

Data Visualization with R

The 4th Vietnam School of Biology (VSOB4)

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1 Introduction to Data Visualization

1.1 Data Visualization

- Represent data in the form of graphs, charts, plots, ...
- A story conveyed through visuals
- Patterns, trends, anomalies in data

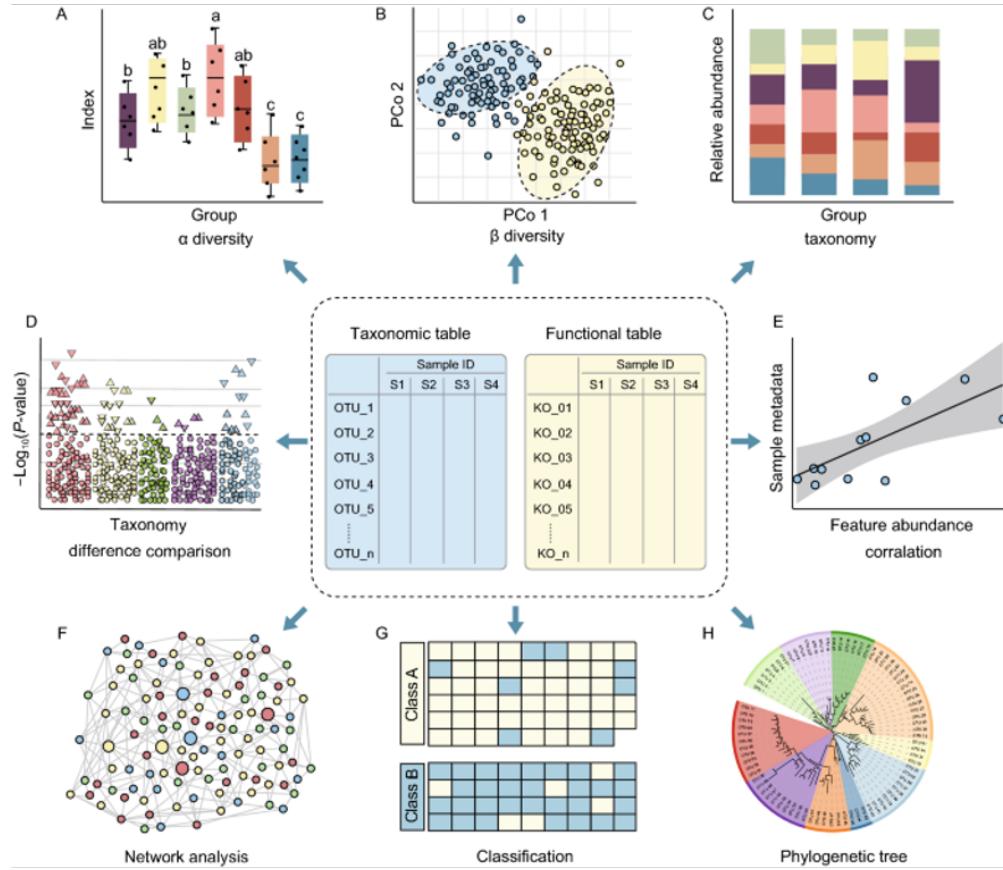


Figure 1: Data Visualization

1.2 Chart types

There are six main categories of chart:

- **Comparisons**: visualizations for comparing categories, such as bar charts, grouped bars, bubble charts, radar charts, and horizontal bar charts.
- **Trends**: charts that show changes over time or sequence, including line charts, area charts, stream graphs, histograms, and box plots.
- **Part to Whole**: charts that illustrate how individual components contribute to a whole, such as pie charts, stacked bars, stacked areas, tree maps, gauges, meters, and waffle plots.
- **Correlations**: visualizations for exploring relationships between variables, including scatterplots, heatmaps, and parallel coordinates.
- **Relationships and Connections**: charts that highlight links or flows, such as alluvial diagrams and tree diagrams.

- **Maps:** spatial data visualizations, including choropleth maps, proportional symbol maps, and connecting lines.

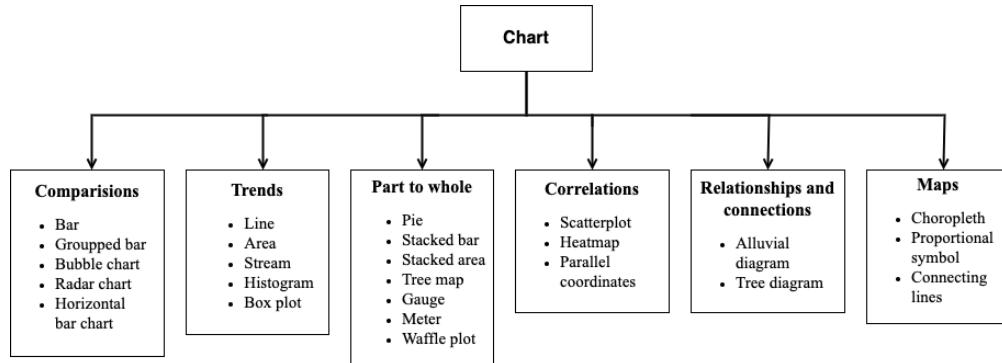


Figure 2: Chart types

1.3 Popular Data Visualization tools

- Microsoft Excel
- Tableau
- Microsoft Power BI
- Google Looker Studio
- Python (Matplotlib, Seaborn)
- R (ggplot2 & Tidyverse)

1.4 R (ggplot2) vs. Python (Matplotlib/Seaborn)

- **R:** The Specialist for Analysis & Graphics
- **Python:** The General-Purpose Swiss Army Knife

Choose R if:

- Your daily work is primarily **analyzing experimental data** (RNA-seq, proteomics, metabolomics, etc.).
- You need to create many **complex, high-quality graphics for reports and scientific publications**.
- You want to leverage the massive **Bioconductor** ecosystem and cutting-edge statistical methods.
- You appreciate the logical and structured approach of the “**Grammar of Graphics**.”

Choose Python if:

- Visualization is just **one step in a larger pipeline** involving image processing, machine learning, automation, or software development.
- You need to **integrate your analyses into a website or application**.
- You are already familiar with Python and want to **keep everything in one environment**.
- You work heavily with deep learning models for biological problems (e.g., AlphaFold).

Advice: A great bioinformatician often knows both. They might use **R for exploration, statistical analysis, and quick plotting**, then switch to **Python to build automated pipelines or complex models**.

2 What is ggplot?

- A package in the tidyverse ecosystem of R
- Developed by Hadley Wickham
- Based on the Grammar of Graphics
- Create high-quality and customizable plots (publication ready)
- Unified syntax for different types of Visualization

2.1 Grammar of Graphics

```
# Do NOT execute
A plot = Data +      # the dataset used
    Aesthetics +   # mapping variables to visual properties (x, y, color, size, shape)
    Geoms +        # geometric objects (points, lines, bars, boxplots, ...)
    Stats +        # statistical transformations (binning, smoothing, summaries)
    Scales +       # how values are translated into position, color, size, ...
    Coordinates + # the coordinate system (Cartesian, polar, log, ...)
    Facets +       # splitting data into multiple small plots
    Theme +        # non-data elements (background, fonts, grid, legend position, ...)
    ...
```

3 Getting familiar with a dataset

3.1 Loading packages

This code chunk shows the loading of the packages required for the analyses. Here, we are using the `p_load()` function from the `pacman` package, which will install a package if necessary **and** load it for use. You can also load installed packages with the `library()` function from `base` R.

```
pacman::p_load(
  tidyverse,          # includes ggplot2 and other data management tools
  janitor,           # cleaning and summary tables
  ggforce,            # ggplot extras
  rio,                # import/export
  here,               # file locator
  stringr,            # working with characters
  patchwork           # ghép nhiều biểu đồ
)
```

3.2 Loading the dataset

There are many ways of importing your dataset. In this tutorial, we upload an Excel file then load it into R with the variable name `mydata`.

```
# 1: uploading your excel file manually
```

```
# 2: using base R function
```

```
#download.file("https://github.com/juhuvn/usob4/blob/0f2675021f67806ce0fb3c93a792d5648d901abf/Day4/myda
```

```

# 3: using `rio::import` function to import data directly from an URL
mydata <- rio::import("https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/mydata.xlsx", trust=TRUE)

# 4: loading the dataset from current directory
#mydata <- rio::import("mydata.xlsx", trust=TRUE)

```

Getting to know the dataset. In this tutorial, we are mainly working with `age` and `wt_kg` (weight in Kilogram).

```
glimpse(mydata)
```

```

## Rows: 5,888
## Columns: 30
## $ case_id          <chr> "5fe599", "8689b7", "11f8ea", "b8812a", "893f25", ~
## $ generation       <dbl> 4, 4, 2, 3, 3, 3, 4, 4, 4, 4, 4, 6, 5, 6, 9, 1~
## $ date_infection   <dttm> 2014-05-08, NA, NA, 2014-05-04, 2014-05-18, 2014~
## $ date_onset        <dttm> 2014-05-13, 2014-05-13, 2014-05-16, 2014-05-18, ~
## $ date_hospitalisation <dttm> 2014-05-15, 2014-05-14, 2014-05-18, 2014-05-20, ~
## $ date_outcome      <dttm> NA, 2014-05-18, 2014-05-30, NA, 2014-05-29, 2014~
## $ outcome            <chr> NA, "Recover", "Recover", NA, "Recover", "Recover~
## $ gender              <chr> "m", "f", "m", "f", "m", "f", "f", "m", "f", ~
## $ age                 <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_unit            <chr> "years", "years", "years", "years", "yea~
## $ age_years           <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_cat             <chr> "0-4", "0-4", "50-69", "15-19", "0-4", "15-19", "~
## $ age_cat5            <chr> "0-4", "0-4", "55-59", "15-19", "0-4", "15-19", "~
## $ hospital            <chr> "Other", "Missing", "St. Mark's Maternity Hospita~
## $ lon                 <dbl> -13.21574, -13.21523, -13.21291, -13.23637, -13.2~
## $ lat                 <dbl> 8.468973, 8.451719, 8.464817, 8.475476, 8.460824, ~
## $ infector            <chr> "f547d6", NA, NA, "f90f5f", "11f8ea", "aec8ec", "~
## $ source              <chr> "other", NA, NA, "other", "other", "other", "othe~
## $ wt_kg               <dbl> 27, 25, 91, 41, 36, 56, 47, 0, 86, 69, 67, 84, 68~
## $ ht_cm                <dbl> 48, 59, 238, 135, 71, 116, 87, 11, 226, 174, 112, ~
## $ ct_blood            <dbl> 22, 22, 21, 23, 23, 21, 21, 22, 22, 22, 22, 2~
## $ fever                <chr> "no", NA, NA, "no", "no", "no", NA, "no", "no", "n~
## $ chills              <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", "n~
## $ cough                <chr> "yes", NA, NA, "no", "yes", "yes", NA, "yes", "ye~
## $ aches                <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", "n~
## $ vomit                <chr> "yes", NA, NA, "no", "yes", "yes", NA, "yes", "ye~
## $ temp                 <dbl> 36.8, 36.9, 36.9, 36.8, 36.9, 37.6, 37.3, 37.0, 3~
## $ time_admission       <chr> NA, "09:36", "16:48", "11:22", "12:60", "14:13", ~
## $ bmi                  <dbl> 117.18750, 71.81844, 16.06525, 22.49657, 71.41440~
## $ days_onset_hosp      <dbl> 2, 1, 2, 2, 1, 1, 2, 1, 2, 2, 1, 0, 2, 0, 1~
```

3.3 Cleaning the dataset

```

# make display version of columns with more friendly names
mydata <- mydata %>%
  mutate(
    gender_disp = case_when(gender == "m" ~ "Male",           # m to Male
                            gender == "f" ~ "Female",         # f to Female,

```

```

        is.na(gender) ~ "Unknown"      # NA to Unknown
    )
)

mydata <- mydata %>% mutate(
    outcome_disp = replace_na(outcome, "Unknown")      # replace NA outcome with "unknown"
)

```

Reviewing the dataset after mutating, look at the number of the columns and the last two columns.

```
glimpse(mydata)
```

```

## Rows: 5,888
## Columns: 32
## $ case_id          <chr> "5fe599", "8689b7", "11f8ea", "b8812a", "893f25", ~
## $ generation       <dbl> 4, 4, 2, 3, 3, 3, 4, 4, 4, 4, 4, 4, 6, 5, 6, 9, 1~
## $ date_infection   <dttm> 2014-05-08, NA, NA, 2014-05-04, 2014-05-18, 2014~
## $ date_onset        <dttm> 2014-05-13, 2014-05-13, 2014-05-16, 2014-05-18, ~
## $ date_hospitalisation <dttm> 2014-05-15, 2014-05-14, 2014-05-18, 2014-05-20, ~
## $ date_outcome      <dttm> NA, 2014-05-18, 2014-05-30, NA, 2014-05-29, 2014~
## $ outcome            <chr> NA, "Recover", "Recover", NA, "Recover", "Recover~
## $ gender              <chr> "m", "f", "m", "f", "m", "f", "f", "m", "f", ~
## $ age                 <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_unit             <chr> "years", "years", "years", "years", "yea~
## $ age_years            <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_cat              <chr> "0-4", "0-4", "50-69", "15-19", "0-4", "15-19", "~
## $ age_cat5             <chr> "0-4", "0-4", "55-59", "15-19", "0-4", "15-19", "~
## $ hospital             <chr> "Other", "Missing", "St. Mark's Maternity Hospita~
## $ lon                  <dbl> -13.21574, -13.21523, -13.21291, -13.23637, -13.2~
## $ lat                  <dbl> 8.468973, 8.451719, 8.464817, 8.475476, 8.460824, ~
## $ infector             <chr> "f547d6", NA, NA, "f90f5f", "11f8ea", "aec8ec", "~
## $ source                <chr> "other", NA, NA, "other", "other", "other", "othe~
## $ wt_kg                 <dbl> 27, 25, 91, 41, 36, 56, 47, 0, 86, 69, 67, 84, 68~
## $ ht_cm                  <dbl> 48, 59, 238, 135, 71, 116, 87, 11, 226, 174, 112, ~
## $ ct_blood               <dbl> 22, 22, 21, 23, 23, 21, 21, 22, 22, 22, 22, 22, 2~
## $ fever                  <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ chills                  <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ cough                  <chr> "yes", NA, NA, "no", "yes", "yes", NA, "yes", "ye~
## $ aches                  <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ vomit                  <chr> "yes", NA, NA, "no", "yes", "yes", NA, "yes", "ye~
## $ temp                   <dbl> 36.8, 36.9, 36.9, 36.8, 36.9, 37.6, 37.3, 37.0, 3~
## $ time_admission         <chr> NA, "09:36", "16:48", "11:22", "12:60", "14:13", ~
## $ bmi                    <dbl> 117.18750, 71.81844, 16.06525, 22.49657, 71.41440~
## $ days_onset_hosp        <dbl> 2, 1, 2, 2, 1, 1, 2, 1, 2, 2, 1, 0, 2, 0, 1~
## $ gender_disp            <chr> "Male", "Female", "Male", "Female", "Male", "Fema~
## $ outcome_disp           <chr> "Unknown", "Recover", "Recover", "Unknown", "Reco~

```

4 Structure of Grammar of Graph

4.1 Scatter plot

A scatter plot is a type of graph used to show the relationship between two numerical variables.

- Each point (or “dot”) on the plot represents one observation in your dataset.
- The x-axis shows the values of one variable, and the y-axis shows the values of the other variable.
- By looking at how the points are distributed, you can see whether there is a pattern, such as a positive relationship (as one variable increases, the other tends to increase), a negative relationship (as one increases, the other decreases), or no clear relationship.

Scatter plots are especially useful for:

- Detecting correlations between variables.
- Identifying clusters of data.
- Spotting outliers (points that are far away from the others).

