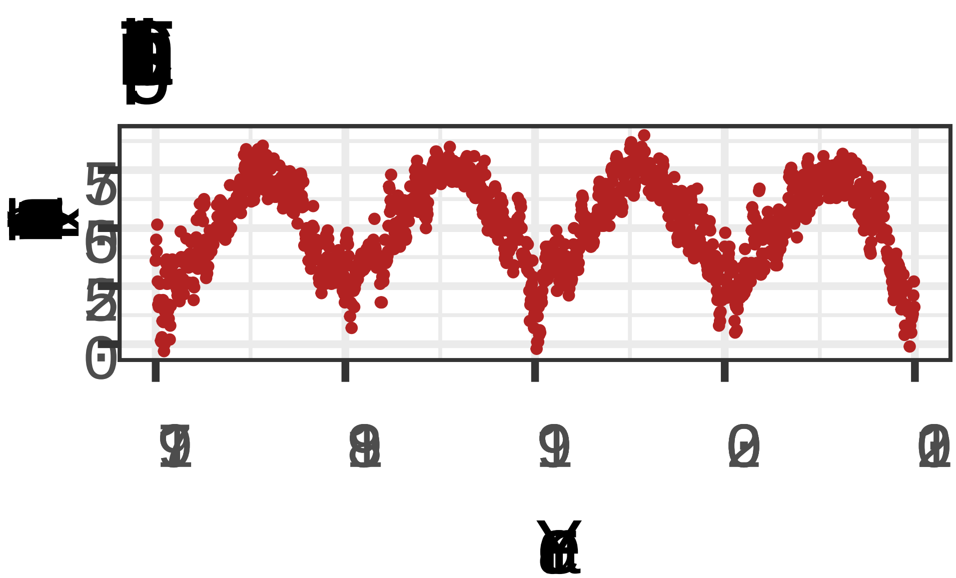
```
g <- ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "firebrick") +
  labs(x = "Year", y = "Temperature (°F)",
       title = "Temperatures in Chicago")

g + theme_bw(base_family = "Playfair Display")
```



11.3 Change the Size of All Text Elements

The `theme_*()` functions also come with several other `base_*` arguments. If you have a closer look at the default theme (see chapter "Create and Use Your Custom Theme" below) you will notice that the sizes of all the elements are relative (`rel()`) to the `base_size`. As a result, you can simply change the `base_size` if you want to increase readability of your plots:

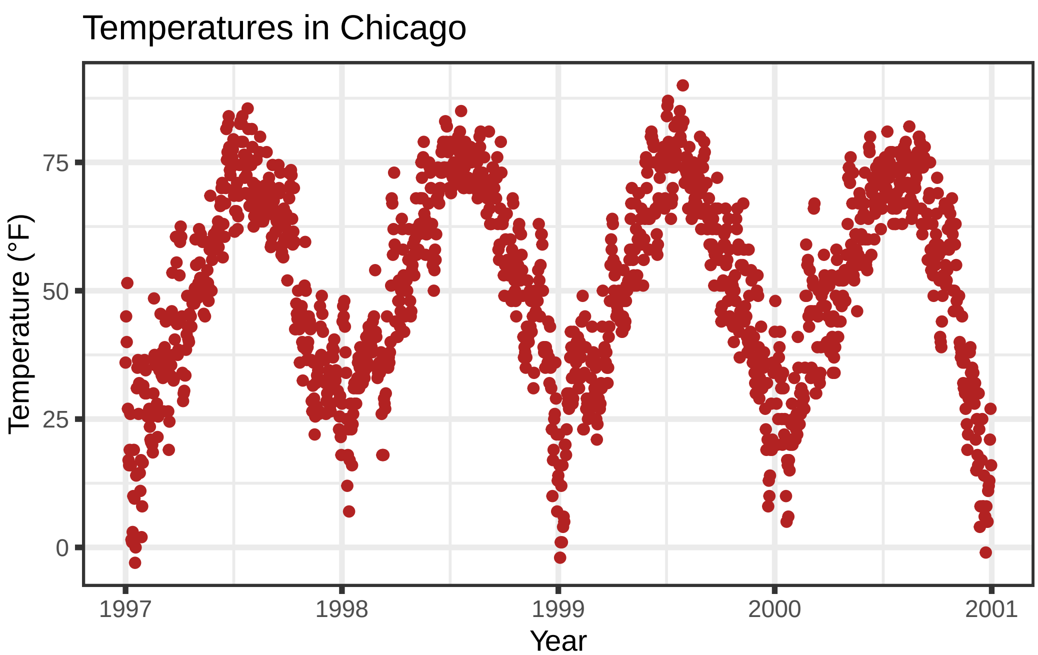
```
g + theme_bw(base_size = 30, base_family = "Roboto Condensed")
```



11.4 Change the Size of All Line and Rect Elements

Similarly, you can change the size of all elements of type `line` and `rect`:

```
g + theme_bw(base_line_size = 1, base_rect_size = 1)
```



11.5 Create Your Own Theme

If you want to change the theme for an entire session you can use `theme_set` as in `theme_set(theme_bw())`. The default is called `theme_gray` (or `theme_gray`). If you wanted to create your own custom theme, you could extract the code directly from the gray theme and modify. Note that the `rel()` function change the sizes relative to the `base_size`.

```
theme_gray
```

```
function (base_size = 11, base_family = "", base_line_size = base_size/22,
    base_rect_size = base_size/22)
{
    half_line <- base_size/2
    t <- theme(line = element_line(colour = "black", linewidth = base_line_size,
        linetype = 1, lineend = "butt"), rect = element_rect(fill = "white",
        colour = "black", linewidth = base_rect_size, linetype = 1),
        text = element_text(family = base_family, face = "plain",
```

```
        colour = "black", size = base_size, lineheight = 0.9,
        hjust = 0.5, vjust = 0.5, angle = 0, margin = margin(),
        debug = FALSE), axis.line = element_blank(), axis.line.x = NULL,
    axis.line.y = NULL, axis.text = element_text(size = rel(0.8),
        colour = "grey30"), axis.text.x = element_text(margin = margin(t = 0.8 *
     half_line/2), vjust = 1), axis.text.x.top = element_text(margin = margin(b = 0.8 *
       half_line/2), vjust = 0), axis.text.y = element_text(margin = margin(r = 0.8 *
    half_line/2), hjust = 1), axis.text.y.right = element_text(margin = margin(l = 0.8 *
       half_line/2), hjust = 0), axis.text.r = element_text(margin = margin(l = 0.8 *
        half_line/2, r = 0.8 * half_line/2), hjust = 0.5),
   axis.ticks = element_line(colour = "grey20"), axis.ticks.length = unit(half_line/2,
        "pt"), axis.ticks.length.x = NULL, axis.ticks.length.x.top = NULL,
    axis.ticks.length.x.bottom = NULL, axis.ticks.length.y = NULL,
    axis.ticks.length.y.left = NULL, axis.ticks.length.y.right = NULL,
axis.minor.ticks.length = rel(0.75), axis.title.x = element_text(margin = margin(t = half_line/2),
        vjust = 1), axis.title.x.top = element_text(margin = margin(b = half_line/2),
        vjust = 0), axis.title.y = element_text(angle = 90,
    margin = margin(r = half_line/2), vjust = 1), axis.title.y.right = element_text(angle = -90,
    margin = margin(l = half_line/2), vjust = 1), legend.background = element_rect(colour = NA),
    legend.spacing = unit(2 * half_line, "pt"), legend.spacing.x = NULL,
    legend.spacing.y = NULL, legend.margin = margin(half_line,
        half_line, half_line, half_line), legend.key = NULL,
    legend.key.size = unit(1.2, "lines"), legend.key.height = NULL,
    legend.key.width = NULL, legend.key.spacing = unit(half_line,
        "pt"), legend.text = element_text(size = rel(0.8)),
    legend.title = element_text(hjust = 0), legend.ticks.length = rel(0.2),
  legend.position = "right", legend.direction = NULL, legend.justification = "center",
    legend.box = NULL, legend.box.margin = margin(0, 0, 0,
        0, "cm"), legend.box.background = element_blank(),
legend.box.spacing = unit(2 * half_line, "pt"), panel.background = element_rect(fill = "grey92",
    colour = NA), panel.border = element_blank(), panel.grid = element_line(colour = "white"),
    panel.grid.minor = element_line(linewidth = rel(0.5)),
    panel.spacing = unit(half_line, "pt"), panel.spacing.x = NULL,
panel.spacing.y = NULL, panel.ontop = FALSE, strip.background = element_rect(fill = "grey85",
     colour = NA), strip.clip = "inherit", strip.text = element_text(colour = "grey10",
        size = rel(0.8), margin = margin(0.8 * half_line,
            0.8 * half_line, 0.8 * half_line, 0.8 * half_line)),
    strip.text.x = NULL, strip.text.y = element_text(angle = -90),
    strip.text.y.left = element_text(angle = 90), strip.placement = "inside",
strip.placement.x = NULL, strip.placement.y = NULL, strip.switch.pad.grid = unit(half_line/2,
        "pt"), strip.switch.pad.wrap = unit(half_line/2,
        "pt"), plot.background = element_rect(colour = "white"),
    plot.title = element_text(size = rel(1.2), hjust = 0,
        vjust = 1, margin = margin(b = half_line)), plot.title.position = "panel",
  plot.subtitle = element_text(hjust = 0, vjust = 1, margin = margin(b = half_line)),
```

```
        plot.caption = element_text(size = rel(0.8), hjust = 1,
            vjust = 1, margin = margin(t = half_line)), plot.caption.position = "panel",
        plot.tag = element_text(size = rel(1.2), hjust = 0.5,
            vjust = 0.5), plot.tag.position = "topleft", plot.margin = margin(half_line,
            half_line, half_line, half_line), complete = TRUE)
    ggplot_global$theme_all_null %+replace% t
}
<bytecode: 0x00000177b8d501b8>
<environment: namespace:ggplot2>
```

Now, let us modify the default theme function and have a look at the result:

```
theme_2hin <- function (base_size = 12, base_family = "Roboto Condensed") {
  half_line <- base_size/2
  theme(
    line = element_line(color = "black", linewidth = .5,
                        linetype = 1, lineend = "butt"),
    rect = element_rect(fill = "white", color = "black",
                        linewidth = .5, linetype = 1),
    text = element_text(family = base_family, face = "plain",
                        color = "black", size = base_size,
                        lineheight = .9, hjust = .5, vjust = .5,
                        angle = 0, margin = margin(), debug = FALSE),
    axis.line = element_blank(),
    axis.line.x = NULL,
    axis.line.y = NULL,
    axis.text = element_text(size = base_size * 1.1, color = "gray30"),
    axis.text.x = element_text(margin = margin(t = .8 * half_line/2),
                               vjust = 1),
    axis.text.x.top = element_text(margin = margin(b = .8 * half_line/2),
                                   vjust = 0),
    axis.text.y = element_text(margin = margin(r = .8 * half_line/2),
                               hjust = 1),
    axis.text.y.right = element_text(margin = margin(l = .8 * half_line/2),
                                     hjust = 0),
    axis.ticks = element_line(color = "gray30", linewidth = .7),
    axis.ticks.length = unit(half_line / 1.5, "pt"),
    axis.ticks.length.x = NULL,
    axis.ticks.length.x.top = NULL,
    axis.ticks.length.x.bottom = NULL,
    axis.ticks.length.y = NULL,
    axis.ticks.length.y.left = NULL,
    axis.ticks.length.y.right = NULL,
    axis.title.x = element_text(margin = margin(t = half_line),
```

```
                            vjust = 1, size = base_size * 1.3,
                            face = "bold"),
    axis.title.x.top = element_text(margin = margin(b = half_line),
                                vjust = 0),
    axis.title.y = element_text(angle = 90, vjust = 1,
                            margin = margin(r = half_line),
                            size = base_size * 1.3, face = "bold"),
    axis.title.y.right = element_text(angle = -90, vjust = 0,
                                  margin = margin(l = half_line)),
    legend.background = element_rect(color = NA),
    legend.spacing = unit(.4, "cm"),
    legend.spacing.x = NULL,
    legend.spacing.y = NULL,
    legend.margin = margin(.2, .2, .2, .2, "cm"),
    legend.key = element_rect(fill = "gray95", color = "white"),
    legend.key.size = unit(1.2, "lines"),
    legend.key.height = NULL,
    legend.key.width = NULL,
    legend.text = element_text(size = rel(.8)),
    legend.text.align = NULL,
    legend.title = element_text(hjust = 0),
    legend.title.align = NULL,
    legend.position = "right",
    legend.direction = NULL,
    legend.justification = "center",
    legend.box = NULL,
    legend.box.margin = margin(0, 0, 0, 0, "cm"),
    legend.box.background = element_blank(),
    legend.box.spacing = unit(.4, "cm"),
    panel.background = element_rect(fill = "white", color = NA),
    panel.border = element_rect(color = "gray30",
                            fill = NA, linewidth = .7),
    panel.grid.major = element_line(color = "gray90", linewidth = 1),
    panel.grid.minor = element_line(color = "gray90", linewidth = .5,
                                linetype = "dashed"),
    panel.spacing = unit(base_size, "pt"),
    panel.spacing.x = NULL,
    panel.spacing.y = NULL,
    panel.ontop = FALSE,
    strip.background = element_rect(fill = "white", color = "gray30"),
    strip.text = element_text(color = "black", size = base_size),
    strip.text.x = element_text(margin = margin(t = half_line,
                                            b = half_line)),
    strip.text.y = element_text(angle = -90,
```

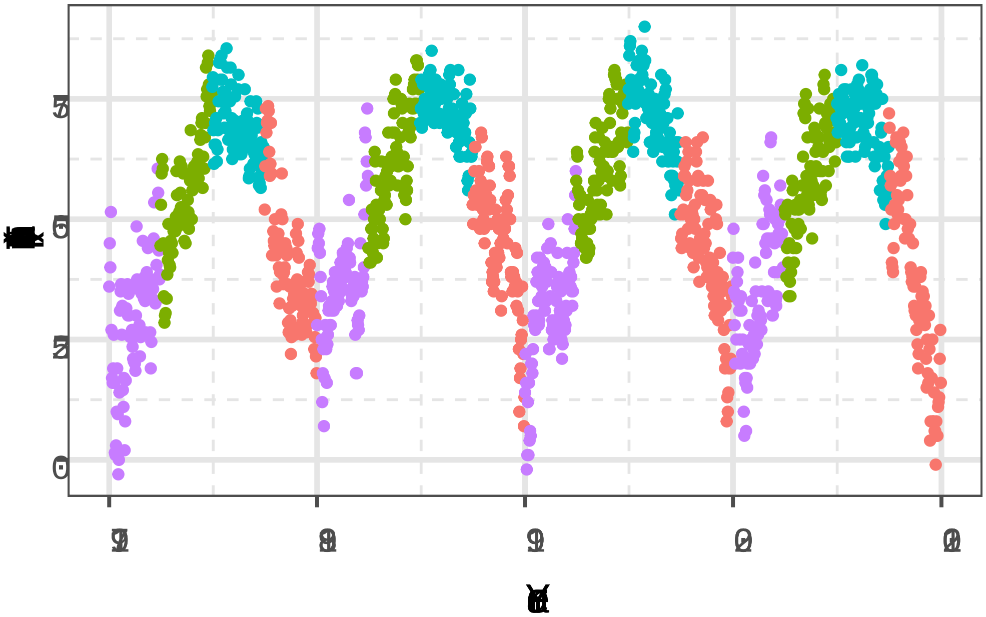
```
                                margin = margin(l = half_line,
                                                r = half_line)),
    strip.text.y.left = element_text(angle = 90),
    strip.placement = "inside",
    strip.placement.x = NULL,
    strip.placement.y = NULL,
    strip.switch.pad.grid = unit(0.1, "cm"),
    strip.switch.pad.wrap = unit(0.1, "cm"),
    plot.background = element_rect(color = NA),
    plot.title = element_text(size = base_size * 1.8, hjust = .5,
                              vjust = 1, face = "bold",
                              margin = margin(b = half_line * 1.2)),
    plot.title.position = "panel",
    plot.subtitle = element_text(size = base_size * 1.3,
                                 hjust = .5, vjust = 1,
                                 margin = margin(b = half_line * .9)),
    plot.caption = element_text(size = rel(0.9), hjust = 1, vjust = 1,
                                margin = margin(t = half_line * .9)),
    plot.caption.position = "panel",
    plot.tag = element_text(size = rel(1.2), hjust = .5, vjust = .5),
    plot.tag.position = "topleft",
    plot.margin = margin(rep(base_size, 4)),
    complete = TRUE
  )
}
```

Note

You can only overwrite the defaults for all elements you want to change. Here I listed all. so you can see that you can change *literally* everything!

Have a look on the modified aesthetics with its new look of panel and gridlines as well as axes ticks, texts and titles:

```
theme_set(theme_2hin())

ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() + labs(x = "Year", y = "Temperature (°F)") + guides(color = "none")
```

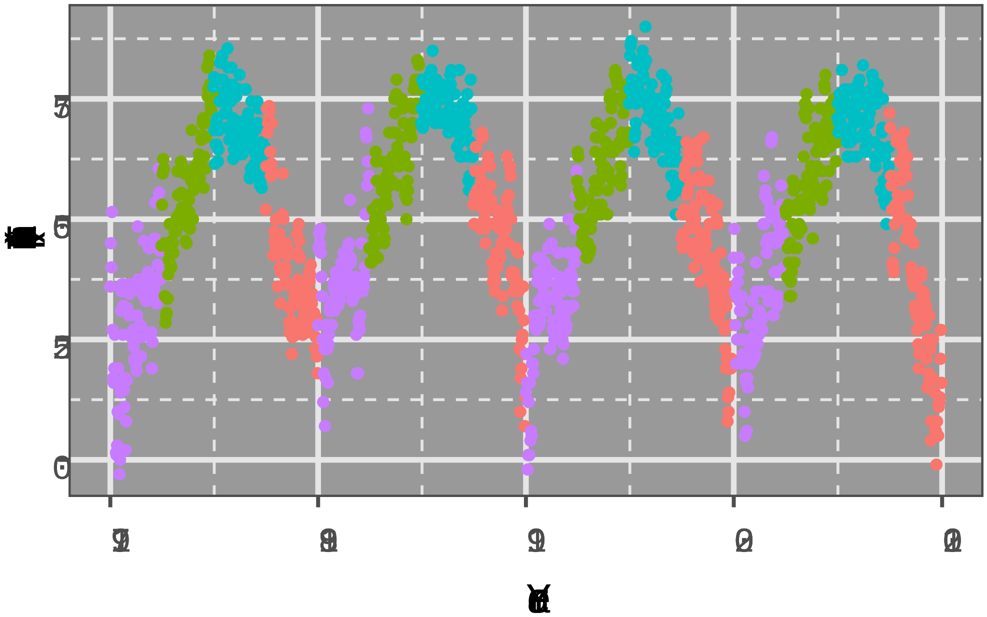


This way of changing the plot design is highly recommended! It allows you to quickly change any element of your plots by changing it once. You can within a few seconds plot all your results in a congruent style and adapt it to other needs (e.g. a presentation with bigger font size or journal requirements).

11.6 Update the Current Theme

You can also set quick changes using `theme_update()`:

```
theme_2hin <- theme_update(panel.background = element_rect(fill = "gray60"))

ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point() + labs(x = "Year", y = "Temperature (°F)") + guides(color = "none")
```



For further exercises, we are going to use our own theme with a white filling and without the minor grid lines:

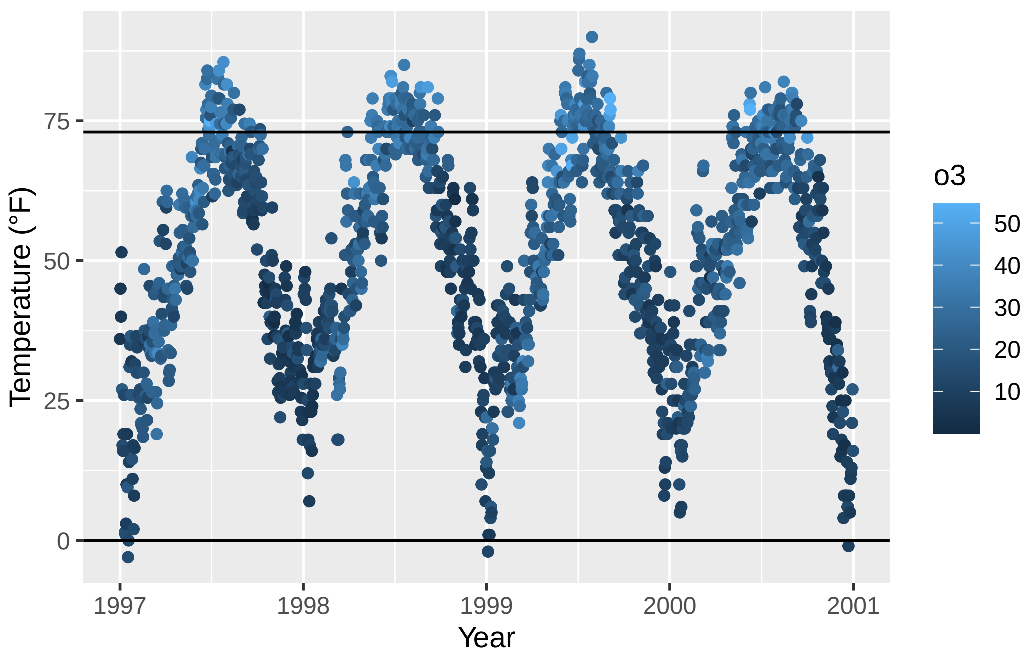
```
theme_2hin <- theme_update(
  panel.background = element_rect(fill = "white"),
  panel.grid.major = element_line(linewidth = .5),
  panel.grid.minor = element_blank()
)
```

12 Working with Lines

12.1 Add Horizonal or Vertical Lines to a Plot

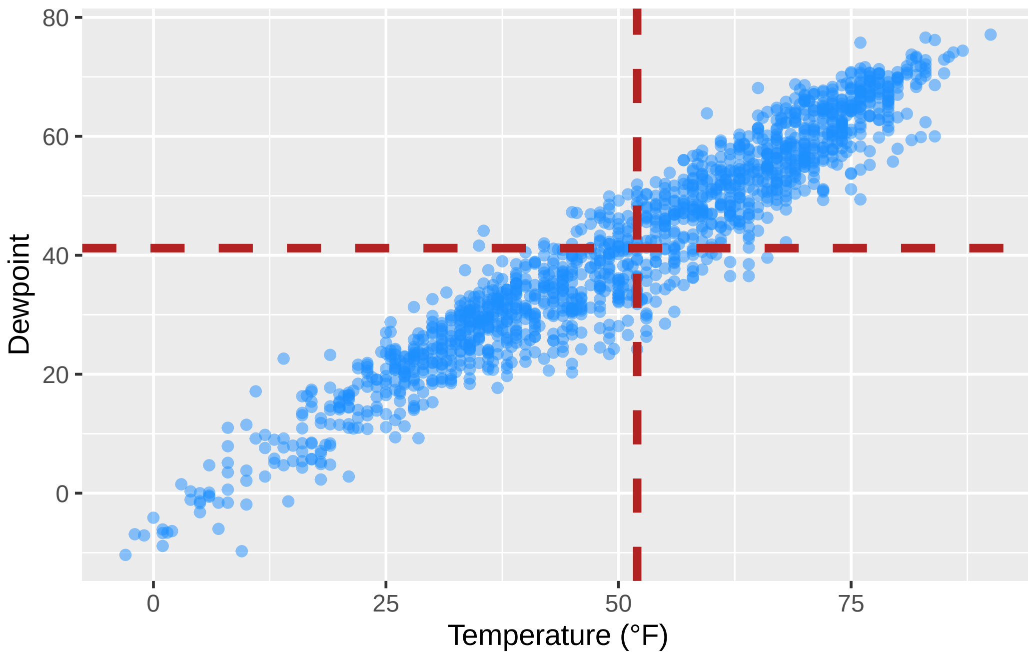
You might want to highlight a given range or threshold, which can be done plotting a line at defined coordinates using `geom_hline()` (for "horizontal lines") or `geom_vline()` (for "vertical lines"):

```
ggplot(chic, aes(x = date, y = temp, color = o3)) +
  geom_point() +
  geom_hline(yintercept = c(0, 73)) +
  labs(x = "Year", y = "Temperature (°F)")
```



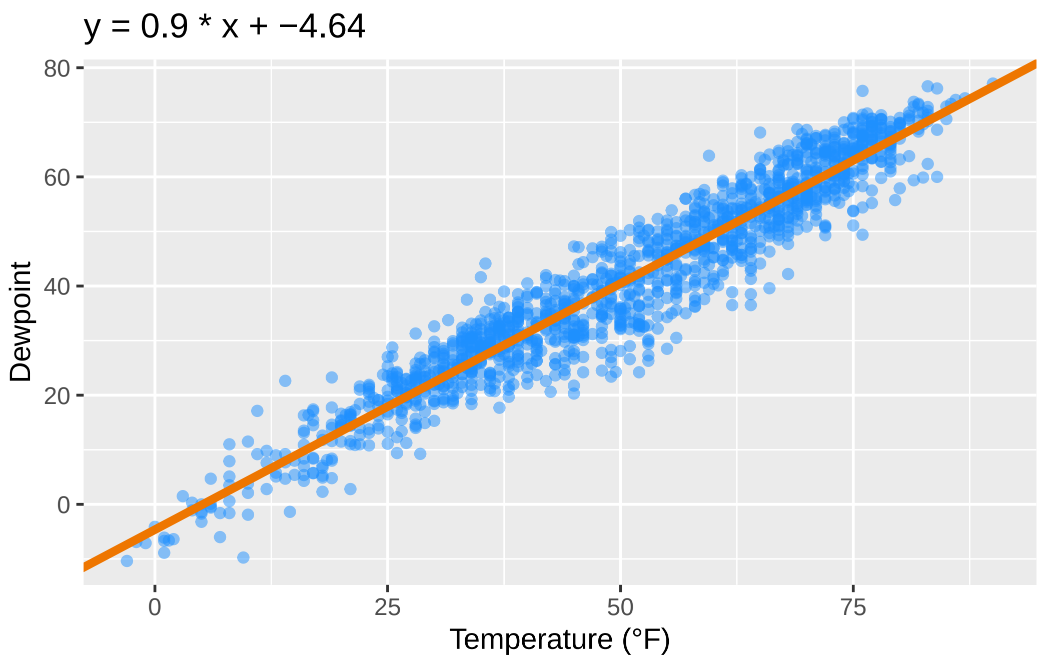

```
g <- ggplot(chic, aes(x = temp, y = dewpoint)) +
  geom_point(color = "dodgerblue", alpha = .5) +
  labs(x = "Temperature (°F)", y = "Dewpoint")

g +
  geom_vline(aes(xintercept = median(temp)), linewidth = 1.5,
             color = "firebrick", linetype = "dashed") +
```

```
  geom_hline(aes(yintercept = median(dewpoint)), linewidth = 1.5,
             color = "firebrick", linetype = "dashed")
```



If you want to add a line with a slope not being 0 or 1, respectively, you need to use `geom_abline()`. This is for example the case if you want to add a regression line using the arguments `intercept` and `slope`:

```
reg <- lm(dewpoint ~ temp, data = chic)

g +
  geom_abline(intercept = coefficients(reg)[1],
              slope = coefficients(reg)[2],
              color = "darkorange2",
              linewidth = 1.5) +
  labs(title = paste0("y = ", round(coefficients(reg)[2], 2),
                      " * x + ", round(coefficients(reg)[1], 2)))
```

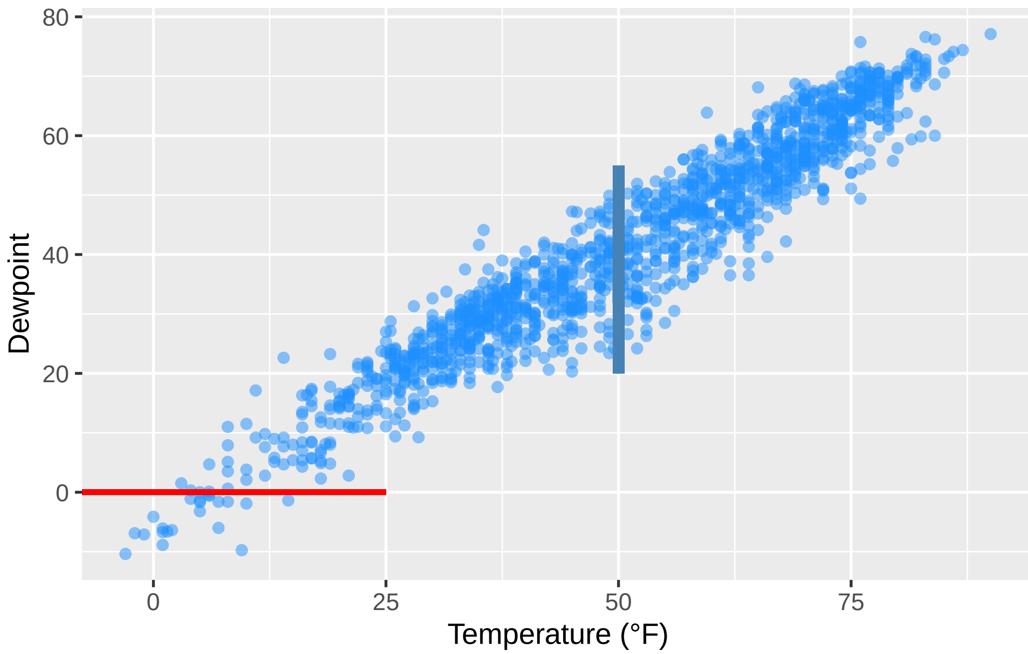


Later, we will learn how to add a linear fit with one command using `stat_smooth(method = "lm")`. However, there might be other reasons to add a line with a given slope and this is how one does it 🤷

12.2 Add a Line within a Plot

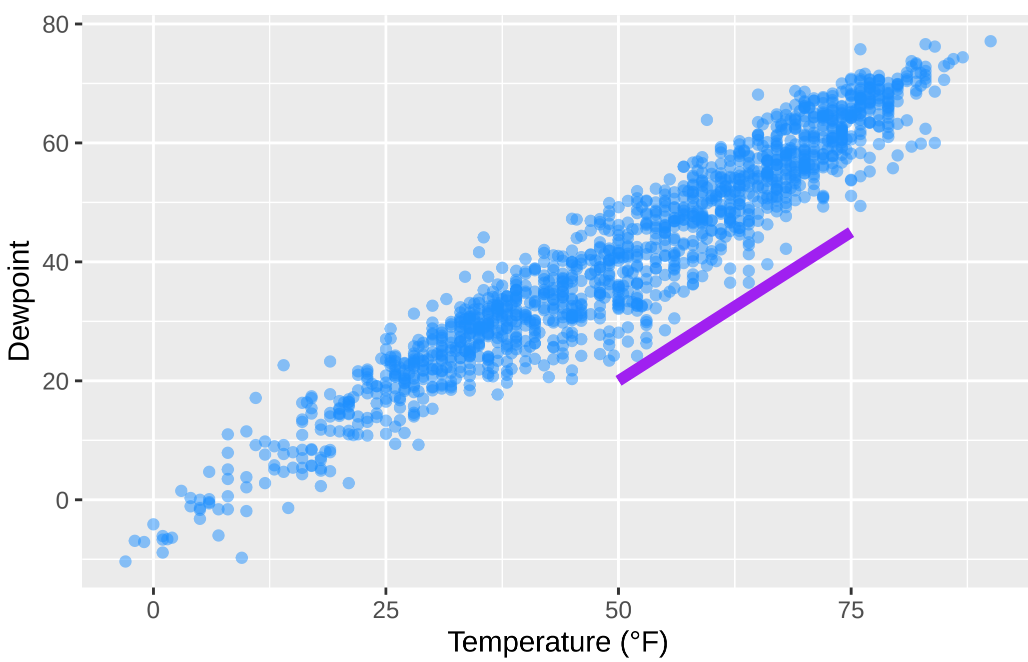
The previous approaches always covered the whole range of the plot panel, but sometimes one wants to highlight only a given area or use lines for annotations. In this case, `geom_linerange()` is here to help:

```
g +
  ## vertical line
  geom_linerange(aes(x = 50, ymin = 20, ymax = 55),
                 color = "steelblue", linewidth = 2) +
  ## horizontal line
  geom_linerange(aes(xmin = -Inf, xmax = 25, y = 0),
                 color = "red", linewidth = 1)
```



Or you can use `annotate(geom = "segment")` to draw lines with a slope differing from 0 and 1:

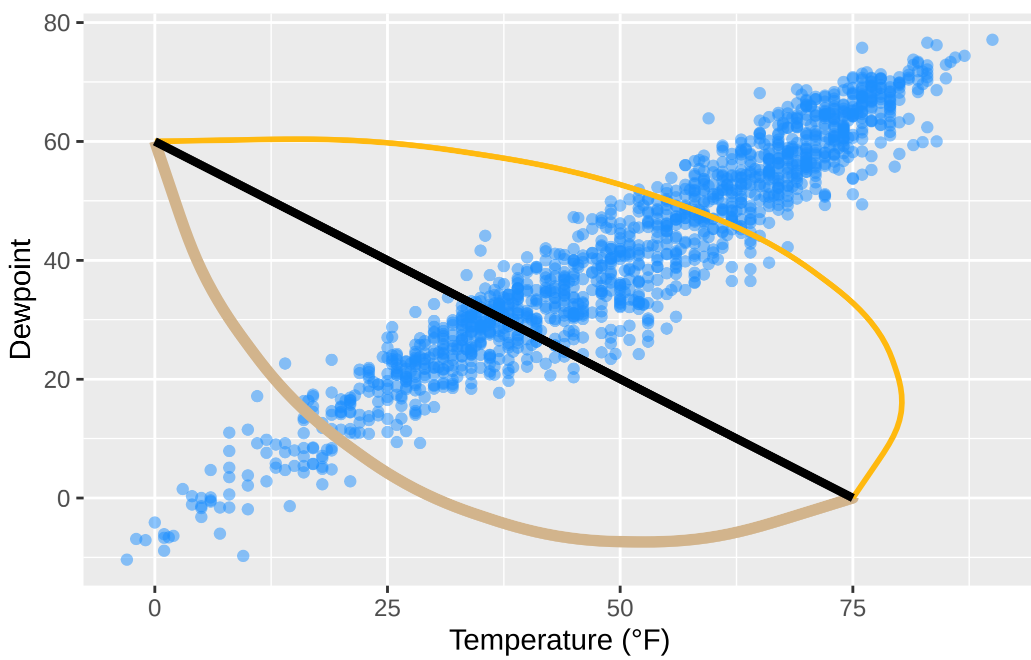
```
g +
  annotate(geom = "segment",
           x = 50, xend = 75,
                   y = 20, yend = 45,
               color = "purple", linewidth = 2)
```



12.3 Add Curved Lines and Arrows to a Plot

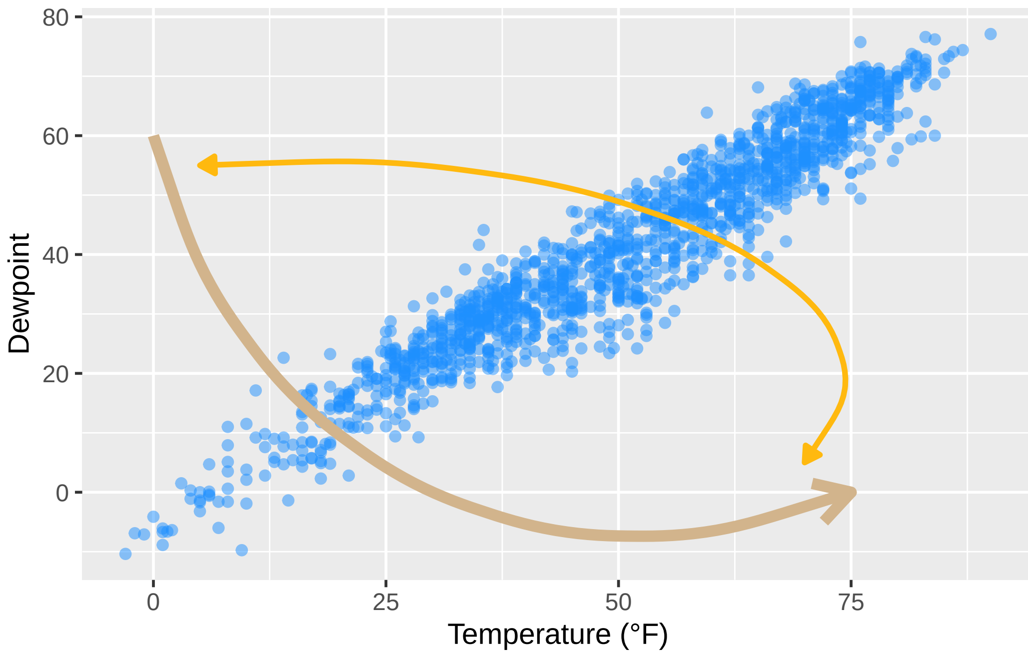
`annotate(geom = "curve")` adds curves. Well, and straight lines if you like:

```
g +
  annotate(geom = "curve",x = 0, y = 60, xend = 75, yend = 0,
           color = "tan", linewidth = 2) +
  annotate(geom = "curve",
          x = 0, y = 60, xend = 75, yend = 0,
           curvature = -0.7, angle = 45,
           color = "darkgoldenrod1", linewidth = 1) +
  annotate(geom = "curve", x = 0, y = 60, xend = 75, yend = 0,
           curvature = 0, linewidth = 1.5)
```



The same geom can be used to draw arrows:

```
g +
  annotate(geom = "curve", x = 0, y = 60, xend = 75, yend = 0,
           color = "tan", linewidth = 2,
           arrow = arrow(length = unit(0.07, "npc"))) +
  annotate(geom = "curve", x = 5, y = 55, xend = 70, yend = 5,
           curvature = -0.7, angle = 45,
           color = "darkgoldenrod1", linewidth = 1,
           arrow = arrow(length = unit(0.03, "npc"),
                         type = "closed",
                         ends = "both"))
```

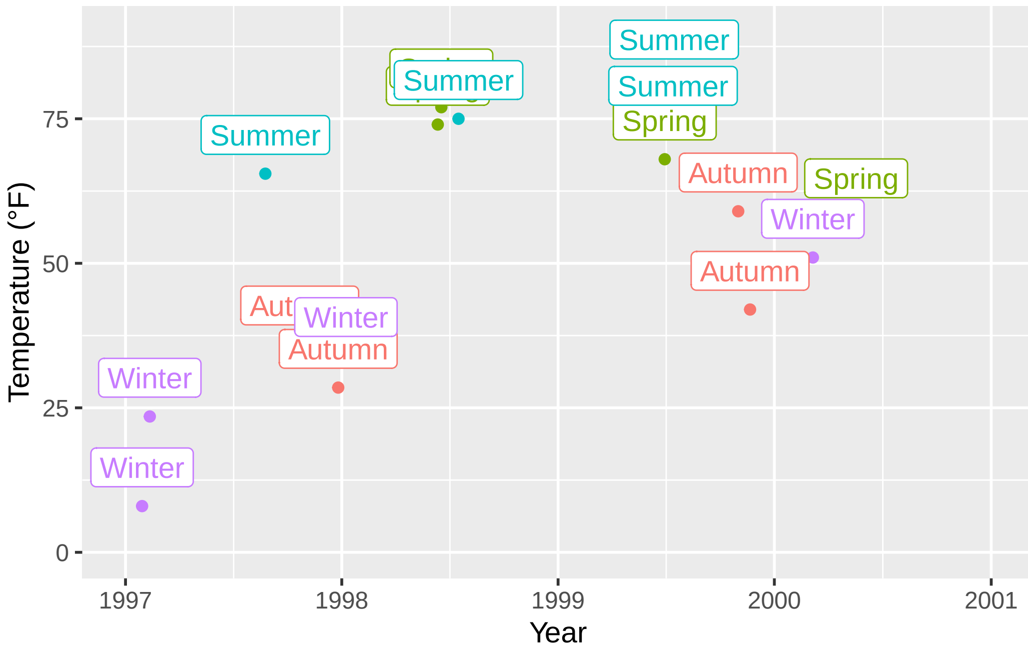

80
60
40
20
0
Dewpoint
0
25
50
75
Temperature (°F)

13 Working with Text

13.1 Add Labels to Your Data

Sometimes, we want to label our data points. To avoid overlaying and crowding by text labels, we use a 1% sample of the original data, equally representing the four seasons. We are using `geom_label()` which comes with a new aesthetic called `label`:

```
set.seed(2020)

sample <- chic |>
  dplyr::group_by(season) |>
  dplyr::sample_frac(0.01)

## code without pipes:
## sample <- sample_frac(group_by(chic, season), .01)

ggplot(sample, aes(x = date, y = temp, color = season)) +
  geom_point() +
  geom_label(aes(label = season), hjust = .5, vjust = -.5) +
  labs(x = "Year", y = "Temperature (°F)") +
  xlim(as.Date(c('1997-01-01', '2000-12-31'))) +
  ylim(c(0, 90)) +
  theme(legend.position = "none")
```

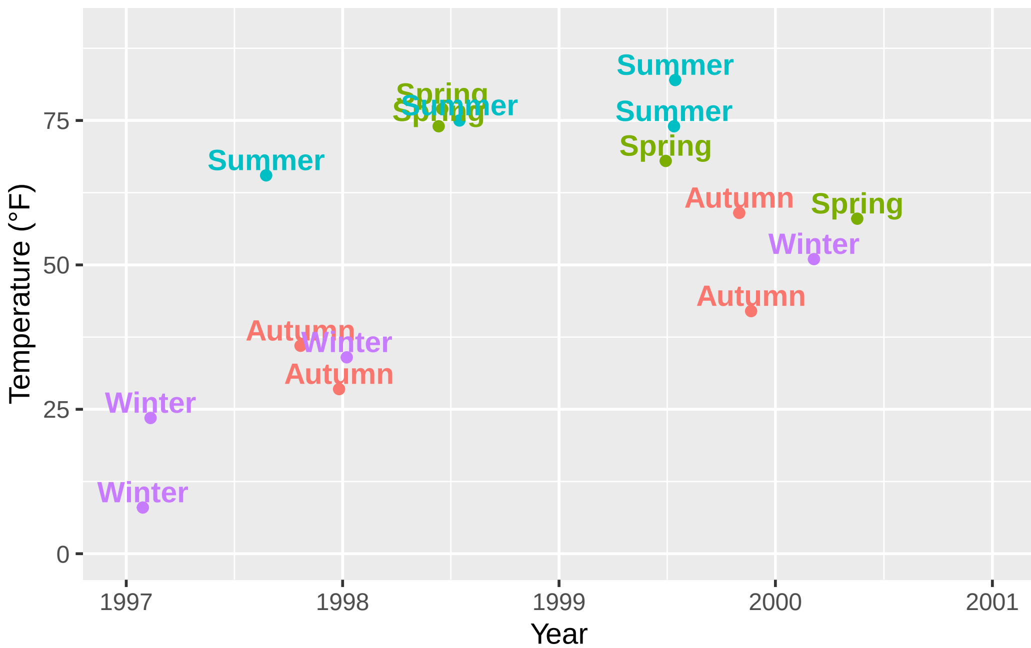


Okay, avoiding overlap of labels did not work out. But don't worry, we are going to fix it in a minute!

Using `geom_text()`

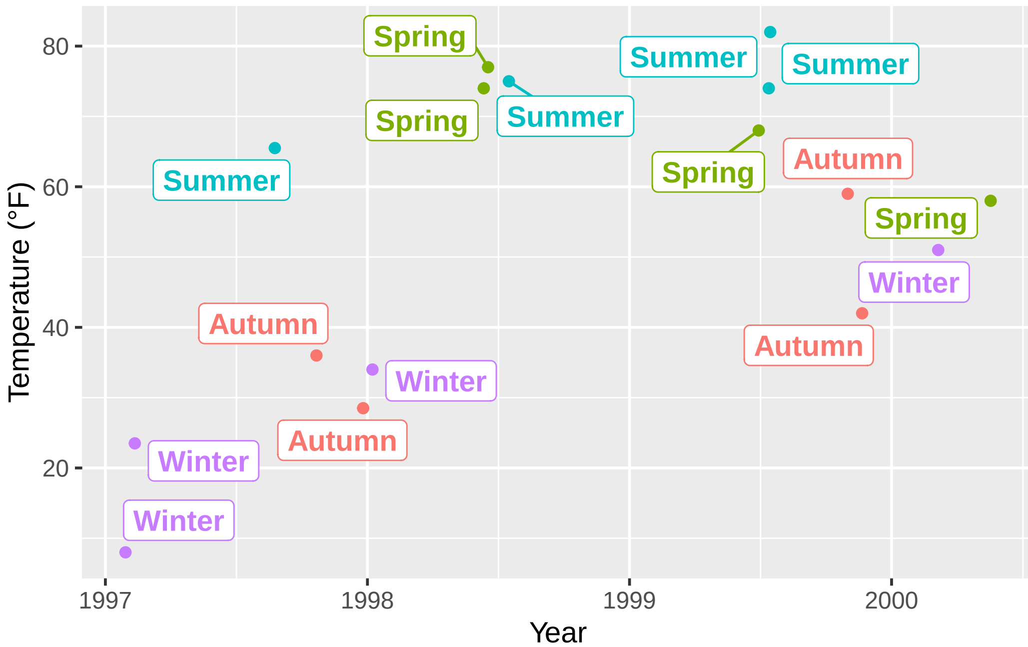
You can also use `geom_text()` if you don't like boxes around your labels. Expand to see example.

```
ggplot(sample, aes(x = date, y = temp, color = season)) +
  geom_point() +
  geom_text(aes(label = season), fontface = "bold",
            hjust = .5, vjust = -.25) +
  labs(x = "Year", y = "Temperature (°F)") +
  xlim(as.Date(c('1997-01-01', '2000-12-31'))) +
  ylim(c(0, 90)) +
  theme(legend.position = "none")
```



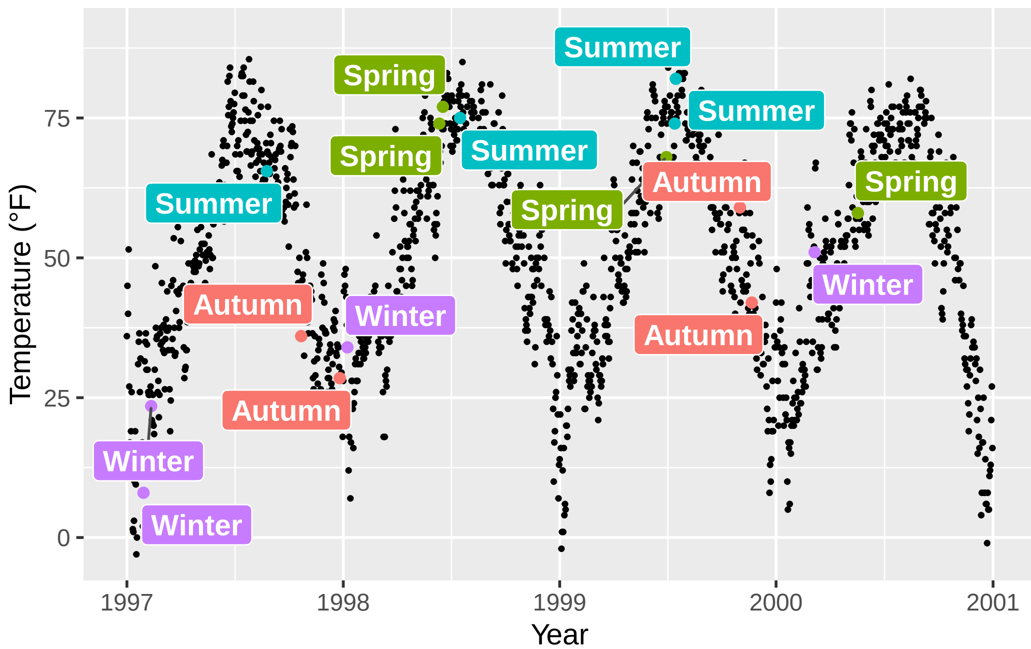
The {ggrepel} package offers some great utilities by providing geoms for {ggplot2} to repel overlapping text as in our examples above. We simply replace `geom_text()` by `geom_text_repel()` and `geom_label()` by `geom_label_repel()`:

```
library(ggrepel)

ggplot(sample, aes(x = date, y = temp, color = season)) +
  geom_point() +
  geom_label_repel(aes(label = season), fontface = "bold") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.position = "none")
```



It may look nicer with filled boxes so we map `season` to `fill` instead to `color` and set a white color for the text:

```
ggplot(sample, aes(x = date, y = temp)) +
  geom_point(data = chic, size = .5) +
  geom_point(aes(color = season), size = 1.5) +
  geom_label_repel(aes(label = season, fill = season),
                   color = "white", fontface = "bold",
                   segment.color = "grey30") +
  labs(x = "Year", y = "Temperature (°F)") +
  theme(legend.position = "none")
```

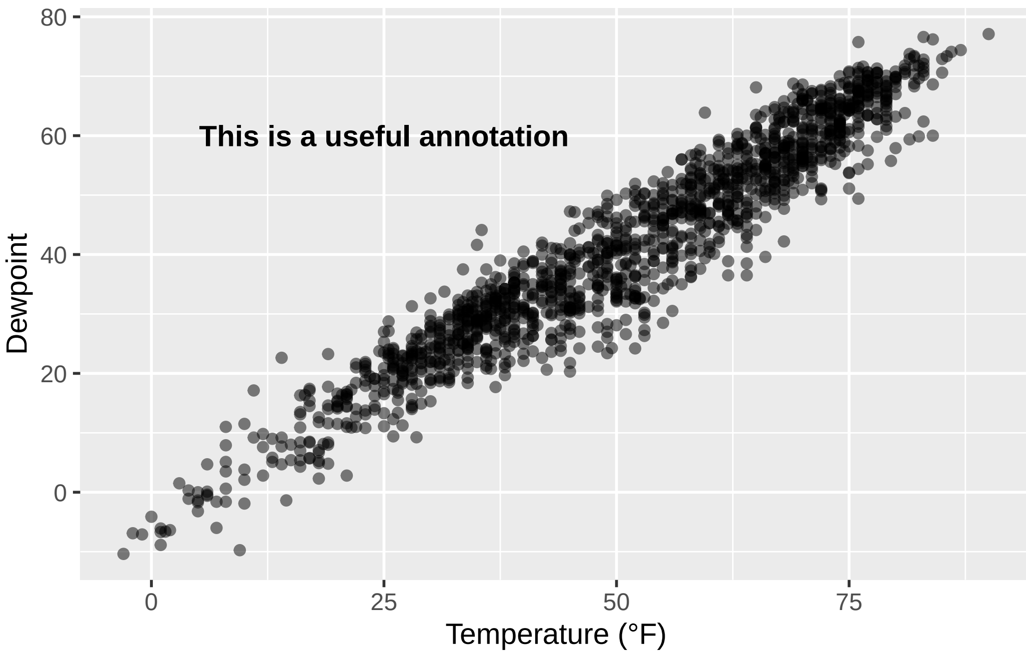


This also works for the pure text labels by using `geom_text_repel()`. Have a look at all the usage examples.

13.2 Add Text Annotations

There are several ways how one can add annotations to a ggplot. We can again use `annotate(geom = "text")`, `annotate(geom = "label")`, `geom_text()` or `geom_label()`:

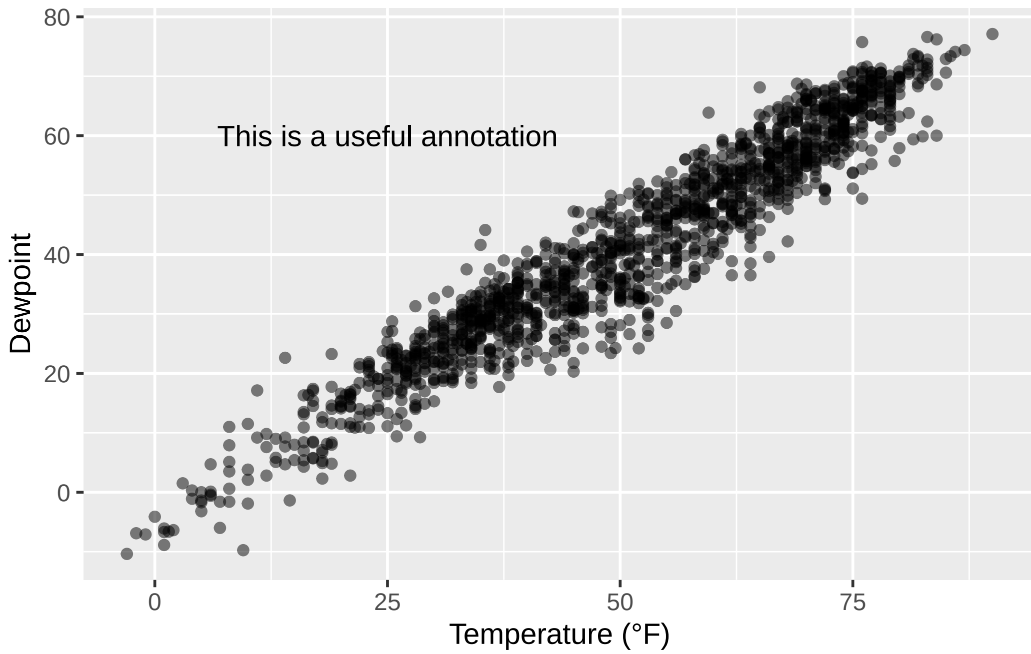
```
g <-
  ggplot(chic, aes(x = temp, y = dewpoint)) +
  geom_point(alpha = .5) +
  labs(x = "Temperature (°F)", y = "Dewpoint")

g +
  annotate(geom = "text", x = 25, y = 60, fontface = "bold",
                label = "This is a useful annotation")
```



However, now ggplot has drawn one text label per data point—that's 1,461 labels and you only see one! You can solve that by setting the stat argument to "unique":

```
g +
  geom_text(aes(x = 25, y = 60,
                label = "This is a useful annotation"),
            stat = "unique")
```

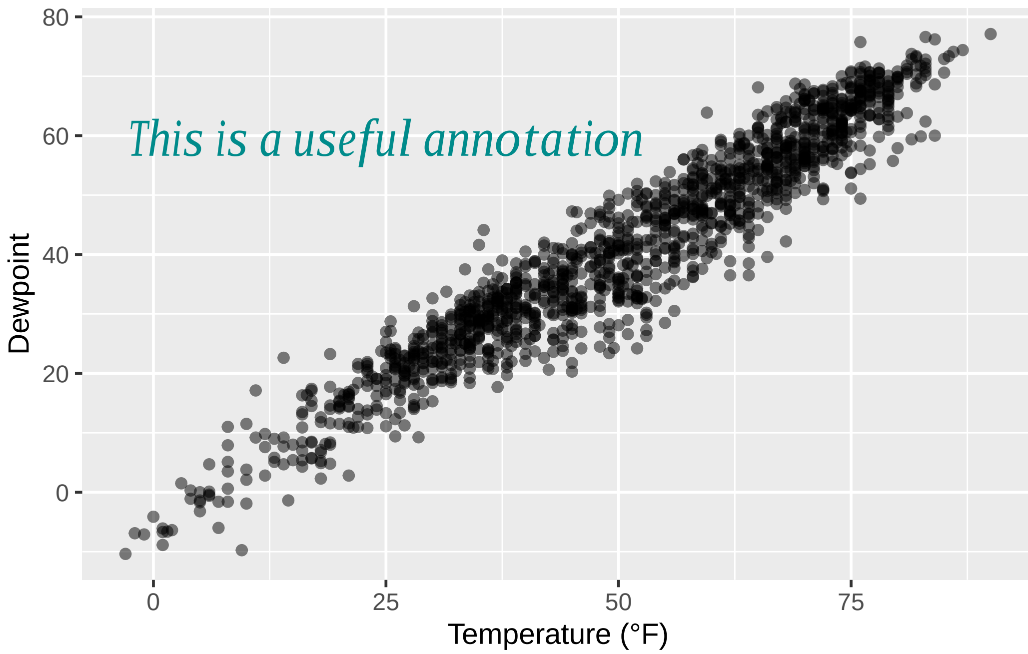
```
Warning in geom_text(aes(x = 25, y = 60, label = "This is a useful annotation"), : All aesthetics have le
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



By the way, of course one can change the properties of the displayed text:

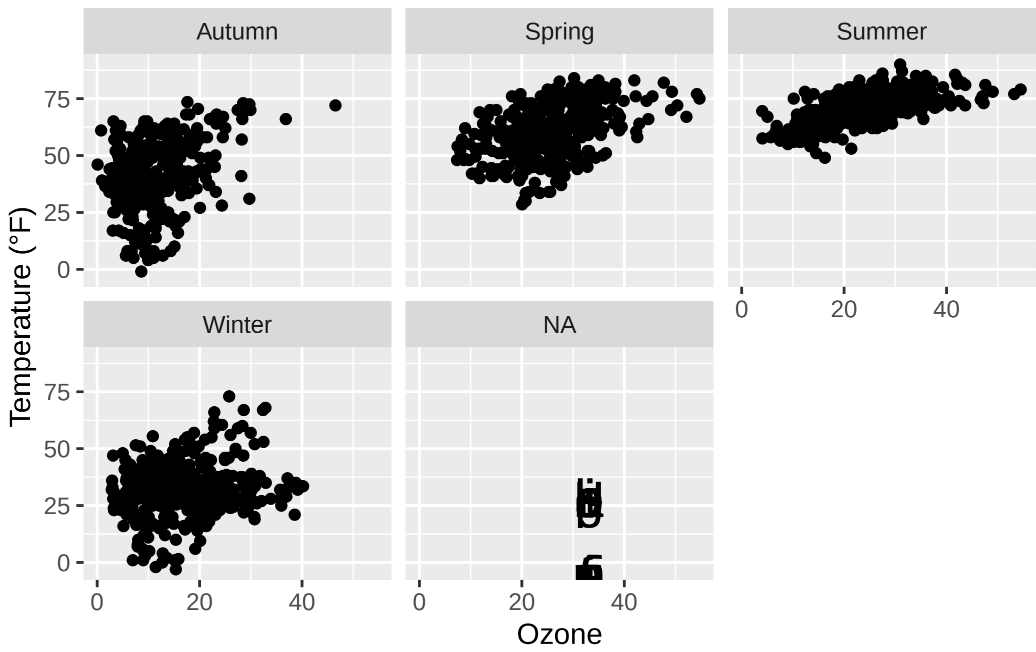
```
g +
  geom_text(aes(x = 25, y = 60,
                label = "This is a useful annotation"),
            stat = "unique", family = "Bangers",
            size = 7, color = "darkcyan")
```

```
Warning in geom_text(aes(x = 25, y = 60, label = "This is a useful annotation"), : All aesthetics have lengt
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



In case you use one of the facet functions to visualize your data you might run into trouble. One thing is that you may want to include the annotation only once:

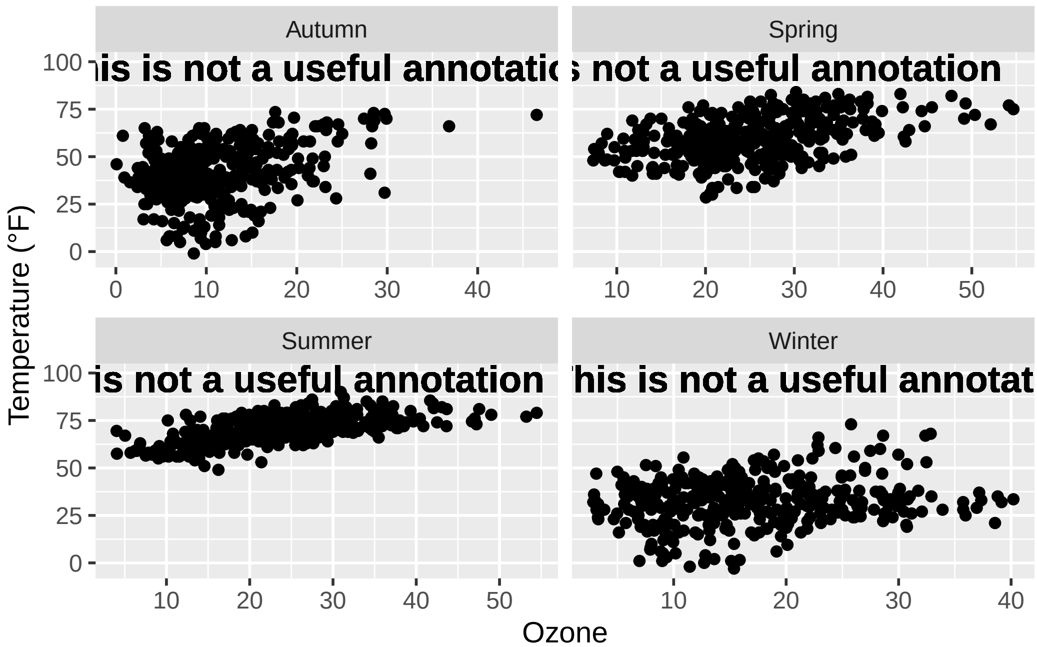
```
ann <- data.frame(
  o3 = 30,
  temp = 20,
  season = factor("Summer", levels = levels(chic$season)),
  label = "Here is enough space\nfor some annotations."
)

g <-
  ggplot(chic, aes(x = o3, y = temp)) +
  geom_point() +
  labs(x = "Ozone", y = "Temperature (°F)")

g +
  geom_text(data = ann, aes(label = label),
            size = 7, fontface = "bold",
            family = "Roboto Condensed") +
  facet_wrap(~season)
```



Another challenge are facets in combination with free scales that might cut your text:

```
g +
  geom_text(aes(x = 23, y = 97,
                label = "This is not a useful annotation"),
            size = 5, fontface = "bold") +
  scale_y_continuous(limits = c(NA, 100)) +
  facet_wrap(~season, scales = "free_x")
```

```
Warning in geom_text(aes(x = 23, y = 97, label = "This is not a useful annotation"), : All aesthetics have le
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



One solution is to calculate the midpoint of the axis, here x, beforehand:

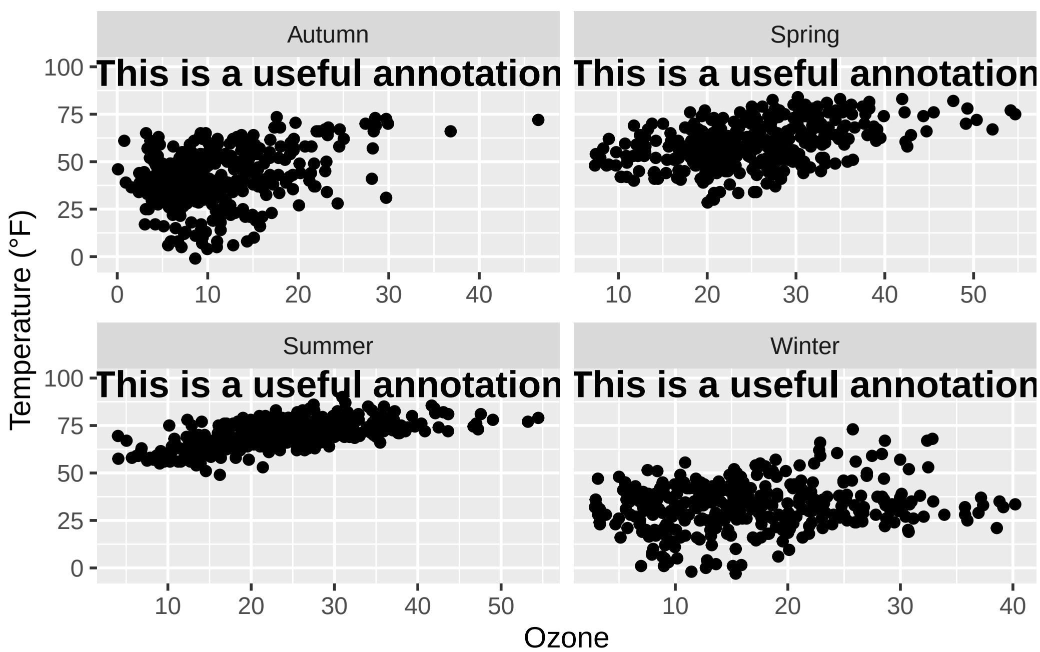
```
ann <-
  chic |>
  dplyr::group_by(season) |>
  dplyr::summarize(
    o3 = min(o3, na.rm = TRUE) +
          (max(o3, na.rm = TRUE) - min(o3, na.rm = TRUE)) / 2
)

ann
```

```
# A tibble: 4 x 2
  season     o3
  <chr>   <dbl>
1 Autumn   23.3
2 Spring   31.0
3 Summer   29.2
4 Winter   21.5
```

… and use the aggreated data to specify the placement of the annotation:

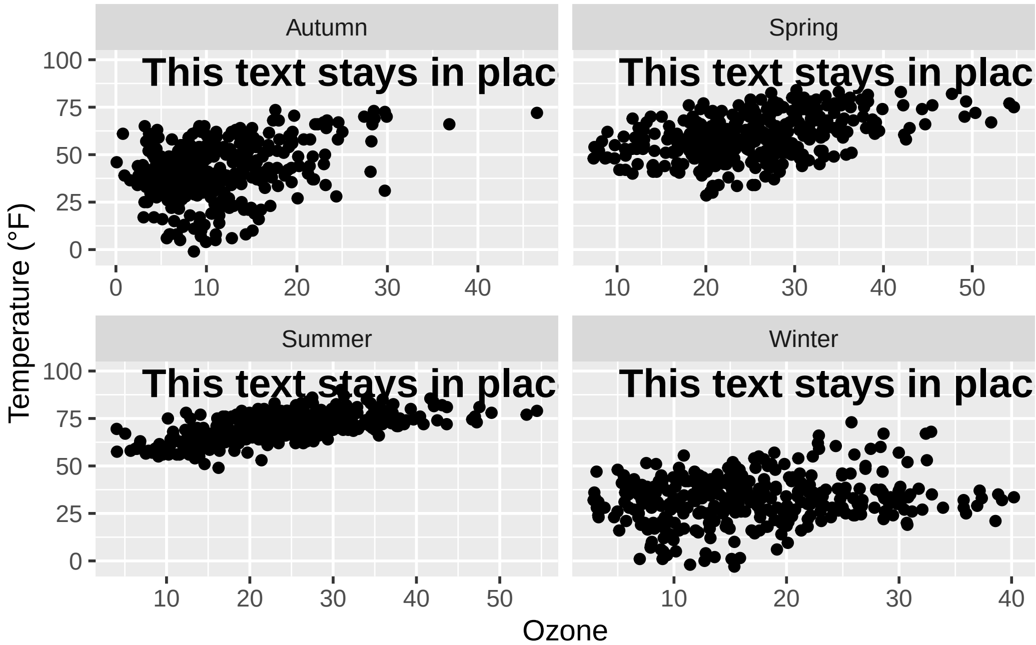
```
g +
  geom_text(data = ann,
            aes(x = o3, y = 97,
                label = "This is a useful annotation"),
```

```
            size = 5, fontface = "bold") +
  scale_y_continuous(limits = c(NA, 100)) +
  facet_wrap(~season, scales = "free_x")
```



However, there is a simpler approach (in terms of fixing the cordinates)—but it also takes a while to know the code by heart. The {grid} package in combination with {ggplot2}'s `annotation_custom()` allows you to specify the location based on scaled coordinates where 0 is low and 1 is high. `grobTree()` creates a grid graphical object and `textGrob` creates the text graphical object. The value of this is particularly evident when you have multiple plots with different scales.

