Creating Publication-Quality Graphics with ggplot2

Overview

Teaching: 60 min
Exercises: 20 min
Questions

- How can I create publication-quality graphics in R?

Objectives

- To be able to use ggplot2 to generate publication-quality graphics.
- To apply geometry, aesthetic, and statistics layers to a ggplot plot.
- To manipulate the aesthetics of a plot using different colors, shapes, and lines.
- To improve data visualization through transforming scales and paneling by group.
- To save a plot created with ggplot to disk.

Plotting our data is one of the best ways to quickly explore it and the various relationships between variables.

There are three main plotting systems in R, the base plotting system (http://www.statmethods.net/graphs/index.html), the lattice (http://www.statmethods.net/advgraphs/trellis.html) package, and the ggplot2 (http://www.statmethods.net/advgraphs/ggplot2.html) package.

Today we'll be learning about the ggplot2 package, because it is the most effective for creating publication-quality graphics.

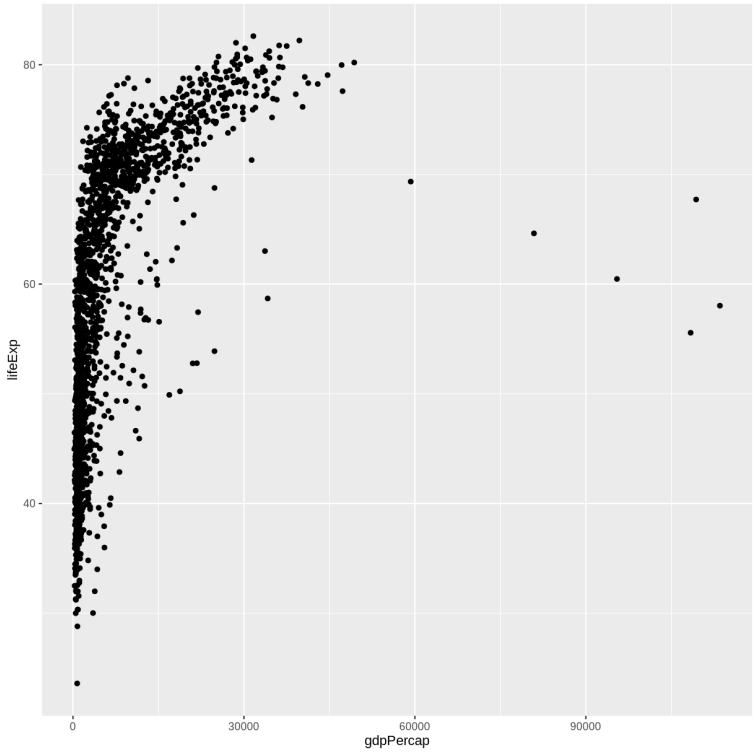
ggplot2 is built on the grammar of graphics, the idea that any plot can be expressed from the same set of components: a **data** set, a **coordinate system**, and a set of **geoms** – the visual representation of data points.

The key to understanding ggplot2 is thinking about a figure in layers. This idea may be familiar to you if you have used image editing programs like Photoshop, Illustrator, or Inkscape.

Let's start off with an example:

R

```
library("ggplot2")
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point()
```



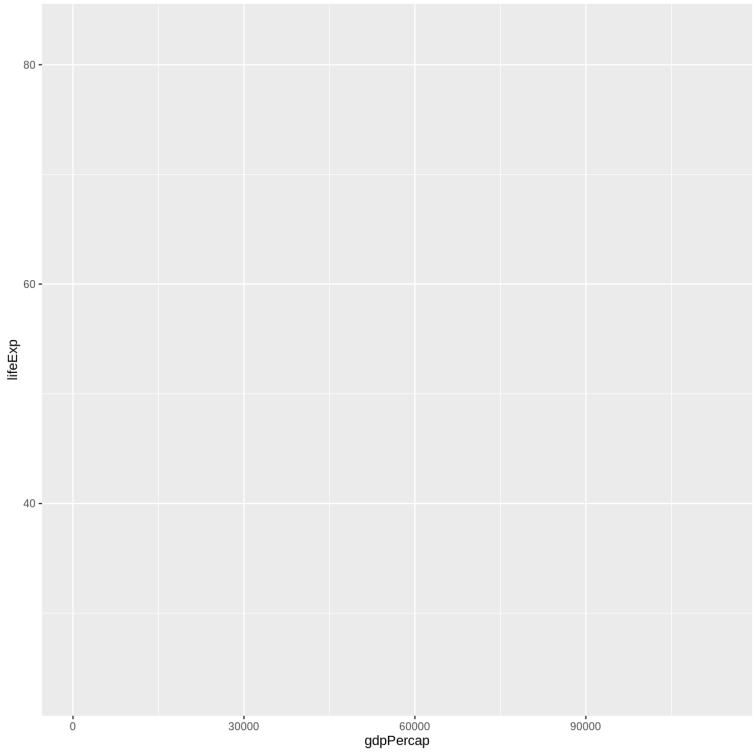
So the first thing we do is call the `ggplot` function. This function lets R know that we're creating a new plot, and any of the arguments we give the `ggplot` function are the *global* options for the plot: they apply to all layers on the plot.

