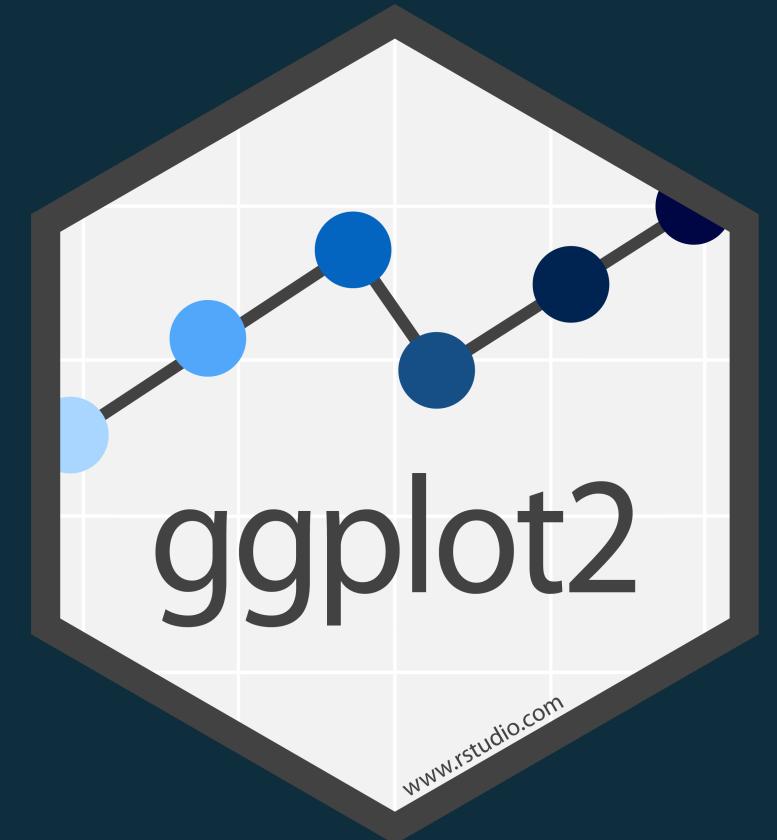


Data visualization with ggplot2

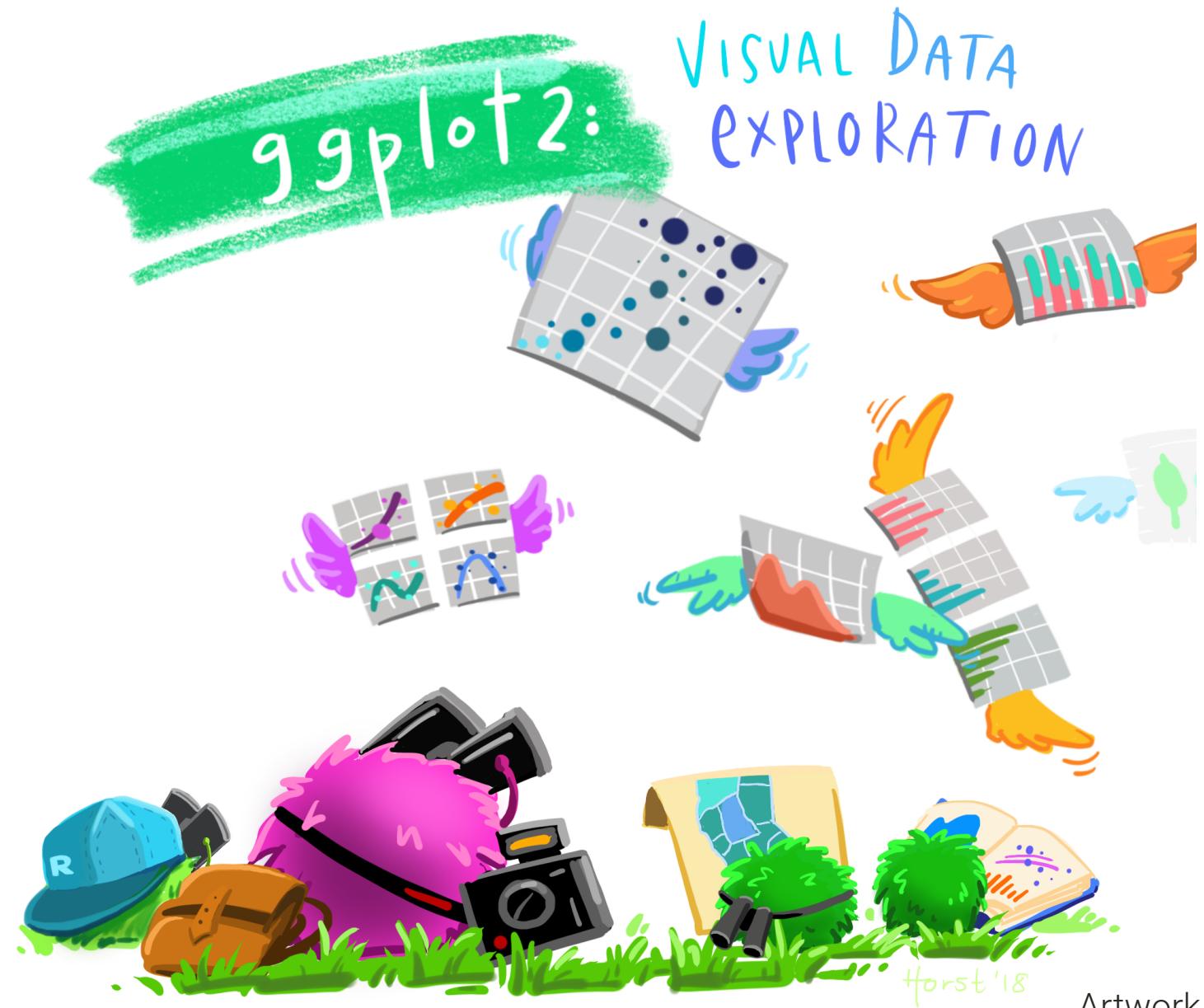
Introduction to R - Day 2

Instructor: Selina Baldauf

Freie Universität Berlin - Theoretical Ecology



2021-08-01 (updated: 2022-08-30)