```
library(grid)
my_grob <- grobTree(textGrob("This text stays in place!",
                             x = .1, y = .9, hjust = 0,
                             gp = gpar(col = "black",
                                       fontsize = 15,
                                       fontface = "bold")))

g +
  annotation_custom(my_grob) +
  facet_wrap(~season, scales = "free_x") +
  scale_y_continuous(limits = c(NA, 100))
```

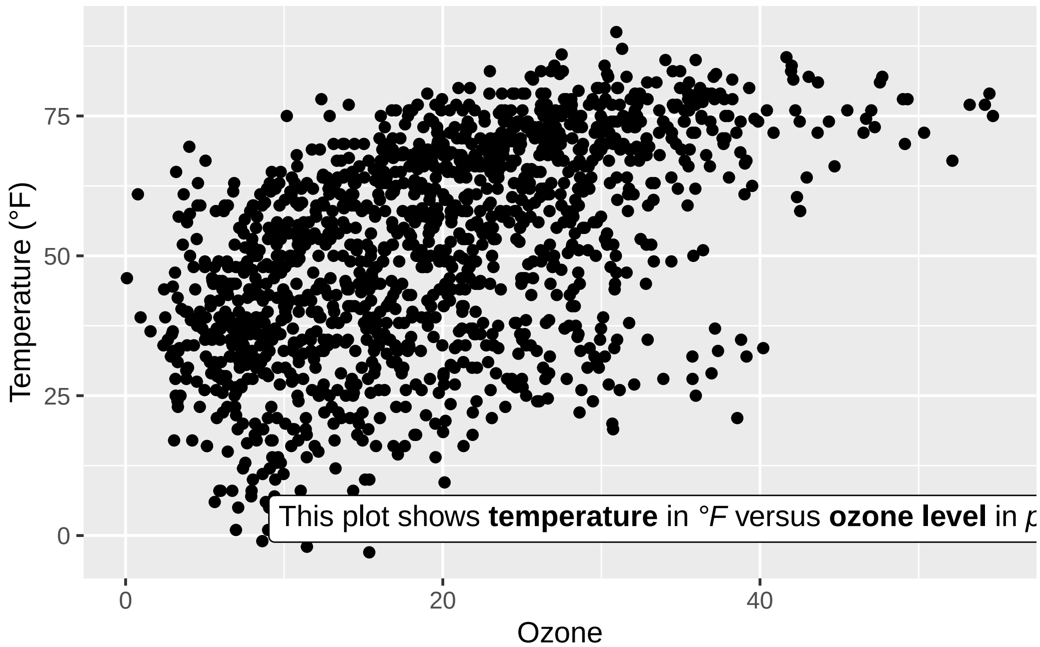


13.3 Use Markdown and HTML Rendering for Annotations

Again, we are using Claus Wilke's {ggtext} package that is designed for improved text rendering support for {ggplot2}. The {ggtext} package defines two new theme elements, `element_markdown()` and `element_textbox()`. The package also provides additional geoms. `geom_richtext()` is a replacement for `geom_text()` and `geom_label()` and renders text as markdown...

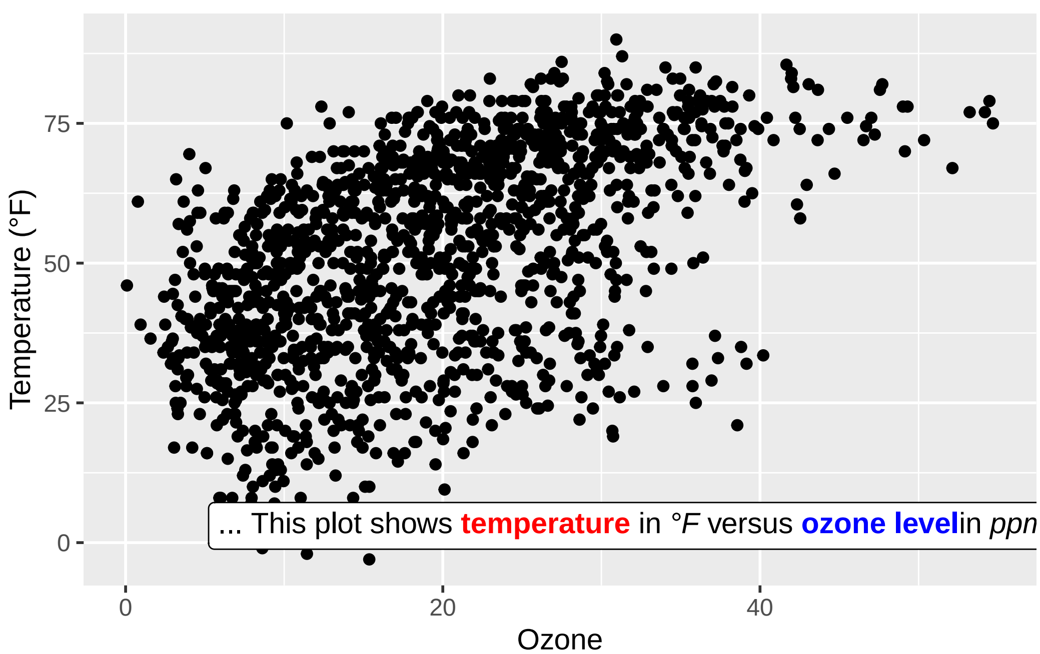
```
library(ggtext)

lab_md <- "This plot shows **temperature** in *°F* versus **ozone level** in *ppm*"

g +
  geom_richtext(aes(x = 35, y = 3, label = lab_md),
                stat = "unique")
```

```
Warning in geom_richtext(aes(x = 35, y = 3, label = lab_md), stat = "unique"): All aesthetics have length
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



... or html:

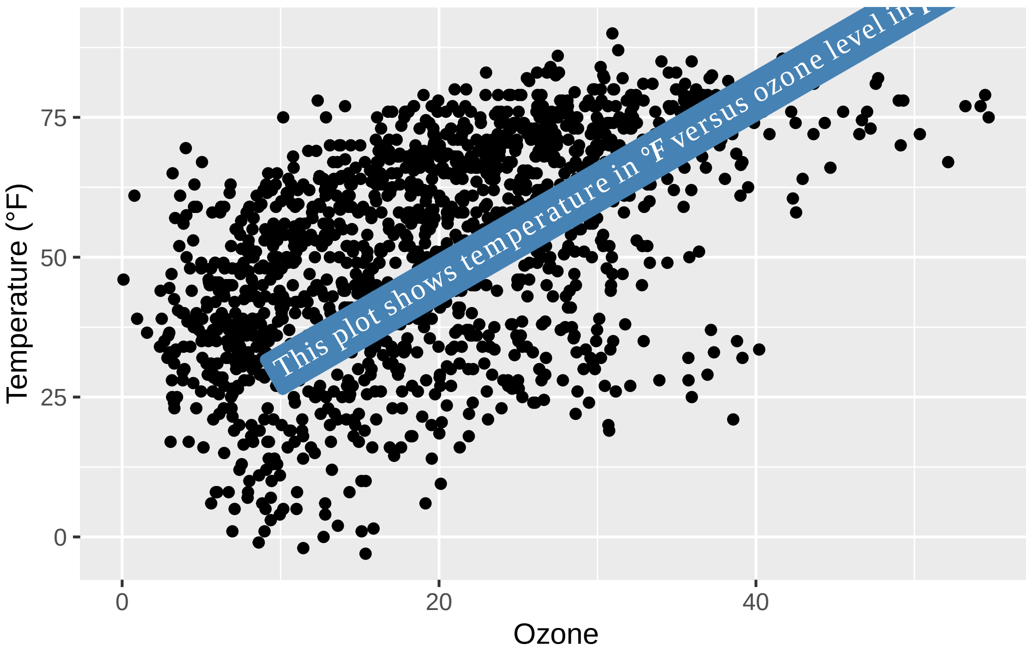
```
lab_html <- "&#9733; This plot shows <b style='color:red;'>temperature</b> in <i>°F</i> versus <b styl

g +
  geom_richtext(aes(x = 33, y = 3, label = lab_html),
                stat = "unique")
```



The geom comes with a lot of details one can modify, such as angle (which is not possible in the default `geom_text()` and `geom_label()`), properties of the box and properties of the text.

```
g +
  geom_richtext(aes(x = 10, y = 25, label = lab_md),
                stat = "unique", angle = 30,
                color = "white", fill = "steelblue",
                label.color = NA, hjust = 0, vjust = 0,
                family = "Playfair Display")
```

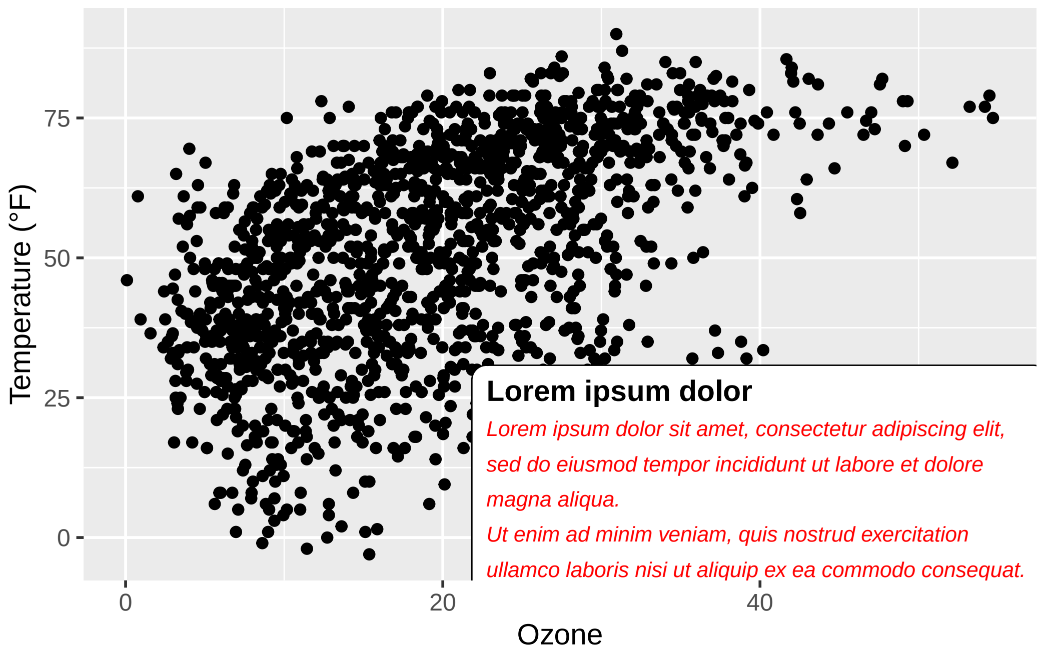
```
Warning in geom_richtext(aes(x = 10, y = 25, label = lab_md), stat = "unique", : All aesthetics have leng
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



The other geom from the `{ggtext}` package is `geom_textbox()`. This geom allows for dynamic wrapping of strings which is very useful for longer annotations such as info boxes and subtitles.

```
lab_long <- "**Lorem ipsum dolor**<br><i style='font-size:8pt;color:red;'>Lorem ipsum dolor sit ame

g +
  geom_textbox(aes(x = 40, y = 10, label = lab_long),
               width = unit(15, "lines"), stat = "unique")
```

```
Warning in geom_textbox(aes(x = 40, y = 10, label = lab_long), width = unit(15, : All aesthetics have len
i Please consider using `annotate()` or provide this layer with data containing
  a single row.
```



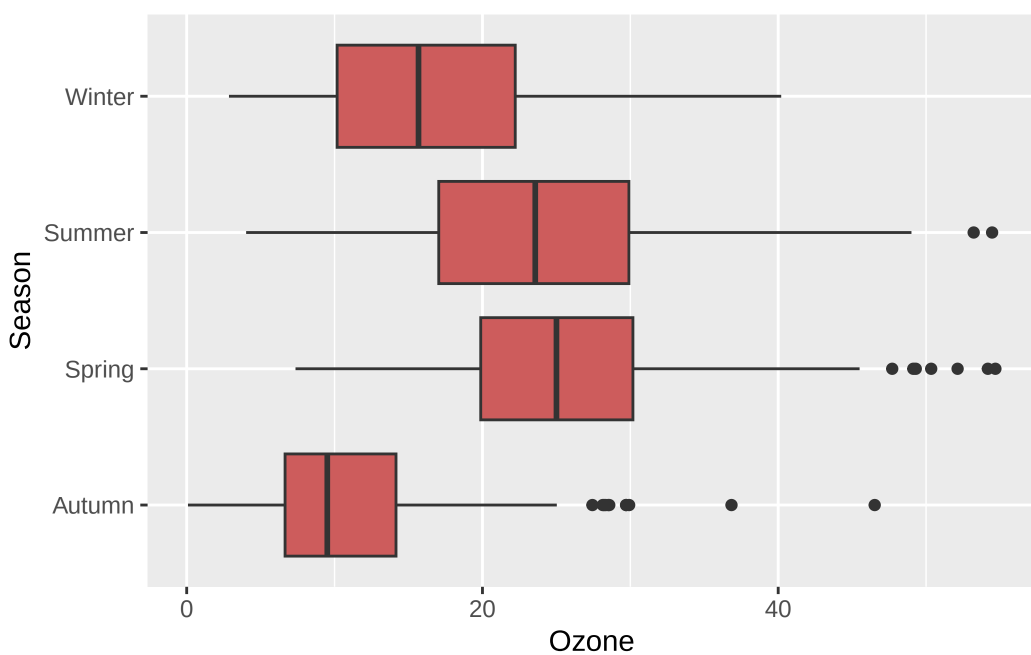
Note that it is not possible to either rotate the textbox (always horizontal) nor to change the justification of the text (always left-aligned).

14 Working with Coordinates

14.1 Flip a Plot

It is incredibly easy to flip a plot on its side. Here I have added the `coord_flip()` which is all you need to flip the plot. This makes most sense when using geom's to represent categorical data, for example bar charts or, as in the following example, box and whiskers plots:

```
ggplot(chic, aes(x = season, y = o3)) +
  geom_boxplot(fill = "indianred") +
  labs(x = "Season", y = "Ozone") +
  coord_flip()
```



Using `orientation = "y"`

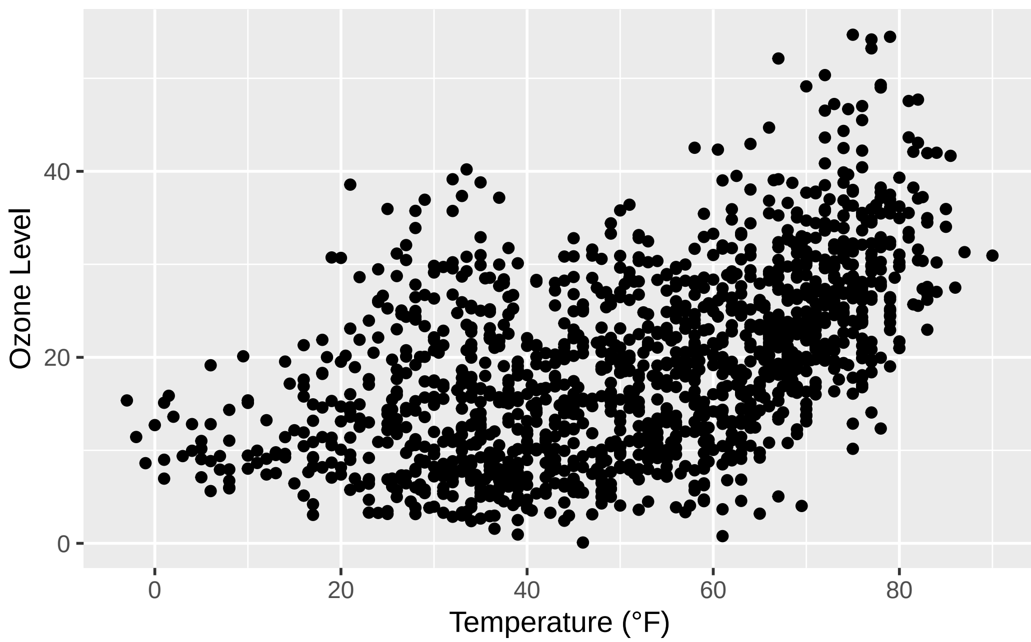
Since {ggplot2} version 3.0.0 it is also possible to draw geom's horizontally via the argument `orientation = "y"`. Expand to see example.

```r
ggplot(chic, aes(x = o3, y = season)) +
  geom_boxplot(fill = "indianred", orientation = "y") +
  labs(x = "Ozone", y = "Season")
```

14.2 Fix an Axis

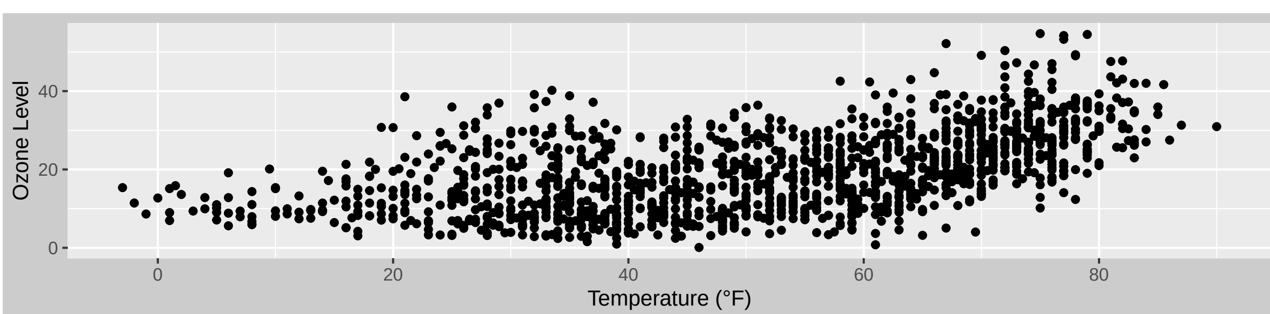
One can fix the aspect ratio of the Cartesian coordinate system and literally force a physical representation of the units along the x and y axes:

```r
ggplot(chic, aes(x = temp, y = o3)) +
  geom_point() +
  labs(x = "Temperature (°F)", y = "Ozone Level") +
  scale_x_continuous(breaks = seq(0, 80, by = 20)) +
  coord_fixed(ratio = 1)
```



This way one can ensure not only a fixed step length on the axes but also that the exported plot looks as expected. However, your saved plot likely contains a lot of white space in case you do not use a suitable aspect ratio:

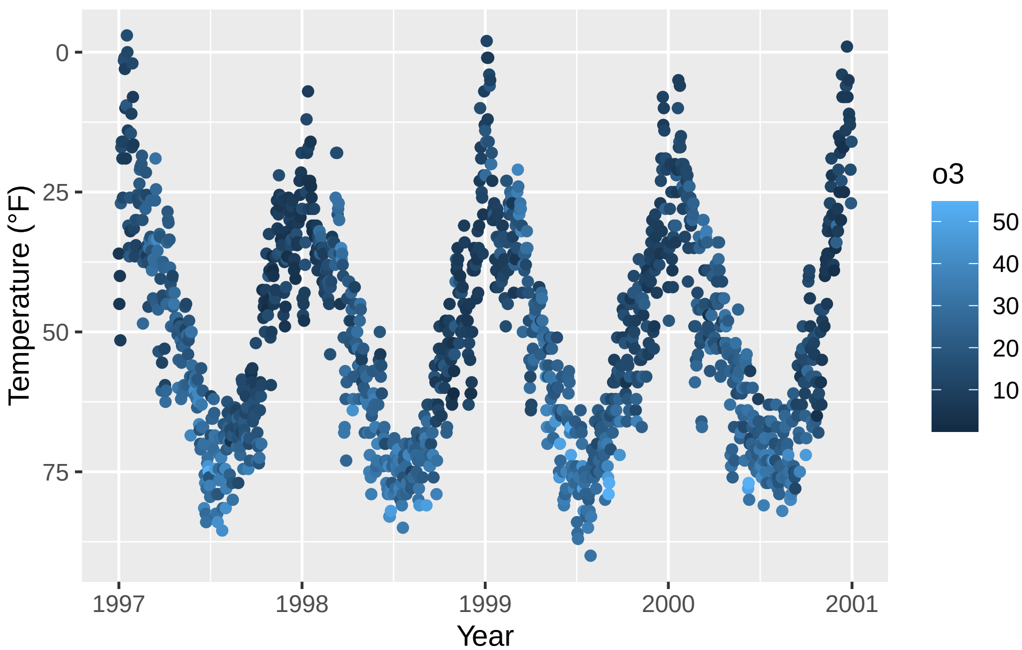
```
ggplot(chic, aes(x = temp, y = o3)) +
  geom_point() +
  labs(x = "Temperature (°F)", y = "Ozone Level") +
  scale_x_continuous(breaks = seq(0, 80, by = 20)) +
  coord_fixed(ratio = 1/3) +
  theme(plot.background = element_rect(fill = "grey80"))
```



14.3 Reverse an Axis

You can also easily reverse an axis using `scale_x_reverse()` or `scale_y_reverse()`, respectively:

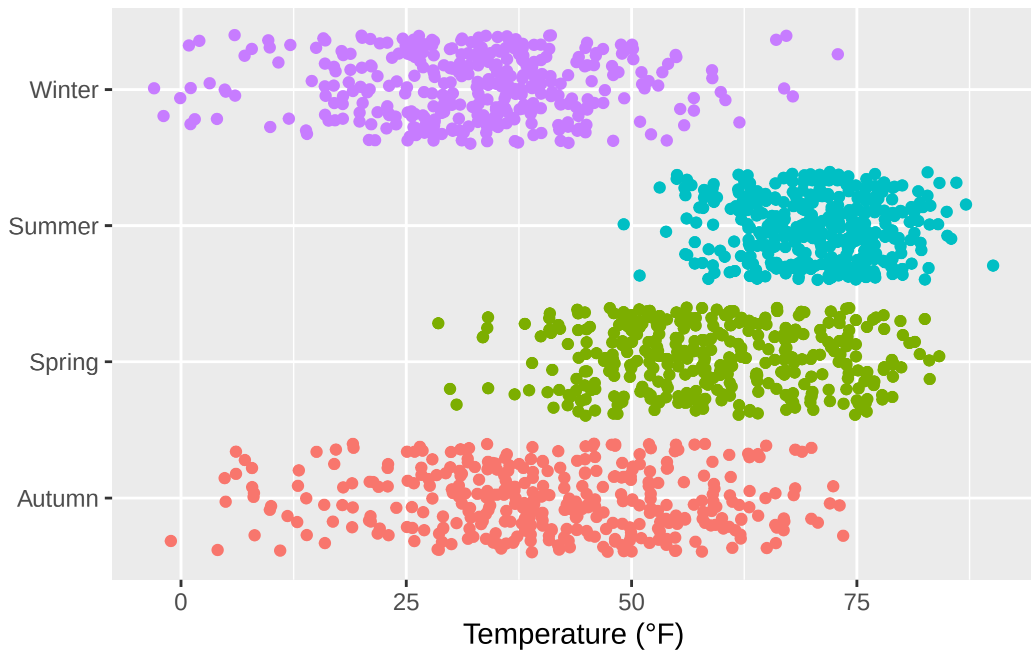
```
ggplot(chic, aes(x = date, y = temp, color = o3)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  scale_y_reverse()
```



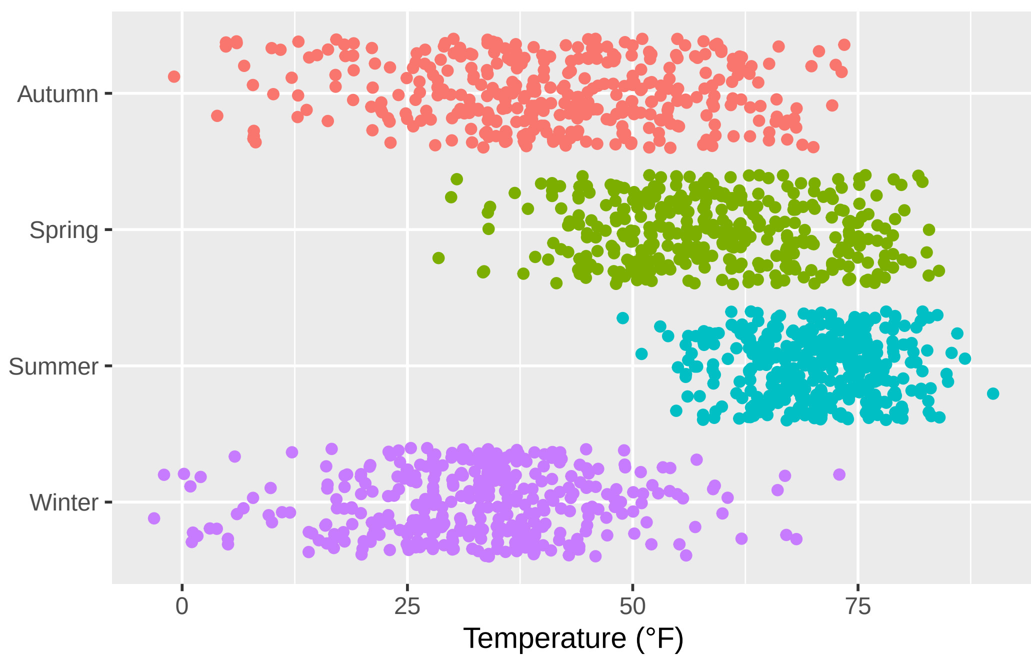
Note

Note that this will only work for continuous data. If you want to reverse discrete data, use the `fct_rev()` function from the `{forcats}` package. Expand to see example.

```
## the default
ggplot(chic, aes(x = temp, y = season)) +
  geom_jitter(aes(color = season), show.legend = FALSE) +
  labs(x = "Temperature (°F)", y = NULL)
```




```
library(forcats)
set.seed(10)
ggplot(chic, aes(x = temp, y = fct_rev(season))) +
  geom_jitter(aes(color = season), show.legend = FALSE) +
  labs(x = "Temperature (°F)", y = NULL)
```



14.4 Transform an Axis

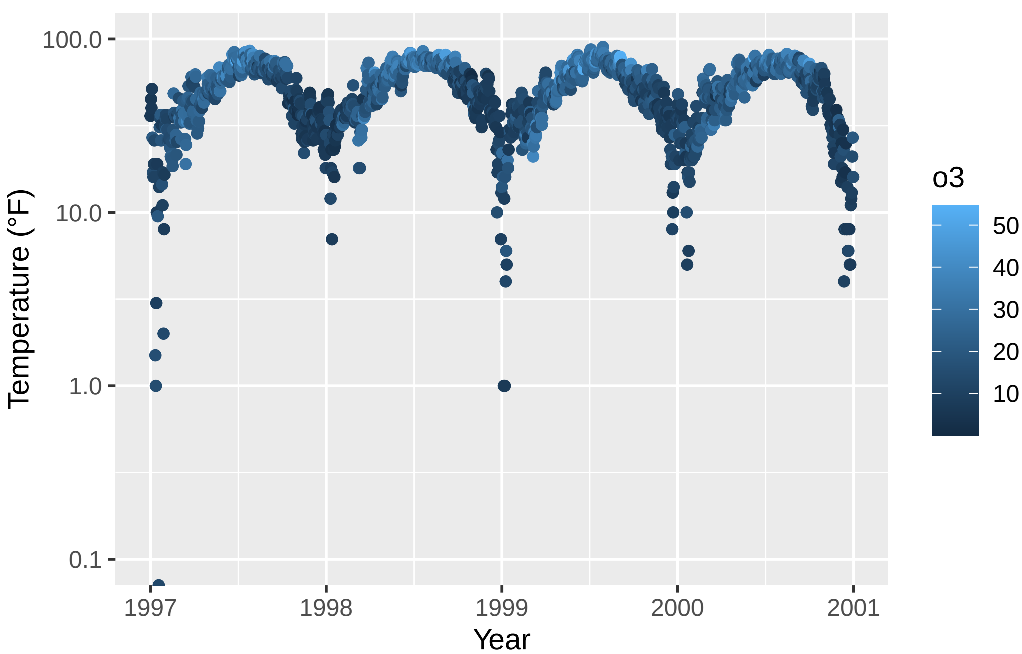
… or transform the default linear mapping by using `scale_y_log10()` or `scale_y_sqrt()`. As an example, here is a log10-transformed axis (which introduces NA's in this case so be careful):

```
ggplot(chic, aes(x = date, y = temp, color = o3)) +
  geom_point() +
  labs(x = "Year", y = "Temperature (°F)") +
  scale_y_log10(lim = c(0.1, 100))
```

```
Warning in transformation$transform(x): NaNs produced
```

```
Warning in scale_y_log10(lim = c(0.1, 100)): log-10 transformation introduced
infinite values.
```

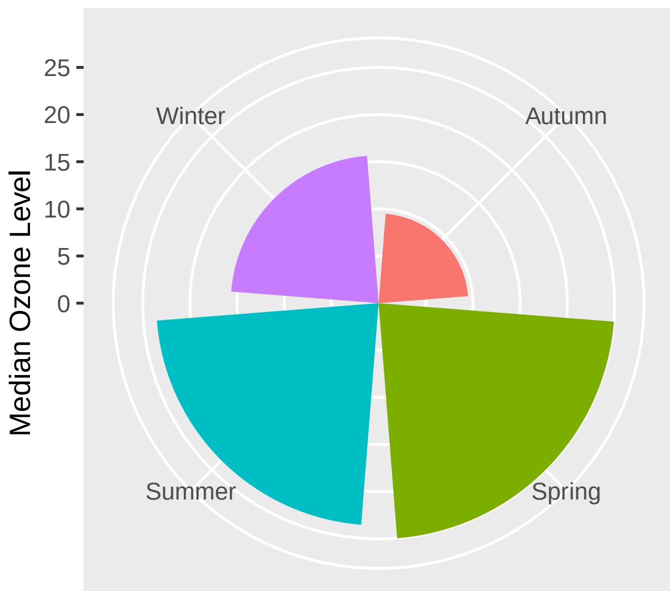
```
Warning: Removed 3 rows containing missing values or values outside the scale range
(`geom_point()`).
```



14.5 Circularize a Plot

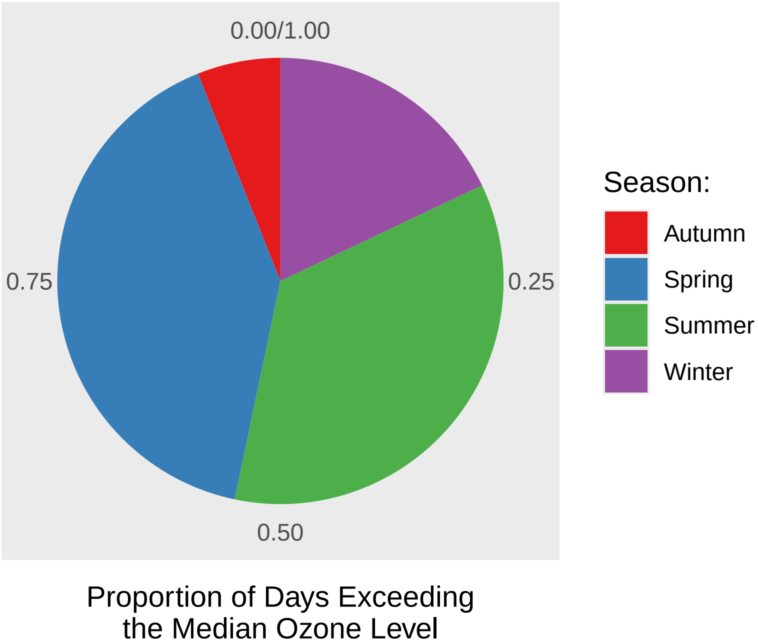
It is also possible to circularize (polarize?) the coordinate system by calling `coord_polar()`.

