Data visualization

2025-01-14

M1 MIDS/MFA/LOGOS
Université Paris Cité
Année 2024
Course Homepage
Moodle

> **Objectives**
>
> This workbook introduces visualization according to the *Grammar of Graphics* framework.
> Using `ggplot2`, we reproduce Rosling's `gapminder` talk.
> This is an opportunity to develop the layered construction of graphical objects.

Grammar of Graphics

We will use the *Grammar of Graphics* approach to visualization

The expression *Grammar of Graphics* was coined by Leiland Wilkinson to describe a principled approach to visualization in Data Analysis (EDA)

A plot is organized around tabular data (a table with rows (observations) and columns (variables))

A *plot* is a *graphical object* that can be built *layer* by *layer*

Building a graphical object consists in *chaining* elementary operations

The acclaimed TED presentation by Hans Rosling illustrates the Grammar of Graphics approach

Visit https://www.youtube.com/embed/jbkSRLYSojo

We will reproduce the animated demonstration using

- `ggplot2`: an implementation of *grammar of graphics* in 'R
- `plotly`: a bridge between `R` and the javascript library `D3.js`
- Using `plotly`, opting for `html` ouput, brings the possibility of interactivity and animation

Setup

We will use the following packages. If needed, we install them.

```
stopifnot(
  require(tidyverse),
```

```
  require(patchwork),
  require(glue),
  require(ggforce),
  require(plotly),
  require(ggthemes),
  require(gapminder),
  require(ggrepel)
)
```

The data we will use can be obtained by loading package `gapminder`

Tip

If the packages have not yet been installed on your hard drive, install them. You can do that using base `R` `install.packages()` function:

```
install.packages("tidyverse")
```

It is often faster to use functions from package `pak`

```
install.packages("pak")
pak::pkg_install("tidyverse")
```

You need to understand the difference between *installing* and *loading* a package

Question

- How do we get the list of *installed* packages?
- How do we get the list of *loaded* packages?
- Which objects are made available by a package?

solution

The (usually very long) list of installed packages can be obtained by a simple function call.

```
df <- installed.packages()
head(df)
##              Package       LibPath
## abind        "abind"       "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
## arkhe        "arkhe"       "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
## arrow        "arrow"       "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
## ash          "ash"         "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
## AsioHeaders "AsioHeaders" "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
## askpass      "askpass"     "/home/boucheron/R/x86_64-pc-linux-gnu-library/4.4"
##              Version    Priority Depends
## abind        "1.4-5"    NA       "R (>= 1.5.0)"
## arkhe        "1.6.0"    NA       "R (>= 3.5)"
## arrow        "16.1.0"   NA       "R (>= 4.0)"
## ash          "1.0-15"   NA       NA
## AsioHeaders "1.22.1-2" NA       NA
## askpass      "1.2.0"    NA       NA
```

Have a look at `gapminder` dataset

The `gapminder` table can be found at `gapminder::gapminder`

- A table has a *schema*: a list of named *columns*, each with a given type
- A table has a *content*: *rows*. Each row is a collection of items, corresponding to the columns

Question

Explore `gapminder::gapminder`, using `glimpse()` and `head()`

- `glimpse()` allows to see the schema and the first rows
- `head()` allows to see the first rows
- Use the pipe `|>` to chain operations

solution

Dataframes

```
gapminder <- gapminder::gapminder

glimpse(gapminder)
## Rows: 1,704
## Columns: 6
## $ country   <fct> "Afghanistan", "Afghanistan", "Afghanistan", "Afghanistan", ~
## $ continent <fct> Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, ~
## $ year      <int> 1952, 1957, 1962, 1967, 1972, 1977, 1982, 1987, 1992, 1997, ~
## $ lifeExp   <dbl> 28.801, 30.332, 31.997, 34.020, 36.088, 38.438, 39.854, 40.8~
## $ pop       <int> 8425333, 9240934, 10267083, 11537966, 13079460, 14880372, 12~
## $ gdpPercap <dbl> 779.4453, 820.8530, 853.1007, 836.1971, 739.9811, 786.1134, ~

gapminder |>
  glimpse()
## Rows: 1,704
## Columns: 6
## $ country   <fct> "Afghanistan", "Afghanistan", "Afghanistan", "Afghanistan", ~
## $ continent <fct> Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, Asia, ~
## $ year      <int> 1952, 1957, 1962, 1967, 1972, 1977, 1982, 1987, 1992, 1997, ~
## $ lifeExp   <dbl> 28.801, 30.332, 31.997, 34.020, 36.088, 38.438, 39.854, 40.8~
## $ pop       <int> 8425333, 9240934, 10267083, 11537966, 13079460, 14880372, 12~
## $ gdpPercap <dbl> 779.4453, 820.8530, 853.1007, 836.1971, 739.9811, 786.1134, ~

gapminder |>
  head()
## # 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.
## 6 Afghanistan Asia       1977    38.4 14880372      786.
```

Even an empty dataframe has a scheme:

```
gapminder |>
  head(0) |>
  glimpse()
```

```
Rows: 0
Columns: 6
$ country   <fct>
$ continent <fct>
$ year      <int>
$ lifeExp   <dbl>
$ pop       <int>
$ gdpPercap <dbl>
```

```
# glimpse(head(gapminder, 0))
```

solution

The schema of a dataframe/tibble is the list of column names and classes. The content of a dataframe is made of the rows. A dataframe may have null content

```
gapminder |>
  filter(FALSE) |>
  glimpse()
## Rows: 0
## Columns: 6
## $ country   <fct>
## $ continent <fct>
## $ year      <int>
## $ lifeExp   <dbl>
## $ pop       <int>
## $ gdpPercap <dbl>
```

Get a feeling of the dataset

Question

Pick two random rows for each continent using `slice_sample()`

solution

To pick a slice at random, we can use function `slice_sample`. We can even perform sampling within groups defined by the value of a column.

```
gapminder |>
  slice_sample(n=2, by=continent)
```

```
# A tibble: 10 x 6
   country             continent  year lifeExp      pop gdpPercap
   <fct>               <fct>     <int>   <dbl>    <int>     <dbl>
 1 Indonesia           Asia       1962    42.5 99028000       849.
 2 Israel              Asia       1962    69.4  2310904      7106.
 3 Ireland             Europe     1997    76.1  3667233     24522.
 4 Italy               Europe     1982    75.0 56535636     16537.
 5 Eritrea             Africa     1952    35.9  1438760       329.
 6 Somalia             Africa     1992    39.7  6099799       927.
 7 Trinidad and Tobago Americas   2002    69.0  1101832     11461.
 8 Honduras            Americas   1967    50.9  2500689      2538.
 9 Australia           Oceania    1962    70.9 10794968     12217.
10 New Zealand         Oceania    1987    74.3  3317166     19007.
```

```
#< or equivalently
# gapminder |>
#   group_by(continent) |>
#   slice_sample(n=2)
```

Question

What makes a table *tidy*?

Tip

Have a look at Data tidying in R for Data Science (2nd ed.)

