

Lab #1 - Gapminder Dataset

Econ 224

August 28th, 2018

Installing Required Packages

Welcome to the first lab of Econ 224! Today we'll be giving you a crash course in two R packages that we'll be using throughout the semester: `dplyr` and `ggplot2`. Before we can get started, you'll need to install both of these packages. A quick way to install both of them at once, along with several other packages that may come in handy later, is `install.packages('tidyverse')`. Note that you only need to do this *once*. The dataset we'll work with today is also available as an R package called `gapminder`. Make sure that you have both `tidyverse` and `gapminder` installed before continuing.

The Gapminder Dataset

Our next step is to load both `tidyverse`, which contains `dplyr` and `ggplot2`, and `gapminder`, which contains the data we'll be analyzing today:

```
library(tidyverse)
library(gapminder)
```

Exercise #1

Now that you've loaded `gapminder`, use the command `?gapminder` to view the R help file for this dataset and read the documentation you find there and answer the following questions:

- What information does this dataset contain?
- How many rows and columns does it have?
- What are the names of each of the columns, and what information does each contain?
- What is the source of the dataset?

Solution to Exercise # 1

Write your answer here.

What is a tibble?

Let's see what happens if we display the `gapminder` dataset:

```
gapminder
```

```
# A tibble: 1,704 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>    <int>    <dbl>
1 Afghanistan Asia      1952   28.8  8425333    779.
2 Afghanistan Asia      1957   30.3  9240934    821.
3 Afghanistan Asia      1962   32.0 10267083    853.
4 Afghanistan Asia      1967   34.0 11537966    836.
5 Afghanistan Asia      1972   36.1 13079460    740.
6 Afghanistan Asia      1977   38.4 14880372    786.
7 Afghanistan Asia      1982   39.9 12881816    978.
8 Afghanistan Asia      1987   40.8 13867957    852.
9 Afghanistan Asia      1992   41.7 16317921    649.
10 Afghanistan Asia      1997   41.8 22227415    635.
# ... with 1,694 more rows
```

If you're used to working with dataframes in R, this may surprise you. Rather than filling up the screen with lots of useless information, R shows us a helpful summary of the information contained in **gapminder**. This is because **gapminder** is *not* a dataframe; it's a *tibble*, often abbreviated *tbl*. For the moment, all you need to know about tibbles is that they are souped up versions of R dataframes that are designed to work seamlessly with **dplyr**. (If you want to learn more, see the chapter entitled "Tibbles" in *R for Data Science*) But what exactly is **dplyr**?

What is dplyr?

The **dplyr** package provides a number of powerful but easy-to-use tools for data manipulation in R. A good reference is the chapter entitled "Data Transformation" in *R for Data Science*. We'll be making heavy use of **dplyr** throughout the semester. Rather than trying to explain everything in advance, let's just dive right in.

Filter Rows with filter

Let's run the following command in R and see what happens:

```
gapminder %>% filter(year == 2007)
```

```
# A tibble: 142 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>    <int>    <dbl>
1 Afghanistan Asia      2007   43.8  31889923    975.
2 Albania      Europe      2007   76.4   3600523   5937.
3 Algeria      Africa      2007   72.3  33333216   6223.
4 Angola      Africa      2007   42.7  12420476   4797.
5 Argentina    Americas      2007   75.3  40301927  12779.
6 Australia    Oceania      2007   81.2  20434176  34435.
7 Austria      Europe      2007   79.8   8199783  36126.
8 Bahrain      Asia      2007   75.6    708573  29796.
9 Bangladesh   Asia      2007   64.1 150448339   1391.
10 Belgium     Europe      2007   79.4  10392226  33693.
# ... with 132 more rows
```

Compare the results of running this command to what we got when we typed `gapminder` into the console above. Rather than displaying the whole dataset, now R is only showing us the 142 rows for which the column `year` has a value of 2007.

So how does this work? The `%>%` symbol is called a *pipe*. Pipes play very nicely with `dplyr` and make our code very easy to understand. The tibble `gapminder` is being piped into the function `filter()`. The argument `year == 2007` tells `filter()` that it should find all the rows such that the logical condition `year == 2007` is TRUE.

Oh no! Have we accidentally deleted all of the other rows of `gapminder`? Nope: we haven't made any changes to `gapminder` at all. If you don't believe me try entering `gapminder` at the console. All that this command does is *display* a subset of `gapminder`. If we wanted to store the result of running this command, we'd need to assign it to a variable, for example

```
gapminder2007 <- gapminder %>% filter(year == 2007)
gapminder2007
```

```
# A tibble: 142 x 6
  country    continent year lifeExp      pop gdpPercap
  <fct>      <fct>    <int>   <dbl>    <int>    <dbl>
1 Afghanistan Asia      2007   43.8  31889923    975.
2 Albania    Europe    2007   76.4   3600523   5937.
3 Algeria    Africa    2007   72.3  33333216   6223.
4 Angola     Africa    2007   42.7  12420476   4797.
5 Argentina  Americas  2007   75.3  40301927  12779.
6 Australia  Oceania   2007   81.2  20434176  34435.
7 Austria    Europe    2007   79.8   8199783   36126.
8 Bahrain    Asia      2007   75.6    708573   29796.
9 Bangladesh Asia      2007   64.1 150448339   1391.
10 Belgium   Europe    2007   79.4  10392226  33693.
# ... with 132 more rows
```

Exercise #2

1. Explain the difference between `x = 3` and `x == 3` in R.
2. Use `filter` to choose the subset of `gapminder` for which `year` is 2002.
3. If you instead try to choose the subset with `year` equal to 2005, something will go wrong. Try it and explain what happens and why.
4. Store the data for Asian countries in a tibble called `gapminder_asia`. Display this tibble.

Solution to Exercise #2

Write your answer and code here

1. The first assigns the value 3 to the variable `x`; the second tests whether `x` is equal to 3 and returns either TRUE or FALSE.
2. Use the following code:

```
gapminder %>% filter(year == 2002)
```

```
# A tibble: 142 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>    <int>    <dbl>
1 Afghanistan Asia      2002   42.1  25268405    727.
2 Albania     Europe    2002   75.7   3508512   4604.
3 Algeria     Africa    2002   71.0  31287142   5288.
4 Angola      Africa    2002   41.0  10866106   2773.
5 Argentina   Americas  2002   74.3  38331121   8798.
6 Australia   Oceania   2002   80.4  19546792  30688.
7 Austria     Europe    2002   79.0   8148312  32418.
8 Bahrain     Asia      2002   74.8    656397  23404.
9 Bangladesh  Asia      2002   62.0 135656790   1136.
10 Belgium    Europe    2002   78.3  10311970  30486.
# ... with 132 more rows
```

3. If you go back to the help file for `gapminder` you'll see that it only contains data for every fifth year. The year 2005 isn't in our dataset so `dplyr` will display an empty tibble:

```
gapminder %>% filter(year == 2005)
```

```
# A tibble: 0 x 6
# ... with 6 variables: country <fct>, continent <fct>, year <int>,
#   lifeExp <dbl>, pop <int>, gdpPercap <dbl>
```