We've passed in two arguments to `ggplot`. First, we tell `ggplot` what data we want to show on our figure, in this example the gapminder data we read in earlier. For the second argument, we passed in the `aes` function, which tells `ggplot` how variables in the **data** map to *aesthetic* properties of the figure, in this case the **x** and **y** locations. Here we told `ggplot` we want to plot the "gdpPercap" column of the gapminder data frame on the x-axis, and the "lifeExp" column on the y-axis. Notice that we didn't need to explicitly pass `aes` these columns (e.g. `x = gapminder[, "gdpPercap"]`), this is because `ggplot` is smart enough to know to look in the **data** for that column!

By itself, the call to `ggplot` isn't enough to draw a figure:

R

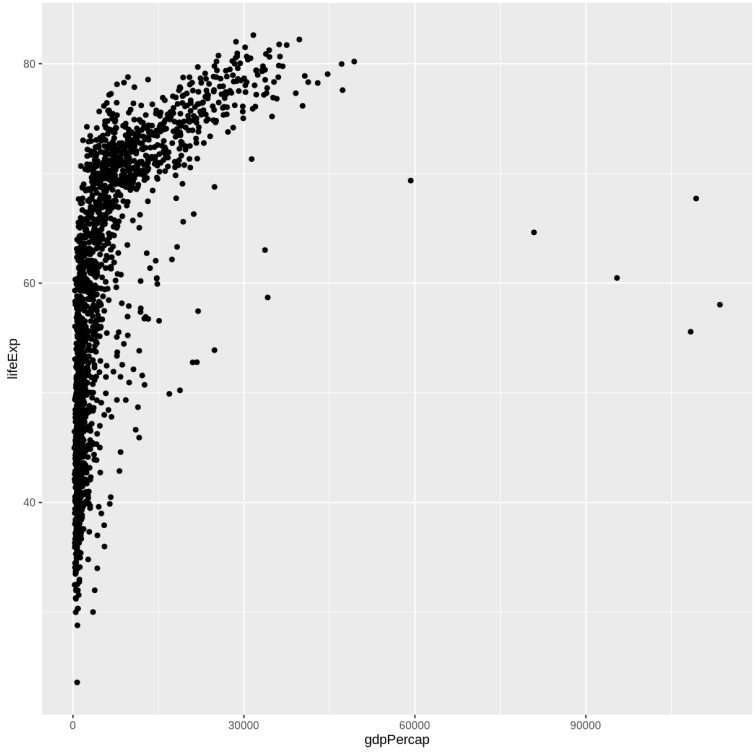
```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp))
```



We need to tell `ggplot` how we want to visually represent the data, which we do by adding a new **geom** layer. In our example, we used `geom_point`, which tells `ggplot` we want to visually represent the relationship between **x** and **y** as a scatterplot of points:

R

```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point()
```



Challenge 1

Modify the example so that the figure shows how life expectancy has changed over time:

```R
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) + geom_point()
```

Hint: the gapminder dataset has a column called “year”, which should appear on the x-axis.

