

Tidy R

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Contents

1 Before we start	5
2 What is tidy R?	7
2.1 Differences between tidy and base R	7
2.2 Literate programming in Rmarkdown	13
2.3 First steps in tidy data analysis	13
3 Data Wrangling	15
3.1 The “tidy” approach to data wrangling	15
3.2 Transforming data using verbs	15
3.3 Pipes	32
3.4 Tidy data	35
3.5 Joins	49
3.6 Recoding	50
3.7 Tidy iteration	50
4 Visualization	57
4.1 The “tidy” approach to data visualization	57
4.2 The Grammar of graphics	57
4.3 Order	82
4.4 Facets	91
4.5 Chart type vocabulary	91
4.6 Polish your plot for publication	115
4.7 Maps	115
4.8 Networks	115

Chapter 1

Before we start

These are the packages we will use during this course.

```
install.packages('devtools')

devtools::install_cran(
  pkgs = c(
    'tidyverse',      # tools for tidy data analysis
    'rmarkdown',      # literate programming
    'plotly',         # interactive visualization
    'ggmap',          # use online map-tiles with ggplot
    'eurostat',       # download data from eurostat
    'sf',             # tidy geo-computing
    'rnaturalearth', # download worldwide map data
    'gapminder',      # data from the gapminder world project
    'cowplot',        # ggplot multiple figures addon
    'skimr'           # nice dataframe summaries
  ),
  repos = "https://cran.rstudio.com/"
)
```


Chapter 2

What is tidy R?

2.1 Differences between tidy and base R

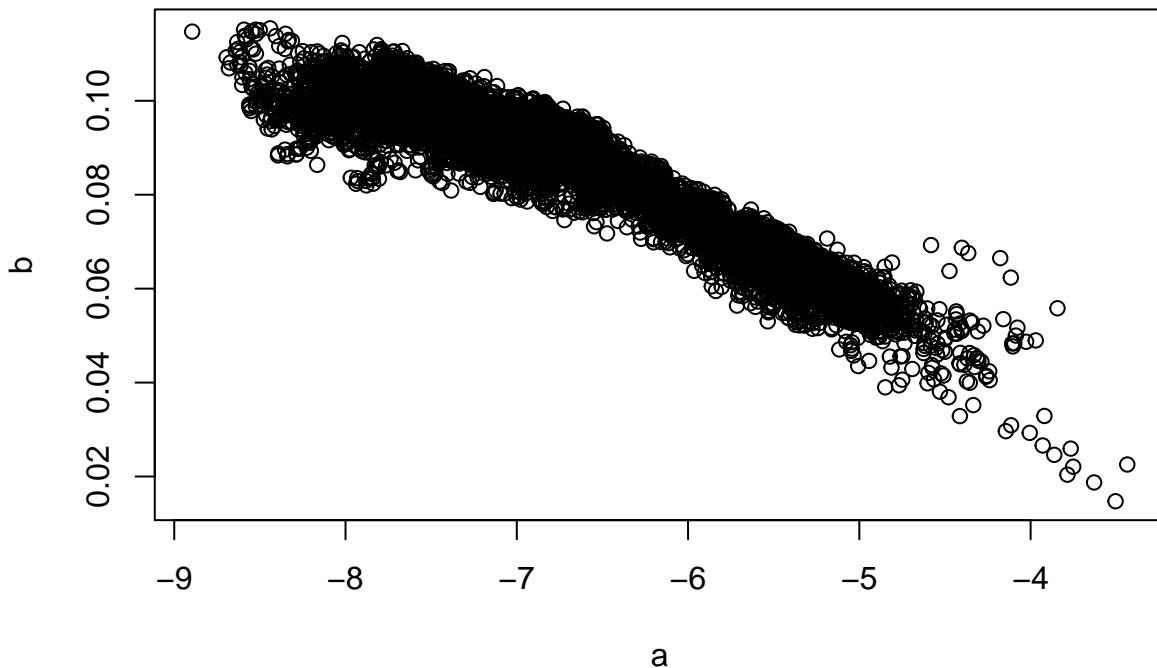
The Gompertz Law describes the exponential relationship between age and mortality rate in human populations. Its two parameters a and b describe the overall mortality level and the relative rate of mortality increase over age. It is well known that both parameters correlate with each other. The code below demonstrates this co-variance by fitting the Gompertz equation to Swedish birth cohorts and plotting the parameter estimates against each other.

$$\mu(x) = ae^{bx}$$

```
# load data
load('data/hmd/hmd_counts.RData')

# select ages 30 to 80, drop total counts, drop NAs
hmd_sub <-
  na.omit(subset(hmd_counts, age >= 30 & age < 80 & sex != 'Total'))
# split the data by sex, country and year
hmd_split <-
  split(hmd_sub, list(hmd_sub$sex, hmd_sub$country, hmd_sub$period),
        drop = TRUE)
# run a linear regression on each subset
hmd_regress <-
  lapply(hmd_split,
         function (lt) glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
                           family = 'poisson', data = lt))
# extract the coefficients from each regression model
hmd_coef <- t(sapply(hmd_regress, coef))
# plot a versus b coefficients
plot(x = hmd_coef[,1], y = hmd_coef[,2],
      main = 'Gompertz correlation', xlab = 'a', ylab = 'b')
```

Gompertz correlation



Here's how I would write the same program today, using the `tidyverse`.

```
library(tidyverse)
# load data
load('data/hmd/hmd_counts.RData')

hmd_counts %>%
  # select ages 30 to 80, drop total counts
  filter(age >= 30, age < 80, sex != 'Total') %>%
  # drop NAs
  drop_na() %>%
  # for each period...
  group_by(period, country, sex) %>%
  # ...run a Poisson regression of deaths versus age
  do(lm = glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
              family = 'poisson', data = .)) %>%
  # extract the regression coefficients
  mutate(a = coef(lm)[1], b = coef(lm)[2]) %>%
  # plot a versus b coefficients and label with year
  ggplot() +
  geom_point(aes(x = a, y = b), shape = 1, size = 3) +
  labs(title = 'Gompertz correlation')
```

```

# load data
load('data/hmd/hmd_counts.RData')

# select ages 30 to 80, drop total counts, drop NAs

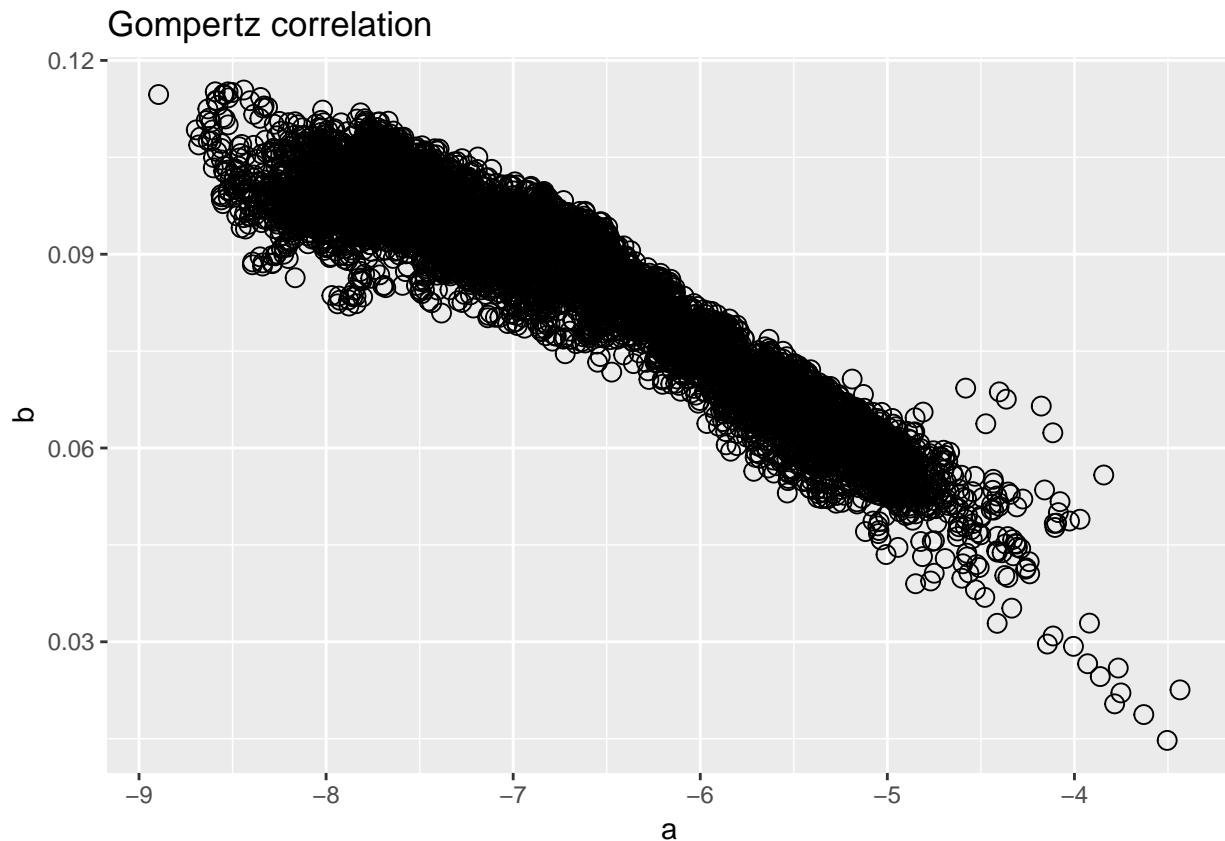
na.omit(subset(hmd_counts, age >= 30 & age < 80 & sex != 'Total'))
# split the data by sex, country and year

split(hmd_sub, list(hmd_sub$sex, hmd_sub$country, hmd_sub$period),
      drop = TRUE)
# run a linear regression on each subset

lapply(hmd_split,
       function (lt) glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
                          family = 'poisson', data = lt))
# extract the coefficients from each regression model


```

Figure 2.1: In base R we stores intermediate results often.



What are the differences?

```

library(tidyverse)
# load data
load('data/hmd/hmd_counts.RData')

hmd_counts %>%
  # select ages 30 to 80, drop total counts
  filter(age >= 30, age < 80, sex != 'Total') %>%
  # drop NAs
  drop_na() %>%
  # for each period...
  group_by(period, country, sex) %>%
  # ...run a Poisson regression of deaths versus age
  do(lm = glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
              family = 'poisson', data = .)) %>%
  # extract the regression coefficients
  mutate(a = coef(lm)[1], b = coef(lm)[2]) %>%
  # plot a versus b coefficients and label with year
  ggplot() +
  geom_point(aes(x = a, y = b), shape = 1, size = 3) +
  labs(title = 'Gompertz correlation')

```

Figure 2.2: In tidy R a single *data pipeline* often gets us from raw data to finished result.

# load data	Dataframe
load('data/hmd/hmd_counts.RData')	
# select ages 30 to 80, drop total counts, drop NAs	List
hmd_sub <- na.omit(subset(hmd_counts , age >= 30 & age < 80 & sex != 'Total'))	Matrix
# split the data by sex, country and year	
hmd_split <- split(hmd_sub , list(hmd_sub\$sex , hmd_sub\$country , hmd_sub\$period), drop = TRUE)	
# run a linear regression on each subset	
hmd_regress <- lapply(hmd_split , function (lt) glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)), family = 'poisson', data = lt))	
# extract the coefficients from each regression model	
hmd_coef <- t(sapply(hmd_regress , coef))	
# plot a versus b coefficients	
plot(x = hmd_coef [,1], y = hmd_coef [,2], main = 'Gompertz correlation', xlab = 'a', ylab = 'b')	

Figure 2.3: In base R data structures change often.

```

library(tidyverse)
# load data
load('data/hmd/hmd_counts.RData')



### Dataframe



hmd_counts %>%
  # select ages 30 to 80, drop total counts
  filter(age >= 30, age < 80, sex != 'Total') %>%
  # drop NAs
  drop_na() %>%
  # for each period...
  group_by(period, country, sex) %>%
  # ...run a Poisson regression of deaths versus age
  do(lm = glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
              family = 'poisson', data = .)) %>%
  # extract the regression coefficients
  mutate(a = coef(lm)[1], b = coef(lm)[2]) %>%
  # plot a versus b coefficients and label with year
  ggplot() +
  geom_point(aes(x = a, y = b), shape = 1, size = 3) +
  labs(title = 'Gompertz correlation')

```

Figure 2.4: In tidy R the dataframe is the most important data structure.

```

# load data
load('data/hmd/hmd_counts.RData')

# select ages 30 to 80, drop total counts, drop NAs
hmd_sub <- na.omit(subset(hmd_counts, age >= 30 & age < 80 & sex != 'Total'))
# split the data by sex, country and year
hmd_split <-
  split(hmd_sub, list(hmd_sub$sex, hmd_sub$country, hmd_sub$period),
        drop = TRUE)
# run a linear regression on each subset
hmd_regress <-
  lapply(hmd_split,
         function (lt) glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
                           family = 'poisson', data = lt))
# extract the coefficients from each regression model
hmd_coef <- t(sapply(hmd_regress, coef))
# plot a versus b coefficients
plot(x = hmd_coef[,1], y = hmd_coef[,2],
      main = 'Gompertz correlation', xlab = 'a', ylab = 'b')

```

NSE

List index

Matrix index

Figure 2.5: In base R we have to use various indexing styles.

```

NSE

library(tidyverse)
# load data
load('data/hmd/hmd_counts.RData')

hmd_counts %>%
  # select ages 30 to 80, drop total counts
  filter(age >= 30, age < 80, sex != 'Total') %>%
  # drop NAs
  drop_na() %>%
  # for each period...
  group_by(period, country, sex) %>%
  # ...run a Poisson regression of deaths versus age
  do(lm = glm(round(nDx, 0) ~ I(age-30) + offset(log(nEx)),
              family = 'poisson', data = .)) %>%
  # extract the regression coefficients
  mutate(a = coef(lm)[1], b = coef(lm)[2]) %>%
  # plot a versus b coefficients and label with year
  ggplot() +
  geom_point(aes(x = a, y = b), shape = 1, size = 3) +
  labs(title = 'Gompertz correlation')

```

Figure 2.6: In tidy R we use a single indexing style.

```

# load data
load('data/hmd/hmd_counts.RData')

# select ages 30 to 80, drop total counts, drop NAs
hmd_sub <-
  na.omit(subset(hmd_counts, age >= 30 & age < 80 & sex != 'Total'))
# split the data by sex, country and year
hmd_split <-
  split(hmd_sub, list(hmd_sub$sex, hmd_sub$country, hmd_sub$period),
        drop = TRUE)
# run a Poisson regression of deaths versus age
hmd_regressions <- lapply(hmd_split, function(x) {
  lm(round(nDx, 0) ~ I(age - 30) + offset(log(nEx)),
     family = 'poisson', data = x))
# extract coefficients
hmd_coef <- lapply(hmd_regressions, coef)
# plot a versus b coefficients
plot(x = hmd_coef[,1], y = hmd_coef[,2],
      main = 'Gompertz correlation', xlab = 'a', ylab = 'b')

```

Figure 2.7: In base R important information is sometimes stored in row names.

```

library(tidyverse)
# load data
load('data/hmd/hmd_counts.RData')

hmd_counts %>%
  # select ages 30 to 80, drop total
  filter(age >= 30, age < 80, sex != "NA")
  # drop NAs
  drop_na() %>%
  # for each period...
  group_by(period, country, sex) %>%
  # ...run a Poisson regression of d
  do(lm = glm(round(ndx, 0) ~ I(age - 30),
              family = 'poisson', data = .))
  # extract the regression coefficients
  mutate(a = coef(lm)[1], b = coef(lm)[2]) %>%
  # plot a versus b coefficients and label with year
  ggplot() +
  geom_point(aes(x = a, y = b), shape = 1, size = 3) +
  labs(title = 'Gompertz correlation')

```

	period	country	sex	lm	a	b
<int>	<chr>	<chr>	<list>	<dbl>	<dbl>	
1	1751	SWE	Female	<S3: glm>	-4.95	0.0538
2	1751	SWE	Male	<S3: glm>	-4.83	0.0546
3	1752	SWE	Female	<S3: glm>	-5.11	0.0533
4	1752	SWE	Male	<S3: glm>	-4.97	0.0531
5	1753	SWE	Female	<S3: glm>	-5.18	0.0555
6	1753	SWE	Male	<S3: glm>	-4.95	0.0526
7	1754	SWE	Female	<S3: glm>	-5.11	0.0561
8	1754	SWE	Male	<S3: glm>	-4.82	0.0528
9	1755	SWE	Female	<S3: glm>	-5.03	0.0551
10	1755	SWE	Male	<S3: glm>	-4.82	0.0523

... with 7,816 more rows

Figure 2.8: In tidy R all information exists in the form of data frame columns.

2.1.1 Excercise: Differences between tidy and base R

- Discuss the differences.

2.2 Literate programming in Rmarkdown

The official Rmarkdown cheat sheet.

2.2.1 Excercise: Literate programming in Rmarkdown

- Rewrite any of your existing R-scripts into an Rmarkdown script. Demonstrate loading data from the hard disc, plot output, text blocks, headers and lists. Export to pdf.

2.3 First steps in tidy data analysis

Chapter 3

Data Wrangling

```
library(tidyverse)

# General social survey
# source: http://gss.norc.org/s
gss <- haven::read_stata('data/gss/GSS2016.DTA')
```

3.1 The “tidy” approach to data wrangling

“Data wrangling” is the process of transforming raw data into a form fit for analysis. This may include operations like filtering, sorting, joining, splitting, recoding or reshaping, nearly always performed in conjunction with each other. The tidy approach to data wrangling aims to make this often mundane but critical task as clear and fast as possible. Tidy data wrangling revolves around 4 concepts:

- 1) **Verbs** A small collection of “verbs” provides basic transformation operations.
- 2) **Pipes** Transformations can be chained together via a “pipe”.
- 3) **Tidy Data** Everything is a data frame with cases as rows and variables as columns.
- 4) **Tidy iteration** Transformations can be repeatedly applied to different row or column subsets without the use of a for loop.

3.2 Transforming data using verbs

The `tidyverse` provides us with an array of *verbs* for data transformation such as `filter()`, `mutate()`, `summarise()` and many more. While each of those verbs performs a distinct action they all have a common design. All verbs...

- ...have as their first argument a data frame:

All verbs *operate on data frames only*. This is one of the helpful restrictions of the tidyverse because you don’t need to consider data structures beyond the tabular form of a data frame. If your data does not come in a data frame, it needs to be converted.

```
# this fails because "WorldPhones" is a matrix and not a data frame
select(WorldPhones, 3)
```

```
## Error in UseMethod("select_"): no applicable method for 'select_' applied to an object of class "c('r'
```

```
# converting World Phones to a data frame resolves the issue
select(as.data.frame(WorldPhones), 3)

##      Asia
## 1951 2876
## 1956 4708
## 1957 5230
## 1958 6662
## 1959 6856
## 1960 8220
## 1961 9053
```

The data frame to operate on is always the first argument in any of the *verb* functions. Here we `select()` the first variable of the data frame `hmd_counts`.

```
# hmd_counts
# Deaths and exposures by age, year, sex and country
# source: Human Mortality Database
load('data/hmd/hmd_counts.RData')

select(hmd_counts, 1)

## # A tibble: 1,304,694 x 1
##   country
##   <chr>
## 1 AUS
## 2 AUS
## 3 AUS
## 4 AUS
## 5 AUS
## # ... with 1.305e+06 more rows
```

Due to the data frame always coming first we can use the `%>%` (pipe) operator to pass data into any of the verbs.

```
hmd_counts %>% select(1)

## # A tibble: 1,304,694 x 1
##   country
##   <chr>
## 1 AUS
## 2 AUS
## 3 AUS
## 4 AUS
## 5 AUS
## # ... with 1.305e+06 more rows
```

- ...don't change the data frame unless you explicitly want to

Note that none of the verbs permanently change the content of a data frame. You need to assign the output of a verb to an object in order to permanently store your computations.

```
# display the result of rename() without changing the data
rename(hmd_counts, deaths = nDx, exposures = nEx)

## # A tibble: 1,304,694 x 7
##   country sex    period    age    nx deaths exposures
##   <chr>   <chr>   <int> <int> <int>  <dbl>     <dbl>
```

```

## 1 AUS   Female  1921    0    1 3842.  64052.
## 2 AUS   Female  1921    1    1  719.  59619.
## 3 AUS   Female  1921    2    1  330.  57126.
## 4 AUS   Female  1921    3    1  166.  57484.
## 5 AUS   Female  1921    4    1  190.  58407.
## # ... with 1.305e+06 more rows
hmd_counts

## # A tibble: 1,304,694 x 7
##   country sex   period  age   nx   nDx   nEx
##   <chr>   <chr>   <int> <int> <dbl> <dbl>
## 1 AUS     Female  1921    0    1 3842.  64052.
## 2 AUS     Female  1921    1    1  719.  59619.
## 3 AUS     Female  1921    2    1  330.  57126.
## 4 AUS     Female  1921    3    1  166.  57484.
## 5 AUS     Female  1921    4    1  190.  58407.
## # ... with 1.305e+06 more rows

# permanently store the results of rename() in a new object called `hmd_counts_new`
hmd_counts_new <- rename(hmd_counts, deaths = nDx, exposures = nEx)
hmd_counts_new

```

```

## # A tibble: 1,304,694 x 7
##   country sex   period  age   nx   deaths   exposures
##   <chr>   <chr>   <int> <int> <dbl>      <dbl>
## 1 AUS     Female  1921    0    1  3842.    64052.
## 2 AUS     Female  1921    1    1  719.    59619.
## 3 AUS     Female  1921    2    1  330.    57126.
## 4 AUS     Female  1921    3    1  166.    57484.
## 5 AUS     Female  1921    4    1  190.    58407.
## # ... with 1.305e+06 more rows

```

- ...let you address columns within the data frame by simply typing the name

The tidyverse functions always work within the context of a data frame – specified as first argument – and columns within that data frame can be addressed by simply typing their name (without quotes).

```
# this returns life-tables entries for Australia, 1921 ages 20 to 25
filter(hmd_counts, country == 'AUS', period == 1921, age %in% 20:25)
```

```

## # A tibble: 18 x 7
##   country sex   period  age   nx   nDx   nEx
##   <chr>   <chr>   <int> <int> <dbl> <dbl>
## 1 AUS     Female  1921    20    1  138.  46387.
## 2 AUS     Female  1921    21    1  118.  46437.
## 3 AUS     Female  1921    22    1  116.  45769.
## 4 AUS     Female  1921    23    1  149.  45746.
## 5 AUS     Female  1921    24    1  146.  46524.
## # ... with 13 more rows

# this is the same, but much more cumbersome to write and read
hmd_counts[hmd_counts$country == 'AUS' &
            hmd_counts$period == 1921 &
            hmd_counts$age %in% 20:25,]
```

```

## # A tibble: 18 x 7
##   country sex   period  age   nx   nDx   nEx
```

```
##   <chr>   <chr>   <int> <int> <dbl>   <dbl>
## 1 AUS    Female   1921     20     1  138. 46387.
## 2 AUS    Female   1921     21     1  118. 46437.
## 3 AUS    Female   1921     22     1  116. 45769.
## 4 AUS    Female   1921     23     1  149. 45746.
## 5 AUS    Female   1921     24     1  146. 46524.
## # ... with 13 more rows
• ...output a data frame
```

3.2.1 Column based transforms

3.2.1.1 `mutate()` columns

`mutate()` adds a column to a data frame or changes an existing column.

```
hmd_counts %>%
  # calculate new column with death rates from
  # columns nDx and nEx
  mutate(nmx = nDx/nEx)

## # A tibble: 1,304,694 x 8
##   country sex    period   age     nx    nDx    nEx    nmx
##   <chr>   <chr>   <int> <int> <dbl>   <dbl>   <dbl>
## 1 AUS    Female   1921     0     1 3842. 64052. 0.0600
## 2 AUS    Female   1921     1     1 719. 59619. 0.0121
## 3 AUS    Female   1921     2     1 330. 57126. 0.00578
## 4 AUS    Female   1921     3     1 166. 57484. 0.00289
## 5 AUS    Female   1921     4     1 190. 58407. 0.00325
## # ... with 1.305e+06 more rows

hmd_counts %>%
  # change unit of exposure variable from person-years
  # to person months
  mutate(nEx = nEx*12)
```

```
## # A tibble: 1,304,694 x 7
##   country sex    period   age     nx    nDx    nEx
##   <chr>   <chr>   <int> <int> <dbl>   <dbl>
## 1 AUS    Female   1921     0     1 3842. 768626.
## 2 AUS    Female   1921     1     1 719. 715431.
## 3 AUS    Female   1921     2     1 330. 685512.
## 4 AUS    Female   1921     3     1 166. 689806.
## 5 AUS    Female   1921     4     1 190. 700884.
## # ... with 1.305e+06 more rows
```

Within a single `mutate()` statement multiple new variables can be created.

```
hmd_counts %>%
  mutate(
    # add discrete age variable
    age_group = cut(age, seq(0, 90, 10), include.lowest = TRUE),
    # add mortality rate
    nmx = nDx/nEx
  )

## # A tibble: 1,304,694 x 9
```

```
##   country sex   period   age   nx   nDx   nEx age_group      nmrx
##   <chr>   <chr>   <int> <int> <dbl> <dbl> <fct>      <dbl>
## 1 AUS     Female  1921     0     1 3842. 64052. [0,10]    0.0600
## 2 AUS     Female  1921     1     1 719. 59619. [0,10]    0.0121
## 3 AUS     Female  1921     2     1 330. 57126. [0,10]    0.00578
## 4 AUS     Female  1921     3     1 166. 57484. [0,10]    0.00289
## 5 AUS     Female  1921     4     1 190. 58407. [0,10]    0.00325
## # ... with 1.305e+06 more rows
```

Newly created variables can immediately be used in the creation of additional variables.

```
hmd_counts %>%
  mutate(
    nmrx = nDx/nEx,
    # convert death rates to death probability
    nqx = 1-exp(-nmrx),
    # and survival probability
    npx = 1-nqx
  )

## # A tibble: 1,304,694 x 10
##   country sex   period   age   nx   nDx   nEx      nmrx      nqx      npx
##   <chr>   <chr>   <int> <int> <dbl> <dbl> <dbl>      <dbl>      <dbl>      <dbl>
## 1 AUS     Female  1921     0     1 3842. 64052. 0.0600  0.0582  0.942
## 2 AUS     Female  1921     1     1 719. 59619. 0.0121  0.0120  0.988
## 3 AUS     Female  1921     2     1 330. 57126. 0.00578 0.00576 0.994
## 4 AUS     Female  1921     3     1 166. 57484. 0.00289 0.00288 0.997
## 5 AUS     Female  1921     4     1 190. 58407. 0.00325 0.00325 0.997
## # ... with 1.305e+06 more rows
```

3.2.1.2 select() columns

Using `select()` we can specify which columns to keep and which columns to delete from a data frame. Let's have a look at a typical panel data set: The General Social Survey. We can see that the `gss` data features 960 columns.

```
# General social survey
# source: http://gss.norc.org/s
gss <- haven::read_stata('data/gss/GSS2016.DTA')
gss

## # A tibble: 2,867 x 960
##   mar1   mar2   mar3   mar4   mar5   mar6   mar7   mar8   mar9   mar10  mar11  mar12
##   <dbl+> <dbl> <dbl>
## 1 1     1     5     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 2 4     <NA> <NA>
## 3 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 4 1     1     5     4     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 5 1     1     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## # ... with 2,862 more rows, and 948 more variables: mar13 <dbl+lbl>,
## #   mar14 <dbl+lbl>, abany <dbl+lbl>, abdefect <dbl+lbl>,
## #   abhlth <dbl+lbl>, ...
```

Here we just select the two columns named `id` and `age`.

```
gss %>% select(id, age)

## # A tibble: 2,867 x 2
##       id   age
##   <dbl> <dbl+lbl>
## 1     1    47
## 2     2    61
## 3     3    72
## 4     4    43
## 5     5    55
## # ... with 2,862 more rows
```

We can also select by column position.

```
gss %>% select(312, 28)
```

```
## # A tibble: 2,867 x 2
##       id   age
##   <dbl> <dbl+lbl>
## 1     1    47
## 2     2    61
## 3     3    72
## 4     4    43
## 5     5    55
## # ... with 2,862 more rows
```

The column operator : selects a range of columns. We can use it to select all variables from `mar1` to `mar14`, the marriage status of up to 14 persons in a household.

```
gss %>% select(mar1:mar14)
```

```
## # A tibble: 2,867 x 14
##   mar1  mar2  mar3  mar4  mar5  mar6  mar7  mar8  mar9  mar10  mar11  mar12
##   <dbl+> <dbl> <dbl>
## 1 1     1     5     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 2 4     <NA> <NA>
## 3 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 4 1     1     5     4     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 5 1     1     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## # ... with 2,862 more rows, and 2 more variables: mar13 <dbl+lbl>,
## #   mar14 <dbl+lbl>
```

Again, the same is possible by specifying the column position, in this case the first 14 columns.

```
gss %>% select(1:14)
```

```
## # A tibble: 2,867 x 14
##   mar1  mar2  mar3  mar4  mar5  mar6  mar7  mar8  mar9  mar10  mar11  mar12
##   <dbl+> <dbl> <dbl>
## 1 1     1     5     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 2 4     <NA> <NA>
## 3 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 4 1     1     5     4     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 5 1     1     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## # ... with 2,862 more rows, and 2 more variables: mar13 <dbl+lbl>,
## #   mar14 <dbl+lbl>
```

A minus preceding a selection returns all columns *apart* from those specified. Notice that a selection of

columns like `mar1:mar14` must be surrounded by parentheses in order to be removed.

```
# select everything apart from mar1
gss %>% select(-mar1)

## # A tibble: 2,867 x 959
##   mar2  mar3  mar4  mar5  mar6  mar7  mar8  mar9  mar10 mar11 mar12 mar13
##   <dbl+> <dbl+> <dbl+> <dbl+> <dbl+> <dbl+> <dbl+> <dbl+> <dbl+> <dbl+>
## 1 1      5      5     <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>
## 2 <NA>  <NA>
## 3 1      <NA>  <NA>
## 4 1      5      4      5     <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>
## 5 1      5      <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>
## # ... with 2,862 more rows, and 947 more variables: mar14 <dbl+lbl>,
## #   abany <dbl+lbl>, abdefect <dbl+lbl>, abhlth <dbl+lbl>,
## #   abnomore <dbl+lbl>, ...
# select everything apart from mar1 to mar14
gss %>% select(-(mar1:mar14))

## # A tibble: 2,867 x 946
##   abany  abdefect abhlth abnomore abpoor abrape absingle acqntsex adforjob
##   <dbl+> <dbl+lb> <dbl+> <dbl+lb> <dbl+> <dbl+> <dbl+lb> <dbl+lb> <dbl+lb>
## 1 1      1      1      1      1      1      1      <NA>  <NA>
## 2 <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  <NA>  2      <NA>
## 3 2      2      1      2      2      1      2      <NA>  <NA>
## 4 2      2      1      2      2      1      2      <NA>  <NA>
## 5 1      1      1      1      1      1      1      <NA>  <NA>
## # ... with 2,862 more rows, and 937 more variables: adults <dbl+lbl>,
## #   advfront <dbl+lbl>, advsched <dbl+lbl>, affrmact <dbl+lbl>,
## #   age <dbl+lbl>, ...
```

You can use functions inside of `select()` as long as they return either a column name or a column position. The standard R function `which()` is handy in that context as it returns the index of the elements for which a conditions holds true.

```
# return all columns of gss which names are 3 characters or less
gss %>% select(which(str_length(names(.)) <= 3))
```

```
## # A tibble: 2,867 x 6
##   age      god      id jew      sex      tax
##   <dbl+lbl> <dbl+lbl> <dbl> <dbl+lbl> <dbl+lbl> <dbl+lbl>
## 1 47      2      1 <NA>    1      2
## 2 61      <NA>    2 <NA>    1      <NA>
## 3 72      6      3 <NA>    1      1
## 4 43      6      4 <NA>    2      1
## 5 55      1      5 <NA>    2      1
## # ... with 2,862 more rows
```

There are a number of functions provided by the `tidyverse` which are designed to help with column selection.

```
# select all columns where name starts with 'age'
gss %>% select(starts_with('age'))

## # A tibble: 2,867 x 6
##   age      age3      aged      agedchld agedpar  agekdbrn
##   <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl>
## 1 47      <NA>    <NA>    <NA>      3      29
```

```

## # ... with 2,862 more rows
# select columns named mar1, mar2, mar3, mar4, mar5
gss %>% select(num_range('mar', 1:5))

## # A tibble: 2,867 x 5
##   mar1     mar2     mar3     mar4     mar5
##   <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl>
## 1 1         1         5         5         <NA>
## 2 4         <NA>     <NA>     <NA>     <NA>
## 3 1         1         <NA>     <NA>     <NA>
## 4 1         1         5         4         5
## 5 1         1         5         <NA>     <NA>
## # ... with 2,862 more rows
# select all columns where name contains 'sex'
gss %>% select(contains('sex'))

## # A tibble: 2,867 x 17
##   acqntsex frndsex homosex intsex  matesex othersex paidsex pikupsex
##   <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl>
## 1 <NA>     <NA>     4         2         <NA>     <NA>     <NA>     <NA>
## 2 2         1         <NA>     2         2         2         2         2
## 3 <NA>     <NA>     4         2         1         <NA>     <NA>     <NA>
## 4 <NA>     <NA>     4         2         <NA>     <NA>     <NA>     <NA>
## 5 <NA>     <NA>     4         2         1         <NA>     <NA>     <NA>
## # ... with 2,862 more rows, and 9 more variables: relatsex <dbl+lbl>,
## #   sex <dbl+lbl>, sexeduc <dbl+lbl>, sexfreq <dbl+lbl>,
## #   sexornt <dbl+lbl>, ...

```

You can also use regular expressions when selecting columns.

```

# select columns where the name contains a number
gss %>% select(matches('[0-9]'))

## # A tibble: 2,867 x 323
##   mar1    mar2    mar3    mar4    mar5    mar6    mar7    mar8    mar9    mar10   mar11   mar12
##   <dbl+> <dbl> <dbl>
## 1 1      1      5      5      <NA>     <NA>     <NA>     <NA>     <NA>     <NA>     <NA>
## 2 4      <NA>   <NA>
## 3 1      1      <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>
## 4 1      1      5      4      5      <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>
## 5 1      1      5      <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>   <NA>
## # ... with 2,862 more rows, and 311 more variables: mar13 <dbl+lbl>,
## #   mar14 <dbl+lbl>, age3 <dbl+lbl>, artatt1 <dbl+lbl>, artatt2 <dbl+lbl>,
## #   ...

```

`select()` returns the columns in the order it selects them. It can therefore be used to reorder the columns of a data frame.

```

# reverse the order of the columns
gss %>% select(rev(names(.)))

```

```

## # A tibble: 2,867 x 960

```

```

##   cogradtounder cobarate  coeftotlt cosector  spgradtounder spbarate
##   <dbl+lbl>      <dbl+lbl> <dbl+lbl> <dbl+lbl> <dbl+lbl>      <dbl+lbl>
## 1 <NA>          <NA>      <NA>      <NA>      2          3
## 2 <NA>          <NA>      <NA>      <NA>      <NA>      <NA>
## 3 <NA>          <NA>      <NA>      <NA>      <NA>      <NA>
## 4 <NA>          <NA>      <NA>      <NA>      <NA>      <NA>
## 5 <NA>          <NA>      <NA>      <NA>      1          1
## # ... with 2,862 more rows, and 954 more variables: speftotlt <dbl+lbl>,
## #   spsector <dbl+lbl>, gradtounder <dbl+lbl>, barate <dbl+lbl>,
## #   eftotlt <dbl+lbl>, ...
# reorder the columns in reverse alphabetical order
gss %>% select(order(names(.), decreasing = TRUE))

## # A tibble: 2,867 x 960
##   zodiac year xnrcsiz xmovie xmarsex xhaustn wwwmin wwwhr wtssnr wtssall
##   <dbl+> <dbl> <dbl+lb> <dbl+> <dbl+l> <dbl+l> <dbl+> <dbl> <dbl+> <dbl+l>
## 1 11     2016 6       <NA>    2       <NA>    0       15     1.260~ 0.9569~
## 2 8      2016 6       2       <NA>    <NA>    0       5      0.630~ 0.4784~
## 3 12    2016 6       2       1       <NA>    <NA>    <NA>  1.260~ 0.9569~
## 4 4      2016 6       <NA>    1       <NA>    0       7      2.520~ 1.9139~
## 5 8      2016 6       2       1       3       <NA>    <NA>  1.890~ 1.4354~
## # ... with 2,862 more rows, and 950 more variables: wtss <dbl+lbl>,
## #   wrkwayup <dbl+lbl>, wrkstat <dbl+lbl>, wrkslf <dbl+lbl>,
## #   wrkshift <dbl+lbl>, ...
# reorder the columns in increasing length of their names
gss %>% select(order(str_length(names(.)))))

## # A tibble: 2,867 x 960
##   id age   god   jew   sex   tax   mar1  mar2  mar3  mar4  mar5  mar6
##   <dbl> <dbl+> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1 1 47    2     <NA>  1     2     1     1     5     5     <NA>  <NA>
## 2 2 61    <NA> <NA>  1     <NA>  4     <NA> <NA>  <NA>  <NA>  <NA>
## 3 3 72    6     <NA>  1     1     1     1     <NA> <NA>  <NA>  <NA>
## 4 4 43    6     <NA>  2     1     1     1     5     4     5     5
## 5 5 55    1     <NA>  2     1     1     1     5     <NA>  <NA>  <NA>
## # ... with 2,862 more rows, and 948 more variables: mar7 <dbl+lbl>,
## #   mar8 <dbl+lbl>, mar9 <dbl+lbl>, age3 <dbl+lbl>, aged <dbl+lbl>, ...
# reorder the columns randomly
gss %>% select(sample(ncol(.)))

## # A tibble: 2,867 x 960
##   stress nateduc cesd5  vine   spsei10 whydisc5 maisco08 contv prideorg
##   <dbl+1> <dbl+lb> <dbl+> <dbl+> <dbl+lb> <dbl+lb> <dbl+lb> <dbl> <dbl+lb>
## 1 <NA>    2       <NA>  <NA>  75.6    <NA>    <NA>    <NA>  <NA>
## 2 <NA>    1       <NA>  2     <NA>    <NA>  5223    3     <NA>
## 3 <NA>    1       1     2     43.1    <NA>    <NA>    2     <NA>
## 4 <NA>    1       <NA>  <NA>  46      <NA>  5321    <NA>  <NA>
## 5 4      <NA>    2     2     70.5    <NA>  3343    2     2
## # ... with 2,862 more rows, and 951 more variables: scibnfts <dbl+lbl>,
## #   wordg <dbl+lbl>, relate6 <dbl+lbl>, region <dbl+lbl>,
## #   spkath <dbl+lbl>, ...

```

Selected columns can be renamed.

```
gss %>% select(ID = id, EDUCATION = educ)

## # A tibble: 2,867 x 2
##   ID    EDUCATION
##   <dbl> <dbl+lbl>
## 1 1     16
## 2 2     12
## 3 3     16
## 4 4     12
## 5 5     18
## # ... with 2,862 more rows
```

3.2.1.3 `rename()` columns

There's not much to `rename()`. We use it to change the names of the columns in a dataframe. Unlike `select()`, which can also change names, `rename()` keeps all columns. We write `new_column_name = old_column_name`.

```
hmd_counts %>% rename(Age = age, Exposure = nEx, Deaths = nDx)
```

```
## # A tibble: 1,304,694 x 7
##   country sex    period  Age    nx Deaths Exposure
##   <chr>   <chr>   <int> <int> <int> <dbl>    <dbl>
## 1 AUS     Female  1921    0     1  3842.  64052.
## 2 AUS     Female  1921    1     1   719.  59619.
## 3 AUS     Female  1921    2     1   330.  57126.
## 4 AUS     Female  1921    3     1   166.  57484.
## 5 AUS     Female  1921    4     1   190.  58407.
## # ... with 1.305e+06 more rows
```

If we want to use spaces in the column names (not recommended though) we have to surround the new name with ‘backticks’.

```
hmd_counts %>% rename(`Person-years exposure` = nEx, `Number of deaths` = nDx)
```

```
## # A tibble: 1,304,694 x 7
##   country sex    period  age    nx `Number of deaths` `Person-years expo~
##   <chr>   <chr>   <int> <int> <int>           <dbl>           <dbl>
## 1 AUS     Female  1921    0     1        3842.        64052.
## 2 AUS     Female  1921    1     1        719.        59619.
## 3 AUS     Female  1921    2     1        330.        57126.
## 4 AUS     Female  1921    3     1        166.        57484.
## 5 AUS     Female  1921    4     1        190.        58407.
## # ... with 1.305e+06 more rows
```

3.2.2 Row based transforms

3.2.2.1 `filter()` rows

You can create subsets of the rows in your data using `filter()`.

```
# euro_regio
# European regional population statistics
load('data/euro_regio/euro_regio.Rdata')
```

```
# return rows of `euro_regio` where year is equal to 2016
euro_regio %>% filter(year == 2016)

## # A tibble: 342 x 21
##   country_code country_name nuts2_code nuts2_name     year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>    <dbl>  <dbl>
## 1 AL          Albania    AL01       Veri       2016  848059    NA
## 2 AL          Albania    AL02       Qender    2016 1110562    NA
## 3 AL          Albania    AL03       Jug       2016  927405    NA
## 4 AL          Albania    ALXX       ALXX Not reg~ 2016      NA    NA
## 5 AT          Austria    AT11       Burgenland (~ 2016 291011   77.1
## # ... with 337 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## #   ...
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

In `filter()` you specify logical tests which are evaluated for each row. If the condition evaluates to TRUE for a row, the row is returned, if it evaluates to FALSE the row is not returned. A row is also not returned if the condition evaluates to NA.

Multiple filtering conditions are separated by a comma. The comma acts as a logical “AND”, i.e. the `&` operator, which only returns TRUE if *all* the conditions are TRUE.