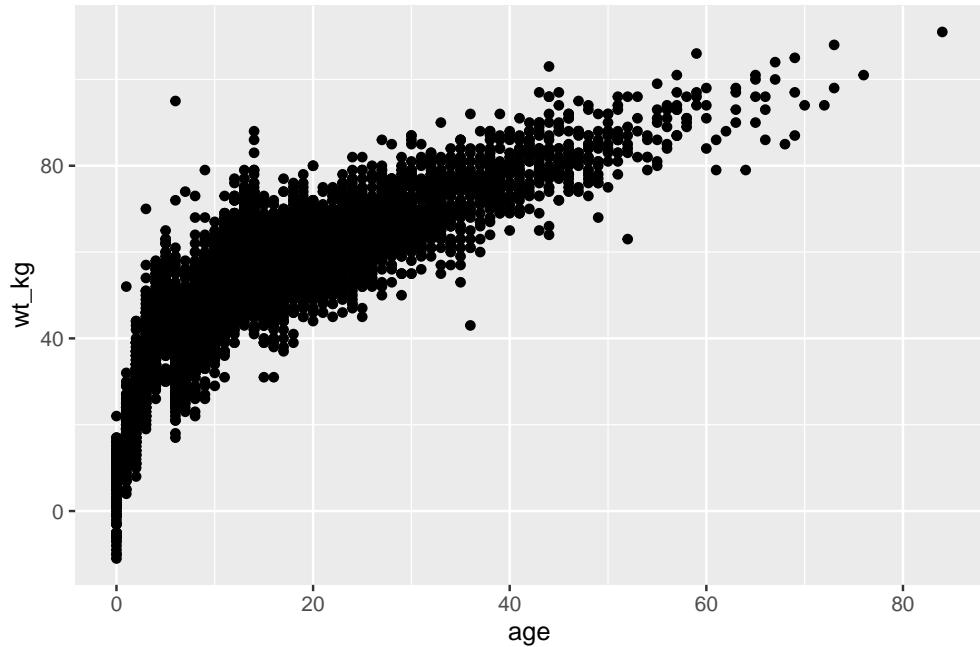
4.2 Basic Structure

The basic structure of the ggplot: Data + Aesthetics + Geom.

```
# do NOT execute
ggplot(data = my_data) +          # the dataset is my_data
  aes(x = column1, y = column2) + # mapping column1 to x axis, column2 to y axis
  geom_point()                  # point geometric
```

An example of scatter plot with basic structure

```
ggplot(data = mydata) +           # the dataset is my_data
  aes(x = age, y = wt_kg) +       # mapping age to x axis, wt_kg to y axis
  geom_point()                   # point geometric
```



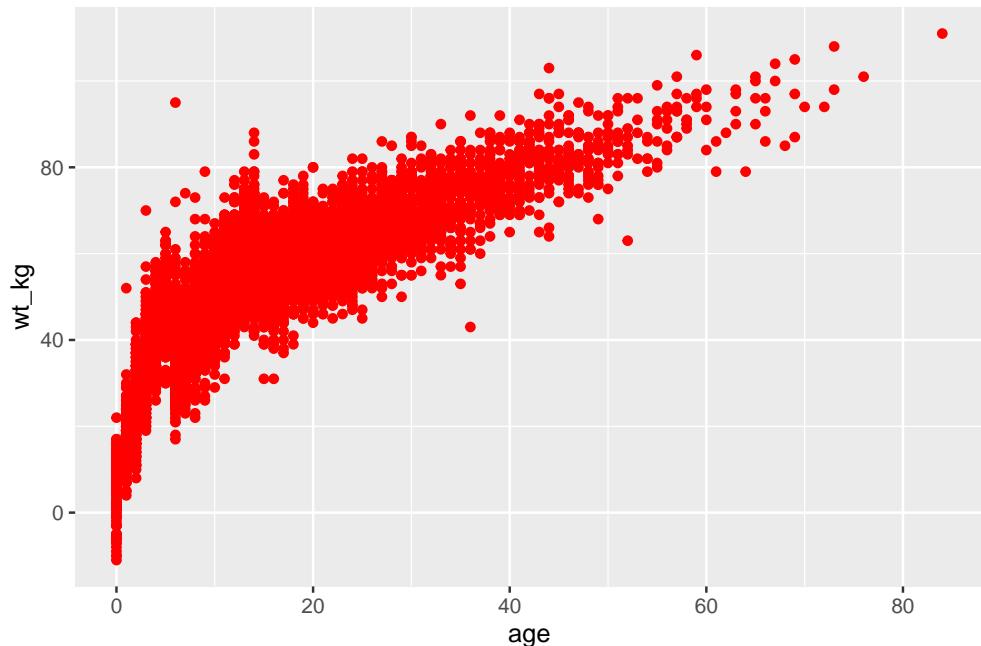
4.3 Aesthetic setting

In ggplot2, an aesthetic setting means you assign a fixed value to a graphical property (like color, shape, size, alpha, linetype) outside of `aes()`.

- It does not depend on the data.
- The value is constant for all points/lines/bars.
- No legend is created, because nothing is mapped to a variable.

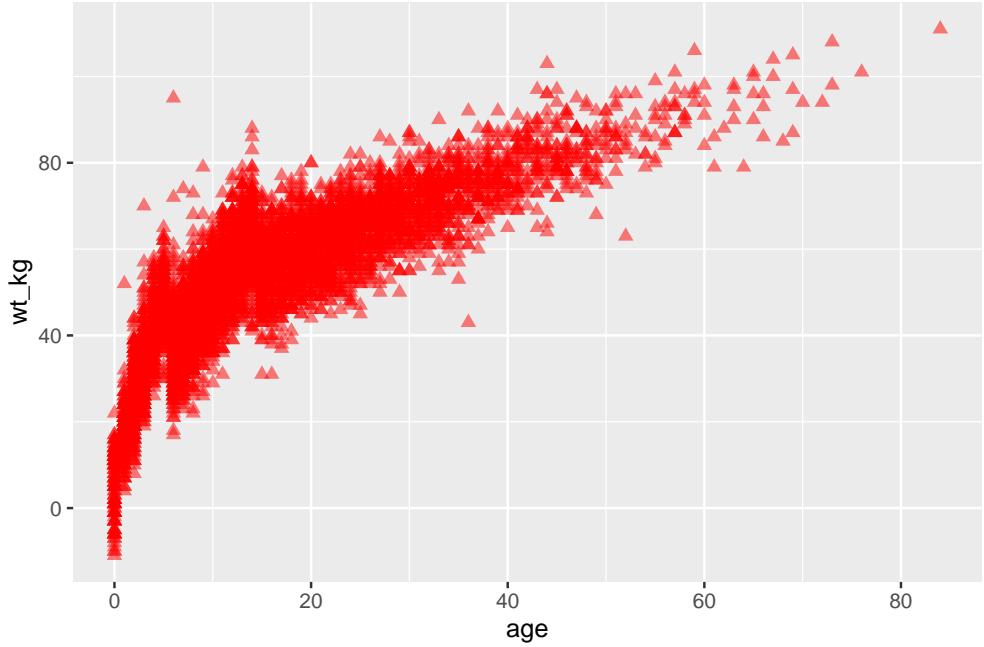
Set color to all dot.

```
ggplot(data = mydata) +          # the dataset is my_data
  aes(x = age, y = wt_kg) +       # mapping age to x axis, wt_kg to y axis
  geom_point(color = "red")        # point geometric
```



Set color, shape, size and transparency to all dot.

```
ggplot(data = mydata) +          # the dataset is my_data
  aes(x = age, y = wt_kg) +       # mapping age to x axis, wt_kg to y axis
  geom_point(color = "red",        # point geometric
             shape = "triangle",
             size = 2,
             alpha = 0.5)
```



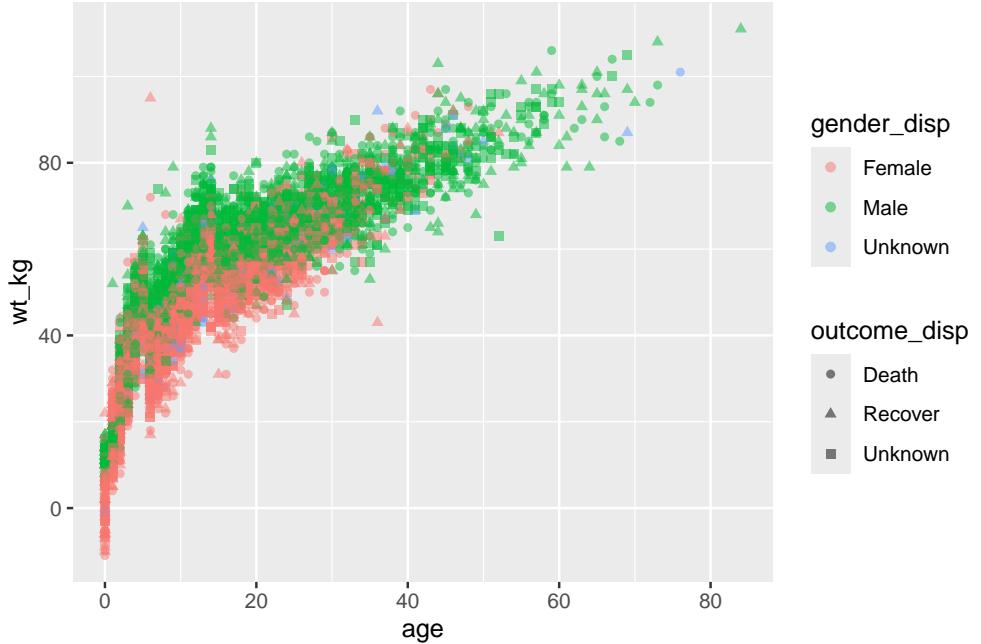
4.4 Aesthetic mapping

In ggplot2, an aesthetic mapping means you connect a data variable to a graphical property (called an aesthetic, e.g., color, size, shape, alpha).

- Write it inside aes().
- The appearance of the plot changes depending on the data values.
- A legend is automatically created, because ggplot2 knows you mapped a variable.

Example:

```
ggplot(data = mydata) +
  aes(x = age, y = wt_kg,
      color = gender_disp,
      shape = outcome_disp) +
  geom_point(alpha = 0.5)
```



5 Faceting the plots

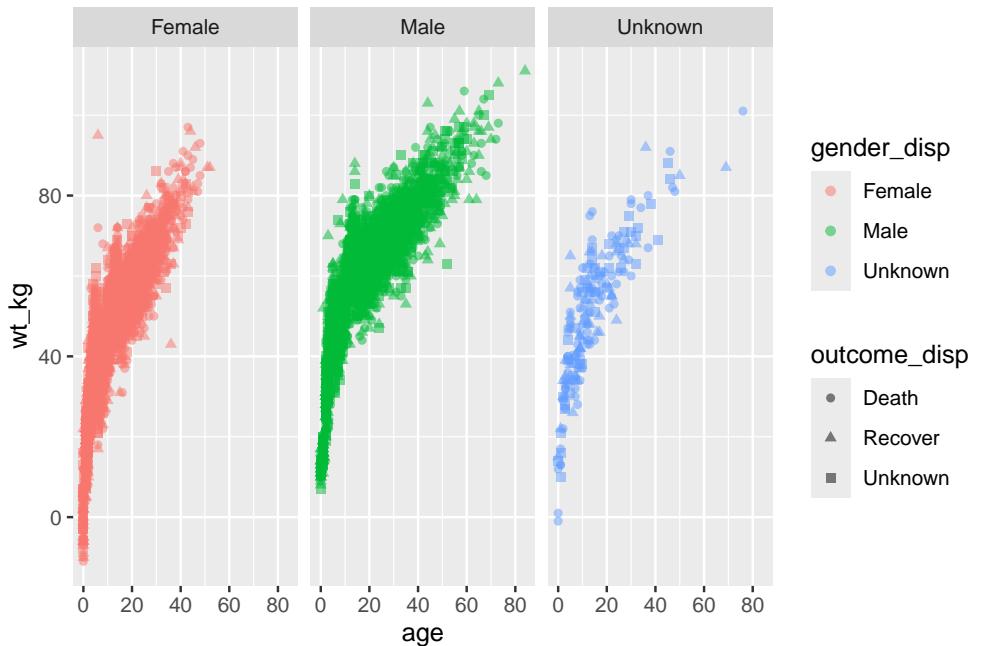
Faceting a plot in `ggplot2` means splitting one plot into multiple small plots (subplots), each showing a subset of the data based on the values of one or more categorical variables.

- Use `facet_wrap()` → lays out subplots in a grid, based on a single variable.
- Use `facet_grid()` → creates a matrix of subplots using two variables (rows × columns).

Faceting is useful to compare patterns across groups while keeping the same scales and style.

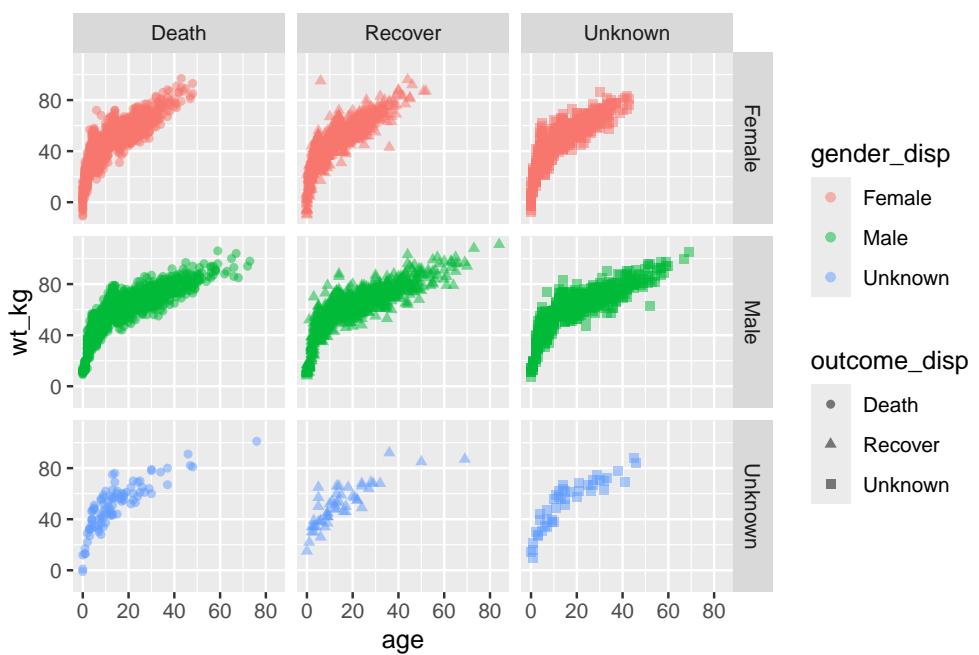
An example of `facet_wrap()`

```
ggplot(data = mydata) +
  aes(x = age, y = wt_kg,
      color = gender_disp,
      shape = outcome_disp) +
  geom_point(alpha = 0.5) +
  facet_wrap(~gender_disp)
```



An example of `facet_grid()`

```
ggplot(data = mydata) +
  aes(x = age, y = wt_kg,
      color = gender_disp,
      shape = outcome_disp) +
  geom_point(alpha = 0.5) +
  facet_grid(gender_disp ~ outcome_disp)
```

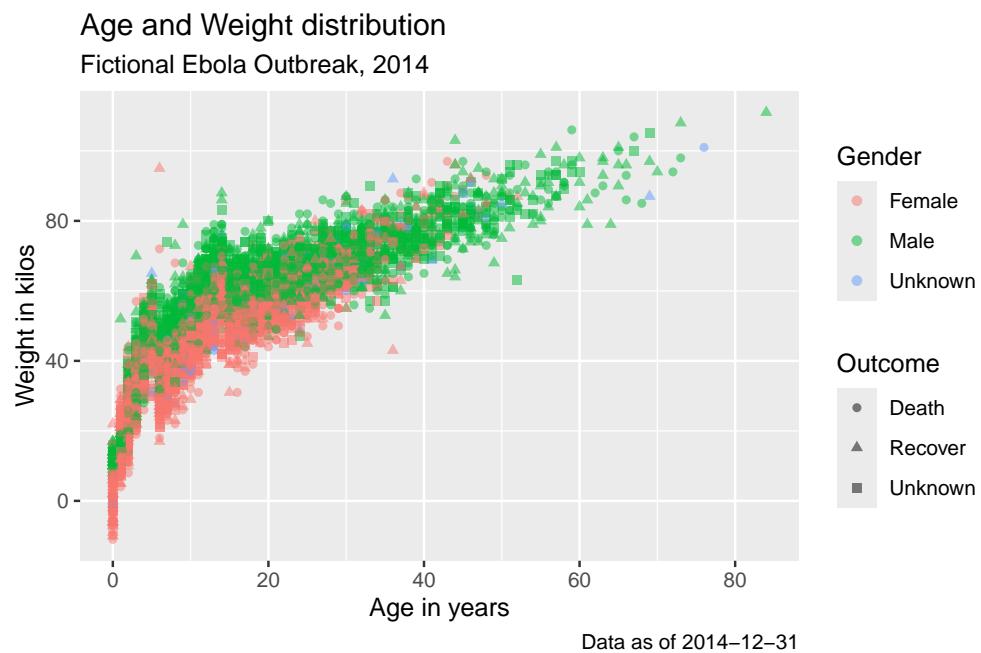


6 Labeling the plot

Labeling the plot means adding descriptive text elements that help readers understand what the plot shows. This usually includes:

- Title → the main heading of the plot.
- Subtitle → additional explanation or context.
- Axis labels → describe what each axis represents.
- Caption → source of data or extra notes.
- Legends → labels for colors, shapes, or other aesthetics mapped to data.
- Annotations → text directly added inside the plot for emphasis.

```
ggplot(data = mydata) +  
  aes(x = age, y = wt_kg,  
      color = gender_disp,  
      shape = outcome_disp) +  
  geom_point(alpha = 0.5) +  
  labs(x = "Age in years",  
       y = "Weight in kilos",  
       title = "Age and Weight distribution",  
       subtitle = "Fictional Ebola Outbreak, 2014",  
       caption = "Data as of 2014-12-31",  
       color = "Gender",  
       shape = "Outcome")
```



7 Themes

In **ggplot2**, a **theme** controls the *non-data* elements of a plot – everything that is not the actual data visualization.