Question

Is the `gapminder` table redundant?

solution

`gapminder` is redundant: column `country` completely determines the content of column `continent`. In database parlance, we have a functional dependancy: `country` → `continent` whereas the *key* of the table is made of columns `country, year`. Table `gapminder` is not in Boyce-Codd Normal Form (BCNF), not even in Third Normal Form (3NF).

Gapminder tibble (extract)

Question

Extract/filter a subset of rows using `dplyr::filter(...)`

- All rows concerning a given country
- All rows concerning a year
- All rows concerning a given continnent and a year

solution

```
# q: in gapminder table extract all raws concerning France

gapminder |>
  filter(country=='France') |>
  head()
```

```
# A tibble: 6 x 6
  country continent  year lifeExp      pop gdpPercap
  <fct>   <fct>     <int>   <dbl>    <int>     <dbl>
1 France  Europe     1952    67.4 42459667     7030.
2 France  Europe     1957    68.9 44310863     8663.
3 France  Europe     1962    70.5 47124000    10560.
4 France  Europe     1967    71.6 49569000    13000.
5 France  Europe     1972    72.4 51732000    16107.
6 France  Europe     1977    73.8 53165019    18293.
```

Equality testing is performed using `==`, not `=` (which is used to implement assignment)

Filtering (selection σ from database theory) : Picking one year of data

There is simple way to filter rows satisfying some condition. It consists in mimicking indexation in a matrix, leaving the colum index empty, replacing the row index by a condition statement (a logical expression) also called a mask.

```
# q: in gapminder table extract all raws concerning year 2002
gapminder_2002 <- gapminder[gapminder$year==2002, ]
```

Have a look at `gapminder$year==2002`. What is the type/class of this expression?

This is possible in base `R` and very often convenient.

Nevertheless, this way of performing row filtering does not emphasize the connection between the dataframe and the condition. Any logical vector with the right length could be used as a mask. Moreover, this way of performing filtering is not very functional.

> In the parlance of Relational Algebra, `filter` performs a *selection* of rows. Relational expression
>
> $$\sigma_{\text{condition}}(\text{Table})$$
>
> translates to
>
> ```
> filter(Table, condition)
> ```
>
> where condition is a boolean expression that can be evaluated on each row of Table. In `SQL`, the relational expression would translate into
>
> ```
> SELECT
>   *
> FROM
>   Table
> WHERE
>   condition
> ```
>
> Check Package `dplyr` docs
> The `posit` cheatsheet on `dplyr` is an unvaluable resource for table manipulation.

Use `dplyr::filter()` to perform row filtering

solution

```
# filter(gapminder, year==2002)

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

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

Data masking

Note that in stating the condition, we simply write `year==2002` even though `year` is not the name of an object in our current session. This is possible because `filter( )` uses *data masking*, `year` is meant to denote a column in `gapminder`. SQL interpreters use the same mechanism.
The ability to use data masking is one of the great strengths of the `R` programming language.

Static plotting: First attempt

Question

Define a plot with respect to `gapminder_2002` along the lines suggested by Rosling's presentation.

solution

```
p <- gapminder_2002 |>
  ggplot()
```

You should define a `ggplot` object with data layer `gapminder_2022` and call this object `p` for further reuse.

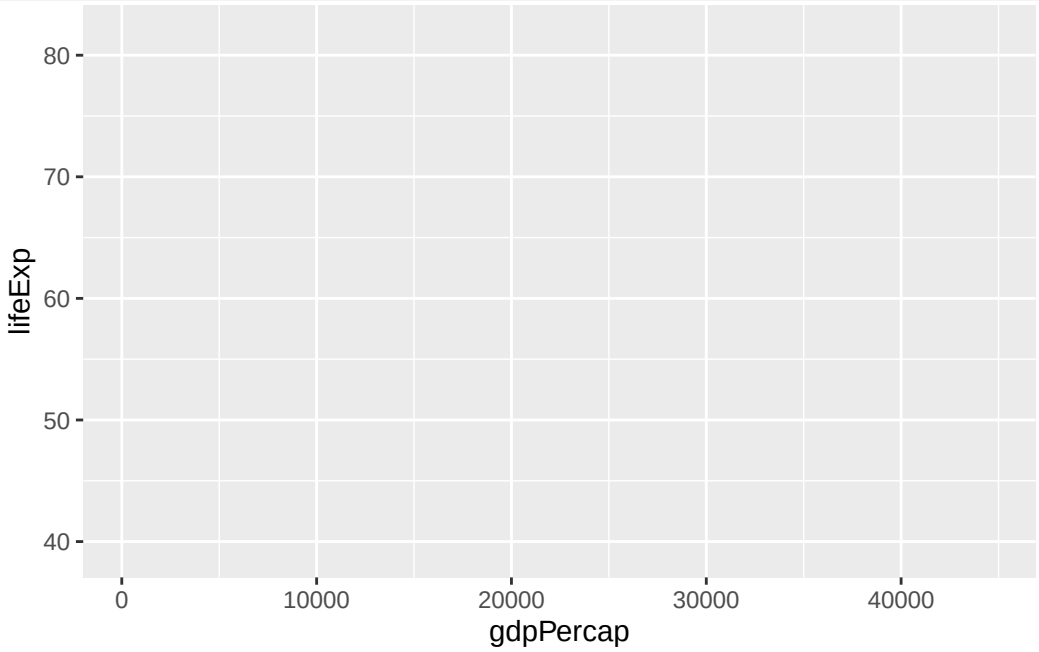
Question

Map variables `gdpPercap` and `lifeExp` to axes `x` and `y`. Define the axes. In `ggplot2` parlance, this is called *aesthetic mapping*. Use `aes()`.

solution

```
# q: Map variables gdpPercap and lifeExp to axes x and y. Define the axes.
p <- p +
  aes(x=gdpPercap, y=lifeExp)

p
```



Use `ggplot` object `p` and add a global aesthetic mapping `gdpPercap` and `lifeExp` to axes `x` and `y` (using `+` from `ggplot2`) .

Question

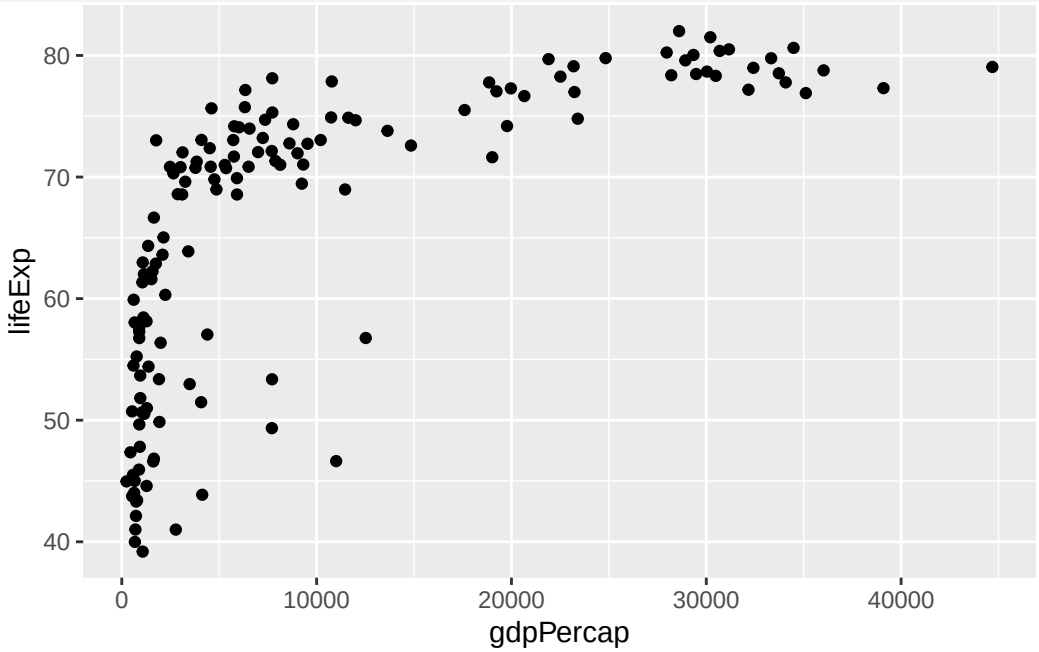
For each row, draw a point at coordinates defined by the mapping. You need to add a `geom_` layer to your `ggplot` object, in this case `geom_point()` will do.

solution

We add another layer to our graphical object.