```
# return rows where year is equal to 2016 and region is Catalonia
euro_regio %>% filter(year == 2016, nuts2_code == 'ES51')
```

```
## # A tibble: 1 x 21
##   country_code country_name nuts2_code nuts2_name     year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>    <dbl>  <dbl>
## 1 ES          Spain      ES51       Cataluña    2016 7408290   232.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
## this is the same as above
euro_regio %>% filter(year == 2016 & nuts2_code == 'ES51')
```

```
## # A tibble: 1 x 21
##   country_code country_name nuts2_code nuts2_name     year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>    <dbl>  <dbl>
## 1 ES          Spain      ES51       Cataluña    2016 7408290   232.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

All of R’s logical operators can be used in `filter()` as well. You use `<`, `>`, `>=`, `<=` for magnitude comparisons.

```
# is 1,2,3,4 larger than 1?
1:4 > 1
```

```
## [1] FALSE  TRUE  TRUE  TRUE

# return all rows where unemployment is higher than 30%
euro_regio %>% filter(unemp > 30)
```

```
## # A tibble: 27 x 21
##   country_code country_name nuts2_code nuts2_name     year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>    <dbl>  <dbl>
## 1 EL          Greece     EL52       Kentriki Make~ 2013 1.91e6   99.6
## 2 EL          Greece     EL53       Dytiki Makedo~ 2013 2.81e5   29.6
## 3 EL          Greece     EL53       Dytiki Makedo~ 2015 2.76e5   29.1
```

```

## 4 EL          Greece      EL53      Dytiki Makedo-  2016 2.74e5 29.5
## 5 ES          Spain       ES43      Extremadura   2012 1.10e6 27.1
## # ... with 22 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## # ...
## # is 1,2,3,4 smaller than 1?
1:4 < 1

## [1] FALSE FALSE FALSE FALSE

# return all rows where net-migration rate is lower than -20%
euro_regio %>% filter(netmigrate < -20)

## # A tibble: 13 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>   <dbl>   <dbl>
## 1 LT          Lithuania   LT00       Lietuva (NUTS~ 2010 3.14e6 49.4
## 2 TR          Turkey      TR33       Manisa, Afyon~ 2011 3.01e6 66.5
## 3 TR          Turkey      TR81       Zonguldak, Ka~ 2011 1.04e6 108.
## 4 TR          Turkey      TRA1       Erzurum, Erzi~ 2013 1.07e6 26.2
## 5 TR          Turkey      TRA2       Agri, Kars, I~ 2009 1.14e6 37.9
## # ... with 8 more rows, and 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
## # is 1,2,3,4 smaller or equal to 1?
1:4 <= 1

## [1] TRUE FALSE FALSE FALSE

# return all rows where life-expectancy is 75 years or less
euro_regio %>% filter(lifeexp <= 75)

## # A tibble: 274 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>   <dbl>   <dbl>
## 1 BG          Bulgaria   BG31       Severozapaden 2005     NA 49.5
## 2 BG          Bulgaria   BG31       Severozapaden 2006 934755 48.5
## 3 BG          Bulgaria   BG31       Severozapaden 2007 916308 47.6
## 4 BG          Bulgaria   BG31       Severozapaden 2008 898371 46.7
## 5 BG          Bulgaria   BG31       Severozapaden 2009 881573 45.8
## # ... with 269 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## # ...
## # is 1,2,3,4 greater than or equal to 1?
1:4 >= 1

## [1] TRUE TRUE TRUE TRUE

# return all rows where life-expectancy is 85 years or more
euro_regio %>% filter(lifeexp >= 85)

## # A tibble: 2 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>      <chr>      <chr>      <int>   <dbl>   <dbl>
## 1 CH          Switzerland CH07       Ticino      2016 3.52e5 129.
## 2 ES          Spain       ES30       Comunidad de ~ 2016 6.42e6 809.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,

```

```
## #  natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

Boolean logic is implemented via `&` (and), `|` (or), and `xor()` (exclusive or).

```
# is 1,2,3,4 greater than 1 AND is 1,2,3,4 smaller than 1?
(1:4 > 1) & (1:4 < 1)
```

```
## [1] FALSE FALSE FALSE FALSE
```

```
# return all rows where unempoloyment is higher than 15% and
# netmigration is lower than -15%
euro_regio %>% filter(unemp > 15, netmigrate < -15)
```

```
## # A tibble: 6 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>       <chr>        <chr>      <int>   <dbl>   <dbl>
## 1 CY           Cyprus       CY00         Kypros      2014 8.58e5  92.5
## 2 LT           Lithuania    LT00         Lietuva (NUTS~ 2010 3.14e6  49.4
## 3 LV           Latvia       LV00         Latvija     2009 2.16e6  34.4
## 4 LV           Latvia       LV00         Latvija     2010 2.12e6  33.7
## 5 TR           Turkey       TRB2         Van, Mus, Bit~ 2010 2.01e6  48.5
## # ... with 1 more row, and 14 more variables: births <dbl>, deaths <dbl>,
## #  natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

```
# is 1,2,3,4 greater than 1 OR is 1,2,3,4 smaller than 1?
(1:4 > 1) | (1:4 < 1)
```

```
## [1] FALSE TRUE TRUE TRUE
```

```
# return all rows where unempoloyment is higher than 15% or
# netmigration is lower than -15%
euro_regio %>% filter(unemp > 15 | netmigrate < -15)
```

```
## # A tibble: 462 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>       <chr>        <chr>      <int>   <dbl>   <dbl>
## 1 AL           Albania     AL01         Veri       2014     NA     NA
## 2 AL           Albania     AL03         Jug        2014     NA     NA
## 3 BE           Belgium     BE10         Région de Br~ 2006 1018804  6366.
## 4 BE           Belgium     BE10         Région de Br~ 2007 1031215  6459.
## 5 BE           Belgium     BE10         Région de Br~ 2008 1048491  6575.
```

```
## # ... with 457 more rows, and 14 more variables: births <dbl>,
## #  deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## #  ...
```

```
# is only one of those statements true?
# 1,2,3,4 greater than 1; 1,2,3,4 smaller than 5
xor(1:4 > 1, 1:4 < 5)
```

```
## [1] TRUE FALSE FALSE FALSE
```

```
# return all rows where unempoloyment is higher than 15% or
# netmigration is lower than -15% but not both
euro_regio %>% filter(xor(unemp > 15, netmigrate < -15))
```

```
## # A tibble: 404 x 21
##   country_code country_name nuts2_code nuts2_name      year     pop popdens
##   <chr>        <chr>       <chr>        <chr>      <int>   <dbl>   <dbl>
## 1 BE           Belgium     BE10         Région de Bru~ 2006 1.02e6  6366.
```

```

## 2 BE           Belgium    BE10     Région de Bru~ 2007 1.03e6 6459.
## 3 BE           Belgium    BE10     Région de Bru~ 2008 1.05e6 6575.
## 4 BE           Belgium    BE10     Région de Bru~ 2009 1.07e6 6702.
## 5 BE           Belgium    BE10     Région de Bru~ 2010 1.09e6 6902
## # ... with 399 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## # ...

```

The `%in%` operator lets you filter rows based on membership `%in%` a set.

```
# is 1,2,3,4 part of the set (2,4)  
1:4 %in% c(2,4)
```

```
## [1] FALSE TRUE FALSE TRUE
```

```
# return all rows for Germany, United Kingdom and France  
euro_regio %>% filter(country_code %in% c('DE', 'UK', 'FR'))
```

```
## # A tibble: 1,404 x 21
##   country_code country_name    nuts2_code nuts2_name year   pop popdens
##   <chr>        <chr>        <chr>      <chr>     <int>   <dbl>   <dbl>
## 1 DE          Germany (until~ DE11    Stuttgart  2005     NA    379.
## 2 DE          Germany (until~ DE11    Stuttgart  2006 4007373  380.
## 3 DE          Germany (until~ DE11    Stuttgart  2007 4005380  380.
## 4 DE          Germany (until~ DE11    Stuttgart  2008 4007095  380.
## 5 DE          Germany (until~ DE11    Stuttgart  2009 4006313  379.
## # ... with 1,399 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## #   ...
```

You can use any combination of functions within `filter()` as long as they return a logical vector as long as the input data frame. This makes it possible to...

```
# ... return the region with the highest population count in 2015
euro_regio %>%
  filter(year == 2015) %>%
  select(-year)
```

```
## # A tibble: 1 x 21
##   country_code country_name nuts2_code nuts2_name   year      pop popdens
##   <chr>        <chr>       <chr>       <chr>     <int>    <dbl>  <dbl>
## 1 TR          Turkey      TR10      Istanbul    2015 14377018  2794.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

```
# ... return the regions with the lowest per head income in 2015, ranks 1 to 3
euro_regio %>%
```

```
## # A tibble: 3 x 21
##   country_code country_name nuts2_code nuts2_name      year    pop popdens
##   <chr>        <chr>       <chr>       <chr>      <int>  <dbl>  <dbl>
## 1 BG          Bulgaria     BG31        Severozapaden 2015 7.97e5   42.5
## 2 BG          Bulgaria     BG42        Yuzhen tsentr~ 2015 1.45e6   66
## 3 FR          France       FRA5        Mayotte (NUTS~ 2015 2.30e5  628.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

```
# ... return the regions with the highest per head income in 2015, ranks 1 to 3
euro_regio %>%
  filter(year == 2015) %>%
  filter(min_rank(desc(income)) <= 3)

## # A tibble: 3 x 21
##   country_code country_name     nuts2_code nuts2_name   year   pop popdens
##   <chr>        <chr>          <chr>      <chr>    <int> <dbl>  <dbl>
## 1 DE          Germany (until ~ DE21      Oberbayern 2015 4.52e6   260.
## 2 LU          Luxembourg       LU00       Luxembourg 2015 5.63e5   220.
## 3 UK          United Kingdom  UKI3       Inner Lon~ 2015 1.13e6  10469.
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
# ... return the regions with the highest absolute net-migration rate in 2015,
# ranks 1 to 3
euro_regio %>%
  filter(year == 2015) %>%
  filter(min_rank(desc(abs(netmigrate))) <= 3)

## # A tibble: 3 x 21
##   country_code country_name     nuts2_code nuts2_name   year   pop popdens
##   <chr>        <chr>          <chr>      <chr>    <int> <dbl>  <dbl>
## 1 DE          Germany (until~ DEB2      Trier      2015 5.22e5   107.
## 2 MT          Malta           MT00       Malta     2015 4.40e5  1408.
## 3 TR          Turkey          TRA2       Agri, Kars~ 2015 1.14e6  37.8
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
# ... return the >99 percentile regions by life expectancy in 2015
euro_regio %>%
  filter(year == 2015) %>%
  filter(cume_dist(lifeexp) >= 0.99)

## # A tibble: 4 x 21
##   country_code country_name     nuts2_code nuts2_name   year   pop popdens
##   <chr>        <chr>          <chr>      <chr>    <int> <dbl>  <dbl>
## 1 ES          Spain           ES22       Comunidad For~ 2015 6.36e5   61.6
## 2 ES          Spain           ES30       Comunidad de ~ 2015 6.39e6   804
## 3 FR          France          FR10       Île de France 2015 1.21e7  1008.
## 4 IT          Italy           ITH2       Provincia Aut~ 2015 5.37e5   86.6
## # ... with 14 more variables: births <dbl>, deaths <dbl>,
## #   natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>, ...
```

Special care has to be taken when filtering NA values. One may be inclined to return all rows including NA in the variable `pop` by writing

```
euro_regio %>% filter(pop == NA)
```

```
## # A tibble: 0 x 21
## # ... with 21 variables: country_code <chr>, country_name <chr>,
## #   nuts2_code <chr>, nuts2_name <chr>, year <int>, ...
```

Zero rows are returned because for R `NA == NA` always returns NA instead of TRUE and `filter()` does not return rows for which a condition evaluates to NA. If we want to test for NA we must use the function `is.na()` which returns TRUE whenever an NA is encountered and FALSE otherwise.

```
euro_regio %>% filter(is.na(pop))

## # A tibble: 683 x 21
##   country_code country_name nuts2_code nuts2_name year   pop popdens
##   <chr>        <chr>      <chr>      <chr>    <int> <dbl>    <dbl>
## 1 AL          Albania     AL01       Veri      2005    NA     NA
## 2 AL          Albania     AL01       Veri      2006    NA     NA
## 3 AL          Albania     AL01       Veri      2007    NA     NA
## 4 AL          Albania     AL01       Veri      2008    NA     NA
## 5 AL          Albania     AL01       Veri      2009    NA     NA
## # ... with 678 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## #   ...
## # ...
```

3.2.2.2 arrange() rows

`arrange()` re-orders the rows of a dataframe according to the values of one or more variables within that dataframe.

```
# eu_timeuse_tot
# European timeuse survey
# source: Eurostat
load('data/eu_timeuse/eu_timeuse_tot.Rdata')

# order data frame by increasing date
eu_timeuse_tot %>% arrange(year)
```

```
## # A tibble: 1,671 x 8
##   country_code country_name  year activity_code activity_name   prtcp_rate
##   <chr>        <chr>      <int> <chr>      <chr>           <dbl>
## 1 BE          Belgium     2000  AC0       Personal care    100
## 2 BE          Belgium     2000  AC01      Sleep          100
## 3 BE          Belgium     2000  AC02      Eating         99.5
## 4 BE          Belgium     2000  AC03      Other and/or u~ 97.6
## 5 BE          Belgium     2000  AC1_TR    Employment, re~ 34.5
## # ... with 1,666 more rows, and 2 more variables: prtcp_time_min <dbl>,
## #   time_spent_min <dbl>
```

If multiple variables are specified, the dataframe is re-ordered in the sequence of specification. This behavior makes it possible to design useful tables, i.e. our `eu_timeuse` data contains the time spent each day on different activities by type of activity, country, and year. Sorting by `activity`, `country` and (at last position) `year` gives a table that allows for quick comparisions along the time axis. Having `country` last would allow for quick comparisions among countries and so on.

```
# order data frame by activity, country and year
eu_timeuse_tot %>% arrange(activity_name, country_name, year)
```

```
## # A tibble: 1,671 x 8
##   country_code country_name  year activity_code activity_name   prtcp_rate
##   <chr>        <chr>      <int> <chr>      <chr>           <dbl>
## 1 AT          Austria     2010  AC1B       Activities rel~    22.6
## 2 BE          Belgium     2000  AC1B       Activities rel~     1.4
## 3 BE          Belgium     2010  AC1B       Activities rel~    12.5
## 4 BG          Bulgaria    2000  AC1B       Activities rel~     7.1
## 5 EE          Estonia     2000  AC1B       Activities rel~    10.9
```

```
## # ... with 1,666 more rows, and 2 more variables: prtcp_time_min <dbl>,
## #   time_spent_min <dbl>
# order data frame by activity, year, and country
eu_timeuse_tot %>% arrange(activity_name, year, country_name)

## # A tibble: 1,671 x 8
##   country_code country_name  year activity_code activity_name  prtcp_rate
##   <chr>        <chr>      <int> <chr>        <chr>           <dbl>
## 1 BE          Belgium     2000 AC1B       Activities    rel~      1.4
## 2 BG          Bulgaria    2000 AC1B       Activities    rel~      7.1
## 3 EE          Estonia     2000 AC1B       Activities    rel~     10.9
## 4 FI          Finland     2000 AC1B       Activities    rel~      7.2
## 5 FR          France      2000 AC1B       Activities    rel~      1.6
## # ... with 1,666 more rows, and 2 more variables: prtcp_time_min <dbl>,
## #   time_spent_min <dbl>
```

By default character variables are ordered in increasing alphabetical order and numeric variables in increasing numerical order. The `desc()` function allows to reverse that behavior.

```
# order data frame by reverse alphabetical activity, and alphabetical country
eu_timeuse_tot %>% arrange(desc(activity_name), country_name)
```

```
## # A tibble: 1,671 x 8
##   country_code country_name  year activity_code activity_name  prtcp_rate
##   <chr>        <chr>      <int> <chr>        <chr>           <dbl>
## 1 AT          Austria     2010 AC344      Walking the dog  6.5
## 2 BE          Belgium     2000 AC344      Walking the dog  7.1
## 3 BE          Belgium     2010 AC344      Walking the dog  8.1
## 4 BG          Bulgaria    2000 AC344      Walking the dog  2.2
## 5 EE          Estonia     2000 AC344      Walking the dog  8.5
## # ... with 1,666 more rows, and 2 more variables: prtcp_time_min <dbl>,
## #   time_spent_min <dbl>
```

3.2.2.3 `slice()` rows

```
#random shuffle
gss %>% slice(sample(1:n()))

## # A tibble: 2,867 x 960
##   mar1  mar2  mar3  mar4  mar5  mar6  mar7  mar8  mar9  mar10  mar11  mar12
##   <dbl+> <dbl> <dbl>
## 1 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 2 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 3 3     <NA> <NA>
## 4 5     5     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## 5 1     1     <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA> <NA>
## # ... with 2,862 more rows, and 948 more variables: mar13 <dbl+lbl>,
## #   mar14 <dbl+lbl>, abany <dbl+lbl>, abdefect <dbl+lbl>,
## #   abhlth <dbl+lbl>, ...
```

3.2.3 Excercise: Basic verbs

- Fix the following code:

```

hmd_counts %>%
  filter(country = 'AUS', age = '0', sex = 'Female') %>%
  mutate(hmd_counts, period_width = diff(period))
#hmd_counts %>%
#  filter(country == 'AUS', age == 0, sex == 'Female') %>%
#  mutate(period_width = c(diff(period), NA))

gss %>% filter(bigbang == NA)
#gss %>% filter(is.na(NA))

```

- Filter `hmd_counts` such that it contains all Swedish life-tables and only life-tables for years 2000+ for countries other than Sweden.
- Why do the results differ?

```

euro_regio %>% filter(year == 2015, rank(-income) <= 3)
euro_regio %>%
  filter(year == 2015) %>%
  filter(rank(-income) <= 3)

```

- With `gss` select
- the first 10 columns
- the last 10 columns
- every 5th column from 1 to 100
- every column where the name does not contain a number
- all columns where the names contain a phrase of your choice

3.3 Pipes

We can chain multiple function and transformations steps into a *data analysis pipeline*. This is a great approach for clear, fast, interactive data analysis.

This is what we need to know in order to build pipelines:

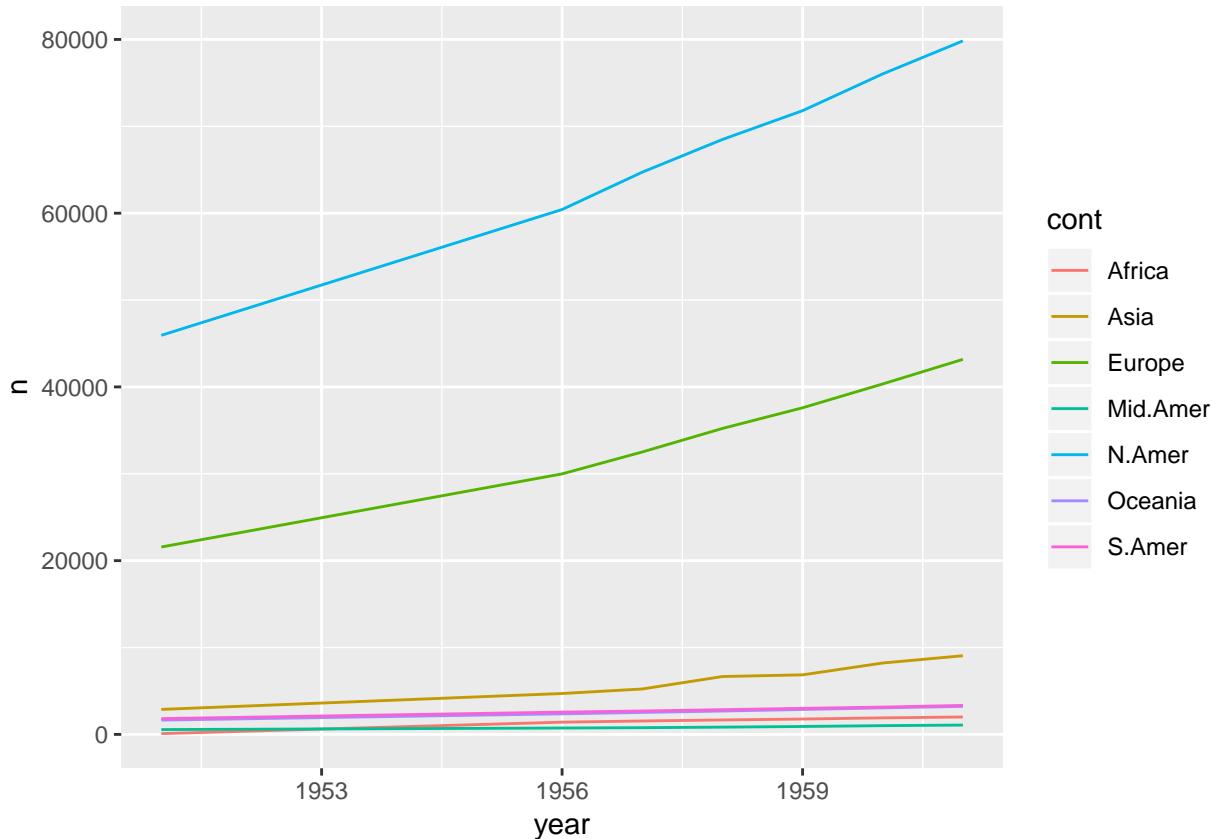
- The object on the left of the pipe operator (`%>%`) is passed onto the first argument of the function on the right
- If we want to use the object on the left in other places than the first argument we can explicitly refer to it by using a dot (`.`)

Here's a pipeline which begins with raw data and ends with a plot after some data transformations steps in between.

```

# the raw data...
WorldPhones %>%
  # ...is converted to a data frame...
  as.data.frame() %>%
  # ...the rownames are added as the column `year`...
  # (note that I use the dot here to explicitly refer to the input data)
  mutate(year = as.integer(rownames(.))) %>%
  # ...the data gets transformed from wide to long format...
  gather(key = cont, value = n, -year) %>%
  # ...and finally plotted
  # (note that I can pipe the tidy data frame directly into ggplot)
  ggplot() +
  geom_line(aes(x = year, y = n, colour = cont))

```



The LHS of the pipe will always be the first argument of the RHS function, with a single exception: When you use the dot variable on its own (non-nested) on the RHS.

3.3.1 Excercise: Pipes

Rewrite the following expressions as pipes:

```
sum(1:100)
```

```
FALSE [1] 5050
```

```
#1:100 %>% sum()
```

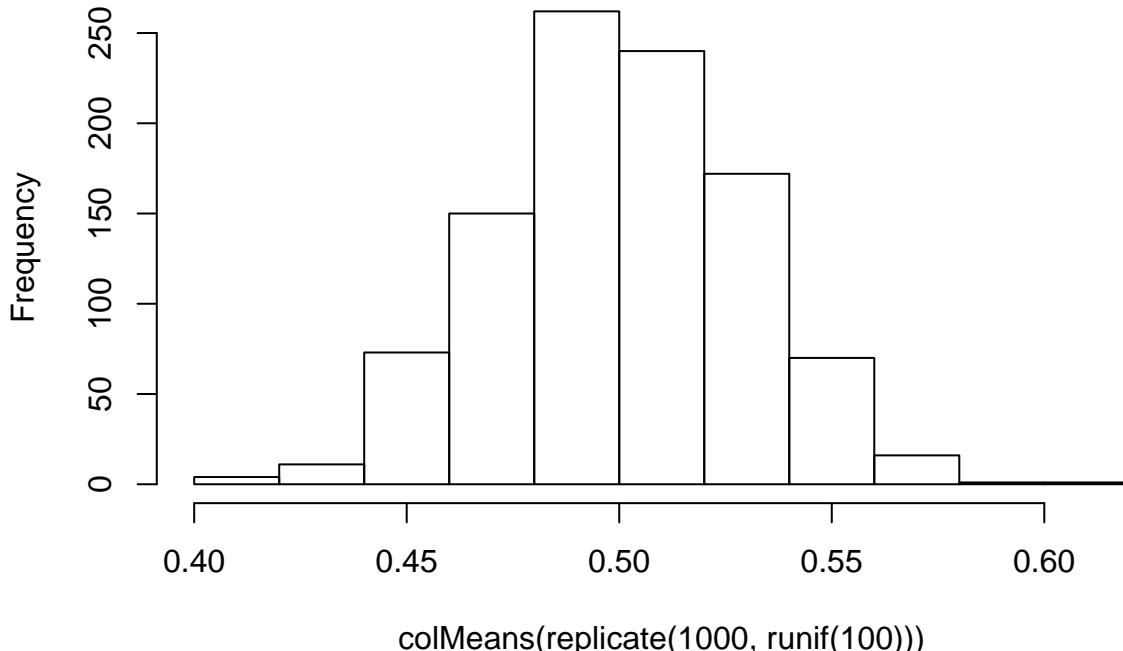
```
sum(cumsum(1:100))
```

```
FALSE [1] 171700
```

```
#1:100 %>% cumsum() %>% sum()
```

```
hist(colMeans(replicate(1000, runif(100))))
```

Histogram of colMeans(replicate(1000, runif(100)))



colMeans(replicate(1000, runif(100)))

```
#replicate(1000, runif(100)) %>% colMeans() %>% hist()
any(is.na(mtcars$cyl))
```

```
FALSE [1] FALSE
#mtcars$cyl %>% is.na() %>% any()

cor.test(~hp+mpg, data = mtcars)

FALSE
FALSE Pearson's product-moment correlation
FALSE
FALSE data: hp and mpg
FALSE t = -6.7424, df = 30, p-value = 1.788e-07
FALSE alternative hypothesis: true correlation is not equal to 0
FALSE 95 percent confidence interval:
FALSE -0.8852686 -0.5860994
FALSE sample estimates:
FALSE       cor
FALSE -0.7761684

#mtcars %>% cor.test(~ hp+mpg, data = .)

cor.test(~hp+mpg, data = mtcars[1:10])
```

```
FALSE
FALSE Pearson's product-moment correlation
FALSE
FALSE data: hp and mpg
FALSE t = -6.7424, df = 30, p-value = 1.788e-07
```

```

FALSE alternative hypothesis: true correlation is not equal to 0
FALSE 95 percent confidence interval:
FALSE -0.8852686 -0.5860994
FALSE sample estimates:
FALSE      cor
FALSE -0.7761684

#mtcars %>% {cor.test(~ hp+mpg, data = .[1:10])}

cor(x = mtcars$mpg, y = mtcars$hp)

FALSE [1] -0.7761684
#mtcars %>% {cor(x = .$mpg, y = .$hp)}

xtabs(~ gear + cyl, data = mtcars, subset = mtcars$gear > 4)

FALSE      cyl
FALSE gear 4 6 8
FALSE      5 2 1 2

#mtcars %>% xtabs(~gear + cyl, data = ., subset = .$gear > 4)

```

3.4 Tidy data

Many programming tasks become easier once the data is in a tidy format. But what is tidy data? Our working definition: **data needs to be a data frame and every variable of interest needs to be a separate column**. Let's explore what that means.

```
head(WorldPhones)
```

```

##      N.Amer Europe Asia S.Amer Oceania Africa Mid.Amer
## 1951  45939 21574 2876   1815   1646    89     555
## 1956  60423 29990 4708   2568   2366   1411    733
## 1957  64721 32510 5230   2695   2526   1546    773
## 1958  68484 35218 6662   2845   2691   1663    836
## 1959  71799 37598 6856   3000   2868   1769    911
## 1960  76036 40341 8220   3145   3054   1905   1008

```

Here's the number of telephone connections over time by continent. The data is not *tidy* because its not a *data frame*, it's a matrix with row and column names. This gives us headaches if we want to use ggplot to plot the data.

```
ggplot(WorldPhones)
```

```
## Error: `data` must be a data frame, or other object coercible by `fortify()`, not a numeric vector
```

We can easily fix this problem by converting the matrix to a data frame.

```
phones <- as.data.frame(WorldPhones)
```

Say we we want to plot the number of telephone connections over time by continent. This implies the following *variables of interest*:

- * the number of telephone connections `n`
- * the continent `cont`
- * the year `year`

Problem is, *none* of these variables are explicitly given in our data frame. Of course the data is all there, just not in a format we can use (with ggplot). So the question is how to reshape the data into a form where all the variables of interest are separate columns in the data frame.

To reshape we are going to use the libraries dplyr and tidyverse. Both are loaded when you load `library(tidyverse)`.

The easiest variable to make explicit is the year. It is given as rownames of the data frame. We take the rownames, convert them from character to integer type, and add them as the variable `year` to the data frame. We use the tidyverse function `mutate()` to add a new variable to a data frame.

```
phones <- mutate(phones, year = as.integer(rownames(phones)))
phones
```

```
##   N.Amer Europe Asia S.Amer Oceania Africa Mid.Amer year
## 1  45939  21574 2876   1815    1646     89      555 1951
## 2  60423  29990 4708   2568    2366    1411      733 1956
## 3  64721  32510 5230   2695    2526    1546      773 1957
## 4  68484  35218 6662   2845    2691    1663      836 1958
## 5  71799  37598 6856   3000    2868    1769      911 1959
## 6  76036  40341 8220   3145    3054    1905     1008 1960
## 7  79831  43173 9053   3338    3224    2005     1076 1961
```

That leaves us with the variables “*number of telephone connections*” and “*continent*” to make explicit. They shall become separate columns in the data frame. With the help of `gather()` we **transform from wide to long format**.

```
phones <- gather(phones, key = cont, value = n, -year)
phones
```

```
##   year     cont     n
## 1 1951 N.Amer 45939
## 2 1956 N.Amer 60423
## 3 1957 N.Amer 64721
## 4 1958 N.Amer 68484
## 5 1959 N.Amer 71799
## 6 1960 N.Amer 76036
## 7 1961 N.Amer 79831
## 8 1951 Europe 21574
## 9 1956 Europe 29990
## 10 1957 Europe 32510
## 11 1958 Europe 35218
## 12 1959 Europe 37598
## 13 1960 Europe 40341
## 14 1961 Europe 43173
## 15 1951     Asia 2876
## 16 1956     Asia 4708
## 17 1957     Asia 5230
## 18 1958     Asia 6662
## 19 1959     Asia 6856
## 20 1960     Asia 8220
## 21 1961     Asia 9053
## 22 1951 S.Amer 1815
## 23 1956 S.Amer 2568
## 24 1957 S.Amer 2695
## 25 1958 S.Amer 2845
## 26 1959 S.Amer 3000
```

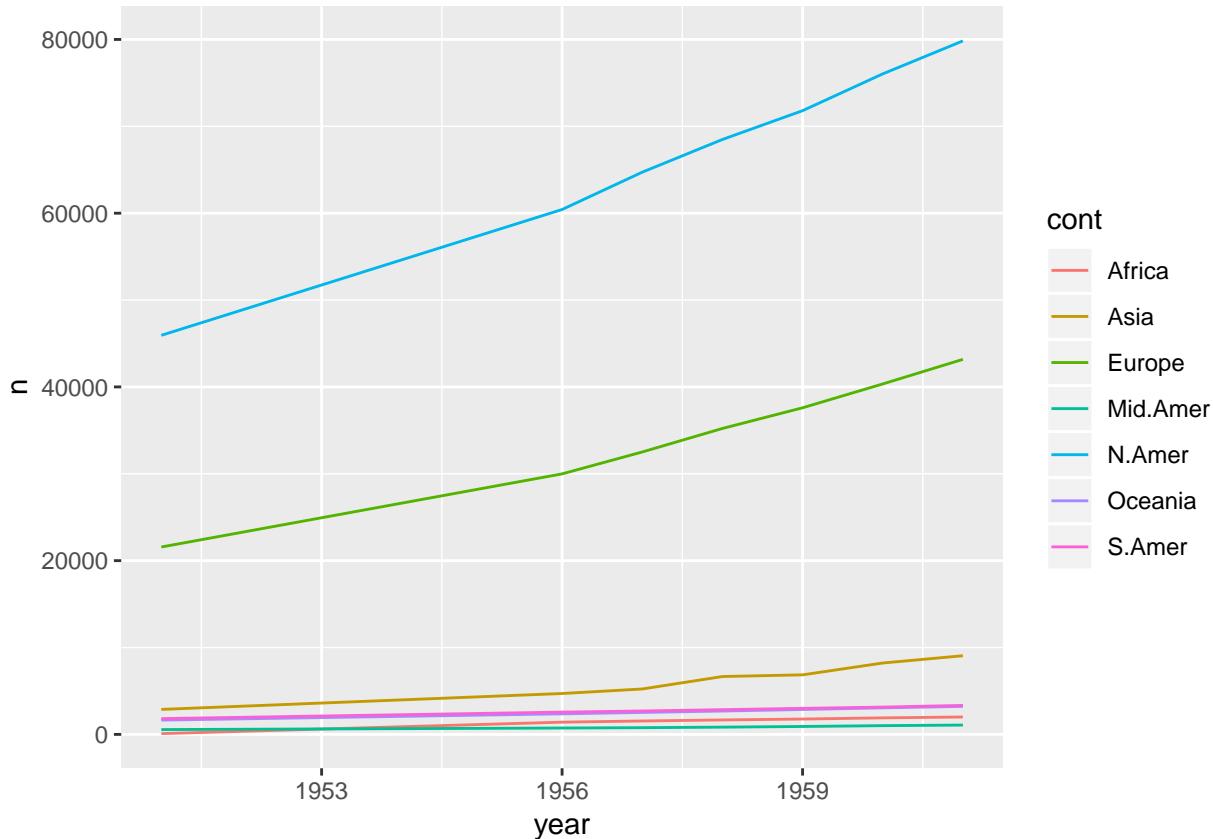
```

## 27 1960   S.Amer  3145
## 28 1961   S.Amer  3338
## 29 1951   Oceania 1646
## 30 1956   Oceania 2366
## 31 1957   Oceania 2526
## 32 1958   Oceania 2691
## 33 1959   Oceania 2868
## 34 1960   Oceania 3054
## 35 1961   Oceania 3224
## 36 1951   Africa   89
## 37 1956   Africa  1411
## 38 1957   Africa  1546
## 39 1958   Africa  1663
## 40 1959   Africa  1769
## 41 1960   Africa  1905
## 42 1961   Africa  2005
## 43 1951   Mid.Amer 555
## 44 1956   Mid.Amer 733
## 45 1957   Mid.Amer 773
## 46 1958   Mid.Amer 836
## 47 1959   Mid.Amer 911
## 48 1960   Mid.Amer 1008
## 49 1961   Mid.Amer 1076

```

We told the computer to look at all columns apart from `year` and transform them into the columns `cont` and `n`. `cont` holds the continent names for the variable `n`, the number of telephone connections. The continent names are taken from the original column names we *gathered* over. We now can plot our data easily.

```
ggplot(phones) +
  geom_line(aes(x = year, y = n, colour = cont))
```



3.4.1 Long versus wide format data

Each table has a *wide format* and a long format representation. The information content is the same in both formats. It's the layout that differs.

Here's a wide format table containing the explicit variables `Female` and `Male`.

```
wide <- data_frame(group = c("a", "b"), Female = 1:2, Male = 3:4)
```

The same table in long format representation containing the explicit variables `Sex` and `N`.

```
long <- gather(wide, key = Sex, value = N, -group)
long
```

```
## # A tibble: 4 x 3
##   group Sex     N
##   <chr> <chr> <int>
## 1 a     Female    1
## 2 b     Female    2
## 3 a     Male      3
## 4 b     Male      4
```

If we want to go back to a wide format we can achieve that by using the function `spread()`.

```
spread(long, key = Sex, value = N)
```

```
## # A tibble: 2 x 3
##   group Female  Male
##   <chr>  <int> <int>
```

```

## 1 a      1      3
## 2 b      2      4

# hmd
# Life tables by year, sex and country
# source: Human Mortality Database
load('data/hmd/hmd.RData')

# common problems: no matching row was found
hmd %>%
  filter(period > 2005, country == 'RUS', age == 0) %>%
  spread(sex, ex) %>%
  select(country, period, age, Female, Male)

## # A tibble: 27 x 5
##   country period  age Female  Male
##   <chr>     <int> <dbl> <dbl>
## 1 RUS       2006    0    73.3    NA
## 2 RUS       2007    0    74.0    NA
## 3 RUS       2008    0    74.2    NA
## 4 RUS       2009    0    74.8    NA
## 5 RUS       2010    0    74.9    NA
## # ... with 22 more rows

# solution
hmd %>%
  filter(period > 2005, country == 'RUS', age == 0) %>%
  select(-(nDx:Tx)) %>%
  spread(sex, ex) %>%
  select(country, period, age, Female, Male)

## # A tibble: 9 x 5
##   country period  age Female  Male
##   <chr>     <int> <dbl> <dbl>
## 1 RUS       2006    0    73.3  60.4
## 2 RUS       2007    0    74.0  61.4
## 3 RUS       2008    0    74.2  61.9
## 4 RUS       2009    0    74.8  62.8
## 5 RUS       2010    0    74.9  63.1
## # ... with 4 more rows

```

3.4.2 Making the implicit explicit

```

# turn implicit NAs into explicit NAs
eu_timeuse_tot %>% skimr::n_missing()

## [1] 17
eu_timeuse_tot %>% complete(activity_code, country_code, year) %>% skimr::n_missing()

## [1] 2862
USArrests %>% rownames_to_column('state')

##           state Murder Assault UrbanPop Rape
## 1 Alabama    13.2     236      58 21.2

```

```

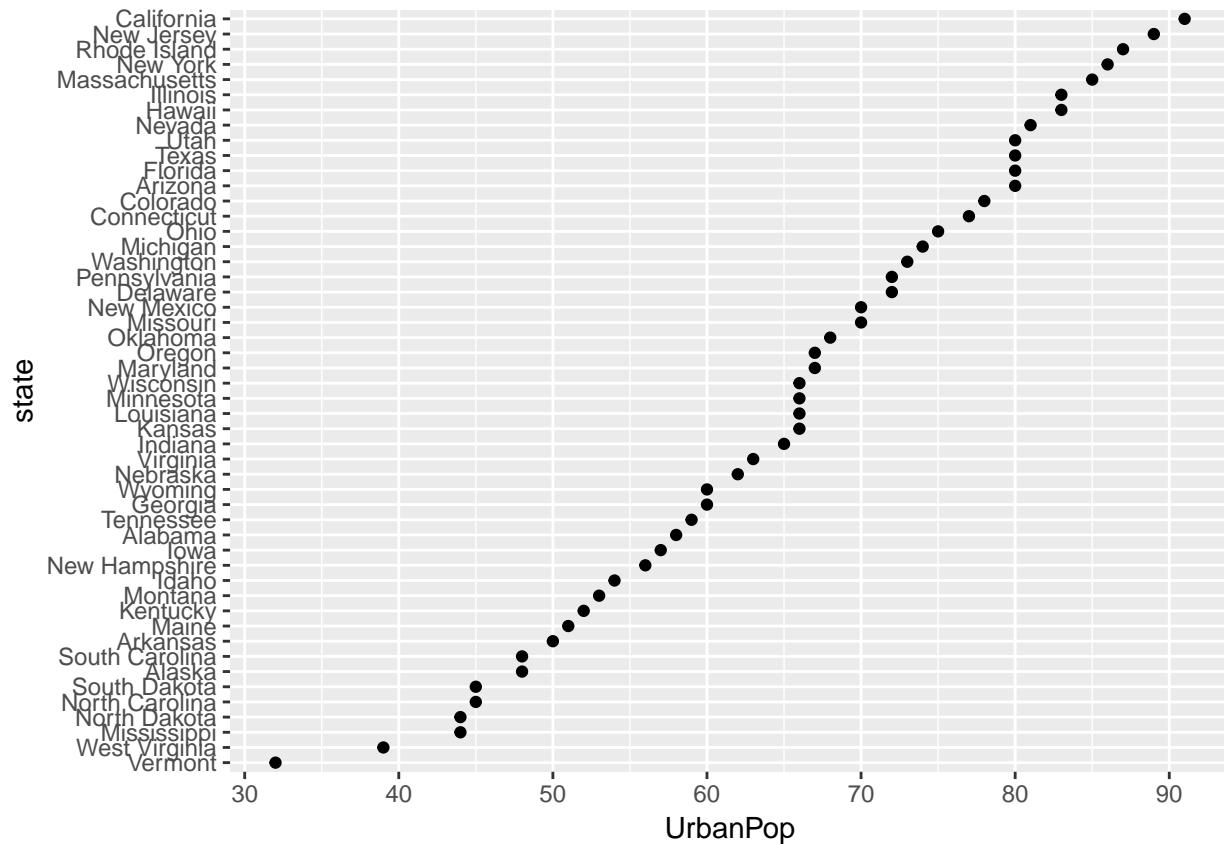
## 2      Alaska  10.0   263   48 44.5
## 3      Arizona  8.1    294   80 31.0
## 4      Arkansas 8.8    190   50 19.5
## 5      California 9.0    276   91 40.6
## 6      Colorado  7.9    204   78 38.7
## 7      Connecticut 3.3    110   77 11.1
## 8      Delaware  5.9    238   72 15.8
## 9      Florida  15.4   335   80 31.9
## 10     Georgia  17.4   211   60 25.8
## 11     Hawaii   5.3    46    83 20.2
## 12     Idaho    2.6    120   54 14.2
## 13     Illinois 10.4   249   83 24.0
## 14     Indiana  7.2    113   65 21.0
## 15     Iowa    2.2    56    57 11.3
## 16     Kansas   6.0    115   66 18.0
## 17     Kentucky 9.7    109   52 16.3
## 18     Louisiana 15.4   249   66 22.2
## 19     Maine   2.1    83    51  7.8
## 20     Maryland 11.3   300   67 27.8
## 21 Massachusetts 4.4    149   85 16.3
## 22     Michigan 12.1   255   74 35.1
## 23     Minnesota 2.7    72    66 14.9
## 24 Mississippi 16.1   259   44 17.1
## 25     Missouri 9.0    178   70 28.2
## 26     Montana  6.0    109   53 16.4
## 27     Nebraska 4.3    102   62 16.5
## 28     Nevada   12.2   252   81 46.0
## 29 New Hampshire 2.1    57    56  9.5
## 30 New Jersey   7.4    159   89 18.8
## 31 New Mexico   11.4   285   70 32.1
## 32 New York    11.1   254   86 26.1
## 33 North Carolina 13.0   337   45 16.1
## 34 North Dakota 0.8    45    44  7.3
## 35 Ohio        7.3    120   75 21.4
## 36 Oklahoma   6.6    151   68 20.0
## 37 Oregon     4.9    159   67 29.3
## 38 Pennsylvania 6.3    106   72 14.9
## 39 Rhode Island 3.4    174   87  8.3
## 40 South Carolina 14.4   279   48 22.5
## 41 South Dakota 3.8    86    45 12.8
## 42 Tennessee  13.2   188   59 26.9
## 43 Texas       12.7   201   80 25.5
## 44 Utah        3.2    120   80 22.9
## 45 Vermont     2.2    48    32 11.2
## 46 Virginia   8.5    156   63 20.7
## 47 Washington  4.0    145   73 26.2
## 48 West Virginia 5.7    81    39  9.3
## 49 Wisconsin  2.6    53    66 10.8
## 50 Wyoming    6.8    161   60 15.6