Solution to challenge 1

Challenge 2

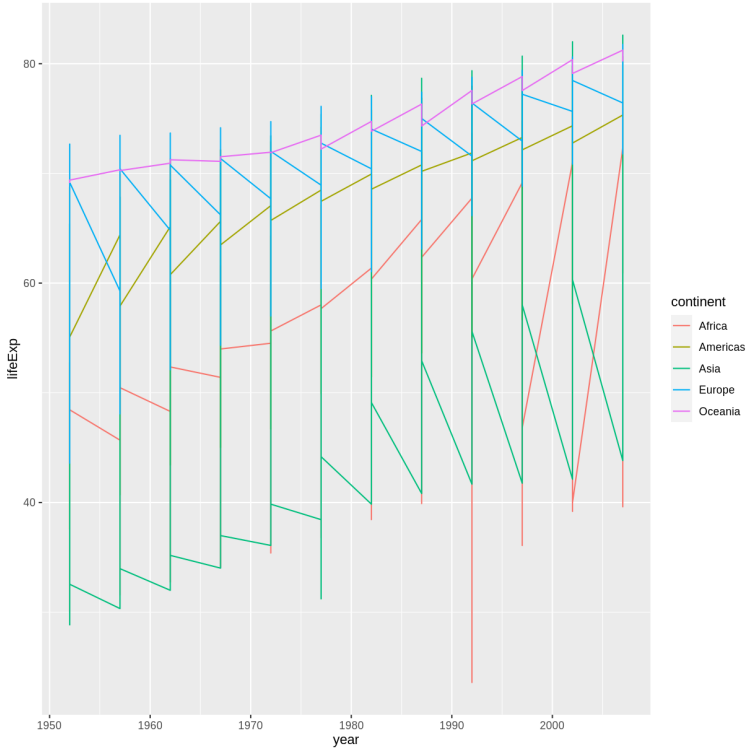
In the previous examples and challenge we’ve used the `aes` function to tell the scatterplot **geom** about the **x** and **y** locations of each point. Another *aesthetic* property we can modify is the point *color*. Modify the code from the previous challenge to **color** the points by the “continent” column. What trends do you see in the data? Are they what you expected?

Solution to challenge 2

Layers

Using a scatterplot probably isn’t the best for visualizing change over time. Instead, let’s tell `ggplot` to visualize the data as a line plot:

```R
ggplot(data = gapminder, mapping = aes(x=year, y=lifeExp, color=continent)) +
  geom_line()
```

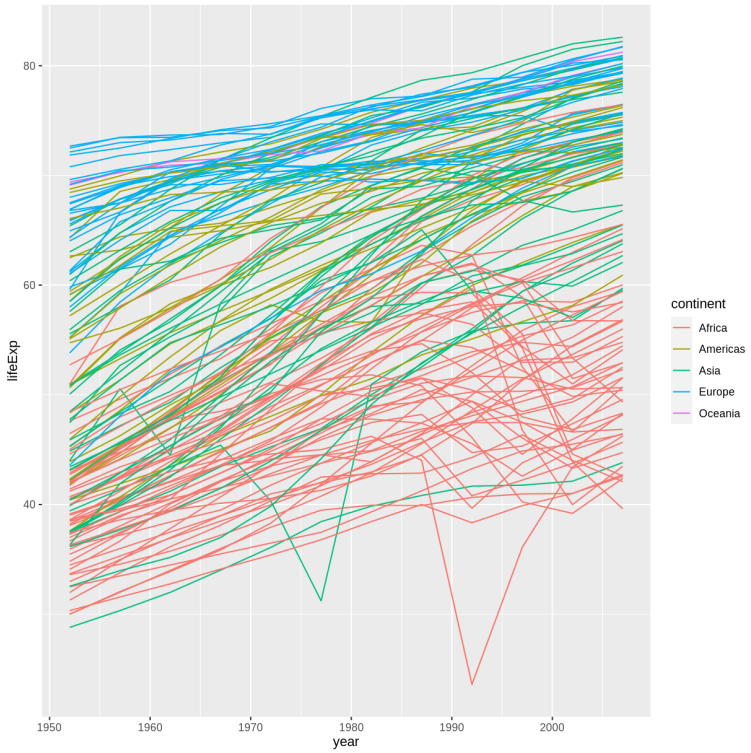


Instead of adding a `geom_point` layer, we've added a `geom_line` layer.