- Themes affect the **background**, **grid lines**, **fonts**, **axis text**, **legend position**, **margins**, and other visual details.
- They do **not** change the data, scales, or geoms; they only change how the plot looks.

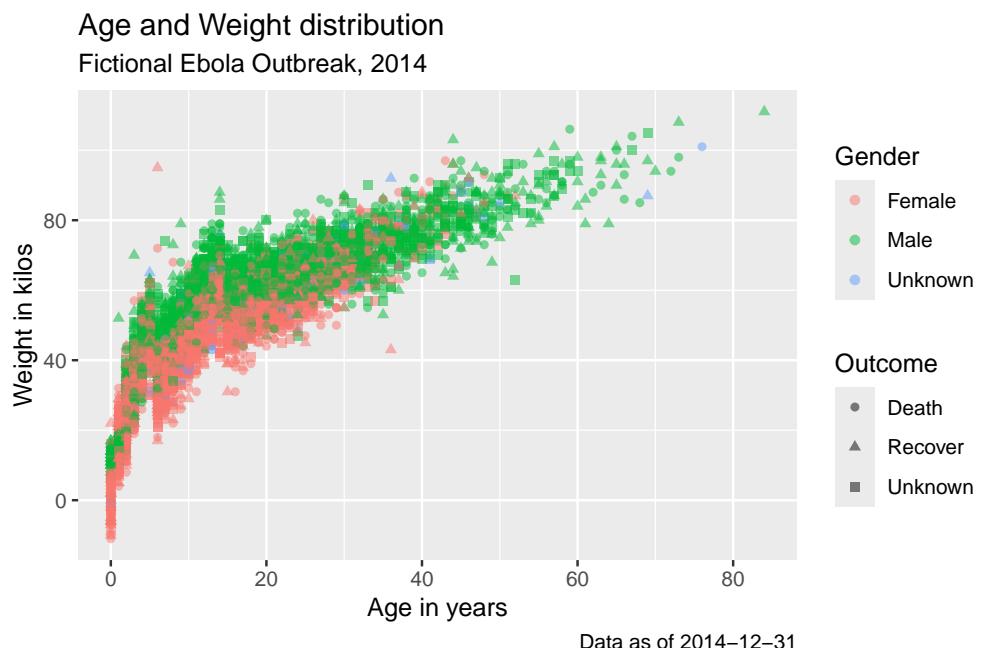
ggplot2 comes with several ready-to-use themes, for example:

- `theme_gray()` (default)
- `theme_light()`
- `theme_dark()`
- `theme_bw()` (black-and-white)
- `theme_minimal()`
- `theme_classic()`
- `theme_void()` (empty background)

A **theme** in ggplot2 is the system for customizing the *appearance* of the plot (background, text, grid, legend, etc.), making it either cleaner, more professional, or tailored to your presentation style.

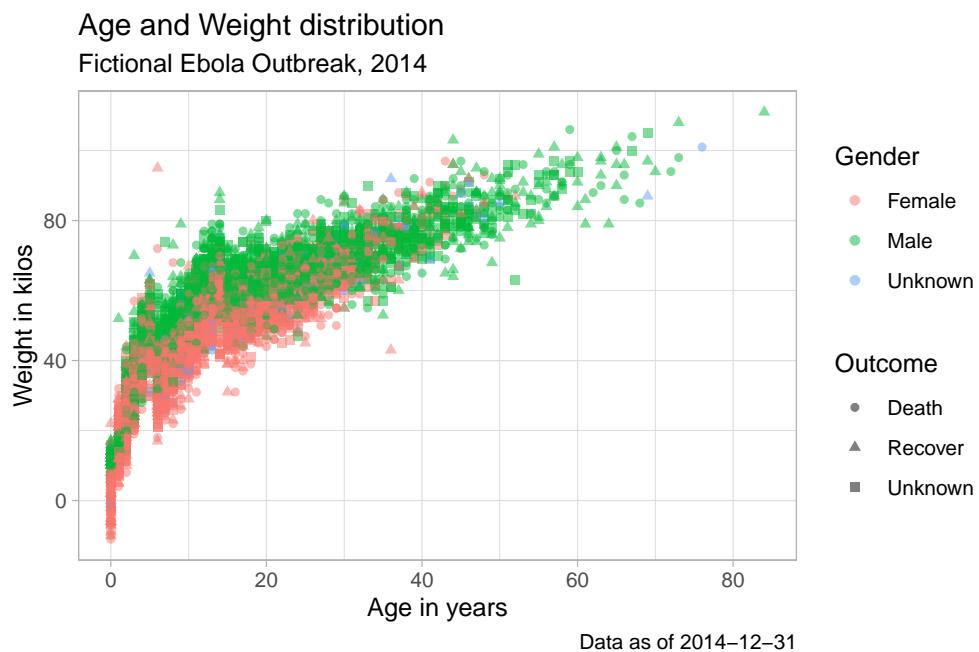
An example of `theme_gray()`

```
ggplot(data = mydata) +
  aes(x = age, y = wt_kg,
      color = gender_disp,
      shape = outcome_disp) +
  geom_point(alpha = 0.5) +
  labs(x = "Age in years",
       y = "Weight in kilos",
       title = "Age and Weight distribution",
       subtitle = "Fictional Ebola Outbreak, 2014",
       caption = "Data as of 2014-12-31",
       color = "Gender",
       shape = "Outcome") +
  theme_gray()
```



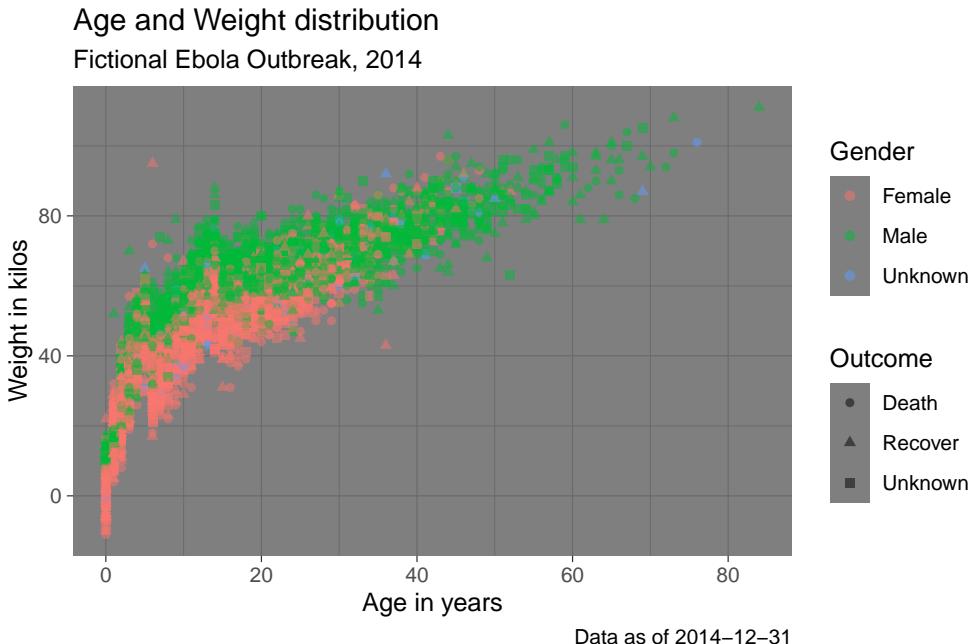
An example of `theme_light()`

```
ggplot(data = mydata) +  
  aes(x = age, y = wt_kg,  
      color = gender_disp,  
      shape = outcome_disp) +  
  geom_point(alpha = 0.5) +  
  labs(x = "Age in years",  
       y = "Weight in kilos",  
       title = "Age and Weight distribution",  
       subtitle = "Fictional Ebola Outbreak, 2014",  
       caption = "Data as of 2014-12-31",  
       color = "Gender",  
       shape = "Outcome") +  
  theme_light()
```



An example of `theme_dark()`

```
ggplot(data = mydata) +  
  aes(x = age, y = wt_kg,  
      color = gender_disp,  
      shape = outcome_disp) +  
  geom_point(alpha = 0.5) +  
  labs(x = "Age in years",  
       y = "Weight in kilos",  
       title = "Age and Weight distribution",  
       subtitle = "Fictional Ebola Outbreak, 2014",  
       caption = "Data as of 2014-12-31",  
       color = "Gender",  
       shape = "Outcome") +  
  theme_dark()
```



7.1 How to customize a theme? (Advanced)

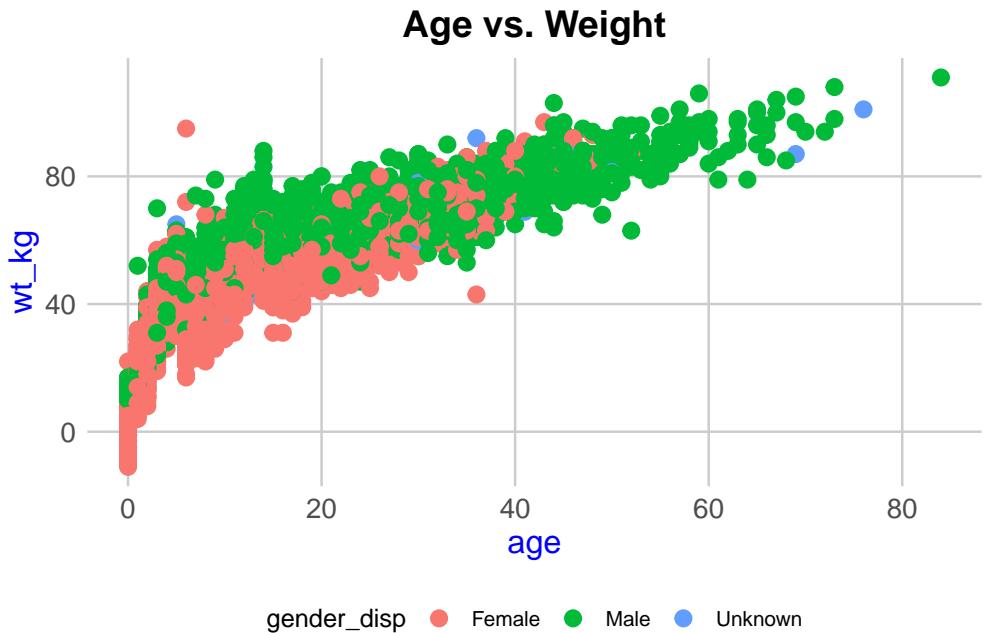
Customizing a theme is one of the most powerful parts of **ggplot2**.

7.1.1 The `theme()` function

You can override or modify individual parts of a theme. Each element (axis, legend, title, etc.) has its own options.

Example:

```
ggplot(data = mydata, aes(x = age, y = wt_kg, color = gender_disp)) +
  geom_point(size = 3) +
  theme_minimal() + # start from a base theme
  theme(
    plot.title = element_text(size = 16, face = "bold", hjust = 0.5),
    axis.title.x = element_text(size = 14, colour = "blue"),
    axis.title.y = element_text(size = 14, colour = "blue"),
    axis.text = element_text(size = 12),
    legend.position = "bottom", # move legend
    panel.grid.major = element_line(color = "grey80"),
    panel.grid.minor = element_blank() # remove minor grid lines
  ) +
  labs(title = "Age vs. Weight")
```



7.1.2 Theme elements you can customize

- Text: `element_text()` → size, color, font, face, alignment
- Lines: `element_line()` → color, size, linetype
- Rectangles: `element_rect()` → fill, border color
- Blank: `element_blank()` → remove an element

Examples:

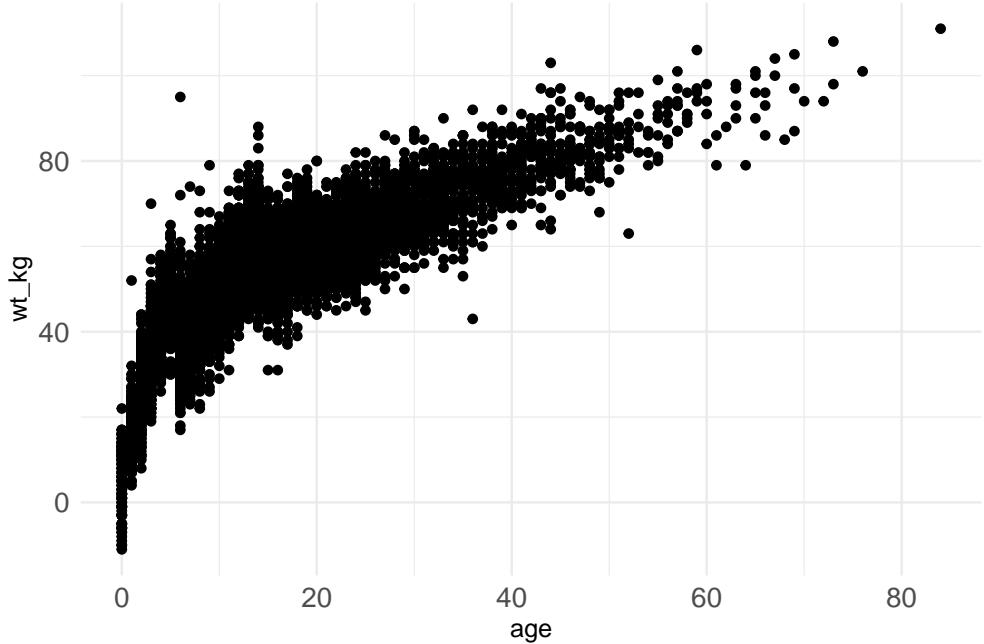
```
axis.title.x = element_text(size = 14, face = "italic")
panel.background = element_rect(fill = "lightyellow")
panel.grid = element_blank()
```

7.1.3 Create your own reusable theme

You can define a function that returns a theme and reuse it:

```
my_theme <- function() {
  theme_minimal() +
  theme(
    plot.title = element_text(size = 18, face = "bold", hjust = 0.5),
    axis.text = element_text(size = 12),
    legend.position = "bottom"
  )
}

ggplot(data = mydata, aes(x = age, y = wt_kg)) +
  geom_point() +
  my_theme()
```



7.1.4 Start with a base theme

It's common to start with a clean base like `theme_minimal()`, `theme_classic()`, or `theme_bw()` and then adjust with `theme()`.

8 Re-use the plot

Creating a plot object

In `ggplot2`, when you assign a plot to a variable (for example `p`), you are **creating a plot object**.

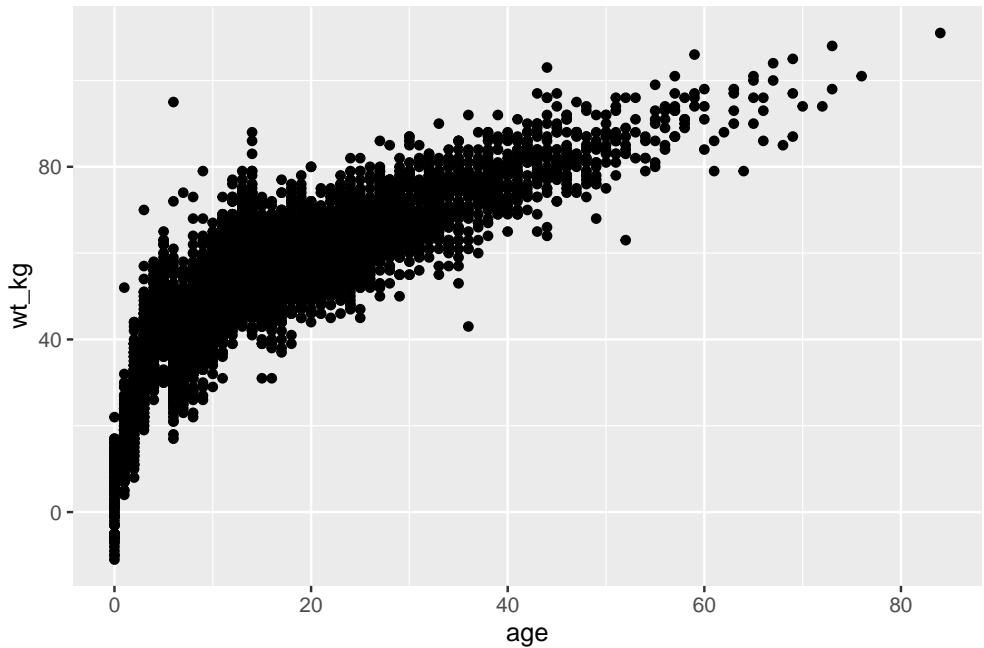
```
p <- ggplot(data = mydata, aes(x = age, y = wt_kg)) +
  geom_point()
```

- Here, `p` is not just an image — it's an **object** that stores all the information about the plot: data, aesthetics, and layers.
- Nothing is drawn to the screen yet unless you call `p` or print it.

Displaying a plot object

When you type `p` in the console (or run `print(p)`), R will **render and display** the plot in the graphics window (e.g., RStudio Plots pane).