```
p <- p +
  geom_point()

p
```



What's up?

We are building a graphical object (a `ggplot` object) around a data frame (`gapminder`)
We supply *aesthetic mappings* (`aes()`) that can be either global or specifically bound to some *geometries* (`geom_point()`) or *statistics*
The global aesthetic mapping defines which columns (variables) are

- mapped to position (which columns are mapped to axes),
- possibly mapped to colours, linetypes, shapes, …

Geometries and Statistics describe the building blocks of graphics

What's missing here?

when comparing to the Gapminder demonstration, we can spot that

- colors are missing
- bubble sizes are all the same. They should reflect the population size of the country
- titles and legends are missing. This means the graphic object is useless.

We will add other layers to the graphical object to complete the plot

Second attempt: display more information

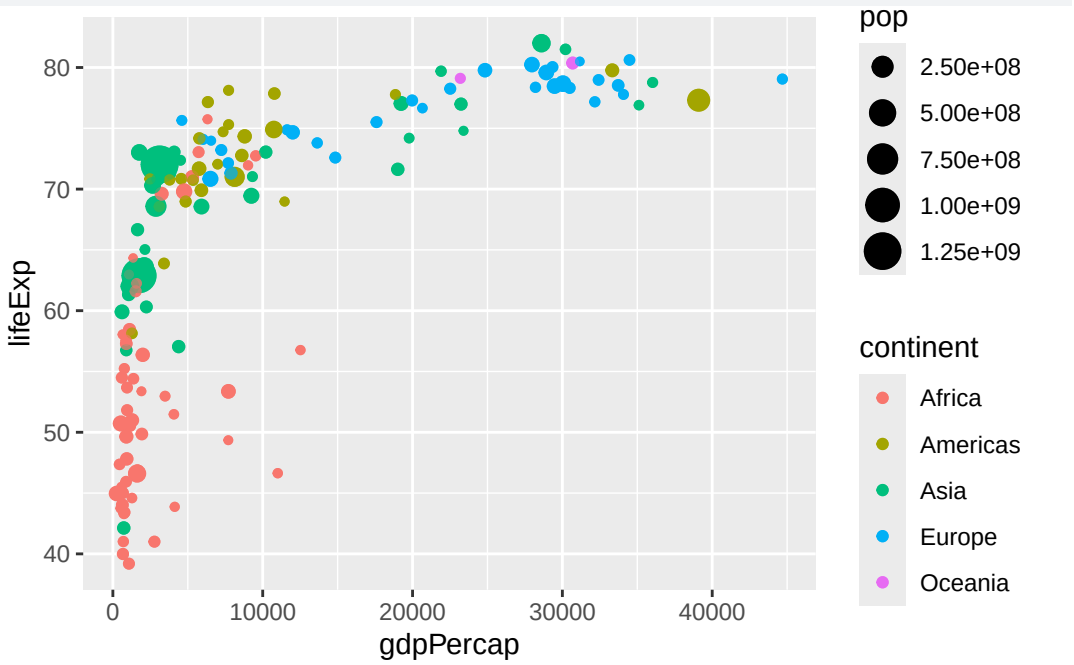
Question

- Map `continent` to color (use `aes()`)
- Map `pop` to bubble size (use `aes()`)
- Make point transparent by tuning `alpha` (inside `geom_point()` avoid *overplotting*)

solution

```
p <- p +
  aes(color=continent, size=pop) +
  geom_point(alpha=.5)

p
```



Note that we only use global aesthetic mappings. This makes sense since we do not need to taylor aesthetics to specific geometries. Indeed we only have one geometry in our graphical object.

solution

In this enrichment of the graphical object, *guides* have been automatically added for two aesthetics: `color` and `size`. Those two guides are deemed necessary since the reader has no way to guess the mapping from the five levels of `continent` to color (the color scale), and the reader needs help to connect population size and bubble size.
`ggplot2` provides us with helpers to fine tune guides.
The scalings on the `x` and `y` axis do not deserve guides: the ticks along the coordinate axes provide enough information.

Scaling

To pay tribute to Hans Rosling, we need to take care of two *scaling* issues:

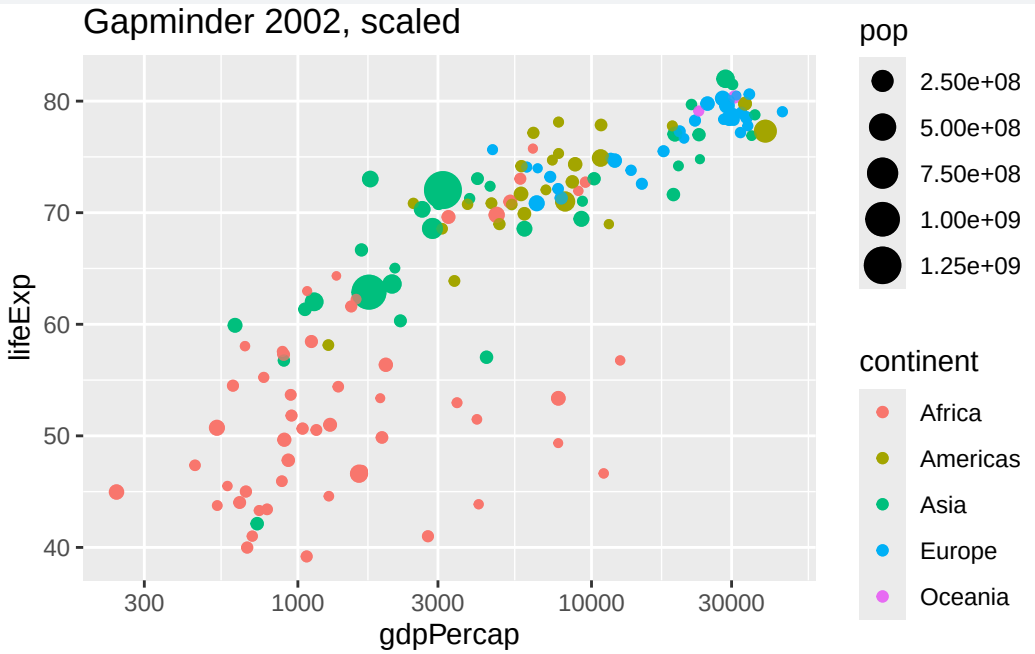
- the gdp per capita axis should be *logarithmic* `scale_x_log10()`
- the *area* of the point should be proportional to the population `scale_size_area()`

Complete the graphical object accordingly

solution