However, the result doesn't look quite as we might have expected: it seems to be jumping around a lot in each continent. Let's try to separate the data by country, plotting one line for each country:

R

```
ggplot(data = gapminder, mapping = aes(x=year, y=lifeExp, group=country, color=continent)) +
  geom_line()
```

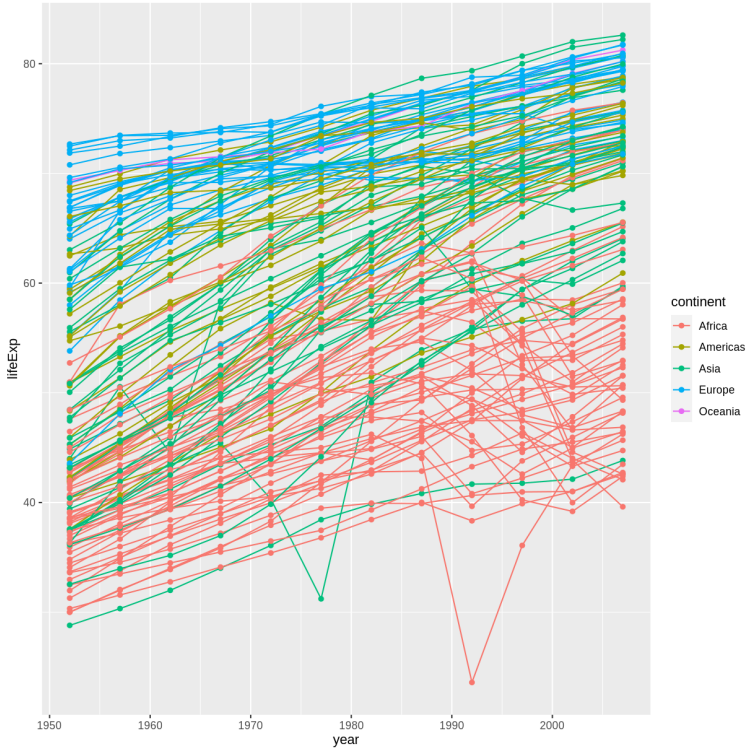


We've added the **group** *aesthetic*, which tells `ggplot` to draw a line for each country.

But what if we want to visualize both lines and points on the plot? We can add another layer to the plot:

R

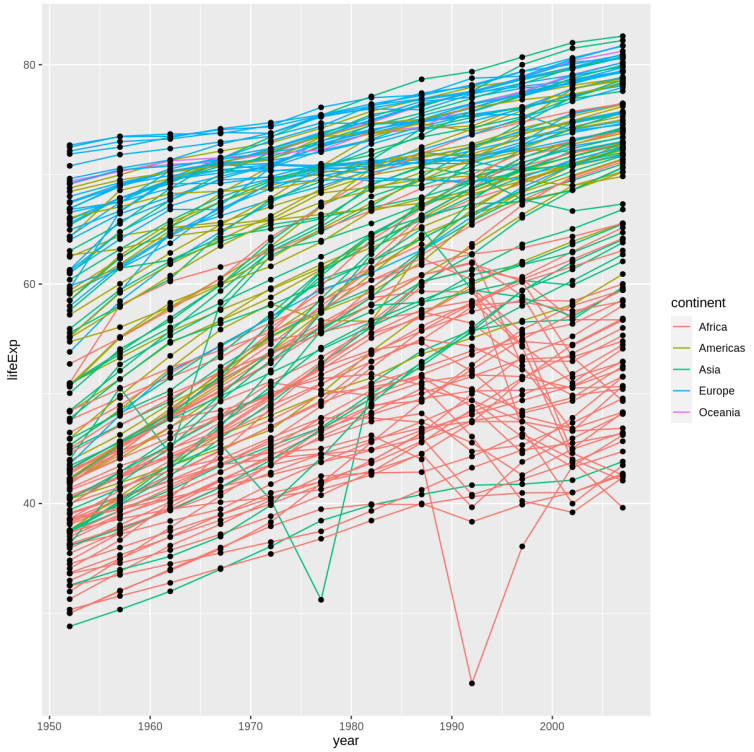
```
ggplot(data = gapminder, mapping = aes(x=year, y=lifeExp, group=country, color=continent)) +
  geom_line() + geom_point()
```



It's important to note that each layer is drawn on top of the previous layer. In this example, the points have been drawn *on top of* the lines. Here's a demonstration:

R

```
ggplot(data = gapminder, mapping = aes(x=year, y=lifeExp, group=country)) +
  geom_line(mapping = aes(color=continent)) + geom_point()
```



In this example, the *aesthetic* mapping of **color** has been moved from the global plot options in `ggplot` to the `geom_line` layer so it no longer applies to the points. Now we can clearly see that the points are drawn on top of the lines.