ggplot2:

Build a data
MASTERpiece



HORST '18

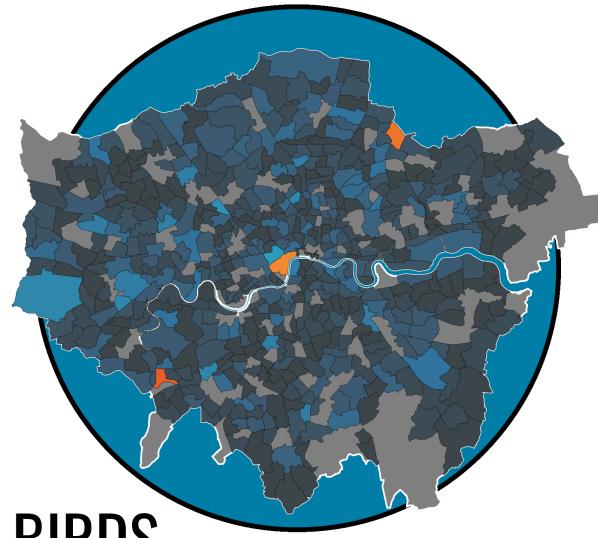
Artwork by Allison Horst 3 / 48

A ggplot showcase

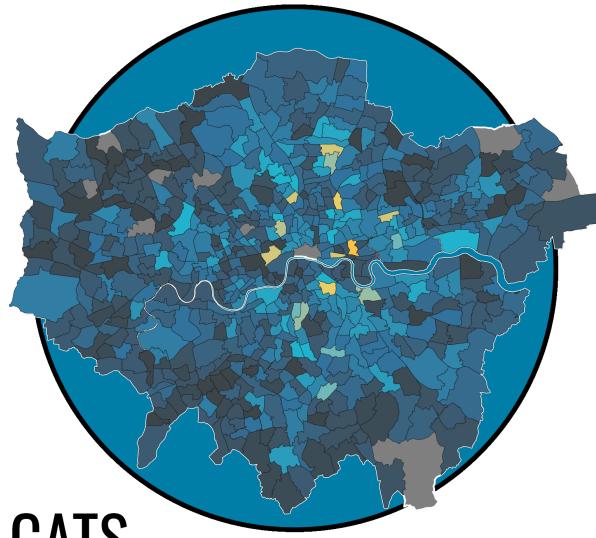
Some examples of plots you can create with ggplot