```
# q: use logarithmic scale for both axes
p <- p +
  scale_x_log10() +
#  scale_size_area() +
  ggtitle("Gapminder 2002, scaled")

p
```



Question

Motivate the proposed scalings.

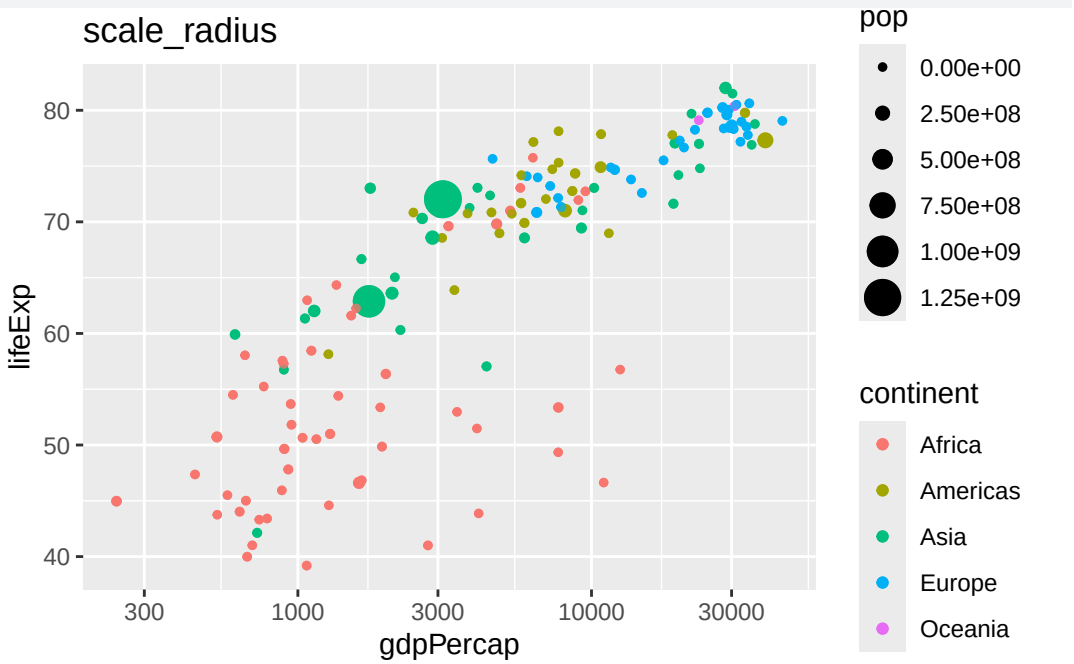
- Why is it important to use logarithmic scaling for gdp per capita?
- When is it important to use logarithmic scaling on some axis (in other contexts)?
- Why is it important to specify `scale_size_area()` ?

solution

To see why using `scale_size_area()` is important, we can check what happens when we use `scale_size()` instead.

```
pop_range <- c(0, max(gapminder_2002$pop))

p +
  scale_radius(limits = pop_range) +
  ggtitle("scale_radius")
```



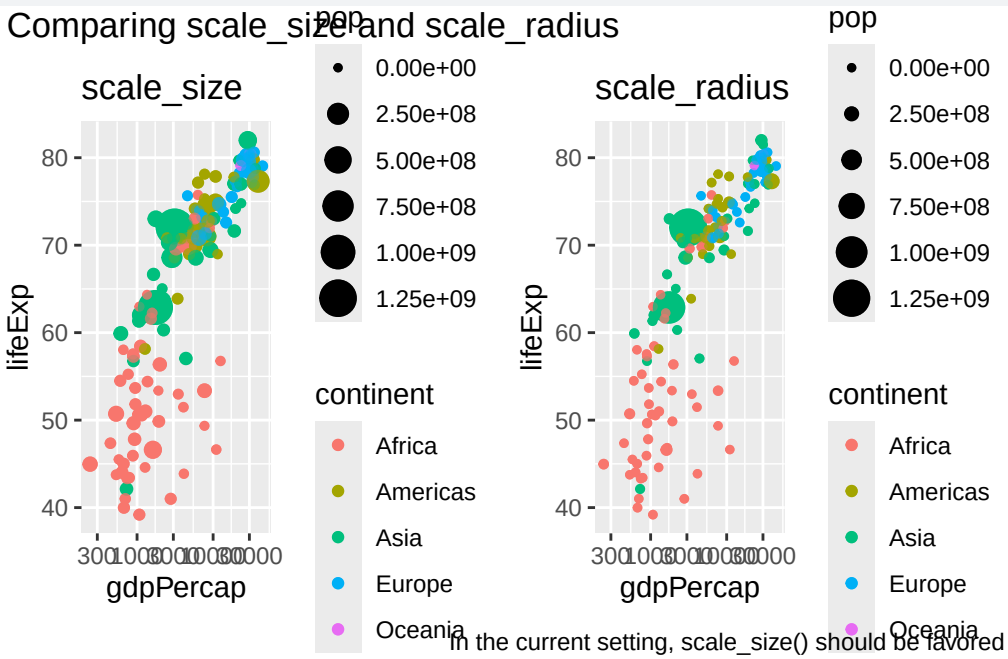
With `scale_size_area()`, the area of the point is proportional to the value of the variable mapped to `size`. With `scale_size()`, the radius of the point is proportional to the value of the variable mapped to `size`, so the area is proportional to the square of the value of the variable. This tends to exaggerate the differences between the sizes of the points. This is a way of lying with statistics.

solution

We use package `patchwork` to collect and present several graphical objects.

```
ptchwrk <- (
  p +
  scale_size(limits = pop_range) +
  ggtitle("scale_size")) +
  (p +
  scale_radius(limits = pop_range) +
  ggtitle("scale_radius"))

ptchwrk + plot_annotation(
  title='Comparing scale_size and scale_radius',
  caption='In the current setting, scale_size() should be favored'
)
```



According to the documentation, `scale_size_area()` ensures that a value of 0 is mapped to a size of 0. This is not the case with `scale_size()`.