```

3.4.3 Tidying data on police arrests

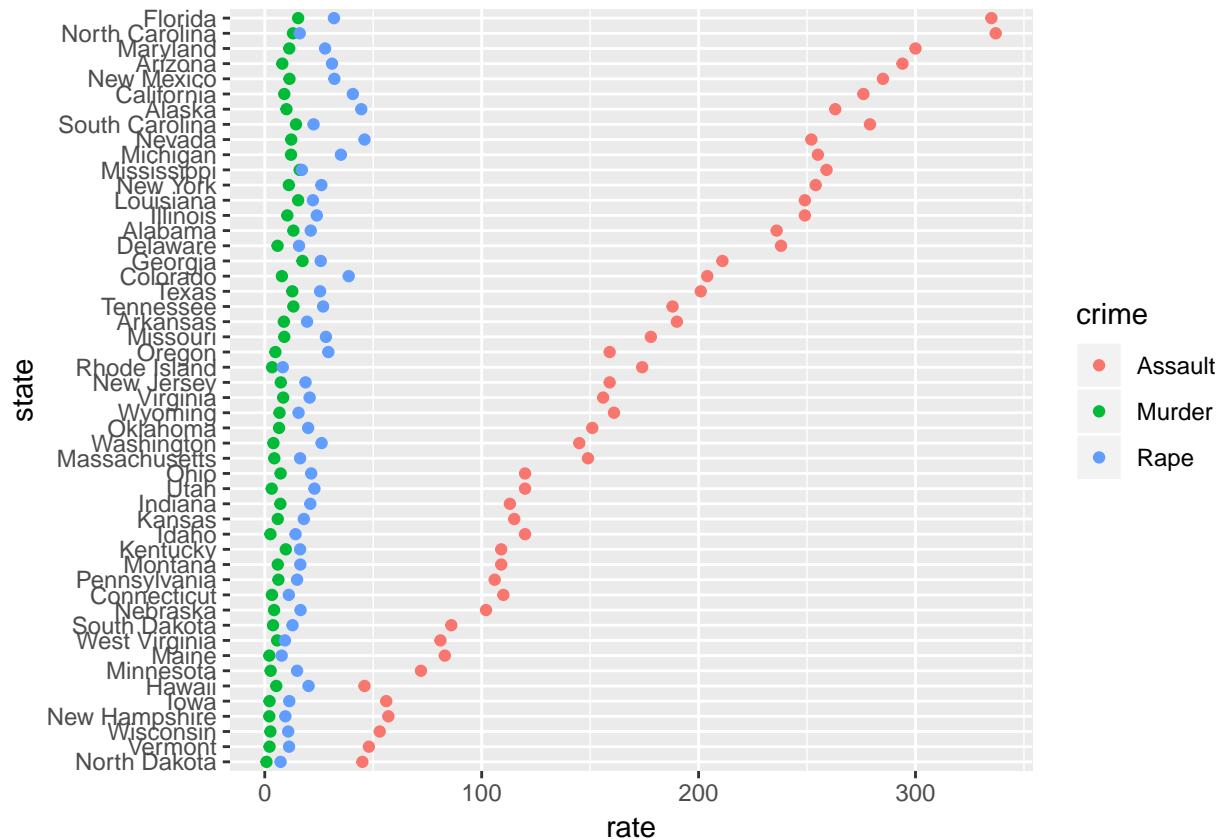
Before we start plotting we need to ask ourselves: *What do we need to do with our data in order to get the plot we want?* Here are some examples.

```
# we start with raw data...
USArrests %>%
  mutate(
    # ...and add the new variable `state` from the rownames...
    state = rownames(.),
    # ...we then reorder the levels of `state` according to the percentage of
    # people living in urban areas...
    state = reorder(state, UrbanPop)) %>%
  # ...and make a dotplot of the percentage of urban population by state...
  ggplot() +
  geom_point(aes(x = UrbanPop, y = state))
```



```
# we start with raw data...
USArrests %>%
  mutate(
    # ...and add the new variable `state` from the rownames...
    state = rownames(.),
    # ...we then reorder the levels of `state` according to the combined
    # murder, assault and crime rates...
    state = reorder(state, Murder+Assault+Rape)) %>%
  # ...we convert to long format, gathering "Assault", "Murder" and "Rape"
  # into "crime"...
  gather(key = crime, value = rate, -state, -UrbanPop) %>%
```

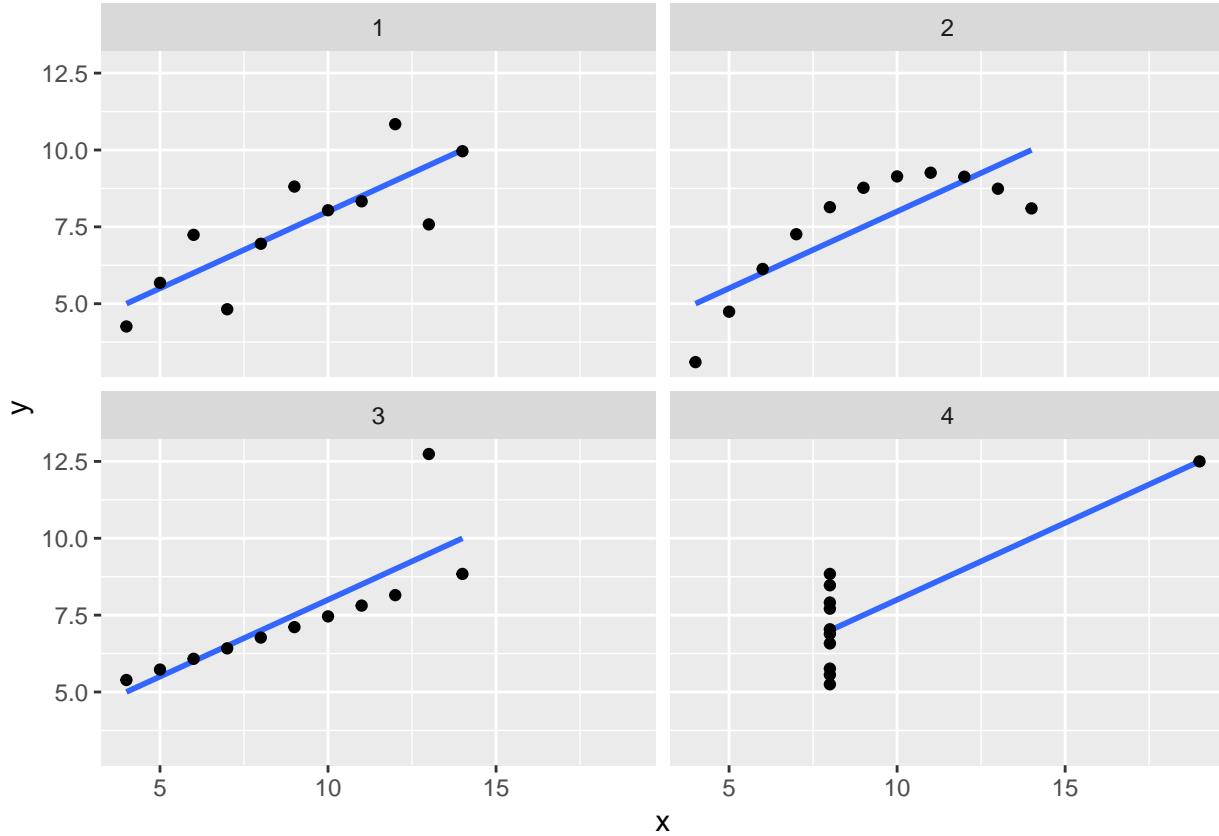
```
# ...and make a dotplot of the crime-rate by crime and state
ggplot() +
  geom_point(aes(x = rate, y = state, colour = crime))
```



3.4.4 Tidying Anscombe's quartet

Can you figure out what happens here? Try running the code yourself line by line.

```
anscombe %>%
  mutate(id = seq_along(x1)) %>%
  gather(... = -id) %>%
  separate(key, sep = 1, into = c("axis", "panel")) %>%
  spread(key = axis, value = value) %>%
  ggplot(aes(x = x, y = y)) +
  geom_smooth(method = "lm", se = FALSE) +
  geom_point() +
  facet_wrap(~panel)
```



3.4.5 Tidying data on test-retest reliability

```
wide <- read_csv("https://raw.githubusercontent.com/jshoeley/idem_viz/master/ggplot_practical/03-tidy_data.csv")
wide

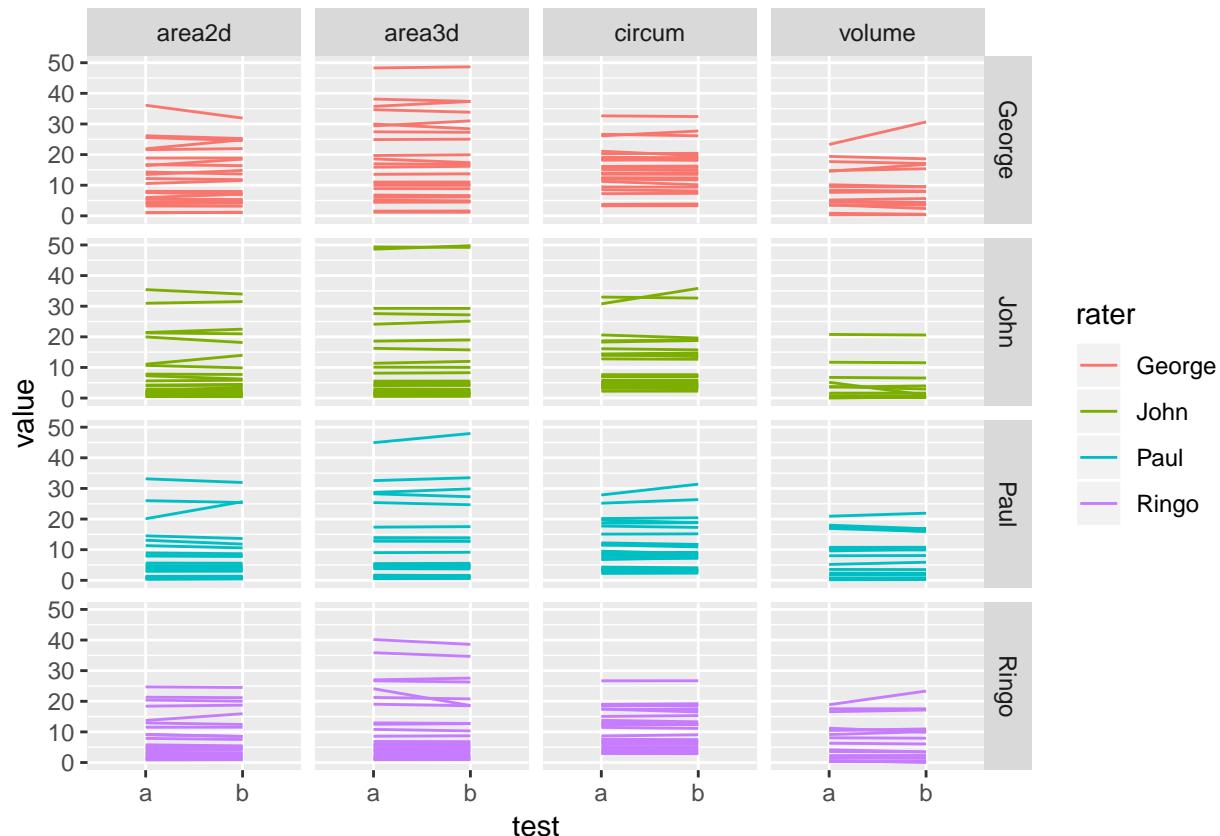
## # A tibble: 48 x 20
##   name_rater1 area2d_camera1a area2d_camera1b area3d_camera1a
##   <chr>          <dbl>          <dbl>          <dbl>
## 1 John           2.03           2.08           2.51
## 2 Paul            0.300          0.420          0.510
## 3 John            4.24           4.46           5.53
## 4 John            2.87           3.08           4.03
## 5 John            5.60           5.83           8.13
## # ... with 43 more rows, and 16 more variables: area3d_camera1b <dbl>,
## #   volume_camera1a <dbl>, volume_camera1b <dbl>, volume_gel1 <dbl>,
## #   circum_camera1a <dbl>, ...
long <-
  wide %>%
  # add a unique identifier to each row (each patient)
  mutate(id = 1:nrow(.)) %>%
  gather(key = type, value = value, -id, -name_rater1, -name_rater2) %>%
  separate(col = type, into = c("measurement", "method"), sep = "_") %>%
  mutate(rater = ifelse(grepl('1', method), name_rater1, name_rater2)) %>%
  separate(col = method, into = c("method", "test"), sep = "\\\d") %>%
  mutate(test = ifelse(test == "", "a", test)) %>%
```

```
# beautification
select(id, rater, test, measurement, method, value) %>%
  arrange(id, measurement, rater, test)
long

## # A tibble: 864 x 6
##       id rater test   measurement method value
##   <int> <chr> <chr> <chr>      <chr> <dbl>
## 1     1 John   a    area2d    camera  2.03
## 2     1 John   b    area2d    camera  2.08
## 3     1 Paul   a    area2d    camera  1.95
## 4     1 Paul   b    area2d    camera  NA
## 5     1 John   a    area3d    camera  2.51
## # ... with 859 more rows

long %>%
  filter(method == "camera") %>%
  ggplot(aes(x = test, y = value)) +
  geom_line(aes(color = rater, group = id)) +
  facet_grid(rater ~ measurement)
```

Warning: Removed 30 rows containing missing values (geom_path).

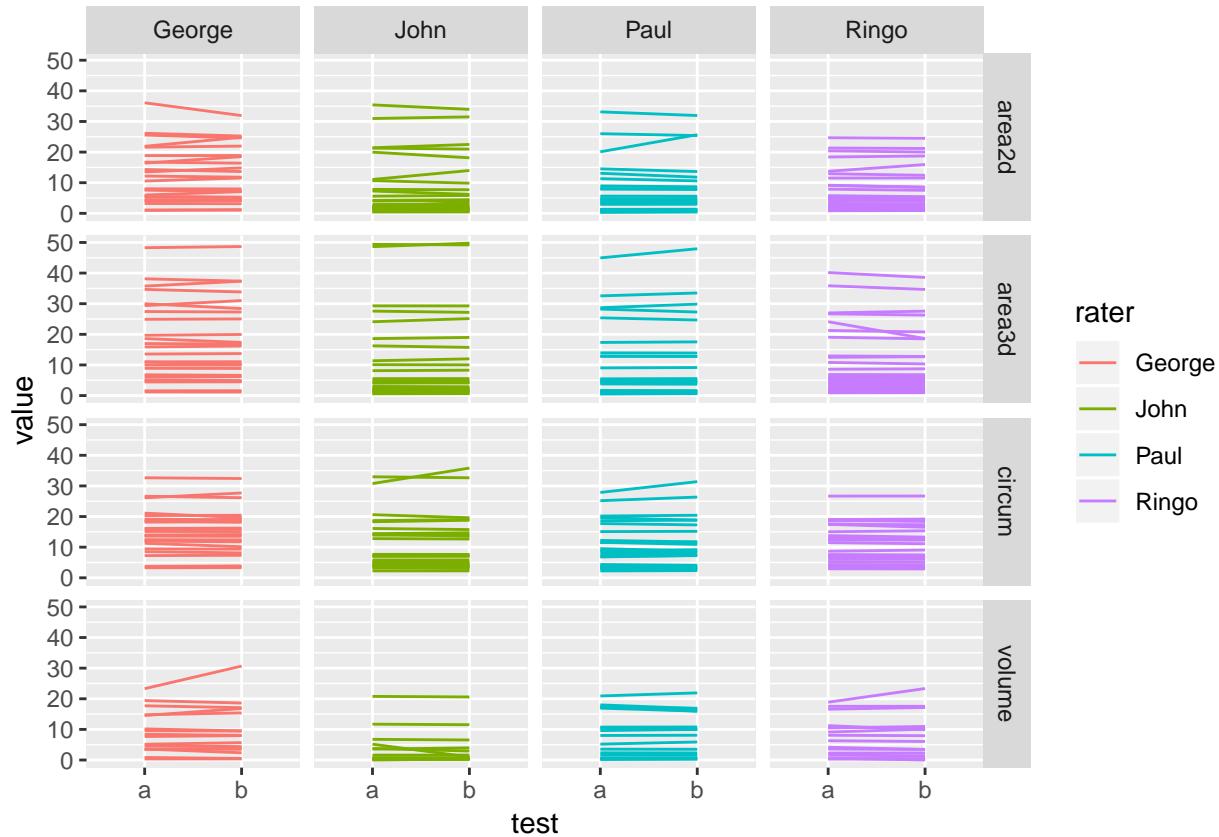


Comparisons along the y-axis is easiest if the scales are aligned therefore it is easier to compare along the horizontal.

```
long %>%
  filter(method == "camera") %>%
```

```
ggplot(aes(x = test, y = value)) +
  geom_line(aes(color= rater, group = id)) +
  facet_grid(measurement~rater)
```

Warning: Removed 54 rows containing missing values (geom_path).

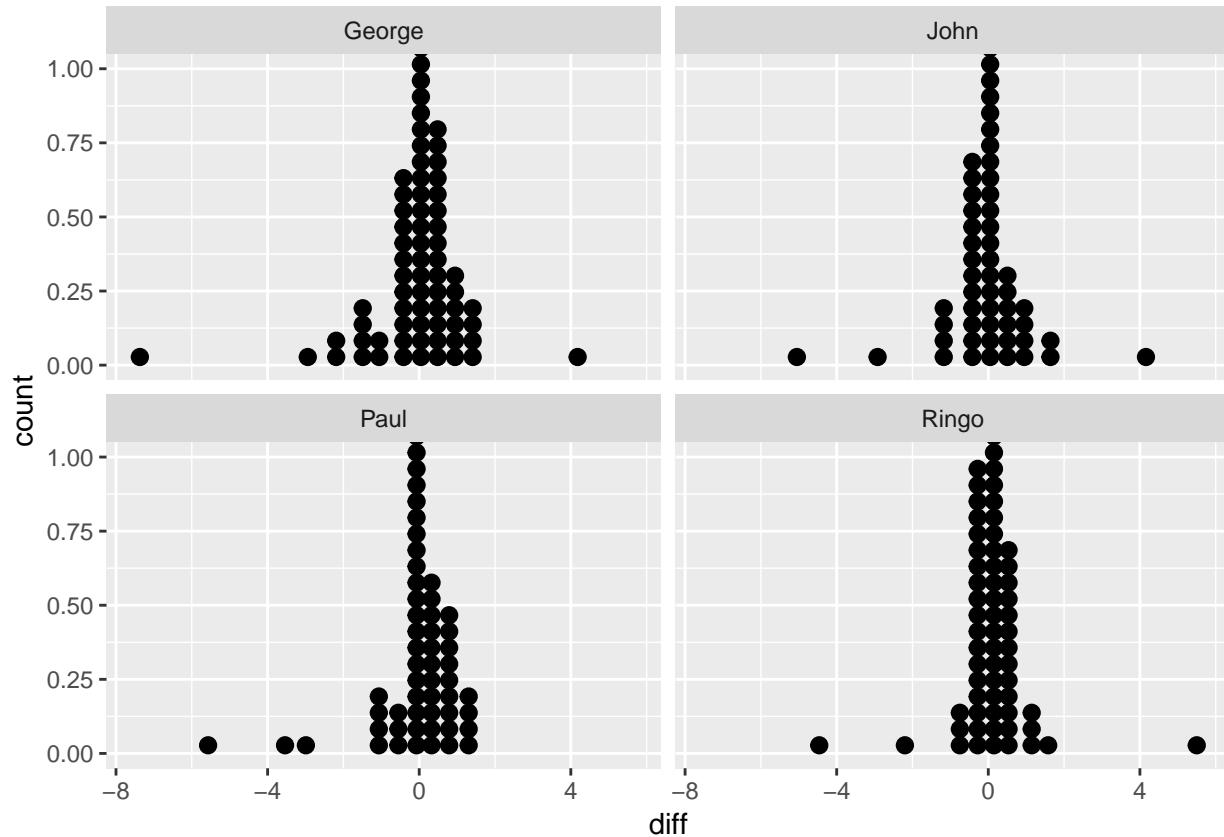


Differences are seen most clearly when plotted directly.

```
long %>%
  filter(method == "camera") %>%
  spread(test, value = value) %>%
  mutate(diff = a-b) %>%
  ggplot() +
  geom_dotplot(aes(x = diff)) +
  facet_wrap(~rater)
```

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

Warning: Removed 39 rows containing non-finite values (stat_bindot).



3.4.6 Tidying the EU time-use-survey

```
library(lubridate)
library(eurostat)

# Eurostat table "tus_00selfstat"
eu_timeuse_complete <- get_eurostat('tus_00selfstat', type = 'label',
                                     stringsAsFactors = FALSE)

eu_timeuse <-
  eu_timeuse_complete %>%
  filter(sex == 'Total', wstatus == 'Population') %>%
  spread(unit, values) %>%
  mutate(year = year(time),
        prtcp_time_min = `Participation time (hh:mm)` %>%
          str_pad(width = 4, side = 'left', pad = '0') %>%
          {str_c(str_sub(., 1, 2), ':', str_sub(., 3, 4))} %>%
          hm() %>% time_length(unit = 'minutes'),
        time_spent_min = `Time spent (hh:mm)` %>%
          str_pad(width = 4, side = 'left', pad = '0') %>%
          {str_c(str_sub(., 1, 2), ':', str_sub(., 3, 4))} %>%
          hm() %>% time_length(unit = 'minutes')
    ) %>%
  select(activity = acl00, country = geo, year,
        prtcp_rate = `Participation rate (%)`,
```

```

prtcp_time_min, time_spent_min)

## Warning in .parse_hms(..., order = "HM", quiet = quiet): Some strings
## failed to parse, or all strings are NAs
eu_timeuse

## # A tibble: 1,671 x 6
##   activity      country  year prtcp_rate prtcp_time_min time_spent_min
##   <chr>        <chr>    <dbl>     <dbl>          <dbl>            <dbl>
## 1 Activities rela~ Austria  2010     22.6           48             11
## 2 Activities rela~ Belgium 2000      1.4            88              1
## 3 Activities rela~ Belgium 2010     12.5           46              6
## 4 Activities rela~ Bulgari~ 2000      7.1            39              3
## 5 Activities rela~ Estonia 2000     10.9           44              5
## 6 Activities rela~ Estonia 2010      6.9            45              3
## 7 Activities rela~ Finland 2000     7.2            23              2
## 8 Activities rela~ Finland 2010     8.3            27              2
## 9 Activities rela~ France  2000      1.6           102             2
## 10 Activities rela~ France 2010     7.1            51              4
## # ... with 1,661 more rows

```

3.4.7 Tidying model output

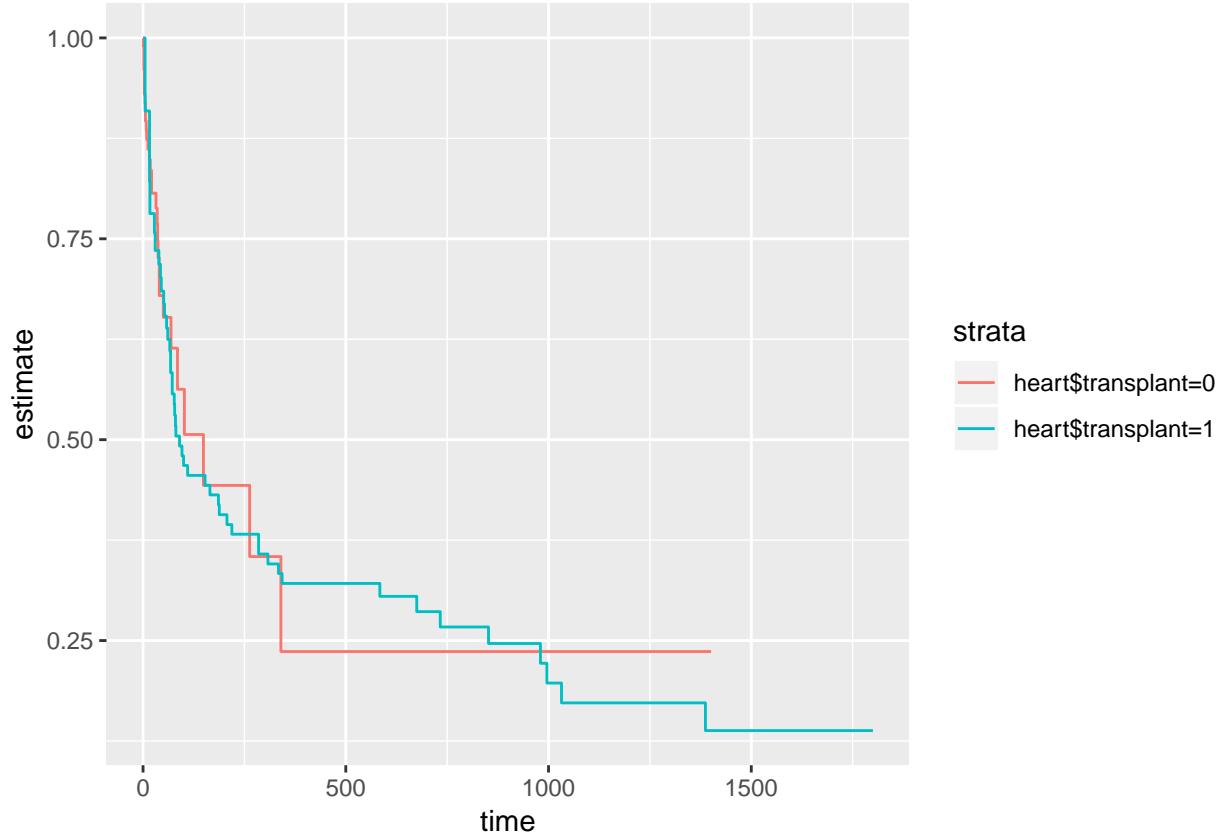
We “tidy” the output of the `survfit` function via the “broom” package.

```

library(survival)
surv <- survfit(
  Surv(time = heart$start,
       time2 = heart$stop,
       event = heart$event) ~ heart$transplant
)
surv

## Call: survfit(formula = Surv(time = heart$start, time2 = heart$stop,
##       event = heart$event) ~ heart$transplant)
##
##               records n.max n.start events median 0.95LCL 0.95UCL
## heart$transplant=0      103    103      0     30    149     69     NA
## heart$transplant=1       69     45      0     45     90     53    334
broom::tidy(surv) %>%
  ggplot(aes(x = time, y = estimate)) +
  geom_step(aes(colour = strata))

```



Dobson (1990) Page 93: Randomized Controlled Trial.

```
dat <- data_frame(
  counts = c(18,17,15,20,10,20,25,13,12),
  outcome = gl(3,1,9),
  treatment = gl(3,3)
)

dat_fit <- glm(counts ~ outcome + treatment, family = poisson(), data = dat)

broom::tidy(dat_fit)

##          term      estimate std.error    statistic   p.value
## 1 (Intercept) 3.044522e+00 0.1708987 1.781478e+01 5.426767e-71
## 2 outcome2 -4.542553e-01 0.2021708 -2.246889e+00 2.464711e-02
## 3 outcome3 -2.929871e-01 0.1927423 -1.520097e+00 1.284865e-01
## 4 treatment2 1.337909e-15 0.2000000 6.689547e-15 1.000000e+00
## 5 treatment3 1.421085e-15 0.2000000 7.105427e-15 1.000000e+00

broom::glance(dat_fit)

##    null.deviance df.null    logLik      AIC      BIC deviance df.residual
## 1       10.58145      8 -23.38066  56.76132  57.74744  5.129141           4
```

3.4.8 Excercise: Tidy data

- Download `get_eurostat('t2020_10', time_format = 'raw')` and write a pipe that calculates the difference between the current value and the target value over time for each country.

3.5 Joins

```
# population change
income <-
  get_eurostat('tgs00026', stringsAsFactors = FALSE) %>%
  select(geo, time, income = values)

## Table tgs00026 cached at /tmp/Rtmpmh6ir2x/eurostat/tgs00026_date_code_FF.rds

# unemployment rate
unemp <-
  get_eurostat('tgs00010', stringsAsFactors = FALSE) %>%
  filter(sex == 'T') %>%
  select(geo, time, unemp = values)

## Table tgs00010 cached at /tmp/Rtmpmh6ir2x/eurostat/tgs00010_date_code_FF.rds

# total fertility rate
totfert <-
  get_eurostat('tgs00100', stringsAsFactors = FALSE) %>%
  select(geo, time, totfert = values)

## Table tgs00100 cached at /tmp/Rtmpmh6ir2x/eurostat/tgs00100_date_code_FF.rds

# total life-expectancy
lifeexp <-
  get_eurostat('tgs00101', stringsAsFactors = FALSE) %>%
  filter(sex == 'T') %>%
  select(geo, time, lifeexp = values)

## Table tgs00101 cached at /tmp/Rtmpmh6ir2x/eurostat/tgs00101_date_code_FF.rds

# population change
popchange <-
  get_eurostat('tgs00099', stringsAsFactors = FALSE) %>%
  spread(indic_de, values) %>%
  select(geo, time,
         netmigrate = CNMIGRATRT,
         growthrate = GROWRT,
         natgrowthrate = NATGROWRT)

## Table tgs00099 cached at /tmp/Rtmpmh6ir2x/eurostat/tgs00099_date_code_FF.rds

#
euRegionalIndicators <-
  unemp %>%
  full_join(totfert) %>%
  full_join(lifeexp) %>%
  full_join(popchange) %>%
  full_join(income) %>%
  filter(str_length(geo) == 4) %>%
  mutate(country = str_sub(geo, end = 2)) %>%
  arrange(geo, time)

## Joining, by = c("geo", "time")
## Joining, by = c("geo", "time")
## Joining, by = c("geo", "time")
```

```
## Joining, by = c("geo", "time")
```

3.5.1 Excercise: Joins

- Create a dataset to a single topic of your choice by joining eurostat tables.

3.6 Recoding

3.6.1 Excercise: Recoding

- Recode the activity variable in dataset `eu_timeuse` into less than 10 meaningful categories of your own choice (make sure to filter out the “Total” values first). Visualize.

3.7 Tidy iteration

3.7.1 Group-wise operations

3.7.1.1 Grouped `mutate()`

If we want to transform some columns in the data frame on a group-by-group basis we can use the `group_by()` together with `mutate()`.

Biologists sometimes express age not in years but in shares of total life-expectancy, i.e. the age of quarter life-expectancy, the age of half life-expectancy... Let's add this *relative* age to each life-table in the data. We need to

1. group our data into sub-groups defined by the values of country, sex and year
2. for each sub-group add a new column “relative age” to the life-table calculated as age over total life-expectancy
3. Re-combine the results of 2 into a data frame with columns identifying the sub-groups

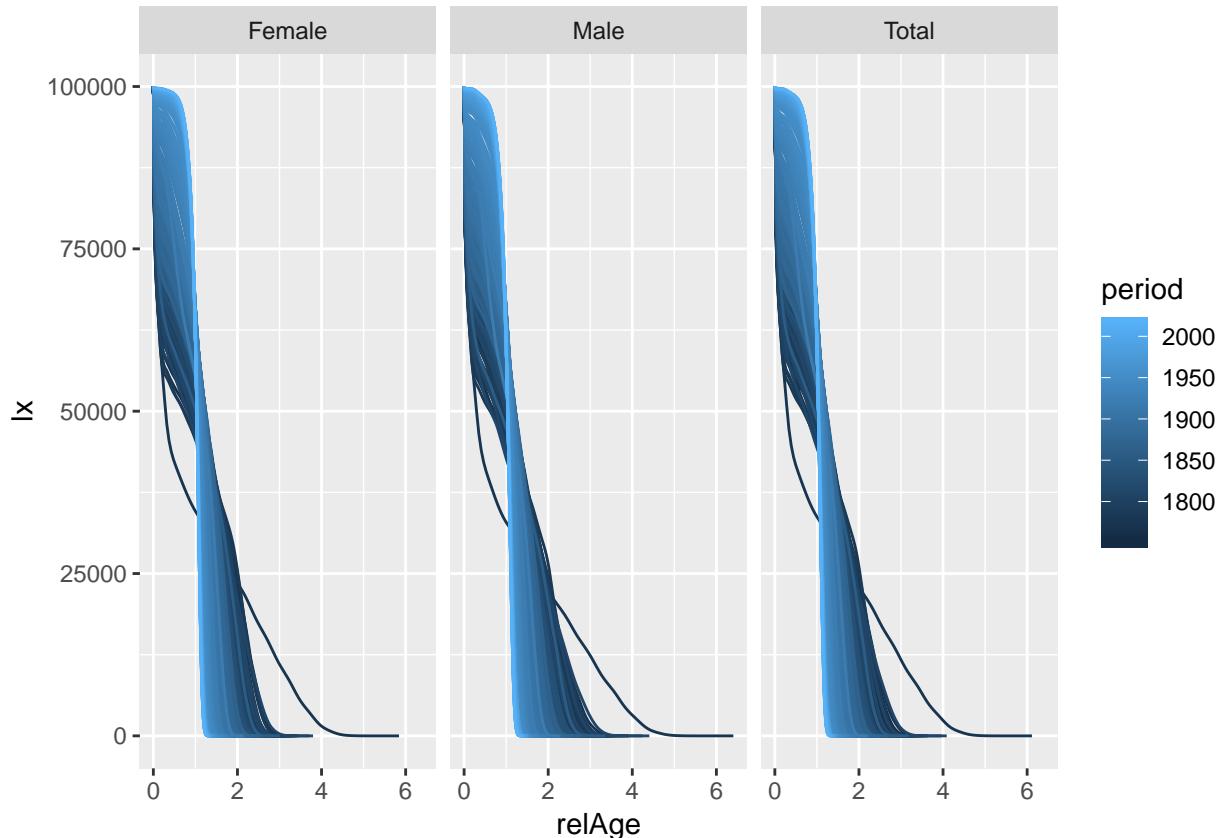
```
# hmd
# Life tables by year, sex and country
# source: Human Mortality Database
load('data/hmd/hmd.RData')

hmd %>%
  group_by(country, sex, period) %>%
  mutate(relAge = age / ex[1]) %>%
  select(-(nx:ex))

## # A tibble: 1,304,694 x 6
## # Groups:   country, sex, period [11,754]
##   country country_name sex     period    age relAge
##   <chr>    <chr>      <chr>    <int> <int>   <dbl>
## 1 AUS      Australia   Female   1921     0 0
## 2 AUS      Australia   Female   1921     1 0.0158
## 3 AUS      Australia   Female   1921     2 0.0317
## 4 AUS      Australia   Female   1921     3 0.0475
## 5 AUS      Australia   Female   1921     4 0.0633
## # ... with 1.305e+06 more rows
```

Let's plot the life-table survivor function over relative age by sex for Sweden across periods.

```
hmd %>%
  group_by(country, sex, period) %>%
  mutate(relAge = age / ex[1]) %>%
  ungroup() %>%
  filter(country == 'SWE') %>%
  ggplot() +
  geom_line(aes(x = relAge, y = lx, group = period, color = period)) +
  facet_wrap(~sex)
```



3.7.1.2 Grouped filter()

3.7.1.3 Grouped slice()

`slice()` selects rows by index. Using `slice()` in a grouped fashion we can return the first and last row for each group – this comes in handy as a quick check for data structure and coverage.

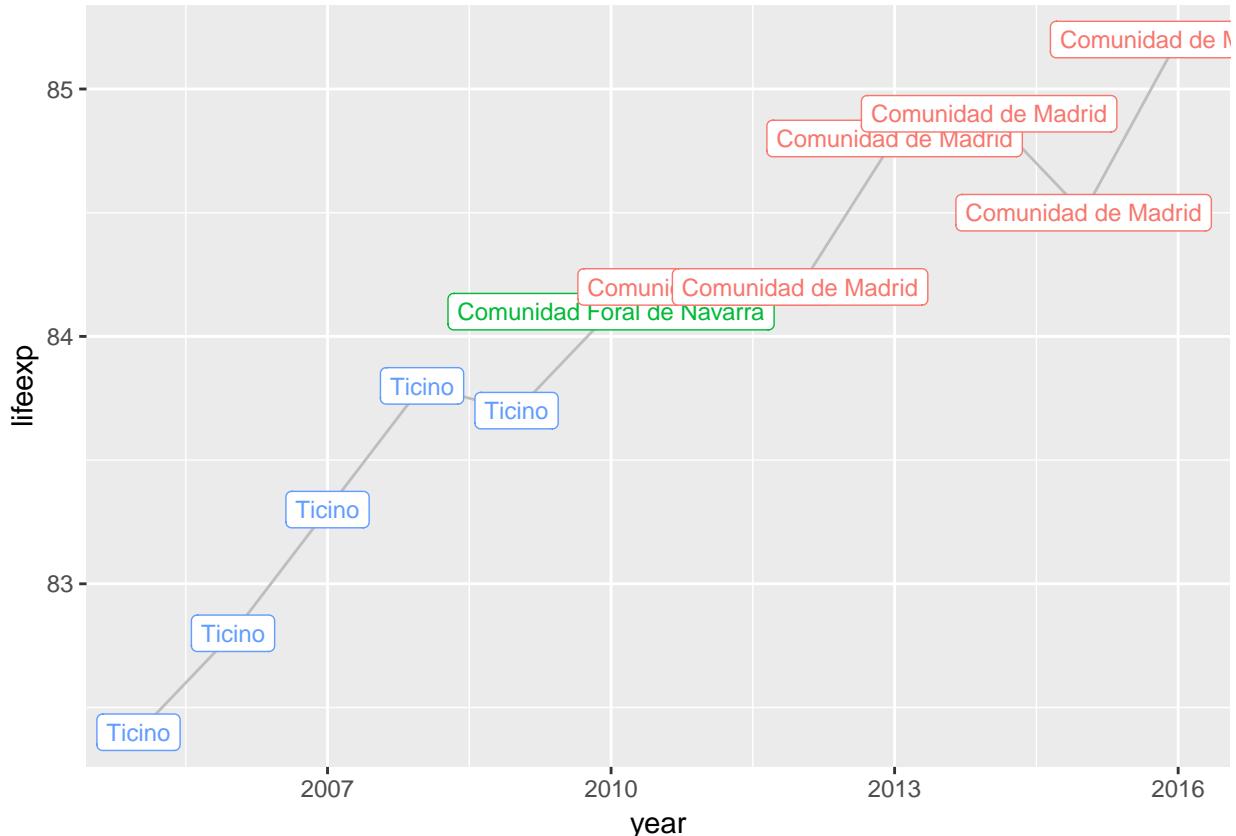
```
# euro_regio
# European regional population statistics
load('data/euro_regio/euro_regio.Rdata')

euro_regio %>%
  # for each country...
  group_by(country_name) %>%
  # ...return the first and last row
  slice(c(1, n()))
```

```
## # A tibble: 72 x 21
## # Groups:   country_name [36]
##   country_code country_name nuts2_code nuts2_name      year   pop popdens
##   <chr>        <chr>       <chr>      <chr>      <int> <dbl>   <dbl>
## 1 AL          Albania     AL01       Veri       2005    NA     NA
## 2 AL          Albania     ALXX       ALXX Not regio~ 2017    NA     NA
## 3 AT          Austria     AT11       Burgenland (AT) 2005    NA   75.7
## 4 AT          Austria     ATZZ       ATZZ Extra-Reg~ 2017    NA     NA
## 5 BE          Belgium     BE10       Région de Brux~ 2005    NA  6290.
## # ... with 67 more rows, and 14 more variables: births <dbl>,
## #   deaths <dbl>, natgrowthrate <dbl>, growthrate <dbl>, netmigrate <dbl>,
## #   ...
## # ...
```

We can use grouped `slice()` to have a closer look at outliers within groups. This replicates the Oeppen-Vaupel line for European regions.

```
euro_regio %>%
  # for each year
  group_by(year) %>%
  #...select the row (region) with the highest life-expectancy
  slice(which.max(lifeexp)) %>%
  # ...and plot the results
  ggplot() +
  geom_line(aes(x = year, y = lifeexp), color = 'grey') +
  geom_label(aes(x = year, y = lifeexp,
                 label = nuts2_name, color = nuts2_name),
             show.legend = FALSE, size = 3)
```



3.7.2 Grouped summarise()

Say we have a collection of life-tables by country, sex, and year and we want to calculate the coefficient of variation for the life-table distribution of deaths. In other words we want to

1. group our data into subgroups defined by the values of country, sex and year (so a single sub-group may be Danish females in 2010)
2. extract total life-expectancy from each sub-group life-table
3. calculate the coefficient of variation for each sub-group
4. Re-combine the results of 2 and 3 into a data frame with columns identifying the sub-groups

All of the above is achieved by the data pipeline below.