4. Use the following code:

```
gapminder_asia <- gapminder %>% filter(continent == 'Asia')
gapminder_asia
```

```
# A tibble: 396 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>    <int>    <dbl>
1 Afghanistan Asia      1952   28.8  8425333    779.
2 Afghanistan Asia      1957   30.3  9240934    821.
3 Afghanistan Asia      1962   32.0 10267083    853.
4 Afghanistan Asia      1967   34.0 11537966    836.
5 Afghanistan Asia      1972   36.1 13079460    740.
6 Afghanistan Asia      1977   38.4 14880372    786.
7 Afghanistan Asia      1982   39.9 12881816    978.
8 Afghanistan Asia      1987   40.8 13867957    852.
9 Afghanistan Asia      1992   41.7 16317921    649.
10 Afghanistan Asia      1997   41.8 22227415    635.
# ... with 386 more rows
```

Filtering two variables

We can use `filter` to subset on two or more variables. For example, here we display data for the US in 2007:

```
gapminder %>% filter(year == 2007, country == 'United States')
```

```
# A tibble: 1 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>
1 United States Americas  2007   78.2 301139947  42952.
```

Exercise #3

1. When I displayed data for the US in 2007, I put quotes around `United States` but not around `year`. Explain why.
2. Which country had the higher life expectancy in 1977: Ireland or Brazil? Which had the higher GDP per capita?

Solution to Exercise #3

Write your answer and code here

1. This is because `year` contains numeric data while `country` contains character data, aka string data.
2. From the results of the following code, we see that Ireland had both a higher life expectancy and GDP per capita.

```
gapminder %>% filter(year == 1977, country == 'Ireland')
```

```
# A tibble: 1 x 6
  country continent year lifeExp      pop gdpPercap
  <fct>    <fct>    <int>  <dbl>    <int>    <dbl>
1 Ireland Europe    1977   72.0 3271900  11151.
```

```
gapminder %>% filter(year == 1977, country == 'Brazil')
```

```
# A tibble: 1 x 6
  country continent year lifeExp      pop gdpPercap
  <fct>    <fct>    <int>  <dbl>    <int>    <dbl>
1 Brazil  Americas  1977   61.5 114313951  6660.
```

Sort data with arrange

Suppose we wanted to sort `gapminder` by `gdpPercap`. To do this we can use the `arrange` command along with the pipe `%>%` as follows:

```
gapminder %>% arrange(gdpPercap)
```

```
# A tibble: 1,704 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>
1 Congo, Dem. Rep. Africa    2002   45.0 55379852    241.
2 Congo, Dem. Rep. Africa    2007   46.5 64606759    278.
3 Lesotho      Africa    1952   42.1  748747     299.
```

```

4 Guinea-Bissau Africa 1952 32.5 580653 300.
5 Congo, Dem. Rep. Africa 1997 42.6 47798986 312.
6 Eritrea Africa 1952 35.9 1438760 329.
7 Myanmar Asia 1952 36.3 20092996 331.
8 Lesotho Africa 1957 45.0 813338 336.
9 Burundi Africa 1952 39.0 2445618 339.
10 Eritrea Africa 1957 38.0 1542611 344.
# ... with 1,694 more rows

```

The logic is very similar to what we saw above for `filter`. Here, we pipe the tibble `gapminder` into the function `arrange()`. The argument `gdpPercap` tells `arrange()` that we want to sort by GDP per capita. Note that by default `arrange()` sorts in *ascending order*. If we want to sort in *descending order*, we use the function `desc()` as follows:

```
gapminder %>% arrange(desc(gdpPercap))
```

```

# A tibble: 1,704 x 6
  country continent year lifeExp pop gdpPercap
  <fct>    <fct>    <int> <dbl> <int> <dbl>
1 Kuwait  Asia      1957  58.0 212846 113523.
2 Kuwait  Asia      1972  67.7 841934 109348.
3 Kuwait  Asia      1952  55.6 160000 108382.
4 Kuwait  Asia      1962  60.5 358266 95458.
5 Kuwait  Asia      1967  64.6 575003 80895.
6 Kuwait  Asia      1977  69.3 1140357 59265.
7 Norway  Europe    2007  80.2 4627926 49357.
8 Kuwait  Asia      2007  77.6 2505559 47307.
9 Singapore Asia    2007  80.0 4553009 47143.
10 Norway  Europe    2002  79.0 4535591 44684.
# ... with 1,694 more rows

```

Exercise #4

1. What is the lowest life expectancy in the `gapminder` dataset? Which country and year does it correspond to?
2. What is the highest life expectancy in the `gapminder` dataset? Which country and year does it correspond to?

Solution to Exercise #4

Write your code and solutions here

1. The lowest life expectancy was Rwanda in 1992: 23.6 years at birth.

```
gapminder %>% arrange(lifeExp)
```

```

# A tibble: 1,704 x 6
  country continent year lifeExp pop gdpPercap
  <fct>    <fct>    <int> <dbl> <int> <dbl>

```

```

1 Rwanda      Africa  1992  23.6 7290203  737.
2 Afghanistan Asia    1952  28.8 8425333  779.
3 Gambia      Africa  1952   30  284320  485.
4 Angola      Africa  1952  30.0 4232095 3521.
5 Sierra Leone Africa  1952  30.3 2143249  880.
6 Afghanistan Asia    1957  30.3 9240934  821.
7 Cambodia    Asia    1977  31.2 6978607  525.
8 Mozambique  Africa  1952  31.3 6446316  469.
9 Sierra Leone Africa  1957  31.6 2295678 1004.
10 Burkina Faso Africa  1952  32.0 4469979  543.
# ... with 1,694 more rows

```

2. The highest life expectancy was in 2007 in Japan: 82.6 years at birth.

```
gapminder %>% arrange(desc(lifeExp))
```

```

# A tibble: 1,704 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>
1 Japan        Asia      2007   82.6 127467972 31656.
2 Hong Kong, China Asia      2007   82.2  6980412 39725.
3 Japan        Asia      2002    82  127065841 28605.
4 Iceland      Europe     2007   81.8   301931 36181.
5 Switzerland  Europe     2007   81.7   7554661 37506.
6 Hong Kong, China Asia      2002   81.5   6762476 30209.
7 Australia    Oceania     2007   81.2  20434176 34435.
8 Spain        Europe     2007   80.9  40448191 28821.
9 Sweden        Europe     2007   80.9   9031088 33860.
10 Israel       Asia      2007   80.7   6426679 25523.
# ... with 1,694 more rows

```

Understanding the pipe: %>%

Let's revisit the pipe, %>%, that we've used in the code examples above. I told you that the command `gapminder %>% filter(year == 2007)` “pipes” the tibble `gapminder` into the function `filter()`. But what exactly does this mean? Take a look at the R help file for the `dplyr` function `filter`. We see that `filter()` takes something called `.data` as its first argument. Moving on to the “Arguments” section of the help file, we see that `.data` is “A `tbl`” i.e. a tibble. To better understand what this means, let's try using `filter` *without* the pipe:

```
filter(gapminder, year == 2007, country == 'United States')
```

```

# A tibble: 1 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>
1 United States Americas  2007   78.2 301139947 42952.