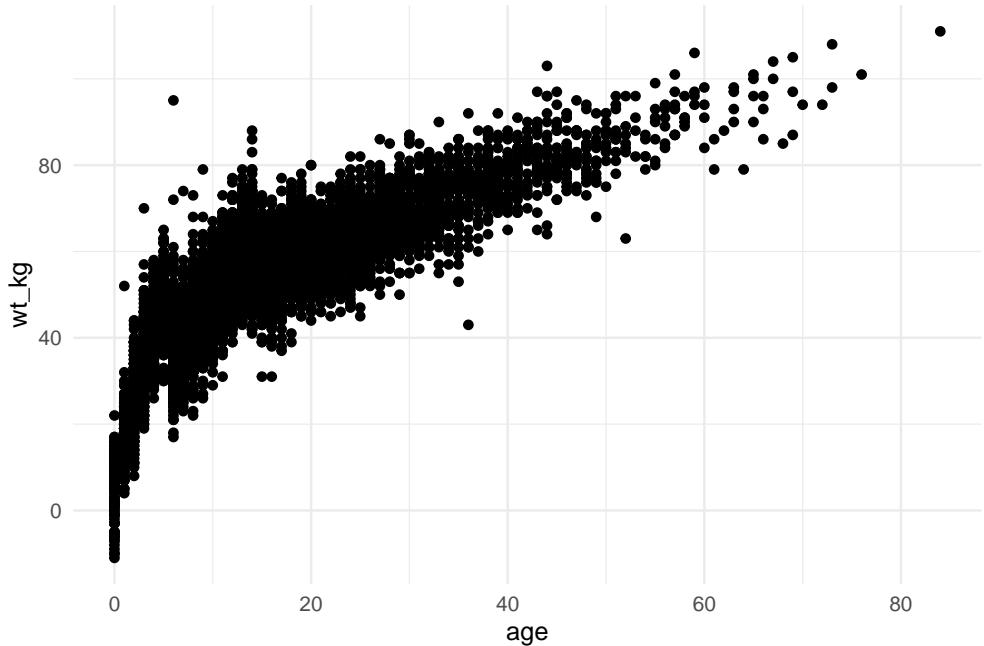
```
p # displays the scatter plot
```



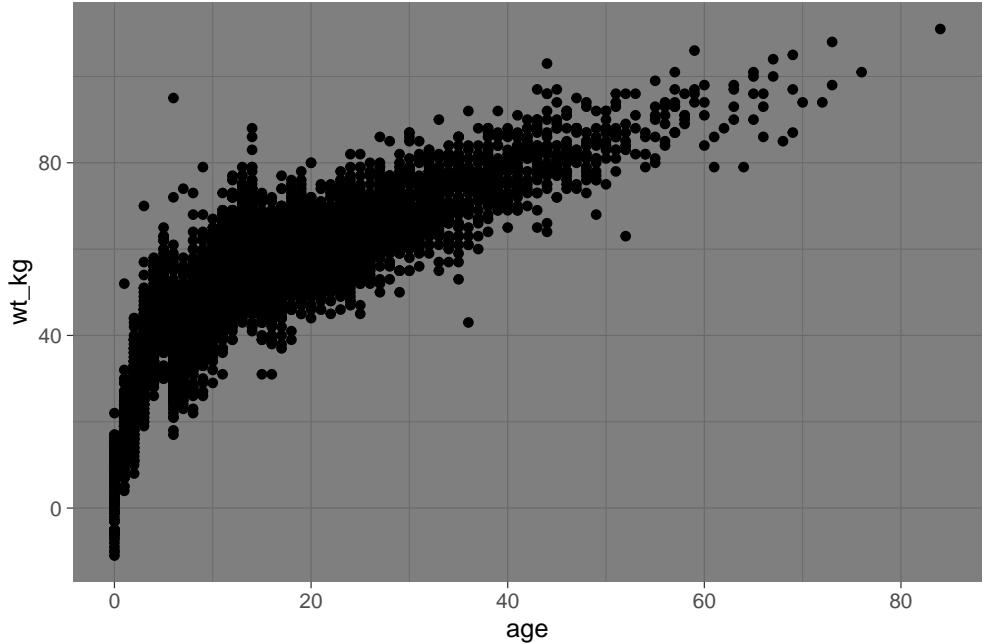
Re-using a plot object

Because the plot is stored in a variable, you can **reuse it** and add new layers, themes, or labels without re-writing everything.

```
p + theme_minimal()
```



```
p + theme_dark()
```



```
p + labs(title = "Age vs. Weight")
```

Age vs. Weight



- The original p remains unchanged.
- You can generate multiple variations of the same plot very quickly.

Why this is useful

- **Efficiency:** build a base plot once, then extend it.
- **Consistency:** ensure all figures in a report share the same core structure.
- **Flexibility:** tweak only what you need (e.g., theme, colors, labels).

9 Exporting Publication-Quality plots

9.1 What does “publication-quality” mean?

A plot is considered **publication-quality** when it meets common journal or conference requirements:

- **High resolution** (usually 300 dpi, sometimes 600 dpi).
- **Correct dimensions** (width × height, often in inches or cm).
- **Readable text** (base font size 12–14 pt or larger).
- **Appropriate format:**
 - **Vector** (PDF, EPS, SVG) → scalable, best for journals.
 - **Raster** (PNG, TIFF) → fixed pixels, often requested for online submission.

9.2 Using `ggsave()` (recommended way)

```
# Create a plot object
p <- ggplot(data = mydata) +
  aes(x = age, y = wt_kg,
      color = gender_disp,
      shape = outcome_disp) +
  geom_point(alpha = 0.5) +
  labs(x = "Age in years",
       y = "Weight in kilos",
       title = "Age and Weight distribution",
       subtitle = "Fictional Ebola Outbreak, 2014",
       caption = "Data as of 2014-12-31",
       color = "Gender",
       shape = "Outcome")

# Export as high-resolution PNG (raster)
ggsave("figure1.png", plot = p, width = 20, height = 15, dpi = 300, units = "cm")

# Export as PDF (vector, scalable, journal-friendly)
ggsave("figure1.pdf", plot = p, width = 20, height = 15, units = "in")
```

- `width` and `height` are in **cm**.
- `dpi` (dot per inch) controls resolution (only for raster formats).

9.3 Using graphic devices (manual method)

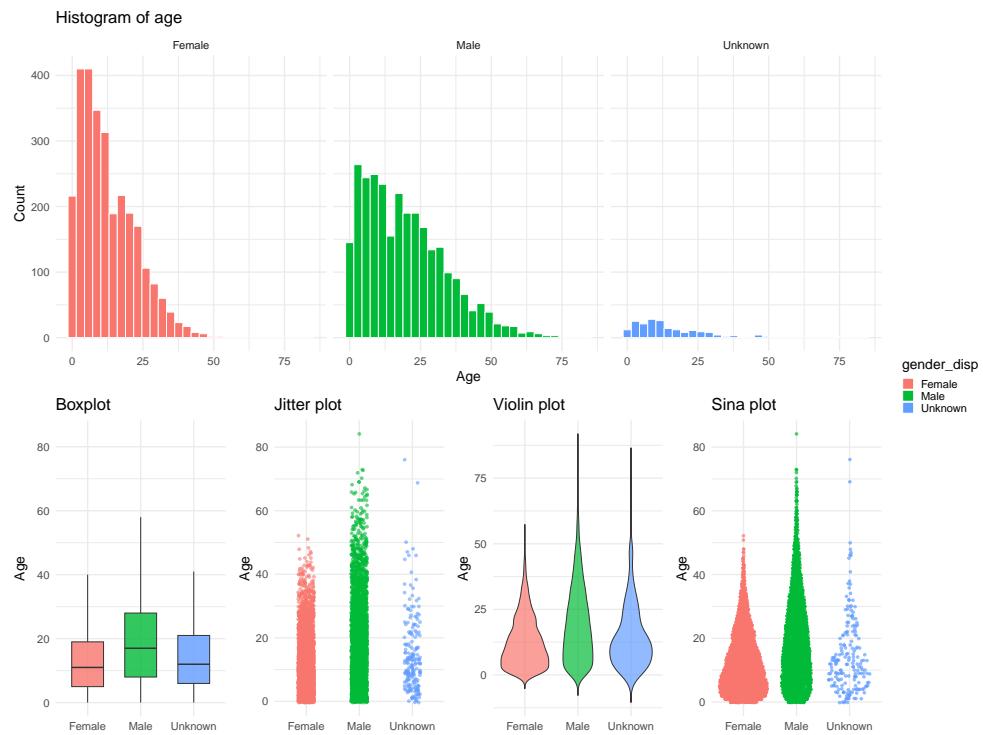
For more control, you can open a graphics device explicitly:

```
# TIFF, 600 dpi (common in biomedical journals)
tiff("figure1.tiff", width = 20, height = 15, units = "in", res = 600)
print(p)
dev.off()
```

10 Plot of continuous data

Continuous data are quantitative variables that can be measured: weight, height, age,

- Histogram: A chart commonly used to show the distribution of a continuous variable.
- Box plot (also known as a box and whisker plot): A plot used to display the 25th, 50th, and 75th percentiles, the ends of the distribution, and important outliers.
- Jitter plot: A plot used to display all values as “jittered” points so they can (mostly) be seen, even when two points have the same value.
- Violin plot: A plot that shows the distribution of a continuous variable based on the symmetrical width of the “violin.”
- Sina plot: A combination of jitter and violin plots, where individual points are shown but within the symmetrical shape of the distribution (using the ggforce package).



10.1 Histogram

A **histogram** is a type of plot that shows the **distribution of a single numerical variable**.

- The range of the data is divided into **bins** (intervals).
- Each bin is represented by a **bar**, where the height of the bar shows how many data points fall into that interval (frequency) or the proportion (density).
- Unlike a bar chart, which is for categorical data, a histogram is specifically for **continuous or numerical data**.

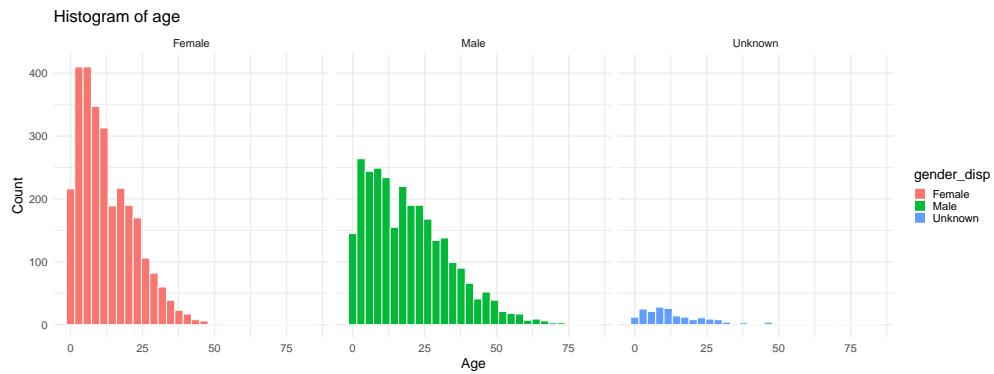
Why use a histogram?

- To understand the **shape of the distribution** (e.g., normal, skewed, uniform).

- To identify **patterns**, **peaks (modes)**, or **gaps** in the data.
- To spot **outliers** or unusual observations.

Note: Play around with **bins**.

```
# Histogram (facet theo giới)
ggplot(mydata, aes(x = age, fill = gender_disp)) +
  geom_histogram(bins = 30, color = "white") +
  facet_wrap(~ gender_disp, nrow = 1) +
  labs(title = "Histogram of age", x = "Age", y = "Count")
```



10.2 Boxplot

A **boxplot** (also called a **box-and-whisker plot**) is a statistical graphic that shows the **distribution of a numerical variable** by summarizing its key values:

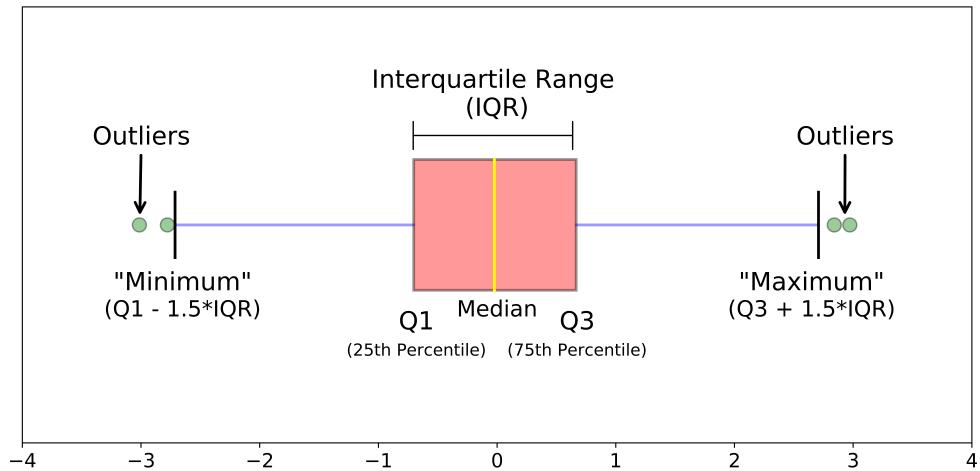


Figure 3: Box plot

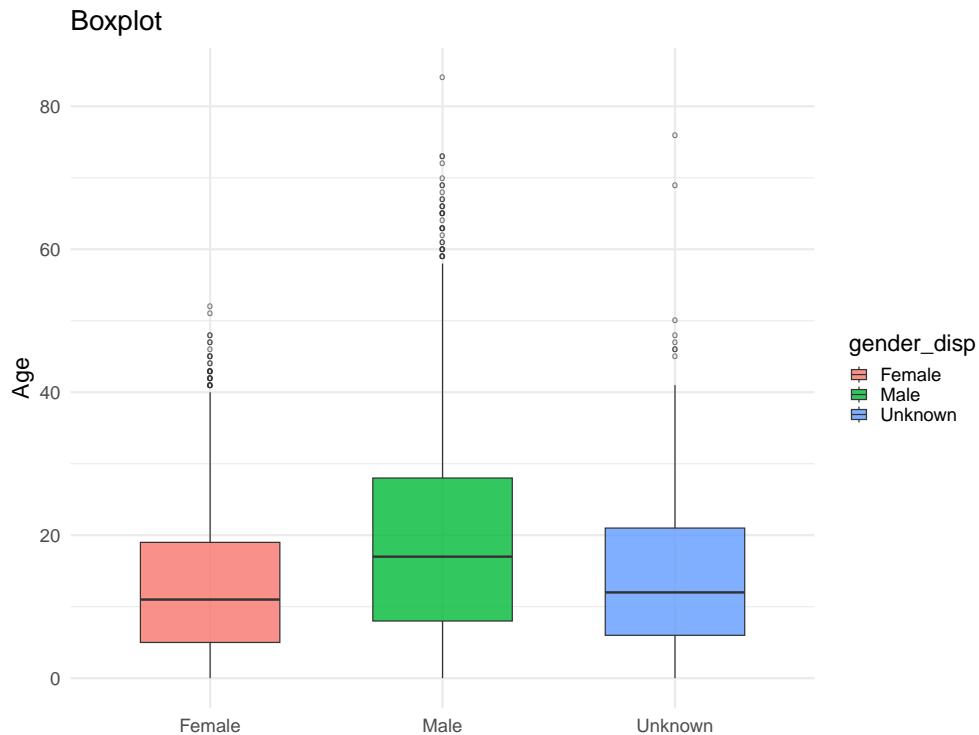
- **Median** (the middle value).
- **First quartile (Q1)** and **third quartile (Q3)** → together form the **box** (the interquartile range, IQR).
- **Whiskers** → extend to the smallest and largest values within $1.5 \times \text{IQR}$ from the quartiles.

- **Outliers** → points beyond the whiskers, plotted individually.

Why use a Boxplot?

- To compare distributions across groups.
- To quickly see **center, spread, and skewness** of data.
- To detect **outliers**.
- To compare **multiple categories** side by side.

```
ggplot(mydata, aes(x = gender_disp, y = age, fill = gender_disp)) +
  geom_boxplot(width = 0.6, outlier.shape = "o", alpha = 0.8, outlier.size = 3) +
  labs(title = "Boxplot", x = NULL, y = "Age")
```



10.3 Jitter plot

A **jitter plot** is a variation of a scatter plot where the data points are slightly **shifted (jittered)** horizontally or vertically by adding a small amount of random noise.

- Purpose: to **avoid overplotting**, which happens when many points overlap at the same position.
- The jitter makes it easier to see the **distribution and density** of points, especially for discrete or categorical variables.