📌 Tip: Setting an aesthetic to a value instead of a mapping

So far, we've seen how to use an aesthetic (such as **color**) as a *mapping* to a variable in the data. For example, when we use `geom_line(mapping = aes(color=continent))`, ggplot will give a different color to each continent. But what if we want to change the color of all lines to blue? You may think that `geom_line(mapping = aes(color="blue"))` should work, but it doesn't. Since we don't want to create a mapping to a specific variable, we can move the color specification outside of the `aes()` function, like this: `geom_line(color="blue")`.

Challenge 3

Switch the order of the point and line layers from the previous example. What happened?

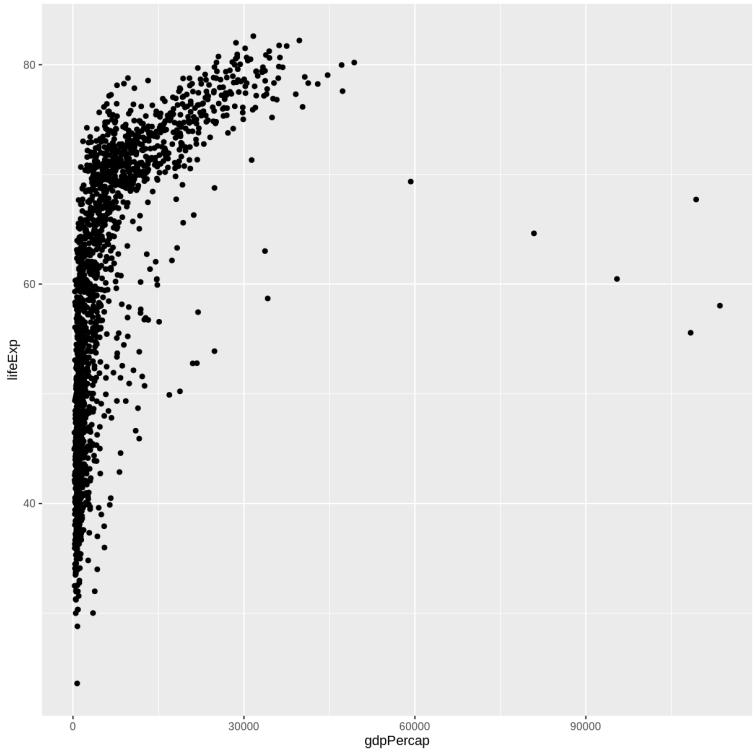
Solution to challenge 3

Transformations and statistics

ggplot2 also makes it easy to overlay statistical models over the data. To demonstrate we'll go back to our first example:

R

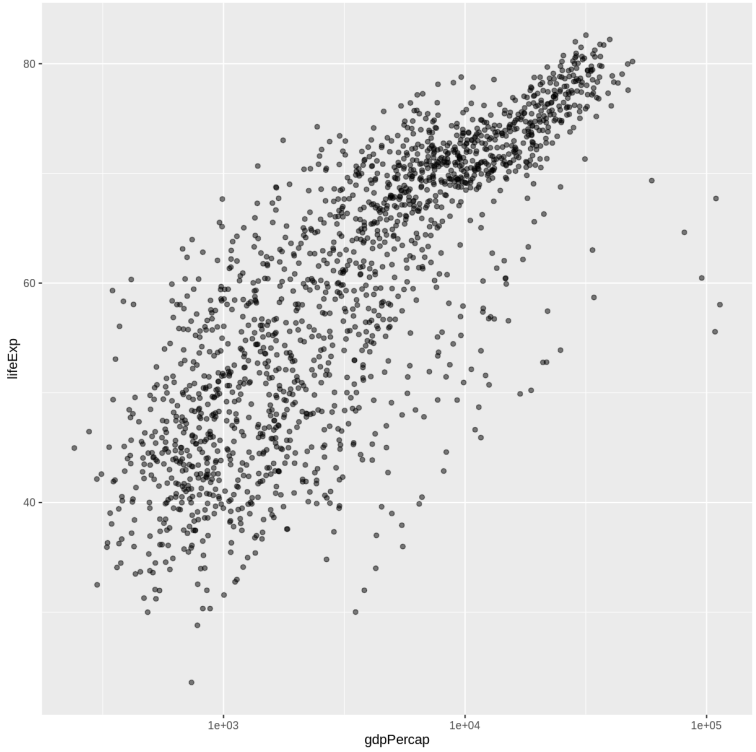
```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point()
```



Currently it's hard to see the relationship between the points due to some strong outliers in GDP per capita. We can change the scale of units on the x axis using the *scale* functions. These control the mapping between the data values and visual values of an aesthetic. We can also modify the transparency of the points, using the *alpha* function, which is especially helpful when you have a large amount of data which is very clustered.