```

Notice that this gives us *exactly* the same result as

```
gapminder %>% filter(year == 2007, country == 'United States')
```

```
# A tibble: 1 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>   <int>    <dbl>
1 United States Americas   2007    78.2 301139947  42952.
```

In other words *The pipe is gives us an alternative way of supplying the first argument to a function*. Let's try this with a more familiar R function: `mean`. The first argument of `mean` is a vector `x`. So let's try using the pipe to compute the mean of some data:

```
x <- c(1, 5, 2, 7, 2)
x %>% mean
```

```
[1] 3.4
```

The pipe supplies a function with its *first* argument. If we want to specify additional arguments, we need to do so within the function call itself. For example, here's how we could use the pipe to compute the mean after dropping missing observations:

```
y <- c(1, 5, NA, 7, 2)
y %>% mean(na.rm = TRUE)
```

```
[1] 3.75
```

One important note about the pipe: it's *not* a base R command. Instead it's a command provided by the package `Magrittr`. (If you're familiar with the Belgian painter Magritte, you may realize that the name of this package is quite witty!) This package is installed automatically along with `dplyr`. So if we load the `tidyverse` package, which includes `dplyr`, the pipe is automatically available.

Exercise #5

1. Write R code that uses the pipe to calculate the sample variance of `z <- c(4, 1, 5, NA, 3)` excluding the missing observation from the calculation.
2. Re-write the code from your solution to Exercise #4 *without* using the pipe.

Solution to Exercise #5

Write your code and solutions here

1. Use the following code:

```
z <- c(4, 1, 5, NA, 3)
z %>% var(na.rm = TRUE)
```

```
[1] 2.916667
```

2. Use the following code:


```
arrange(gapminder, lifeExp)
```

```
# A tibble: 1,704 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>   <int>   <dbl>
1 Rwanda      Africa    1992   23.6 7290203    737.
2 Afghanistan Asia     1952   28.8 8425333    779.
3 Gambia       Africa    1952    30  284320     485.
4 Angola       Africa    1952   30.0 4232095   3521.
5 Sierra Leone Africa    1952   30.3 2143249    880.
6 Afghanistan Asia     1957   30.3 9240934    821.
7 Cambodia     Asia     1977   31.2 6978607    525.
8 Mozambique   Africa    1952   31.3 6446316    469.
9 Sierra Leone Africa    1957   31.6 2295678   1004.
10 Burkina Faso Africa    1952   32.0 4469979    543.
# ... with 1,694 more rows
```

```
arrange(gapminder, desc(lifeExp))
```

```
# A tibble: 1,704 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>   <int>   <dbl>
1 Japan      Asia     2007   82.6 127467972  31656.
2 Hong Kong, China Asia     2007   82.2  6980412  39725.
3 Japan      Asia     2002    82  127065841  28605.
4 Iceland    Europe    2007   81.8   301931  36181.
5 Switzerland Europe    2007   81.7   7554661  37506.
6 Hong Kong, China Asia     2002   81.5   6762476  30209.
7 Australia  Oceania    2007   81.2  20434176  34435.
8 Spain      Europe    2007   80.9  40448191  28821.
9 Sweden     Europe    2007   80.9   9031088  33860.
10 Israel     Asia     2007   80.7   6426679  25523.
# ... with 1,694 more rows
```

Chaining commands

In the examples we've looked at so far, the pipe doesn't seem all that useful: it's just an alternative way of specifying the first argument to a function. The true power and convenience of the pipe only becomes apparent we need to *chain* a series of commands together. For example, suppose we wanted to display the 1952 data from `gapminder` sorted by `gdpPercap` in descending order. Using the pipe, this is easy:

```
gapminder %>%
  filter(year == 1952) %>%
  arrange(desc(gdpPercap))
```

```
# A tibble: 142 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>   <dbl>   <int>   <dbl>
1 Kuwait      Asia     1952   55.6  160000  108382.
2 Switzerland Europe    1952   69.6  4815000  14734.
```

```

3 United States Americas 1952 68.4 157553000 13990.
4 Canada Americas 1952 68.8 14785584 11367.
5 New Zealand Oceania 1952 69.4 1994794 10557.
6 Norway Europe 1952 72.7 3327728 10095.
7 Australia Oceania 1952 69.1 8691212 10040.
8 United Kingdom Europe 1952 69.2 50430000 9980.
9 Bahrain Asia 1952 50.9 120447 9867.
10 Denmark Europe 1952 70.8 4334000 9692.
# ... with 132 more rows

```

Notice how I split the commands across multiple lines. This is good practice: it makes your code much easier to read. So what's happening when we chain commands in this way? The first step in the chain `gapminder %>% filter(year == 1952)` returns a tibble: the subset of `gapminder` for which `year` is 1952. The next step `%>% arrange(gdpPercap)` pipes this *new* tibble into the function `arrange()`, giving us the desired result. I hope you agree with me that this is pretty intuitive: even if we didn't know anything about `dplyr` we could *almost* figure out what this code is supposed to do. In stark contrast, let's look at the code we'd have to use if we wanted to accomplish the same task *without* using the pipe:

```
arrange(filter(gapminder, year == 1952), desc(gdpPercap))
```

```

# A tibble: 142 x 6
  country      continent year lifeExp      pop gdpPercap
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>
1 Kuwait      Asia      1952   55.6   160000  108382.
2 Switzerland Europe    1952   69.6   4815000  14734.
3 United States Americas 1952   68.4 157553000 13990.
4 Canada      Americas 1952   68.8 14785584 11367.
5 New Zealand Oceania 1952   69.4 1994794 10557.
6 Norway      Europe 1952   72.7 3327728 10095.
7 Australia   Oceania 1952   69.1 8691212 10040.
8 United Kingdom Europe 1952   69.2 50430000 9980.
9 Bahrain     Asia 1952   50.9 120447 9867.
10 Denmark    Europe 1952   70.8 4334000 9692.
# ... with 132 more rows

```

There are many reasons why this code is harder to read, but the most important one is that the commands `arrange` and `filter` have to appear in the code in the *opposite* of the order in which they are actually being carried out. This is because parentheses are evaluated from *inside to outside*. This is what's great about the pipe: it lets us write our code in a way that accords with the actual order of the steps we want to carry out.

Exercise #6

1. What was the most populous European country in 1992? Write appropriate `dplyr` code using the pipe to display the information you need to answer this question.
2. Re-write your code from part 1. *without* using the pipe.