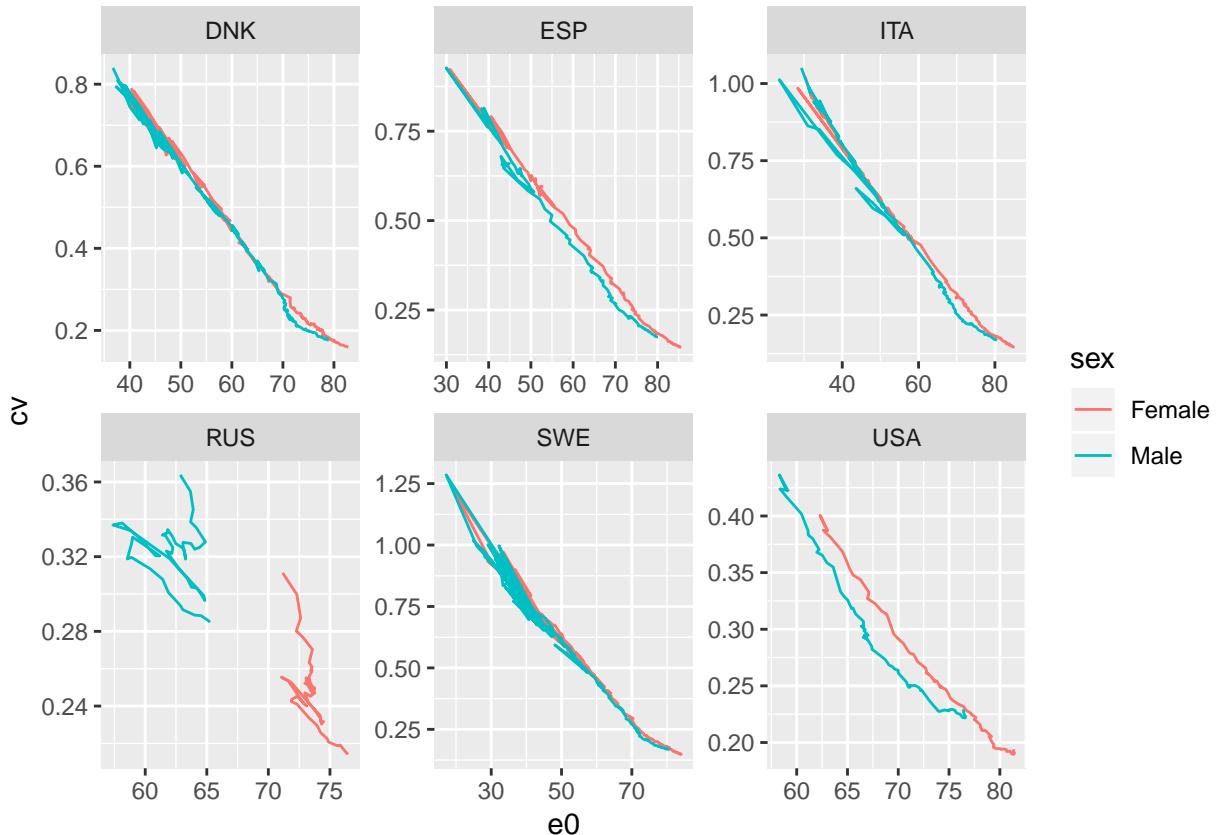
```
hmd %>%
  group_by(country, sex, period) %>%
  summarise(
    e0 = first(ex),
    cv = sqrt(sum(ndx/100000*(age+nax-e0)^2)) / e0
  )
```

```
## # A tibble: 11,754 x 5
## # Groups:   country, sex [?]
##   country sex   period     e0     cv
##   <chr>   <chr>   <int> <dbl> <dbl>
## 1 AUS     Female  1921  63.2  0.409
## 2 AUS     Female  1922  65.1  0.370
## 3 AUS     Female  1923  63.7  0.388
## 4 AUS     Female  1924  64.5  0.383
## 5 AUS     Female  1925  65.4  0.370
## # ... with 1.175e+04 more rows
```

We use the `group_by()` function to group our data into sub-groups, then we use the `summarise()` command to calculate the “summary statistics” for each sub-group. The `ungroup()` function in the end is optional but its good practice to ungroup after you’re done with the group-wise operations.

Let’s plot the results (for a subset of all countries):

```
hmd %>%
  filter(sex != 'Total') %>%
  group_by(country, sex, period) %>%
  summarise(
    e0 = first(ex),
    cv = sqrt(sum(ndx/100000*(age+nax-e0)^2)) / e0
  ) %>% ungroup() %>%
  filter(country %in% c('SWE', 'RUS', 'ITA', 'DNK', 'USA', 'ESP')) %>%
  ggplot() +
  geom_path(aes(x = e0, y = cv, color = sex)) +
  facet_wrap(~country, scales = 'free')
```



3.7.2.1 Grouped do()

3.7.2.2 Fitting and summarising many models

3.7.2.3 Excercise: Group-wise operations

- Calculate five year abridged mortality rates for the whole `hmd_counts` data.

3.7.3 Column-wise operations

3.7.3.1 *_at()

```
# apply function "toupper()" to the columns country, sex
mutate_at(hmd_counts, vars(country, sex), toupper)
```

```
## # A tibble: 1,304,694 x 7
##   country sex   period   age     nx    nDx    nEx
##   <chr>   <chr>   <int> <int> <int> <dbl> <dbl>
## 1 AUS     FEMALE  1921     0     1 3842. 64052.
## 2 AUS     FEMALE  1921     1     1 719. 59619.
## 3 AUS     FEMALE  1921     2     1 330. 57126.
## 4 AUS     FEMALE  1921     3     1 166. 57484.
## 5 AUS     FEMALE  1921     4     1 190. 58407.
## # ... with 1.305e+06 more rows
```

```
# this returns the same as above
mutate(hmd_counts,
       country = toupper(country),
       sex = toupper(sex))

## # A tibble: 1,304,694 x 7
##   country sex   period   age   nx   nDx   nEx
##   <chr>   <chr>   <int> <int> <dbl> <dbl>
## 1 AUS     FEMALE  1921     0     1 3842. 64052.
## 2 AUS     FEMALE  1921     1     1 719. 59619.
## 3 AUS     FEMALE  1921     2     1 330. 57126.
## 4 AUS     FEMALE  1921     3     1 166. 57484.
## 5 AUS     FEMALE  1921     4     1 190. 58407.
## # ... with 1.305e+06 more rows
```

3.7.3.2 *_if()

```
# convert any character variable to a factor
mutate_if(hmd_counts, is.character, as.factor)

## # A tibble: 1,304,694 x 7
##   country sex   period   age   nx   nDx   nEx
##   <fct>   <fct>   <int> <int> <dbl> <dbl>
## 1 AUS     Female  1921     0     1 3842. 64052.
## 2 AUS     Female  1921     1     1 719. 59619.
## 3 AUS     Female  1921     2     1 330. 57126.
## 4 AUS     Female  1921     3     1 166. 57484.
## 5 AUS     Female  1921     4     1 190. 58407.
## # ... with 1.305e+06 more rows

# this returns the same as above
mutate(hmd_counts,
       country = as.factor(country),
       sex = as.factor(sex))

## # A tibble: 1,304,694 x 7
##   country sex   period   age   nx   nDx   nEx
##   <fct>   <fct>   <int> <int> <dbl> <dbl>
## 1 AUS     Female  1921     0     1 3842. 64052.
## 2 AUS     Female  1921     1     1 719. 59619.
## 3 AUS     Female  1921     2     1 330. 57126.
## 4 AUS     Female  1921     3     1 166. 57484.
## 5 AUS     Female  1921     4     1 190. 58407.
## # ... with 1.305e+06 more rows
```

3.7.3.3 *_all()

Chapter 4

Visualization

4.1 The “tidy” approach to data visualization

Data visualization in the `tidyverse` revolves around three concepts:

- 1) **Tidy Data** Data is stored in a data frame with cases as rows and variables as columns.
- 2) **Mappings** Variables are mapped to visual attributes, called *aesthetics*.
- 3) **Layers** Plots are built layer by layer. There are different types of layers, each changing a different aspect of a plot, i.e. coordinate system, scales, statistical transformations or visual marks.

Part of the `tidyverse` is a package called `ggplot2` which is what we are going to use to produce plots. `ggplot2` is an implementation of the *Grammar of Graphics*, a domain specific language to specify visualizations.

4.2 The Grammar of graphics

Data, Statistics, Aesthetics, Scales, Geometry, Coordinates.

Data Observations of one or more variables.

Statistics Transformations of the data prior to plotting.

- Algebraic transformations (log, exp, sqrt, identical...)
- Aggregating statistical transformations (mean, median, mode, bin, linear regression...)
- Non-aggregating statistical transformations (sort, rank, cut...)

Aesthetics The visual representation of a variable.

- Position. `x`, `y`, `xmin`, `xmax`, `ymin`, `ymax`, `xend`, `yend`
- Colour. `colour`, `fill`, `alpha`
- Size. `size`
- Shape, Pattern. `shape`, `linetype`
- Group. `group`
- Angle, Slope, Intercept, Texture, ...

Scales The way a variable is mapped to a visual representation.

- Discrete, Continuous. e.g. `scale_x_discrete`, `scale_colour_continuous`
- Concerning Position, Colour, Size, Shape... e.g. `scale_y_continuous`, `scale_size`, `scale_shape()`
- Breakpoints, Labels
- Transformations (log, sqrt, reverse)



Figure 4.1: Gapminder World

Geometry General “shape” or “type” of the graphic

- Scatterplots use `geom_point`,
- Timelines use `geom_line`,
- Area charts use `geom_area`,
- Heatmaps use `geom_tile`,
- Bar charts use `geom_bar`,
- there are many more...

Coordinates The coordinate system of the plot area.

- Cartesian coordinates
- Polar coordinates

4.2.1 Aesthetics, geometries, and layers

Interactive plots displayed in a web-browser have long arrived in the mainstream with Gapminder World being a true classic of the genre.

Today we shall recreate the above chart and in doing so learn the basics of ggplot. Key concepts we will tackle are *aesthetics*, *layers*, *scales*, and *facets*.

Each ggplot starts with *data*. **Data must be a data frame!** Today we will use data which comes in form of an R package: The gapminder data.

```
library(tidyverse)

library(gapminder)
is.data.frame(gapminder)

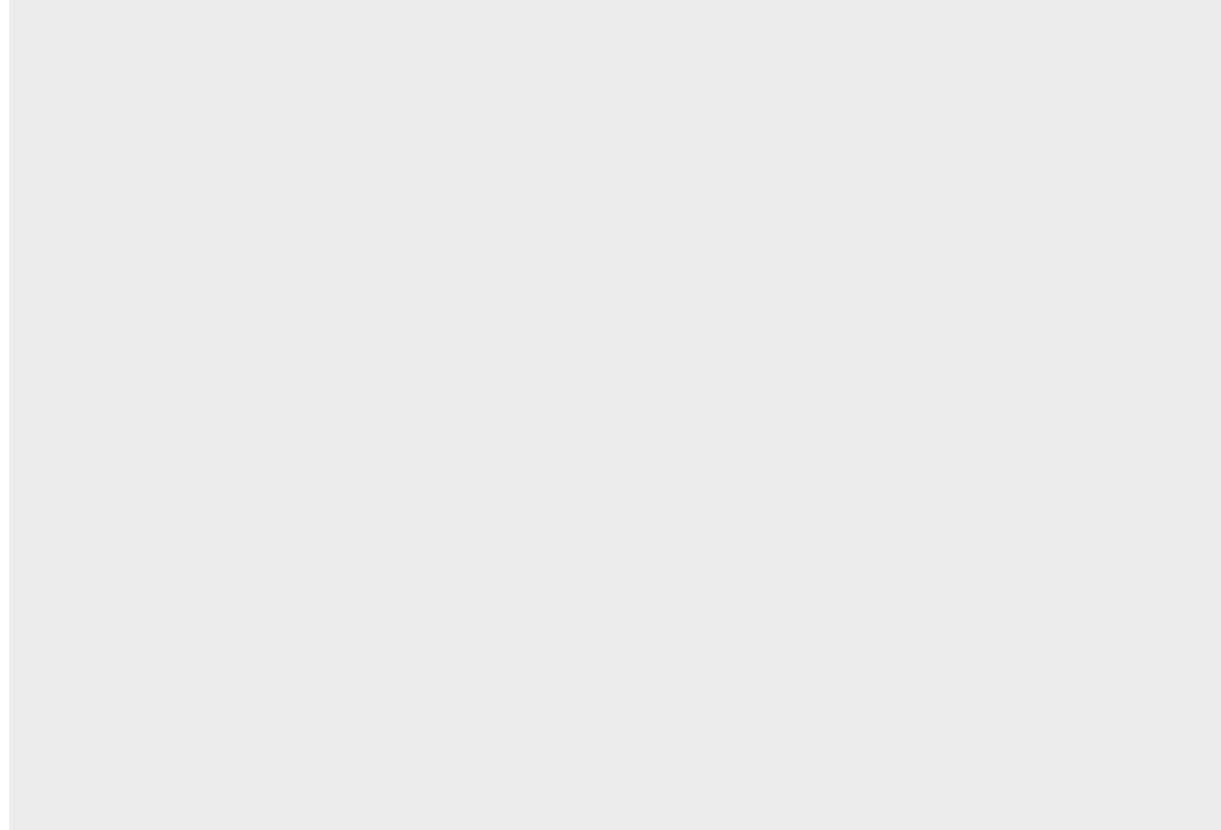
## [1] TRUE

head(gapminder)

## # A tibble: 6 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.
## # ... with 1 more row
```

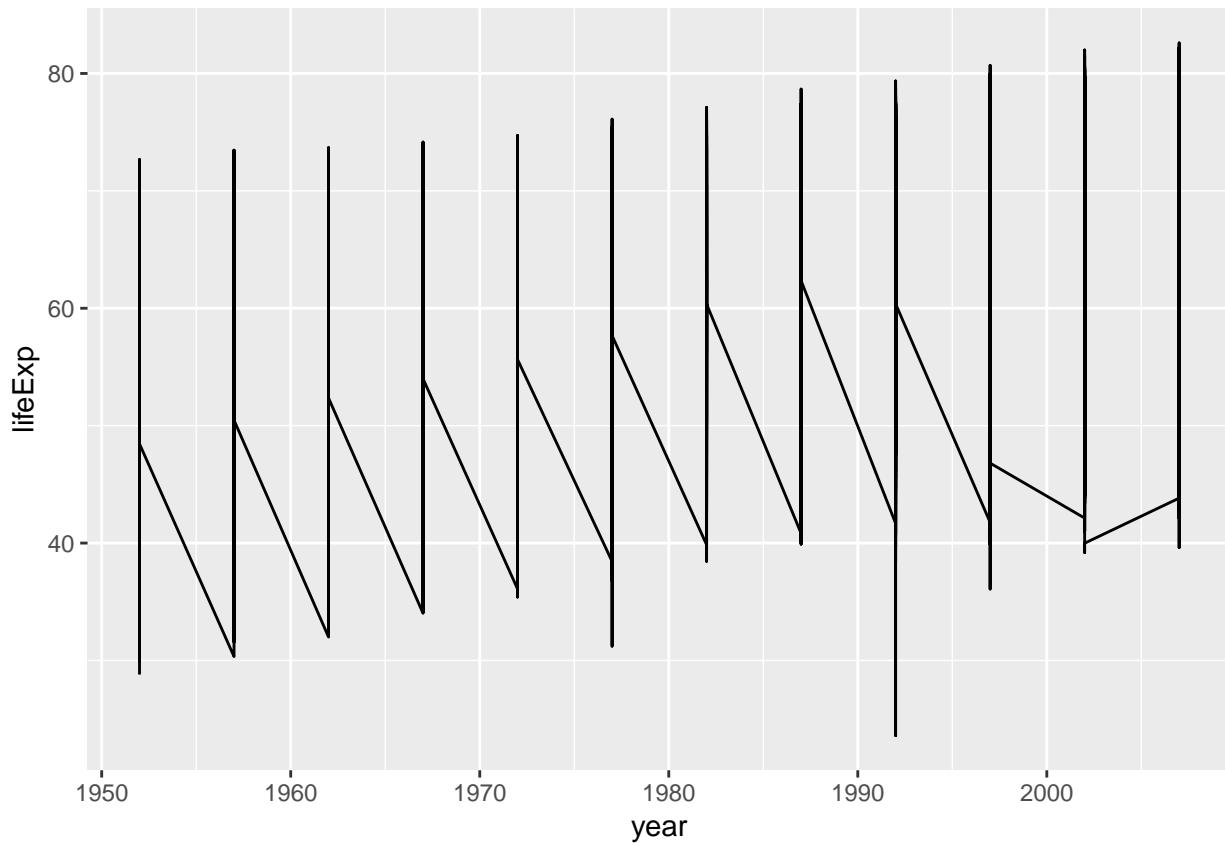
First step in plotting with ggplot – provide ggplot with a data frame:

```
ggplot(data = gapminder)
```



ggplot knows about our data but nothing happens yet. We need to add a *layer*. **We add elements to a plot by adding them with a +.**

```
ggplot(data = gapminder) +
  geom_line(aes(x = year, y = lifeExp))
```

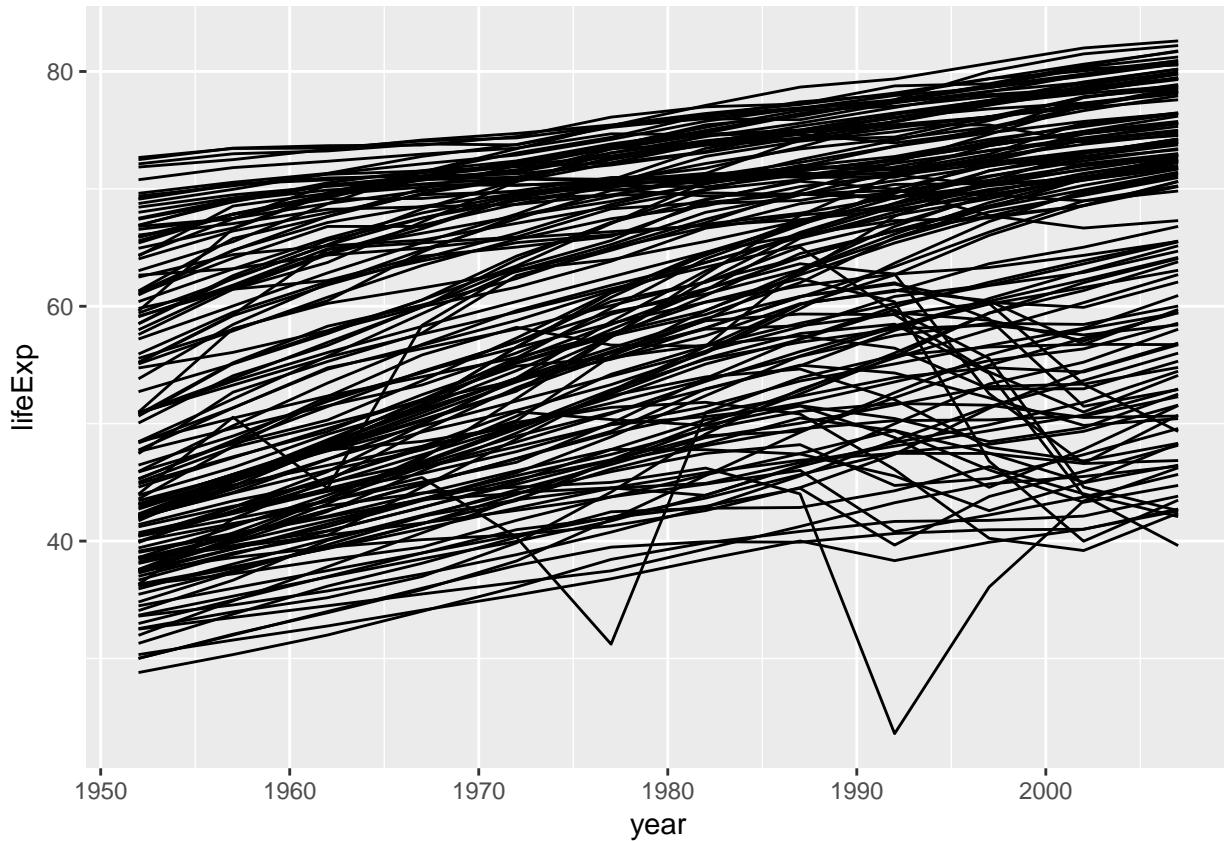


`aes` stands for *aesthetics*: Mappings between variables in our data and visual properties. Each column in our data frame is a variable. Visual properties are manifold and can be `x`, `y`, `colour`, `size`, `shape`, `alpha`, `fill`, `radius`, `linetype`, `group`...

We use the `aes()` function to map x-position to the variable `Time` and y-position to the variable `weight`. **Every time you map a variable to a visual property you do it inside `aes()`**

The plot looks strange. A single line is drawn across all data points. We want separate lines – one time series per country...

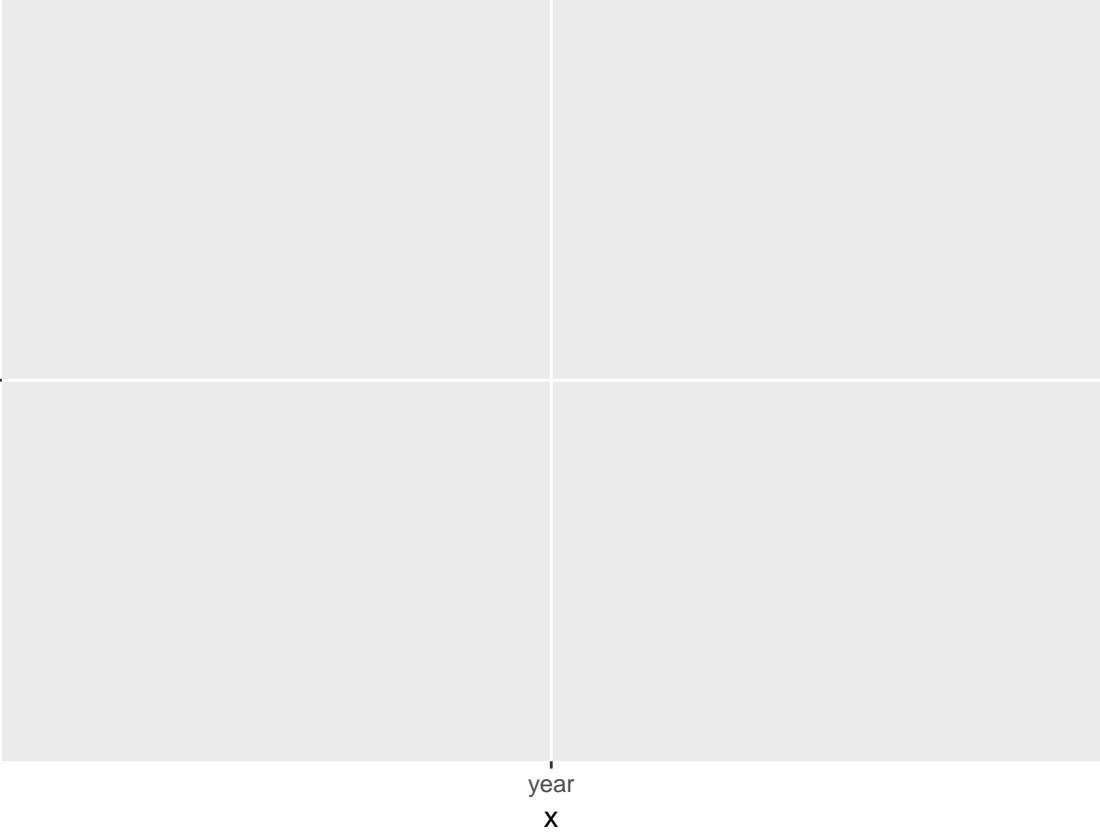
```
ggplot(data = gapminder) +
  geom_line(aes(x = year, y = lifeExp, group = country))
```



Note that we don't write `x = gapminder$year` or `y = "lifeExp"`. We simply spell out the name of the variable we wish to work with. `ggplot` is aware of the dataset we work with – it is *attached*. Quoting the variable names would actually produce unexpected results:

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

```
> lifeExp -
```

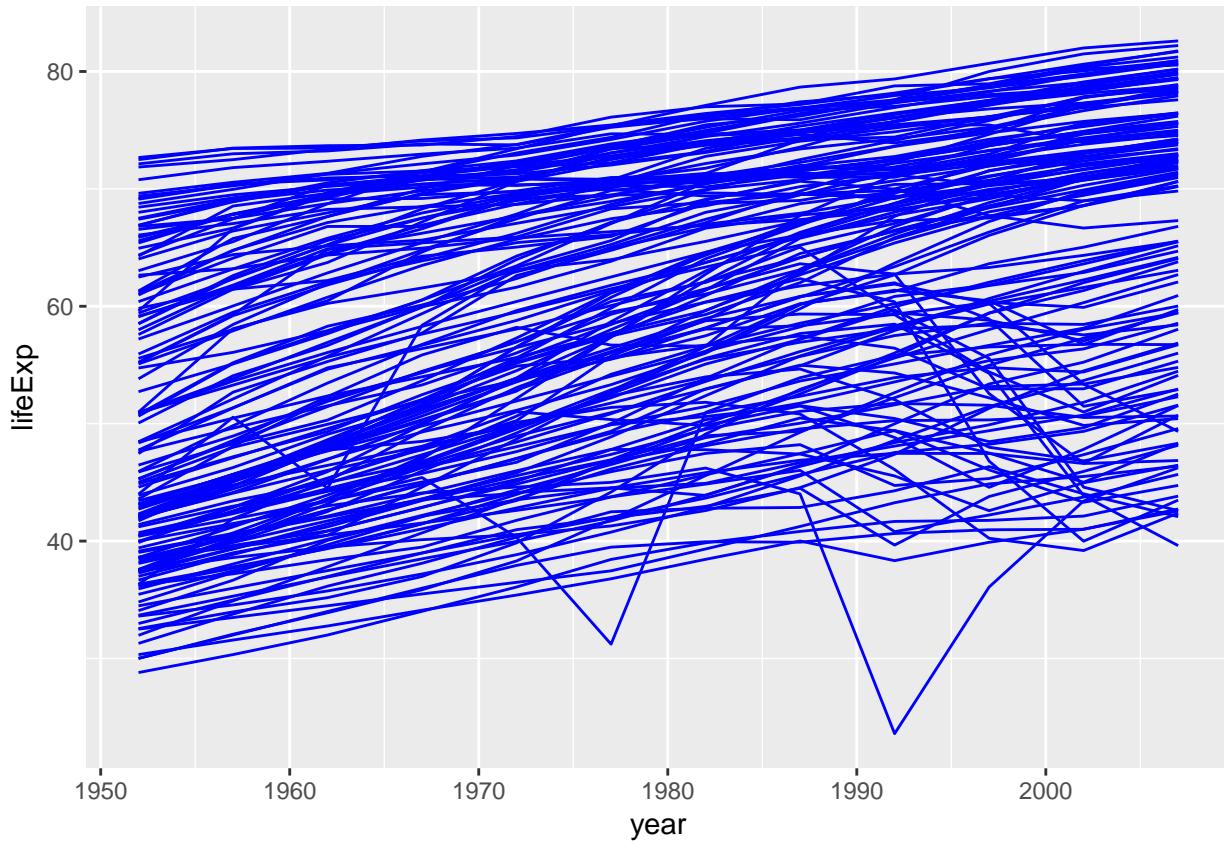


year
x

What happened? ggplot interpreted the quoted strings as raw data instead of variable names of our data frame. It then tries to plot it... **Always use unquoted column names to address the variables in your data.**

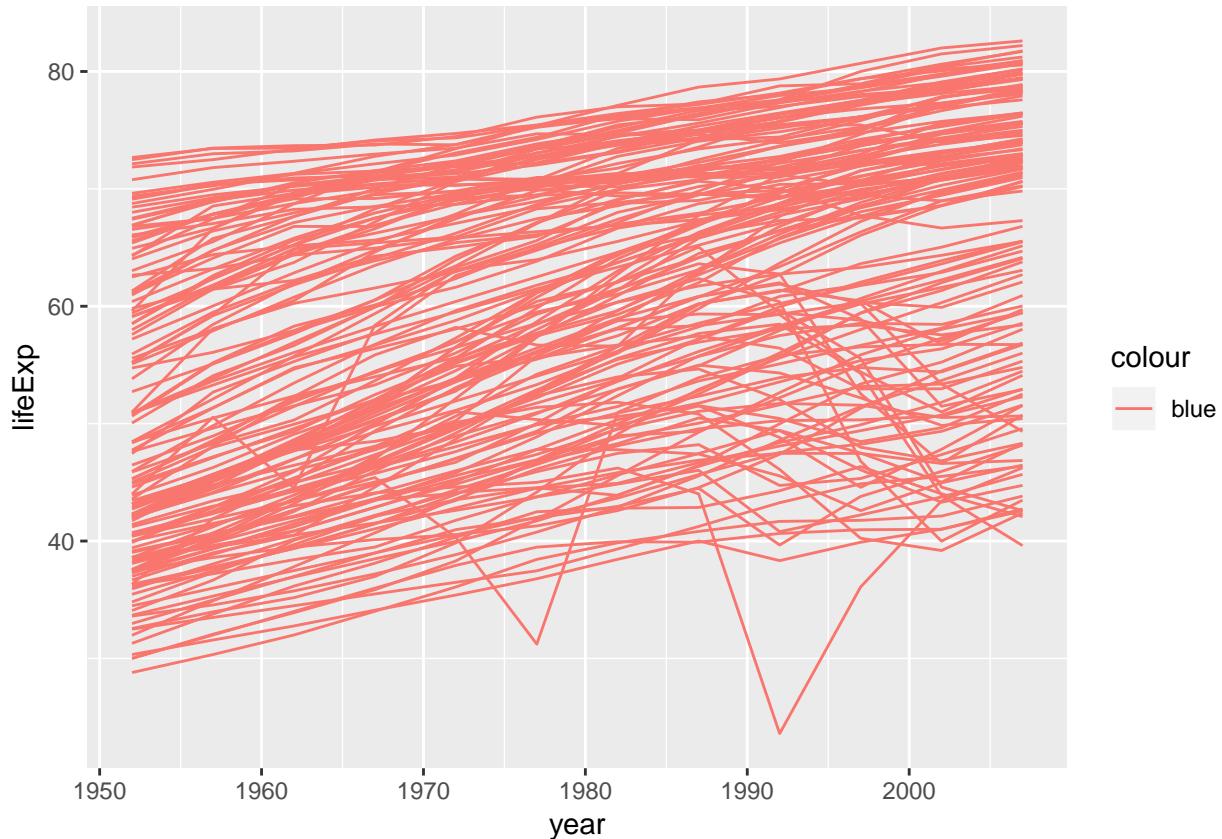
Let's colour all of the lines blue.

```
ggplot(data = gapminder) +  
  geom_line(aes(x = year, y = lifeExp, group = country), colour = "blue")
```



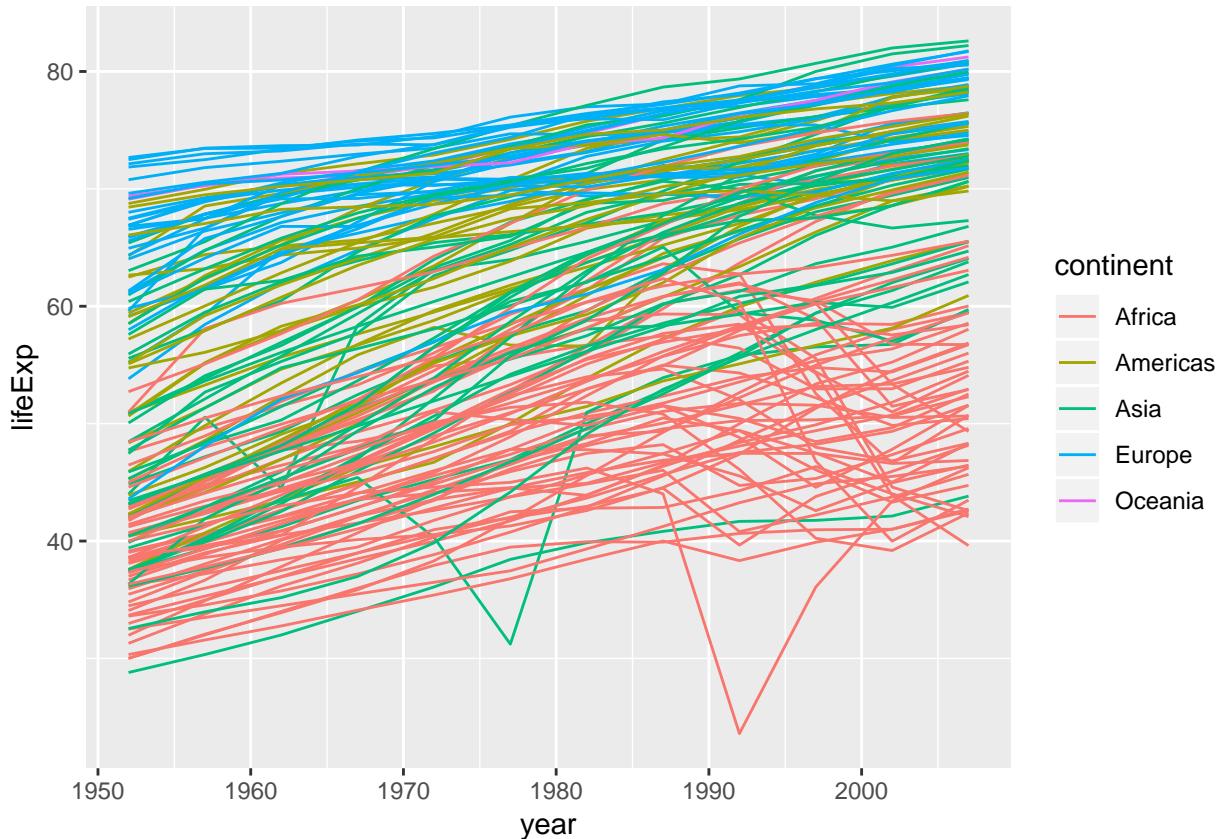
We wrote `colour = "blue"` outside of the `aes()` function as we *set* the visual property to a fixed value instead of *mapping* a visual property to a variable in the data frame. For comparison, let's move the colour specification into the `aes()` function:

```
ggplot(data = gapminder) +
  geom_line(aes(x = year, y = lifeExp, group = country, colour = "blue"))
```



Classic ggplot moment here... "blue" gets interpreted as raw data as we have written it inside of the `aes()` function. ggplot thinks all of our rows belong to group "blue", mapped to the visual property colour. ggplot assigns a default colour scale of which the first colour is a light red. Here's the same behaviour, but this time it makes sense as we map colour to an actual variable in our data set.

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

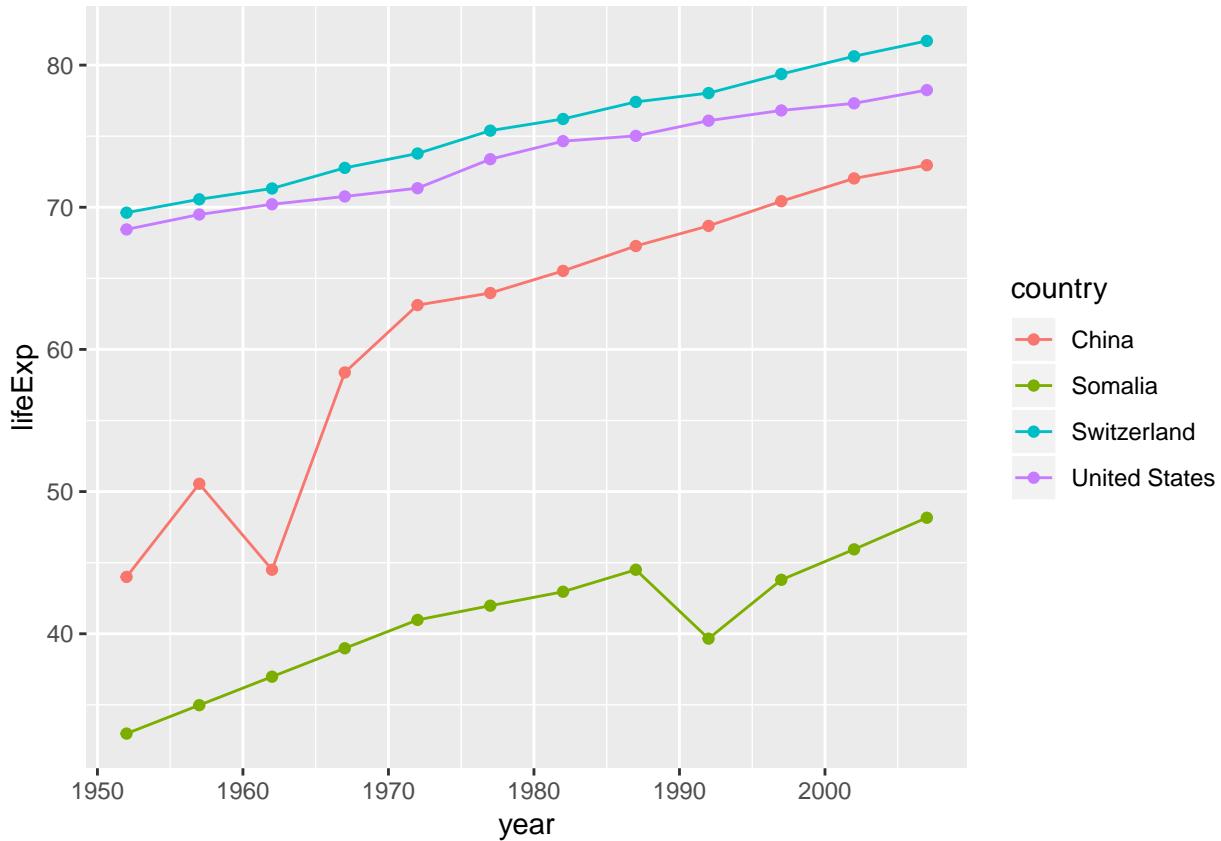


Lesson to be learned: The difference between *mapping* and *setting* a visual property. **You map visual properties to variables inside `aes()`, you set visual properties to a fixed value outside of `aes()`.**

We can add more than a single layer to a plot. ggplot 2.0.0 comes with 27 *geometries* (`geom`). Some of them are super straightforward and just draw points or lines or rectangles. Some draw complex shapes after transforming your data in various ways. **Think of geometries as flexible templates for different plot types.** Combining different geometries is a common workflow in ggplot. E.g. adding `geom_point` to `geom_line` gives lines with points on them:

```
# filter data to 4 countries only
gapminder_sub <-
  filter(gapminder,
         country %in% c("China", "Switzerland", "United States", "Somalia"))

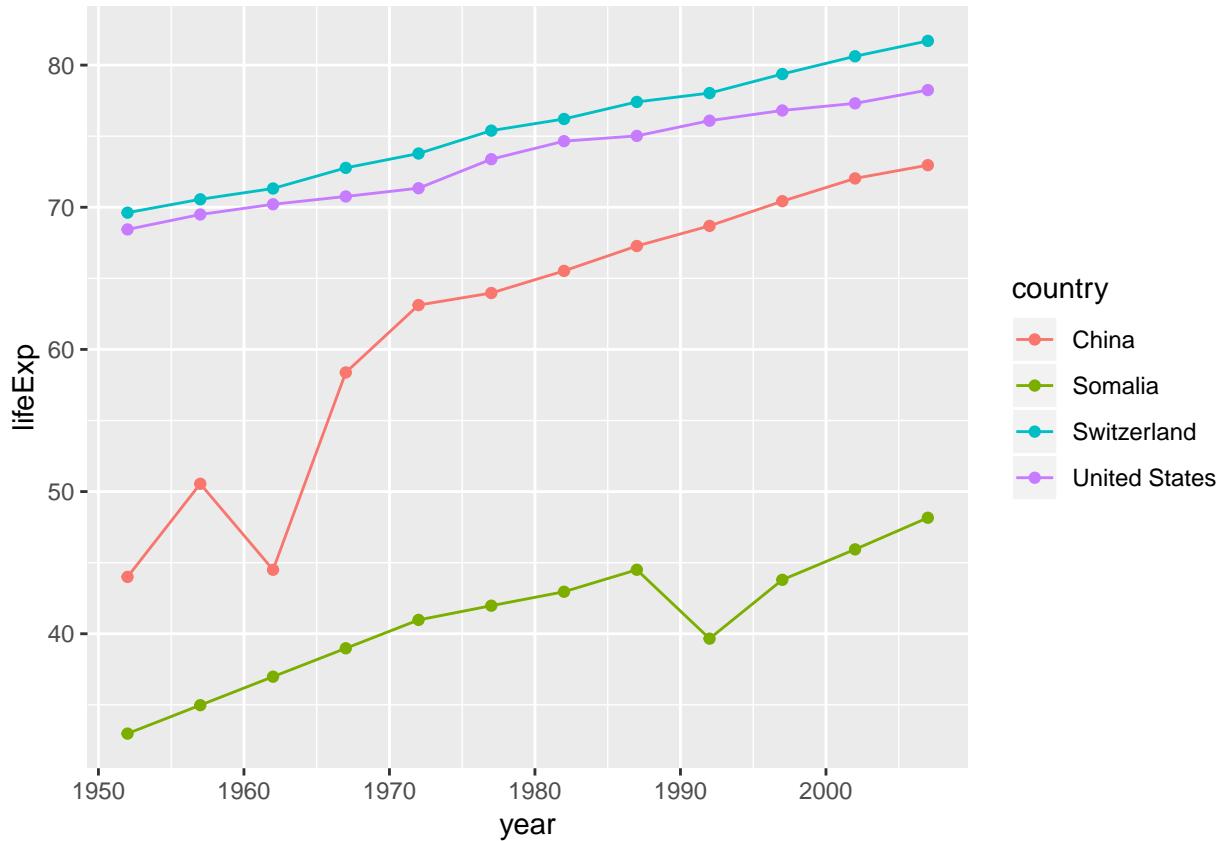
ggplot(data = gapminder_sub) +
  geom_line(aes(x = year, y = lifeExp, color = country)) +
  geom_point(aes(x = year, y = lifeExp, color = country))
```



Note that we did not need to specify the `group` argument in the last `ggplot` call. The have mapped colour to country and therefore implicitly specified the grouping structure of our data. We use `group` only if `ggplot` fails to correctly guess the grouping.