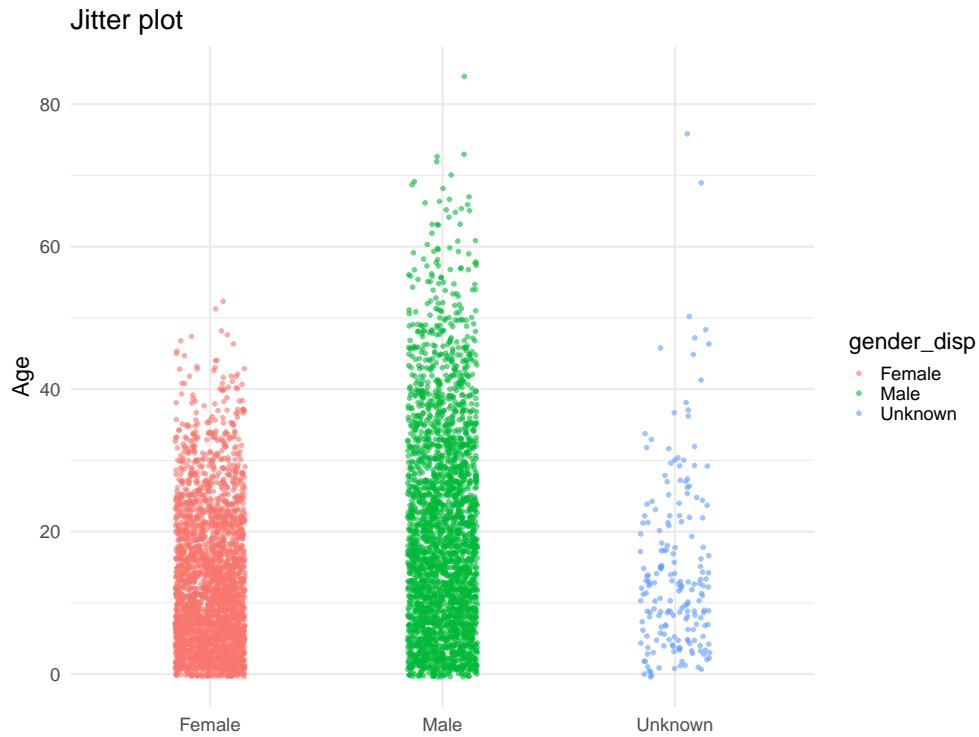
Jitter helps you see **clusters, duplicates, and density** that would otherwise be hidden in overlapping points.

Why use a Jitter Plot?

- To reveal **how many points share the same value**.

- To show the **spread of data** when x or y is categorical.
- To make patterns clearer compared to raw scatter plots where points may overlap.

```
ggplot(mydata, aes(x = gender_disp, y = age, color = gender_disp)) +
  geom_jitter(width = 0.15, alpha = 0.6, size = 1.5) +
  labs(title = "Jitter plot", x = NULL, y = "Age")
```



10.4 Violin plot

A **violin plot** is a data visualization that combines features of a **boxplot** and a **density plot**:

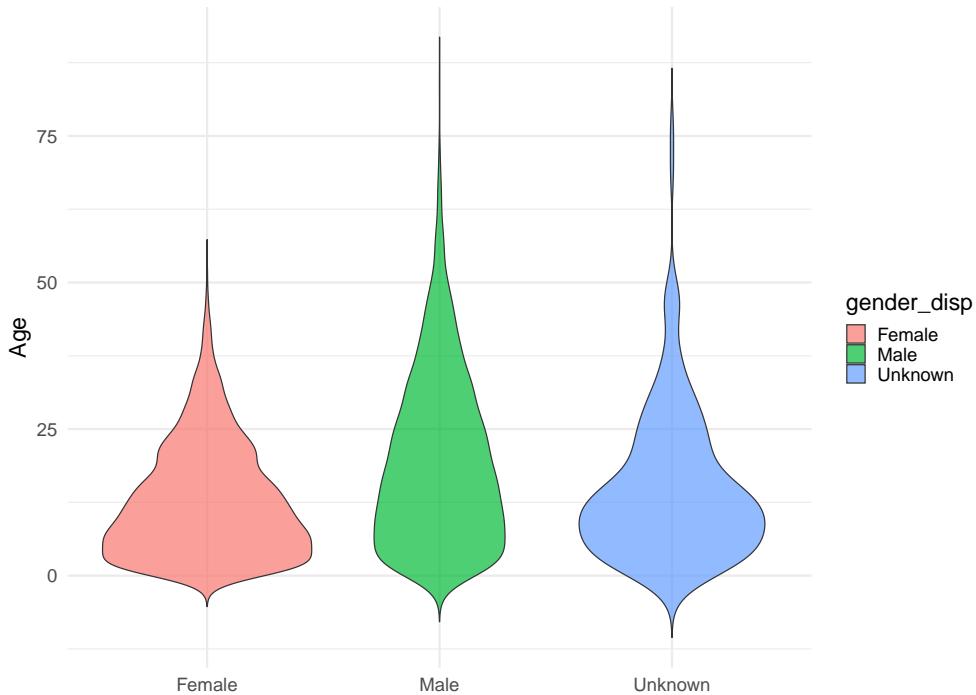
- Like a boxplot, it shows the **median**, **quartiles**, and **spread** of the data.
- Like a density plot, it shows the **distribution shape** (using kernel density estimation) mirrored on both sides, giving it a “violin” shape.

Why use a Violin Plot?

- To see both **summary statistics** (median, IQR) and the **full distribution shape**.
- To detect **multimodal distributions** (e.g., data with multiple peaks).
- Useful when comparing **several groups** side by side.

```
ggplot(mydata, aes(x = gender_disp, y = age, fill = gender_disp)) +
  geom_violin(trim = FALSE, alpha = 0.7) +
  labs(title = "Violin plot", x = NULL, y = "Age")
```

Violin plot



10.5 Sina plot

A **sina plot** is a type of visualization similar to a **violin plot** and a **jitter plot**, designed to show the **distribution of data points along with their density**.

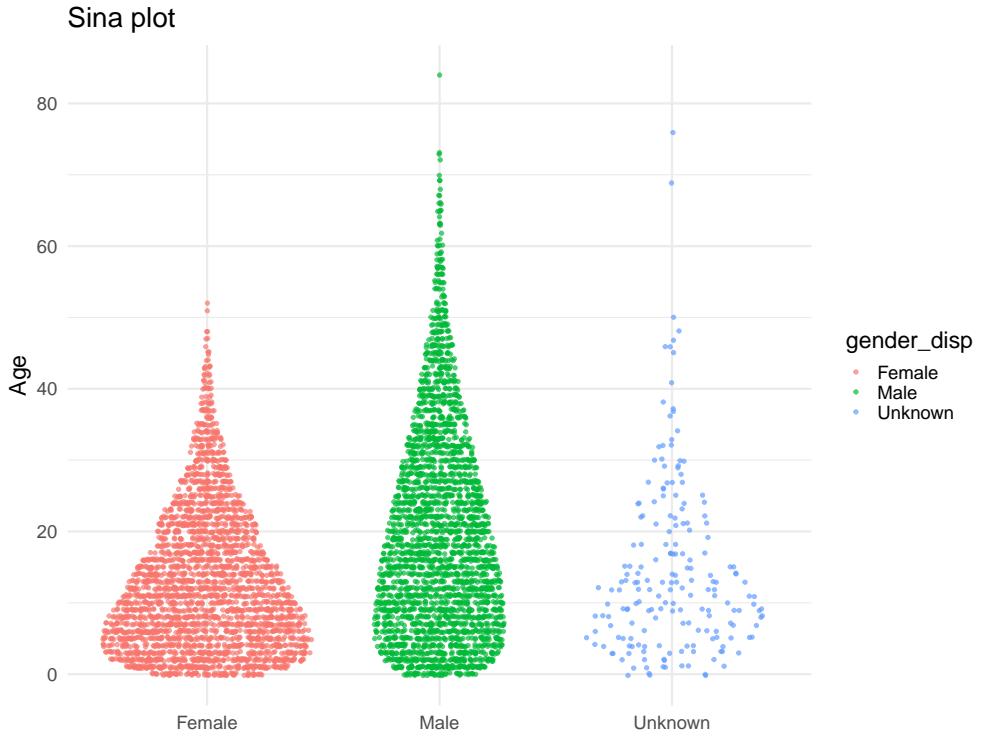
- Each individual observation is shown as a **dot** (like a jitter plot).
- The dots are spread out **horizontally based on the density** of the data (like in a violin plot).
- This creates a shape similar to a violin but made up of points, so you can see **both the distribution shape and the raw data**.

It was introduced in the **ggforce** package in R.

Why use a Sina Plot?

- To **combine the advantages** of violin plots (distribution shape) and jitter plots (raw data visibility).
- To see whether the density shape is **caused by a few points or by many**.
- Useful for comparing distributions across categories with **transparent and detailed data representation**.

```
ggplot(mydata, aes(x = gender_disp, y = age, color = gender_disp)) +  
  ggforce::geom_sina(alpha = 0.7, size = 1.4) +  
  labs(title = "Sina plot", x = NULL, y = "Age")
```



11 Plot of categorical data

11.1 Categorical Data

Categorical data refers to variables that represent **categories or groups** rather than numerical values.

- The values are **labels** (words or codes) that classify observations into distinct groups.
- They do **not have inherent numerical meaning** (e.g., you can't add or average them in a meaningful way).

Types of Categorical Data

1. Nominal data

- Categories have **no natural order**.
- Examples: blood type (A, B, AB, O), gender (male, female, other), colors (red, blue, green).

2. Ordinal data

- Categories have **a meaningful order**, but the intervals between them are not necessarily equal.
- Examples: education level (high school < bachelor < master < PhD), survey responses (poor, fair, good, excellent).

Examples

- **Yes/No questions** → categorical (binary).
- **Country of origin** → categorical (nominal).

- Customer satisfaction rating: low/medium/high → categorical (ordinal).

How it's used in analysis

- Often summarized with **frequency tables** or **percentages**.
- Visualized with **bar charts**, **pie charts**, **stacked plots**.
- Can be converted into **dummy variables** (0/1) for statistical models or machine learning.

Review `mydata`,

- How many continuous variable are there?
- How many categorical variable are there?

```
glimpse(mydata)
```

```
## Rows: 5,888
## Columns: 32
## $ case_id          <chr> "5fe599", "8689b7", "11f8ea", "b8812a", "893f25", ~
## $ generation       <dbl> 4, 4, 2, 3, 3, 3, 4, 4, 4, 4, 4, 4, 6, 5, 6, 9, 1~
## $ date_infection   <dttm> 2014-05-08, NA, NA, 2014-05-04, 2014-05-18, 2014-
## $ date_onset        <dttm> 2014-05-13, 2014-05-13, 2014-05-16, 2014-05-18, ~
## $ date_hospitalisation <dttm> 2014-05-15, 2014-05-14, 2014-05-18, 2014-05-20, ~
## $ date_outcome      <dttm> NA, 2014-05-18, 2014-05-30, NA, 2014-05-29, 2014-
## $ outcome            <chr> NA, "Recover", "Recover", NA, "Recover", "Recover~
## $ gender             <chr> "m", "f", "m", "f", "m", "f", "f", "m", "f", ~
## $ age                <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_unit           <chr> "years", "years", "years", "years", "yea~
## $ age_years          <dbl> 2, 3, 56, 18, 3, 16, 16, 0, 61, 27, 12, 42, 19, 7~
## $ age_cat            <chr> "0-4", "0-4", "50-69", "15-19", "0-4", "15-19", "~
## $ age_cat5           <chr> "0-4", "0-4", "55-59", "15-19", "0-4", "15-19", "~
## $ hospital           <chr> "Other", "Missing", "St. Mark's Maternity Hospita~
## $ lon                <dbl> -13.21574, -13.21523, -13.21291, -13.23637, -13.2~
## $ lat                <dbl> 8.468973, 8.451719, 8.464817, 8.475476, 8.460824, ~
## $ infector           <chr> "f547d6", NA, NA, "f90f5f", "11f8ea", "aec8ec", "~
## $ source              <chr> "other", NA, NA, "other", "other", "other", "othe~
## $ wt_kg              <dbl> 27, 25, 91, 41, 36, 56, 47, 0, 86, 69, 67, 84, 68~
## $ ht_cm               <dbl> 48, 59, 238, 135, 71, 116, 87, 11, 226, 174, 112, ~
## $ ct_blood            <dbl> 22, 22, 21, 23, 23, 21, 21, 22, 22, 22, 22, 22, 2~
## $ fever               <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ chills              <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ cough               <chr> "yes", NA, NA, "no", "yes", NA, "yes", "ye~
## $ aches               <chr> "no", NA, NA, "no", "no", NA, "no", "no", "no", ~
## $ vomit               <chr> "yes", NA, NA, "no", "yes", "yes", NA, "yes", "ye~
## $ temp                <dbl> 36.8, 36.9, 36.9, 36.8, 36.9, 37.6, 37.3, 37.0, 3~
## $ time_admission      <chr> NA, "09:36", "16:48", "11:22", "12:60", "14:13", ~
## $ bmi                 <dbl> 117.18750, 71.81844, 16.06525, 22.49657, 71.41440~
## $ days_onset_hosp     <dbl> 2, 1, 2, 2, 1, 1, 2, 1, 2, 2, 1, 0, 2, 0, 1~
## $ gender_disp         <fct> Male, Female, Male, Female, Male, Female, Female, ~
## $ outcome_disp        <chr> "Unknown", "Recover", "Recover", "Unknown", "Reco~
```

11.2 Bar chart

A **bar chart** (or bar graph) is a plot used to display and compare the **frequency, count, or value of categorical data**.

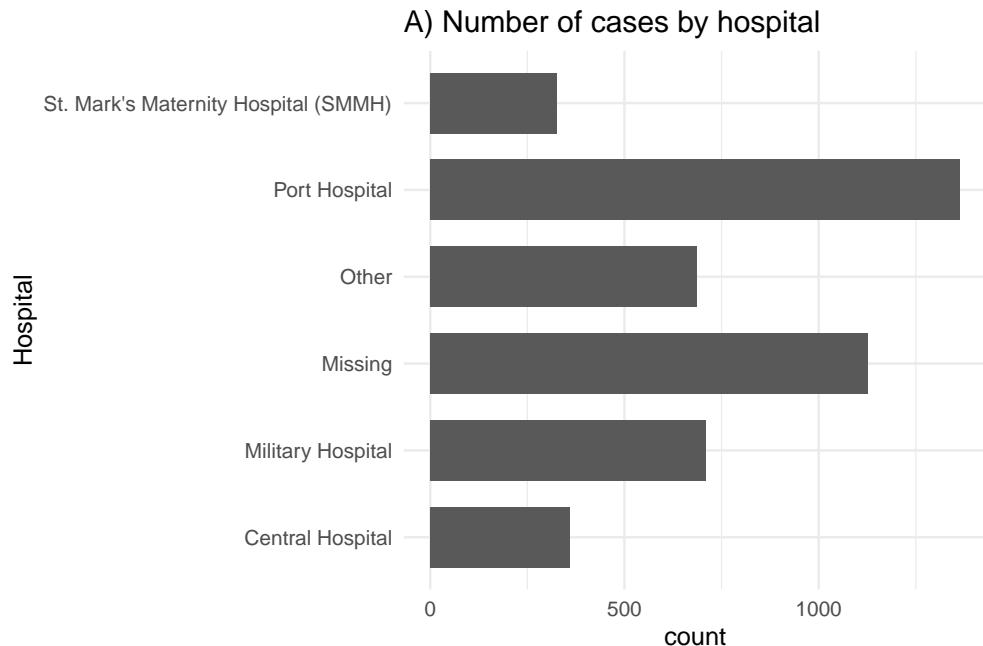
- Each **bar** represents a category.
- The **length or height** of the bar shows the size of the value (count, percentage, or another summary statistic).
- Bars can be oriented **vertically or horizontally**.

Why use a Bar Chart?

- To compare **different categories** easily.
- To highlight **largest/smallest groups**.
- To visualize **distribution of categorical data**.

```
# A) Outcomes in all cases
```

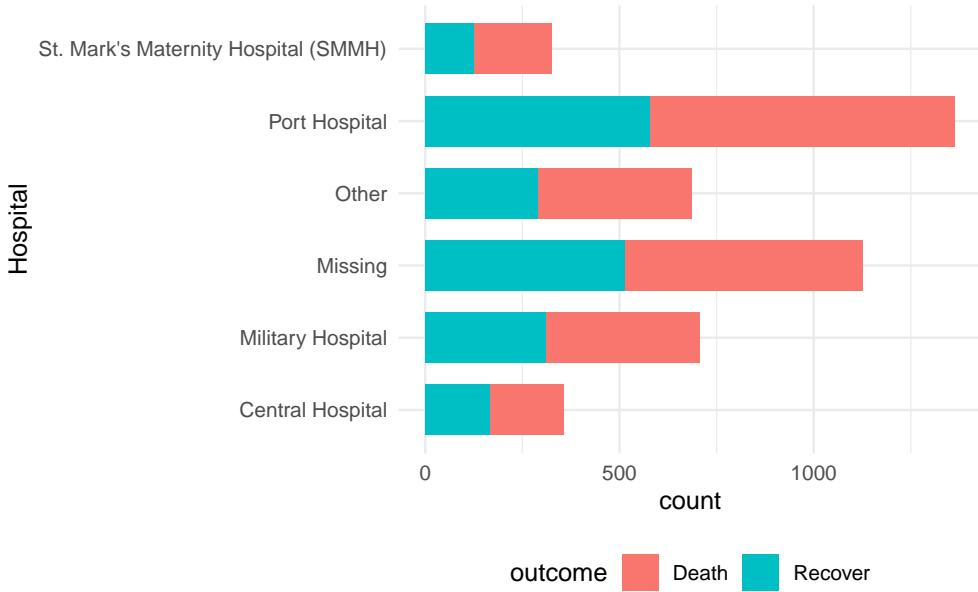
```
ggplot(mydata %>% drop_na(outcome)) +  
  geom_bar(aes(y = hospital), width = 0.7) +  
  theme_minimal() +  
  labs(title = "A) Number of cases by hospital",  
       y = "Hospital")
```



```
# B) Outcomes in all cases by hospital
```

```
ggplot(mydata %>% drop_na(outcome)) +  
  geom_bar(aes(y = hospital, fill = outcome), width = 0.7) +  
  theme_minimal() +  
  theme(legend.position = "bottom") +  
  labs(title = "B) Number of recovered and dead Ebola cases, by hospital",  
       y = "Hospital")
```

B) Number of recovered and dead Ebola cases, by hospital



Current order (A-Z default, bottom-top): “Central Hospital” > “Military Hospital” > “Missing” > “Other” > “Port Hospital” > “St. Mark’s Maternity Hospital (SMMH)”.