Solution to Exercise #6

Write your code and solutions here

1. The most populous European country in 1992 was Germany.

```
gapminder %>%  
  filter(year == 1992, continent == 'Europe') %>%  
  arrange(desc(pop))
```

```
# A tibble: 30 x 6  
  country      continent year lifeExp      pop gdpPercap  
  <fct>        <fct>    <int>   <dbl>   <int>    <dbl>  
1 Germany      Europe    1992   76.1 80597764 26505.  
2 Turkey      Europe    1992   66.1 58179144  5678.  
3 United Kingdom Europe    1992   76.4 57866349 22705.  
4 France      Europe    1992   77.5 57374179 24704.  
5 Italy      Europe    1992   77.4 56840847 22014.  
6 Spain      Europe    1992   77.6 39549438 18603.  
7 Poland      Europe    1992   71.0 38370697  7739.  
8 Romania     Europe    1992   69.4 22797027  6598.  
9 Netherlands Europe    1992   77.4 15174244 26791.  
10 Hungary     Europe    1992   69.2 10348684 10536.  
# ... with 20 more rows
```

2. Use the following code:

```
arrange(filter(gapminder, year == 1992, continent == 'Europe'), desc(pop))
```

```
# A tibble: 30 x 6  
  country      continent year lifeExp      pop gdpPercap  
  <fct>        <fct>    <int>   <dbl>   <int>    <dbl>  
1 Germany      Europe    1992   76.1 80597764 26505.  
2 Turkey      Europe    1992   66.1 58179144  5678.  
3 United Kingdom Europe    1992   76.4 57866349 22705.  
4 France      Europe    1992   77.5 57374179 24704.  
5 Italy      Europe    1992   77.4 56840847 22014.  
6 Spain      Europe    1992   77.6 39549438 18603.  
7 Poland      Europe    1992   71.0 38370697  7739.  
8 Romania     Europe    1992   69.4 22797027  6598.  
9 Netherlands Europe    1992   77.4 15174244 26791.  
10 Hungary     Europe    1992   69.2 10348684 10536.  
# ... with 20 more rows
```

Change an existing variable or create a new one with mutate

It's a little hard to read the column `pop` in `gapminder` since there are so many digits. Suppose that, instead of raw population, we wanted to display population *in millions*. This requires us to `pop` by 1000000, which we can do using the function `mutate()` from `dplyr` as follows:

```
gapminder %>%  
  mutate(pop = pop / 1000000)
```

```
# A tibble: 1,704 x 6
```

```

  country      continent  year lifeExp  pop gdpPercap
  <fct>        <fct>    <int>  <dbl> <dbl>    <dbl>
1 Afghanistan Asia      1952   28.8  8.43     779.
2 Afghanistan Asia      1957   30.3  9.24     821.
3 Afghanistan Asia      1962   32.0 10.3     853.
4 Afghanistan Asia      1967   34.0 11.5     836.
5 Afghanistan Asia      1972   36.1 13.1     740.
6 Afghanistan Asia      1977   38.4 14.9     786.
7 Afghanistan Asia      1982   39.9 12.9     978.
8 Afghanistan Asia      1987   40.8 13.9     852.
9 Afghanistan Asia      1992   41.7 16.3     649.
10 Afghanistan Asia      1997   41.8 22.2     635.
# ... with 1,694 more rows

```

Note the syntax here: within `mutate()` we have an assignment statement, namely `pop = pop / 1000000`. This tells R to calculate `pop / 1000000` and assign the result to `pop`, in place of the original variable.

We can also use `mutate()` to create a new variable. The `gapminder` dataset doesn't contain overall GDP, only GDP per capita. To calculate GDP, we need to multiply `gdpPercap` by `pop`. But wait! Didn't we just change `pop` so it's expressed in millions? No: we never *stored* the results of our previous command, we simply displayed them. Just as I discussed above, unless you *overwrite* it, the original `gapminder` dataset will be unchanged. With this in mind, we can create the `gdp` variable as follows:

```
gapminder %>% mutate(gdp = pop * gdpPercap)
```

```

# A tibble: 1,704 x 7
  country      continent  year lifeExp      pop gdpPercap      gdp
  <fct>        <fct>    <int>  <dbl>    <int>    <dbl>    <dbl>
1 Afghanistan Asia      1952   28.8  8425333    779.  6567086330.
2 Afghanistan Asia      1957   30.3  9240934    821.  7585448670.
3 Afghanistan Asia      1962   32.0 10267083    853.  8758855797.
4 Afghanistan Asia      1967   34.0 11537966    836.  9648014150.
5 Afghanistan Asia      1972   36.1 13079460    740.  9678553274.
6 Afghanistan Asia      1977   38.4 14880372    786. 11697659231.
7 Afghanistan Asia      1982   39.9 12881816    978. 12598563401.
8 Afghanistan Asia      1987   40.8 13867957    852. 11820990309.
9 Afghanistan Asia      1992   41.7 16317921    649. 10595901589.
10 Afghanistan Asia      1997   41.8 22227415    635. 14121995875.
# ... with 1,694 more rows

```

Exercise #7

1. Explain why we used `=` rather than `==` in the `mutate()` examples above.
2. Which country in the Americas had the shortest life expectancy *in months* in the year 1962? Write appropriate dplyr code using the pipe to display the information you need to answer this question.

Solution to Exercise #7

Write your code and solutions here

1. We used `=` because this is the assignment operator. In contrast `==` tests for equality, returning `TRUE` or `FALSE`.
2. Bolivia had the shortest life expectancy: 521 months.

```
gapminder %>%
  mutate(lifeExpMonths = 12 * lifeExp) %>%
  filter(year == 1962, continent == 'Americas') %>%
  arrange(lifeExpMonths)
```

```
# A tibble: 25 x 7
  country      continent year lifeExp      pop gdpPercap lifeExpMonths
  <fct>        <fct>    <int>   <dbl>   <int>   <dbl>         <dbl>
1 Bolivia      Americas  1962   43.4  3.59e6  2181.         521.
2 Haiti        Americas  1962   43.6  3.88e6  1797.         523.
3 Guatemala    Americas  1962   47.0  4.21e6  2750.         563.
4 Honduras     Americas  1962   48.0  2.09e6  2291.         576.
5 Nicaragua    Americas  1962   48.6  1.59e6  3634.         584.
6 Peru         Americas  1962   49.1  1.05e7  4957.         589.
7 El Salvador  Americas  1962   52.3  2.75e6  3777.         628.
8 Dominican Repu~ Americas  1962   53.5  3.45e6  1662.         642.
9 Ecuador      Americas  1962   54.6  4.68e6  4086.         656.
10 Brazil      Americas  1962   55.7  7.60e7  3337.         668.
# ... with 15 more rows
```