```
chic |>
  dplyr::group_by(season) |>
  dplyr::summarize(o3 = median(o3)) |>
  ggplot(aes(x = season, y = o3)) +
    geom_col(aes(fill = season), color = NA) +
    labs(x = "", y = "Median Ozone Level") +
    coord_polar() +
    guides(fill = "none")
```



This coordinate system allows to draw pie charts as well:

```
chic_sum <-
  chic |>
  dplyr::mutate(o3_avg = median(o3)) |>
  dplyr::filter(o3 > o3_avg) |>
  dplyr::mutate(n_all = n()) |>
  dplyr::group_by(season) |>
  dplyr::summarize(rel = n() / unique(n_all))

ggplot(chic_sum, aes(x = "", y = rel)) +
  geom_col(aes(fill = season), width = 1, color = NA) +
  labs(x = "", y = "Proportion of Days Exceeding\nthe Median Ozone Level") +
  coord_polar(theta = "y") +
  scale_fill_brewer(palette = "Set1", name = "Season:") +
  theme(axis.ticks = element_blank(),
        panel.grid = element_blank())
```



I suggest to always look also at the outcome of the same code in a Cartesian coordinate system, which is the default, to understand the logic behind `coord_polar()` and `theta`:

```
ggplot(chic_sum, aes(x = "", y = rel)) +
  geom_col(aes(fill = season), width = 1, color = NA) +
  labs(x = "", y = "Proportion of Days Exceeding\nthe Median Ozone Level") +
  #coord_polar(theta = "y") +
  scale_fill_brewer(palette = "Set1", name = "Season:") +
  theme(axis.ticks = element_blank(),
        panel.grid = element_blank())
```


Proportion of Days Exceeding
the Median Ozone Level
1.00
0.75
0.50
0.25
0.00
Season:
Autumn
Spring
Summer
Winter

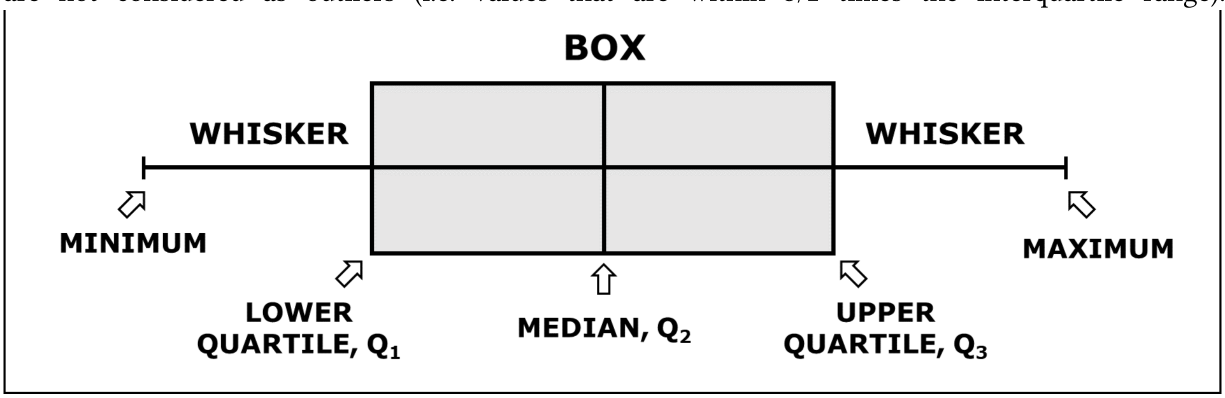
15 Working with Chart Types

15.1 Alternatives to a Box Plot

Box plots are great, but they can be so incredibly boring. Also, even if you are used to looking at box plots, remember there might be plenty people looking at your plot that have never seen a box and whisker plot before.

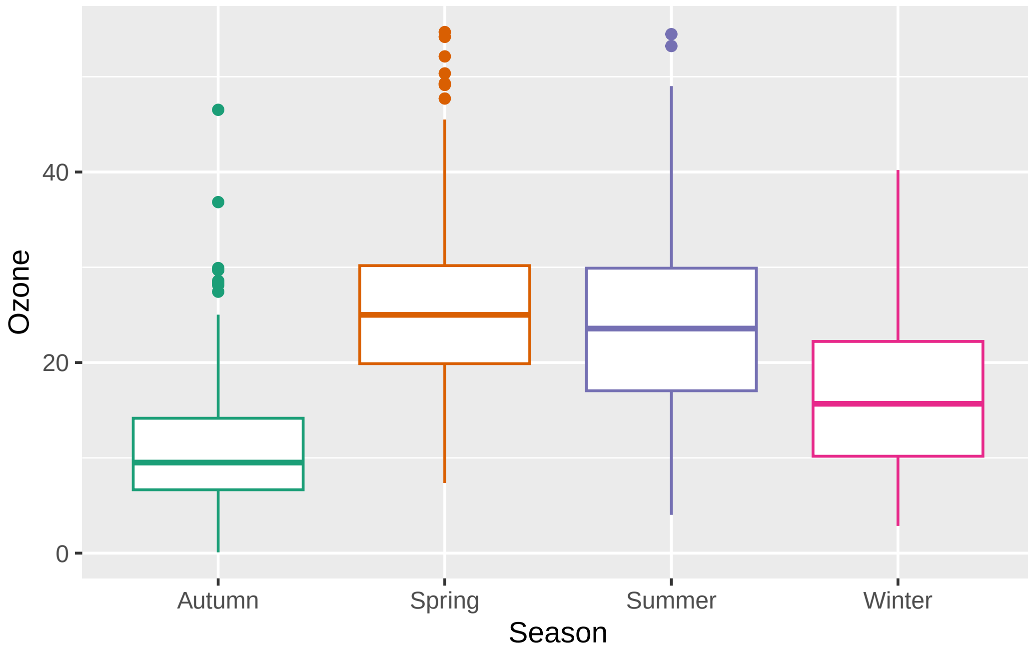
Recall: Box and Whiskers Plot

A box-and-whisker plot (sometimes called simply a box plot) is a histogram-like method of displaying data, invented by J. Tukey. The thick **middle line** notates the median, also known as quartile Q2. The limits of the **box** are determined by the lower and upper quartiles, Q1 and Q3. The box contains thus 50% of the data and is called *"interquartile range"* (IQR). The length of the **whiskers** is determined by the most extreme values that are not considered as outliers (i.e. values that are within 3/2 times the interquartile range).



There are alternatives, but first we are plotting a common box plot:

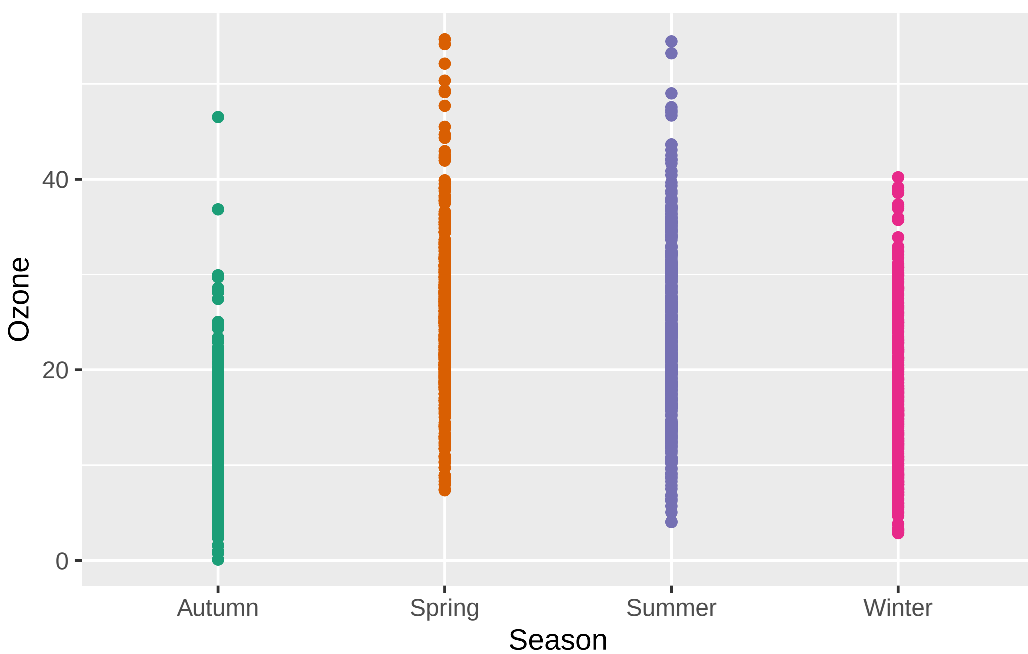
```
g <-
  ggplot(chic, aes(x = season, y = o3,
                   color = season)) +
    labs(x = "Season", y = "Ozone") +
    scale_color_brewer(palette = "Dark2", guide = "none")

g + geom_boxplot()
```



15.1.1 Alternative: Plot of Points

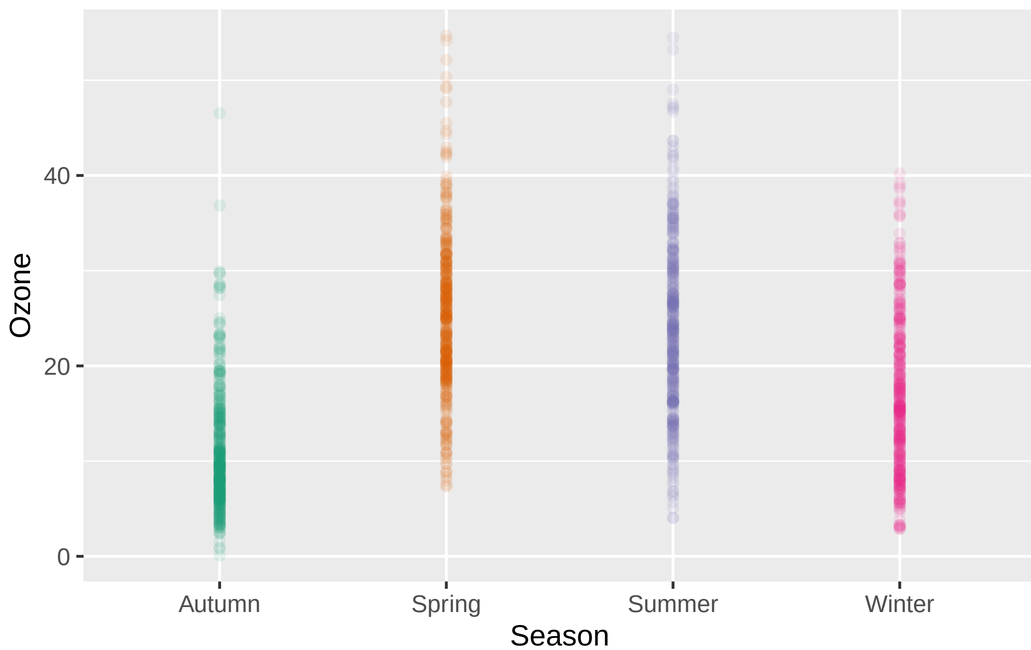
Let's plot just each data point of the raw data:

```
g + geom_point()
```



Not only boring but uninformative. To improve the plot, one could add transparency to deal with overplotting:

```
g + geom_point(alpha = .1)
```

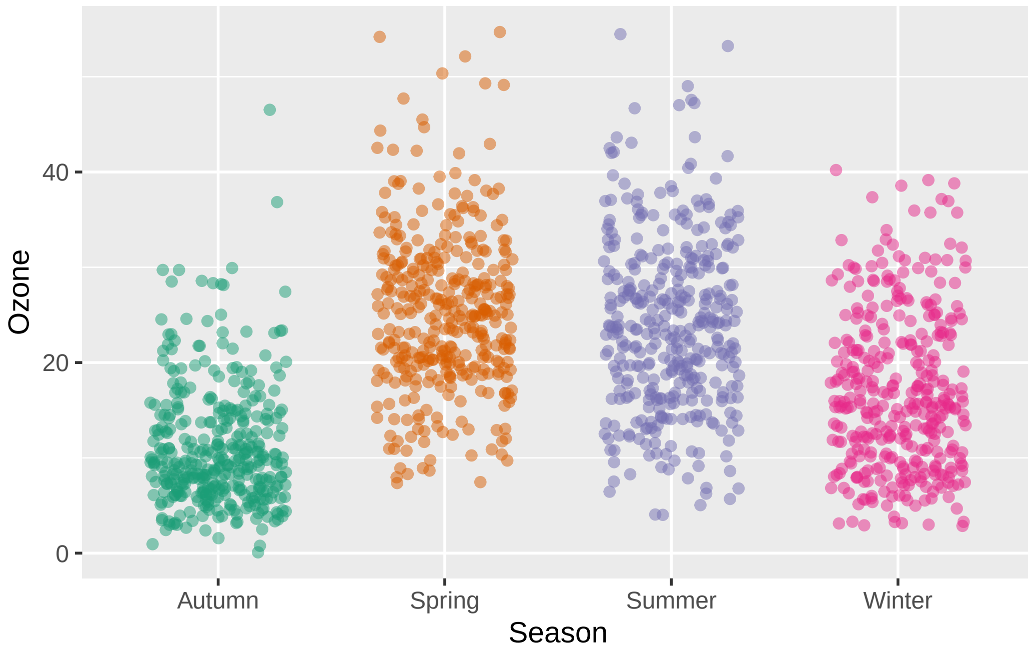


However, setting transparency is difficult here since either the overlap is still too high or the extreme values are not visible. Bad, so let's try something else.

15.1.2 Alternative: Jitter the Points

Try adding a little jitter to the data. I like this for in-house visualization but be careful using jittering because you are purposely adding noise to your data and this can result in misinterpretation of your data.

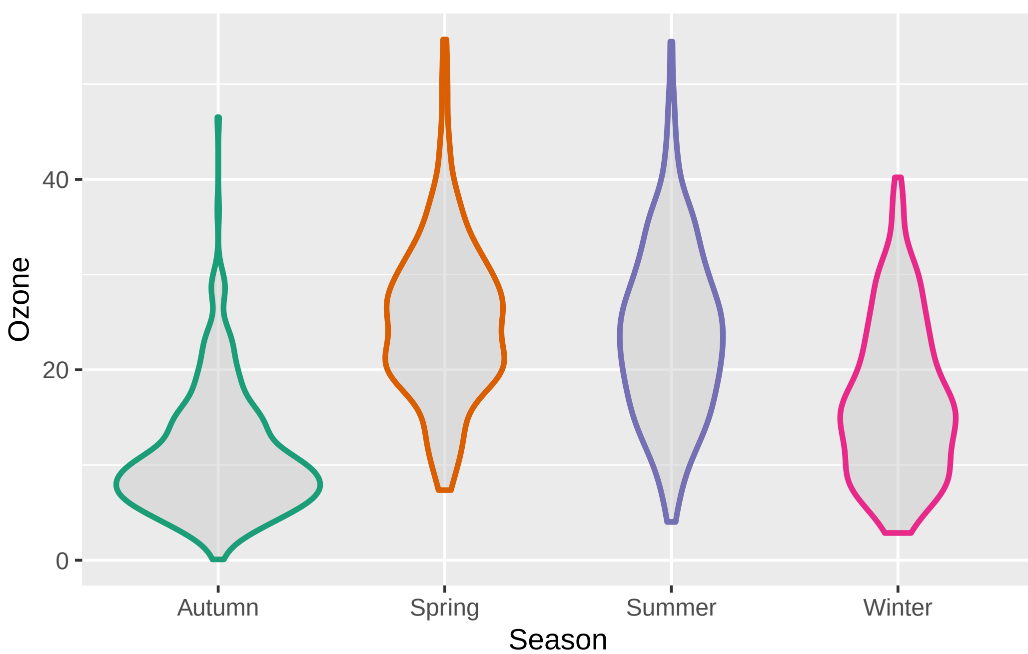
```
g + geom_jitter(width = .3, alpha = .5)
```



15.1.3 Alternative: Violin Plots

Violin plots, similar to box plots except you are using a kernel density to show where you have the most data, are a useful visualization.

```
g + geom_violin(fill = "gray80", linewidth = 1, alpha = .5)
```



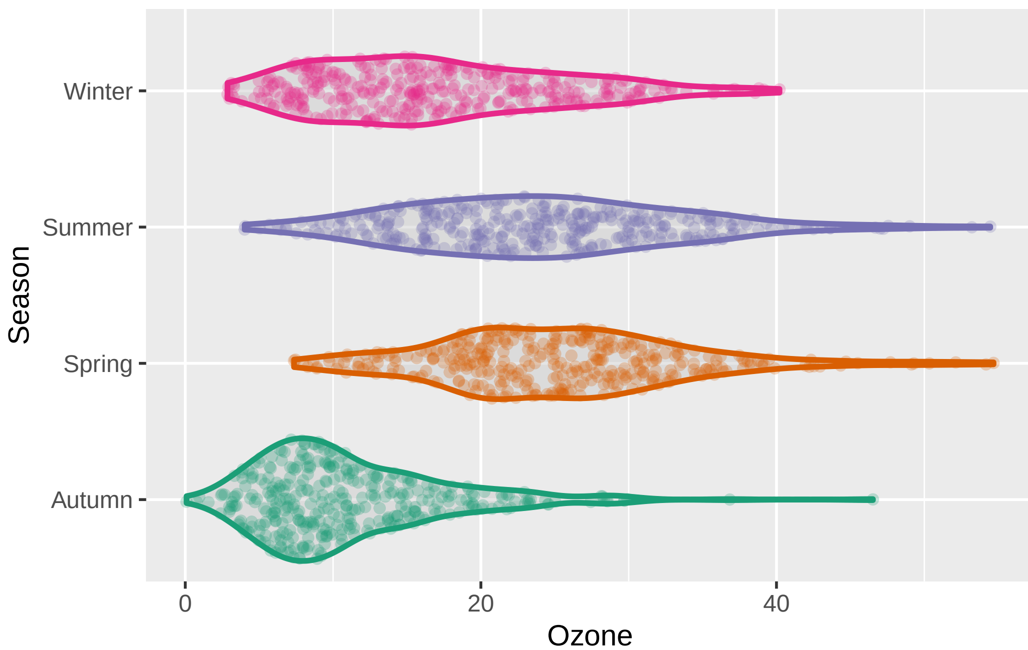
15.1.4 Alternative: Combining Violin Plots with Jitter

We can of course combine both, estimated densities and the raw data points:

```
g + geom_violin(fill = "gray80", linewidth = 1, alpha = .5) +
    geom_jitter(alpha = .25, width = .3) +
    coord_flip()
```

The {ggforce} package provides so-called sina functions where the width of the jitter is controlled by the density distribution of the data—that makes the jittering a bit more visually appealing:

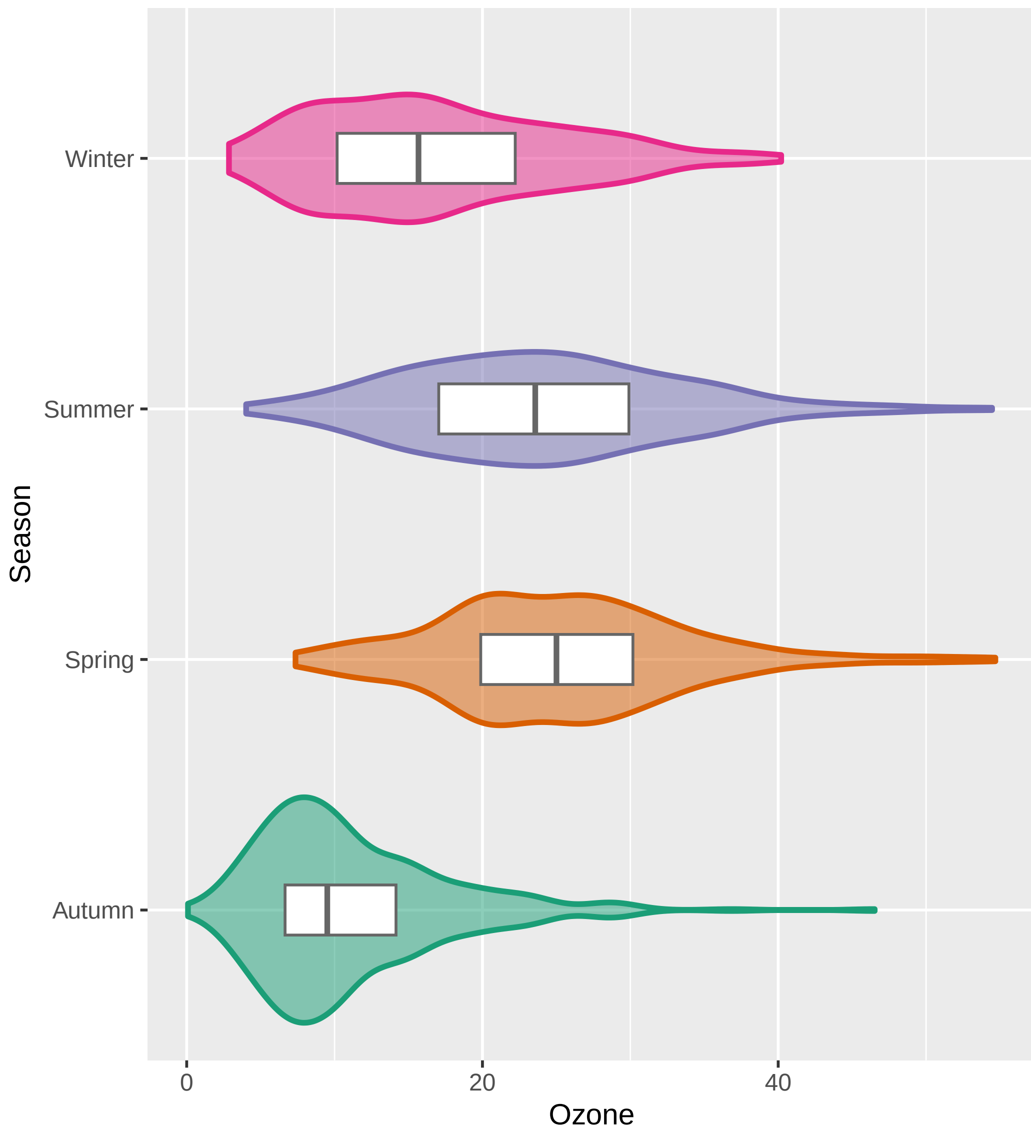
```
library(ggforce)

g + geom_violin(fill = "gray80", linewidth = 1, alpha = .5) +
    geom_sina(alpha = .25) +
    coord_flip()
```



15.1.5 Alternative: Combining Violin Plots with Box Plots

To allow for easy estimation of quantiles, we can also add the box of the box plot inside the violins to indicate 25%-quartile, median and 75%-quartile:

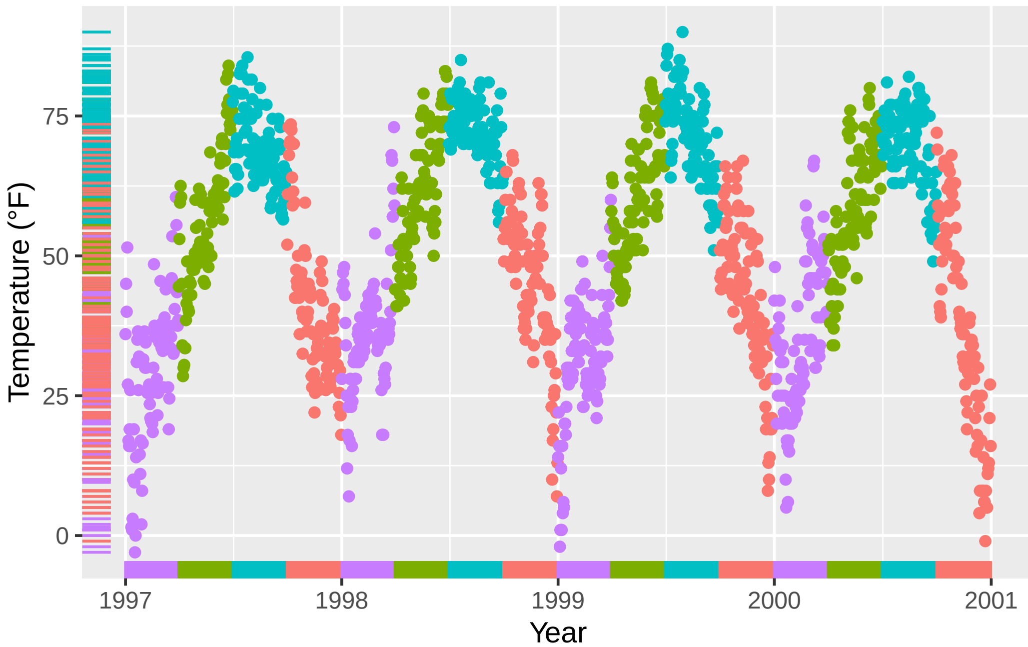
```
g + geom_violin(aes(fill = season), linewidth = 1, alpha = .5) +
    geom_boxplot(outlier.alpha = 0, coef = 0,
                 color = "gray40", width = .2) +
    scale_fill_brewer(palette = "Dark2", guide = "none") +
    coord_flip()
```



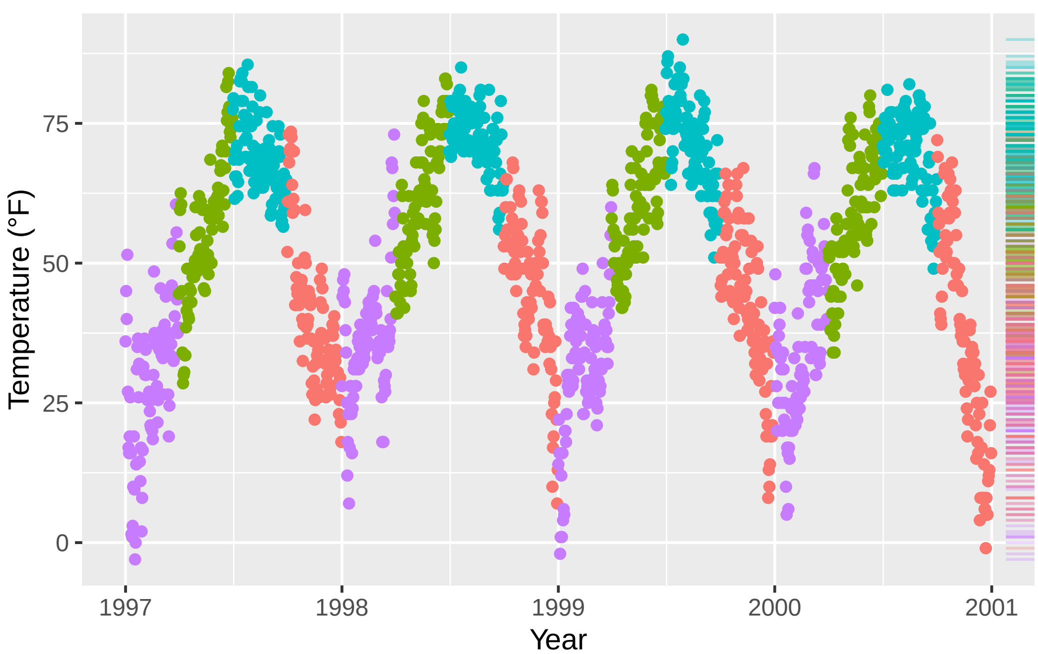
15.2 Create a Rug Representation to a Plot

A rug represents the data of a single quantitative variable, displayed as marks along an axis. In most cases, it is used in addition to scatter plots or heatmaps to visualize the overall distribution of one or both of the variables:

```
ggplot(chic, aes(x = date, y = temp,
                 color = season)) +
  geom_point(show.legend = FALSE) +
  geom_rug(show.legend = FALSE) +
  labs(x = "Year", y = "Temperature (°F)")
```




```
ggplot(chic, aes(x = date, y = temp, color = season)) +
  geom_point(show.legend = FALSE) +
  geom_rug(sides = "r", alpha = .3, show.legend = FALSE) +
  labs(x = "Year", y = "Temperature (°F)")
```



15.3 Create a Correlation Matrix

There are several packages that allow to create correlation matrix plots, some also using the `{ggplot2}` infrastructure and thus returning ggplots. I am going to show you how to do this without extension packages.

First step is to create the correlation matrix. Here, we use the `{corrr}` package that works nicely with pipes but there are also many others out there. We are using Pearson because all the variables are fairly normally distributed (but you may consider Spearman if your variables follow a different pattern). Note that since a correlation matrix has redundant information we are setting half of it to `NA`.

```
corm <-
  chic |>
  dplyr::select(temp, dewpoint, pm10, o3) |>
  corrr::correlate(diagonal = 1) |>
  corrr::shave(upper = FALSE)
```

```
Correlation computed with
* Method: 'pearson'
* Missing treated using: 'pairwise.complete.obs'
```

```
library(gt)
corm %>% gt()
```

term	temp	dewpoint	pm10	o3
temp	1	0.9577391	0.3679648	0.5349655
dewpoint	NA	1.0000000	0.3274569	0.4539134
pm10	NA	NA	1.0000000	0.2060732
o3	NA	NA	NA	1.0000000

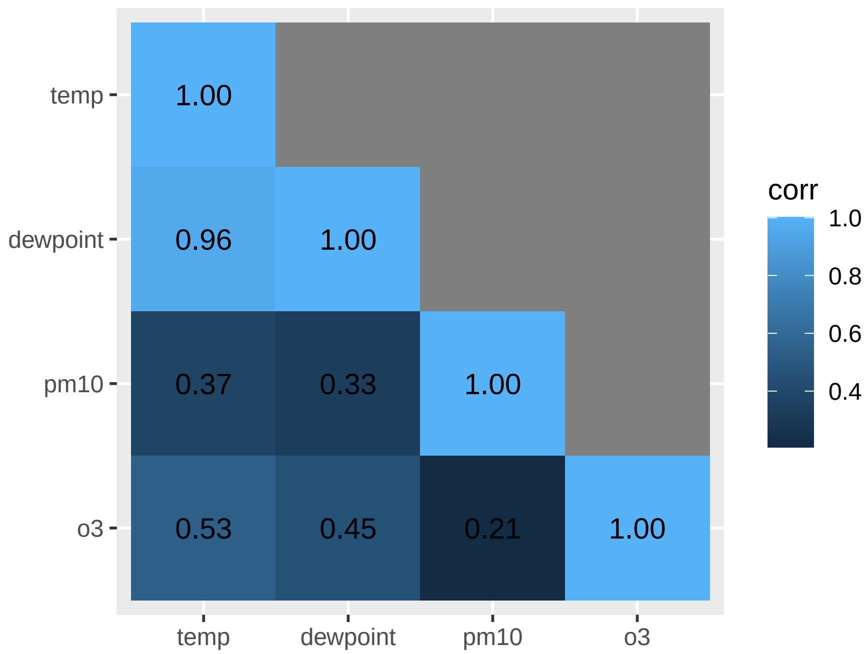
Now we put the resulting matrix in **long** format using the `pivot_longer()` function from the `{tidyr}` package. We also directly format the labels and place empty quotes for the upper triangle. Note that I use `sprintf()` to ensure that the label always display two digits.