R

```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point(alpha = 0.5) + scale_x_log10()
```



The `scale_x_log10` function applied a transformation to the coordinate system of the plot, so that each multiple of 10 is evenly spaced from left to right. For example, a GDP per capita of 1,000 is the same horizontal distance away from a value of 10,000 as the 10,000 value is from 100,000. This helps to visualize the spread of the data along the x-axis.

📌 Tip Reminder: Setting an aesthetic to a value instead of a mapping

Notice that we used `geom_point(alpha = 0.5)`. As the previous tip mentioned, using a setting outside of the `aes()` function will cause this value to be used for all points, which is what we want in this case. But just like any other aesthetic setting, *alpha* can also be mapped to a variable in the data. For example, we can give a different transparency to each continent with `geom_point(mapping = aes(alpha = continent))`.

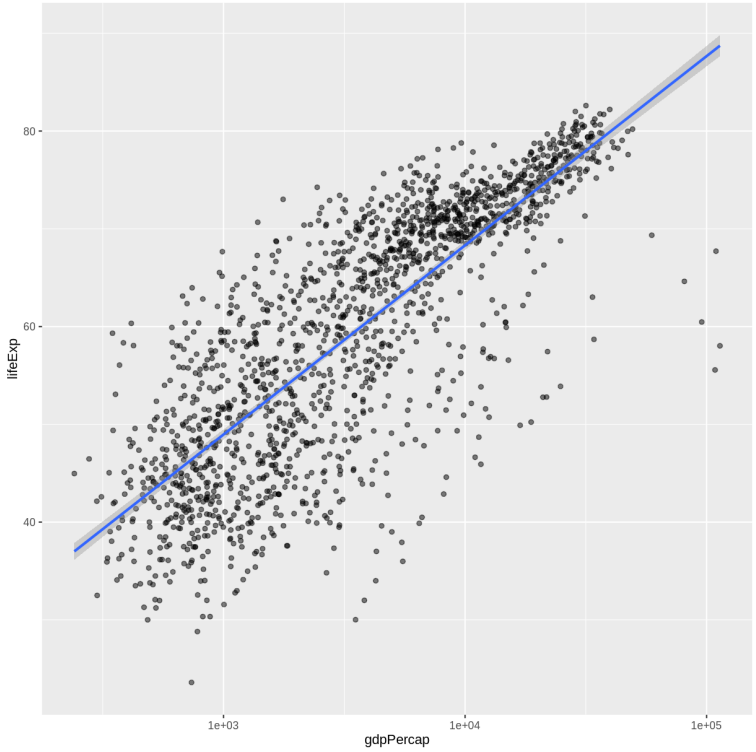
We can fit a simple relationship to the data by adding another layer, `geom_smooth`:

R

```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point(alpha = 0.5) + scale_x_log10() + geom_smooth(method="lm")
```

Output

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



We can make the line thicker by *setting* the **size** aesthetic in the `geom_smooth` layer:

R

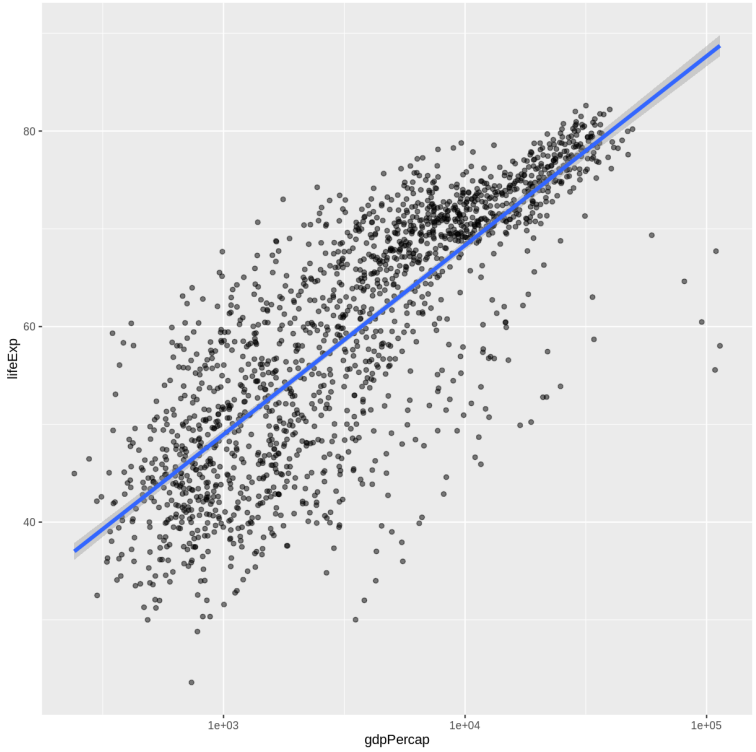
```
ggplot(data = gapminder, mapping = aes(x = gdpPercap, y = lifeExp)) +
  geom_point(alpha = 0.5) + scale_x_log10() + geom_smooth(method="lm", size=1.5)
```