A simple scatterplot using ggplot2

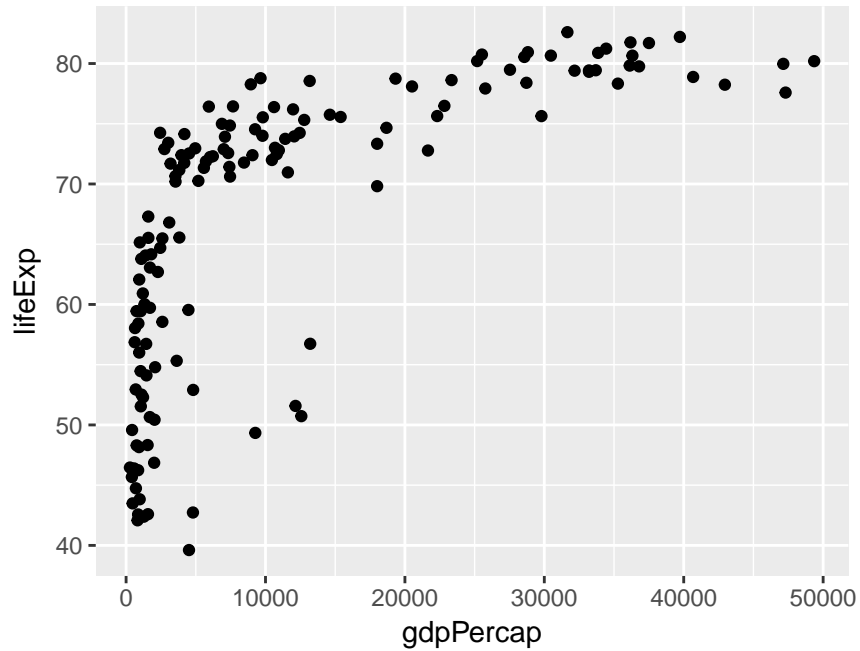
Now that we know the basics of `dplyr`, we'll turn our attention to graphics. R has many powerful build-in graphics functions that may be familiar to you from Econ 103. In this class, however, we'll use a very powerful package for statistical visualization called `ggplot2`. There's nothing more for you to instead or load, since `ggplot2` is included in the `tidyverse` package, which you've already installed and loaded. For more details on `ggplot2` see the chapter entitled "Data Visualisation" in *R for Data Science*.

We'll start off by constructing a subset of the `gapminder` dataset that contains information from the year 2007 that we'll use for our plots below.

```
gapminder_2007 <- gapminder %>% filter(year == 2007)
```

It takes some time to grow accustomed to `ggplot2` syntax, so rather than giving you a lot of detail, we're going to look at a series of increasingly more complicated examples. Our first example will be a simple scatterplot using `gapminder_2007`. Each point will correspond to a single country in 2007. Its x-coordinate will be GDP per capita and its y-coordinate will be life expectancy. Here's the code:

```
ggplot(gapminder_2007) + geom_point(mapping = aes(x = gdpPercap, y = lifeExp))
```



We see that GDP per capita is a very strong predictor of life expectancy, although the relationship is non-linear.

Exercise #8

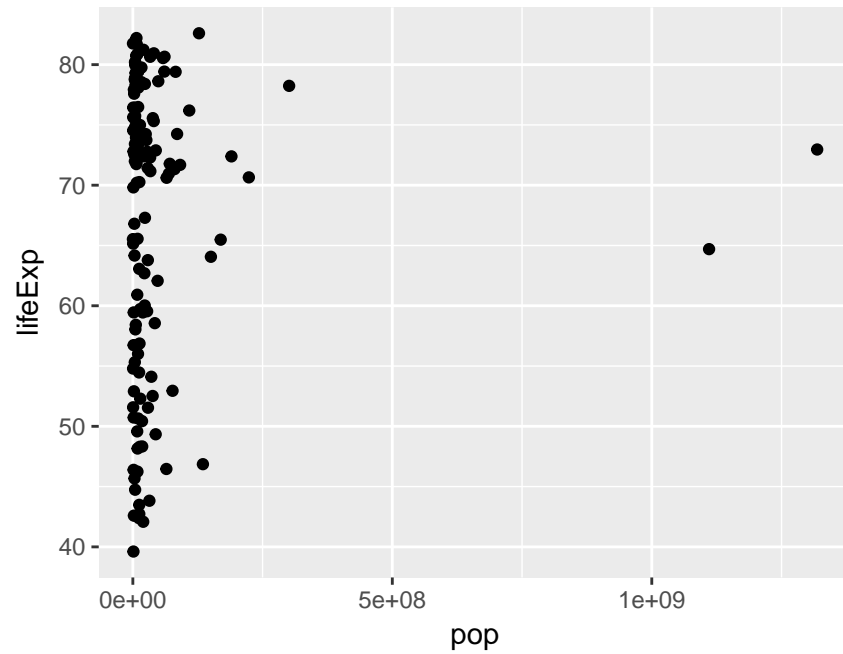
1. Using my code example as a template, make a scatterplot with `pop` on the x-axis and `lifeExp` on the y-axis using `gapminder_2007`. Does there appear to be a relationship between population and life expectancy?
2. Repeat 1. with `gdpPerCap` on the y-axis.

Solution to Exercise #8

Write your code and solutions here

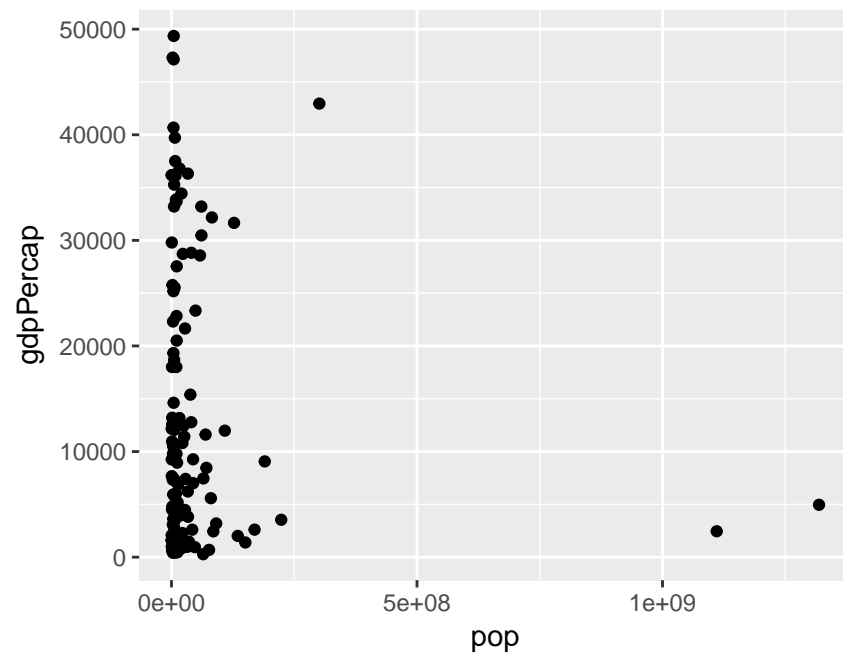
1. There is no clear relationship between population and life expectancy based on the 2007 data:

```
ggplot(gapminder_2007) + geom_point(mapping = aes(x = pop, y = lifeExp))
```