```
ptchwrk <- (
  p +
  scale_size(limits = pop_range) +
  ggtitle("scale_size")) +
  (p +
  scale_size_area() +
```

In perspective

Question

Using copilots completions, we can summarize the construcion of the graphical object in a series of questions.

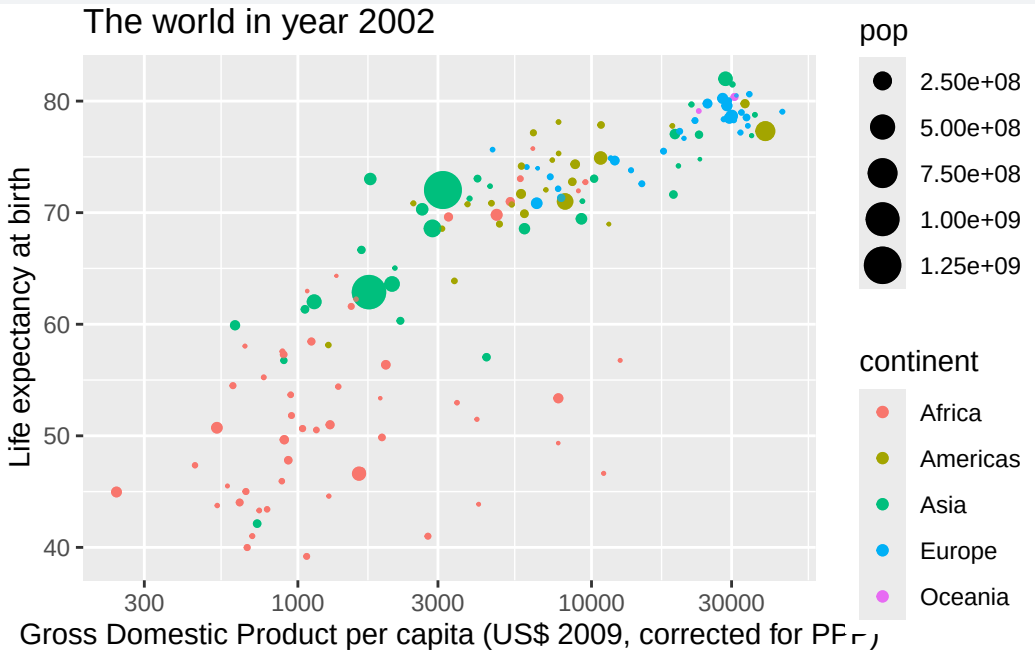
```
# q: Define a plot with respect to table gapminder_2002 along the lines suggested by P
# q: Map variables gdpPercap and lifeExp to axes x and y. Define the axes.
# q: For each row, draw a point at coordinates defined by the mapping.
# q: Map continent to color
# q: Map pop to bubble size
# q: Make point transparent by tuning alpha (inside geom_point() avoid overplotting)
# q: Add a plot title
# q: Make axes titles explicit and readable
# q: Use labs(...)
# q: Use scale_x_log10() and scale_size_area()
# q: Fine tune the guides: replace pop by Population and titlecase continent
# q: Use theme_minimal()
# q: Use scale_color_manual(...) to fine tune the color aesthetic mapping.
# q: Use facet_zoom() from package ggforce
# q: Add labels to points. This can be done by aesthetic mapping. Use aes(label=..)
```

solution

```
yoi <- 2002

p <-  p +
  labs(
    title=glue('The world in year {yoi}'),
    x="Gross Domestic Product per capita (US$ 2009, corrected for PPP)",
    y="Life expectancy at birth"
  )

p
```



solution

We should also fine tune the guides: replace `pop` by `Population` and titlecase `continent`.

```
# q: fine tune the guides: replace `pop` by `Population` and titlecase `continent`.
p <- p +
  guides(color = guide_legend(title = "Continent",
                              override.aes = list(size = 5),
                              order = 1),
         size = guide_legend(title = "Population",
                             order = 2))
```

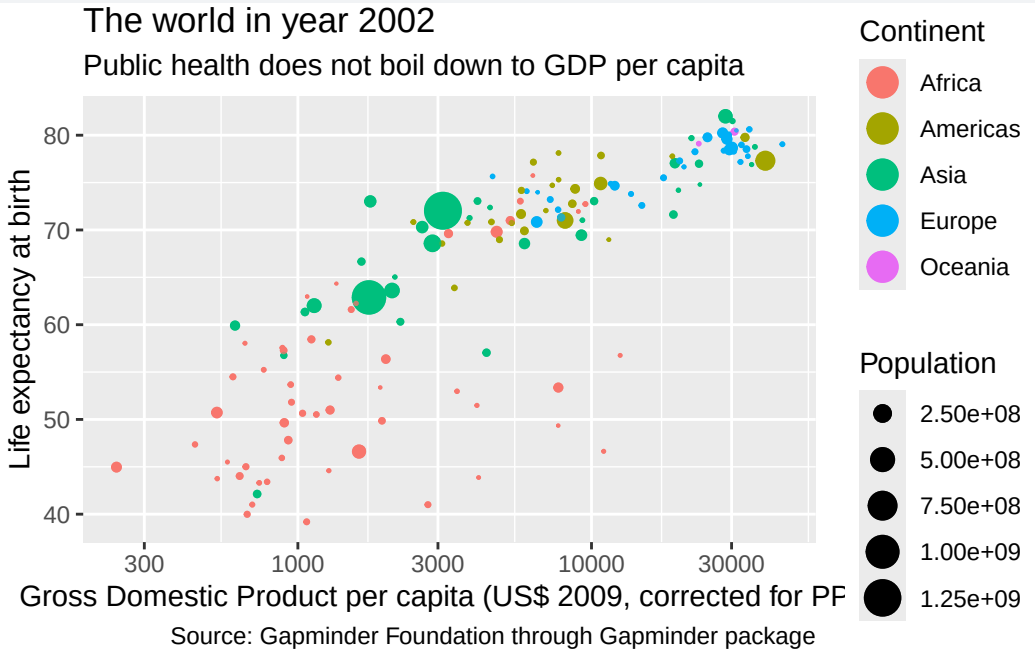
Question

What should be the respective purposes of Title, Subtitle, Caption, … ?

solution

- The title should be explicit and concise. It should summarize the content of the graphic object. Our title here "The world in year 2002" is concise but not explicit enough. The world may signify widely different things. Here, we mean world countries
- The subtitle should provide additional information: "Public health does not boil down to GDP per capita"
- The caption should provide additional information. Here we could explain the meaning of the axes, the color scale, the size scale, … provided guides are not enough. Here we could spot the source(s) of the data: UNO, WHO, World Bank, …, Gapminder foundation.