```
corm <- corm |>
  tidyr::pivot_longer(
    cols = -term,
    names_to = "colname",
    values_to = "corr"
  ) |>
  dplyr::mutate(
    rowname = forcats::fct_inorder(term),
    colname = forcats::fct_inorder(colname),
    label = dplyr::if_else(is.na(corr), "", sprintf("%1.2f", corr))
  )
```

	term	colname	corr	label
temp	temp	temp	1.0000000	1.00
temp	temp	dewpoint	0.9577391	0.96
temp	temp	pm10	0.3679648	0.37
temp	temp	o3	0.5349655	0.53
dewpoint	dewpoint	temp	NA	
dewpoint	dewpoint	dewpoint	1.0000000	1.00
dewpoint	dewpoint	pm10	0.3274569	0.33
dewpoint	dewpoint	o3	0.4539134	0.45
pm10	pm10	temp	NA	
pm10	pm10	dewpoint	NA	
pm10	pm10	pm10	1.0000000	1.00
pm10	pm10	o3	0.2060732	0.21
o3	o3	temp	NA	
o3	o3	dewpoint	NA	
o3	o3	pm10	NA	
o3	o3	o3	1.0000000	1.00

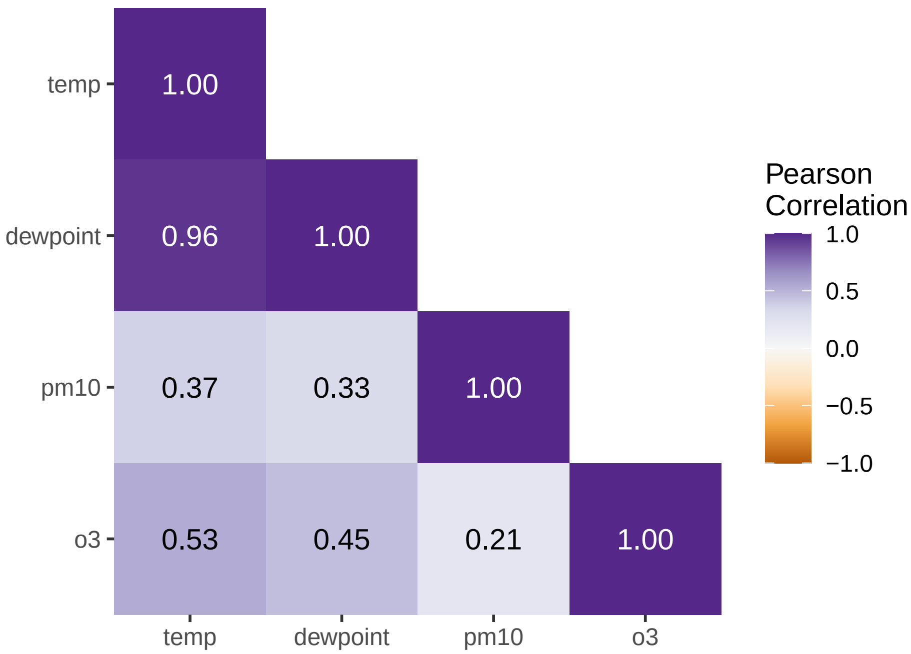
For the plot we will use `geom_tile()` for the heatmap and `geom_text()` for the labels:

```r
ggplot(corm, aes(rowname, fct_rev(colname),
                 fill = corr)) +
  geom_tile() +
  geom_text(aes(label = label)) +
  coord_fixed() +
  labs(x = NULL, y = NULL)
```



I like to have a diverging color palette—it is important that the scale is centered at zero correlation!—with white indicating missing data. Also I like to have no grid lines and padding around the heatmap as well as labels that are colored depending on the underlying fill:

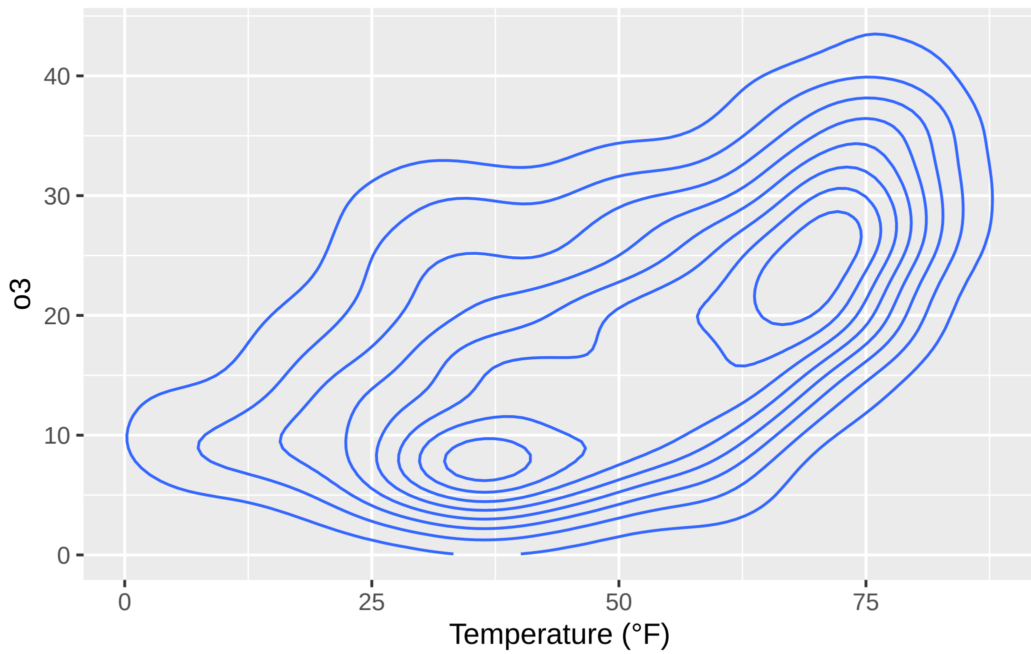
```
ggplot(corm, aes(rowname, fct_rev(colname),
                 fill = corr)) +
  geom_tile() +
  geom_text(aes(
    label = label,
    color = abs(corr) < .75
  )) +
  coord_fixed(expand = FALSE) +
  scale_color_manual(
    values = c("white", "black"),
    guide = "none"
  ) +
  scale_fill_distiller(
    palette = "PuOr", na.value = "white",
    direction = 1, limits = c(-1, 1),
    name = "Pearson\nCorrelation:"
  ) +
  labs(x = NULL, y = NULL) +
  theme(panel.border = element_rect(color = NA, fill = NA),
        legend.position.inside = c(.85, .8))
```



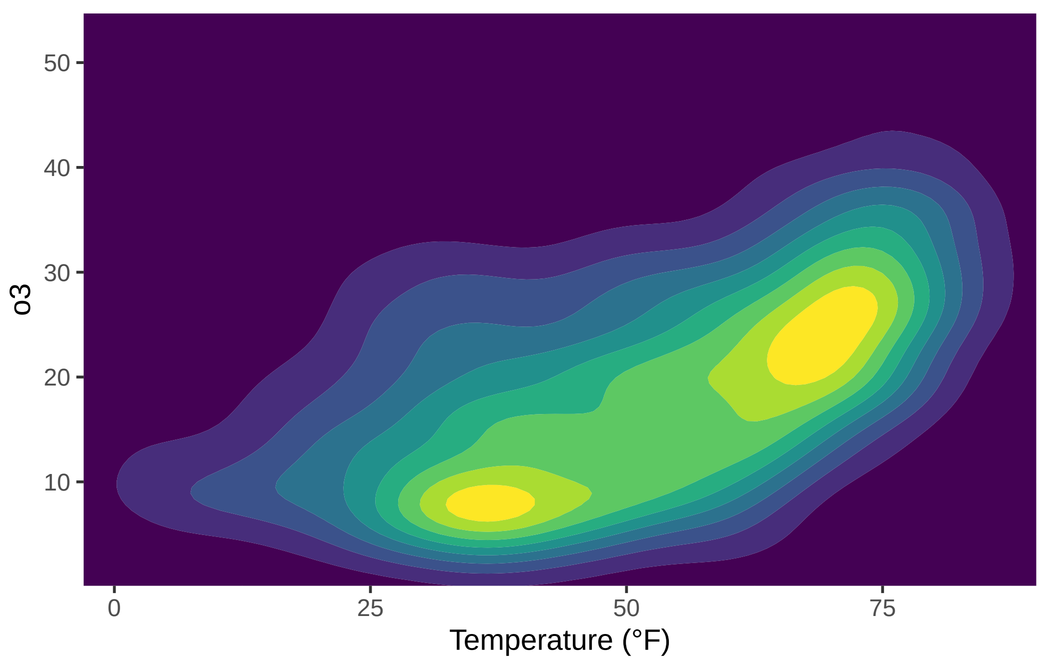
15.4 Create a Contour Plot

Contour plots are nice way to display eatesholds of values. One can use them to bin data, showing the density of observations:

```
ggplot(chic, aes(temp, o3)) +
  geom_density_2d() +
  labs(x = "Temperature (°F)", x = "Ozone Level")
```

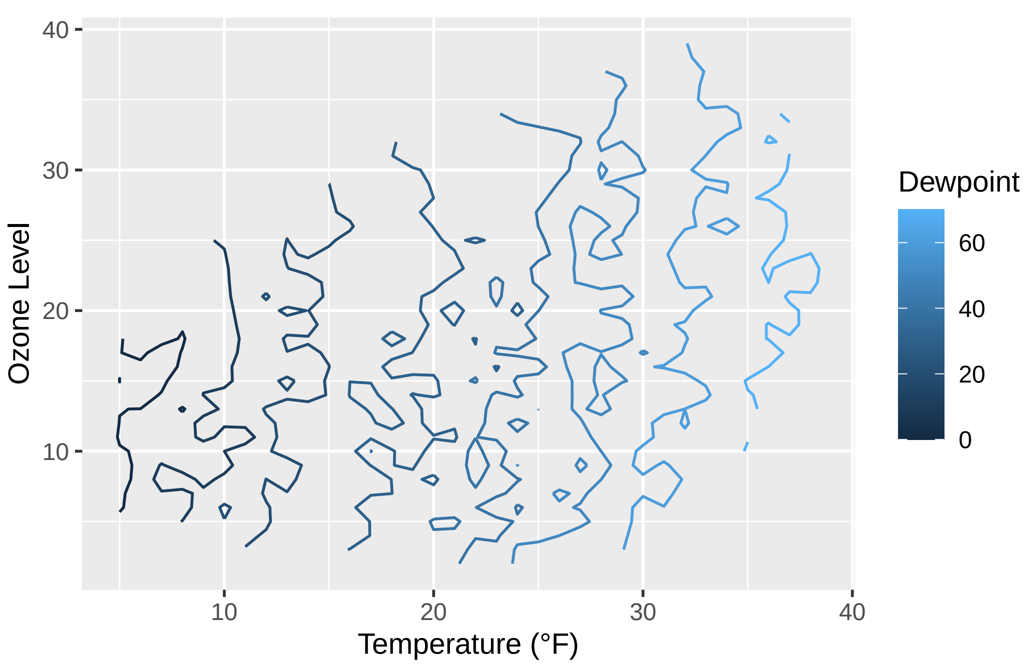



```
ggplot(chic, aes(temp, o3)) +
  geom_density_2d_filled(show.legend = FALSE) +
  coord_cartesian(expand = FALSE) +
  labs(x = "Temperature (°F)", x = "Ozone Level")
```



But now, we are plotting three-dimensional data. We are going to plot the thresholds in dewpoint (i.e. the temperature at which airborne water vapor will condense to form liquid dew) related to temperature and ozone levels:

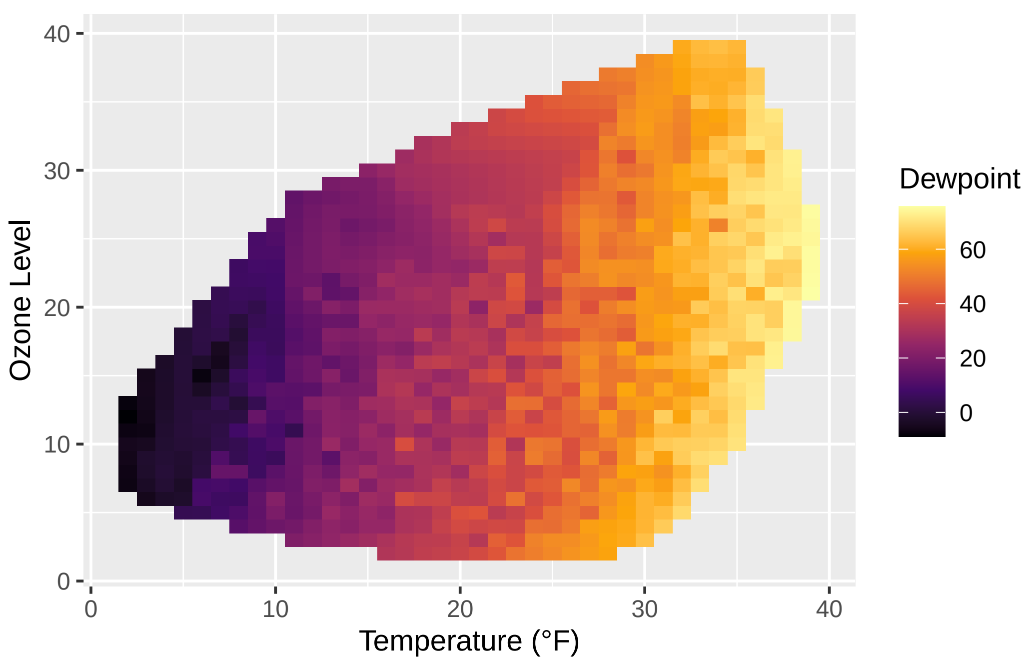
```
## interpolate data
fld <- with(chic, akima::interp(x = temp, y = o3, z = dewpoint))

## prepare data in long format
df <- fld$z |>
  tibble::as_tibble(.name_repair = "universal_quiet") |>
  dplyr::mutate(x = dplyr::row_number()) |>
  tidyr::pivot_longer(
    cols = -x,
    names_to = "y",
    names_transform = as.integer,
    values_to = "Dewpoint",
    names_prefix = "...",
    values_drop_na = TRUE
  )

g <- ggplot(data = df, aes(x = x, y = y, z = Dewpoint))  +
  labs(x = "Temperature (°F)", y = "Ozone Level",
       color = "Dewpoint")

g + stat_contour(aes(color = after_stat(level)))
```



Surprise! As it is defined, the drew point is in most cases equal to the measured temperature.

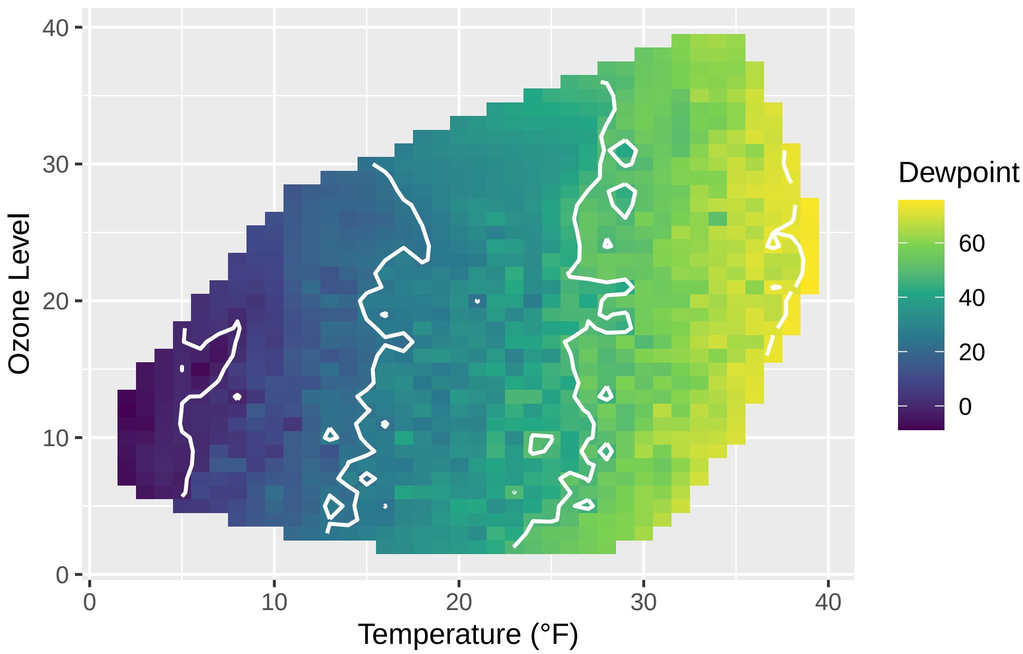
The lines are indicating different levels of drew points, but this is not a pretty plot and also hard to read due to missing borders. Let's try a tile plot using the viridis color palette to encode the dewpoint of each combination of ozone level and temperature:

```
g + geom_tile(aes(fill = Dewpoint)) +
    scale_fill_viridis_c(option = "inferno")
```



How does it look if we combine a contour plot and a tile plot to fill the area under the contour lines?

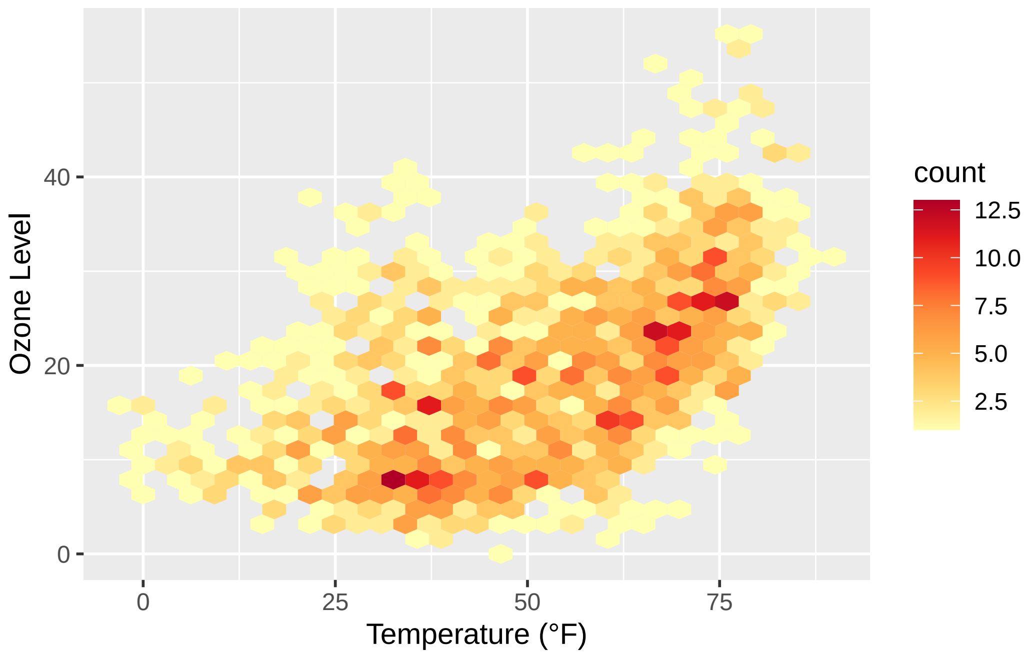
```
g + geom_tile(aes(fill = Dewpoint)) +
    stat_contour(color = "white", linewidth = .7, bins = 5) +
    scale_fill_viridis_c()
```



15.5 Create a Heatmap of Counts

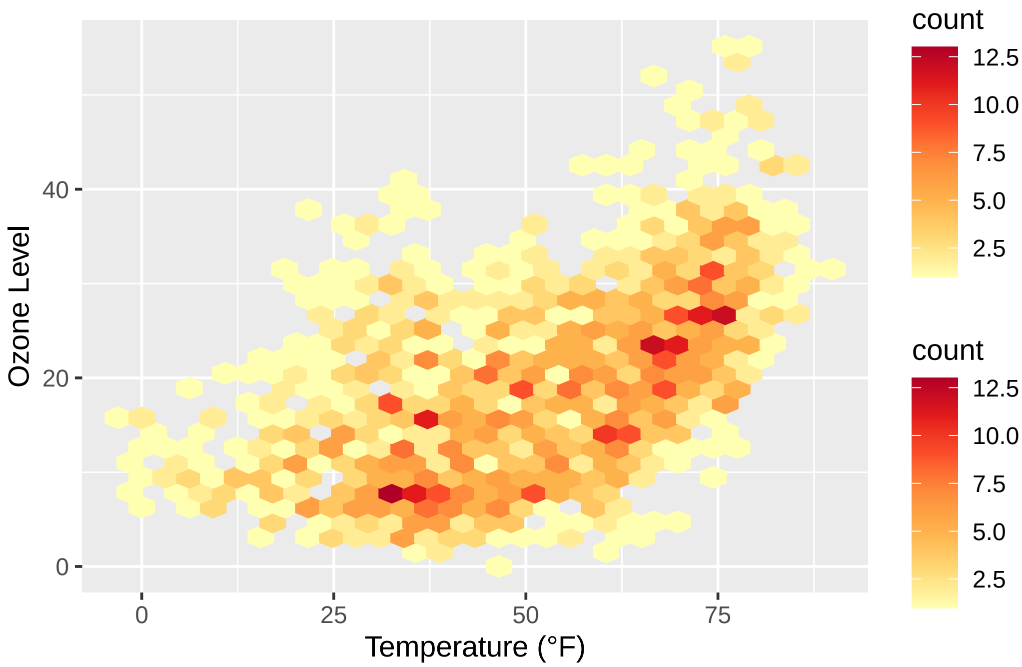
Similarly to our first contour maps, one can easily show the counts or densities of points binned to a hexagonal grid via `geom_hex()`:

```
library(hexbin)
ggplot(chic, aes(temp, o3)) +
  geom_hex() +
  scale_fill_distiller(palette = "YlOrRd", direction = 1) +
  labs(x = "Temperature (°F)", y = "Ozone Level")
```



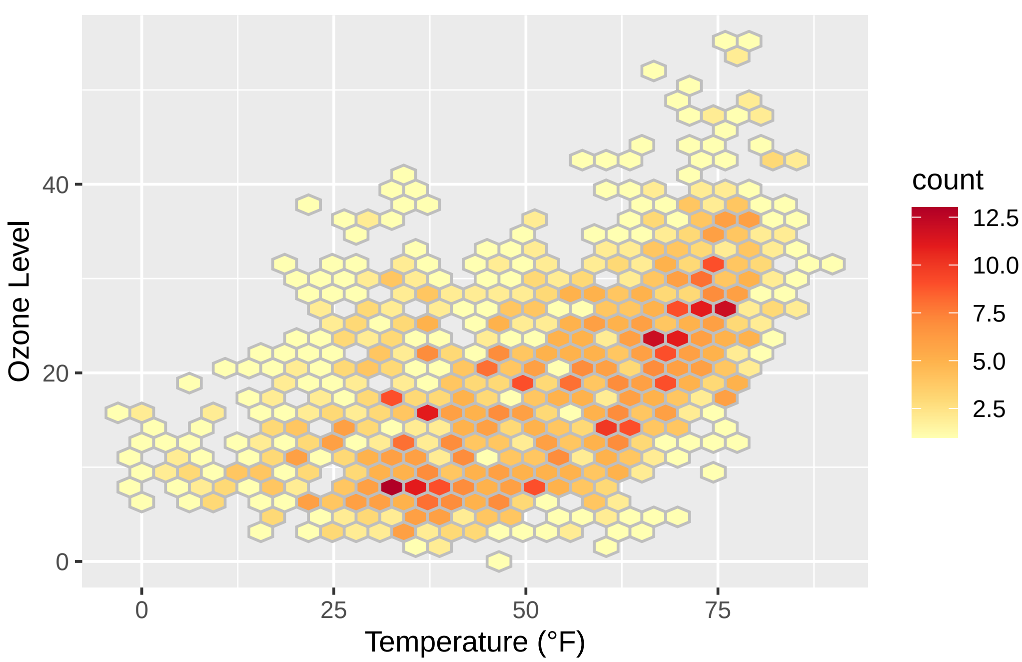
Often, white lines pop up in the resulting plot. One can fix that by mapping also color to either `after_stat(count)` (the default) or `after_stat(density)`…

```
ggplot(chic, aes(temp, o3)) +
  geom_hex(aes(color = after_stat(count))) +
  scale_fill_distiller(palette = "YlOrRd", direction = 1) +
  scale_color_distiller(palette = "YlOrRd", direction = 1) +
  labs(x = "Temperature (°F)", y = "Ozone Level")
```



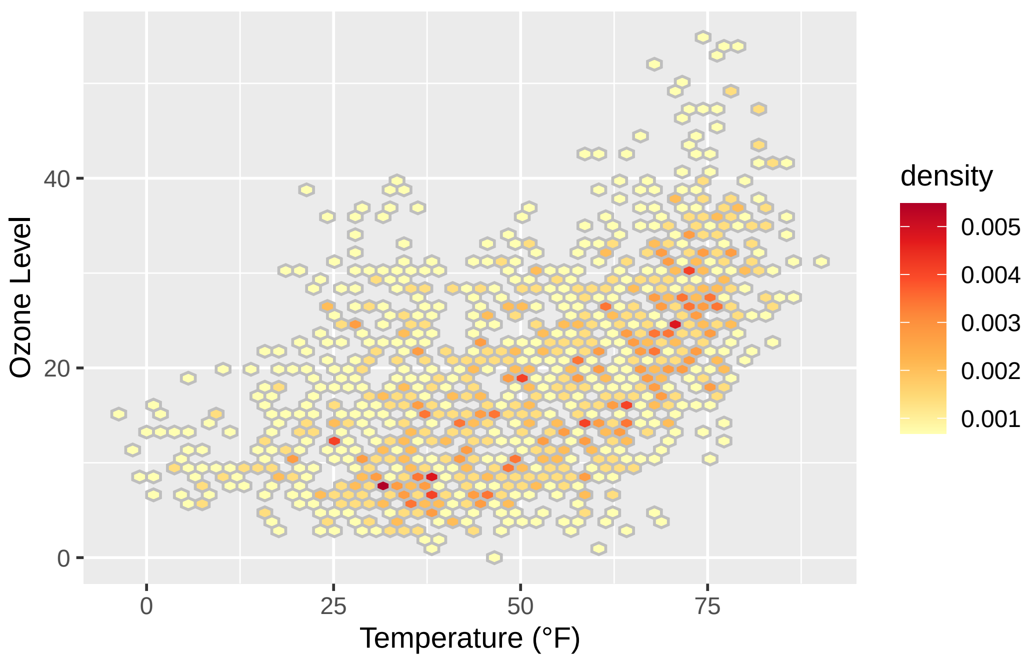
… or by setting the same color as outline for all hexagonal cells:

```
ggplot(chic, aes(temp, o3)) +
  geom_hex(color = "grey") +
  scale_fill_distiller(palette = "YlOrRd", direction = 1) +
  labs(x = "Temperature (°F)", y = "Ozone Level")
```



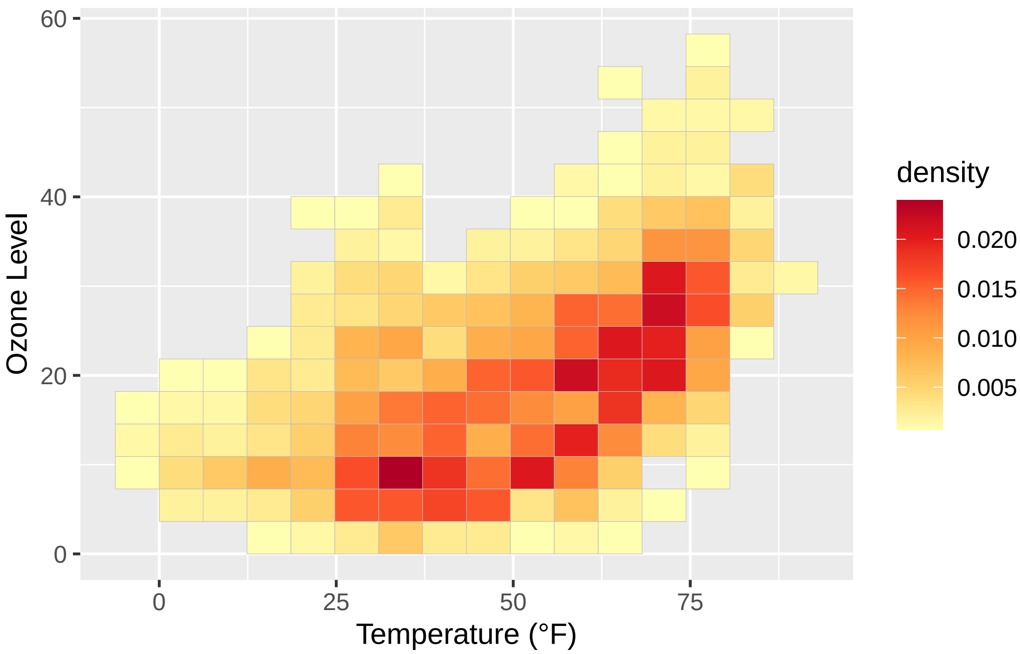
One can also change the default binning to in- or decrease the number of hexagonal cells:

```
ggplot(chic, aes(temp, o3, fill = after_stat(density))) +
  geom_hex(bins = 50, color = "grey") +
  scale_fill_distiller(palette = "YlOrRd", direction = 1) +
  labs(x = "Temperature (°F)", y = "Ozone Level")
```



If you want to have a regular grid, one can also use `geom_bin2d()` which summarizes the data to rectangular grid cells based on `bins`:

```
ggplot(chic, aes(temp, o3, fill = after_stat(density))) +
  geom_bin2d(bins = 15, color = "grey") +
  scale_fill_distiller(palette = "YlOrRd", direction = 1) +
  labs(x = "Temperature (°F)", y = "Ozone Level")
```



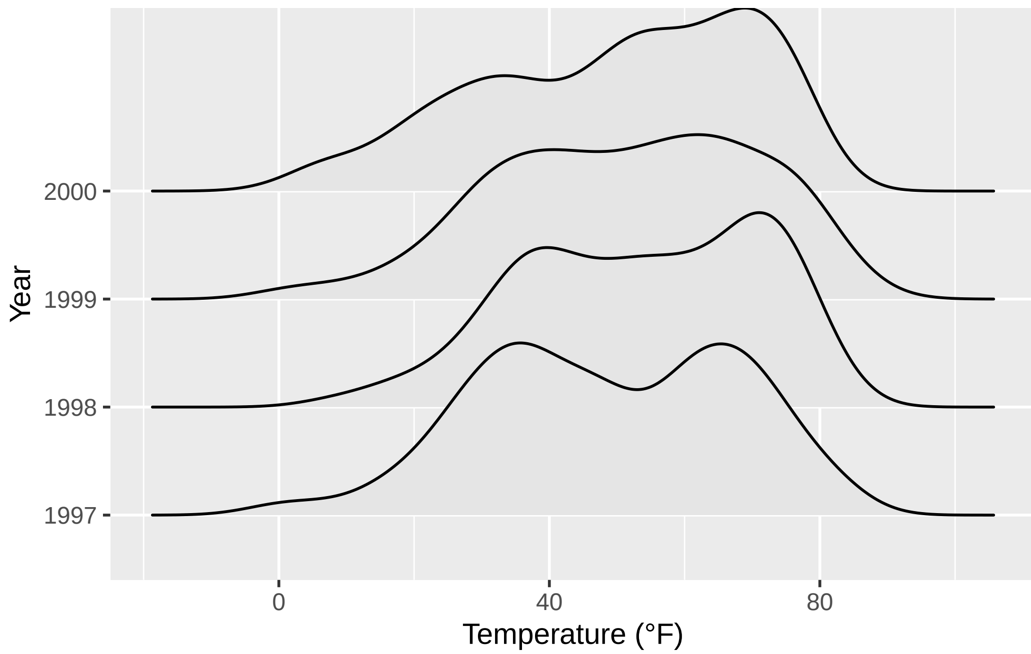
15.6 Create a Ridge Plot

Ridge(line) plots are a new type of plots which is very popular at the moment.

While you can create those plots with basic {ggplot2} commands the popularity lead to a package that make it easier create those plots: {ggridges}. We are going to use this package here.