Frequency of Rescues of Birds, Cats and Dogs in London from 2009-2021

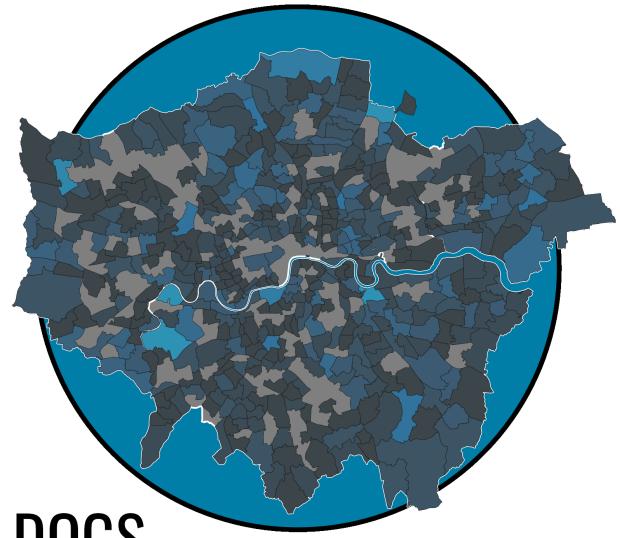
Illustrated below in three choropleth maps are rescues of birds, cats and dogs in London wards. Darker colors indicate lower rescue numbers while brighter colors indicate a greater number of rescues in that ward.