```
p <- p +
  labs(
    subtitle="Public health does not boil down to GDP per capita",
    caption="Source: Gapminder Foundation through Gapminder package"
  )
p
```



Theming using `ggthemes` (or not)

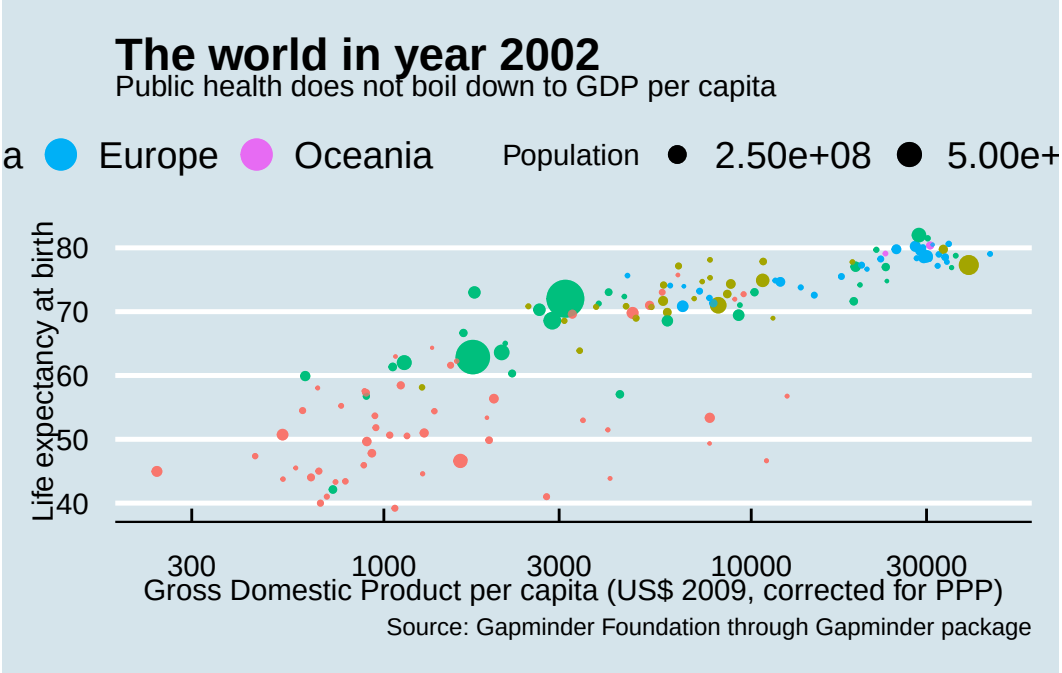
```
stopifnot(
  require("ggthemes")
)
```

A theme defines the *look and feel* of plots

Within a single document, we should use only one theme

See Getting the theme for a gallery of available themes

```
p +
  theme_economist()
```



Tuning scales

> **Question**
>
> Use `scale_color_manual(...)` to fine tune the color aesthetic mapping.

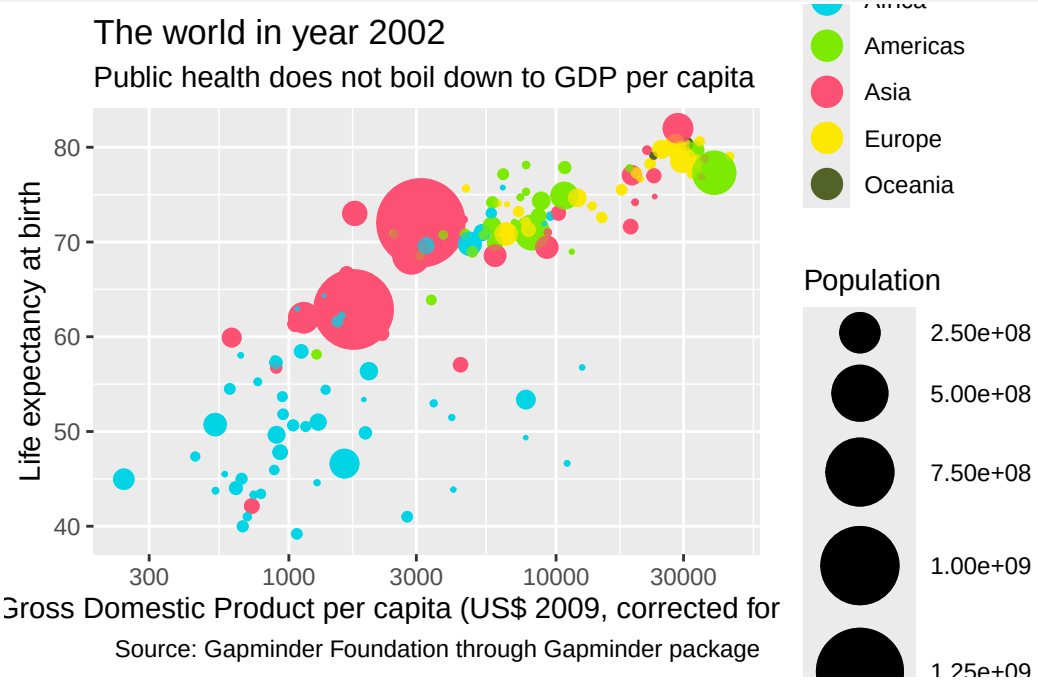
Solution

````
```{r}
#| label: theme_scale
neat_color_scale <-
      c("Africa" = "#01d4e5",
        "Americas" = "#7dea01" ,
        "Asia" = "#fc5173",
        "Europe" = "#fde803",
        "Oceania" = "#536227")
```
````

```
p <- p +
  scale_size_area(max_size = 15) + #<<
  scale_color_manual(values = neat_color_scale) #<<
```

```
Scale for size is already present.
Adding another scale for size, which will replace the existing scale.
```

```
p
```



Tip

Choosing a color scale is a difficult task
`viridis` is often a good pick.

solution

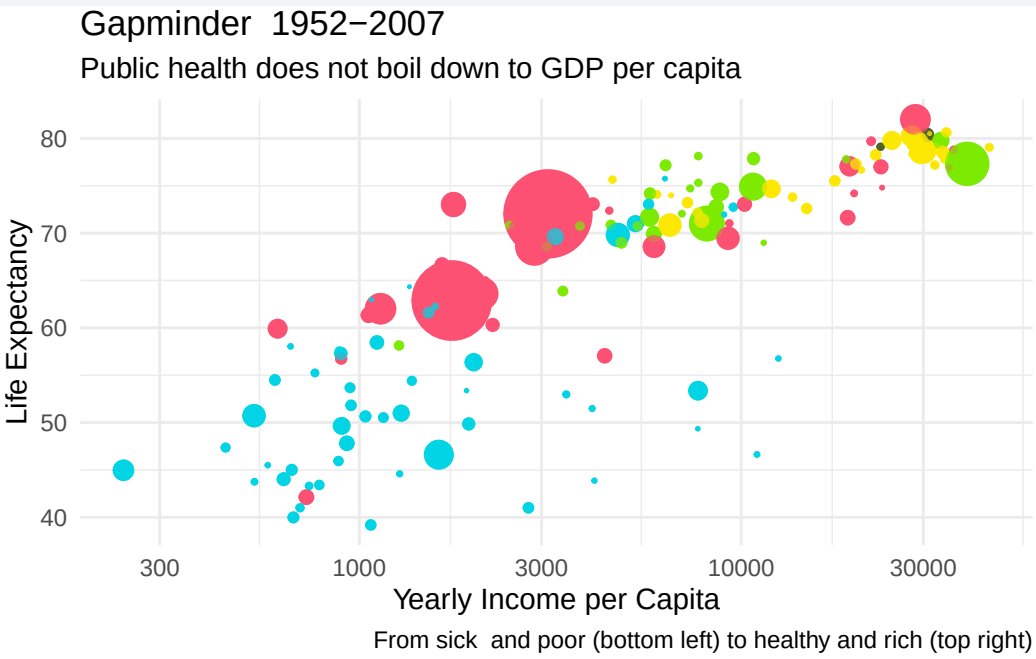
Mimnimalist themes are often a good pick.