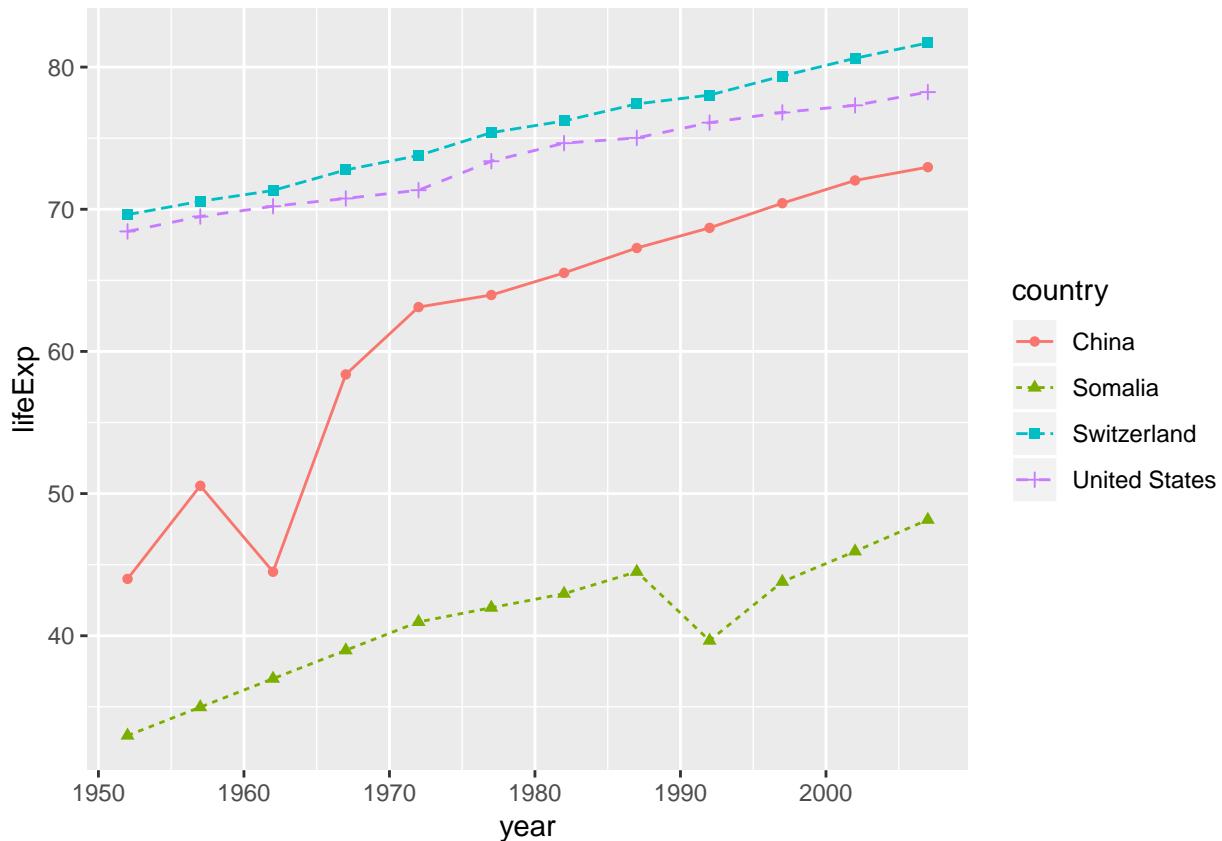
If we use identical mappings in our layers we can move them into the `ggplot()` function. **Everything inside the `ggplot()` function is passed down to all other plot elements.**

```
ggplot(data = gapminder_sub, aes(x = year, y = lifeExp, color = country)) +
  geom_line() +
  geom_point()
```



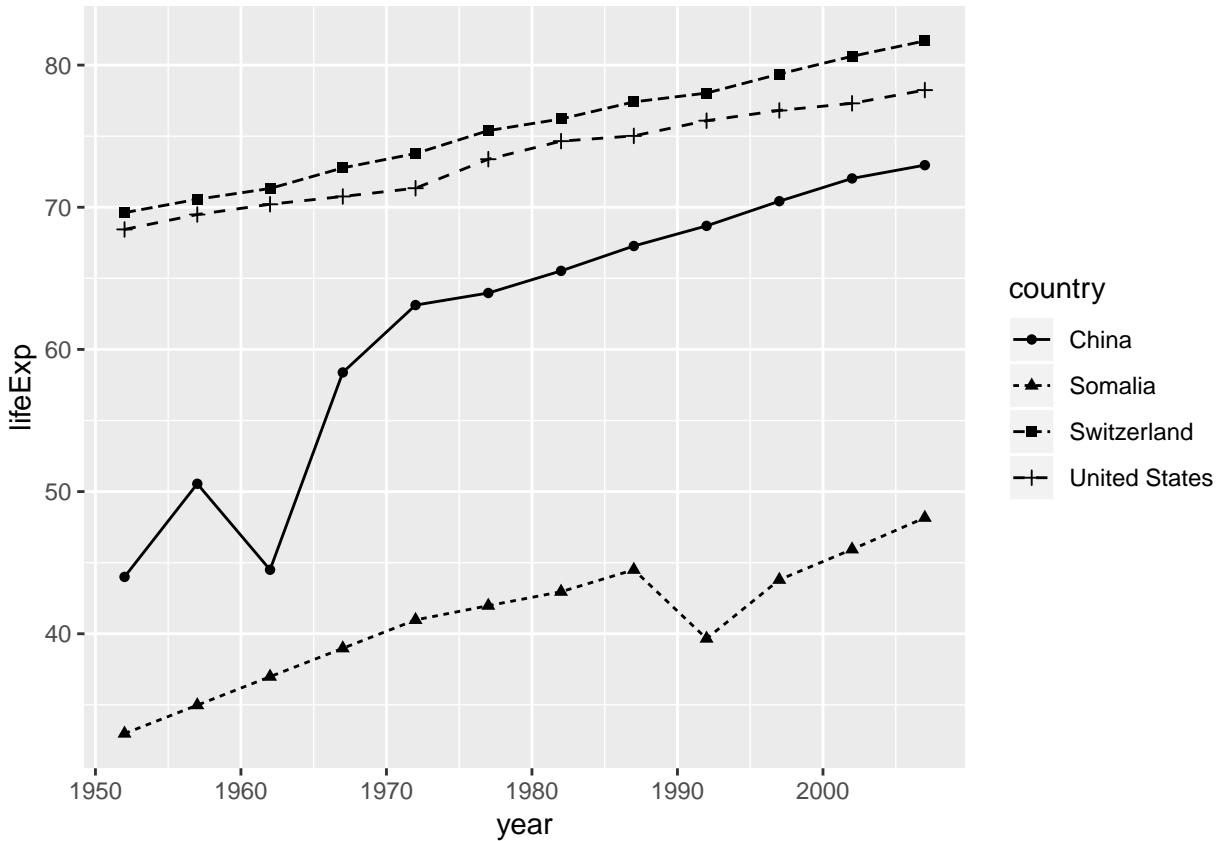
We can still add arguments to the individual layers.

```
ggplot(data = gapminder_sub, aes(x = year, y = lifeExp, color = country)) +
  geom_line(aes(linetype = country)) +
  geom_point(aes(shape = country))
```



We also have the power to override commands from above:

```
ggplot(data = gapminder_sub, aes(x = year, y = lifeExp, color = country)) +
  geom_line(aes(linetype = country), colour = "black") +
  geom_point(aes(shape = country), colour = "black")
```



4.2.2 Scales

We already know that *aesthetics* are mappings from data dimensions to visual properties. They tell ggplot what goes where. What are the aesthetics in **Gapminder World**?

Data dimension	Visual property	Scale
GDP per capita	position on x-axis (x)	<code>scale_x_*</code>
Life expectancy	position on y-axis (y)	<code>scale_y_*</code>
Population size	size of plotting symbols (size)	<code>scale_size_*</code>
Geographical Region	colour of plotting symbols (colour)	<code>scale_colour_*</code>

Each aesthetic has its own scale

The four aesthetics in *Gapminder World* are connected to four different scales. The scales are named after the corresponding aesthetic. The naming scheme is `scale_<name of aesthetic>_<continuous|discrete|specialized>`.

Aesthetics specify the *what*, scales specify the *how*

Which colour to use for which level in the data? Where to put the labels on the axis? Which labels to put? The size of the largest plotting symbol, the name of the legends, log-transformation of the y-axis, the range of the axis... These are all examples of scale specifications – specifications on *how* to map a data dimension to a visual attribute.

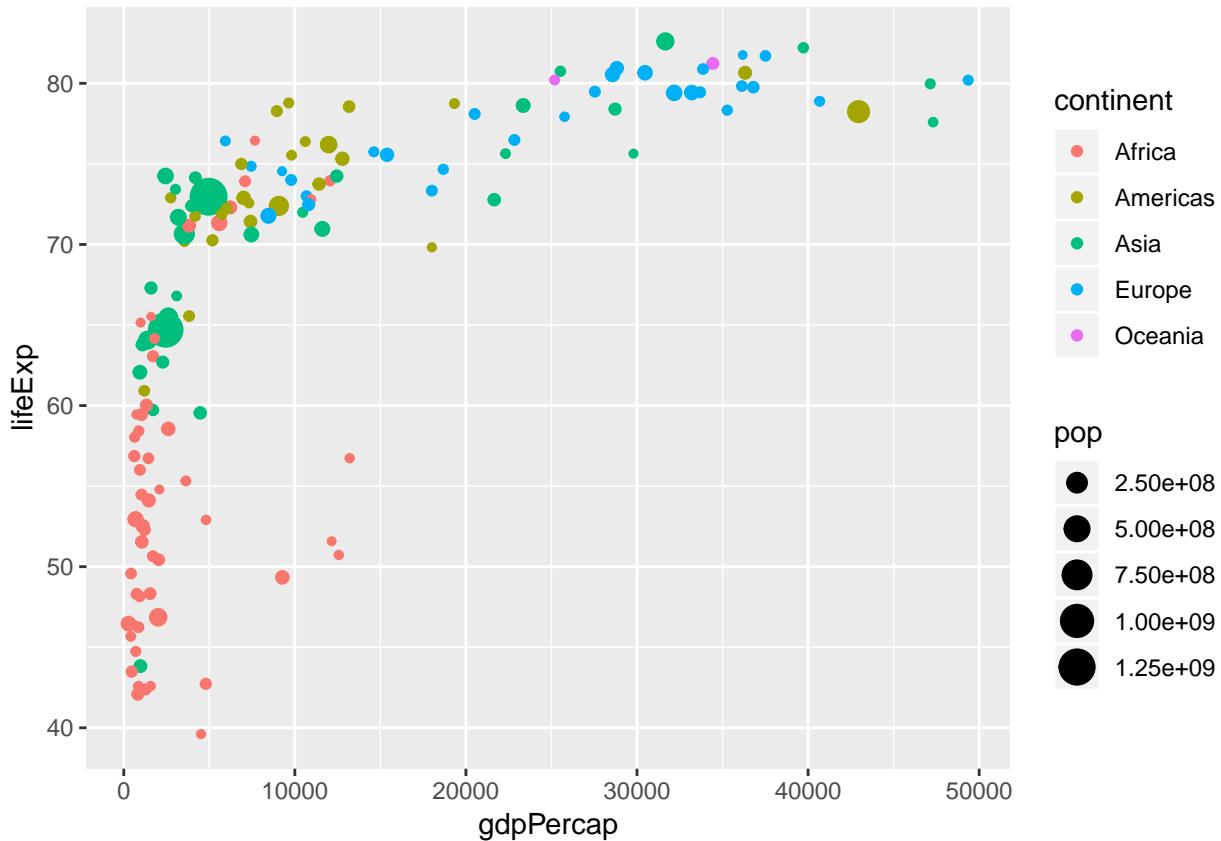
Off to work!

```
library(gapminder)
head(gapminder)

## # A tibble: 6 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.
## # ... with 1 more row
```

The data already looks tidy. All we have to do is to subset to a single year. Let's see what ggplot produces if we simply specify the aesthetics to an appropriate geometry.

```
gapminder %>% filter(year == 2007) %>
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point()
```



A solid foundation. But to close in on the *Gapminder World* chart we need to customize our scales.

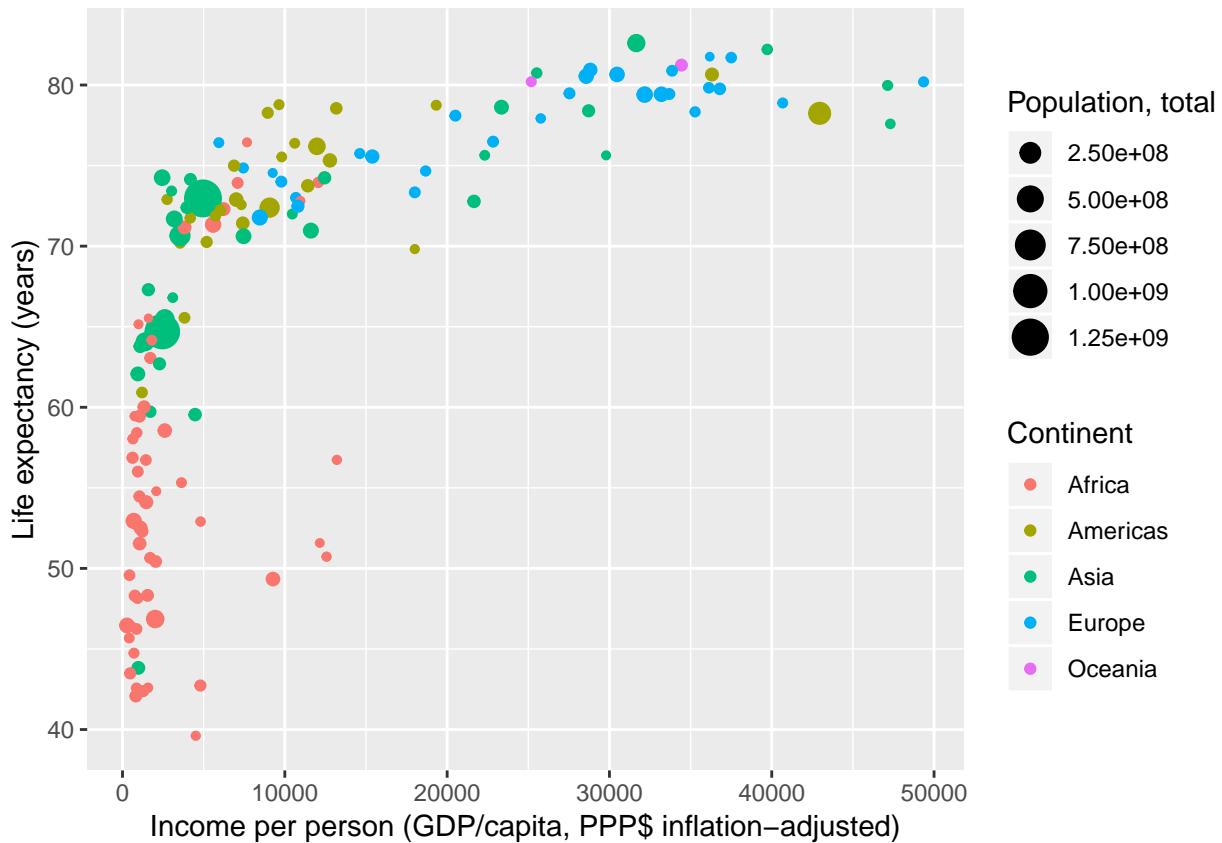
When changing scale attributes we have to make sure to make the changes on the appropriate scale. Just ask yourself:

- 1) What aesthetic does the scale correspond to? `scale_<name of aesthetic>_*`
- 2) Am I dealing with a *discrete* or *continuous* variable? `scale_*_<continuous|discrete>`

4.2.2.1 Naming scales

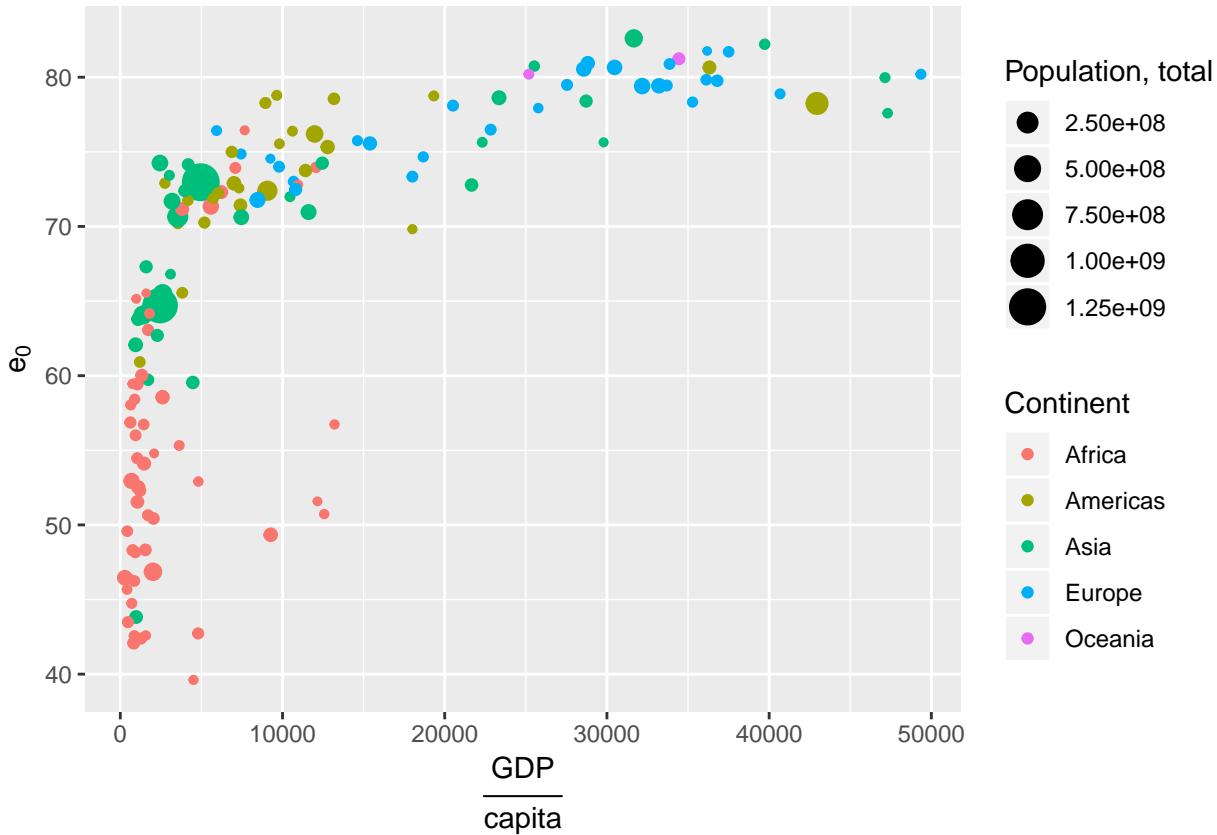
Once you know which scales to use, names are trivial to change.

```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)") +
  scale_y_continuous(name = "Life expectancy (years)") +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



You can also use mathematical annotation in your scale names. For further information consult `?plotmath`.

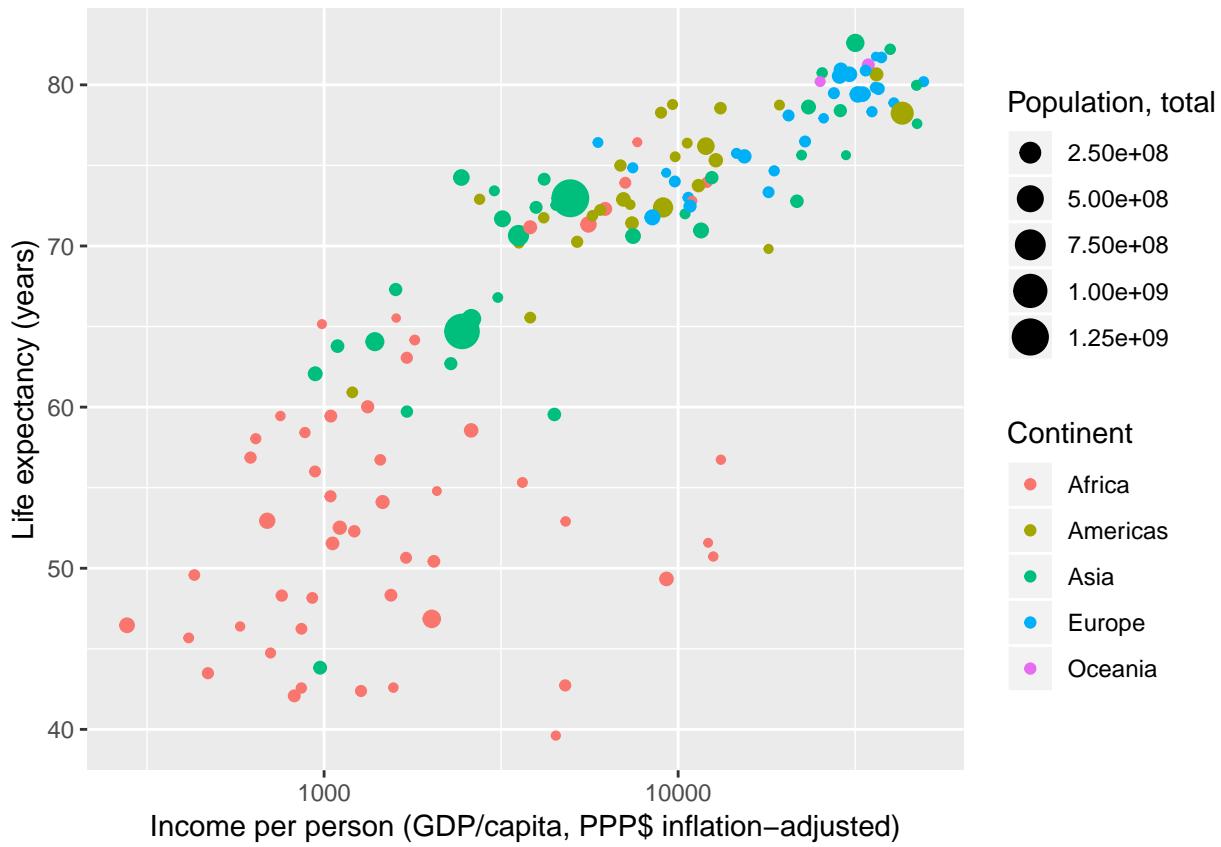
```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = expression(over(GDP, capita))) +
  scale_y_continuous(name = expression(e[0])) +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



4.2.2.2 Scale transformations

Next, we deal with *scale transformations*. In **Gapminder World** the x-axis is log-scaled meaning that the log of the x-axis data is taken before plotting. However, the labels remain on the linear scale. In that regard transforming scales is different from directly transforming the underlying data.

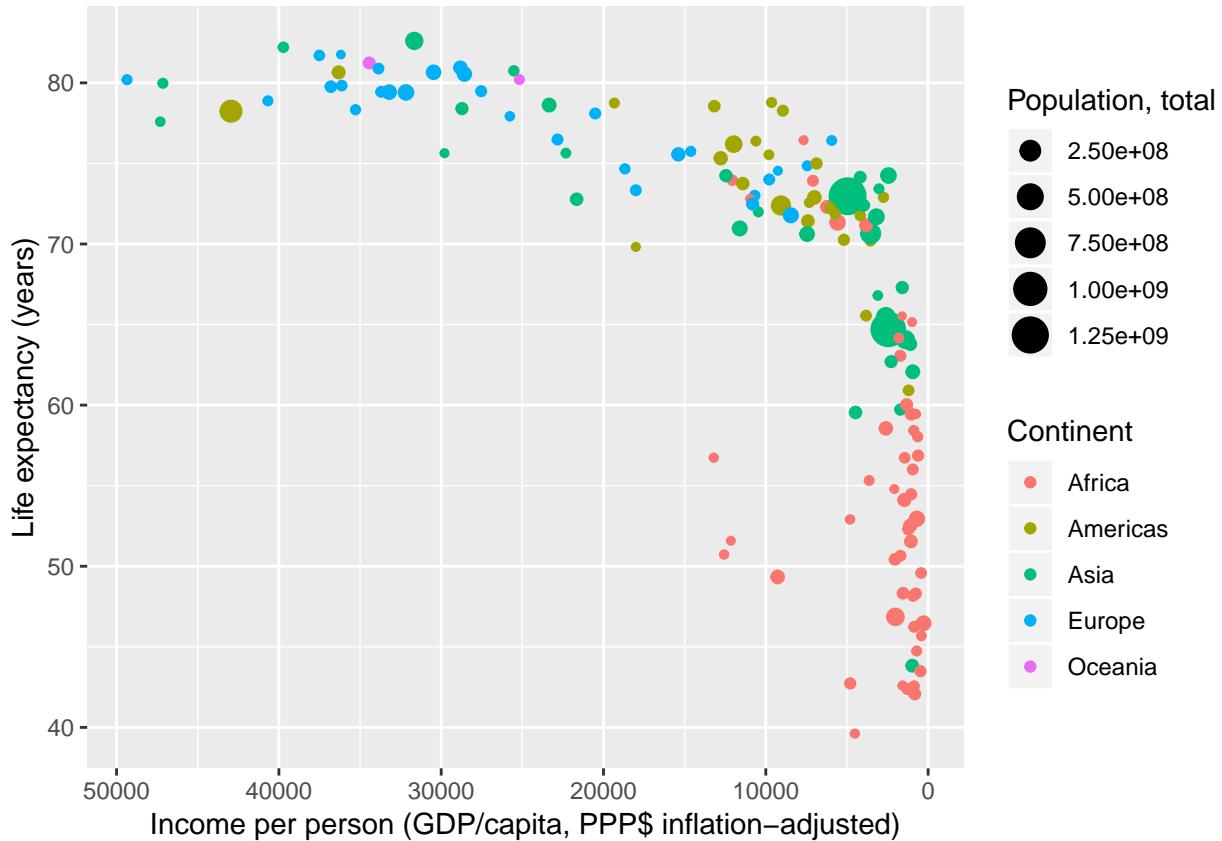
```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10") +
  scale_y_continuous(name = "Life expectancy (years)") +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



There are many different scale transformations built into ggplot. From the documentation:

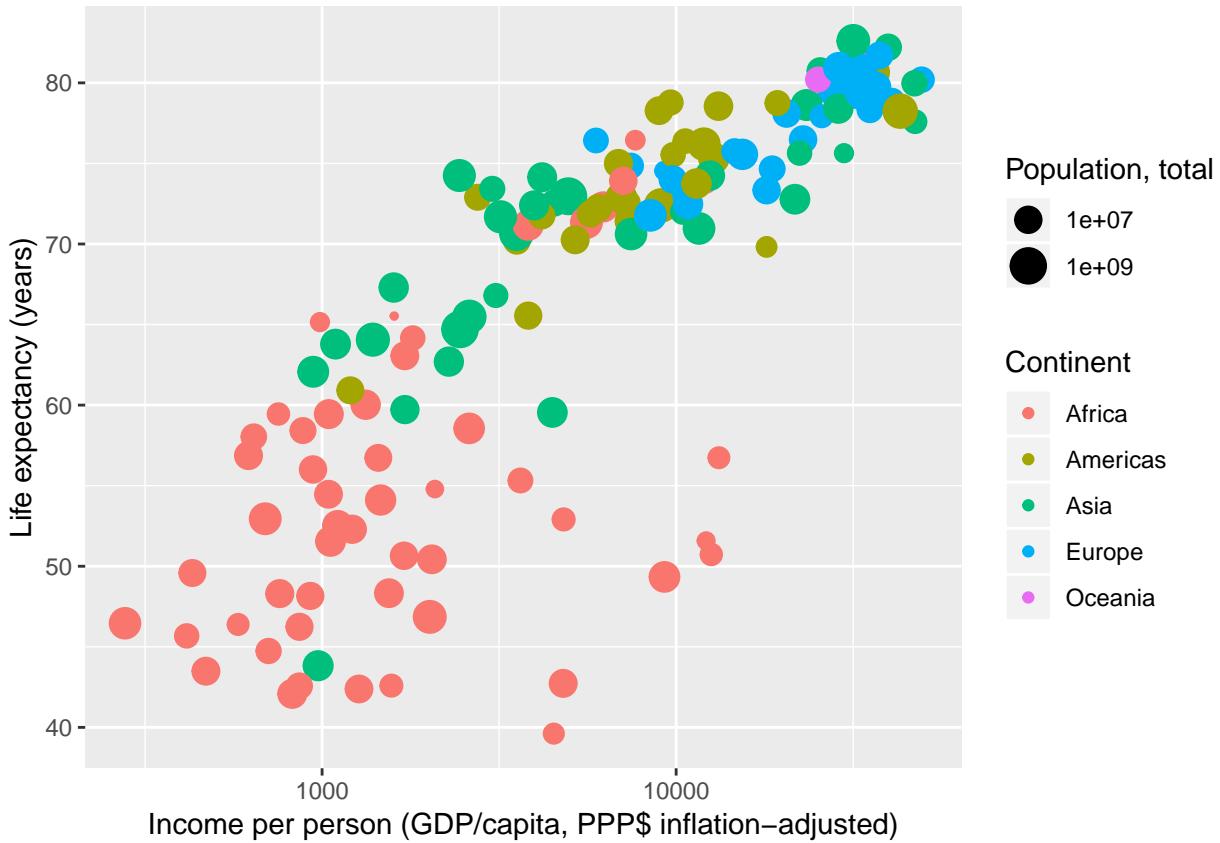
Built-in transformations include “asn”, “atanh”, “boxcox”, “exp”, “identity”, “log”, “log10”, “log1p”, “log2”, “logit”, “probability”, “probit”, “reciprocal”, “reverse” and “sqrt”.

```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "reverse") +
  scale_y_continuous(name = "Life expectancy (years)") +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



Note that the concept of scale transformations is not limited to position scales.

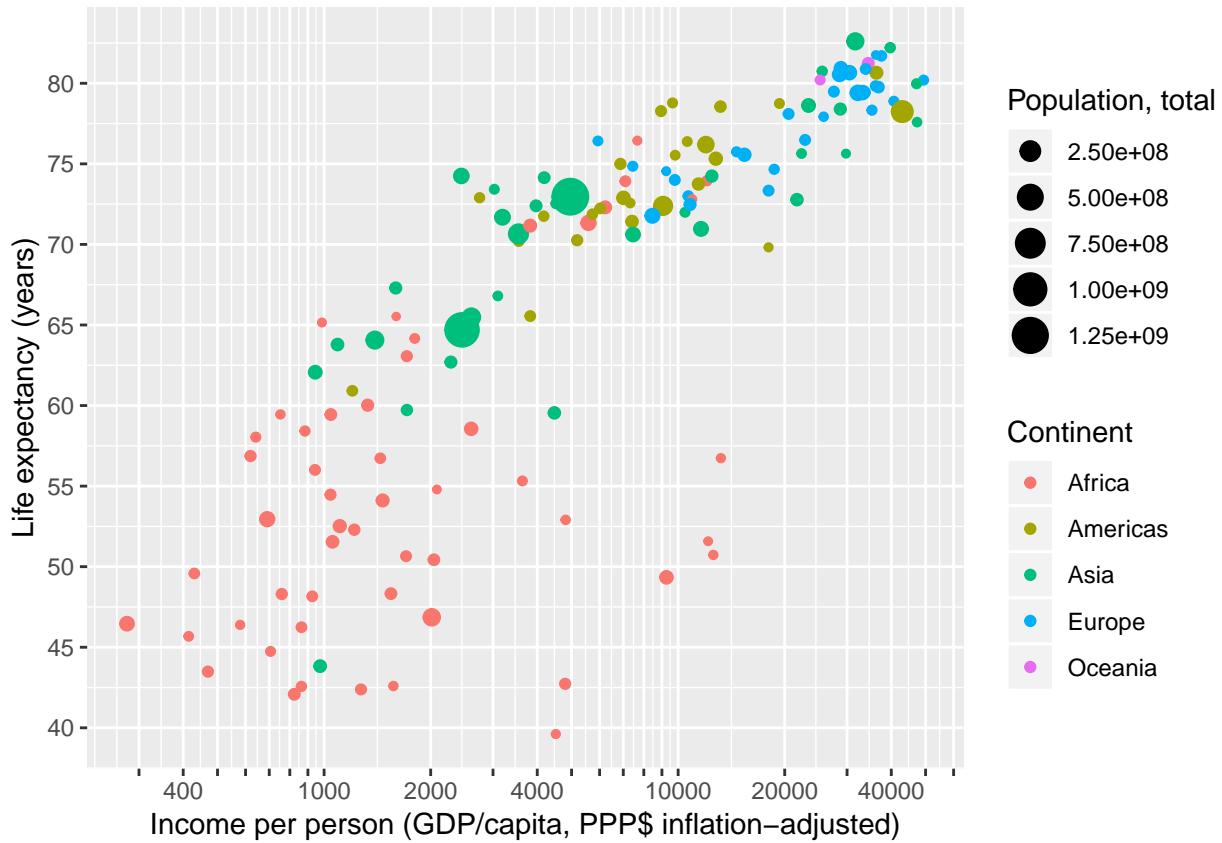
```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10") +
  scale_y_continuous(name = "Life expectancy (years)") +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total", trans = "log10")
```



4.2.2.3 Scale breaks and labels

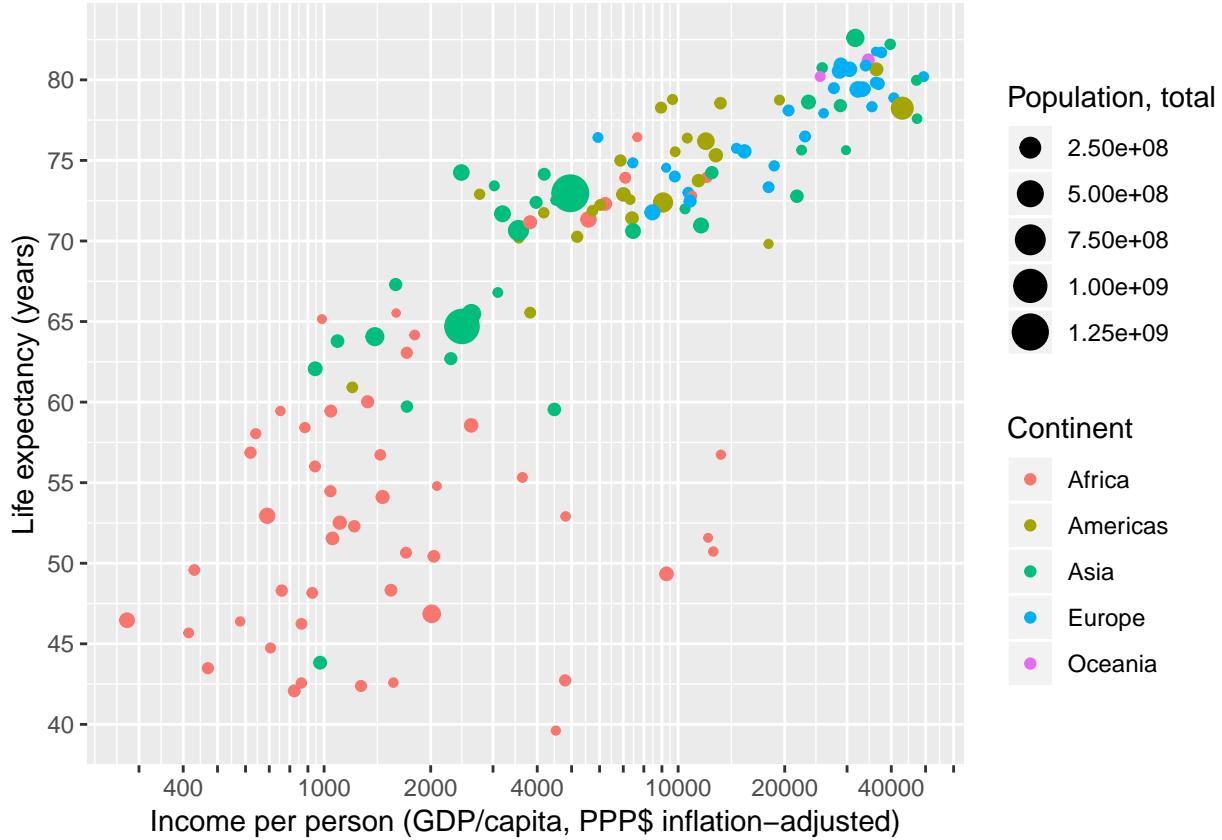
Next, we manually specify the axis *breaks* and *labels* to be the same as in *Gapminder World*. Axis breaks are the positions where tick-marks and grid-lines are drawn. Labels specify what text to put at the breaks. **Breaks and labels have to be vectors of equal length.**

```
scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



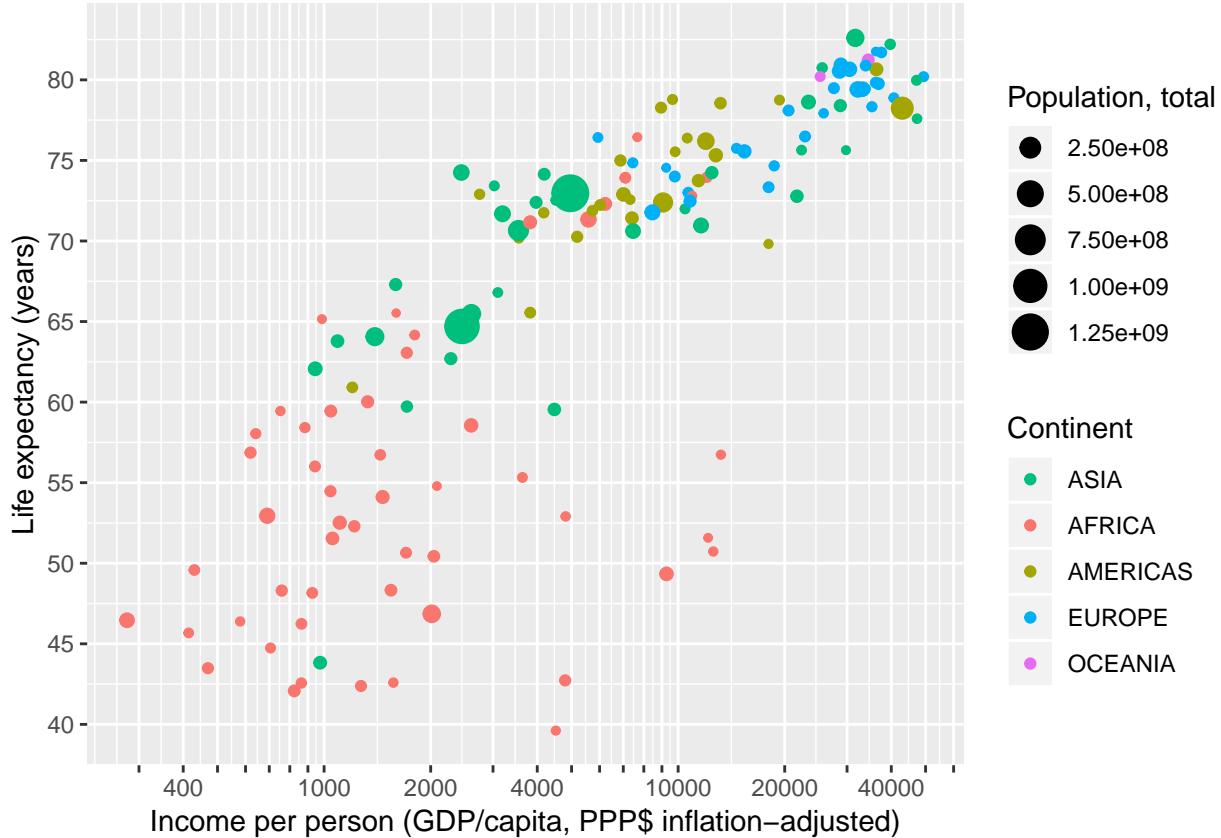
OK, that was effective but clumsy. Luckily ggplot does not care *how* we generate the vector of breaks. We can use any R function as long as it outputs a vector. Even better, instead of manually spelling out the labels for each break we can write a short function that takes the breaks as input and formats them. Much nicer code – same result.

```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10",
                     breaks = apply(expand.grid(1:9, 10^(2:4)), 1, FUN = prod)[-1],
                     labels = function(x) ifelse(grep('^[124]', x), x, '')) +
  scale_y_continuous(name = "Life expectancy (years)",
                     breaks = seq(25, 85, 5)) +
  scale_color_discrete(name = "Continent") +
  scale_size_continuous(name = "Population, total")
```



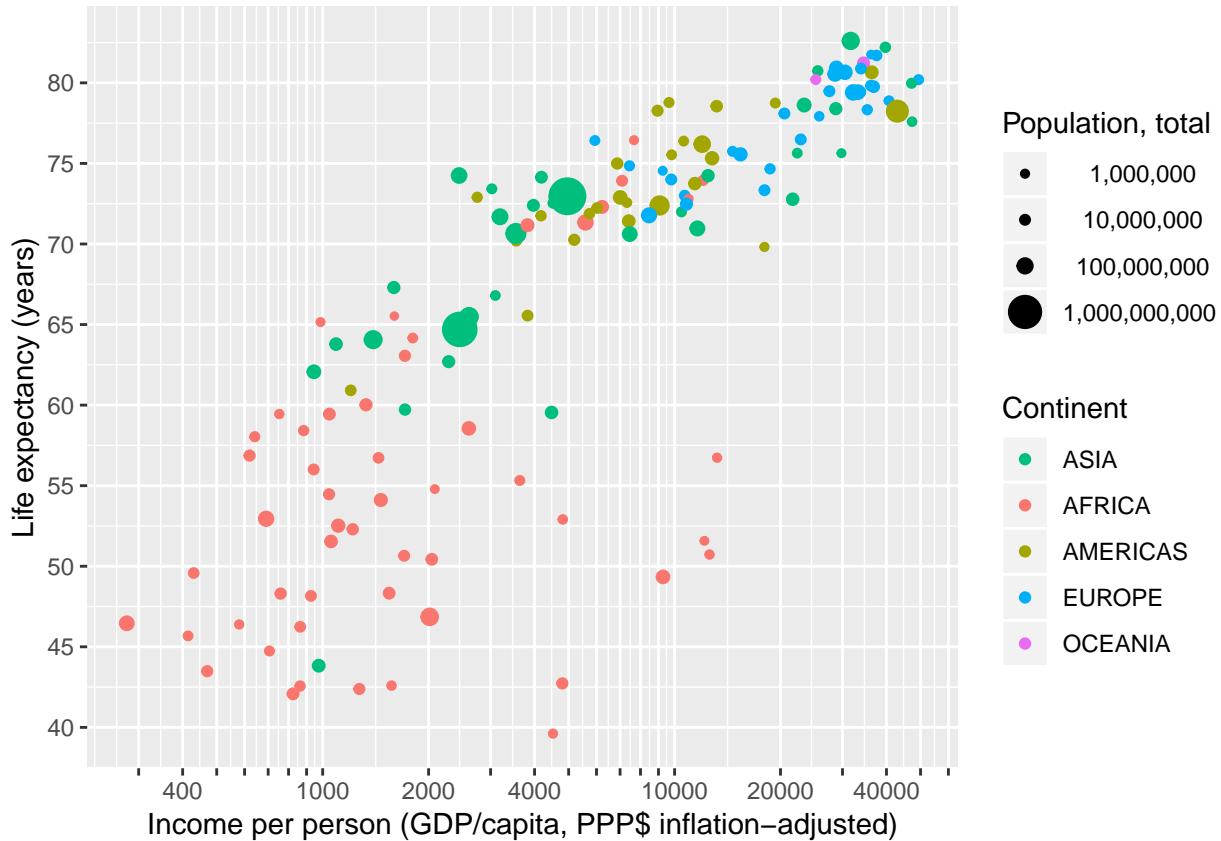
The concept of *breaks* and *labels* does not only apply to continuous axis. All scales have breaks and labels. E.g. on a colour scale the breaks are the colour keys, the labels are – well – the labels. We reorder the items on our discrete scale by specifying the breaks in the required order. We also use an R function to capitalize the labels.