Warning

```
Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
ℹ Please use `linewidth` instead.
This warning is displayed once every 8 hours.
Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
generated.
```

Output

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



There are two ways an *aesthetic* can be specified. Here we *set* the **size** aesthetic by passing it as an argument to `geom_smooth`. Previously in the lesson we've used the `aes` function to define a *mapping* between data variables and their visual representation.

Challenge 4a

Modify the color and size of the points on the point layer in the previous example.

Hint: do not use the `aes` function.

Solution to challenge 4a

Challenge 4b

Modify your solution to Challenge 4a so that the points are now a different shape and are colored by continent with new trendlines. Hint: The color argument can be used inside the aesthetic.

Solution to challenge 4b

Multi-panel figures

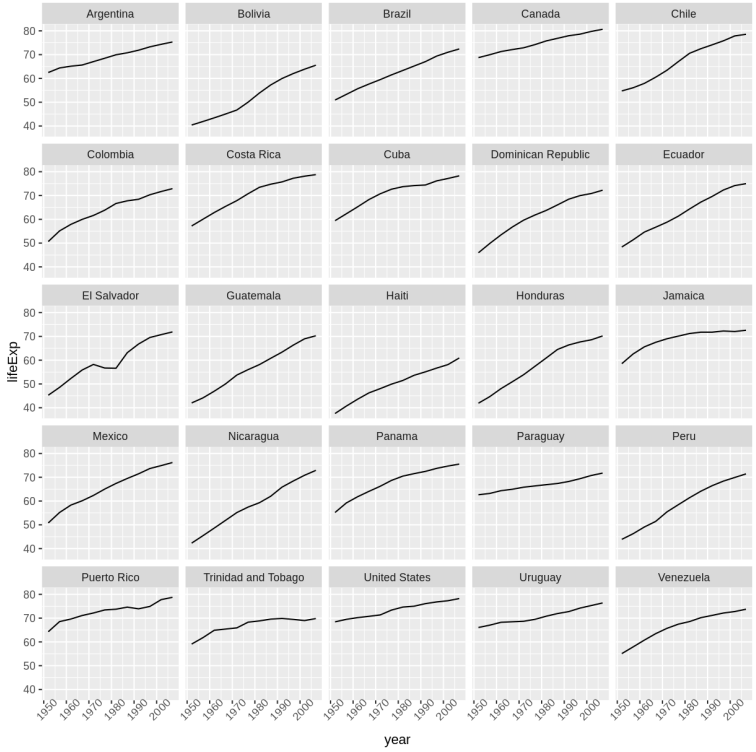
Earlier we visualized the change in life expectancy over time across all countries in one plot. Alternatively, we can split this out over multiple panels by adding a layer of **facet** panels.

Tip

We start by making a subset of data including only countries located in the Americas. This includes 25 countries, which will begin to clutter the figure. Note that we apply a "theme" definition to rotate the x-axis labels to maintain readability. Nearly everything in ggplot2 is customizable.

R

```
americas <- gapminder[gapminder$continent == "Americas",]
ggplot(data = americas, mapping = aes(x = year, y = lifeExp)) +
  geom_line() +
  facet_wrap( ~ country) +
  theme(axis.text.x = element_text(angle = 45))
```



The `facet_wrap` layer took a "formula" as its argument, denoted by the tilde (~). This tells R to draw a panel for each unique value in the country column of the gapminder dataset.