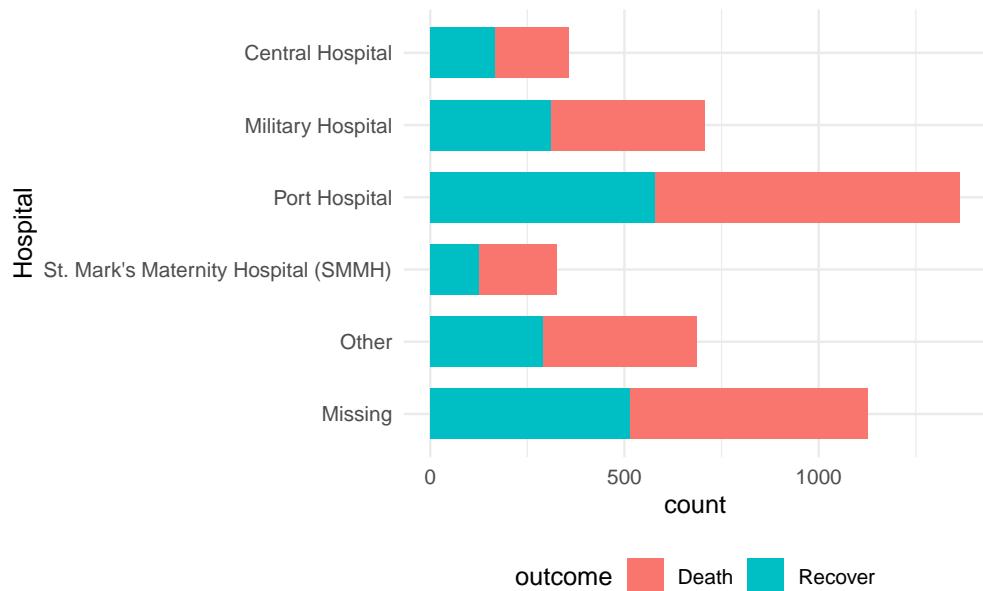
We will change the order as we want:

“Central Hospital” > “Military Hospital” > “Port Hospital” > “St. Mark’s Maternity Hospital (SMMH)” > “Other” > “Missing”

```
# set orders of the categorical data
mydata <- mydata %>% mutate(hospital = fct_relevel(hospital,
                                                       "Central Hospital",
                                                       "Military Hospital",
                                                       "Port Hospital",
                                                       "St. Mark's Maternity Hospital (SMMH)",
                                                       "Other",
                                                       "Missing"))
)

# bar plot
ggplot(mydata %>% drop_na(outcome)) +
  geom_bar(aes(y = fct_rev(hospital), fill = outcome), width = 0.7) +
  theme_minimal() +
  theme(legend.position = "bottom") +
  labs(title = "B) Number of recovered and dead Ebola cases, by hospital",
       y = "Hospital")
```

B) Number of recovered and dead Ebola cases



11.3 Pie chart

A **pie chart** is a circular chart divided into slices, where each slice represents a **proportion or percentage** of the whole.

- The **whole circle = 100%** of the data.
- Each **slice angle** corresponds to the share of a category.
- Usually used for **categorical data** with proportions.

Why use a Pie Chart?

- To show how a whole is divided into parts.
- To emphasize the **relative sizes** of categories.
- Works best when there are only a few categories (5–6).

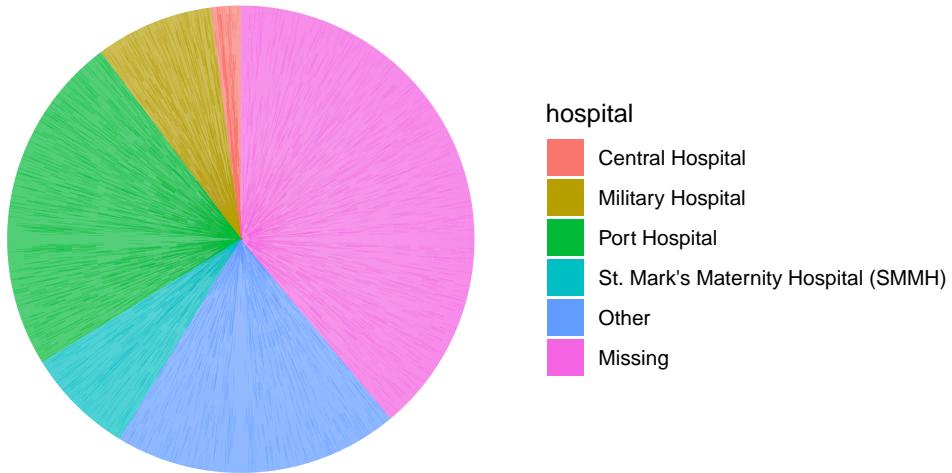
Example

- `geom_col()` creates bars.
- `coord_polar(theta = "y")` transforms them into a pie chart.
- `theme_void()` removes background and axes.

Note: turn on/off `coord_polar(theta = "y")` to see different.

```
ggplot(data = mydata %>% drop_na(outcome)) +
  aes(x = "", y = hospital, fill = hospital) +
  geom_col(width = 1) +
  coord_polar(theta = "y") + # Use coord_polar(theta = "y") to transform a bar chart into a pie chart
  labs(title = "Pie Chart") +
  theme_void()
```

Pie Chart



12 Combining Multiple Plots into One Figure

Multi-chart in a figure means combining several individual plots into a single figure layout.

- Instead of showing each chart separately, you arrange them together (side-by-side, stacked, or in a grid).
- This makes it easier to **compare patterns across datasets, groups, or visualization types**.
- In R, common tools include **patchwork**, **cowplot**, or **gridExtra** to assemble multiple ggplot2 charts.

Why use multi-charts?

- To show **different perspectives** on the same data (e.g., histogram + boxplot).
- To compare **different variables** across the same group of observations.
- To create **publication-ready composite figures** (often required in journals).

```
# install.packages(c("ggplot2", "ggforce", "patchwork")) # nếu chưa có
library(ggplot2)
library(ggforce)    # geom_sina()
library(patchwork) # ghép nhiều biểu đồ

# đảm bảo kiểu dữ liệu
mydata$gender_disp <- as.factor(mydata$gender_disp)

theme_set(theme_minimal(base_size = 20))

# 1) Histogram (facet theo giới)
p_hist <- ggplot(mydata, aes(x = age, fill = gender_disp)) +
  geom_histogram(bins = 30, color = "white") +
  facet_wrap(~ gender_disp, nrow = 1) +
```

```

  labs(title = "Histogram of age", x = "Age", y = "Count")

# 2) Boxplot
p_box <- ggplot(mydata, aes(x = gender_disp, y = age, fill = gender_disp)) +
  geom_boxplot(width = 0.6, outlier.shape = NA, alpha = 0.8) +
  labs(title = "Boxplot", x = NULL, y = "Age") +
  theme(legend.position = "none")

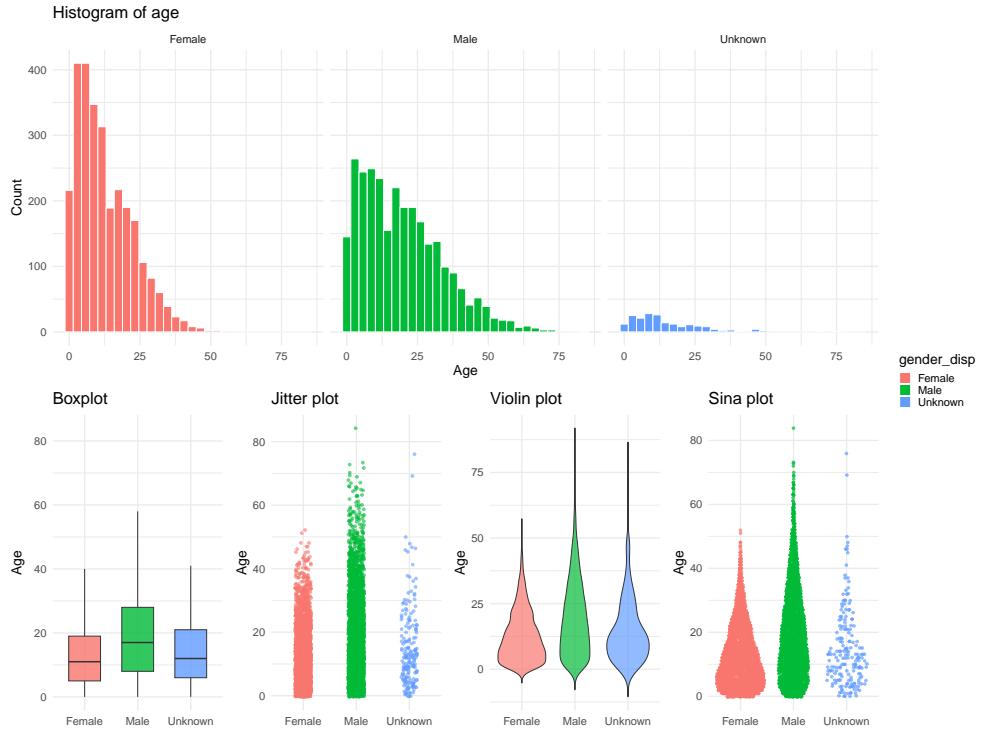
# 3) Jitter plot
p_jitter <- ggplot(mydata, aes(x = gender_disp, y = age, color = gender_disp)) +
  geom_jitter(width = 0.15, alpha = 0.6, size = 1.5) +
  labs(title = "Jitter plot", x = NULL, y = "Age") +
  theme(legend.position = "none")

# 4) Violin plot
p_violin <- ggplot(mydata, aes(x = gender_disp, y = age, fill = gender_disp)) +
  geom_violin(trim = FALSE, alpha = 0.7) +
  labs(title = "Violin plot", x = NULL, y = "Age") +
  theme(legend.position = "none")

# 5) Sina plot (điểm phân tán theo mật độ)
p_sina <- ggplot(mydata, aes(x = gender_disp, y = age, color = gender_disp)) +
  ggforce::geom_sina(alpha = 0.7, size = 1.4) +
  labs(title = "Sina plot", x = NULL, y = "Age") +
  theme(legend.position = "none")

# Layout: histogram chiếm hàng trên; 4 plot còn lại ở hàng dưới
design <- "
AAAA
BCDE
"
(p_hist + p_box + p_jitter + p_violin + p_sina) +
  plot_layout(design = design, guides = "collect")

```



13 Headmap

A **heatmap** is a data visualization technique that represents values in a matrix ($\text{rows} \times \text{columns}$) using **colors**. Otherword, a **heatmap** is a graphical representation of data where **color is used to encode values**, making it easy to see patterns in complex datasets like correlation matrices, gene expression data, or user behavior logs.

- Each cell in the grid corresponds to a value.
- The **color intensity (or hue)** reflects the magnitude of the value.
- Warmer colors (e.g., red, orange) often represent higher values, while cooler colors (e.g., blue) represent lower values.

Why use a Heatmap?

- To quickly identify **patterns, trends, and anomalies** in large datasets.
- To visualize **correlations** between variables.
- To highlight areas of **high or low concentration**.

13.1 Heatmap of Pairwise Sequence Similarity

13.1.1 Dataset Description

We have a collection of **40 *E. coli* isolates**, consisting of:

- **20 resistant** to amoxicillin
- **20 non-resistant**

The metadata is stored in an Excel file named `ecoli_amr.xlsx`, and the sequences of the blaTEM gene for each isolate are stored in a FASTA file named `ecoli_amr_blaTEM.fasta`.

Our goal is to generate a heatmap of pairwise sequence similarity among the 40 isolates.

13.1.2 Pseudo Code

INPUT:

- Excel file "ecoli_amr.xlsx" with phenotype metadata (resistant / non-resistant)
- FASTA file "ecoli_amr_blaTEM.fa" with blaTEM sequences

STEP 1: Load data

- Read Excel file (for isolate IDs and resistance status)
- Read FASTA file (for blaTEM sequences)

STEP 2: Sequence alignment (optional but recommended)

- Align blaTEM sequences across all isolates

STEP 3: Compute pairwise distances

- For each pair of sequences (i, j):
 - Calculate p-distance (proportion of mismatched sites)

STEP 4: Convert distances to similarity

- Similarity(i, j) = 1 - Distance(i, j)
- Set diagonal values = 1

STEP 5: Reorder sequences

- Perform hierarchical clustering based on similarity
- Reorder rows and columns of similarity matrix

STEP 6: Plot heatmap

- Use similarity matrix as input
- Color scale: white → red (low → high similarity)
- Add isolate labels and optionally annotate resistance phenotype

OUTPUT:

- Heatmap showing pairwise blaTEM sequence similarity among 40 isolates

13.1.3 Code

```
# Packages
pacman::p_load(ape,
                scales,
                DECIPHER,
                Biostrings)

# ---- Input ----
meta_file <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_amr.xlsx" # côte: 4
fasta_file <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_amr_blaTEM.fasta"

# ---- Load metadata & sequences ----
meta <- rio::import(meta_file, trust = TRUE) %>%
```

```

  mutate(
    amr_status = factor(
      amr_status,
      levels=c("Susceptible","Resistant")
    )
  )

  dna_raw <- readDNAStringSet(fasta_file)

# ---- Multiple Sequence Alignment ----
aln <- AlignSeqs(dna_raw, processors = 2)

## Determining distance matrix based on shared 9-mers:
## =====
##
## Time difference of 0.01 secs
##
## Clustering into groups by similarity:
## =====
##
## Time difference of 0.02 secs
##
## Aligning Sequences:
## =====
##
## Time difference of 0.23 secs
##
## Iteration 1 of 2:
##
## Determining distance matrix based on alignment:
## =====
##
## Time difference of 0 secs
##
## Reclustering into groups by similarity:
## =====
##
## Time difference of 0.12 secs
##
## Realigning Sequences:
## =====
##
## Time difference of 0.15 secs
##
## Alignment converged - skipping remaining iteration.

# convert aligned sequences to DNAbin to calculate similarity
aln_bin <- ape::as.DNAbin(as.matrix(aln))

# ---- Pairwise distance -> similarity ----
dist_mat <- dist.dna(aln_bin,
  model = "raw",

```

```

        pairwise.deletion = TRUE,
        as.matrix = TRUE)

sim_mat <- 1 - dist_mat
diag(sim_mat) <- 1

# ---- Clustering (UPGMA) trên 1 - similarity ----
d_for_clust <- as.dist(1 - sim_mat)
hc <- hclust(d_for_clust, method = "average")
ord_ids <- rownames(sim_mat)[hc$order]

# ---- Đưa matrix về long + áp thứ tự hàng/cột theo clustering ----
sim_df <- sim_mat %>%
  as.data.frame() %>%
  tibble::rownames_to_column("row_id") %>%
  pivot_longer(-row_id, names_to = "col_id", values_to = "similarity") %>%
  mutate(
    row_id = factor(row_id, levels = ord_ids),
    col_id = factor(col_id, levels = ord_ids)
  )

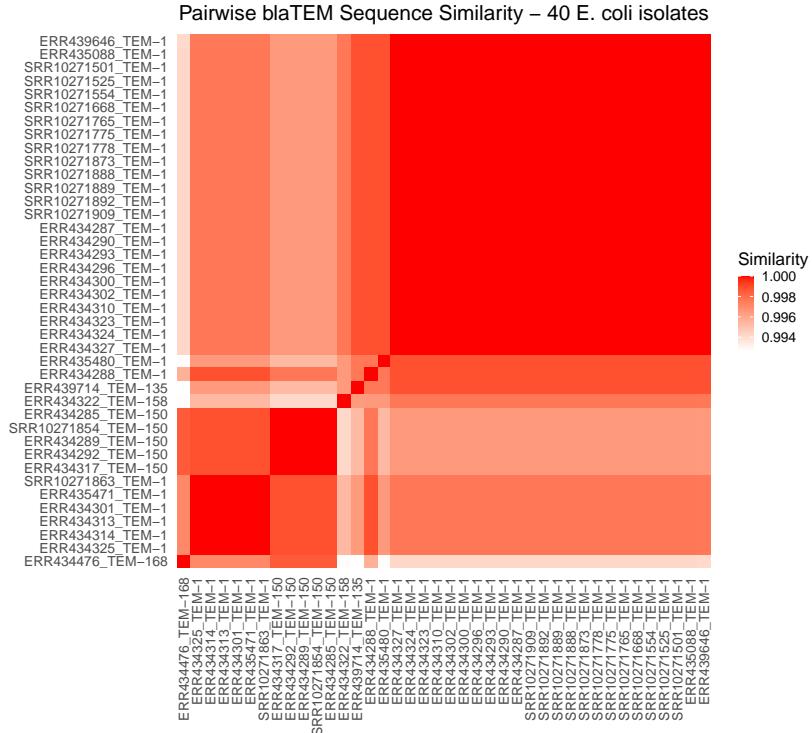
# ---- Chuẩn bị annotation (khớp theo ord_ids) ----
ann_df <- meta %>%
  dplyr::select(isolate_id, amr_status) %>%
  dplyr::filter(isolate_id %in% ord_ids) %>%
  dplyr::mutate(isolate_id = factor(isolate_id, levels = ord_ids))

ann_cols <- c("Resistant" = "#D55E00", "Susceptible" = "#0072B2")

# tính min-max trên data frame long 'sim_df' có cột 'similarity'
vmin <- min(sim_df$similarity, na.rm = TRUE)
vmax <- max(sim_df$similarity, na.rm = TRUE)

# ---- Heatmap bằng ggplot2 ----
ggplot(sim_df, aes(x = col_id, y = row_id, fill = similarity)) +
  geom_tile() +
  scale_fill_gradient(
    low = "white", high = "red",
    limits = c(vmin, vmax),
    oob = squish,                      # kẹp ngoài khoảng
    name = "Similarity"
  ) +
  coord_fixed() +
  labs(x = NULL, y = NULL,
       title = "Pairwise blaTEM Sequence Similarity - 40 E. coli isolates") +
  theme_minimal(base_size = 20) +
  theme(
    axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1),
    panel.grid = element_blank(),
    plot.title = element_text(hjust = 0.5)
  )

```



13.1.3.1 Using package `pheatmap` The `pheatmap` package in R is a specialized tool for creating heatmaps. Unlike general-purpose plotting libraries, it is designed specifically for matrix-style visualizations and comes with many convenient features built-in: hierarchical clustering of rows and columns, customizable color scales, annotation bars, and the option to display numeric values inside cells. Because of its simplicity and flexibility, `pheatmap` is widely used in bioinformatics and data science to visualize similarity matrices, gene expression data, and other high-dimensional datasets.