```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10",
                     breaks = apply(expand.grid(1:9, 10^(2:4)), 1, FUN = prod)[-1],
                     labels = function(x) ifelse(grepl("^[124]", x), x, ""))
  scale_y_continuous(name = "Life expectancy (years)",
                     breaks = seq(25, 85, 5)) +
  scale_color_discrete(name = "Continent",
                       breaks = c("Asia", "Africa", "Americas", "Europe", "Oceania"),
                       labels = toupper) +
  scale_size_continuous(name = "Population, total")
```



Finally, let's choose some sensible breaks and labels for the size scale.

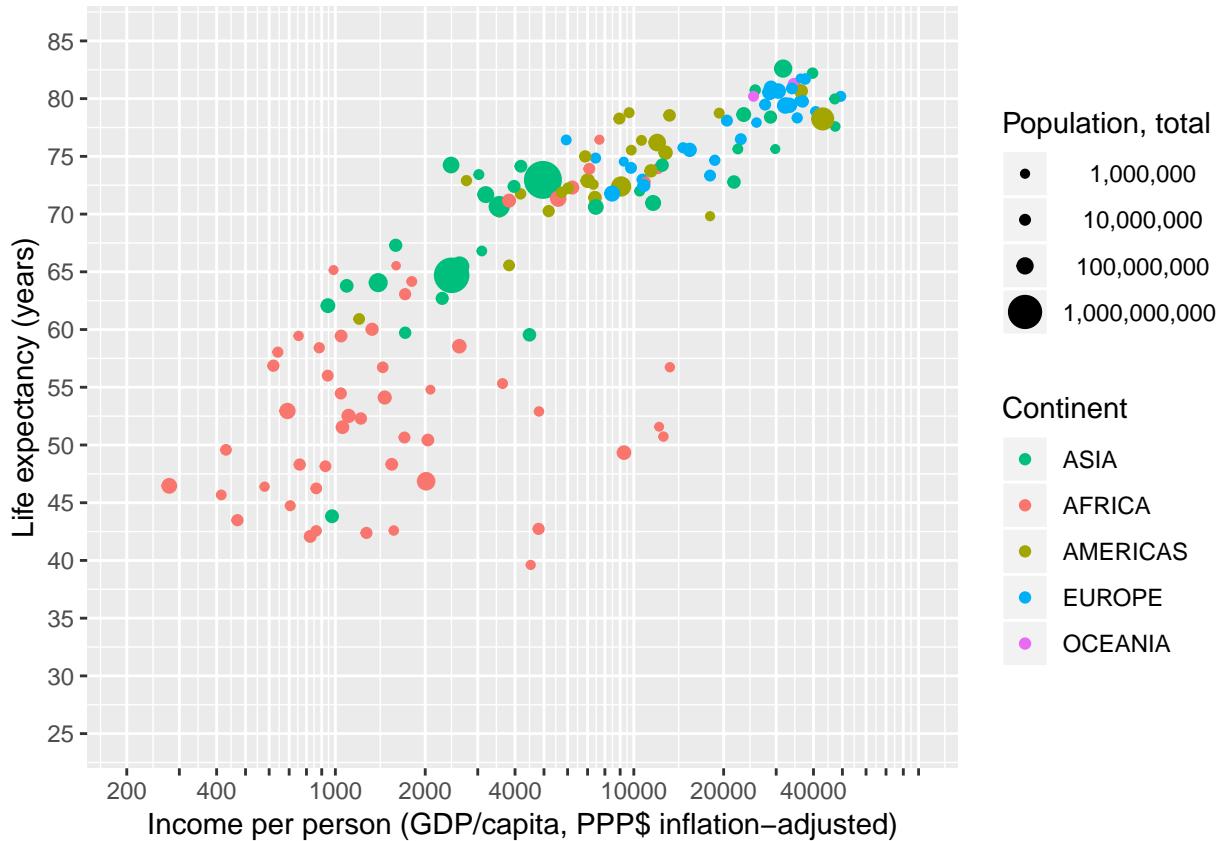
```
gapminder %>% filter(year == 2007) %>
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10",
                     breaks = apply(expand.grid(1:9, 10^(2:4)), 1, FUN = prod)[-1],
                     labels = function(x) ifelse(grepl("^[124]", x), x, ""))
  scale_y_continuous(name = "Life expectancy (years)",
                     breaks = seq(25, 85, 5)) +
  scale_color_discrete(name = "Continent",
                       breaks = c("Asia", "Africa", "Americas", "Europe", "Oceania"),
                       labels = toupper) +
  scale_size_continuous(name = "Population, total",
                        breaks = c(1E6, 10E6, 100E6, 1E9),
                        labels = function(x) format(x, big.mark = ",", scientific = FALSE))
```



4.2.2.4 Scale limits

We match the maximum and minimum value of our xy-scales with those of the *Gapminder World* chart by specifying the *limits* of the scales.

```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPerCap, y = lifeExp, size = pop, colour = continent)) +
  geom_point() +
  scale_x_continuous(name = "Income per person (GDP/capita, PPP$ inflation-adjusted)",
                     trans = "log10",
                     breaks = apply(expand.grid(1:9, 10^(2:4)), 1, FUN = prod)[-1],
                     labels = function(x) ifelse(grepl("^[124]", x), x, ""),
                     limits = c(200, 90000)) +
  scale_y_continuous(name = "Life expectancy (years)",
                     breaks = seq(25, 85, 5),
                     limits = c(25, 85)) +
  scale_color_discrete(name = "Continent",
                       breaks = c("Asia", "Africa", "Americas", "Europe", "Oceania"),
                       labels = toupper) +
  scale_size_continuous(name = "Population, total",
                        breaks = c(1E6, 10E6, 100E6, 1E9),
                        labels = function(x) format(x, big.mark = ",", scientific = FALSE))
```

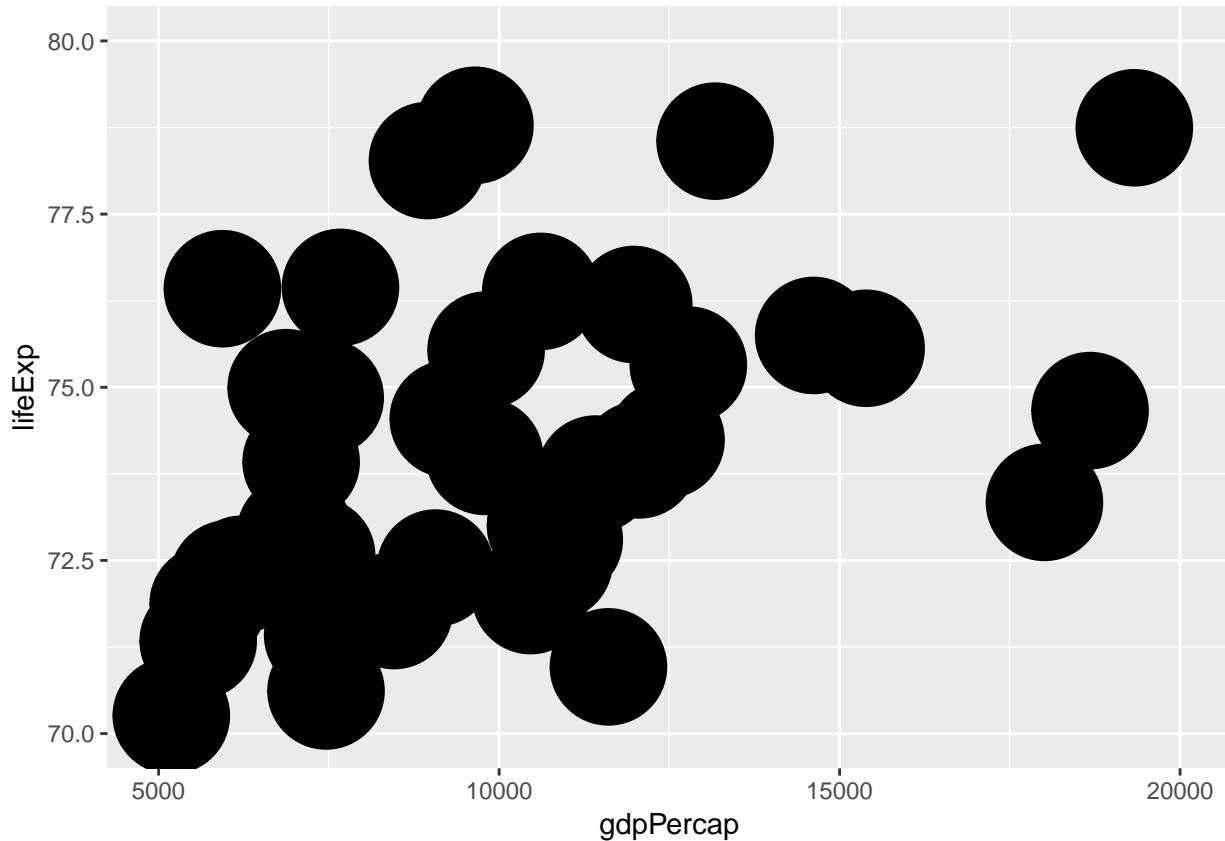


4.2.2.5 Limiting versus zooming

Note that values outside of the limits will be discarded. This is of importance if you want to zoom into a plot. Here we “zoom” by changing the limits of the scales...

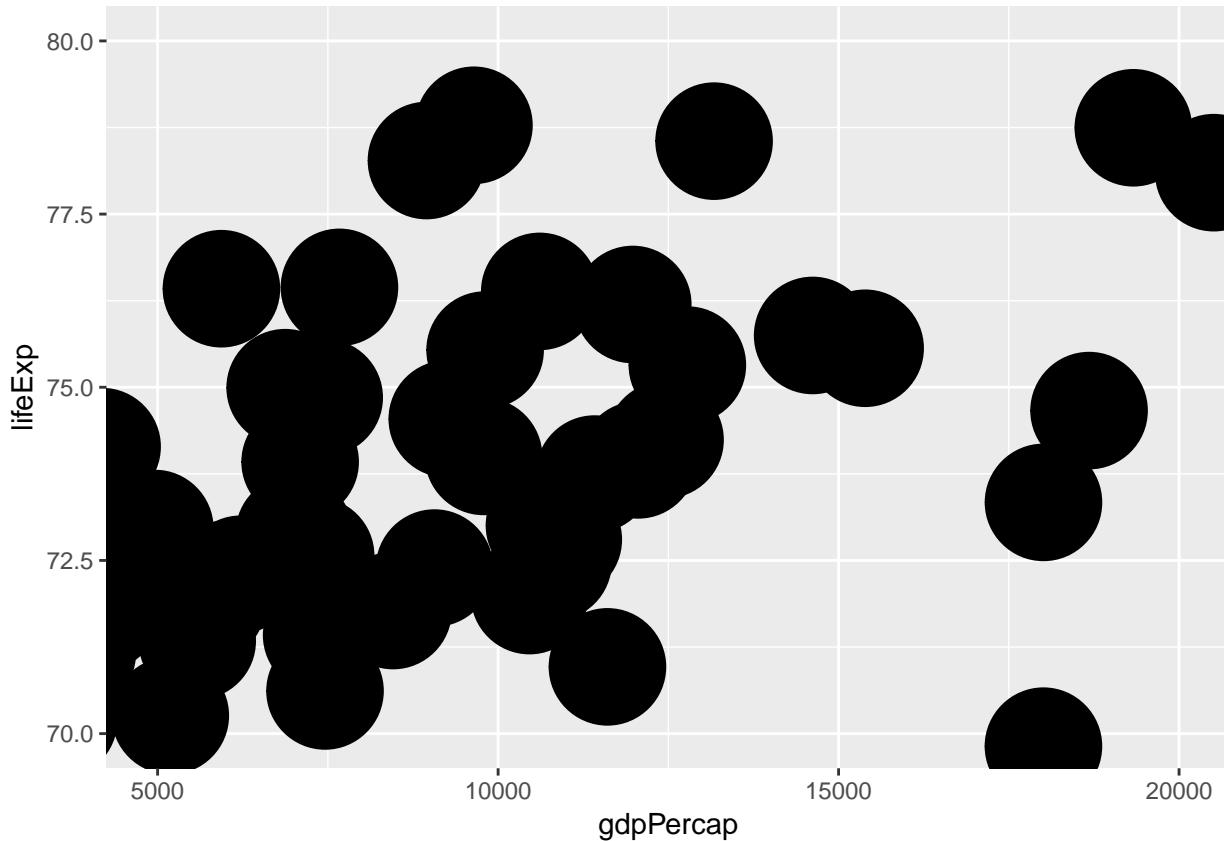
```
gapminder %>% filter(year == 2007) %>%
  ggplot(aes(x = gdpPerCap, y = lifeExp)) +
  geom_point(size = 20) +
  scale_x_continuous(limits = c(5000, 20000)) +
  scale_y_continuous(limits = c(70, 80))
```

```
## Warning: Removed 104 rows containing missing values (geom_point).
```



...and here we zoom by changing the limits of the coordinate system

```
gapminder %>% filter(year == 2007) %>%  
  ggplot(aes(x = gdpPercap, y = lifeExp)) +  
  geom_point(size = 20) +  
  coord_cartesian(xlim = c(5000, 20000), ylim = c(70, 80))
```



4.2.3 Excercise: The grammar of graphics

4.3 Order

4.3.1 Factor levels control the order of discrete scales

It is easy to order items on a numerical scale. One just puts them on the number line. Usually low on the left and high to the right. But what about discrete items? ggplot orders them according to the order of their factor levels. An example:

```
# test data
foo <- data.frame(id = 1:4,
                    sex = c("Female", "Female", "Male", "Male"))
foo
```

```
##   id   sex
## 1  1 Female
## 2  2 Female
## 3  3   Male
## 4  4   Male
```

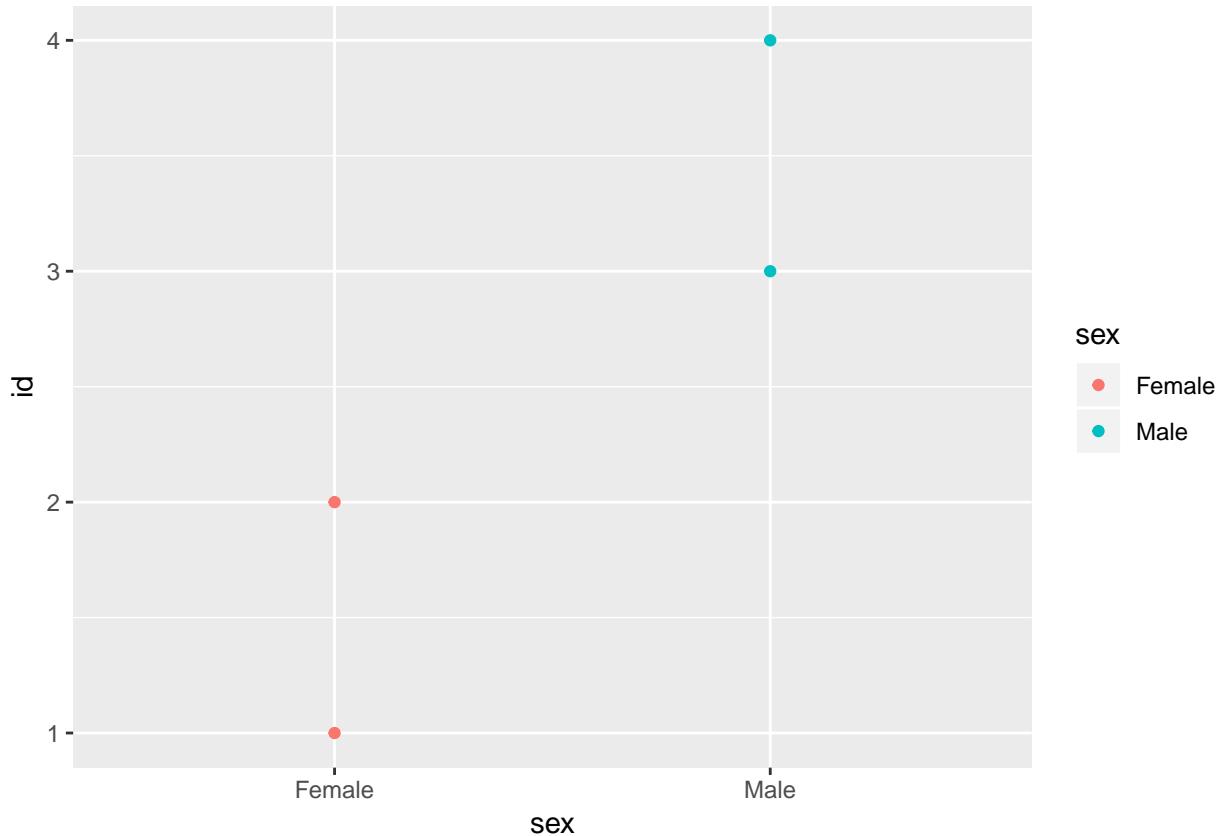
`data.frame`, just like ggplot, automatically converts a character vector to a factor using `as.factor`. The levels order of that factor follows the sequence of occurrence in the data.

```
levels(foo$sex)
```

```
## [1] "Female" "Male"
```

ggplot constructs discrete scales in the order of the levels of the underlying factor variable. Here, Females first, males after.

```
ggplot(foo) +
  geom_point(aes(x = sex, y = id, color = sex))
```



If we reverse the level order of the sex variable we change the way ggplot orders the discrete items.

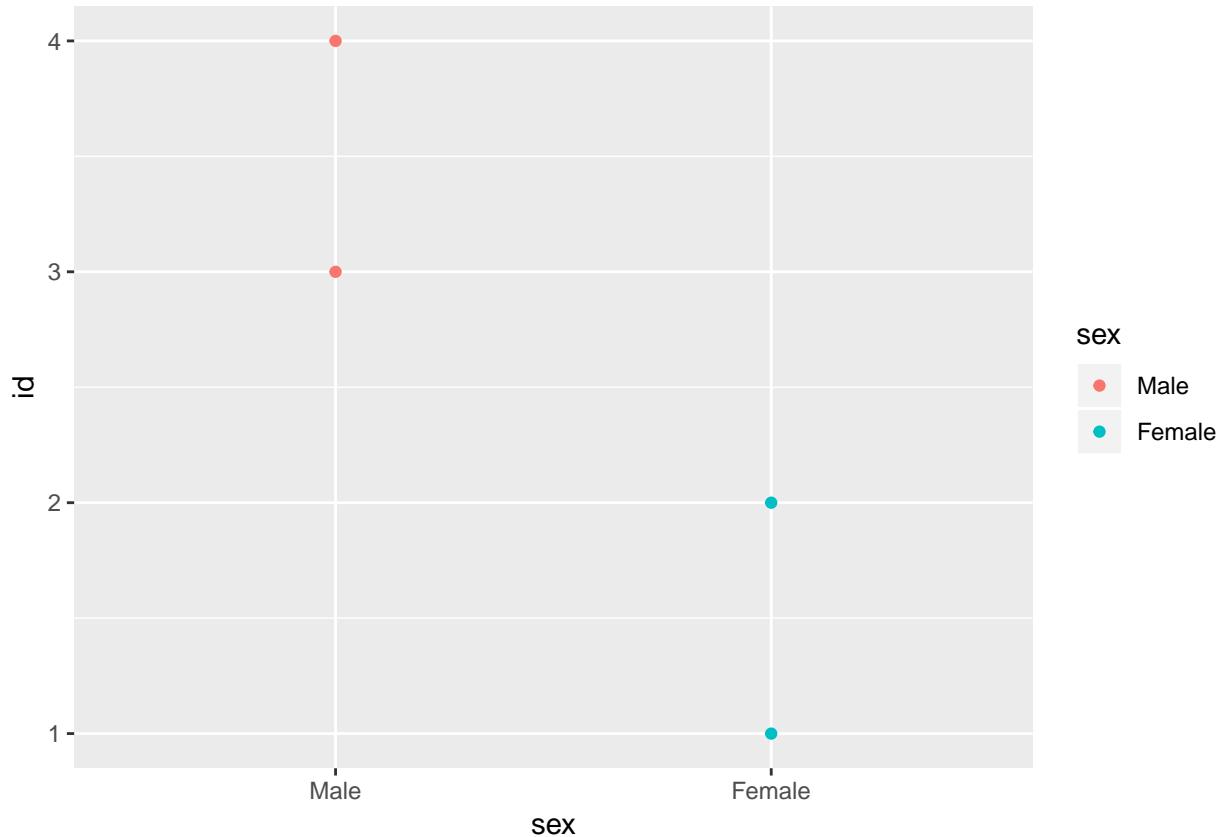
```
foo$sex
```

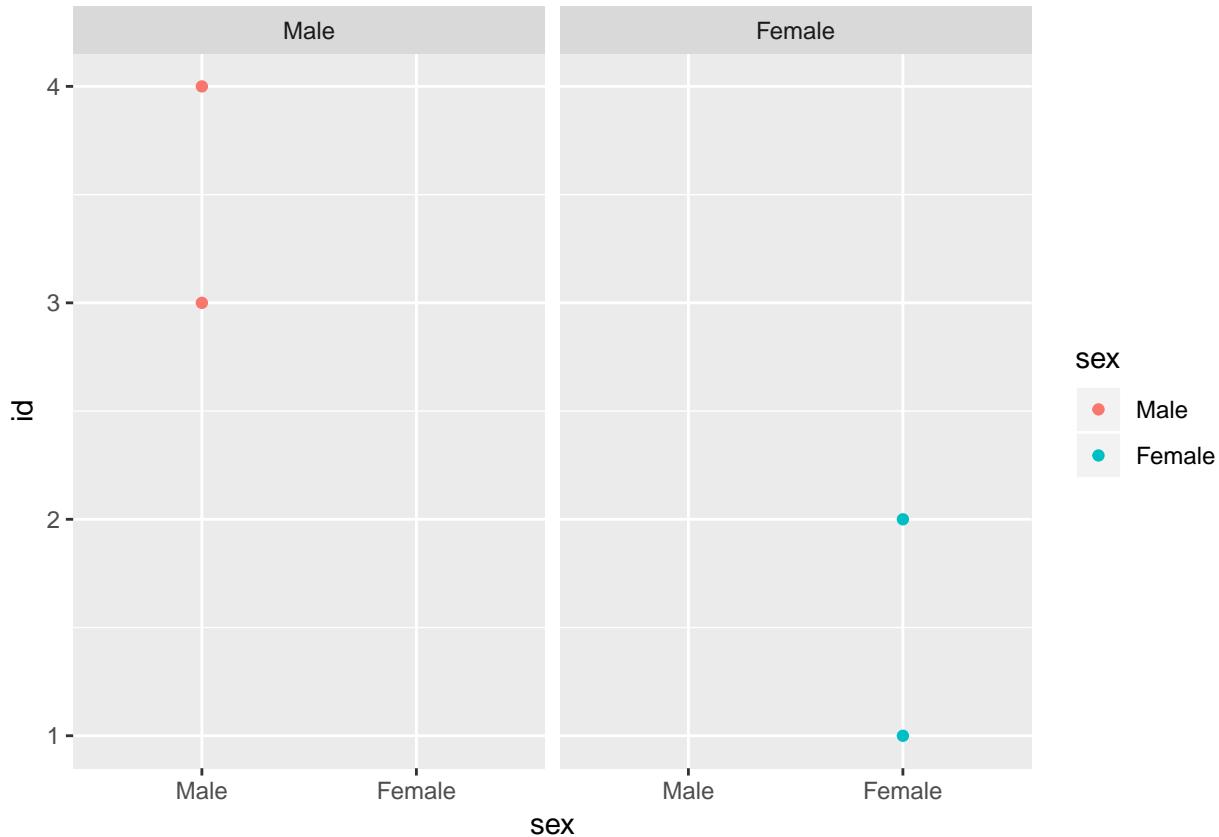
```
## [1] Female Female Male   Male
## Levels: Female Male
foo$sex <- factor(foo$sex, levels = c("Male", "Female"))
foo$sex
```

```
## [1] Female Female Male   Male
## Levels: Male Female
```

Now we have males first and females last.

```
ggplot(foo) +
  geom_point(aes(x = sex, y = id, color = sex))
```





NEVER OVERRIDE THE LEVELS DIRECTLY WHEN JUST MEANING TO CHANGE THE ORDER! You'll screw up your data. In our case we just changed the sex of the participants.

```
foo$sex

## [1] Female Female Male   Male
## Levels: Male Female

levels(foo$sex) <- c("Female", "Male")
foo$sex

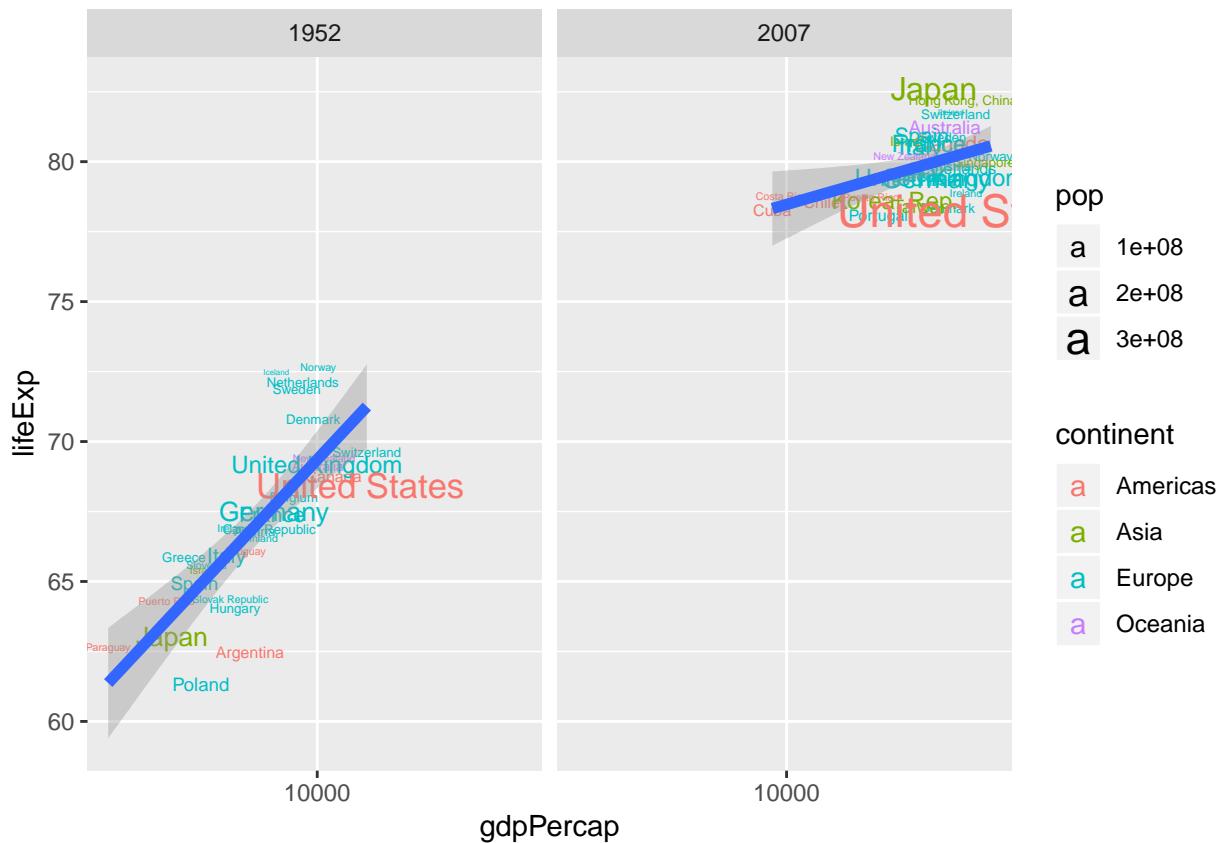
## [1] Male   Male   Female Female
## Levels: Female Male
```

4.3.2 Layers are plotted on top of each other

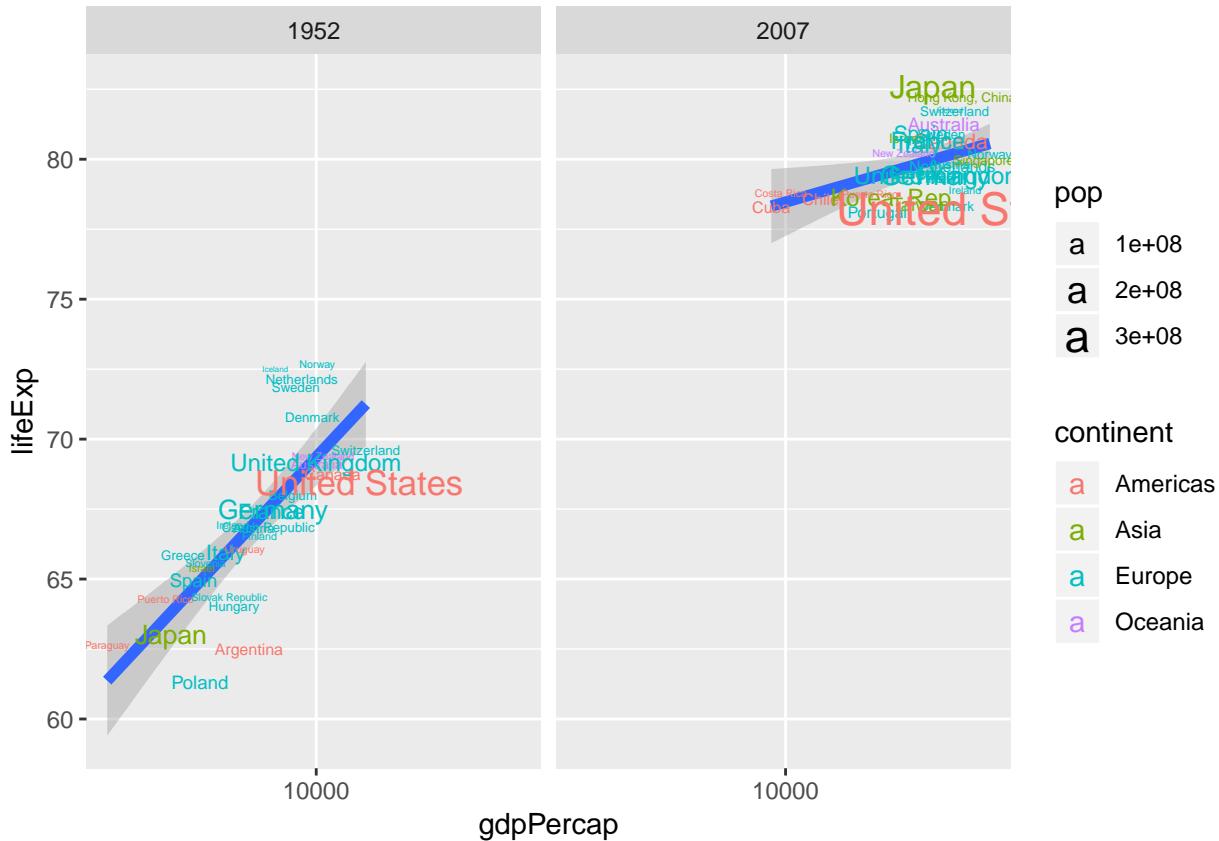
```
library(gapminder)

gapminder %>%
  filter(year %in% c(1952, 2007)) %>%
  group_by(year) %>%
  mutate(e0rank = n() - rank(lifeExp)) %>%
  filter(e0rank <= 30) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp)) +
  geom_text(aes(label = country, color = continent, size = pop)) +
  scale_x_log10() +
  geom_smooth(method = "lm", size = 2) +
```

```
facet_wrap(~year)
```



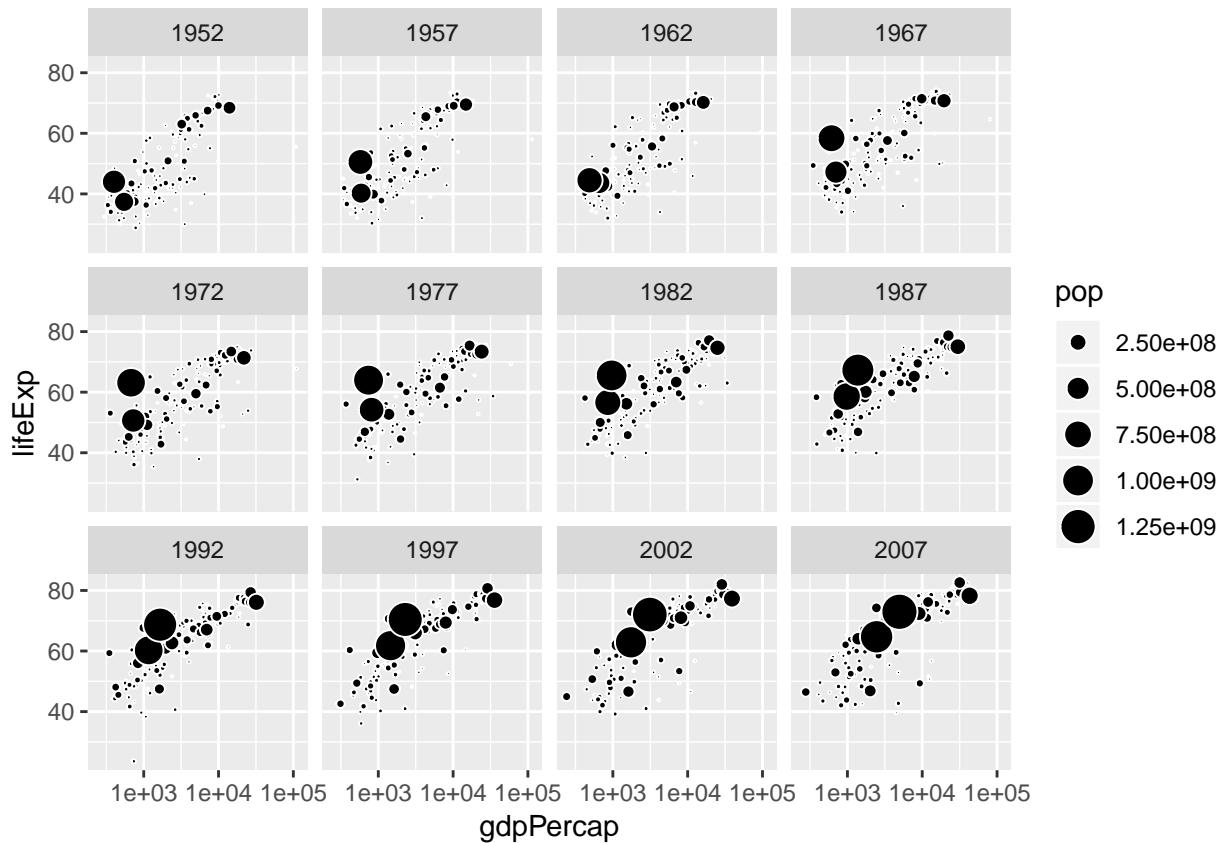
```
gapminder %>%
  filter(year %in% c(1952, 2007)) %>%
  group_by(year) %>%
  mutate(e0rank = n() - rank(lifeExp)) %>%
  filter(e0rank <= 30) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp)) +
  geom_smooth(method = "lm", size = 2) +
  geom_text(aes(label = country, color = continent, size = pop)) +
  scale_x_log10() +
  facet_wrap(~year)
```



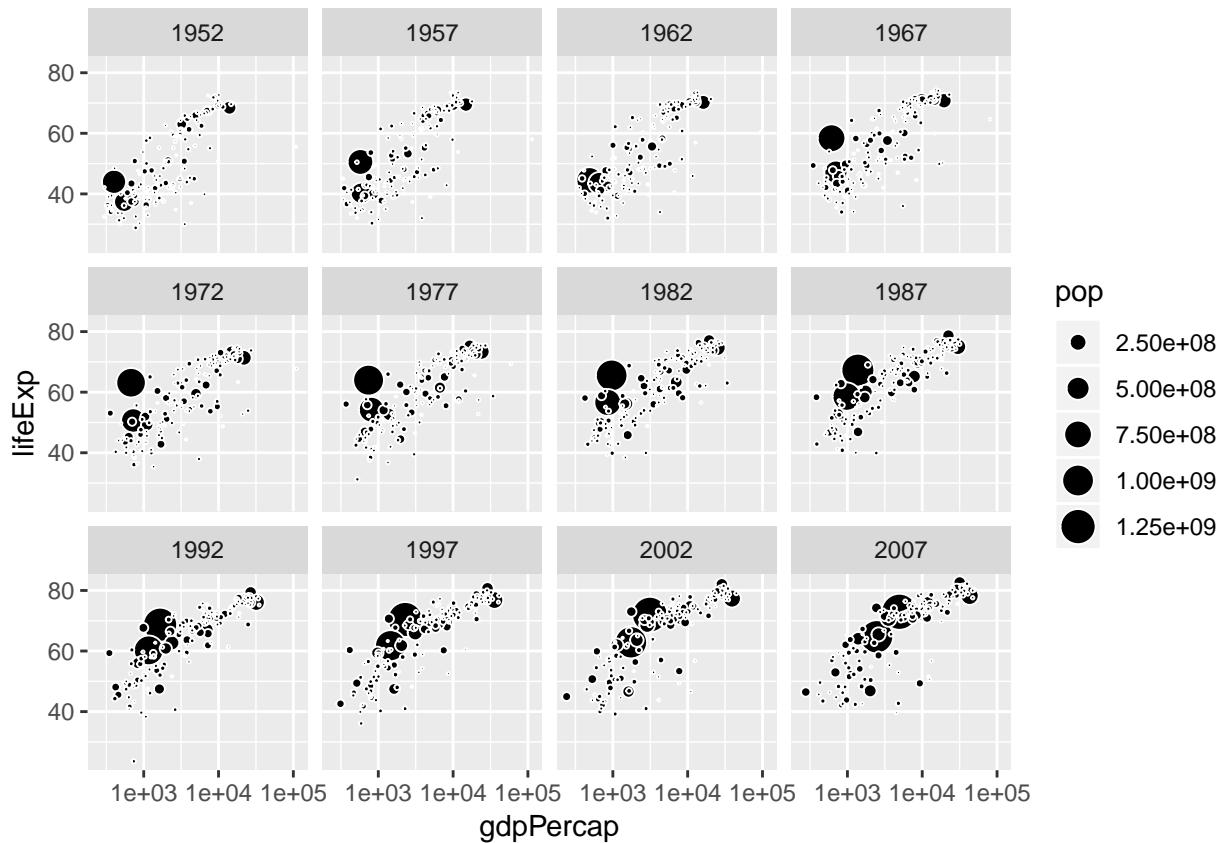
4.3.3 Sometimes the row-order of the data matters

Sometimes the row-order of a dataframe has implications for visualization. This is true for ggplots `geom_point()` which draws points in the order of occurrence in a dataframe. In the example below we scale the points by the population size of a country. Arranging the dataframe by decreasing population size makes sure that the smaller points are drawn last, i.e. on top of the larger points.

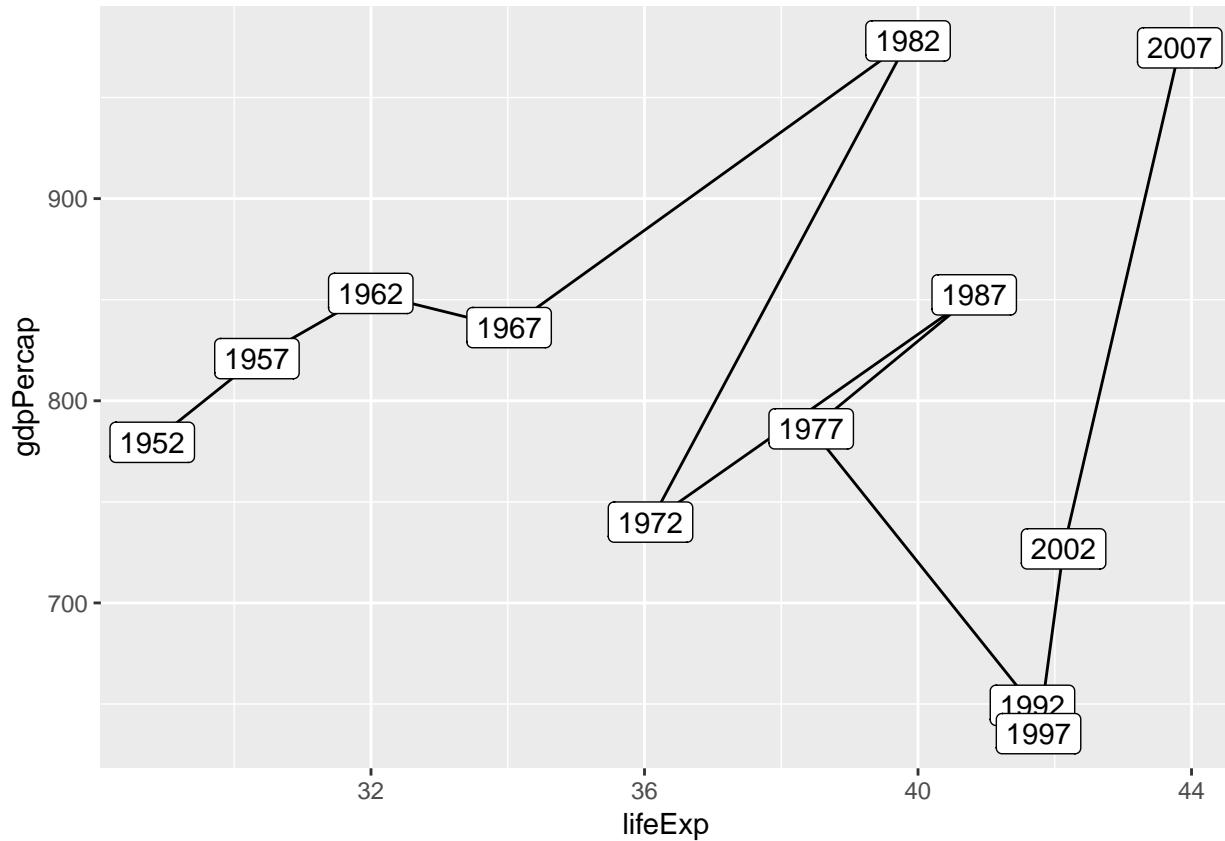
```
gapminder %>%
  arrange(pop) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop)) +
  geom_point(fill = 'black', color = 'white', shape = 21) +
  scale_x_log10() +
  scale_size_area() +
  facet_wrap(~year)
```



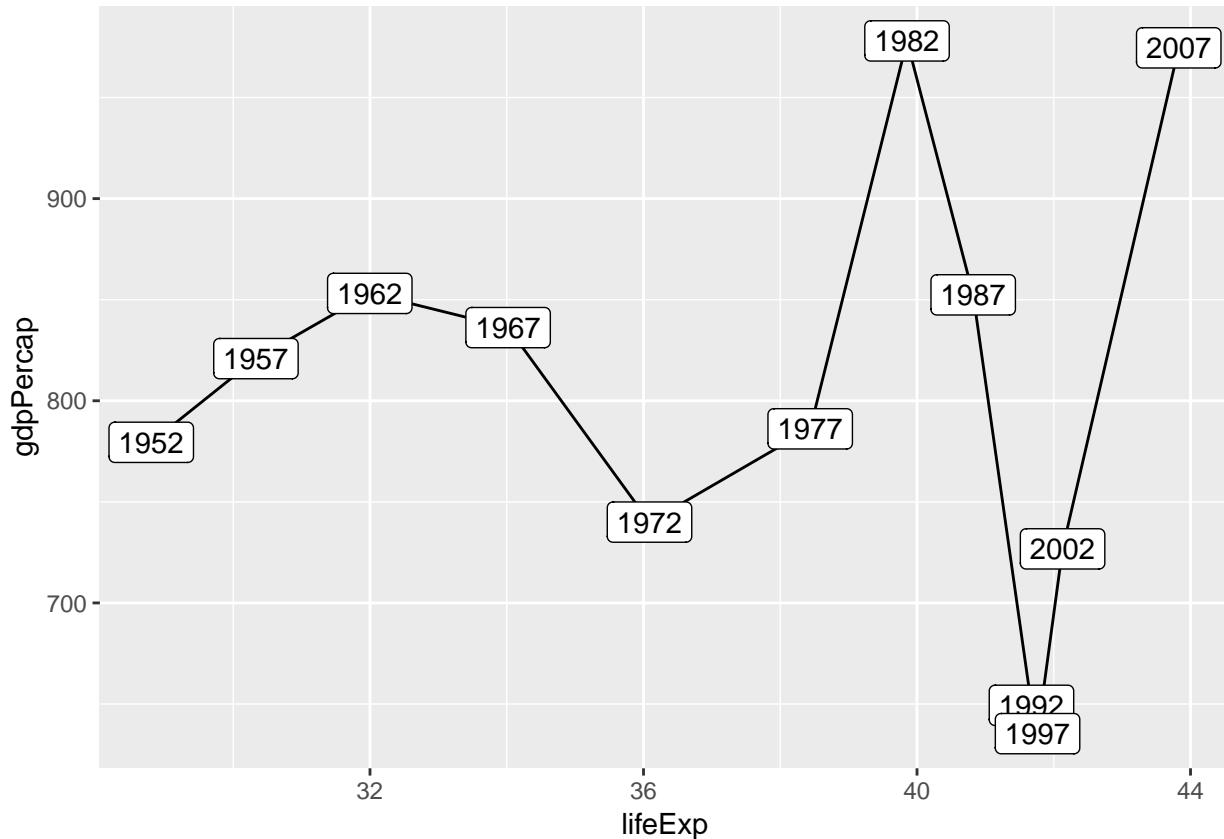
```
gapminder %>%
  arrange(desc(pop)) %>%
  ggplot(aes(x = gdpPercap, y = lifeExp, size = pop)) +
  geom_point(fill = 'black', color = 'white', shape = 21) +
  scale_x_log10() +
  scale_size_area() +
  facet_wrap(~year)
```