Modifying text

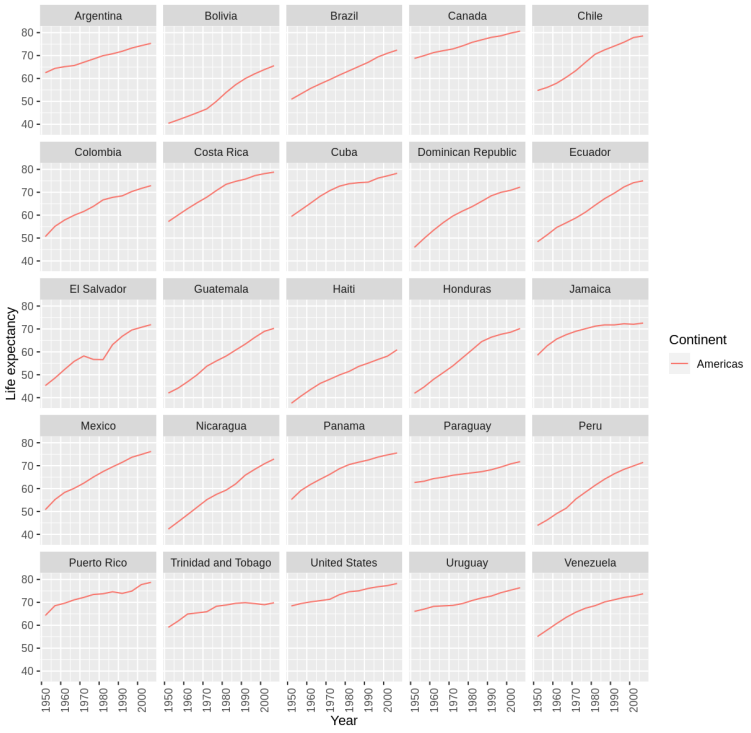
To clean this figure up for a publication we need to change some of the text elements. The x-axis is too cluttered, and the y axis should read "Life expectancy", rather than the column name in the data frame.

We can do this by adding a couple of different layers. The **theme** layer controls the axis text, and overall text size. Labels for the axes, plot title and any legend can be set using the `labs` function. Legend titles are set using the same names we used in the `aes` specification. Thus below the color legend title is set using `color = "Continent"`, while the title of a fill legend would be set using `fill = "MyTitle"`.

R

```
ggplot(data = americas, mapping = aes(x = year, y = lifeExp, color=continent)) +
  geom_line() + facet_wrap( ~ country) +
  labs(
    x = "Year",              # x axis title
    y = "Life expectancy",   # y axis title
    title = "Figure 1",      # main title of figure
    color = "Continent"      # title of legend
  ) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))
```

Figure 1



Exporting the plot

The `ggsave()` function allows you to export a plot created with ggplot. You can specify the dimension and resolution of your plot by adjusting the appropriate arguments (`width`, `height` and `dpi`) to create high quality graphics for publication. In order to save the plot from above, we first assign it to a variable `lifeExp_plot`, then tell `ggsave` to save that plot in `png` format to a directory called `results`. (Make sure you have a `results/` folder in your working directory.)

R

```
lifeExp_plot <- ggplot(data = americas, mapping = aes(x = year, y = lifeExp, color=continent)) +
  geom_line() + facet_wrap( ~ country) +
  labs(
    x = "Year",              # x axis title
    y = "Life expectancy",   # y axis title
    title = "Figure 1",      # main title of figure
    color = "Continent"      # title of legend
  ) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))

ggsave(filename = "results/lifeExp.png", plot = lifeExp_plot, width = 12, height = 10, dpi = 300, units = "cm")
```

There are two nice things about `ggsave`. First, it defaults to the last plot, so if you omit the `plot` argument it will automatically save the last plot you created with `ggplot`. Secondly, it tries to determine the format you want to save your plot in from the file extension you provide for the filename (for example `.png` or `.pdf`). If you need to, you can specify the format explicitly in the `device` argument.

This is a taste of what you can do with ggplot2. RStudio provides a really useful cheat sheet (https://www.rstudio.org/links/data_visualization_cheat_sheet) of the different layers available, and more extensive documentation is available on the ggplot2 website (https://ggplot2.tidyverse.org/reference/). Finally, if you have no idea how to change something, a quick Google search will usually send you to a relevant question and answer on Stack Overflow with reusable code to modify!

Challenge 5

Generate boxplots to compare life expectancy between the different continents during the available years.

Advanced:

- Rename y axis as Life Expectancy.
- Remove x axis labels.

Solution to Challenge 5

Key Points

- Use `ggplot2` to create plots.
- Think about graphics in layers: aesthetics, geometry, statistics, scale transformation, and grouping.

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