```
old_theme <- theme_set(theme_minimal())
```

```
p <- p +
   scale_size_area(max_size = 15,
                   labels= scales::label_number(scale=1/1e6,
                                                suffix=" M")) +
   scale_color_manual(values = neat_color_scale) +
    labs(title= glue("Gapminder  {min(gapminder$year)}-{max(gapminder$year)}"),
         x = "Yearly Income per Capita",
         y = "Life Expectancy",
       caption="From sick  and poor (bottom left) to healthy and rich (top right)")
```

```
Scale for size is already present.
Adding another scale for size, which will replace the existing scale.
Scale for colour is already present.
Adding another scale for colour, which will replace the existing scale.
```

```
p + theme(legend.position = "none")
```



Zooming on a continent

```
zoom_continent <- 'Europe'  # choose another continent at your convenience
```

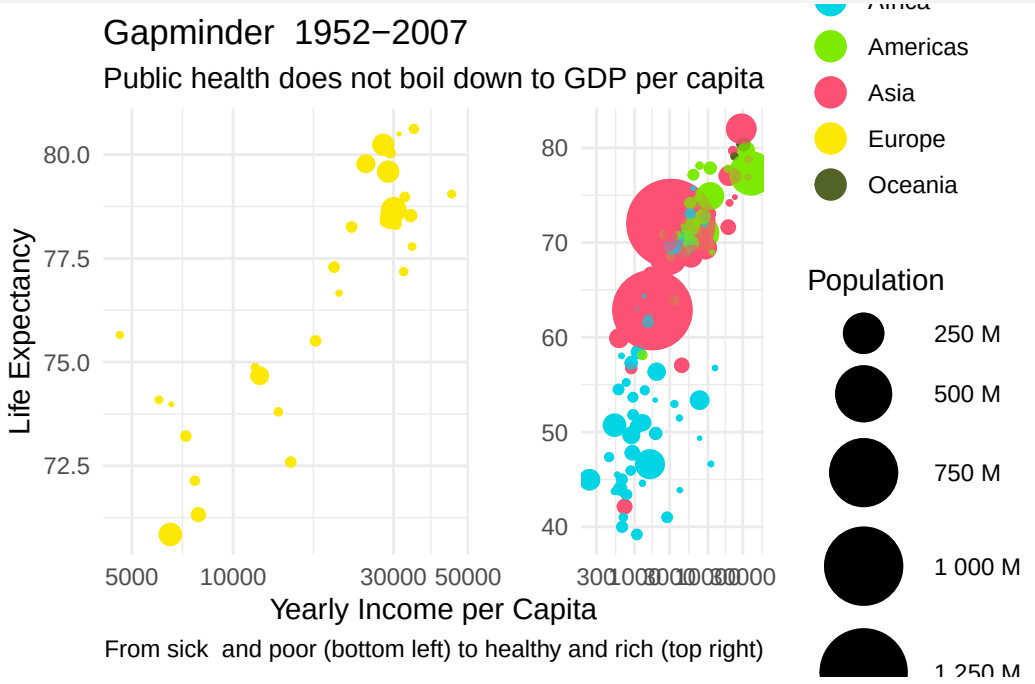
Use `facet_zoom()` from package `ggforce`

solution

```
stopifnot(
  require("ggforce") #<<
)

p_zoom_continent <- p +
  facet_zoom( #<<
    xy= continent==zoom_continent, #<<
    zoom.data= continent==zoom_continent #<<
    ) #<<

p_zoom_continent
```



Adding labels

Question

Add labels to points. This can be done by aesthetic mapping. Use `aes(label=..)` To avoid text cluttering, package `ggrepel` offers interesting tools.

solution

```
stopifnot(
require(ggrepel) #<<
)

p +
   aes(label=country) + #<<
   ggrepel::geom_label_repel(max.overlaps = 5) + #<<
   scale_size_area(max_size = 15,
                   labels= scales::label_number(scale=1/1e6,
                                                suffix=" M"))  #+
```

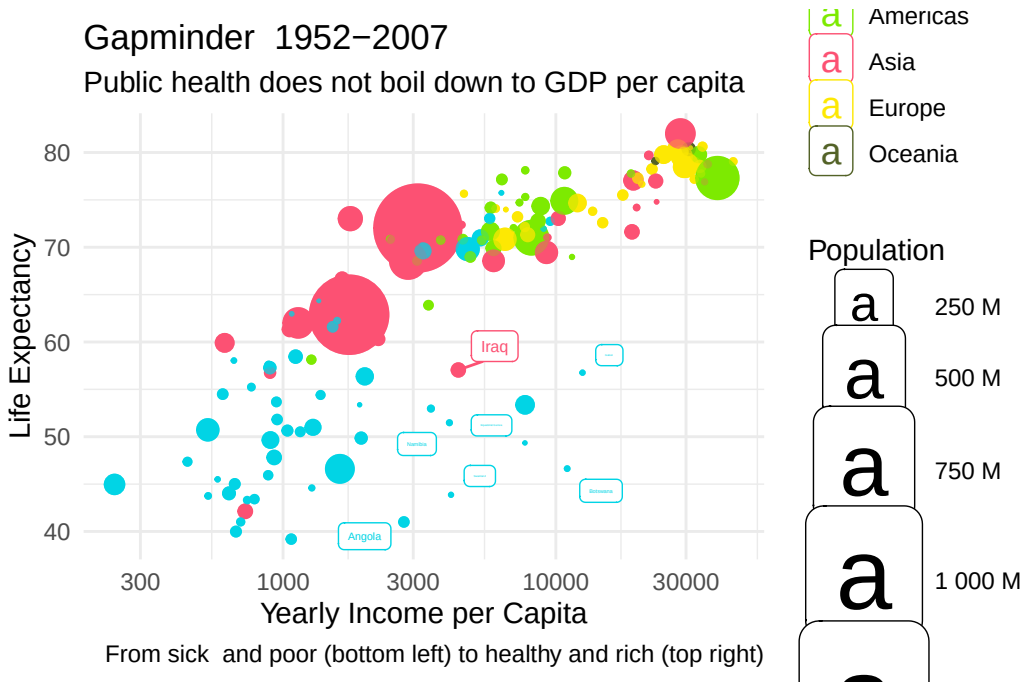


Figure 1: Gapminder 2002 layer by layer