```
library(ggridges)
ggplot(chic, aes(x = temp, y = factor(year))) +
   geom_density_ridges(fill = "gray90") +
   labs(x = "Temperature (°F)", y = "Year")
```

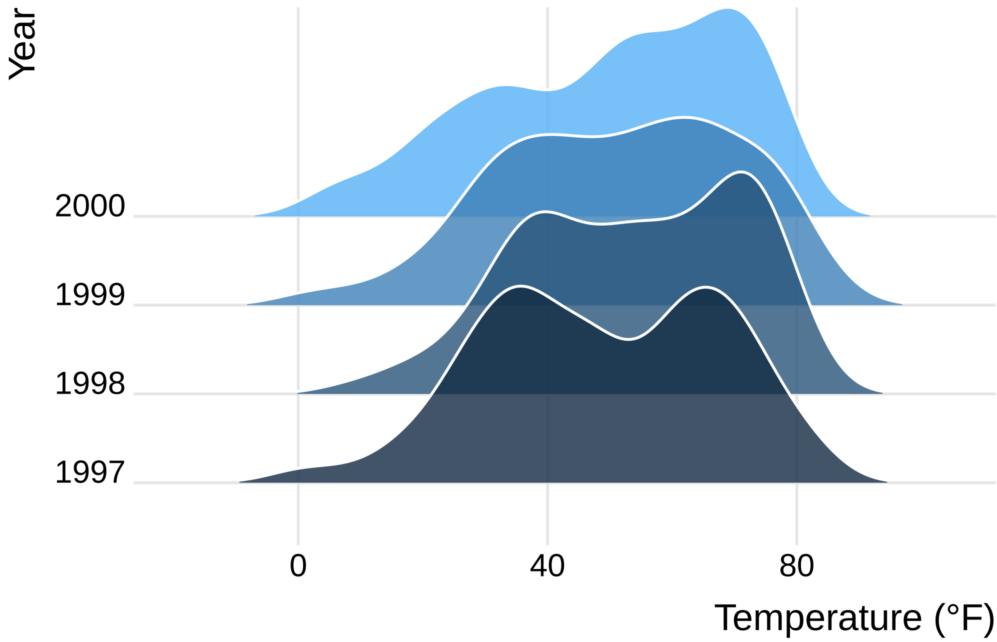
```
Picking joint bandwidth of 5.23
```



You can easily specify the overlap and the trailing tails by using the arguments `rel_min_height` and `scale`, respectively. The package also comes with its own theme (but I would prefer to build my own, see chapter "Create and Use Your Custom Theme"). Additionally, we change the colors based on year to make it more appealing.

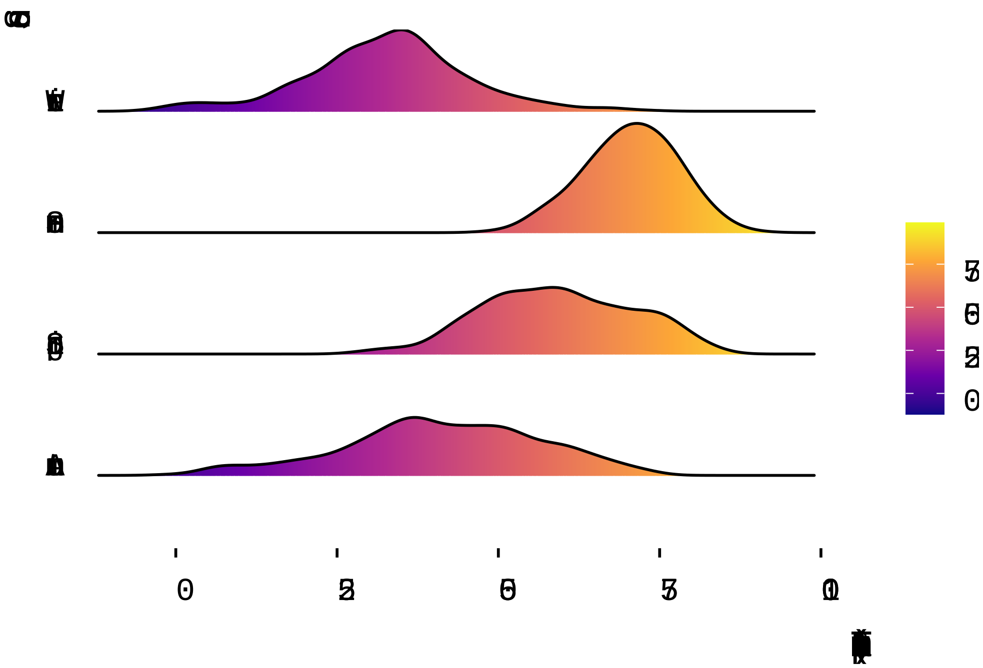
```
ggplot(chic, aes(x = temp, y = factor(year), fill = year)) +
  geom_density_ridges(alpha = .8, color = "white",
                      scale = 2.5, rel_min_height = .01) +
  labs(x = "Temperature (°F)", y = "Year") +
  guides(fill = "none") +
  theme_ridges()
```

```
Picking joint bandwidth of 5.23
```



You can also get rid of the overlap using values below 1 for the scaling argument (but this somehow contradicts the idea of ridge plots...). Here is an example additionally using the viridis color gradient and the in-build theme:

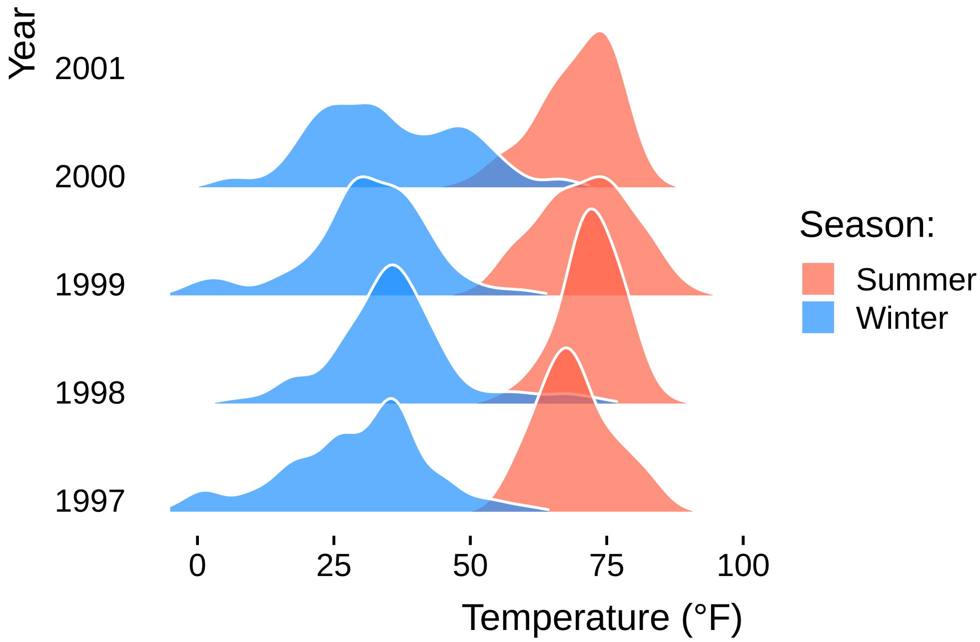
```
ggplot(chic, aes(x = temp, y = season, fill = after_stat(x))) +
  geom_density_ridges_gradient(scale = .9, gradient_lwd = .5,
                               color = "black") +
  scale_fill_viridis_c(option = "plasma", name = "") +
  labs(x = "Temperature (°F)", y = "Season") +
  theme_ridges(font_family = "Roboto Condensed", grid = FALSE)
```



We can also compare several groups per ridgeline and coloring them according to their group. This follows the idea of Marc Belzunces.

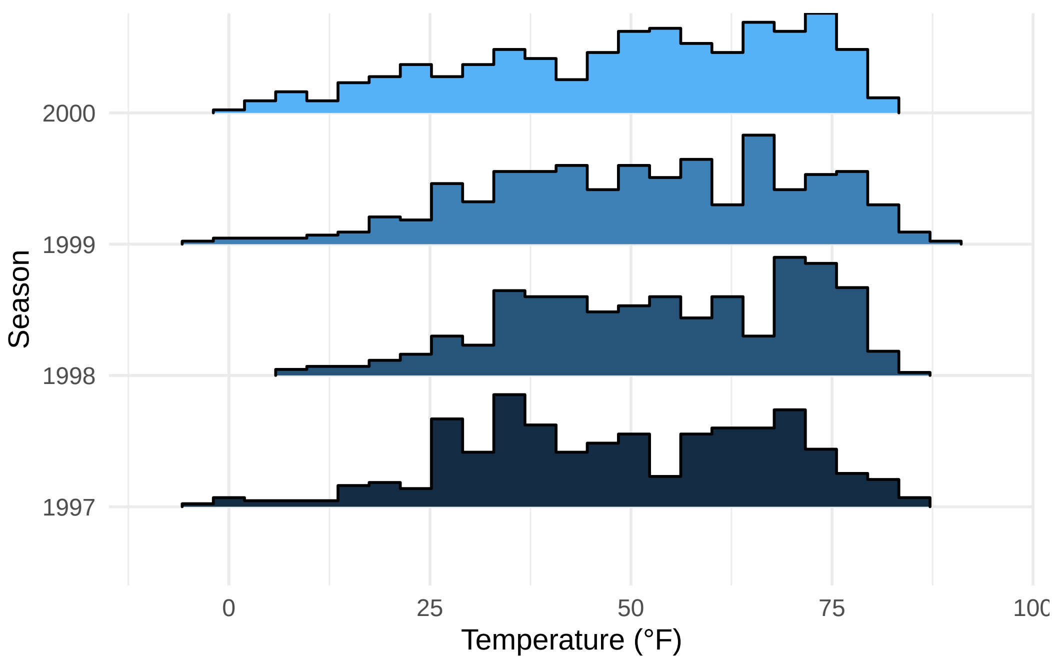
```
library(dplyr)

## only plot extreme season using dplyr from the tidyverse
ggplot(data = dplyr::filter(chic, season %in% c("Summer", "Winter")),
         aes(x = temp, y = year, fill = paste(year, season))) +
  geom_density_ridges(alpha = .7, rel_min_height = .01,
                      color = "white", from = -5, to = 95) +
  scale_fill_cyclical(breaks = c("1997 Summer", "1997 Winter"),
                      labels = c(`1997 Summer` = "Summer",
                                 `1997 Winter` = "Winter"),
                      values = c("tomato", "dodgerblue"),
                      name = "Season:", guide = "legend") +
  theme_ridges(grid = FALSE) +
  labs(x = "Temperature (°F)", y = "Year")
```

```
Picking joint bandwidth of 3.17
```



The {ggridges} package is also helpful to create histograms for different groups using `stat = "binline"` in the `geom_density_ridges()` command:

```
ggplot(chic, aes(x = temp, y = factor(year), fill = year)) +
  geom_density_ridges(stat = "binline", bins = 25, scale = .9,
                      draw_baseline = FALSE, show.legend = FALSE) +
  theme_minimal() +
  labs(x = "Temperature (°F)", y = "Season")
```

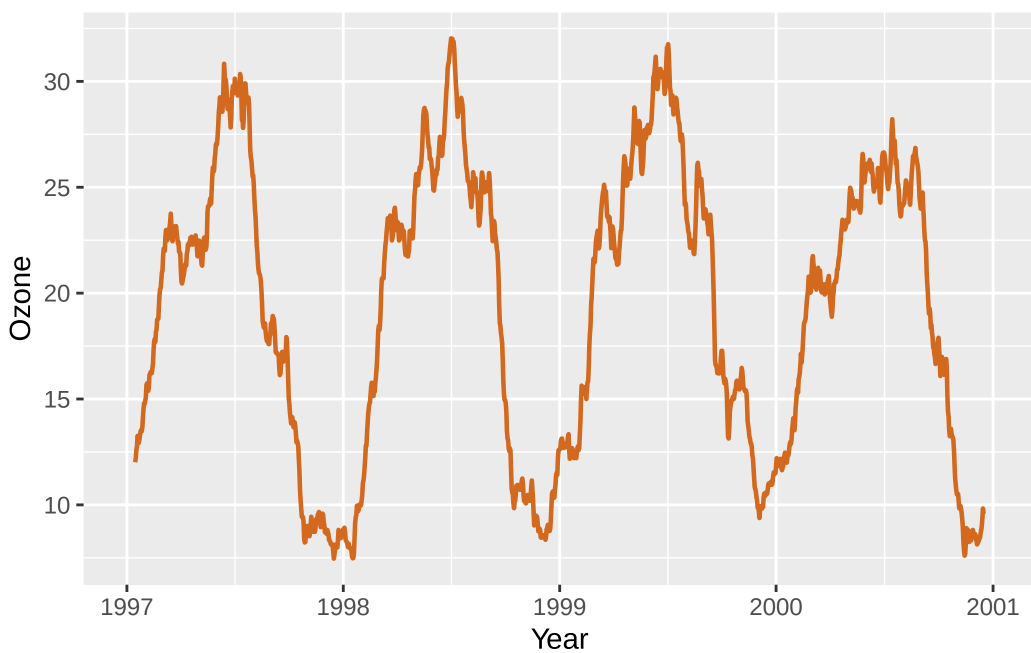


16 Working with Ribbons (AUC, CI, etc.)

This is not a perfect dataset for demonstrating this, but using ribbon can be useful. In this example we will create a 30-day running average using the filter() function so that our ribbon is not too noisy.

```
chic$o3run <- as.numeric(stats::filter(chic$o3, rep(1/30, 30), sides = 2))

ggplot(chic, aes(x = date, y = o3run)) +
   geom_line(color = "chocolate", lwd = .8) +
   labs(x = "Year", y = "Ozone")
```

```
Warning: Removed 29 rows containing missing values or values outside the scale range
(`geom_line()`).
```

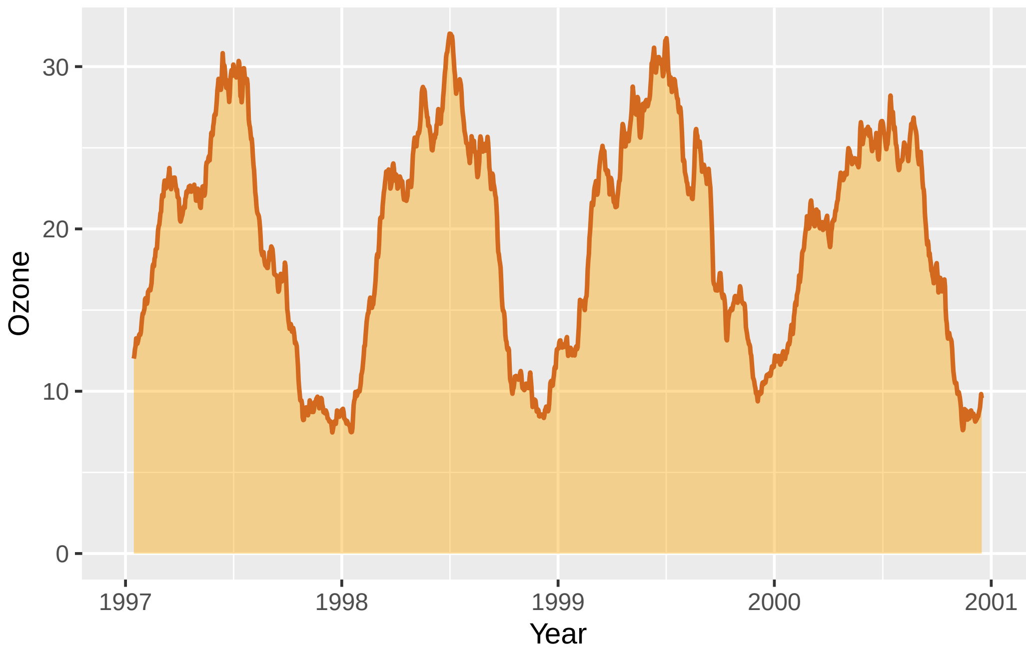


How does it look if we fill in the area below the curve using the `geom_ribbon()` function?

```
ggplot(chic, aes(x = date, y = o3run)) +
   geom_ribbon(aes(ymin = 0, ymax = o3run),
               fill = "orange", alpha = .4) +
```

```
  geom_line(color = "chocolate", lwd = .8) +
  labs(x = "Year", y = "Ozone")
```

```
Warning: Removed 29 rows containing missing values or values outside the scale range
(`geom_line()`).
```



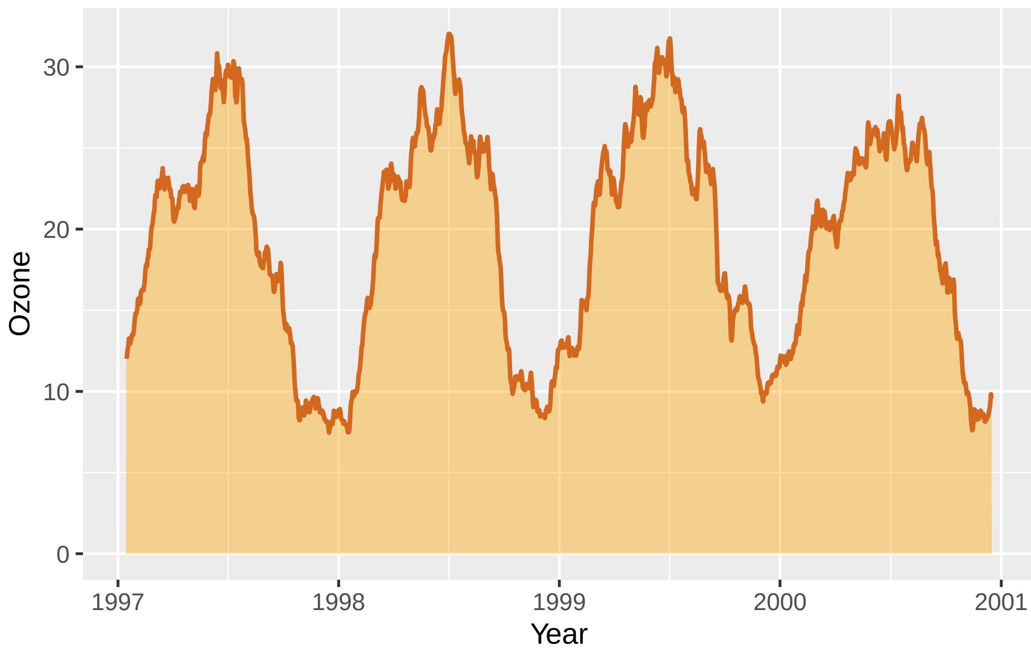
Nice to indicate the area under the curve (AUC) but this is not the conventional way to use `geom_ribbon()`.

Using `geom_area()`

Actually a nicer way to achieve the same is `geom_area()`.

```
ggplot(chic, aes(x = date, y = o3run)) +
  geom_area(color = "chocolate", lwd = .8,
            fill = "orange", alpha = .4) +
  labs(x = "Year", y = "Ozone")
```

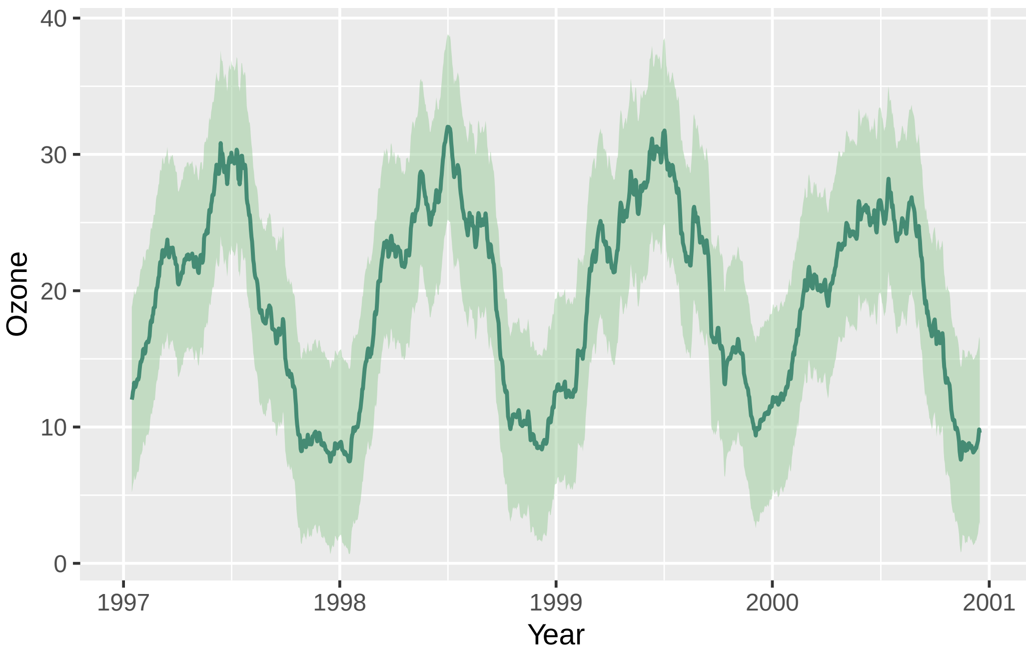
```
Warning: Removed 29 rows containing non-finite outside the scale range
(`stat_align()`).
```



Instead, we draw a ribbon that gives us one standard deviation above and below our data:

```
chic$mino3 <- chic$o3run - sd(chic$o3run, na.rm = TRUE)
chic$maxo3 <- chic$o3run + sd(chic$o3run, na.rm = TRUE)

ggplot(chic, aes(x = date, y = o3run)) +
   geom_ribbon(aes(ymin = mino3, ymax = maxo3), alpha = .5,
               fill = "darkseagreen3", color = "transparent") +
   geom_line(color = "aquamarine4", lwd = .7) +
   labs(x = "Year", y = "Ozone")
```

```
Warning: Removed 29 rows containing missing values or values outside the scale range
(`geom_line()`).
```



40
30
20
10
0
Ozone
1997
1998
1999
2000
2001
Year

17 Working with Smoothings

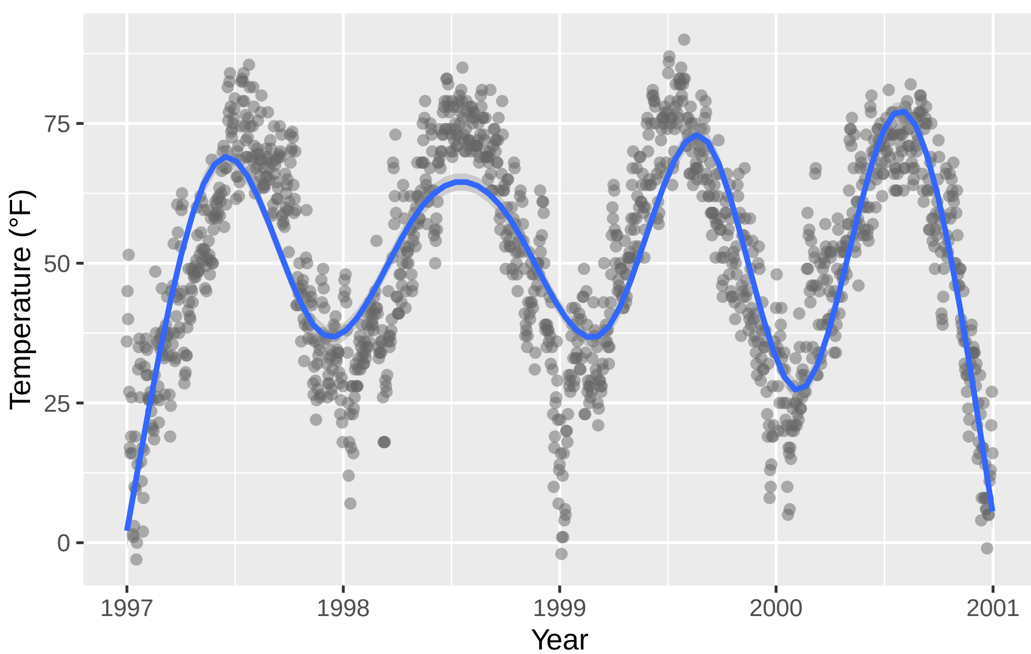
It is amazingly easy to add smoothing to your data using {ggplot2}.

17.1 Default: Adding a LOESS or GAM Smoothing

You can simply use stat_smooth()—not even a formula is required. This adds a LOESS (locally weighted scatter plot smoothing, method = "loess") if you have fewer than 1000 points or a GAM (generalized additive model, method = "gam") otherwise. Since we have more than 1000 points, the smoothing is based on a GAM:

```
ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "gray40", alpha = .5) +
  stat_smooth() +
  labs(x = "Year", y = "Temperature (°F)")
```

```
`geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```



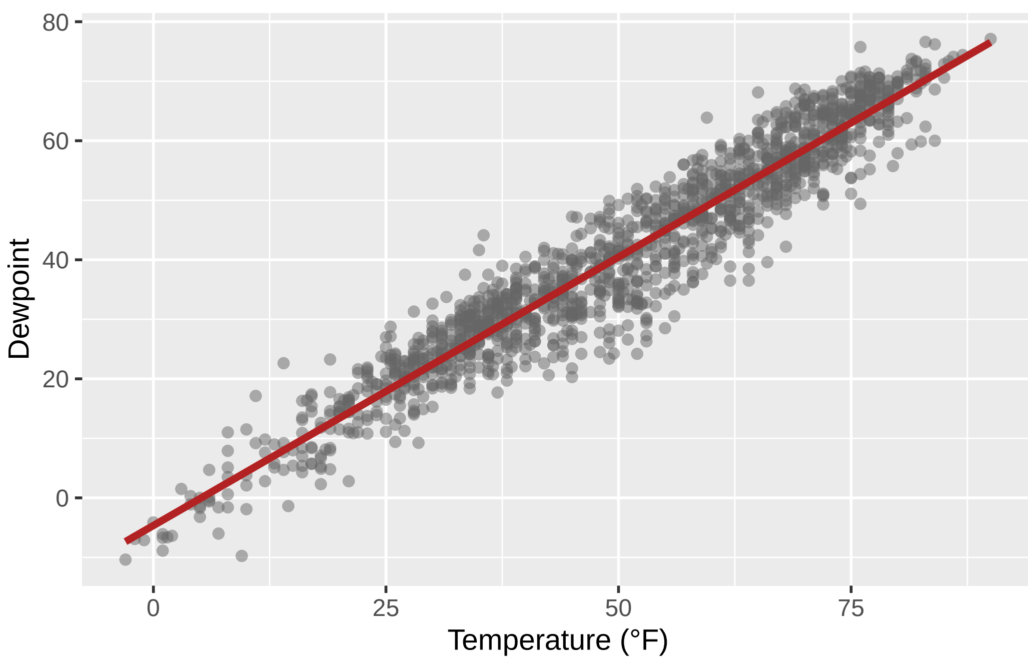
> **Note**
>
> In most cases one wants the points to be on top of the ribbon so make sure you always call the smoothing before you add the points.

17.2 Adding a Linear Fit

Though the default is a LOESS or GAM smoothing, it is also easy to add a standard linear fit:

```
ggplot(chic, aes(x = temp, y = dewpoint)) +
  geom_point(color = "gray40", alpha = .5) +
  stat_smooth(method = "lm", se = FALSE,
              color = "firebrick", linewidth = 1.3) +
  labs(x = "Temperature (°F)", y = "Dewpoint")
```

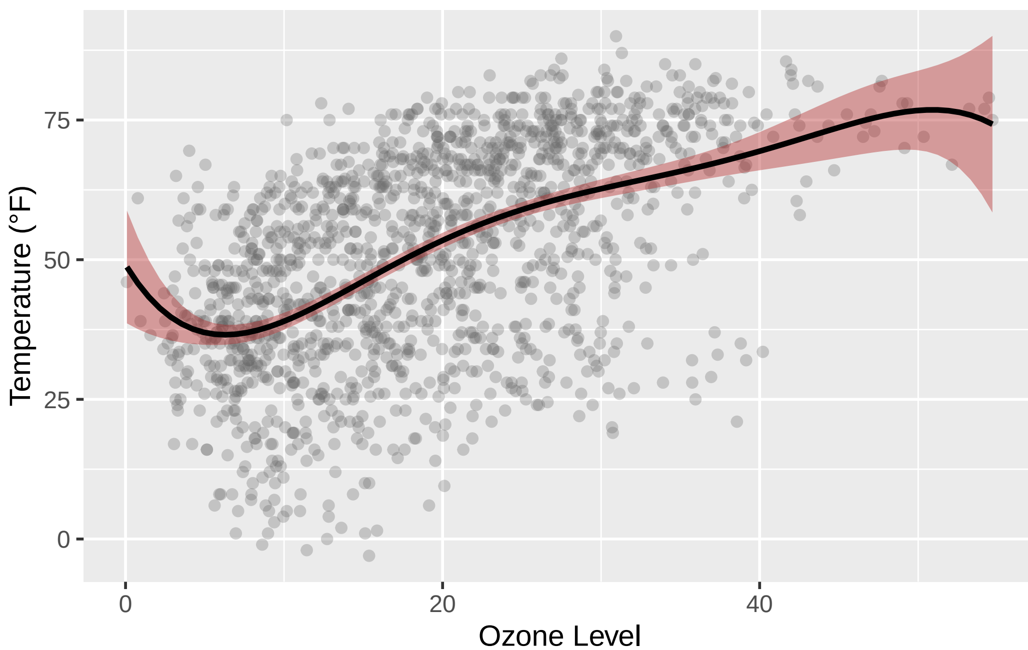
```
`geom_smooth()` using formula = 'y ~ x'
```



17.3 Specifying the Formula for Smoothing

`{ggplot2}` allows you to specify the model you want it to use. Maybe you want to use a polynomial regression?

```
ggplot(chic, aes(x = o3, y = temp)) +
  geom_point(color = "gray40", alpha = .3) +
  geom_smooth(
    method = "lm",
    formula = y ~ x + I(x^2) + I(x^3) + I(x^4) + I(x^5),
    color = "black",
    fill = "firebrick"
  ) +
  labs(x = "Ozone Level", y = "Temperature (°F)")
```

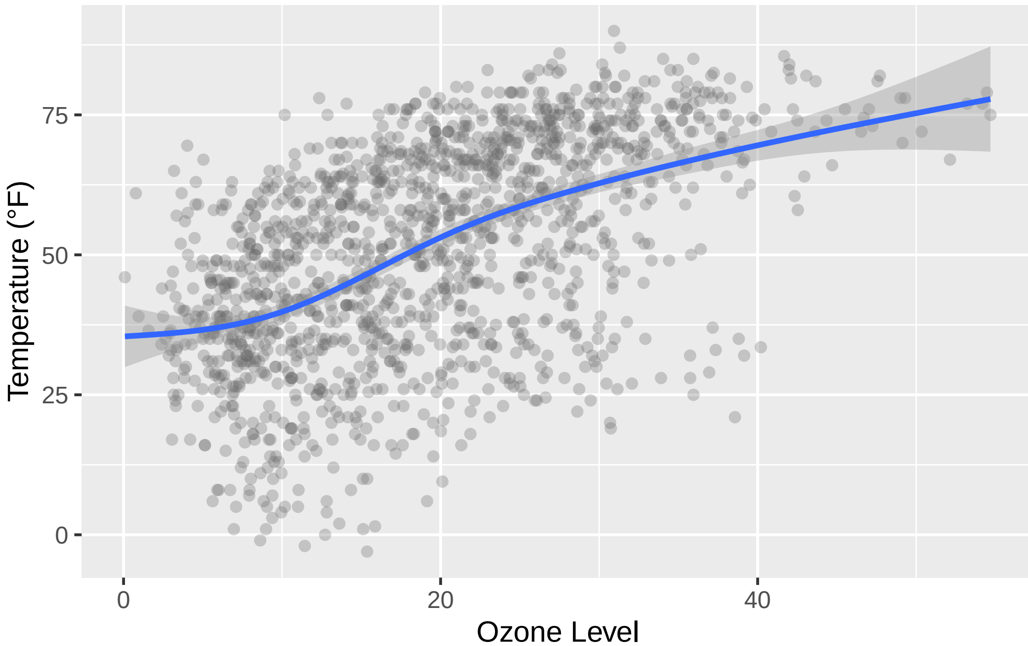


Difference between geom and stat

Huh, geom_smooth()? There is an important difference between geom and stat but here it really doesn't matter which one you use. Expand to compare both.

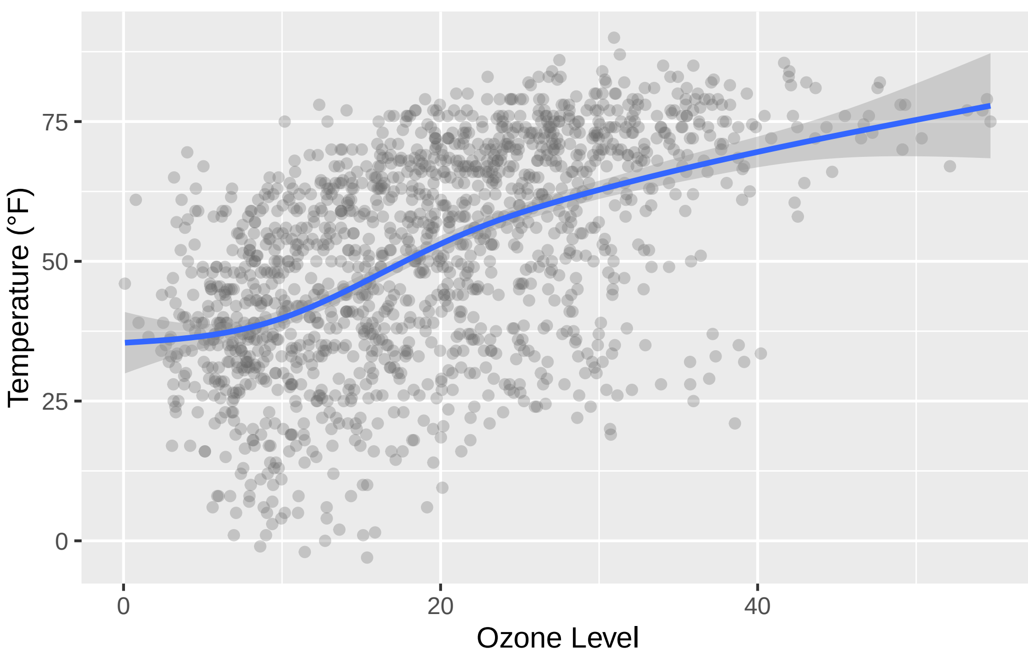
```
ggplot(chic, aes(x = o3, y = temp)) +
  geom_point(color = "gray40", alpha = .3) +
  geom_smooth(stat = "smooth") + ## the default
  labs(x = "Ozone Level", y = "Temperature (°F)")
```

```
`geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```



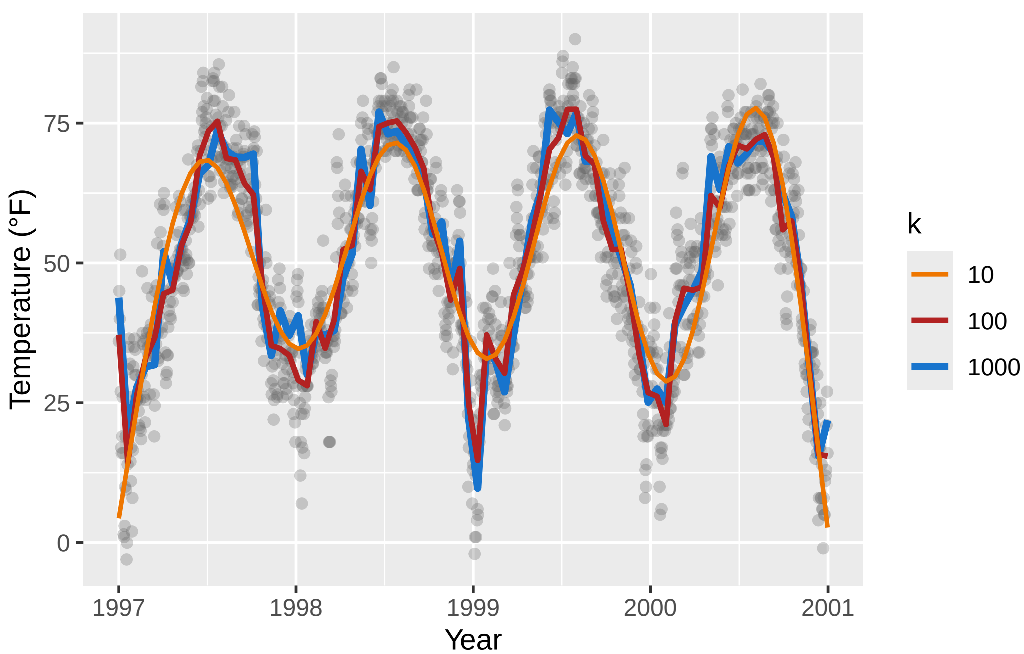

```
ggplot(chic, aes(x = o3, y = temp)) +
  geom_point(color = "gray40", alpha = .3) +
  stat_smooth(geom = "smooth") + ## the default
  labs(x = "Ozone Level", y = "Temperature (°F)")
```

```
`geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```



Or lets say you want to increase the GAM dimension (add some additional wiggles to the smooth):

```
cols <- c("darkorange2", "firebrick", "dodgerblue3")

ggplot(chic, aes(x = date, y = temp)) +
  geom_point(color = "gray40", alpha = .3) +
  stat_smooth(aes(col = "1000"),
              method = "gam",
              formula = y ~ s(x, k = 1000),
              se = FALSE, linewidth = 1.3) +
  stat_smooth(aes(col = "100"),
              method = "gam",
              formula = y ~ s(x, k = 100),
              se = FALSE, linewidth = 1) +
  stat_smooth(aes(col = "10"),
              method = "gam",
              formula = y ~ s(x, k = 10),
              se = FALSE, linewidth = .8) +
  scale_color_manual(name = "k", values = cols) +
  labs(x = "Year", y = "Temperature (°F)")
```



18 Working with Interactive Plots

The following collection lists libraries that can be used in combination with `{ggplot2}` or on their own to create interactive visualizations in R (often making use of existing JavaScript libraries).