```
gapminder %>%
  filter(country == 'Afghanistan') %>%
  arrange(pop) %>%
  ggplot(aes(x = lifeExp, y = gdpPercap)) +
  geom_path() +
  geom_label(aes(label = year))
```



```
gapminder %>%
  filter(country == 'Afghanistan') %>%
  arrange(year) %>%
  ggplot(aes(x = lifeExp, y = gdpPercap)) +
  geom_path() +
  geom_label(aes(label = year))
```



4.4 Facets

4.4.1 Comparing sub-groups to totals

<https://drsimonj.svbtle.com/plotting-background-data-for-groups-with-ggplot2>

4.5 Chart type vocabulary

4.5.1 Visualizing distributions

Distributions are at the heart of statistics as they inform us about the “typical” in a population, the degree of deviation from the typical, the “extreme”, and everything in between. Visualizing the distribution of a collection of values allows us to

- appreciate the diversity in our sample,
- understand the variability around a mean,
- choose the correct model specification,
- decide if the data is iid.

4.5.1.1 Continuous

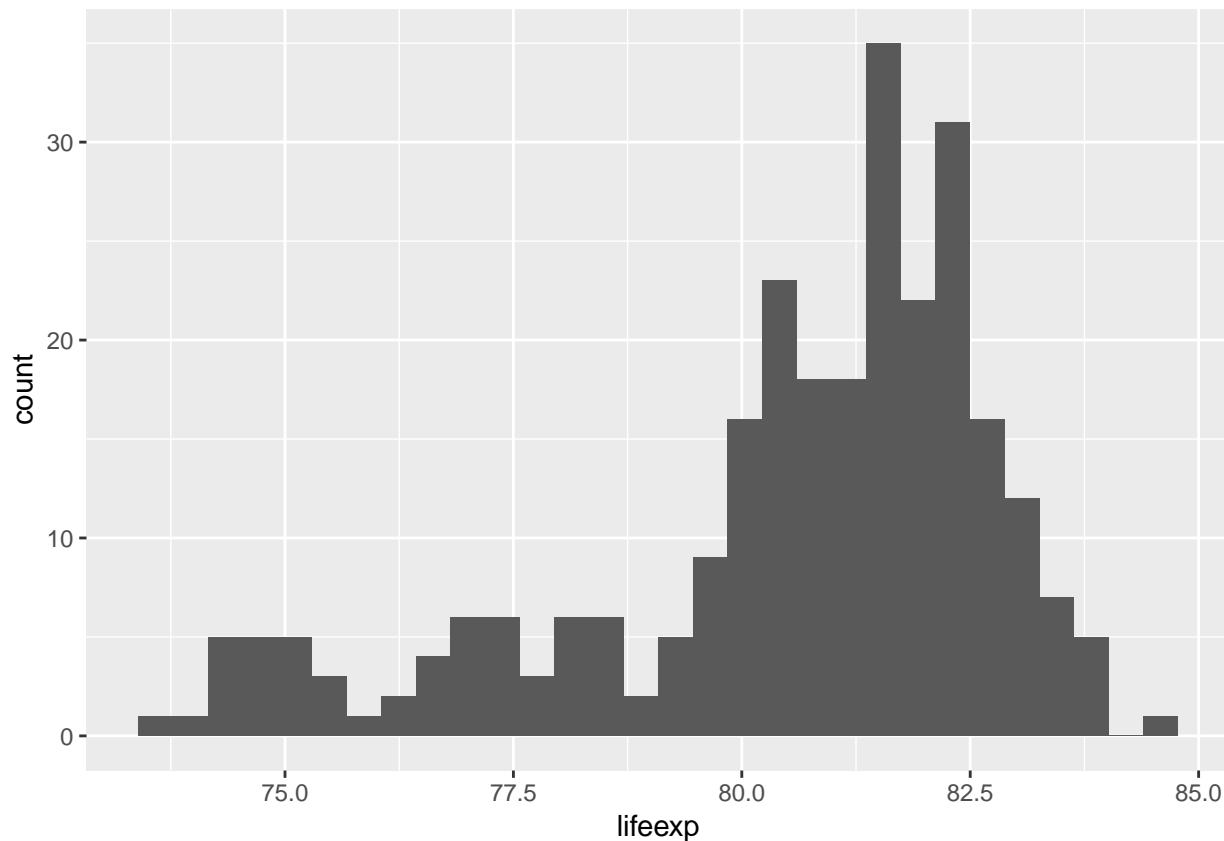
```
# European regional population statistics
load('data/euro_regio/euro_regio_eu.Rdata')
```

The most popular technique to visualize a distribution is the **histogram**. Here we use it to show how life-expectancy is distributed across the regions of the European Union in 2015.

```
euro_regio_eu %>%
  filter(year == 2015) %>%
  ggplot() +
  geom_histogram(aes(x = lifeexp))
```

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

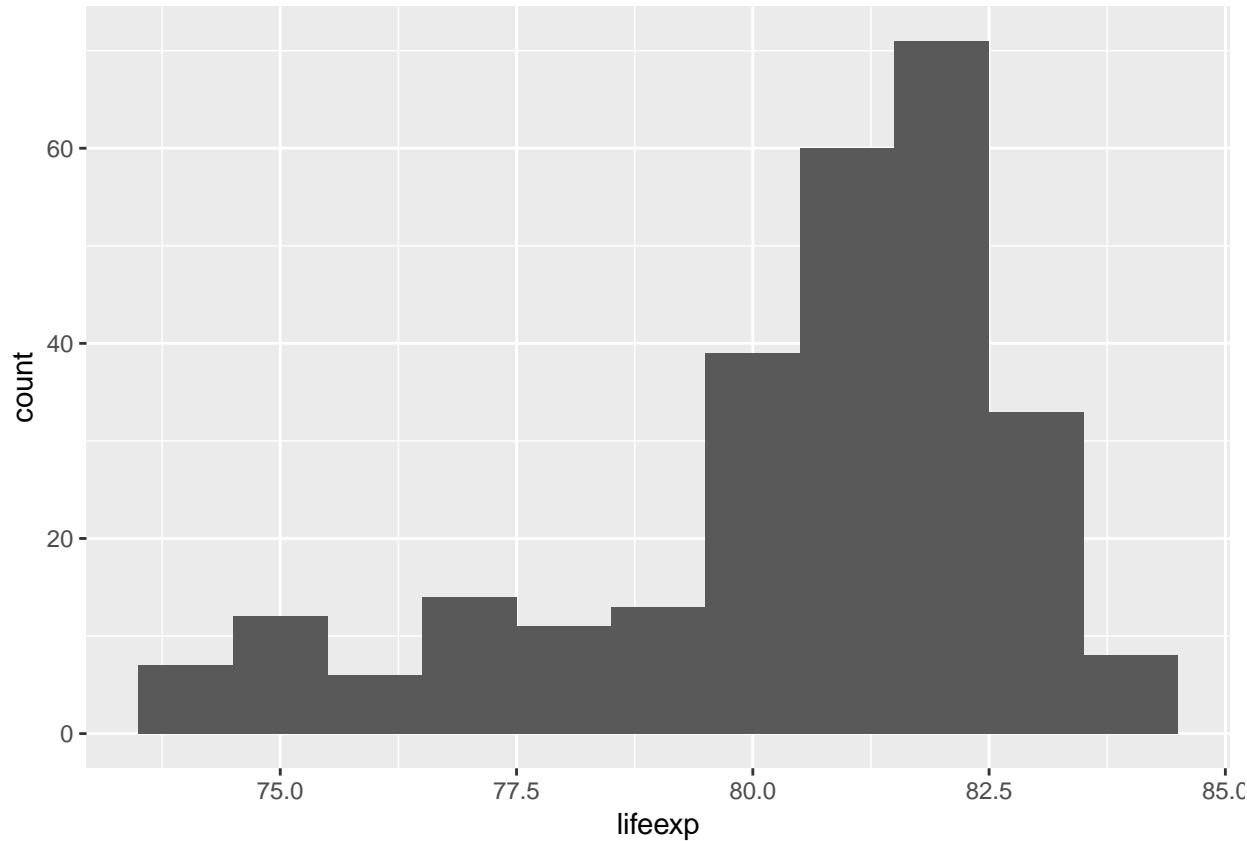
```
## Warning: Removed 18 rows containing non-finite values (stat_bin).
```



A histogram is a visual representation of *binned data*: a variable gets cut into intervals, the cases tabulated over those intervals and the resulting counts plotted as a shaded region. This whole binning operation is performed by `geom_histogram()`. We can change the details of that data transformation, e.g. using single year bins.

```
euro_regio_eu %>%
  filter(year == 2015) %>%
  ggplot() +
  geom_histogram(aes(x = lifeexp), binwidth = 1)
```

```
## Warning: Removed 18 rows containing non-finite values (stat_bin).
```



By default ggplot picks a binwidth of 1/30th the range of the data, yet **the optimal binwidth for a histogram depends on the range of your data, the number of observations, and the desired trade-off between detail and smoothing**. The fewer the observations, the bigger the bins need to be in order to create a usefull histogram. Say we want to show the distribution of life-expectancy among the 29 French NUTS-2 regions in 2015. Below you see 3 variations of doing that, using a binwidth of A) 1 month, B) half a year, and C) a year.

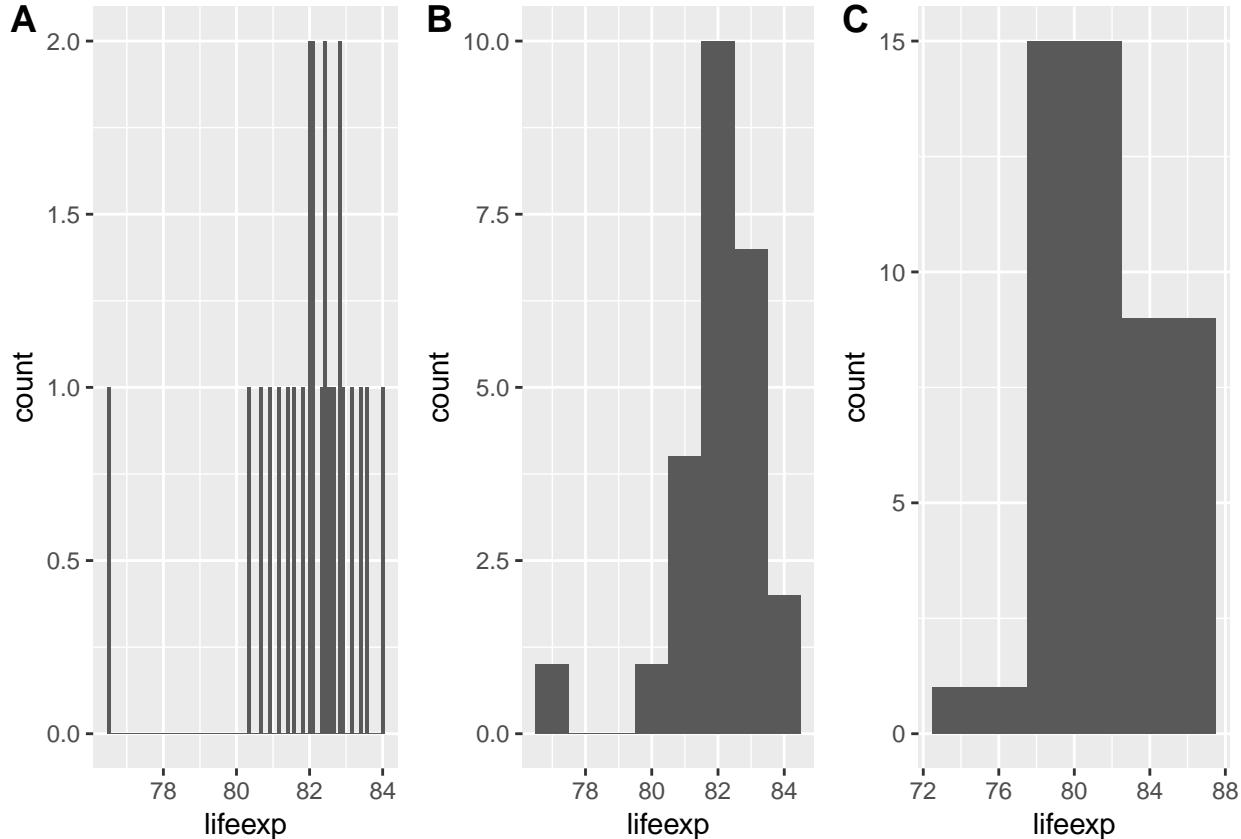
```
cowplot:::plot_grid(
  euro_regio_eu %>%
    filter(year == 2015, country_code == 'FR') %>%
    ggplot() +
    geom_histogram(aes(x = lifeexp), binwidth = 1/12),

  euro_regio_eu %>%
    filter(year == 2015, country_code == 'FR') %>%
    ggplot() +
    geom_histogram(aes(x = lifeexp), binwidth = 1),

  euro_regio_eu %>%
    filter(year == 2015, country_code == 'FR') %>%
    ggplot() +
    geom_histogram(aes(x = lifeexp), binwidth = 5),

  labels = 'AUTO', ncol = 3
)
```

```
## Warning: Removed 4 rows containing non-finite values (stat_bin).
## Warning: Removed 4 rows containing non-finite values (stat_bin).
## Warning: Removed 4 rows containing non-finite values (stat_bin).
```



Consider using a **dot-histogram** when observations are few (<100). A dot-histogram¹ draws a single point for each observation, located at the center of the respective bin. This makes for a very intuitive visualization as the individual observations are still visible despite being aggregated into bins. Sadly the implementation of dot-histograms in ggplot is a bit lacking at the time of writing which necessitates to use our data wrangling skills to get a nice result.

```
# A trick I've learned from John Tukey's EDA: Label individual cases in
# dot-histograms. Aggregate and individual view at once!
# Here's how you do it in R: (link)

the_data <-
  euro_regio_eu %>%
  filter(year == 2015, country_code == 'ES') %>%
  select(id = nuts2_code, value = unemp)

# Label by id -----
the_data %>%
  mutate(bin = cut(value, seq(0, 30, 5))) %>%
  na.omit()
```

¹ Wilkinson, L. (1999). Dot Plots. The American Statistician, 53(3), 276. <https://doi.org/10.2307/2686111>

```
group_by(bin) %>%
arrange(value) %>%
mutate(count = 1:n()) %>%
ggplot(aes(x = bin, y = count)) +
geom_point(aes(color = id), size = 11, color = 'grey80') +
geom_text(aes(label = id), size = 3.4) +
scale_x_discrete(drop = FALSE) +
theme_minimal()
```



```
# Label by value ----

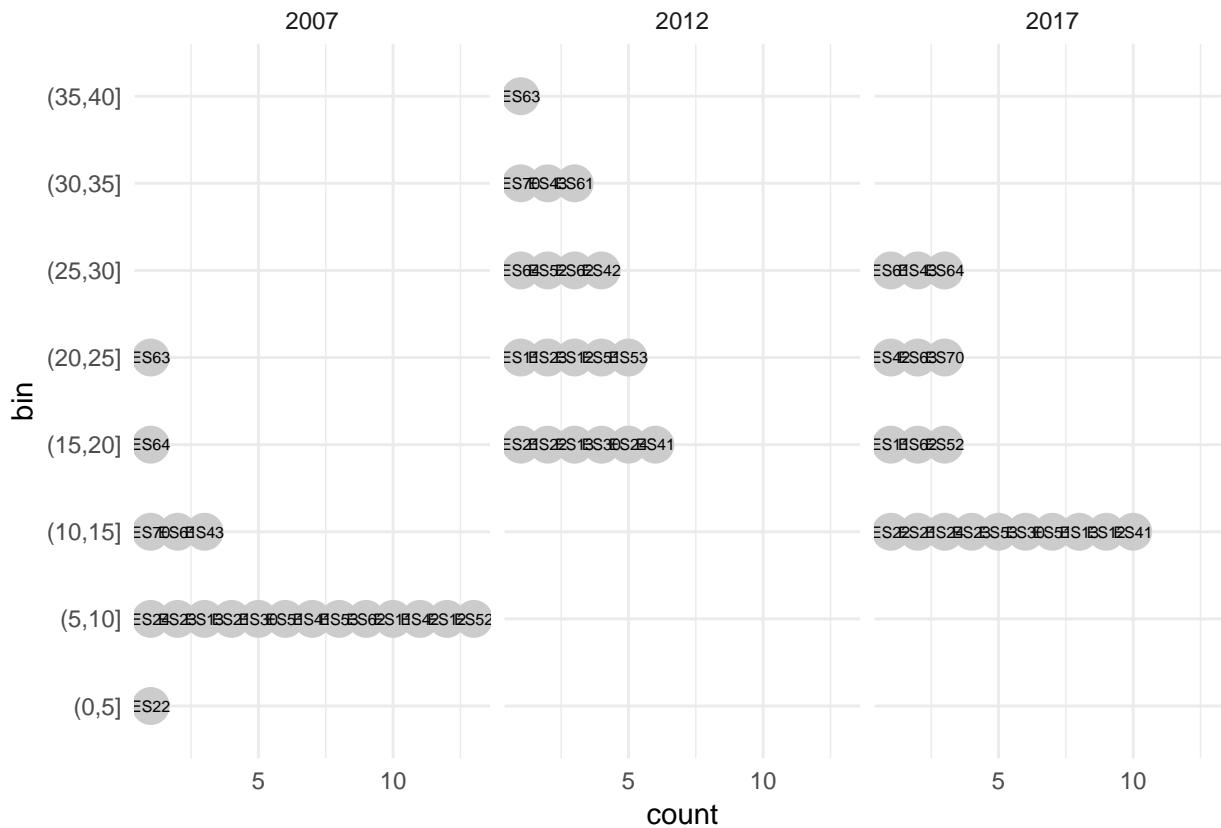
the_data %>%
  mutate(bin = cut(value, seq(0, 30, 5))) %>%
  na.omit() %>%
  group_by(bin) %>%
  arrange(value) %>%
  mutate(count = 1:n()) %>%
  ggplot(aes(x = bin, y = count)) +
  geom_point(aes(color = id), size = 11, color = 'grey80') +
  geom_text(aes(label = value), size = 3.4) +
  scale_x_discrete(drop = FALSE) +
  theme_minimal()
```



```
# Works with grouping as well ----

the_data2 <-
  euro_regio_eu %>%
  filter(country_code == 'ES', year %in% c(2007, 2012, 2017)) %>%
  select(group = year, id = nuts2_code, value = unemp)

the_data2 %>%
  mutate(bin = cut(value, seq(0, 40, 5))) %>%
  na.omit() %>%
  group_by(group, bin) %>%
  arrange(value) %>%
  mutate(count = 1:n()) %>%
  ggplot(aes(x = bin, y = count)) +
  geom_point(aes(color = id), size = 6, color = 'grey80') +
  geom_text(aes(label = id), size = 2) +
  scale_x_discrete(drop = FALSE) +
  theme_minimal() +
  coord_flip() +
  facet_wrap(~group)
```



Whenever a `geom` uses a statistical transformation, such as the binning in `geom_histogram()`, a number of new variables are internally computed by `ggplot` prior to plotting. In case of `geom_histogram()` these new variables are

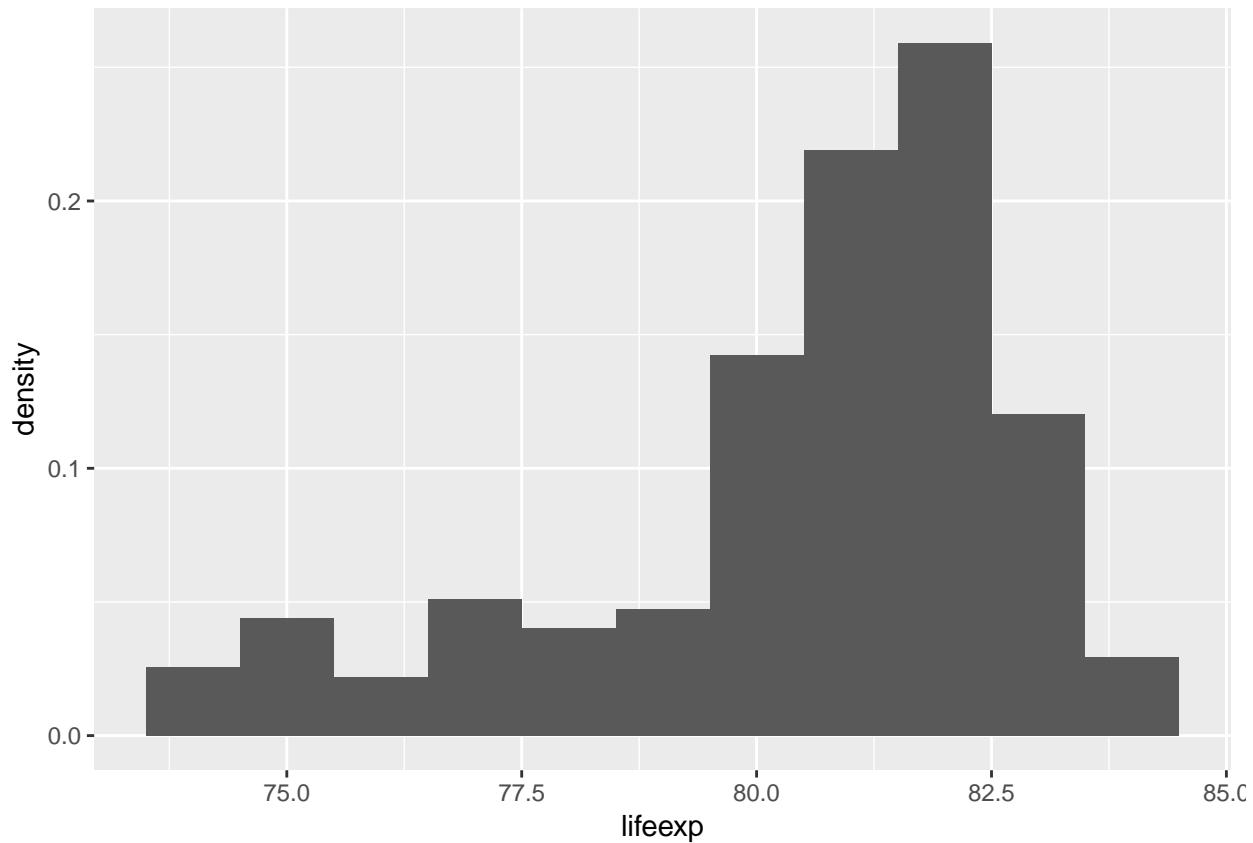
- `count`: number of points in bin
- `density`: density of points in bin
- `ncount`: count, scaled to a maximum of 1
- `ndensity`: density, scaled to a maximum of 1²

Via the `stat()` function we can use any of the computed variables in our plot. This makes it possible to draw histograms with density on the y axis instead of the default count.

```
euro_regio_eu %>%
  filter(year == 2015) %>%
  ggplot() +
  geom_histogram(aes(x = lifeexp, y = stat(density)), binwidth = 1)
```

```
## Warning: Removed 18 rows containing non-finite values (stat_bin).
```

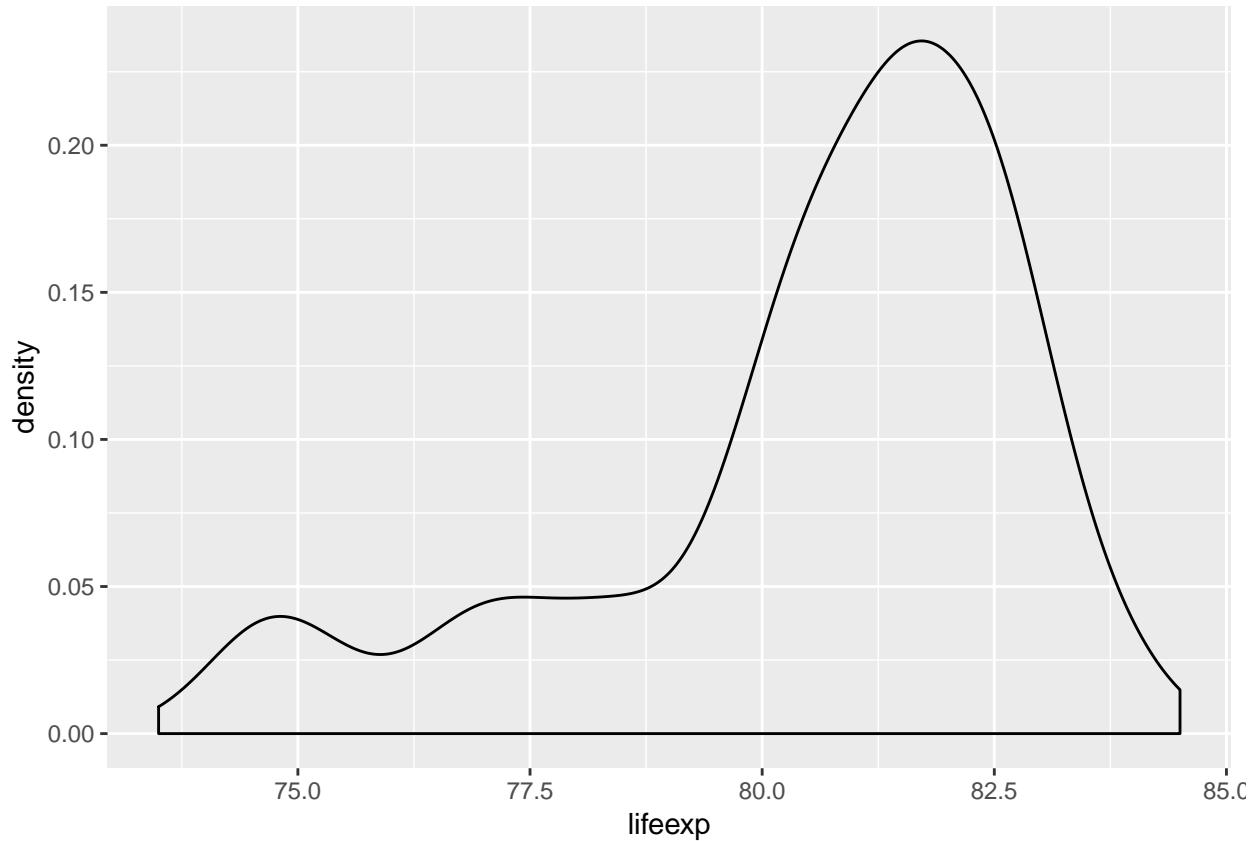
²you can find out about the computed variables by looking into the help page of a `geom`.



An alternative to the histogram is the **density plot**.

```
euro_regio_eu %>%
  filter(year == 2015) %>%
  ggplot() +
  geom_density(aes(x = lifeexp))
```

```
## Warning: Removed 18 rows containing non-finite values (stat_density).
```



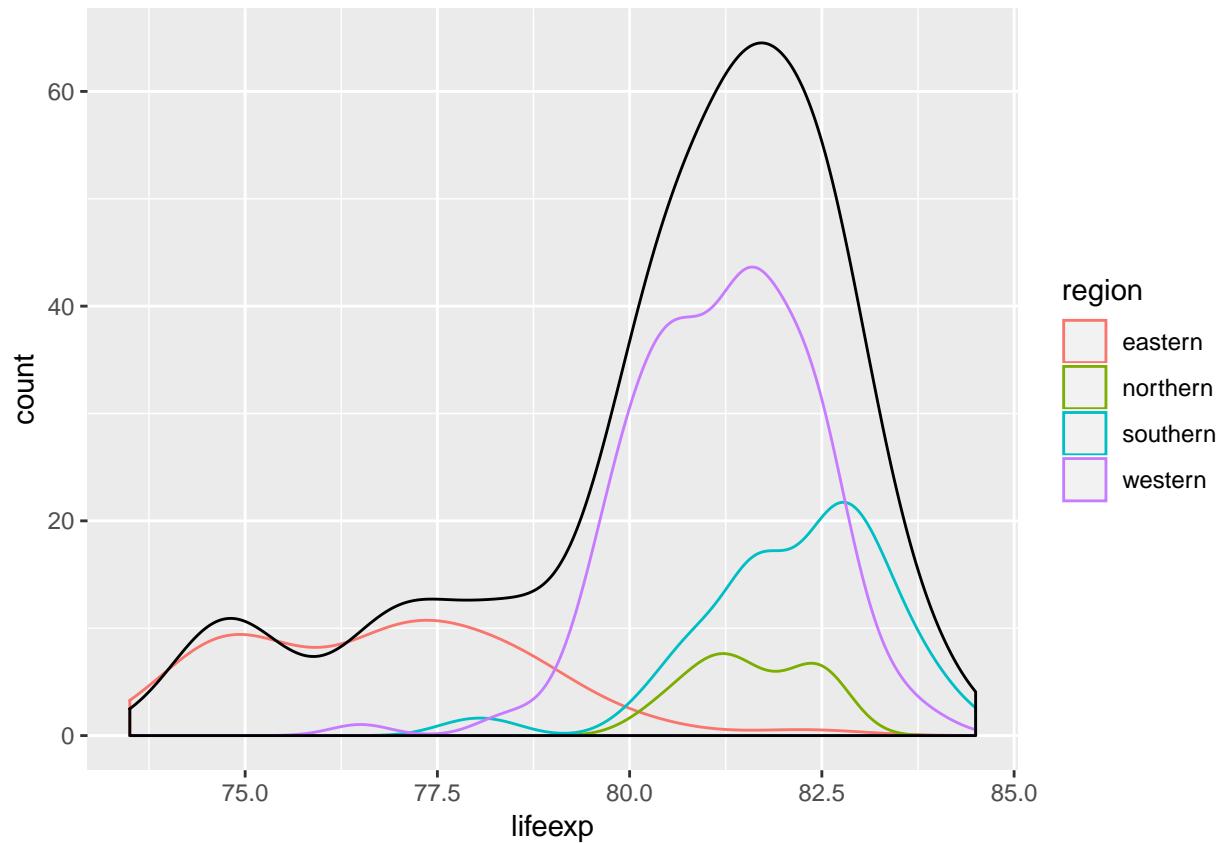
4.5.1.2 Discrete

4.5.1.3 Multivariate

```
euro_regio_eu %>%
  filter(year == 2015) %>%
  ggplot() +
  geom_density(aes(x = lifeexp, y = stat(count), color = region)) +
  geom_density(aes(x = lifeexp, y = stat(count)))
```

```
## Warning: Removed 18 rows containing non-finite values (stat_density).
```

```
## Warning: Removed 18 rows containing non-finite values (stat_density).
```



4.5.2 Visualizing association

4.5.2.1 continuous vs. continuous

```
# scatterplot  
# different symbols  
# fill versus color  
# white outline / overlap  
# dot chart  
# bubble chart  
# dot density map
```

4.5.2.2 continuous vs. discrete

4.5.2.3 discrete vs. discrete

4.5.3 Visualizing change

4.5.3.1 Lines

4.5.3.2 Slope

4.5.3.3 Connected dots

4.5.3.4 Waterfall

4.5.3.5 Bump

4.5.4 Visualizing surfaces

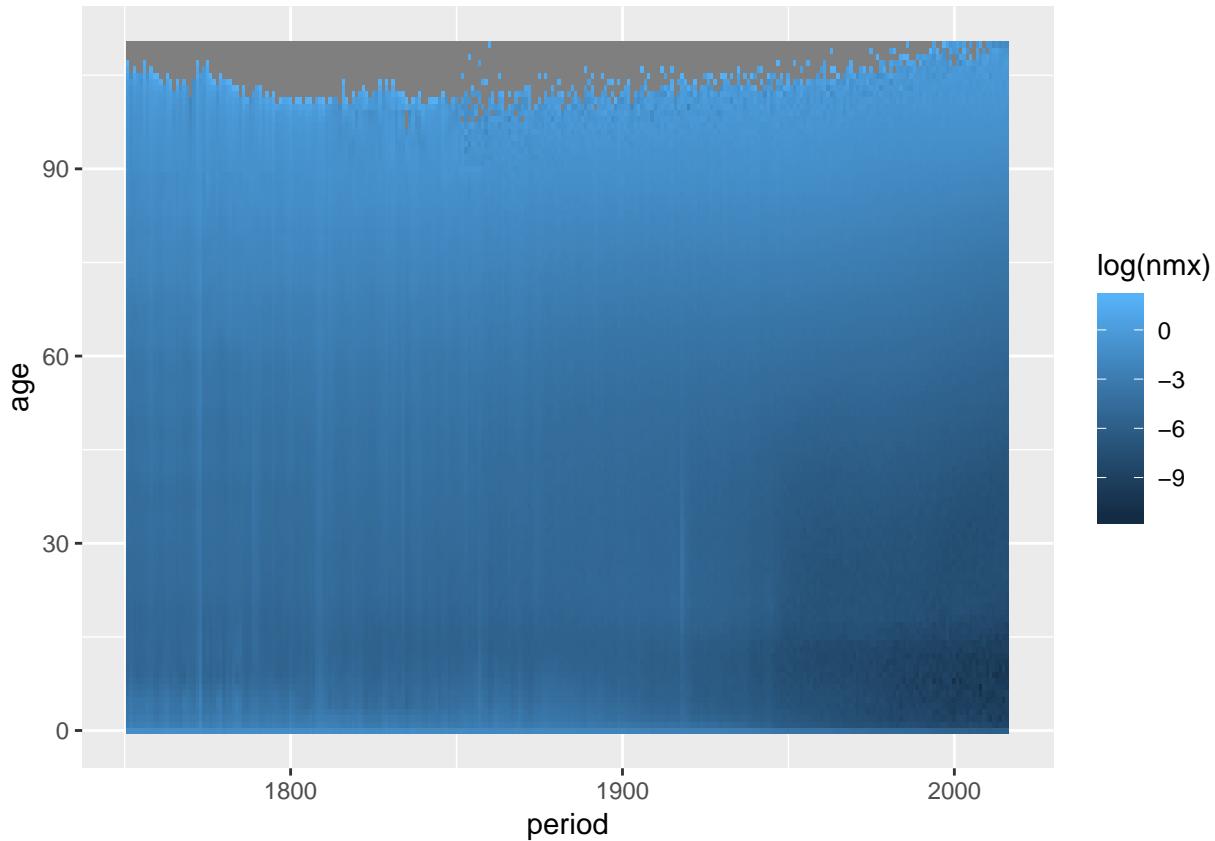
4.5.4.1 Contours

4.5.4.2 Heatmap

`geom_tile()` draws rectangles at specified xy-positions. A common use-case is to visualize the value of a variable across a surface by coloring the rectangles according to value. This plot type is also known as a *heatmap*. Demographers refer to heatmaps as *Lexis Surfaces* if the surface is defined by period/cohort and age. Here's an example showing Swedish age specific, logged death rates over time:

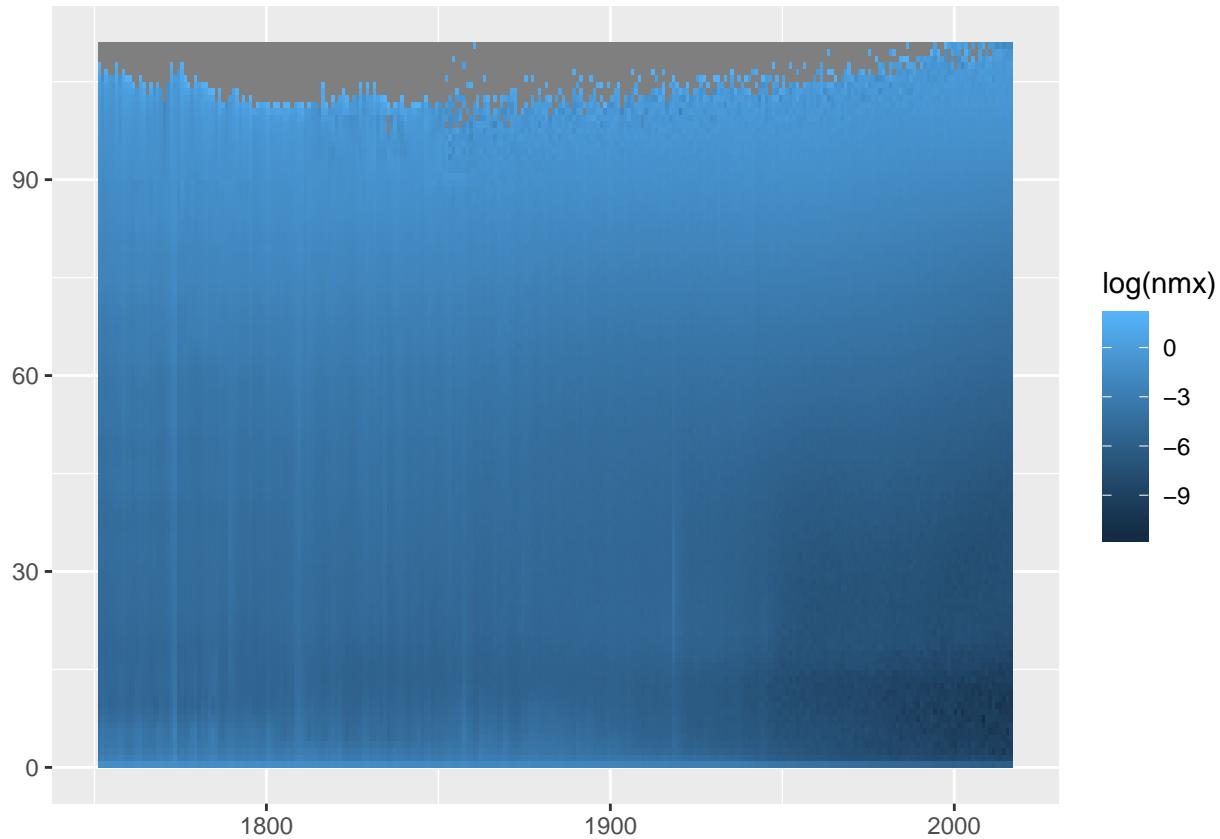
```
load('data/hmd/hmd_swe.RData')
swe <- mutate(hmd_swe, nmx = nDx/nEx)

ggplot(swe) +
  geom_tile(aes(x = period, y = age, fill = log(nmx)))
```



`geom_rect()` is an alternative to `geom_tile()` but we need to specify all four corners of each rectangle we wish to draw. As each age and period group is a single year wide, we specify rectangles which have a width and height of one unit.

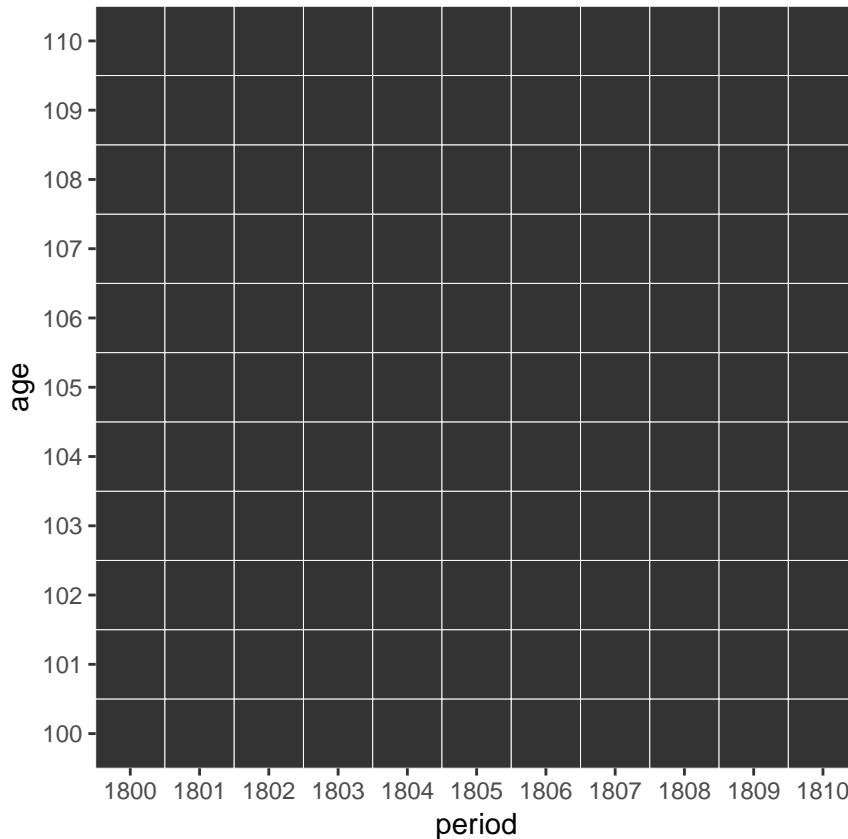
```
ggplot(swe) +
  geom_rect(aes(xmin = period, xmax = period+1, ymin = age, ymax = age+1,
                 fill = log(nmx)))
```



Only specifying x and y position and omitting colour puts a grey rectangle at every xy position that appears in the data. The resulting plot gives us information about the period-ages where we have mortality data on Swedish females.

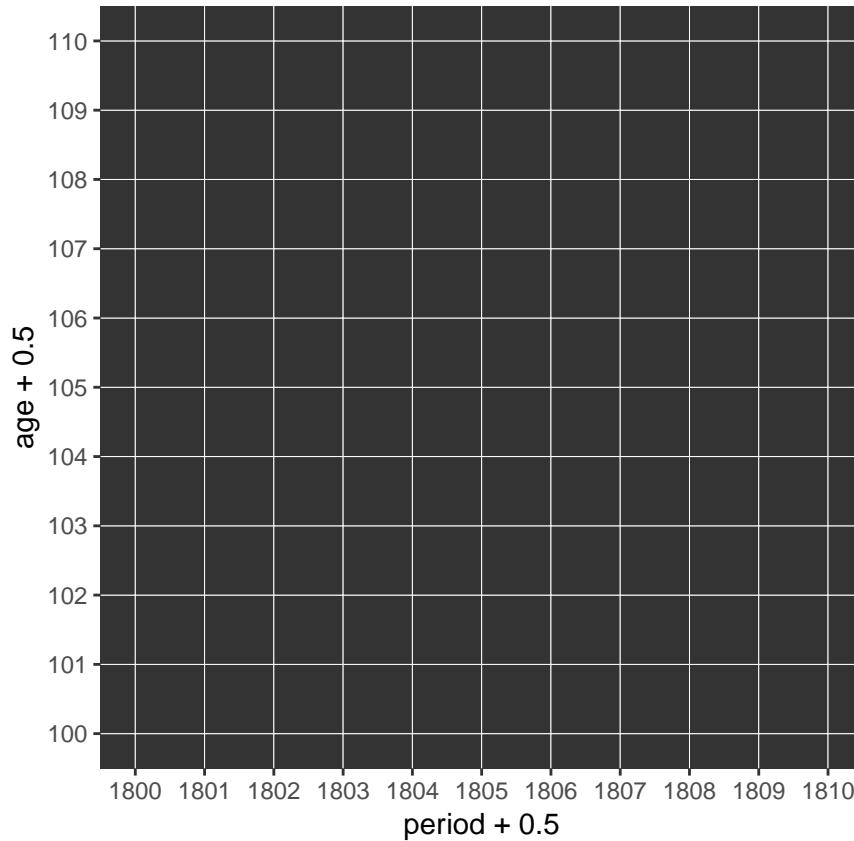
By default the small rectangles have a width and height of 1 scale unit and are drawn over the mid-points of the corresponding x and y values.