2. There is no clear relationship between population and GDP per capita based on the 2007 data:

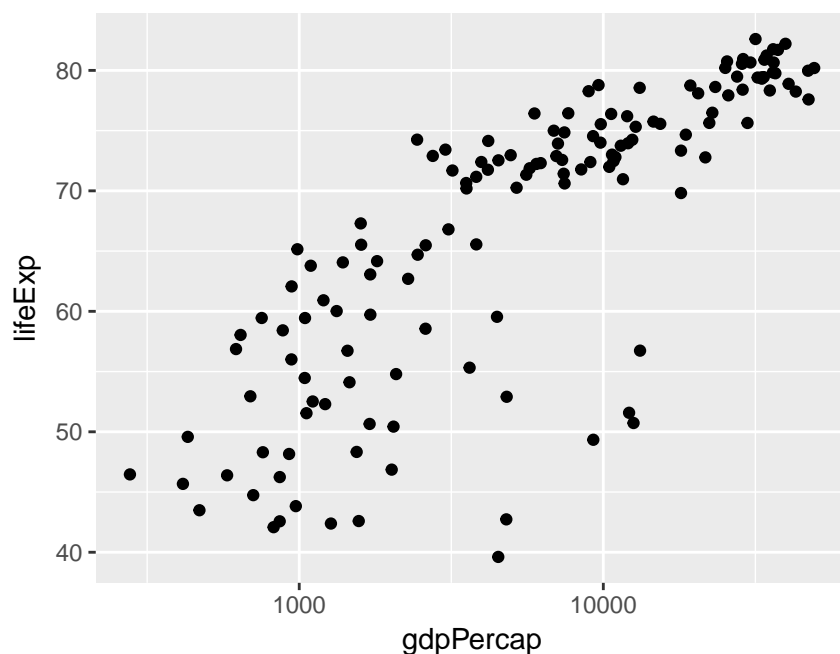
```
ggplot(gapminder_2007) + geom_point(mapping = aes(x = pop, y = gdpPercap))
```



Plotting on the log scale

It's fairly common to transform data onto a log scale before carrying out further analysis or plotting. If you've taken Econ 104, you may already be familiar with log transformations. If not, don't worry about it: we'll discuss them later in the course. For now, we'll content ourselves with learning how to transform the axes in a `ggplot` to the log base 10 scale. To transform the x-axis, it's as easy as adding a `+ scale_x_log10()` to the end of our command from above:

```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = gdpPercap, y = lifeExp)) +  
  scale_x_log10()
```



Notice how I split the code across multiple lines and ended each of the intermediate lines with the `+`. This makes things much easier to read.

Exercise #9

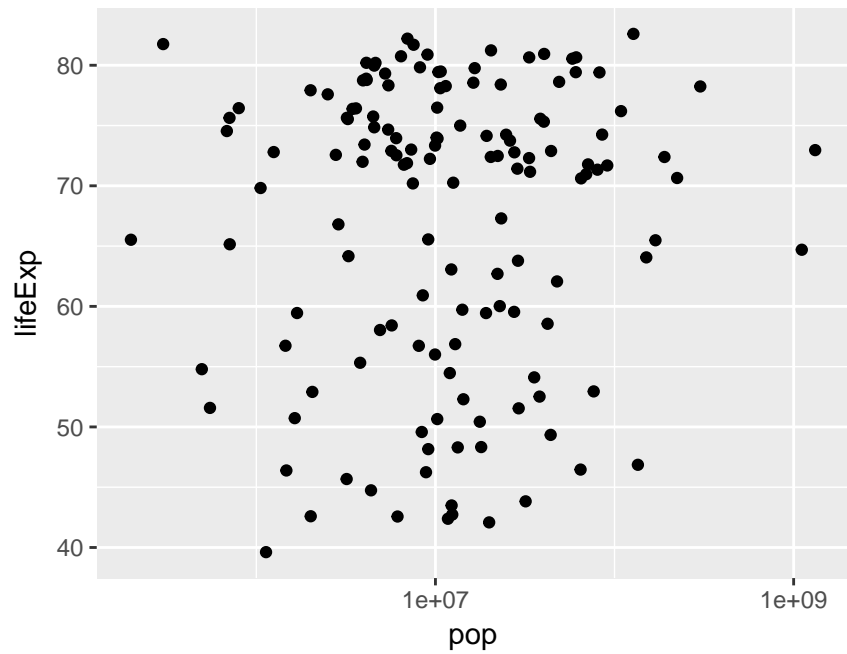
1. Using my code example as a template, make a scatterplot with the log base 10 of `pop` on the x-axis and `lifeExp` on the y-axis using the `gapminder_2007` dataset.
2. Suppose that rather than putting the x-axis on the log scale, we wanted to put the *y-axis* on the log scale. Figure out how to do this, either by clever guesswork or a google search, and then redo my example with `gdpPercap` and `lifeExp` with `gdpPercap` in levels and `lifeExp` in logs.
3. Repeat 2. but with *both* axes on the log scale.

Solution to Exercise #9

Write your code and solutions here

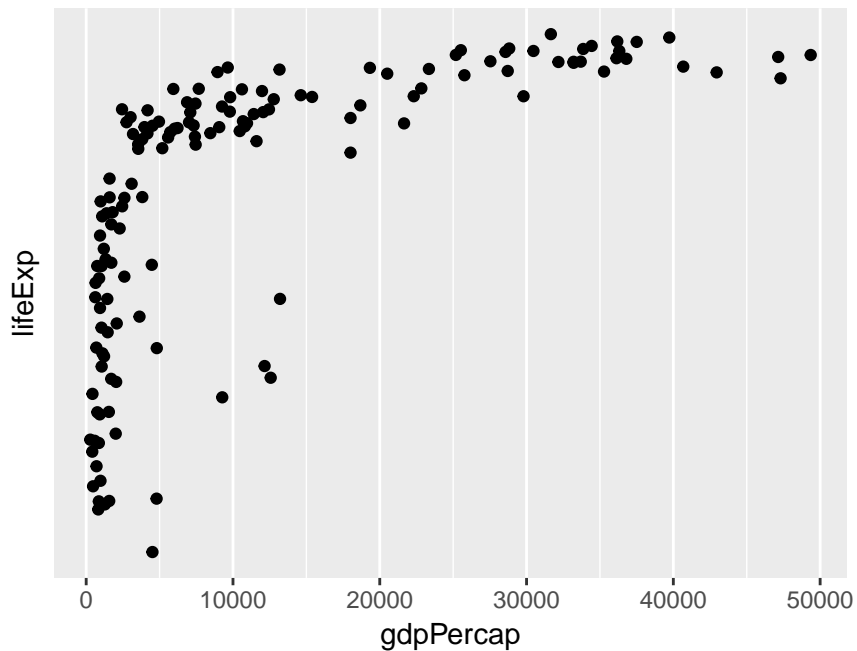
1. Use the following code:


```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = pop, y = lifeExp)) +  
  scale_x_log10()
```