18.1 Combination of {ggplot2} and {shiny}

`{shiny}` is a package from RStudio that makes it incredibly easy to build interactive web applications with R. For an introduction and live examples, visit the Shiny homepage.

To look at the potential use, you can check out the Hello Shiny examples. This is the first one:

```
library(shiny)
runExample("01_hello")
```

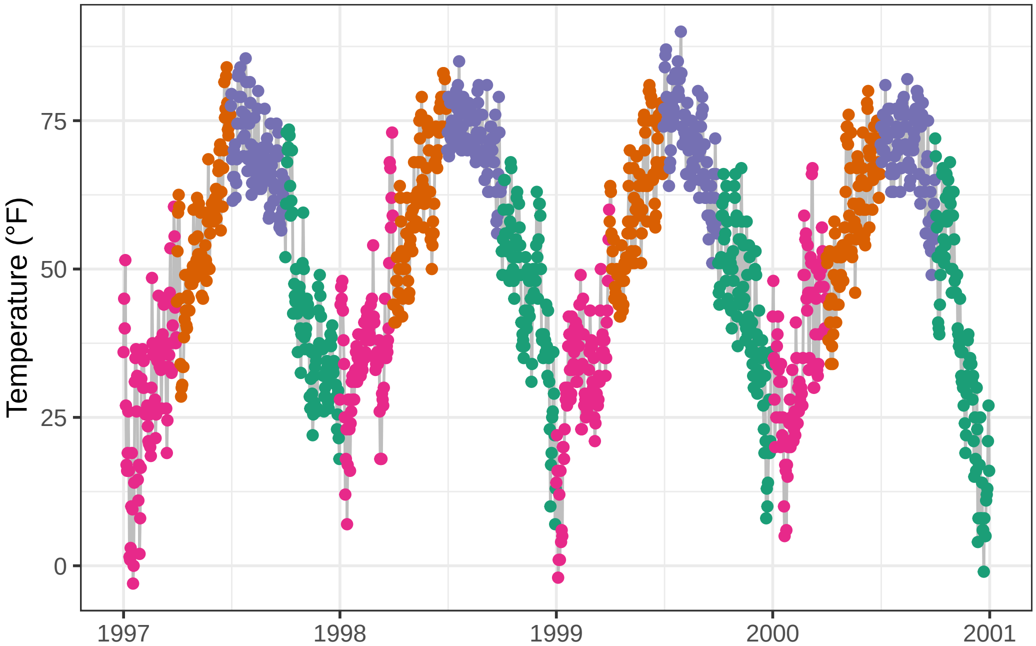
Of course, one can use ggplots in these apps. This example demonstrates the possibility to add some interactive user experience:

```
runExample("04_mpg")
```

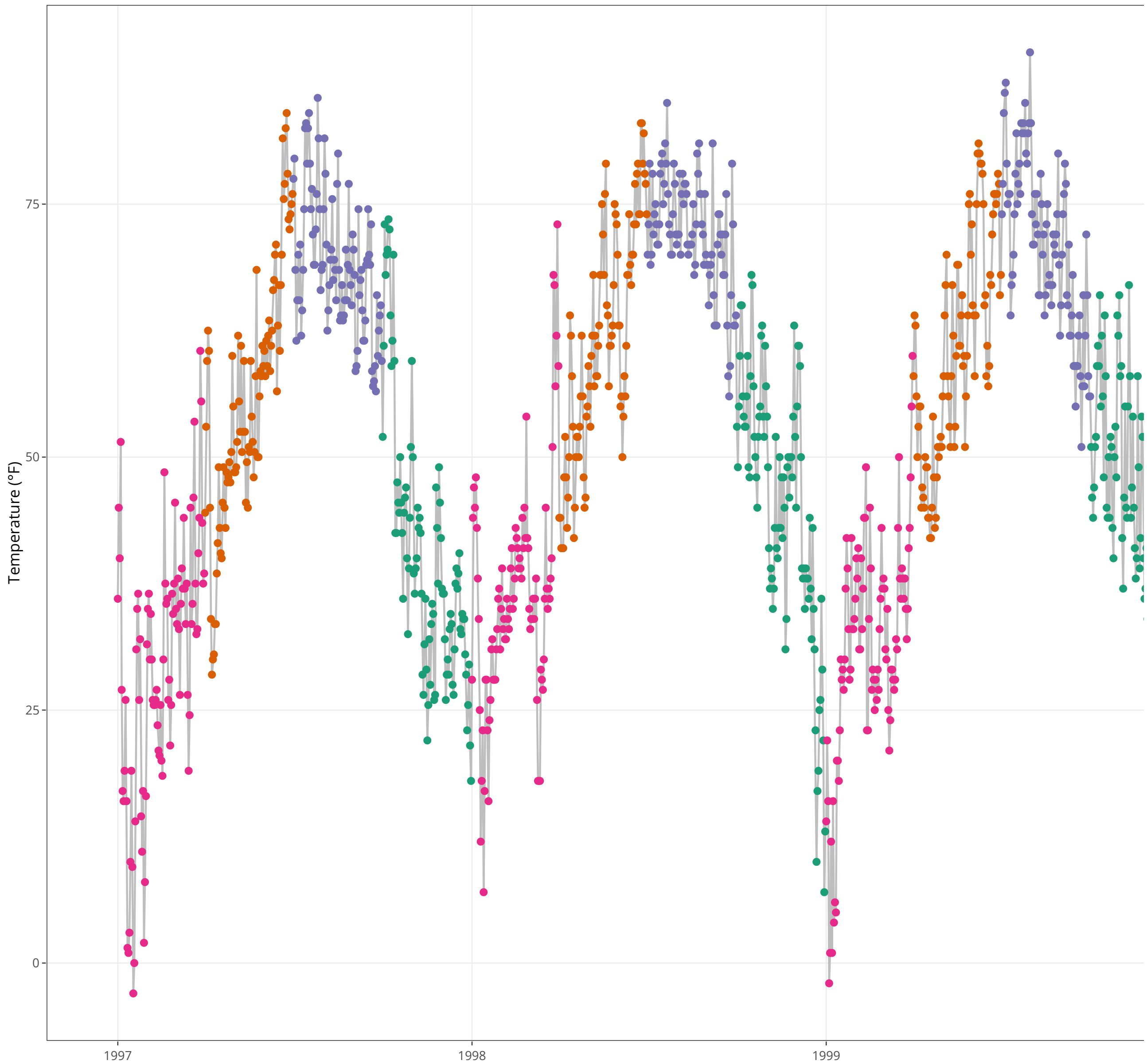
18.2 Plot.ly via {plotly} and {ggplot2}

Plot.ly is a tool for creating online, interactive graphics and web apps. The `{plotly}` package enables you to create those directly from your `{ggplot2}` plots and the workflow is surprisingly easy and can be done from within R. However, some of your theme settings might be changed and need to be modified manually afterwards. Also, and unfortunately, it is not straightforward to create facets or true multi-panel plots that scale nicely.

```
g <- ggplot(chic, aes(date, temp)) +
  geom_line(color = "grey") +
  geom_point(aes(color = season)) +
  scale_color_brewer(palette = "Dark2", guide = "none") +
  labs(x = NULL, y = "Temperature (°F)") +
  theme_bw()

g
```




```
library(plotly)

ggplotly(g)
```

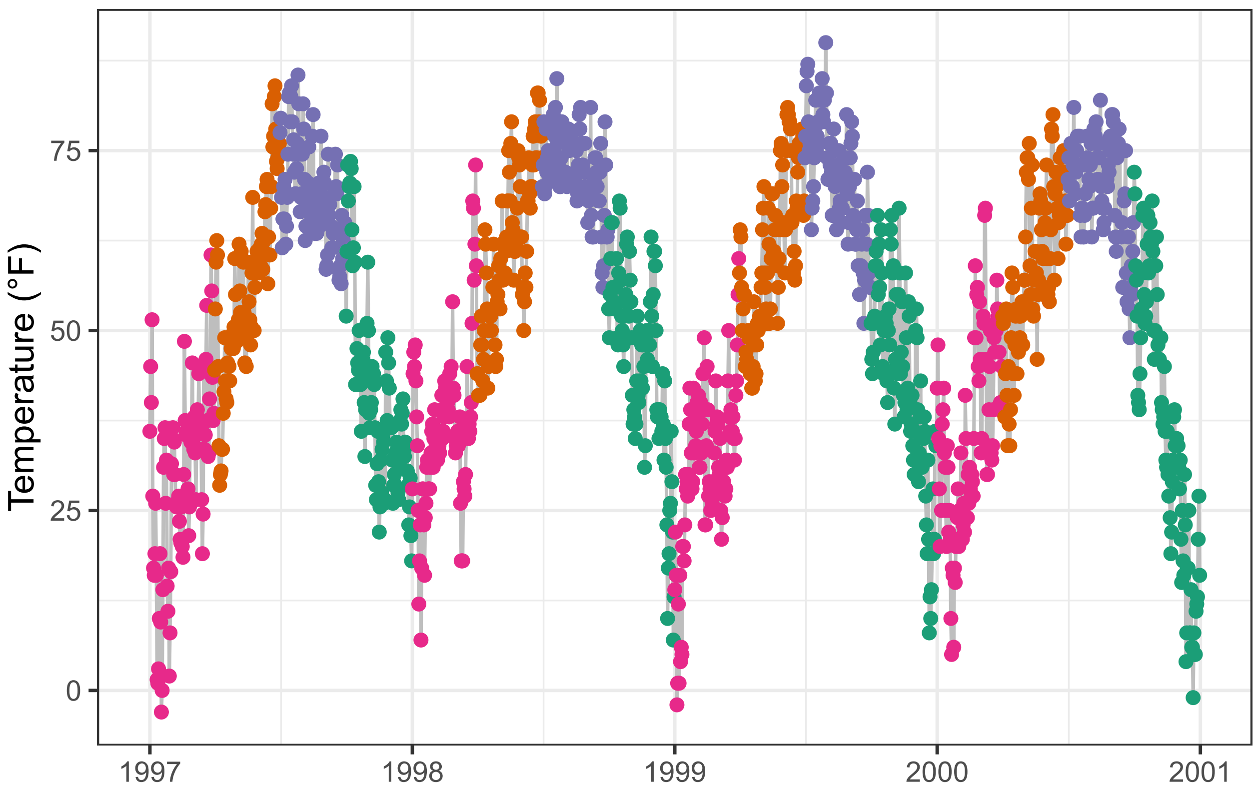


Here, for example, it keeps the overall theme setting but adds the legend again.

18.3 ggiraph and ggplot2

`{ggiraph}` is an R package that allows you to create dynamic `{ggplot2}` graphs. This allows you to add tooltips, animations and JavaScript actions to the graphics. The package also allows the selection of graphical elements when used in Shiny applications.

```
library(ggiraph)

g <- ggplot(chic, aes(date, temp)) +
  geom_line(color = "grey") +
  geom_point_interactive(
    aes(color = season, tooltip = season, data_id = season)
  ) +
  scale_color_brewer(palette = "Dark2", guide = "none") +
  labs(x = NULL, y = "Temperature (°F)") +
  theme_bw()

girafe(ggobj = g)
```



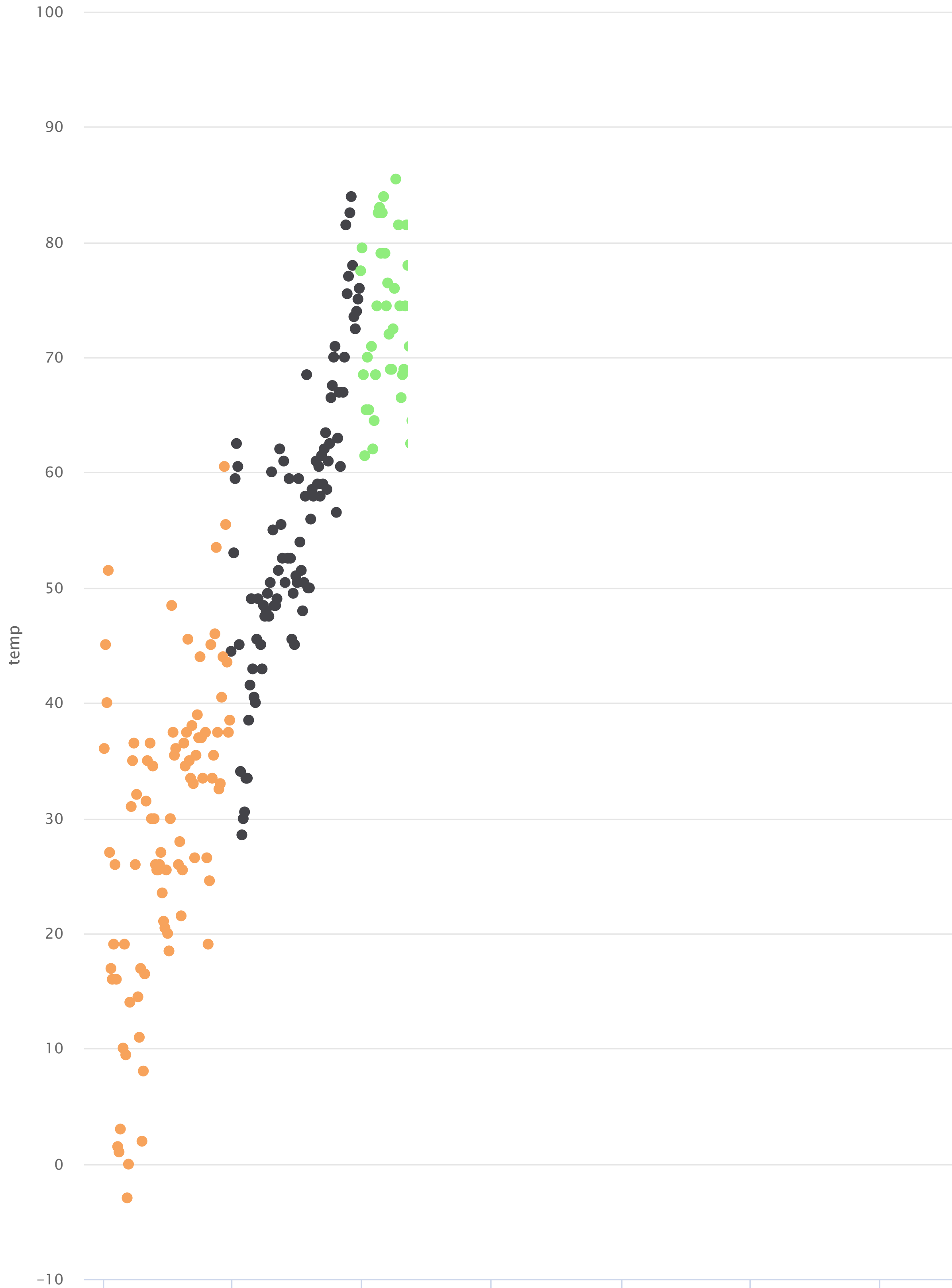
18.4 Highcharts via {highcharter}

Highcharts, a software library for interactive charting, is another visualization library written in pure JavaScript that has been ported to R. The package {highcharter} makes it possible to use them—but be aware that Highcharts is only free in case of non-commercial use.

```r
library(highcharter)
```

```
Registered S3 method overwritten by 'quantmod':
  method            from
  as.zoo.data.frame zoo
```

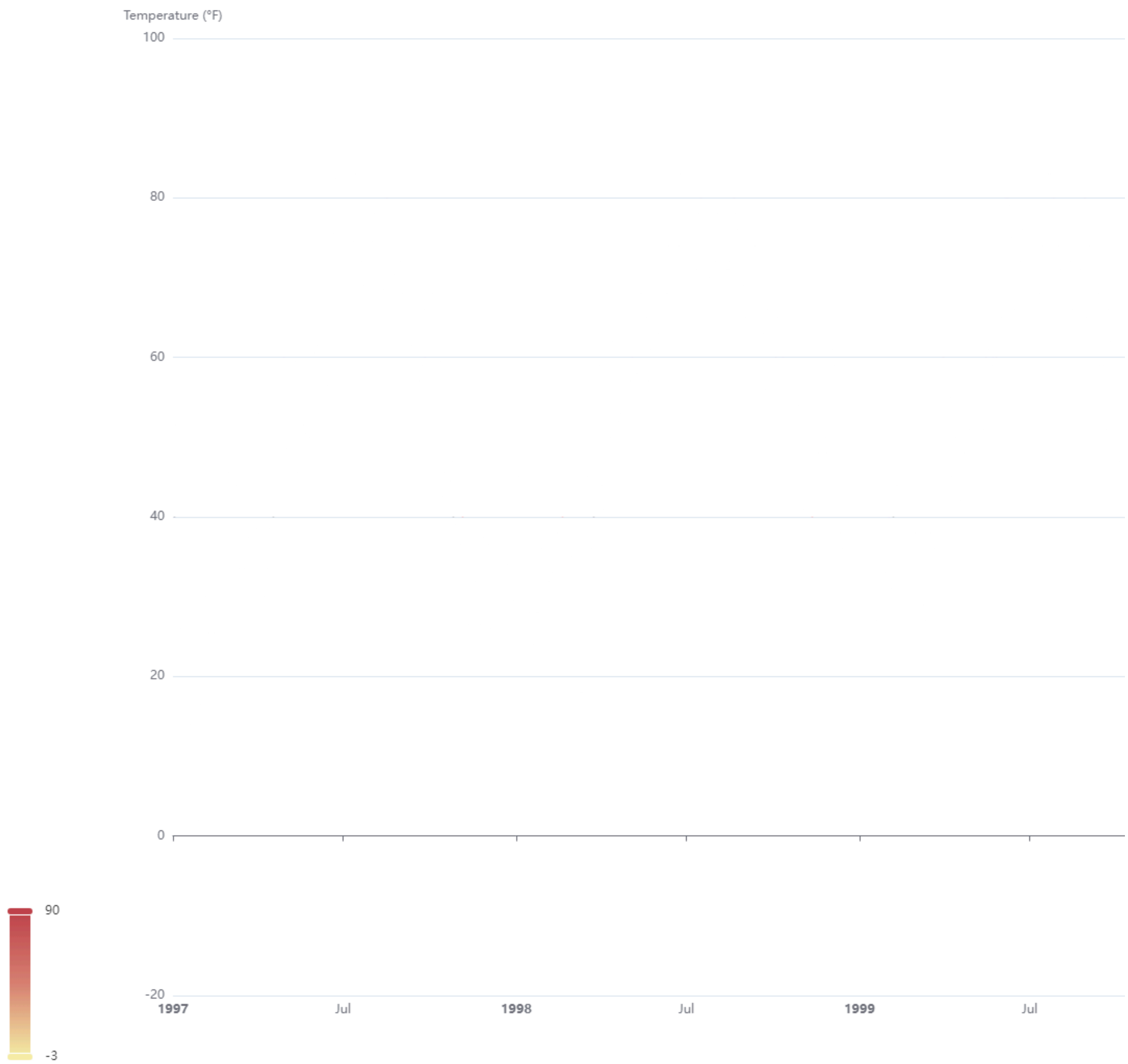
```r
hchart(chic, "scatter", hcaes(x = date, y = temp, group = season))
```


100
90
80
70
60
50
40
30
20
10
0
−10
temp

18.5 Echarts via {echarts4r}

Apache ECharts is a free, powerful charting and visualization library offering an easy way of building intuitive, interactive, and highly customizable charts. Even though it is written in pure JavaScript, one can use it in R via the `{echarts4r}` library thanks to John Coene. Check out the impressive example gallery or this app made by the package developer John Coene.

```
library(echarts4r)

chic |>
  e_charts(date) |>
  e_scatter(temp, symbol_size = 7) |>
  e_visual_map(temp) |>
  e_y_axis(name = "Temperature (°F)") |>
  e_legend(FALSE)
```

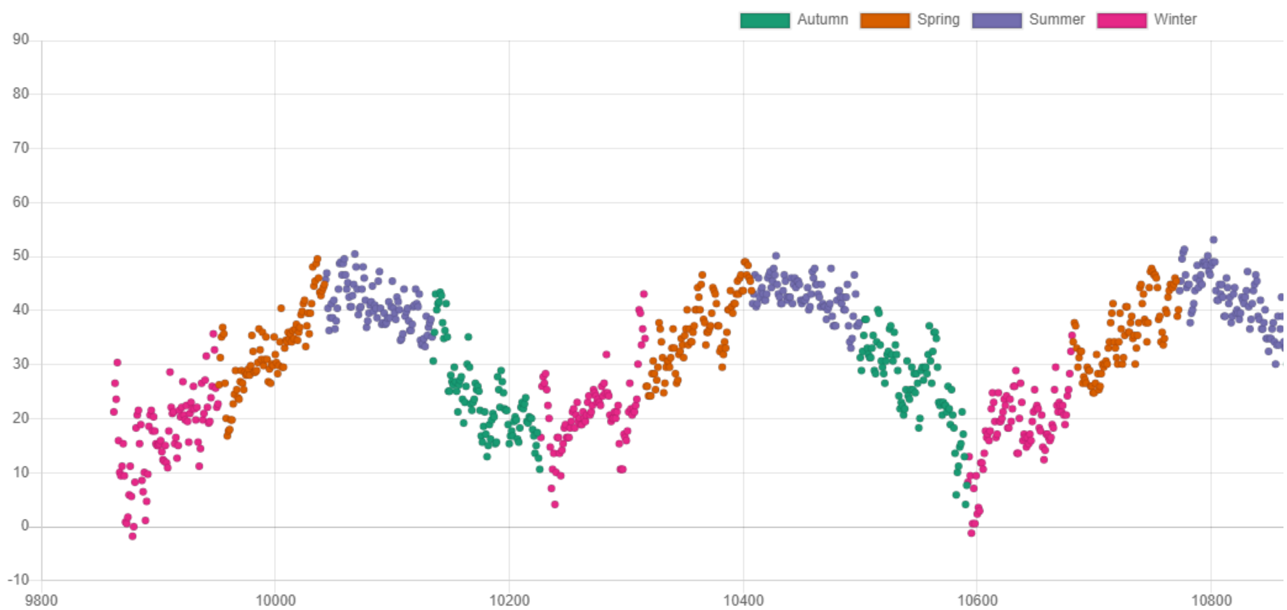


18.6 Chart.js via {charter}

charter is another package developed by John Coene that enables the use of a JavaScript visualization library in R. The package allows you to build interactive plots with the help of the Charts.js framework.

```
library(charter)
```

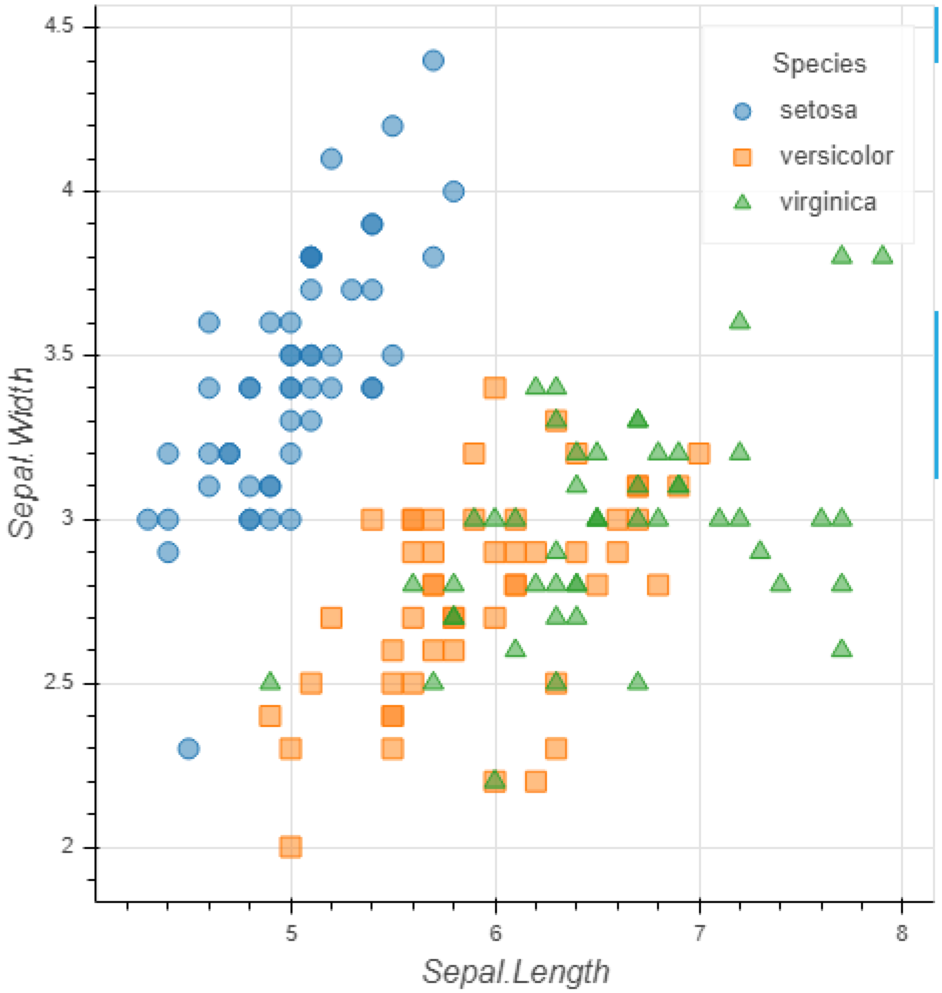
```
chic$date_num <- as.numeric(chic$date)
## doesn't work with class date

chart(data = chic, caes(date_num, temp)) |>
  c_scatter(caes(color = season, group = season)) |>
  c_colors(RColorBrewer::brewer.pal(4, name = "Dark2"))
```



18.7 Bokeh via {rbokeh}

{rbokeh} is an R package that allows you to create interactive visualizations using the Bokeh library. It is a powerful tool for creating interactive plots and adding interactivity to your visualizations. The following example demonstrates how to create an interactive scatter plot using {rbokeh}. You can find more examples and documentation on the rbokeh website.

```
library(rbokeh)
p <- figure() %>%
  ly_points(Sepal.Length, Sepal.Width, data = iris,
    color = Species, glyph = Species,
    hover = list(Sepal.Length, Sepal.Width))
p
```

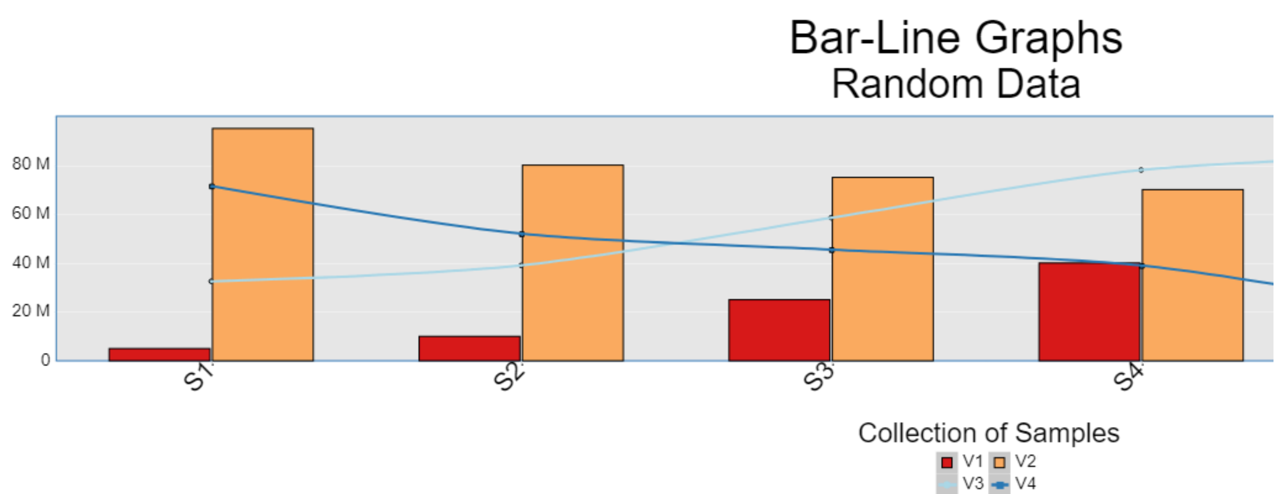


18.8 Advanced Interactive plots using CanvasExpress

CanvasXpress is a JavaScript library that allows you to create interactive visualizations. The package {canvasXpress} for R enables the creation of interactive plots directly from R. It is a powerful tool for creating visualizations and adding interactivity to your plots. The following example demonstrates how to create a bar-line graph using CanvasXpress. You can find more examples and documentation on the CanvasXpress website.

```
library(canvasXpress)
y=read.table("https://www.canvasxpress.org/data/cX-generic-dat.txt", header=TRUE, sep="\t", quote="
x=read.table("https://www.canvasxpress.org/data/cX-generic-smp.txt", header=TRUE, sep="\t", quote="
z=read.table("https://www.canvasxpress.org/data/cX-generic-var.txt", header=TRUE, sep="\t", quote="
canvasXpress(
  data=y,
```

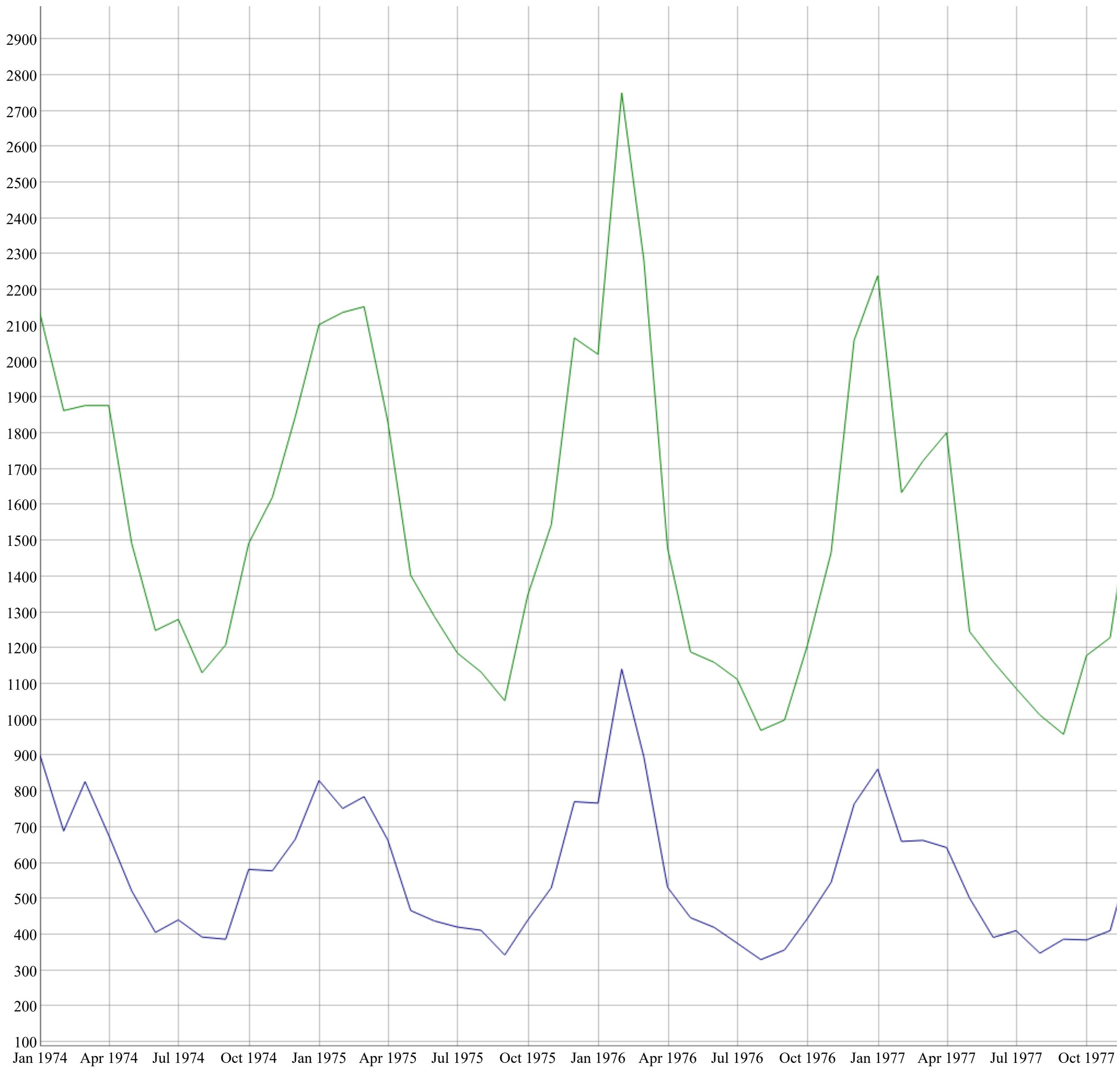
```
  smpAnnot=x,
  varAnnot=z,
  graphOrientation="vertical",
  graphType="BarLine",
  legendColumns=2,
  legendPosition="bottom",
  lineThickness=2,
  lineType="spline",
  showTransition=FALSE,
  smpLabelRotate=45,
  smpTitle="Collection of Samples",
  subtitle="Random Data",
  theme="CanvasXpress",
  title="Bar-Line Graphs",
  xAxis=list("V1", "V2"),
  xAxis2=list("V3", "V4"),
  xAxis2TickFormat="%.0f T",
  xAxisTickFormat="%.0f M"
)
```



18.9 Dygraphs via {dygraphs}

{dygraphs} is an R package that allows you to create interactive time series plots. It is based on the JavaScript library Dygraphs.

```
library(dygraphs)
lungDeaths <- cbind(mdeaths, fdeaths)
dygraph(lungDeaths)
```



And there are many more options to create interactive plots in R. The choice of the right library depends on the specific requirements of your project and the desired level of interactivity. The examples above should give you a good starting point to explore the possibilities of interactive plots in R. We'll add more examples in the future.