```
ggplot(swe) +
  geom_tile(aes(x = period, y = age), colour = "white") +
  scale_x_continuous(breaks = 1800:1810) +
  scale_y_continuous(breaks = 100:110) +
  coord_equal(xlim = c(1800, 1810), ylim = c(100, 110))
```



Shifting the data by 0.5 in x and y aligns things neatly.

```
ggplot(swe) +  
  geom_tile(aes(x = period+0.5, y = age+0.5),  
            colour = "white") +  
  scale_x_continuous(breaks = 1800:1810) +  
  scale_y_continuous(breaks = 100:110) +  
  coord_equal(xlim = c(1800, 1810), ylim = c(100, 110))
```



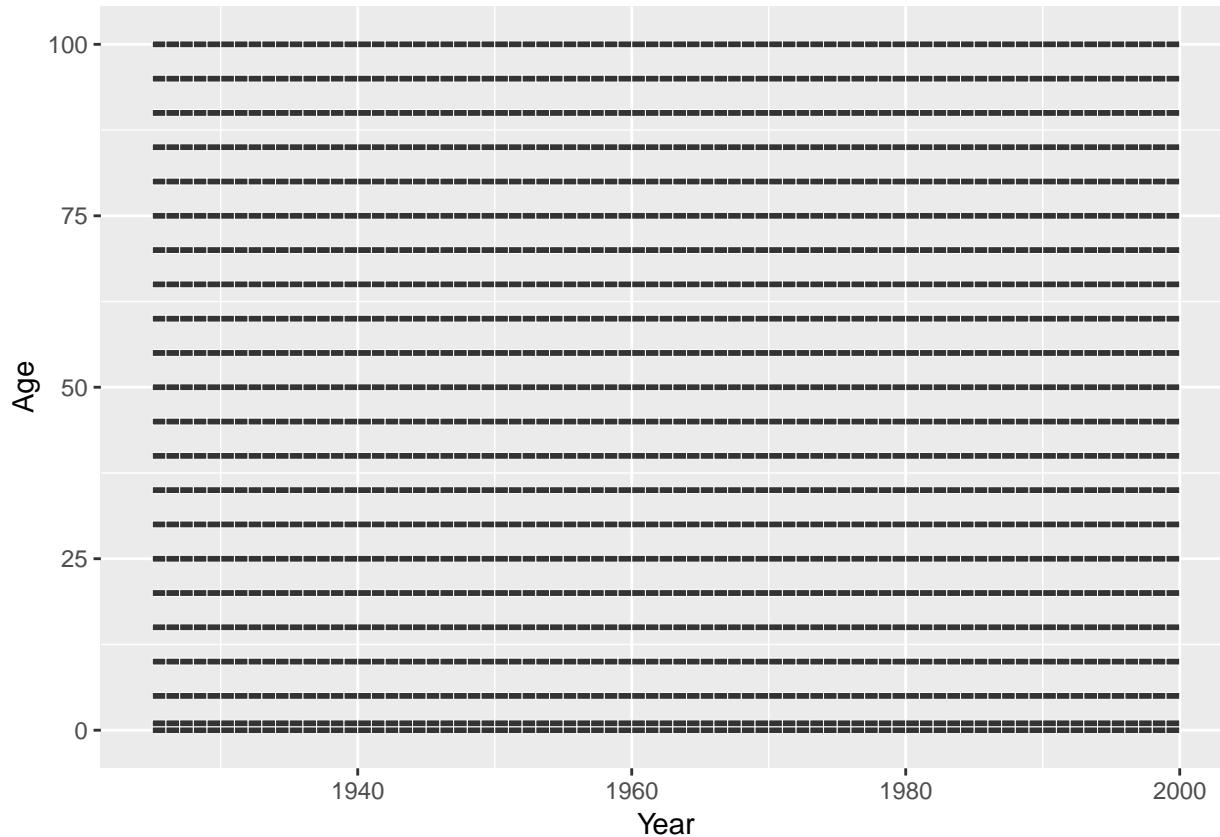
If our data does not come in 1 by 1 units we have to adjust the `width` and/or `height` of the rectangles. `width` and `height` are regular aesthetics and can be mapped to variables in the data.

```
cod <- read_csv('data/cod/cod.csv')
```

```
## Parsed with column specification:
## cols(
##   Year = col_integer(),
##   Age = col_integer(),
##   AgeGr = col_character(),
##   w = col_integer(),
##   Sex = col_character(),
##   COD = col_character()
## )
```

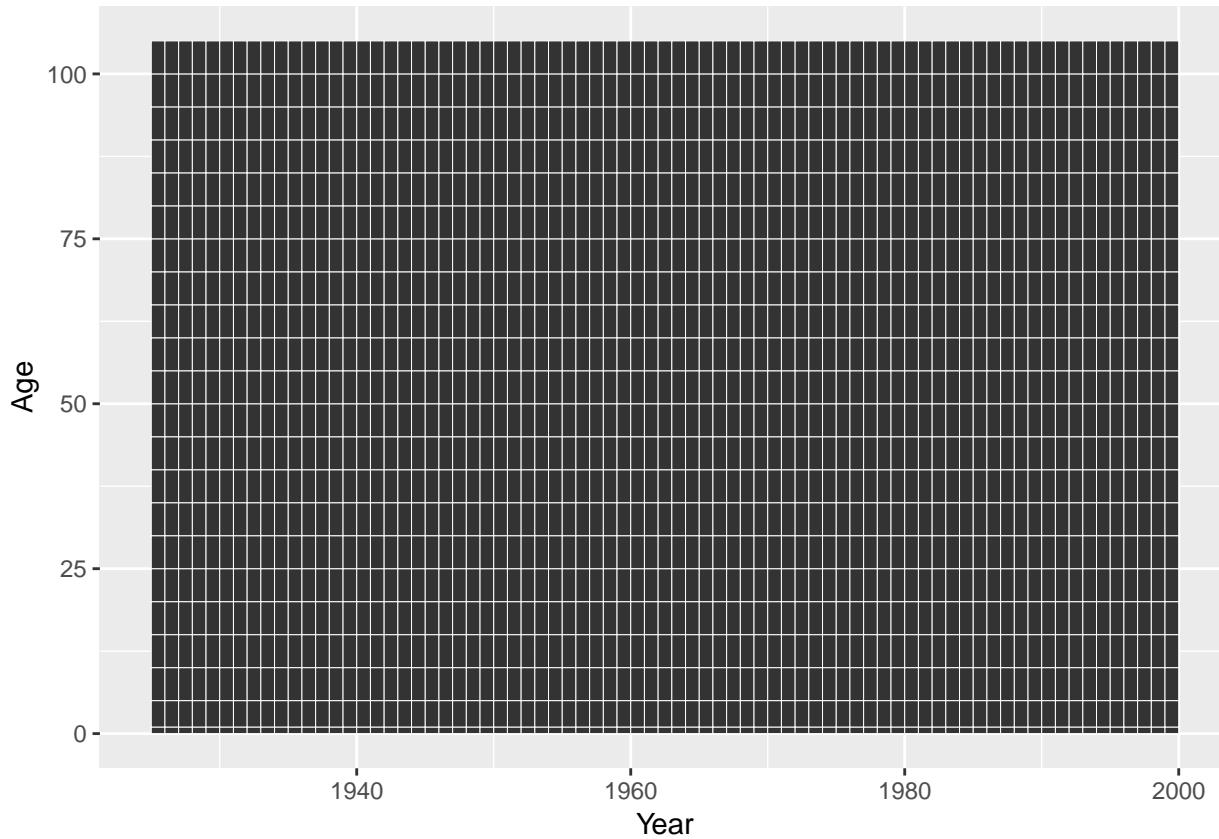
The Cause of Death data features age groups of different sizes (1, 4, or 5 years). This is how it looks like if we plot it without any regard to the size of the age groups.

```
cod %>% filter(Sex == "Female") %>%
  mutate(Year = Year + 0.5) %>%
  ggplot() +
  geom_tile(aes(x = Year, y = Age),
            colour = "white")
```



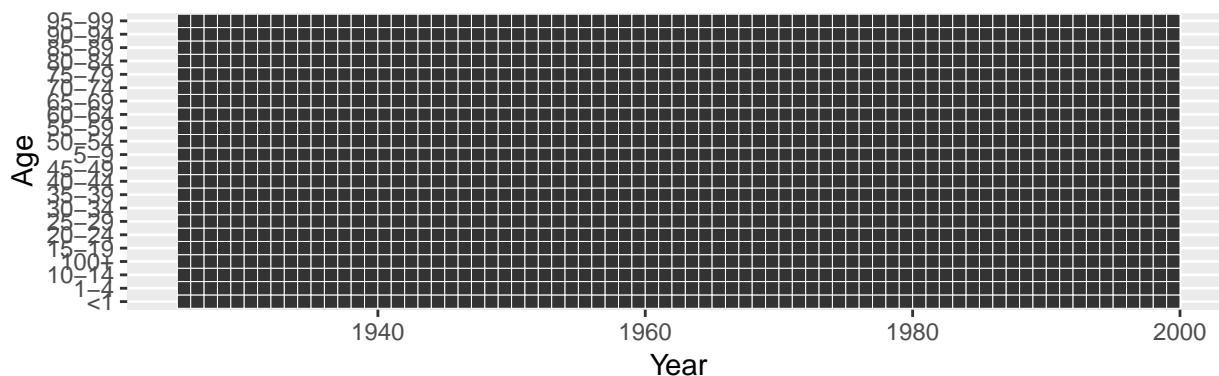
Now we shift the rectangles away from the age midpoint and scale them in height according to the width of the age group.

```
cod %>% filter(Sex == "Female") %>%
  mutate(Year = Year + 0.5, Age = Age + w/2) %>%
  ggplot() +
  geom_tile(aes(x = Year, y = Age, height = w),
            colour = "white")
```



If we use discrete axis (happens automatically if we supply a non-numeric variable to the x or y aesthetic) we loose any control over the placement of the age or period groups. They will be equally spaced along the axis.

```
cod %>% filter(Sex == "Female") %>%
  mutate(Year = Year + 0.5, Age = AgeGr) %>%
  ggplot() +
  geom_tile(aes(x = Year, y = Age), colour = "white") +
  coord_equal()
```



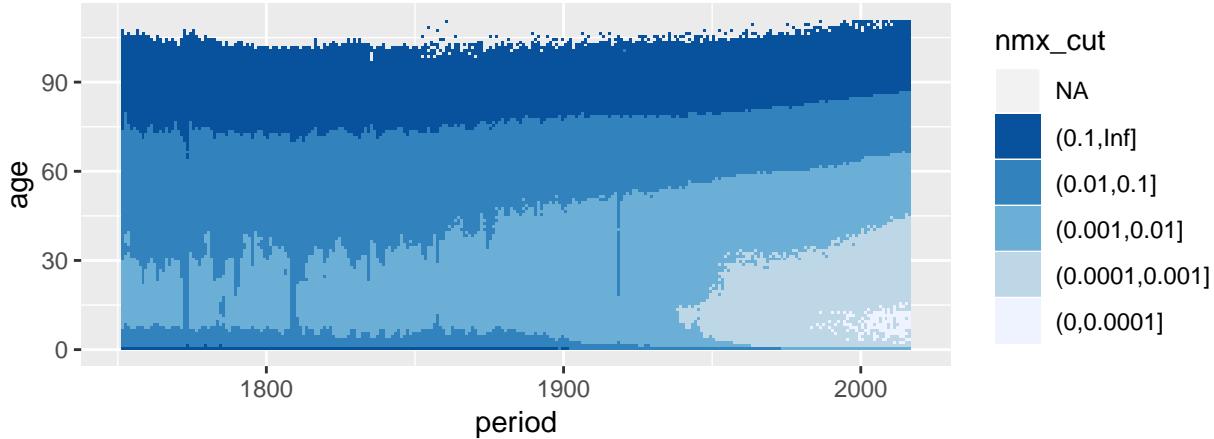
Avoid character or factor variables as your period or age groups. Whenever possible go with numeric “Start of Interval” and “Interval Width” variables.

4.5.4.2.1 Sequential Colour Scales: Plotting Magnitudes

If we plot magnitudes we would like to use a colour scale which has an intrinsic ordering to it. Scales that

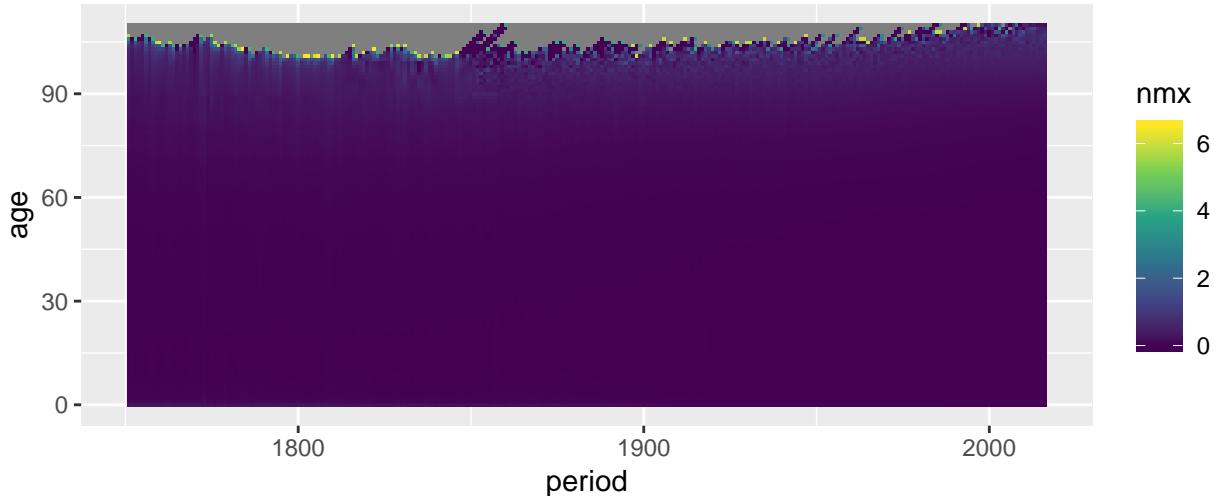
vary from dark to light are suitable and we call them “sequential”. `scale_fill_brewer(type = "seq")` provides you with such a scale.

```
breaks_nmx <- c(0, 0.0001, 0.001, 0.01, 0.1, Inf)
swe %>%
  mutate(nmx_cut = cut(nmx, breaks = breaks_nmx)) %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx_cut),
            position = position_nudge(0.5, 0.5)) +
  scale_fill_brewer(type = "seq") +
  guides(fill = guide_legend(reverse = TRUE)) +
  coord_equal()
```



Continuous colour scales take the form of a smooth colour gradient. Getting the gradient to look like you want can be tricky.

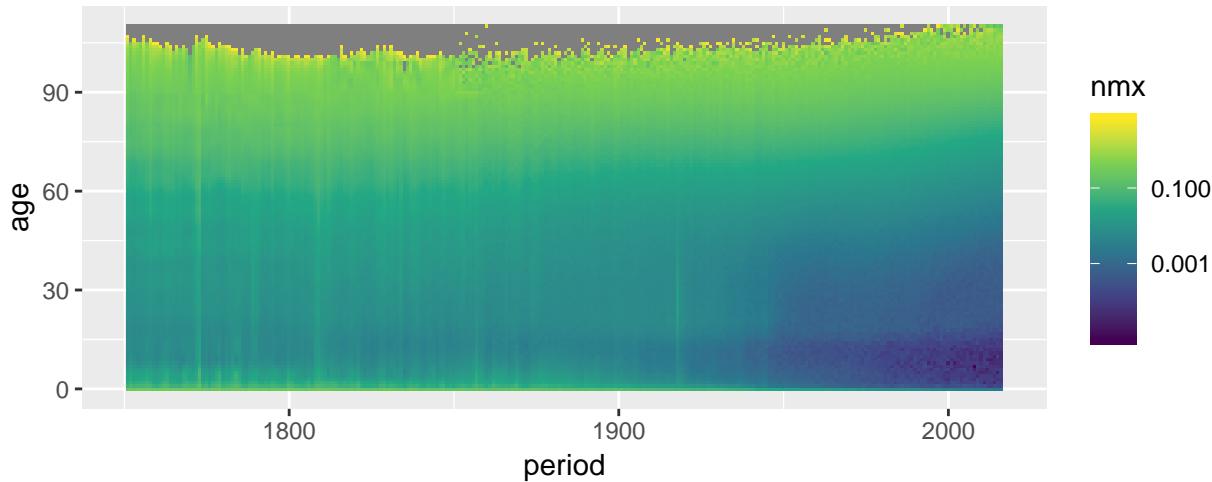
```
swe %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx)) +
  scale_fill_viridis_c() +
  coord_equal()
```



Log transform the colour scale.

```
swe %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx)) +
  scale_fill_viridis_c(trans = 'log10') +
  coord_equal()
```

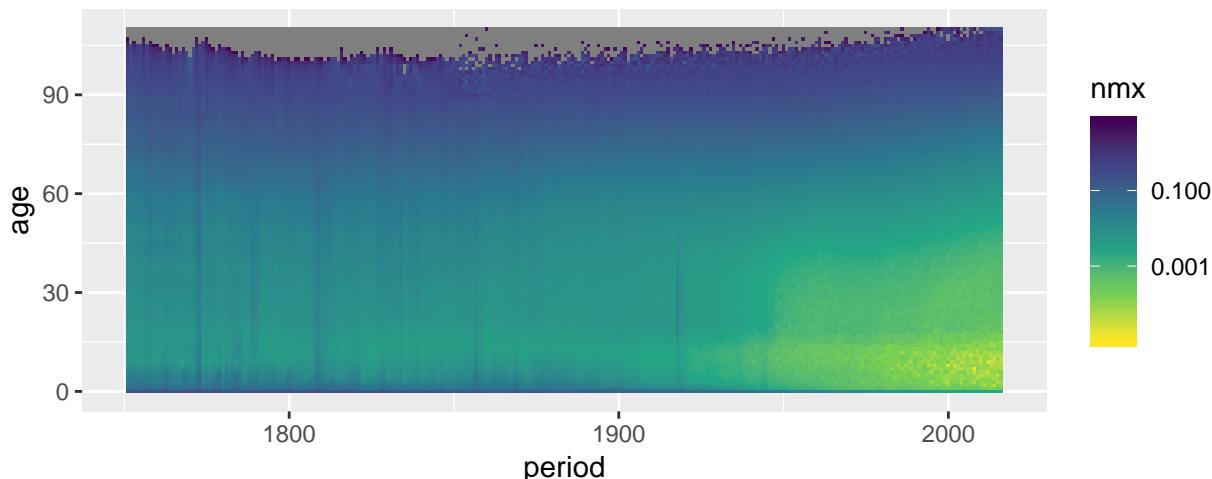
Warning: Transformation introduced infinite values in discrete y-axis



Make high values dark and low values light.

```
swe %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx)) +
  scale_fill_viridis_c(trans = 'log10',
                       direction = -1) +
  coord_equal()
```

Warning: Transformation introduced infinite values in discrete y-axis



Rescale the colour gradient to increase contrast.

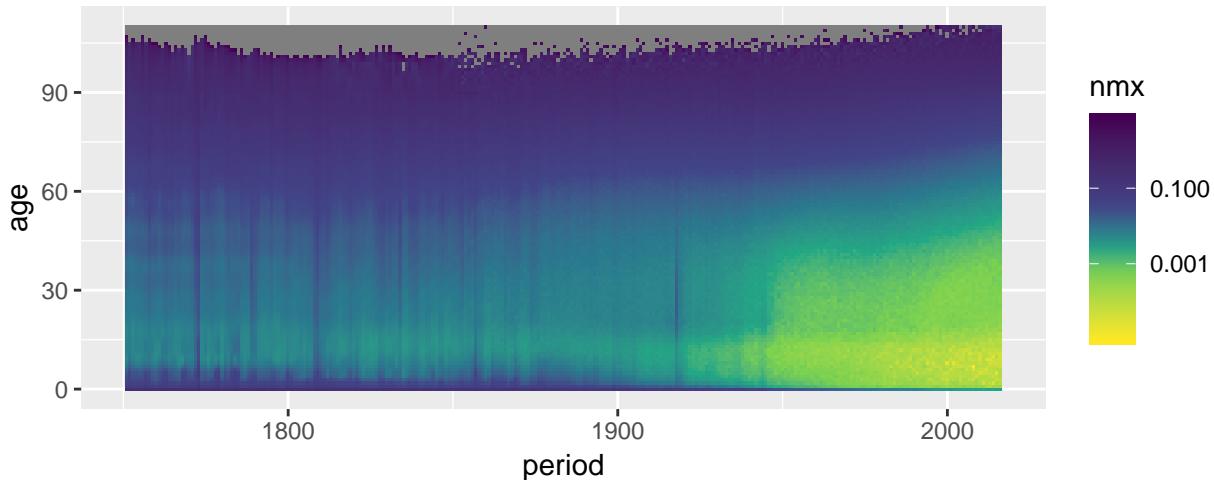
```
swe %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx)) +
```

```

scale_fill_viridis_c(trans = 'log10',
                     direction = -1,
                     values = c(0, 0.3, 0.4, 0.5, 0.6, 1)) +
coord_equal()

## Warning: Transformation introduced infinite values in discrete y-axis

```



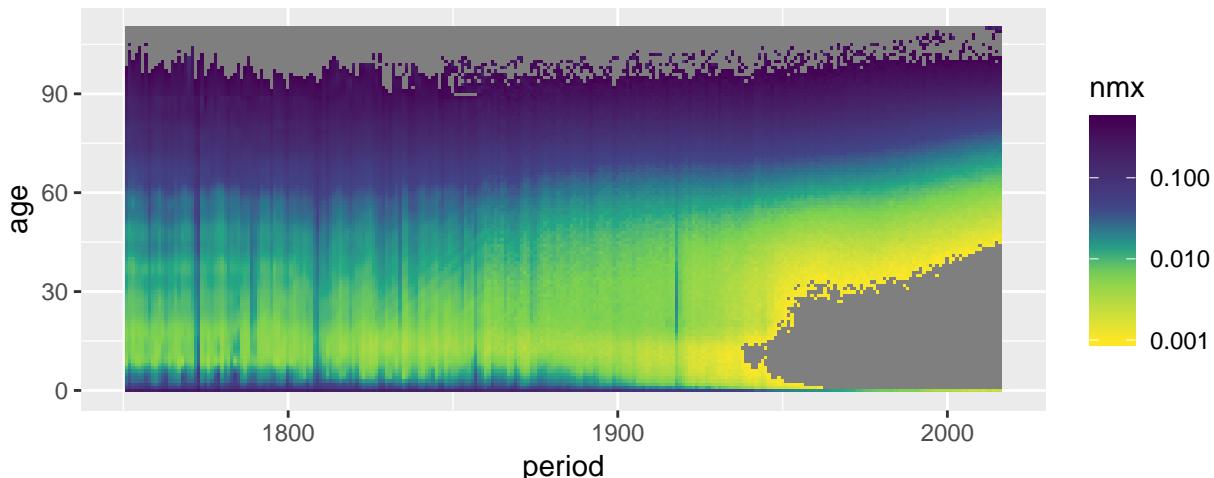
Throw away data outside of the limits.

```

swe %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = nmx)) +
  scale_fill_viridis_c(trans = 'log10',
                       direction = -1,
                       values = c(0, 0.3, 0.4, 0.5, 0.6, 1),
                       limits = c(0.001, 0.5)) +
  coord_equal()

## Warning: Transformation introduced infinite values in discrete y-axis

```



Or instead *squish* the out-of-bounds data into the limits.

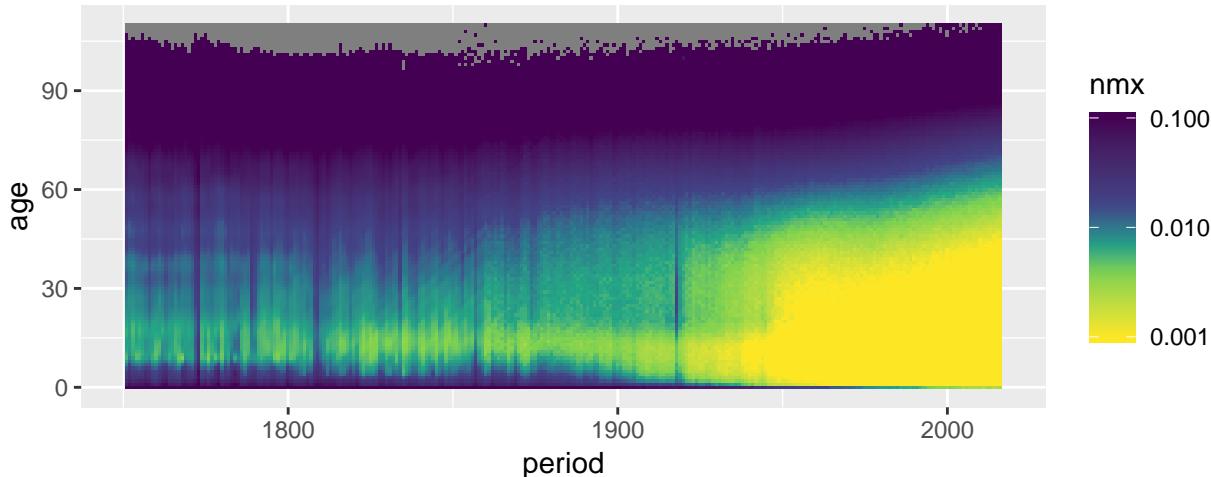
```

swe %>%
  ggplot() +

```

```
geom_tile(aes(x = period, y = age, fill = nmx)) +
  scale_fill_viridis_c(trans = 'log10',
    direction = -1,
    values = c(0, 0.3, 0.4, 0.5, 0.6, 1),
    limits = c(0.001, 0.1),
    oob = scales::squish) +
  coord_equal()
```

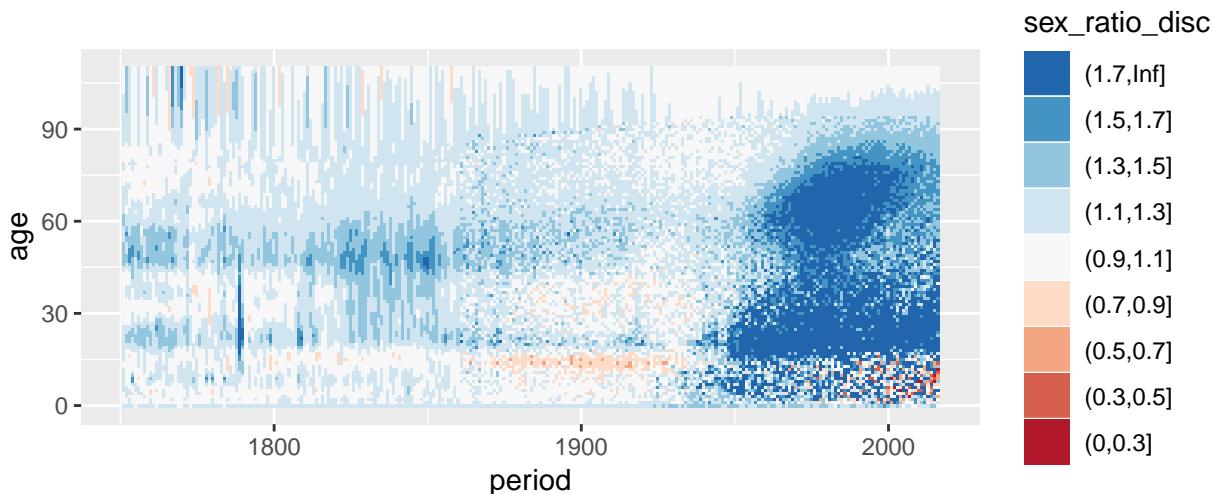
Warning: Transformation introduced infinite values in discrete y-axis



4.5.4.2.2 Divergent colour scales: Plotting Differences & Proportions

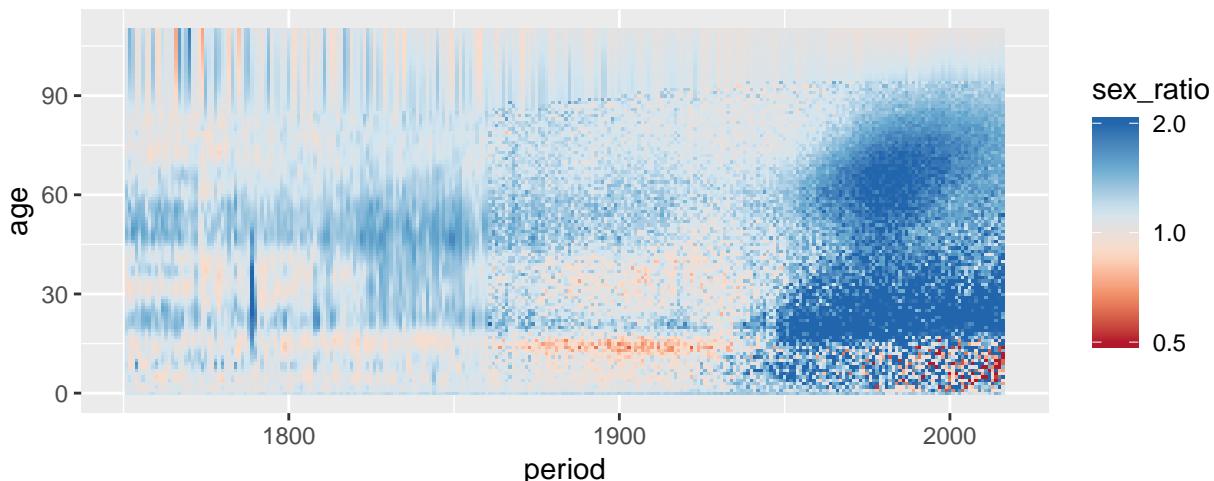
```
load('data/hmd/hmd.RData')
breaks_prop_nmx <- c(0, 0.3, 0.5, 0.7, 0.9,
  1.1, 1.3, 1.5, 1.7, Inf)

hmd %>%
  filter(country == 'SWE') %>%
  select(sex, period, age, nmx) %>%
  spread(sex, nmx) %>%
  mutate(sex_ratio = Male/Female,
    sex_ratio_disc = cut(sex_ratio, breaks_prop_nmx)) %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = sex_ratio_disc)) +
  scale_fill_brewer(type = "div",
    palette = 5) +
  guides(fill = guide_legend(reverse = TRUE)) +
  coord_equal()
```



Continuous variant.

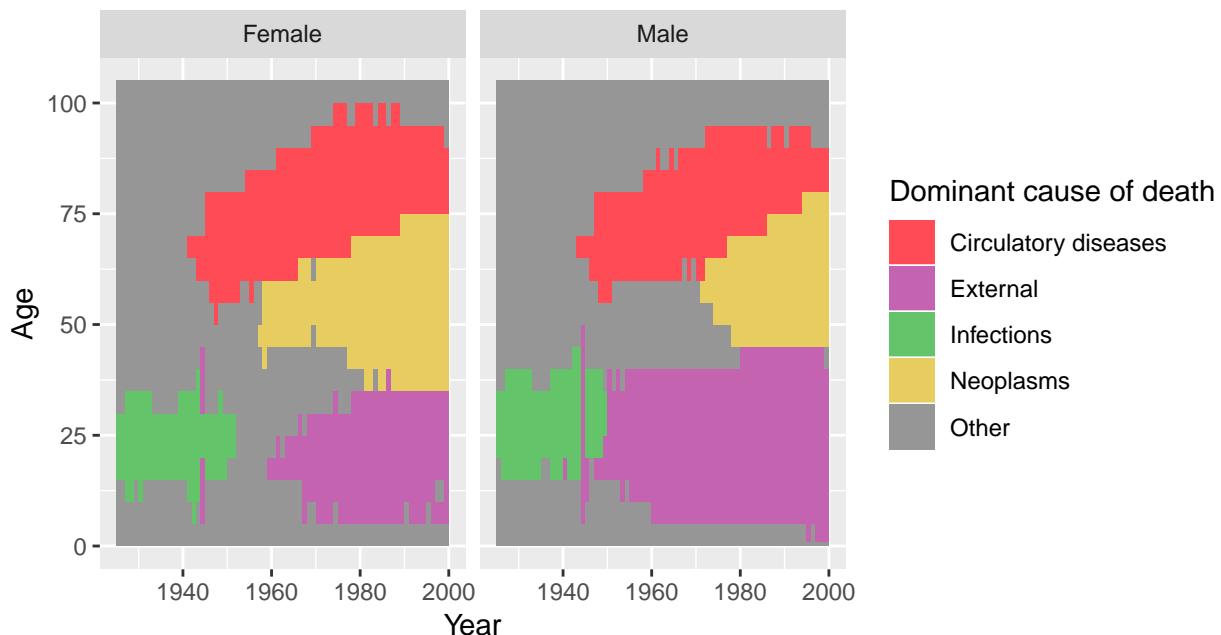
```
hmd %>%
  filter(country == 'SWE') %>%
  select(sex, period, age, nmx) %>%
  spread(sex, nmx) %>%
  mutate(sex_ratio = Male/Female) %>%
  ggplot() +
  geom_tile(aes(x = period, y = age, fill = sex_ratio)) +
  # takes 6 colours from a brewer palette and interpolates
  scale_fill_distiller(type = "div",
    palette = "RdBu",
    trans = "log2",
    limits = c(0.5, 2),
    direction = 1,
    oob = scales::squish) +
  coord_equal()
```



4.5.4.2.3 Qualitative colour scales: Plotting Group Membership

```
cod %>%
  mutate(Year = Year + 0.5, Age = Age + w/2) %>%
```

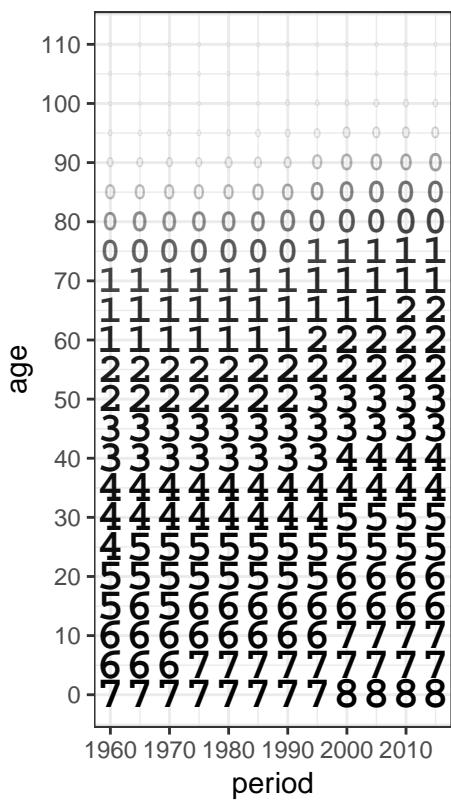
```
ggplot() +
  geom_tile(aes(x = Year, y = Age, height = w, fill = COD)) +
  coord_equal() +
  facet_wrap(~Sex, ncol = 2) +
  scale_fill_manual("Dominant cause of death",
                    values = c("Infections" = "#63C46A",
                               "Neoplasms" = "#E7CC60",
                               "Circulatory diseases" = "#FF4B56",
                               "External" = "#C463AF",
                               "Other" = "#969696"))
```



4.5.4.3 Tables

```
hmd %>%
  filter(country == 'DEUTE', sex == 'Female',
        (period %% 5) == 0, (age %% 5) == 0) %>%
  ggplot(aes(x = period, y = age, alpha = lx, size = lx)) +
  geom_text(aes(label = ex%/%10),
            family = 'mono', fontface = 'bold',
            show.legend = FALSE) +
  scale_x_continuous(breaks = seq(1900, 2010, 10)) +
  scale_y_continuous(breaks = seq(0, 110, 10)) +
  theme_bw() +
  coord_equal() +
  labs(title = 'Decades left to live.')
```

Decades left to live.

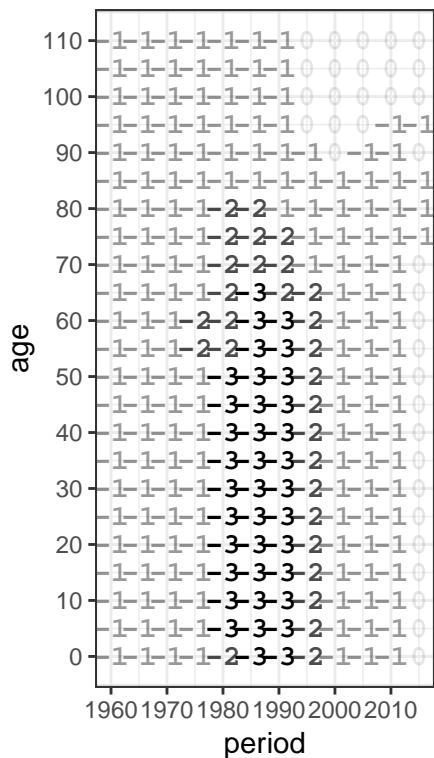


```

hmd %>%
  filter(country %in% c('DEUTE', 'DEUTW'), sex == 'Female',
         (period %% 5) == 0, (age %% 5) == 0) %>%
  select(country, period, age, ex) %>%
  spread(country, ex) %>%
  mutate(d_ex = DEUTE - DEUTW) %>%
  ggplot(aes(x = period, y = age)) +
  geom_text(aes(label = d_ex%/%1, alpha = abs(d_ex%/%1)),
            family = 'mono', fontface = 'bold',
            show.legend = FALSE) +
  scale_x_continuous(breaks = seq(1900, 2010, 10)) +
  scale_y_continuous(breaks = seq(0, 110, 10)) +
  theme_bw() +
  coord_equal() +
  labs(title = 'East-West German difference\nin years of remaining life-expectancy.')

```

East–West German difference in years of remaining life-expectancy.



4.5.5 Excercise: Chart type vocabulary

- 1) Using `ggplot2`, plot a population pyramid using data of your choice.
- 2) Calculate the differences of Danish and Swedish remaining male life-expectancies by period and age. Visualize the result as a Lexis surface with a discrete divergent color scale. The choice of breaks is up to you.

4.6 Polish your plot for publication

4.6.1 Highlight

4.6.2 Annotate

4.7 Maps

4.8 Networks