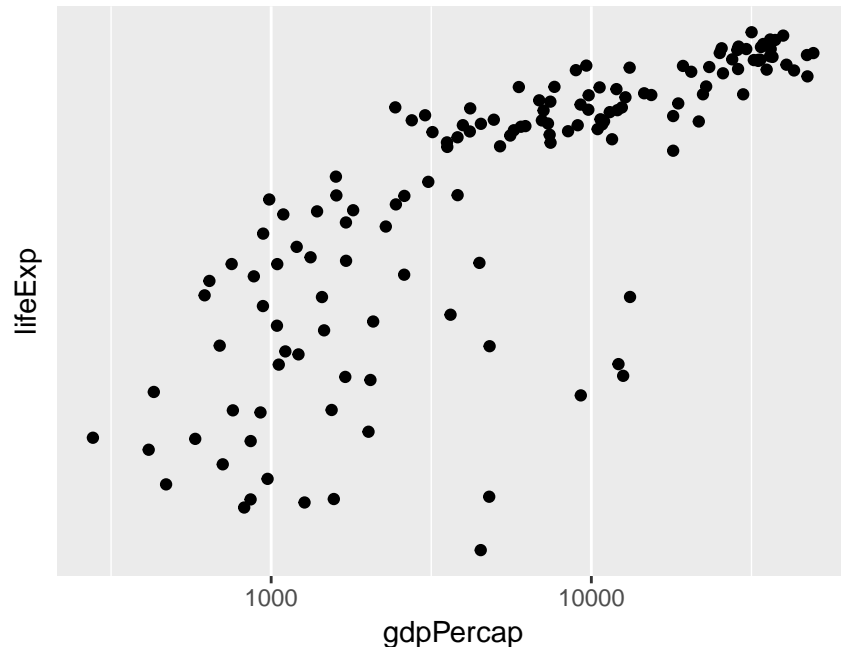
2. Use the following code:

```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = gdpPercap, y = lifeExp)) +  
  scale_y_log10()
```



3. Use the following code:

```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = gdpPercap, y = lifeExp)) +  
  scale_x_log10() +  
  scale_y_log10()
```



The color and size aesthetics

It's time to start unraveling the somewhat mysterious-looking syntax of `ggplot`. To make a graph using `ggplot` we use the following template:

```
ggplot(data = <DATA>) +  
  <GEOM_FUNCTION>(mapping = aes(<MAPPINGS>))
```

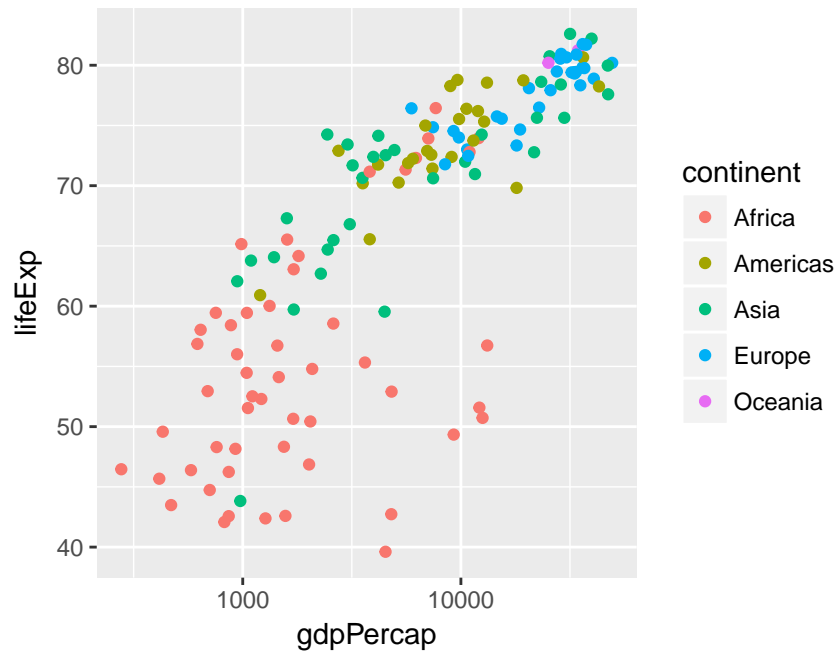
replacing `<DATA>`, `<GEOM_FUNCTION>`, and `<MAPPINGS>` to specify what we want to plot and how it should appear. The first part is easy: we replace `<DATA>` with the dataset we want to plot, for example `gapminder_2007` in the example from above. The second part is also fairly straightforward: we replace `<GEOM_FUNCTION>` with the name of a function that specifies the kind of plot we want to make. So far we've only seen one example: `geom_point()` which tells `ggplot` that we want to make a scatterplot. We'll see more examples in a future lab. For now, I want to focus on the somewhat more complicated-looking `mapping = aes(<MAPPINGS>)`.

The abbreviation `aes` is short for *aesthetic* and the code `mapping = aes(<MAPPINGS>)` defines what is called an *aesthetic mapping*. This is just a fancy way of saying that it tells R how we want our plot to look. The information we need to put in place of `<MAPPINGS>` depends on what kind of plot we're making. Thus far we've only examined `geom_point()` which produces a scatterplot. For this kind of plot, the minimum information we need to provide is the location of each point. For example, in our example above we wrote `aes(x = gdpPercap, y = lifeExp)` to tell R that `gdpPercap` gives the x-axis location of each point, and `lifeExp` gives the y-axis location.

When making a scatterplot with `geom_point` we are not limited to specifying the x and y coordinates of each point; we can also specify the size and color of each point. This gives us a useful way of displaying more than

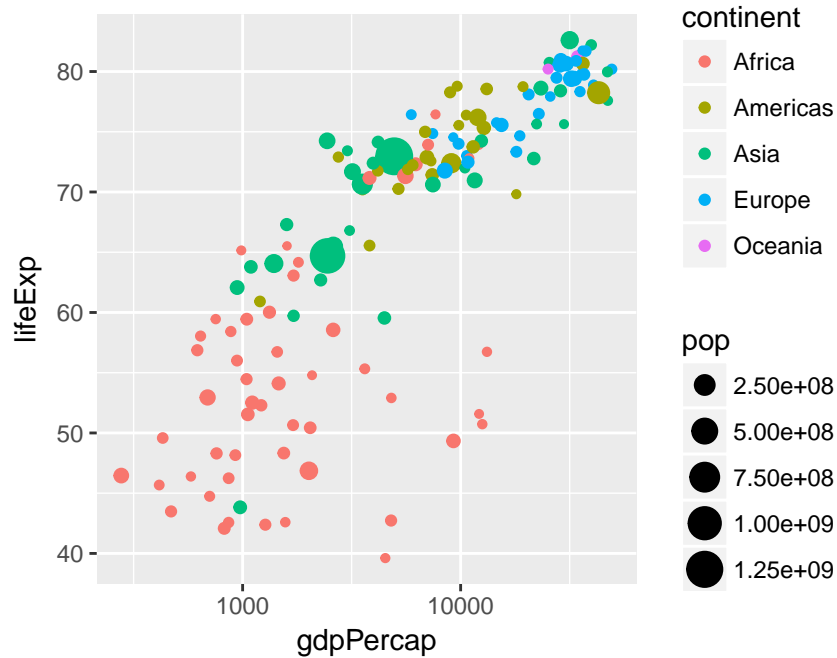
two variables in a two-dimensional plot. We do this using `aes`. For example, let's use the color of each point to indicate `continent`

```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = gdpPercap, y = lifeExp, color = continent)) +  
  scale_x_log10()
```