Note

Try to change ‘model = “raw”’ to ‘model = “K80”’ to see the difference if any.

```
# Packages
pacman::p_load(ape, pheatmap)

# ----- Input -----
meta_file  <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_amr.xlsx"          # cột:
fasta_file <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_amr_blaTEM.fasta"      # 4

# ----- Load metadata & sequences -----
meta <- rio::import(meta_file, trust = TRUE) %>%
  mutate(
    amr_status = factor(
      amr_status,
      levels=c("Susceptible", "Resistant")
    )
  )

dna_raw <- readDNAStringSet(fasta_file)
```

```

# ---- Multiple Sequence Alignment ----
aln <- AlignSeqs(dna_raw, processors = 2)

## Determining distance matrix based on shared 9-mers:
## =====
## 
## Time difference of 0.01 secs
##
## Clustering into groups by similarity:
## =====
## 
## Time difference of 0.03 secs
##
## Aligning Sequences:
## =====
## 
## Time difference of 0.24 secs
##
## Iteration 1 of 2:
##
## Determining distance matrix based on alignment:
## =====
## 
## Time difference of 0 secs
##
## Reclustering into groups by similarity:
## =====
## 
## Time difference of 0.02 secs
##
## Realigning Sequences:
## =====
## 
## Time difference of 0.15 secs
##
## Alignment converged - skipping remaining iteration.

# convert aligned sequences to DNAbin to calculate similarity
aln_bin <- ape::as.DNAbin(as.matrix(aln))

# ---- Pairwise distance -> similarity ----
dist_mat <- dist.dna(aln_bin, model = "raw", pairwise.deletion = TRUE, as.matrix = TRUE)
sim_mat <- 1 - dist_mat
diag(sim_mat) <- 1

# ---- Bảo đảm metadata khớp thứ tự với ma trận ----
# Tạo vector AMR cho đúng thứ tự row/col của sim_mat
amr_by_id <- setNames(meta$amr_status, meta$isolate_id) # map id -> status
amr_vec <- amr_by_id[rownames(sim_mat)] # theo thứ tự matrix

# Nếu muốn chuẩn hóa nhãn:
amr_vec <- factor(amr_vec, levels = c("Susceptible", "Resistant"))

```

```

# ---- Annotation (hàng & cột) ----
ann_df <- data.frame(AMR = amr_vec)
rownames(ann_df) <- rownames(sim_mat)

ann_colors <- list(
  AMR = c("Resistant" = "#D55E00", "Susceptible" = "#0072B2")
)

# ---- Clustering options ----
# Dùng khoảng cách = 1 - similarity và phương pháp average (UPGMA)
row_dist <- as.dist(1 - sim_mat)
col_dist <- as.dist(1 - sim_mat)

# ---- Adjusting scale bar ----
# ví dụ với ma trận similarity 'sim' (0..1)
sim4range <- sim_mat
diag(sim4range) <- NA # (tùy chọn) không cho 1.0 trên đường chéo ảnh hưởng range

vmin <- min(sim4range, na.rm = TRUE)
vmax <- max(sim4range, na.rm = TRUE)

# tạo palette và breaks phủ sát [vmin, vmax]
pal <- colorRampPalette(c("white", "yellow", "red"))(200)
brks <- seq(vmin, vmax, length.out = length(pal) + 1)

# ---- Plot heatmap ----
pheatmap(
  sim_mat,
  color = pal,
  breaks = brks,
  main = "Pairwise blaTEM Sequence Similarity - 40 E. coli isolates",
  legend = TRUE,

  # Clustering
  cluster_rows = TRUE,
  cluster_cols = TRUE,
  clustering_distance_rows = row_dist,
  clustering_distance_cols = col_dist,
  clustering_method = "average",

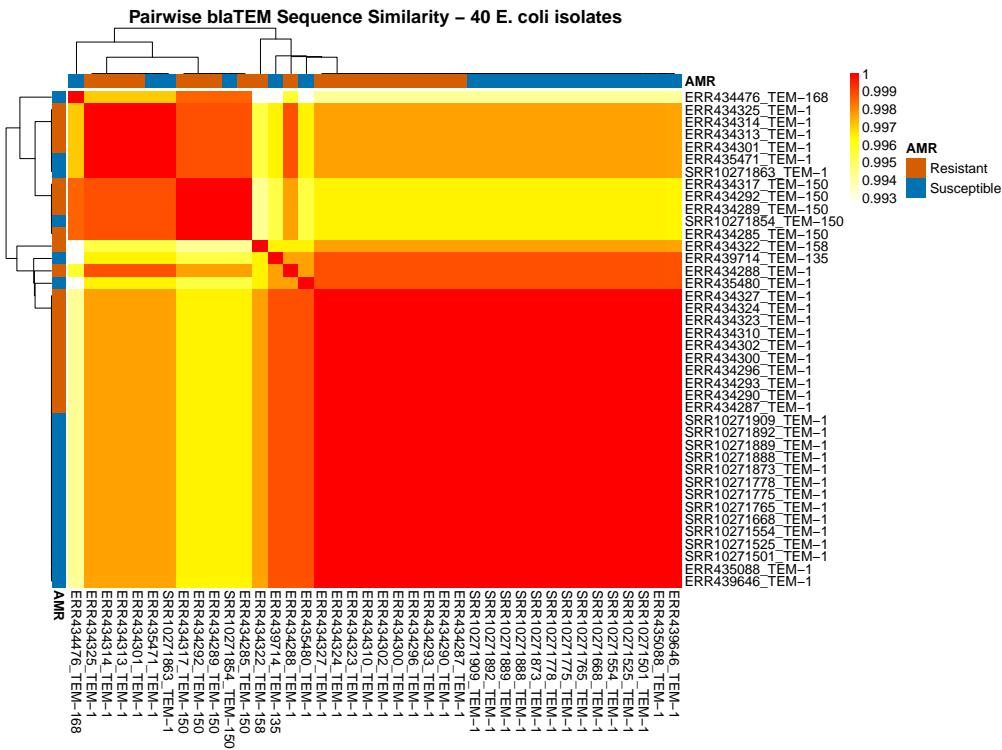
  # Annotation bars (trên và bên trái)
  annotation_row = ann_df,
  annotation_col = ann_df,
  annotation_colors = ann_colors,

  # Nhãn (nếu muốn dùng isolate_id từ metadata)
  labels_row = rownames(sim_mat),
  labels_col = colnames(sim_mat),

  # Thẩm mỹ
  border_color = NA,
  fontsize = 16
)

```

)



14 Specialized R Packages for Specific Chart Types

When creating data visualizations in R, some packages are designed with a very narrow focus, making them extremely effective for specific chart types. For example, **pheatmap** specializes in heatmaps, offering convenient features like clustering and annotations. Similarly, there are dedicated packages for other visualization needs: **ape** and **ggtree** for phylogenetic trees, **sf** and **tmap** for maps, and **igraph** or **ggraph** for network diagrams. These specialized tools provide ready-made functions, advanced options, and domain-specific features that make them more efficient than general-purpose plotting libraries.

Chart type	Specialized packages	Notes / Key features
Heatmap	pheatmap , ComplexHeatmap , heatmaply , superheat	Matrix visualization; clustering, annotations; static (pheatmap , ComplexHeatmap) or interactive (heatmaply).
Phylogenetic tree / tree diagram	ape , phytools , ggtree	Phylogenetics, evolutionary biology; ggtree built on ggplot2 for customizable trees.
Maps (spatial data)	sf , sp , tmap , leaflet	Spatial vector data; sf is modern standard, tmap for thematic maps, leaflet for interactive web maps.
Networks / Graphs	igraph , ggraph , visNetwork	Network analysis & visualization; igraph for analysis, ggraph (ggplot2 style), visNetwork for interactive HTML.
Time series / Forecasting	forecast , tsibble , fable , ggfortify	Specialized for time series analysis, decomposition, and forecasting.

Chart type	Specialized packages	Notes / Key features
Genome / sequence data	circlize, karyoploterR, RCircos	Circular genome plots, karyotypes, genomic track visualization.

15 Phylogeny / tree

15.1 Dataset Description

We have **40** *E. coli* isolates:

- **20** resistant to amoxicillin
- **20** non-resistant

Metadata is stored in an Excel file named **ecoli_amr.xlsx**, and the **blaTEM gene sequences** of all isolates are stored in a FASTA file named **ecoli_amr_blaTEM.fasta**.

Our goal is to **construct a phylogenetic tree** of the 40 isolates and annotate the tips according to resistance status (Resistant vs Non-resistant).

15.2 Pseudo Code

INPUT:

- Excel file "ecoli_amr.xlsx" (contains isolate IDs and AMR status)
- FASTA file "ecoli_amr_blaTEM.fa" (contains blaTEM sequences of 40 isolates)

STEP 1: Load metadata (Excel) and sequences (FASTA)

STEP 2: Perform multiple sequence alignment

- Align all blaTEM sequences
- Output: aligned sequence matrix

STEP 3: Compute genetic distance matrix

- Based on aligned sequences (e.g., p-distance or substitution model)

STEP 4: Build phylogenetic tree

- Use Neighbor-Joining (NJ) or Maximum Likelihood method

STEP 5: Annotate tree

- Map AMR status from metadata to tree tips
- Assign different colors for Resistant vs Non-resistant

STEP 6: Visualize tree

- Plot tree with tip labels colored by AMR status
- Add legend for interpretation

OUTPUT:

- A phylogenetic tree of 40 *E. coli* isolates with AMR annotation

15.3 code using ggtree

```
# Packages
library(Biostrings)
library(DECIPHER)
library(ape)
library(phangorn)
library(readxl)
library(ggtree)

## ggtree v3.16.3 Learn more at https://yulab-smu.top/contribution-tree-data/
##
## Please cite:
##
## Shuangbin Xu, Lin Li, Xiao Luo, Meijun Chen, Wenli Tang, Li Zhan, Zehan
## Dai, Tommy T. Lam, Yi Guan, Guangchuang Yu. Ggtree: A serialized data
## object for visualization of a phylogenetic tree and annotation data.
## iMeta 2022, 1(4):e56. doi:10.1002/imt2.56

##
## Attaching package: 'ggtree'

## The following object is masked from 'package:Biostrings':
##
##     collapse

## The following object is masked from 'package:IRanges':
##
##     collapse

## The following object is masked from 'package:S4Vectors':
##
##     expand

## The following object is masked from 'package:ape':
##
##     rotate

## The following object is masked from 'package:tidyverse':
##
##     expand

# ---- Inputs ----
meta_file <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_amr.xlsx"
fasta_file <- "https://github.com/juhuvn/vsob4/raw/refs/heads/main/Day4/ecoli_blaTEM.fasta" # cột: # 4

# ---- 1) Load metadata & raw sequences ----
meta <- rio::import(meta_file, trust=TRUE)
meta$amr_status <- factor(meta$amr_status, levels = c("Susceptible", "Resistant"))
```

```

  dna_raw <- readDNAStringSet(fasta_file)           # Biostrings object
  # ensure unique names (and trim spaces)
  names(dna_raw) <- make.unique(trimws(names(dna_raw)))

  # Optional sanity check: do FASTA names match metadata IDs?
  if (!all(names(dna_raw) %in% meta$isolate_id)) {
    warning("Some FASTA names are not present in metadata isolate_id.")
  }

  # ---- 2) MSA (Multiple Sequence Alignment) ----
  # DECIPHER::AlignSeqs uses SSE2-optimized Needleman-Wunsch under the hood (global alignment)
  # processors = 0 uses all cores; adjust if needed.
  aln <- AlignSeqs(dna_raw, processors = 1)

## Determining distance matrix based on shared 9-mers:
## =====
##
## Time difference of 0.01 secs
##
## Clustering into groups by similarity:
## =====
##
## Time difference of 0.02 secs
##
## Aligning Sequences:
## =====
##
## Time difference of 0.27 secs
##
## Iteration 1 of 2:
##
## Determining distance matrix based on alignment:
## =====
##
## Time difference of 0 secs
##
## Reclustering into groups by similarity:
## =====
##
## Time difference of 0.02 secs
##
## Realigning Sequences:
## =====
##
## Time difference of 0.15 secs
##
## Alignment converged - skipping remaining iteration.

# (Optional) save aligned FASTA for record
writeXStringSet(aln, filepath = "ecoli_amr_blaTEM_aligned.fa", format = "fasta")

# Convert aligned sequences to DNAbin for downstream distance/tree functions
# as.matrix(aln) yields a character matrix with gaps; ape::as.DNAbin can consume it.

```

```

aln_bin <- ape::as.DNAbin(as.matrix(aln))

# ---- 3) Genetic distance on aligned sequences ----
# Choose a substitution model (K80 is a good default for DNA; you can also try "JC69", "TN93", etc.)
dist_mat <- dist.dna(aln_bin, model = "K80", pairwise.deletion = FALSE) # no pairwise deletion after M

# ---- 4) Build phylogenetic tree ----
# (a) Neighbor-Joining
tree_nj <- nj(dist_mat)

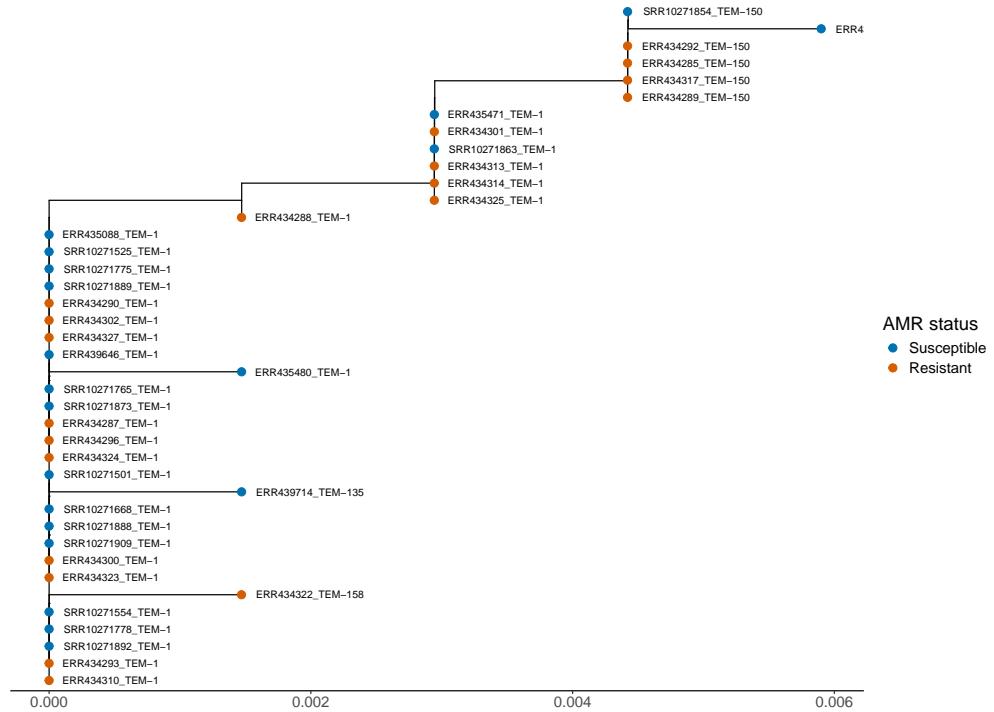
# ---- 5) Annotate tree with AMR status ----
# Ensure metadata aligns by tip labels:
rownames(meta) <- meta$isolate_id

# ---- 6) Visualize (choose NJ or ML) ----
# NJ tree
ggtree(tree_nj) %<+% meta +
  geom_tippoint(aes(color = amr_status), size = 3) +
  geom_tiplab(aes(label = label), size = 3, hjust = -0.1) +
  scale_color_manual(values = c("Susceptible" = "#0072B2", "Resistant" = "#D55E00")) +
  theme_tree2(text = element_text(size = 16)) +
  labs(title = "Phylogenetic Tree (NJ) – blaTEM, 40 E. coli isolates", color = "AMR status")

```

! The tree contained negative edge lengths. If you want to ignore the edges,
you can set `options(ignore.negative.edge=TRUE)`, then re-run ggtree.