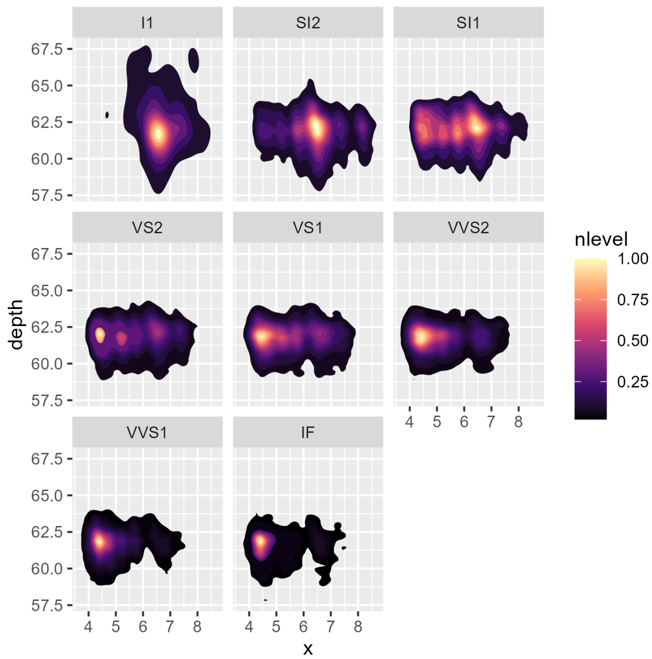
19 3D Plots Using {rayshader} package

rayshader is an open source package for producing 2D and 3D data visualizations in R. rayshader uses elevation data in a base R matrix and a combination of raytracing, hillshading algorithms, and overlays to generate stunning 2D and 3D maps. In addition to maps, rayshader also allows the user to translate ggplot2 objects into beautiful 3D data visualizations.

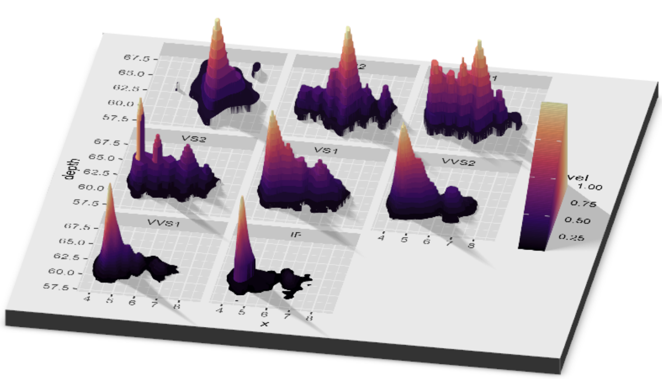
The models can be rotated and examined interactively or the camera movement can be scripted to create animations. Scenes can also be rendered using a high-quality pathtracer, rayrender. The user can also create a cinematic depth of field post-processing effect to direct the user's focus to important regions in the figure. The 3D models can also be exported to a 3D-printable format with a built-in STL export function, and can be exported to an OBJ file for use in other 3D modeling software. rayshader is a powerful tool for creating 3D visualizations of data, and can be used to create stunning visualizations for scientific research, data analysis, and art. You can find more information about rayshader at https://www.rayshader.com/.

Let's see some 3D plots using rayshader.

```
library(ggplot2)
library(rayshader)

ggdiamonds = ggplot(diamonds) +
  stat_density_2d(aes(x = x, y = depth, fill = after_stat(nlevel)),
                  geom = "polygon", n = 200, bins = 50,contour = TRUE) +
  facet_wrap(clarity~.) +
  scale_fill_viridis_c(option = "A")

plot_gg(ggdiamonds, width = 5, height = 5, raytrace = FALSE, preview = TRUE)
```



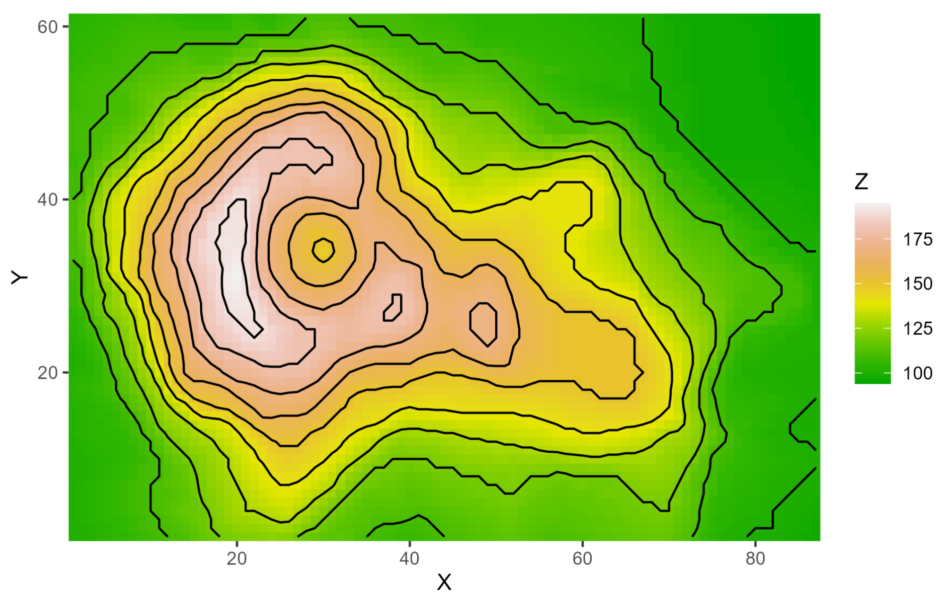

```
plot_gg(ggdiamonds, width = 5, height = 5, multicore = TRUE, scale = 250,
        zoom = 0.7, theta = 10, phi = 30, windowsize = c(800, 800))
Sys.sleep(0.2)
render_snapshot(clear = TRUE)
```



Rayshader will automatically ignore lines and other elements that should not be mapped to 3D. Here's a contour plot of the volcano dataset.

```
library(reshape2)
#Contours and other lines will automatically be ignored. Here is the volcano dataset:

ggvolcano = volcano %>%
  melt() %>%
  ggplot() +
  geom_tile(aes(x = Var1, y = Var2, fill = value)) +
  geom_contour(aes(x = Var1, y = Var2, z = value), color = "black") +
  scale_x_continuous("X", expand = c(0, 0)) +
  scale_y_continuous("Y", expand = c(0, 0)) +
  scale_fill_gradientn("Z", colours = terrain.colors(10)) +
  coord_fixed()

par(mfrow = c(1, 2))
plot_gg(ggvolcano, width = 7, height = 4, raytrace = FALSE, preview = TRUE)
```

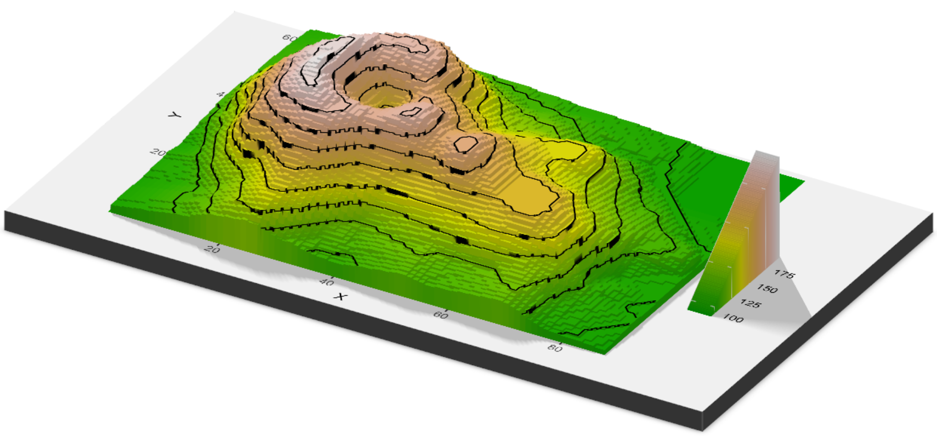
```
Warning: Removed 1861 rows containing missing values or values outside the scale range
(`geom_contour()`).
```




```
plot_gg(ggvolcano, multicore = TRUE, raytrace = TRUE, width = 7, height = 4,
        scale = 300, windowsize = c(1400, 866), zoom = 0.6, phi = 30, theta = 30)
```

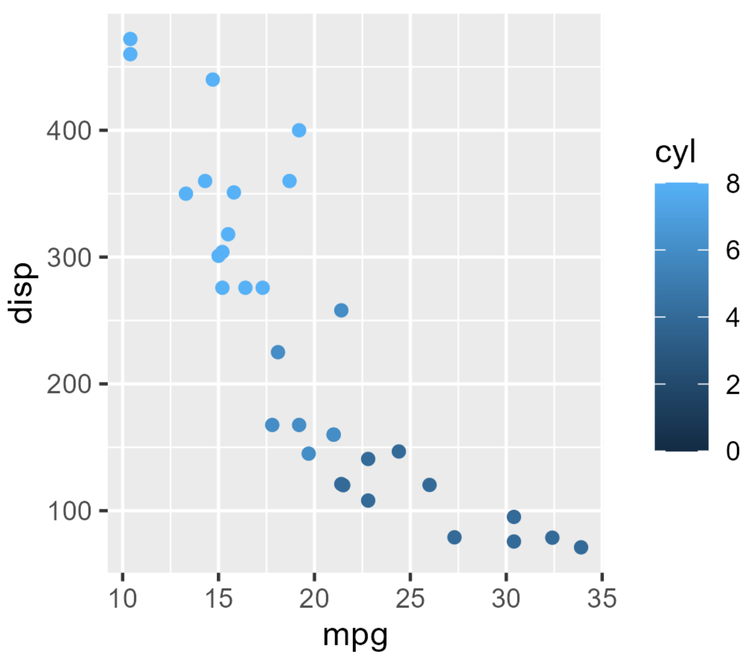
```
Warning: Removed 1861 rows containing missing values or values outside the scale range
(`geom_contour()`).
```

```r
Sys.sleep(0.2)
render_snapshot(clear = TRUE)
```

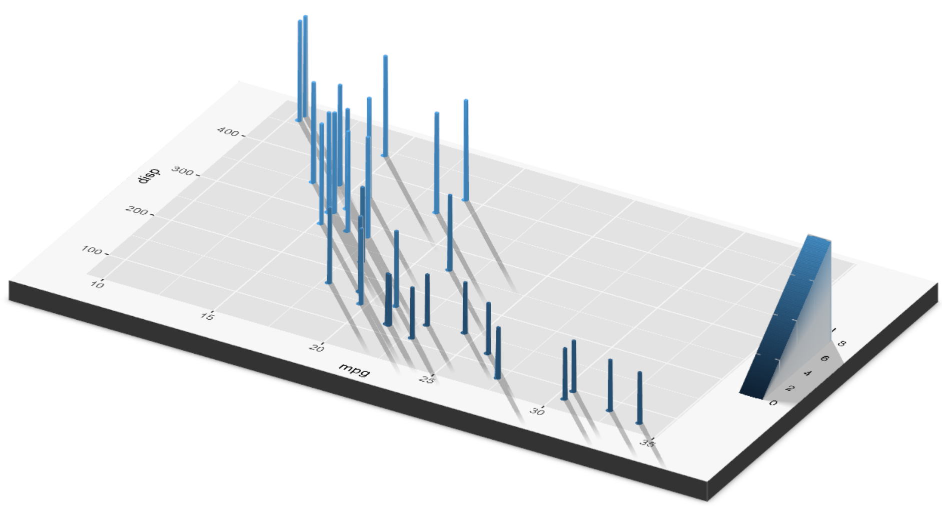


Rayshader also detects when the user passes the color aesthetic, and maps those values to 3D. If both color and fill are passed, however, rayshader will default to fill.

```r
mtplot = ggplot(mtcars) +
  geom_point(aes(x = mpg, y = disp, color = cyl)) +
  scale_color_continuous(limits = c(0, 8))

par(mfrow = c(1, 2))
plot_gg(mtplot, width = 3.5, raytrace = FALSE, preview = TRUE)
```




```
plot_gg(mtplot, multicore = TRUE, raytrace = TRUE, width = 7, height = 4,
        scale = 300, windowsize = c(1400, 866), zoom = 0.6, phi = 30, theta = 30)
Sys.sleep(0.2)
render_snapshot(clear = TRUE)
```

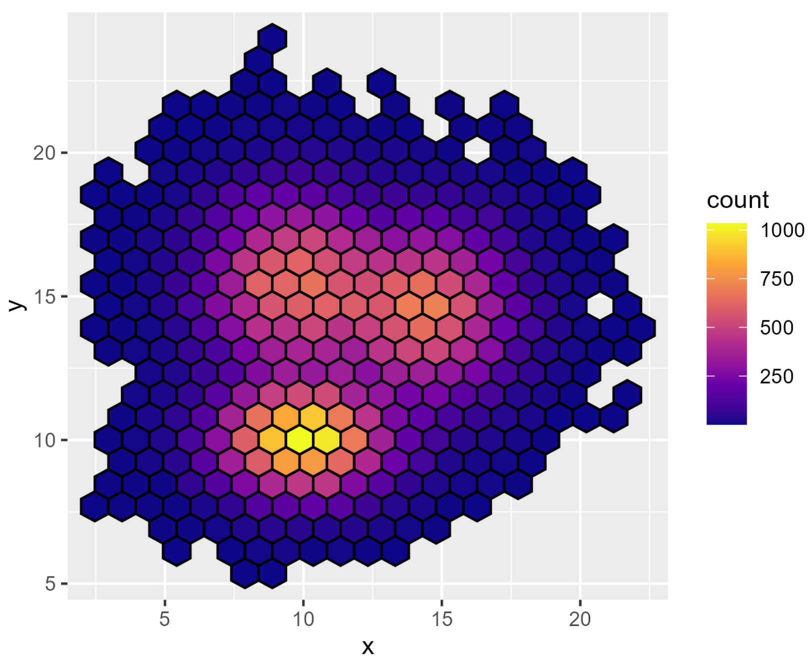


Utilize combinations of line color and fill to create different effects. Here is a terraced hexbin plot, created by mapping the line colors of the hexagons to black.

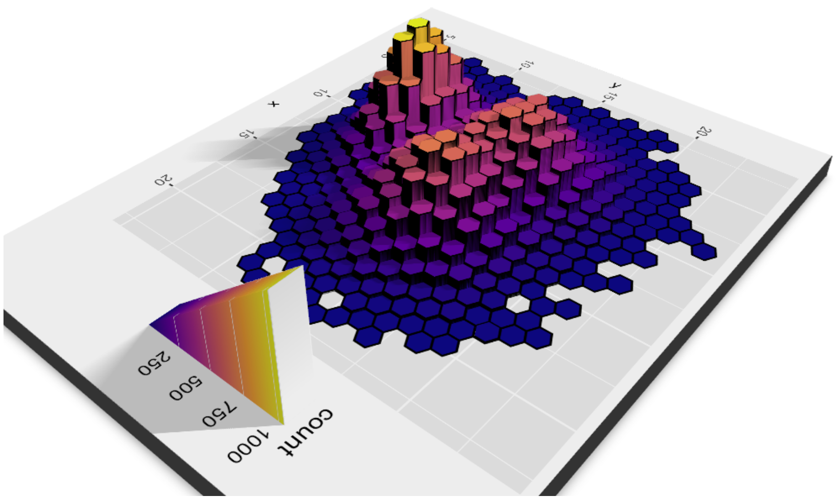
```
a = data.frame(x = rnorm(20000, 10, 1.9), y = rnorm(20000, 10, 1.2))
b = data.frame(x = rnorm(20000, 14.5, 1.9), y = rnorm(20000, 14.5, 1.9))
c = data.frame(x = rnorm(20000, 9.5, 1.9), y = rnorm(20000, 15.5, 1.9))
data = rbind(a, b, c)

#Lines
library(hexbin)
pp = ggplot(data, aes(x = x, y = y)) +
  geom_hex(bins = 20, size = 0.5, color = "black") +
  scale_fill_viridis_c(option = "C")
```

```
Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
i Please use `linewidth` instead.
```

```
par(mfrow = c(1, 2))
plot_gg(pp, width = 5, height = 4, scale = 300, raytrace = FALSE, preview = TRUE)
```




```
plot_gg(pp, width = 5, height = 4, scale = 300, multicore = TRUE, windowsize = c(1000, 800))
render_camera(fov = 70, zoom = 0.5, theta = 130, phi = 35)
Sys.sleep(0.2)
render_snapshot(clear = TRUE)
```



Pretty cool, right? You can create stunning 3D visualizations using rayshader. You can find more information about rayshader at https://www.rayshader.com/.

We can also Use `rayshader` to create 3D maps. That will be whole another book, we'll publish that soon. Stay tuned!

20 Geographical Data Analysis using {sf} and

R has well-supported classes for storing spatial data (sp) and interfacing to the above mentioned environments (`rgdal`, `rgeos`), but has so far lacked a complete implementation of simple features, making conversions at times convoluted, inefficient or incomplete. The package `sf` tries to fill this gap, and aims at succeeding sp in the long term. However This is a Huge topic to cover that we need a separate book for this.

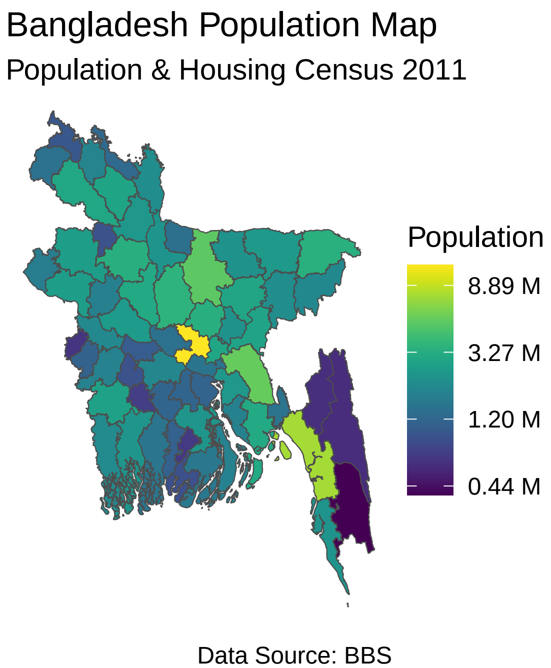
We'll just give you a brief overview of how to plot maps using `sf` and `ggplot2`.

```
# Load necessary libraries
library(bangladesh)
library(ggplot2)
library(tidyverse)
```

```
-- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
v dplyr     1.1.4     v readr     2.1.5
v forcats   1.0.0     v stringr   1.5.1
v lubridate 1.9.3     v tibble    3.2.1
v purrr     1.0.2     v tidyr     1.3.1
-- Conflicts ------------------------------------------ tidyverse_conflicts() --
x dplyr::filter() masks stats::filter()
x dplyr::lag()    masks stats::lag()
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
# Get map data, join with population data, and plot in a single pipeline
data <- get_map("district") %>%
  left_join(bangladesh::pop_district_2011[, c("district", "population")], by = c("District" = "distric

pp <- data %>%
  ggplot() +
  geom_sf(aes(fill = population), col = "grey30") +
  theme_void() +
  viridis::scale_fill_viridis(trans = "log", name="Population", labels = scales::unit_format(unit = "M
  labs(
    title = "Bangladesh Population Map",
    subtitle = "Population & Housing Census 2011",
    caption = "Data Source: BBS"
  )
```

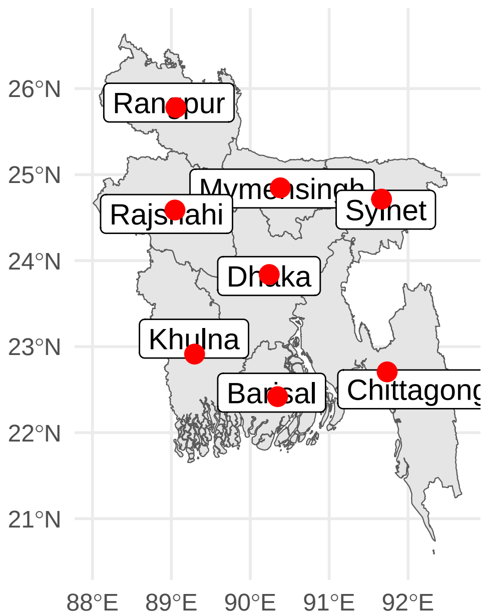
```
pp
```



Here is another example:

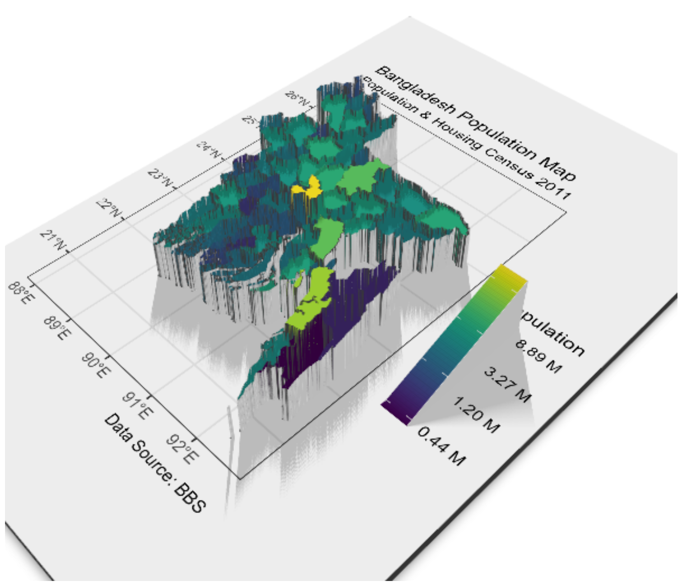
```
division_data <- get_map("division")
division_centroids <- bangladesh::get_coordinates(level = "division")
ggplot(data = division_data) +
  geom_sf() +
  geom_sf_label(aes(label = Division)) +
  geom_point(data = division_centroids, x = division_centroids$lon, y = division_centroids$lat, col
  xlab("")+ ylab("")+
  theme_minimal()
```

```
Warning in st_point_on_surface.sfc(sf::st_zm(x)): st_point_on_surface may not
give correct results for longitude/latitude data
```



You can also make 3D map using `rayshader` `sf` and `ggplot2` package. Here is an example:

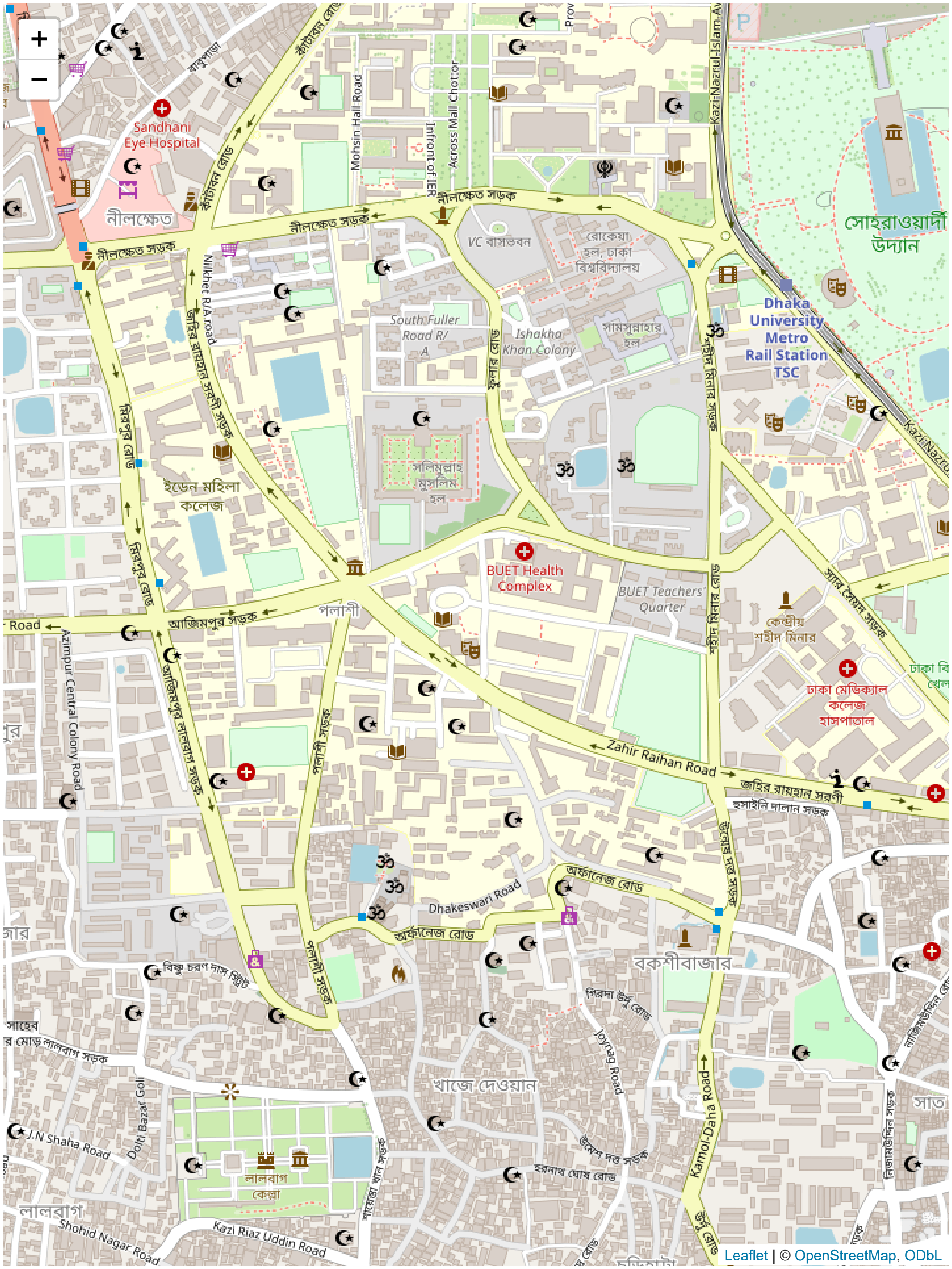
```
library(rayshader)

plot_gg(pp+theme_bw(), multicore = TRUE, width = 4 ,height=6, fov = 70, zoom = 0.5)
Sys.sleep(0.2)
render_snapshot(clear = TRUE)
```



If You Want to make maps Interactive like this 🗺 [Interactive Maps](), here is an example:

```
library(leaflet)

leaflet() %>%
  addTiles() %>%
  addMarkers(lng=90.40155705289271, lat=23.725810762885487, popup="Shahidullah Hall")
```

```
PhantomJS not found. You can install it with webshot::install_phantomjs(). If it is installed, please ma
```


+
−
Sandhani Eye Hospital
নীলক্ষেত
নীলক্ষেত সড়ক
কাঁটাবন রোড
Mohsin Hall Road
Infront of IER
Across Mall Chottor
VC বাসভবন
রোকেয়া হল, ঢাকা বিশ্ববিদ্যালয়
সোহরাওয়ার্দী উদ্যান
Dhaka University Metro Rail Station TSC
South Fuller Road R/A
Ishakha Khan Colony
সামসুন্নাহার হল
Nilkhet R/A road
সলিমুল্লাহ মুসলিম হল
ইডেন মহিলা কলেজ
BUET Health Complex
BUET Teachers' Quarter
পলাশী
আজিমপুর সড়ক
Azimpur Central Colony Road
কেন্দ্রীয় শহীদ মিনার
ঢাকা মেডিক্যাল কলেজ হাসপাতাল
Zahir Raihan Road
জহির রায়হান সরণী
হুসাইনি দালান সড়ক
Dhakeswari Road
অর্ফানেজ রোড
বকশীবাজার
খাজে দেওয়ান
J.N Shaha Road
Dolti Bazar Goli
লালবাগ কেল্লা
লালবাগ
Shohid Nagar Road
Kazi Riaz Uddin Road
Kamol-Dana Road
Leaflet | © OpenStreetMap, ODbL

The field of geographical data analysis is a vast and ever-evolving domain, offering an array of techniques and tools to explore and understand spatial data. In this book, we have provided a glimpse into the fascinating world of Data Visualization using `ggplot2` and introducing you to the fundamental concepts and methods that form the foundation of spatial analysis.

While we have covered a range of topics, it is important to recognize that this is merely the tip of the iceberg. Geographical data analysis encompasses a multitude of specialized areas, each with its own unique challenges and solutions. As we continue our journey through this field, we are working on a dedicated book that will delve deeper into the intricacies of geographic data analysis.

In this forthcoming work, we will explore in greater depth the realm of shapefiles, a crucial data format for representing geographical features. Additionally, we will dive into the powerful capabilities of the `sf` package, which provides a comprehensive set of tools for working with spatial vector data in R.

Furthermore, we will introduce you to `leaflet`, a cutting-edge library that enables the creation of interactive web maps, allowing you to visualize and analyze spatial data in a dynamic and engaging manner. The `rayshader` package will also be explored, offering techniques for generating stunning 3D visualizations of geographical data, providing new perspectives and insights.

Another exciting area we will cover is the `tmap` package, a versatile tool for creating thematic maps and visualizing spatial patterns. With its rich set of features and extensive customization options, `tmap` empowers you to communicate your spatial data in a clear and compelling way.

Beyond these specific packages and techniques, we are actively engaged in the development of new and innovative tools for geographical data analysis. Our goal is to push the boundaries of what is possible, providing researchers, analysts, and practitioners with cutting-edge solutions to tackle complex spatial problems.

As we continue to explore the depths of this fascinating field, we invite you to stay tuned for our upcoming work. Together, we will embark on a journey of discovery, unlocking the full potential of geographical data analysis and shaping the future of spatial research and applications.

Remarks, Tipps & Resources

Using ggplot2 in Loops and Functions

The grid-based graphics functions in `lattice` and `ggplot2` create a graph object. When you use these functions interactively at the command line, the result is automatically printed. However, when using `source()` or inside your own functions, you will need an explicit `print()` statement, i.e., `print(g)` in most of our examples. For more information, see also the R FAQ page.

Additional Resources

- "ggplot2: Elegant Graphics for Data Analysis" by Hadley Wickham, available via open-access!
- "Fundamentals of Data Visualization" by Claus O. Wilke about data visualization in general but using `{ggplot2}`. (You can find the codes on his GitHub profile.)
- "Cookbook for R" by Winston Chang with recipes to produce R plots
- Gallery of the Top 50 ggplot2 visualizations
- Gallery of `{ggplot2}` extension packages
- How to extend `{ggplot2}` by Hadley Wickham
- The fantastic R4DS Online Learning Community that offers help and mentoring for all things related to the content of the "R for Data Science" book by Hadley Wickham
- #TidyTuesday, a weekly social data project focusing on ggplots—check also #TidyTuesday on Twitter and this collection of contributions by Neil Grantham
- A two-part, 4.5-hours tutorial series by Thomas Linn Pedersen (Part 1 | Part 2)