Notice how `ggplot` automatically generates a helpful legend. This plot makes it easy to see at a glance that the European countries in 2007 tend to have high GDP per capita and high life expectancy, while the African countries have the opposite. We can also use the *size* of each point to encode information, e.g. population:

```
ggplot(data = gapminder_2007) +  
  geom_point(mapping = aes(x = gdpPercap, y = lifeExp, color = continent, size = pop)) +  
  scale_x_log10()
```



Exercise #10

1. Would it make sense to set `size = continent`? What about setting `col = pop`? Explain briefly.
2. The following code is slightly different from what I've written above. What is different. Try running it. What happens? Explain briefly.

```
ggplot(gapminder_2007) +
  geom_point(aes(x = gdpPercap, y = lifeExp)) +
  scale_x_log10()
```

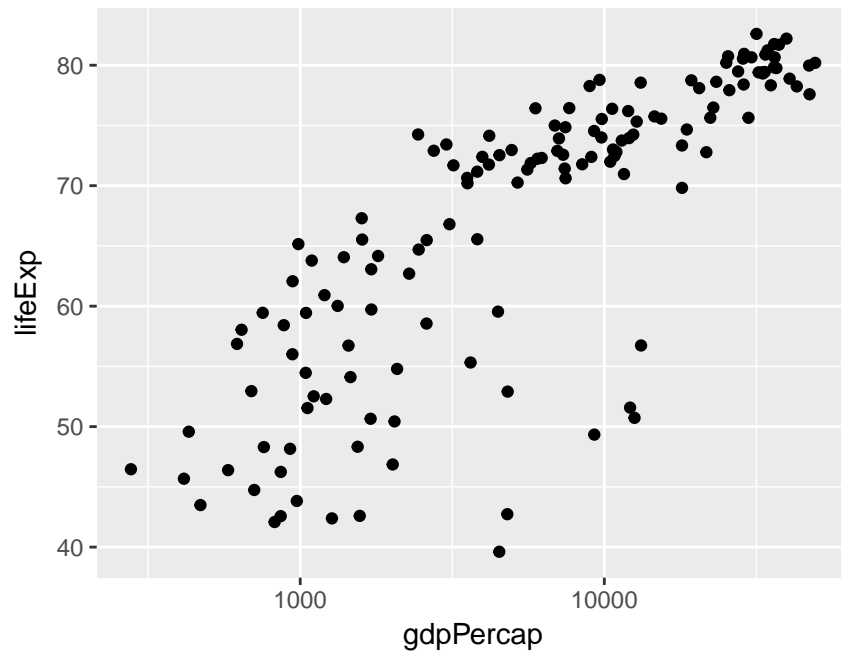
3. Create a tibble called `gapminder_1952` that contains data from `gapminder` from 1952.
4. Use `gapminder_1952` from the previous part to create a scatter plot with population on the x-axis, life expectancy on the y-axis, and continent represented by the color of the points. Plot population on the log scale (base 10).
5. Suppose that instead of indicating continent using color, you wanted all the points in the plot from 3. to be blue. Consult the chapter "Visualising Data" from *R for Data Science* to find out how to do this.

Solution to Exercise #10

Write your code and solutions here

1. Neither of these makes sense since `continent` is categorical and `pop` is continuous: `color` is useful for categorical variables and `size` for continuous ones.
2. It still works! You don't have to explicitly write `data` or `mapping` when using `ggplot`. I only included these above for clarity. In the future I'll leave them out to make my code more succinct.

```
ggplot(gapminder_2007) +
  geom_point(aes(x = gdpPercap, y = lifeExp)) +
  scale_x_log10()
```

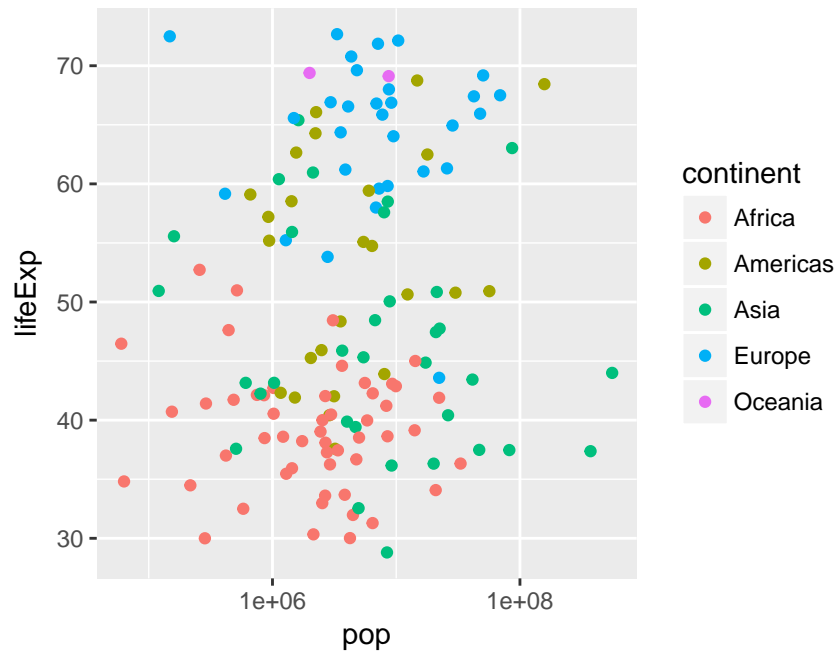


3. Use the following code:

```
gapminder_1952 <- gapminder %>%
  filter(year == 1952)
```

4. Use the following code:

```
ggplot(gapminder_1952) +
  geom_point(aes(x = pop, y = lifeExp, color = continent)) +
  scale_x_log10()
```



5. When you want color to be a variable from your dataset, put `color = <VARIABLE>` *inside* of `aes`; when you simply want to set the colors of all the points, put `color = '<COLOR>'` *outside* of `aes`, for example

```
ggplot(gapminder_1952) +  
  geom_point(aes(x = pop, y = lifeExp), color = 'blue') +  
  scale_x_log10()
```