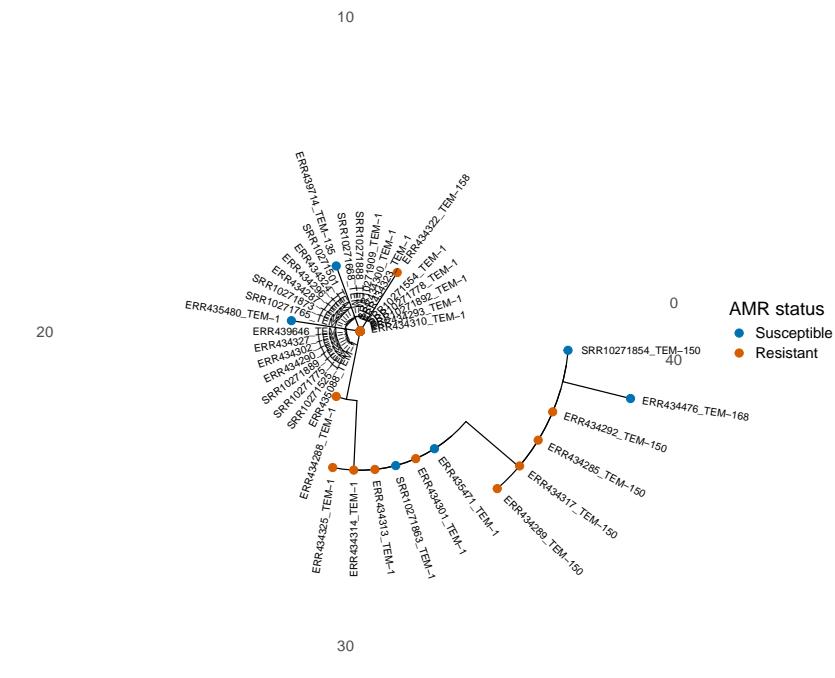
Phylogenetic Tree (NJ) – blaTEM, 40 E. coli isolates



```
# circular NJ tree
ggtree(tree_nj, layout = "circular") %<+% meta +
  geom_tippoint(aes(color = amr_status), size = 3) +
  geom_tiplab(aes(label = label), size = 3, hjust = -0.1) +
  scale_color_manual(values = c("Susceptible" = "#0072B2", "Resistant" = "#D55E00")) +
  theme_tree2(text = element_text(size = 16)) +
  labs(title = "Phylogenetic Circular Tree (NJ) - blaTEM, 40 E. coli isolates", color = "AMR status")
```

! The tree contained negative edge lengths. If you want to ignore the edges,
you can set `options(ignore.negative.edge=TRUE)`, then re-run ggtree.

Phylogenetic Circular Tree (NJ) – blaTEM, 40 E. coli isolates



Nhìn vào cây phát sinh loài này (**Neighbor-Joining tree** từ blaTEM gene, *E. coli*), ta có thể diễn giải như sau:

Cấu trúc tổng thể

- Cây bao gồm nhiều isolate mang **các allele blaTEM khác nhau**: TEM-1, TEM-135, TEM-150, TEM-158.
- **Trục ngang biểu thị độ dài nhánh (genetic distance)**. Giá trị nhỏ (0.000–0.006) cho thấy các trình tự **rất giống nhau**, khác biệt chỉ ở mức vài đột biến điểm (SNP).

Nhóm TEM-1

- Phần lớn isolate nằm trong nhóm **TEM-1**.
- Trong nhóm này, các isolate **Resistant** (màu cam) và **Susceptible** (màu xanh) lẩn lộn → điều này chứng tỏ **khả năng kháng không hoàn toàn phân biệt** bởi **toàn bộ** trình tự TEM-1, mà có thể chỉ do **một vài đột biến quan trọng** hoặc do **cơ chế khác** ngoài blaTEM.

Các allele biến thể khác

- TEM-135, TEM-150, TEM-158 tạo thành **nhánh riêng biệt** so với TEM-1 → nghĩa là chúng là **phái sinh** của blaTEM-1 nhưng đã tích lũy nhiều đột biến hơn.
- Trong các nhóm TEM-150, TEM-158, ... ta thấy cả **Resistant và Susceptible**, cho thấy:
 - không phải mọi biến thể TEM-X đều đồng nghĩa với kháng,
 - hoặc dữ liệu AMR phenotype chịu ảnh hưởng bởi nhiều yếu tố ngoài gene blaTEM (như biểu hiện gene, cơ chế kháng khác).

Điểm đáng chú ý

- **Khoảng cách di truyền (0.006 ~ 0.6% khác biệt nucleotide)** vẫn khá nhỏ → tất cả blaTEM này có quan hệ rất gần.
- Một số isolate cùng allele (ví dụ TEM-150) tạo cụm chặt → phản ánh **nguồn gốc chung gần**.
- Việc **Resistant/Susceptible không tách thành clade riêng** cho thấy AMR không phải **đặc trưng toàn cục của allele**, mà phụ thuộc vào **đột biến cục bộ**.

Tóm lại

- Cây cho thấy blaTEM trong 40 isolate *E. coli* **đa phần là TEM-1**, với một số allele phái sinh (TEM-135, TEM-150, TEM-158).
- Các allele này hình thành **cụm riêng biệt** trong cây, phản ánh sự tiến hóa từ TEM-1.
- **AMR phenotype không phân tách rõ rệt theo allele** → chứng tỏ tính kháng amoxicillin có thể do **một số mutation đặc hiệu trong blaTEM hoặc cơ chế bổ sung ngoài blaTEM**.

15.4 Neighbor-Joining (NJ)

Neighbor-Joining (NJ) is a **distance-based algorithm** for building phylogenetic trees. It is widely used in evolutionary biology because it is **fast, simple, and effective** for analyzing large sets of sequences.

15.4.1 How does it work?

1. **Start** with a star-like tree where all taxa (sequences) are connected to a common node.
2. **Compute pairwise distances** between all taxa (usually from an alignment).
3. **Find the pair of taxa (“neighbors”)** that minimizes the total branch length (i.e., the best local fit to the distance matrix).
4. **Join them together** as a single node and recalculate distances between this new node and all other taxa.
5. **Repeat** until all taxa are connected into a single tree.

15.4.2 Key features

- **Input:** a distance matrix (e.g., from `dist.dna` in R).
- **Output:** an unrooted phylogenetic tree.
- **Efficiency:** much faster than maximum likelihood or Bayesian methods → suitable for large datasets.
- **Approximation:** NJ does not model evolution explicitly; it is a heuristic method based only on pairwise distances.

15.4.3 Interpretation

- Branch lengths in an NJ tree are proportional to the genetic distances between sequences.
- NJ is good for getting a **quick overview of clustering and relationships**, but for more accurate evolutionary inference, model-based methods (e.g., Maximum Likelihood, Bayesian) are often preferred.

16 Map

There are `lon` (longitude) and ‘`lat`’ (latitude) variables in the `mydata` dataset. You might want to know where the samples are on the map.

There are several packages to plot map:

- **sf**: A modern framework for handling, analyzing, and visualizing spatial vector data in R, based on the “simple features” standard, fully compatible with tidyverse workflows.
- **rnaturrearth**: Provides convenient access to Natural Earth map data (countries, regions, coastlines) at multiple scales, returned as `sf` objects for easy use.
- **rnaturrearthdata**: Contains the actual Natural Earth datasets that support `rnaturrearth`, so maps can be loaded directly without extra downloads.
- **leaflet**: An R interface to the popular JavaScript library Leaflet, enabling interactive maps with zoom, pan, tooltips, and multiple tile providers (OpenStreetMap, Carto, Esri, etc.).
- **ggspatial**: Extends `ggplot2` with spatial utilities such as scale bars, north arrows, and basemap tiles (`annotation_map_tile()`), making it easy to combine spatial data with `ggplot`-style graphics.

```
# packages
pacman::p_load(sf, rnaturalearth, rnaturalearthdata)

# 1) chuyển sang sf (WGS84)
pts <- st_as_sf(mydata, coords = c("lon", "lat"), crs = 4326)

# 2) nền bản đồ (thé giới)
world <- ne_countries(scale = "medium", returnclass = "sf")

# 3) vẽ
ggplot() +
  geom_sf(data = world, fill = "grey95", color = "grey70", linewidth = 0.2) +
  geom_sf(data = pts, color = "red", size = 2) +
  coord_sf() + # có thé giới hạn phạm vi nếu muốn
  labs(x = NULL, y = NULL, title = "Locations from lon/lat (WGS84)") +
  theme_minimal()
```

Locations from lon/lat (WGS84)



We need to zoom in ...

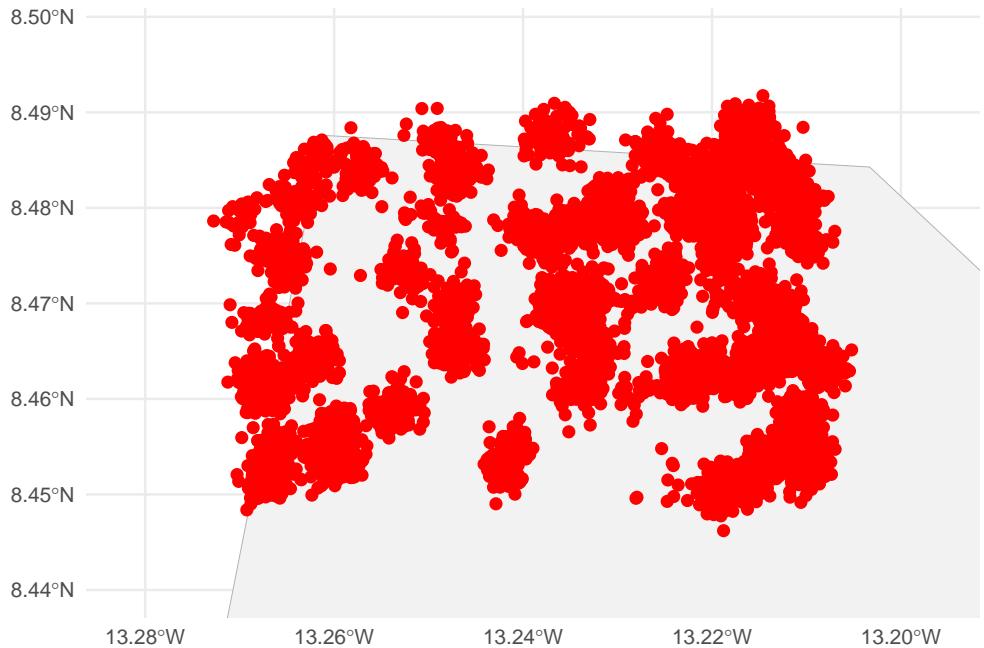
```
# limit regions

# dữ liệu điểm sf (CRS WGS84)
pts <- st_as_sf(mydata, coords = c("lon","lat"), crs = 4326)

# bounding box của dữ liệu
bb <- st_bbox(pts) # xmin, ymin, xmax, ymax

# tùy chọn: thêm padding 5% để hình thoáng hơn
pad_bb <- function(bb, pad = 0.05){
  dx <- (bb["xmax"] - bb["xmin"])*pad
  dy <- (bb["ymax"] - bb["ymin"])*pad
  c(xmin = bb["xmin"]-dx, ymin = bb["ymin"]-dy,
    xmax = bb["xmax"]+dx, ymax = bb["ymax"]+dy)
}
bbp <- pad_bb(bb, 0.2)

ggplot() +
  geom_sf(data = world, fill = "grey95", color = "grey70", linewidth = 0.2) +
  geom_sf(data = pts, color = "red", size = 2) +
  coord_sf(xlim = c(bbp["xmin.xmin"], bbp["xmax.xmax"]),
            ylim = c(bbp["ymin.ymin"], bbp["ymax.ymax"]),
            expand = FALSE) +
  theme_minimal()
```



Still bad, ...

```

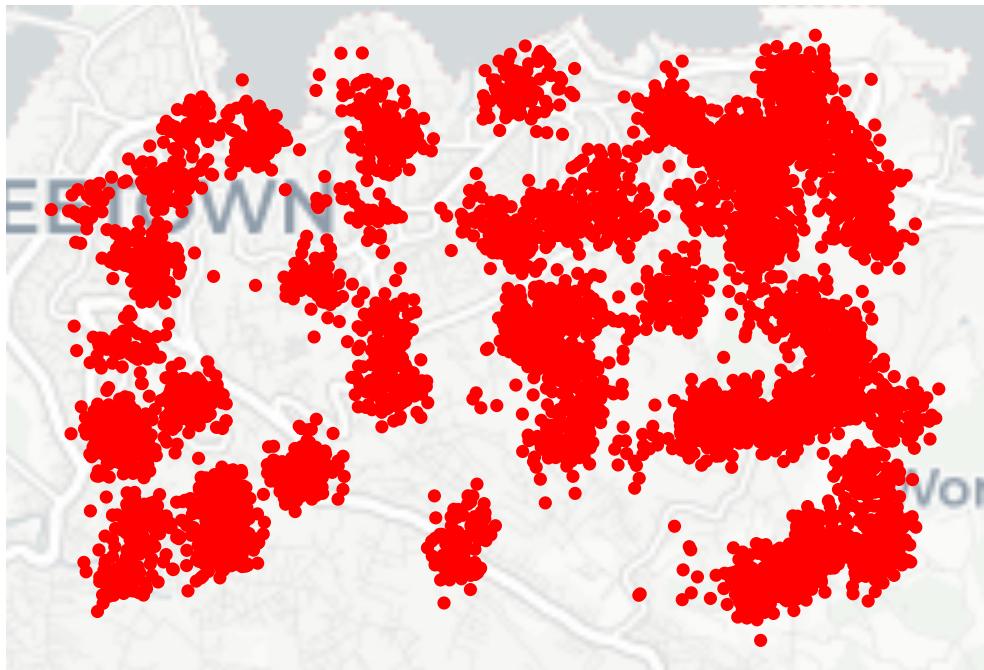
pacman::p_load(sf, ggplot2, ggspatial, prettymapr)

pts <- st_as_sf(mydata, coords = c("lon","lat"), crs = 4326)
bb  <- st_bbox(pts)
pad <- 500
xlim <- c(bb["xmin"] - diff(bb[c("xmin","xmax")])*pad,
           bb["xmax"] + diff(bb[c("xmin","xmax")])*pad)
ylim <- c(bb["ymin"] - diff(bb[c("ymin","ymax")])*pad,
           bb["ymax"] + diff(bb[c("ymin","ymax")])*pad)

ggplot() +
  # tải tile nền chi tiết (OSM/CARTO); chọn 'osm', 'cartolight', 'stamenbw', 'esri'
  annotation_map_tile(type = "cartolight", zoom = 12) +
  coord_sf(xlim = xlim, ylim = ylim, expand = FALSE) +
  geom_sf(data = pts, color = "red", size = 2) +
  theme_void()

## Coordinate system already present. Adding new coordinate system, which will
## replace the existing one.
## Zoom: 12

```



We might want to have an interactive map using `leaflet` package.

```
pacman::p_load(leaflet)

leaflet(mydata) |>
  addTiles() |>
  addMarkers(lng = ~lon, lat = ~lat,
             popup = ~case_id,
             clusterOptions = markerClusterOptions())
```

17 Additional Resources

17.1 R Graph Gallery

R graph gallery, a collection of charts made with the R programming language. Hundreds of charts are displayed in several sections, always with their reproducible code available. The gallery makes a focus on the tidyverse and `ggplot2`.

[Link to R Graph Gallery](#)

17.2 ggplot cheat sheet

[Link to ggplot PDF cheat sheet](#)

18 References

- Cẩm nǎng dịch tễ học
- R Graph Gallery