```
  # scale_color_manual(values = neat_color_scale) +
  # theme(legend.position = "none") +
    # labs(title= glue("Gapminder  {min(gapminder$year)}-{max(gapminder$year)}"),
    #      x = "Yearly Income per Capita",
    #      y = "Life Expectancy",
    #    caption="From sick  and poor (bottom left) to healthy and rich (top right)")
```

Facetting

So far we have only presented one year of data (2002)

Rosling used an *animation* to display the flow of time

If we have to deliver a printable report, we cannot rely on animation, but we can rely on *facetting*

Facets are collections of small plots constructed in the same way on subsets of the data

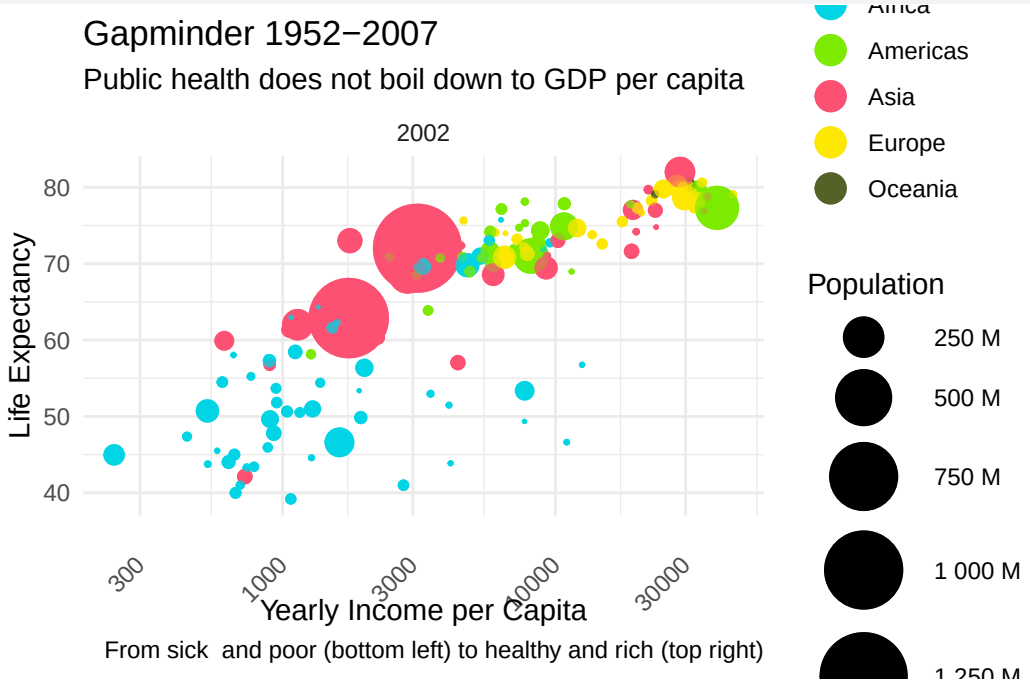
Question

Add a layer to the graphical object using `facet_wrap()`

solution

```
p <- p +
  aes(text=country) +
  guides(color = guide_legend(title = "Continent",
                              override.aes = list(size = 5),
                              order = 1),
         size = guide_legend(title = "Population",
                             order = 2)) +
  theme(axis.text.x = element_text(angle = 45, vjust = 0.5, hjust=1)) +
  facet_wrap(vars(year), ncol=6) +
  ggtitle("Gapminder 1952-2007")

p
```



As all rows in `gapminder_2002` are all related to `year` 2002, we need to rebuild the graphical object along the same lines (using the same *graphical pipeline*) but starting from the whole `gapminder` dataset.

Should we do this using *cut and paste*?

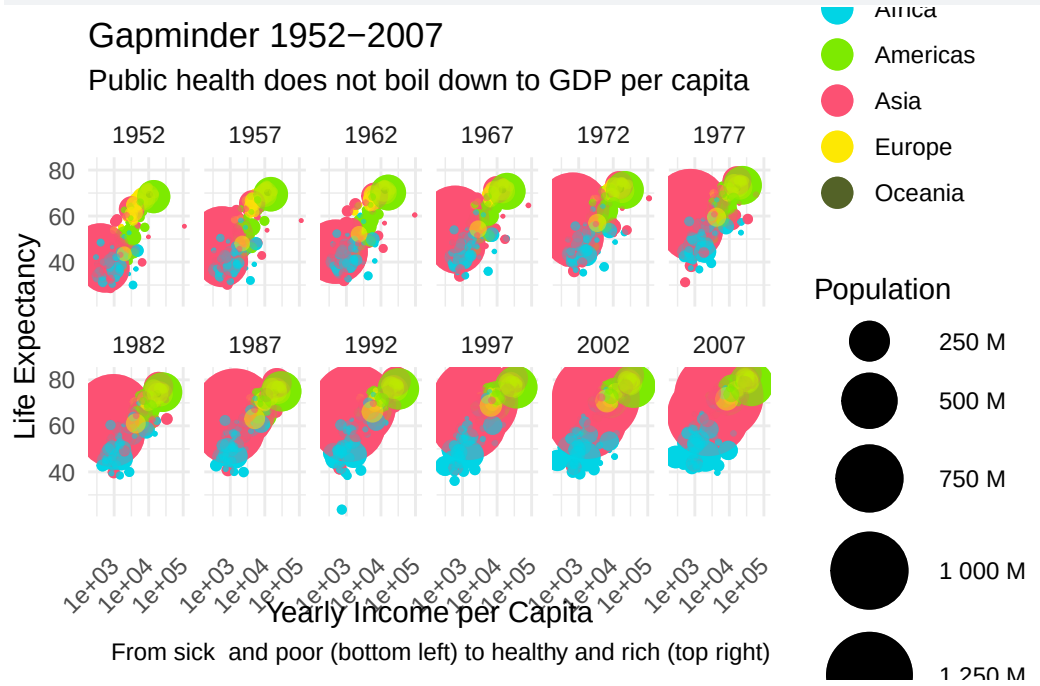
☠ No!!!

Don't Repeat Yourself (DRY)

Abide to the DRY principle using operator `%+%`: the `ggplot2` object `p` can be fed with another dataframe and all you need is proper facetting.

solution

```
p %+% gapminder
```



Animate for free with `plotly`

Question

Use `plotly::ggplotly()` to create a Rosling like animation.
Use `frame` aesthetics.

solution

````
```{r}
#| label: animate
#| eval: !expr knitr::is_html_output()
#| code-annotations: hover

q <- filter(gapminder, FALSE) |>
   ggplot() +
   aes(x = gdpPercap) +
   aes(y = lifeExp) +
   aes(size = pop) +
   aes(text = country) +                    #
   aes(fill = continent) +
   # aes(frame = year) +                      #
  geom_point(alpha=.5, colour='black') +
  scale_x_log10() +
  scale_size_area(max_size = 15,
                  labels= scales::label_number(scale=1/1e6,
                                               suffix=" M")) +
  scale_fill_manual(values = neat_color_scale) +
  theme(legend.position = "none") +
  labs(title= glue("Gapminder  {min(gapminder$year)}-{max(gapminder$year)}"),
       x = "Yearly Income per Capita",
       y = "Life Expectancy",
       caption="From sick  and poor (bottom left) to healthy and rich (top right)")


(q %+% gapminder) |>
  plotly::ggplotly(height = 500, width=750)
```
````

1. `text` will be used while *hovering*
2. `frame` is used by `plotly` to drive the animation. One `frame` per year

solution

````
```{r}
#| eval: !expr knitr::is_html_output()

(p %+% gapminder +
 facet_null() +
 aes(frame=year)) |>
 plotly::ggplotly(height = 500, width=750)
```
````

Suggestions

Think about ways to visualize specific aspects of the gapminder data.

- How could you overlay the world in 1952 and 2007?
- How could you visualize the evolution of life expectancy and population across the different countries?

- Visualize the evolution of former colonies and their colonizers.
- Visualize the evolution of countries from the former Soviet Union, Warsaw Pact, and Yugoslavia.
- Visualize the evolution of countries from the former British Empire.

More material

Visit Data visualization using ggplot2 and its extensions, UseR 2021 Tutorial

Read Visualization in R for Data Science