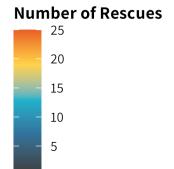
BIRDS



CATS



DOGS

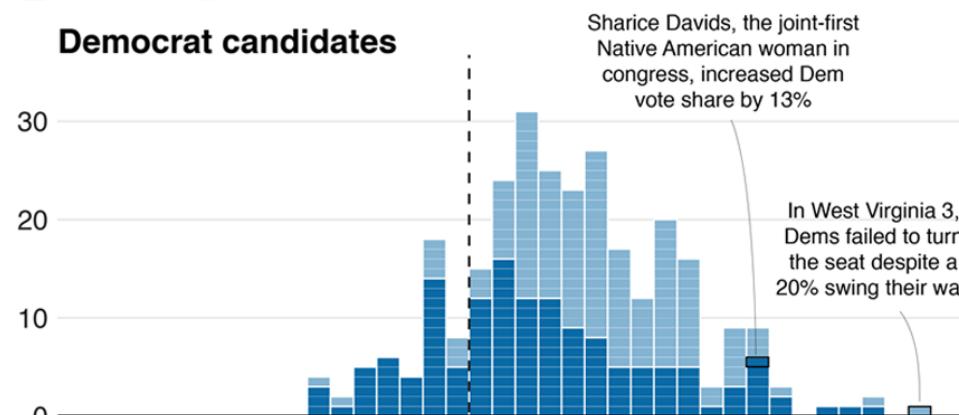


Data: London.gov | Graphic: @jakekaupp

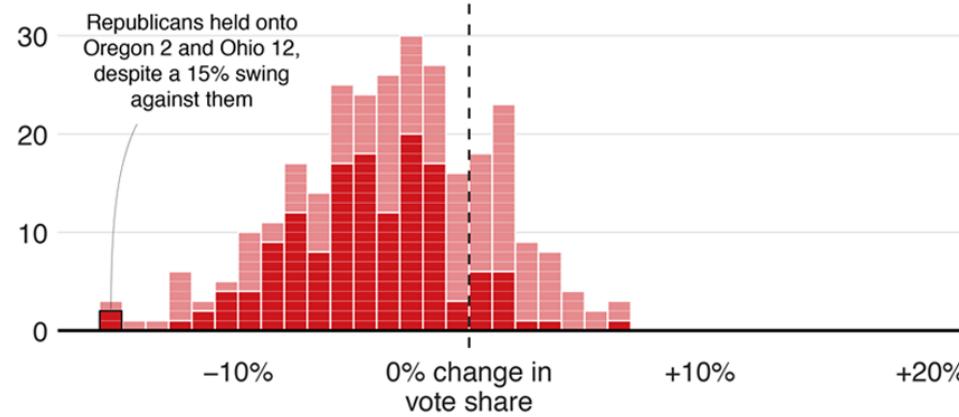
Blue wave

■ Won seat ■ Didn't win

Democrat candidates

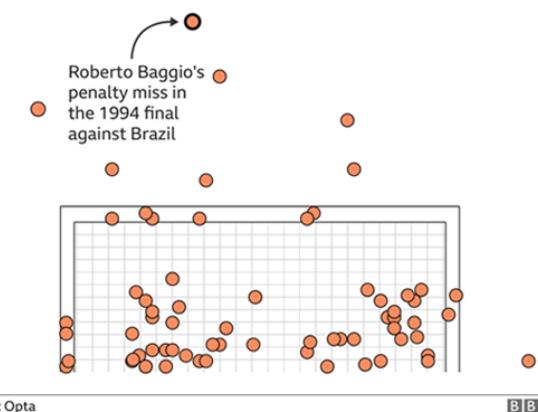


Republican candidates



Where penalties are saved

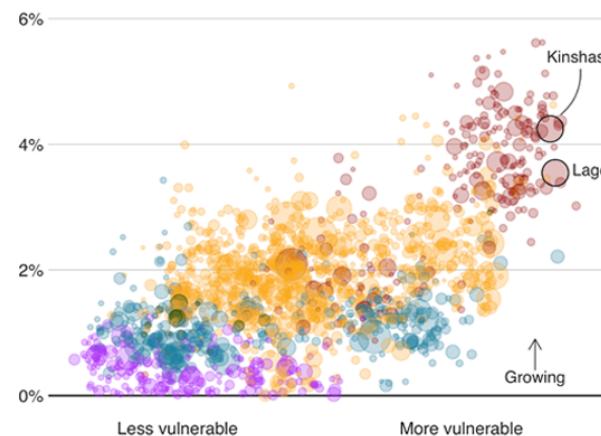
World Cup shootout misses and saves, 1982-2014



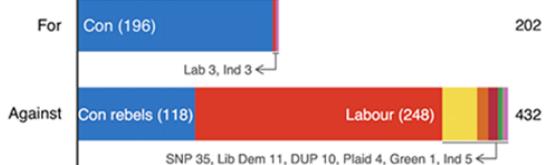
Fast-growing cities face worse climate risks

Population growth 2018-2035 over climate change vulnerability

■ Africa ■ Asia ■ Americas ■ Europe ■ Oceania

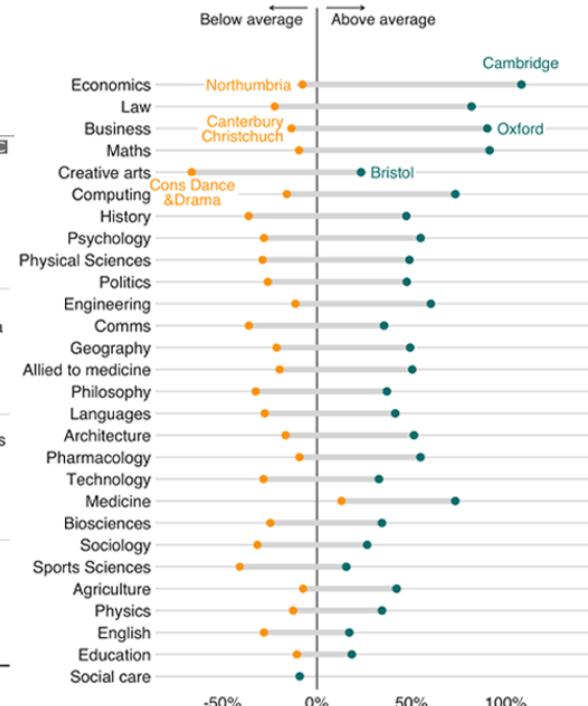


MPs rejected Theresa May's deal by 230 votes



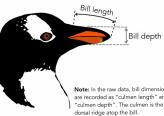
Earnings vary across unis even within subjects

Impact on men's earnings relative to the average degree

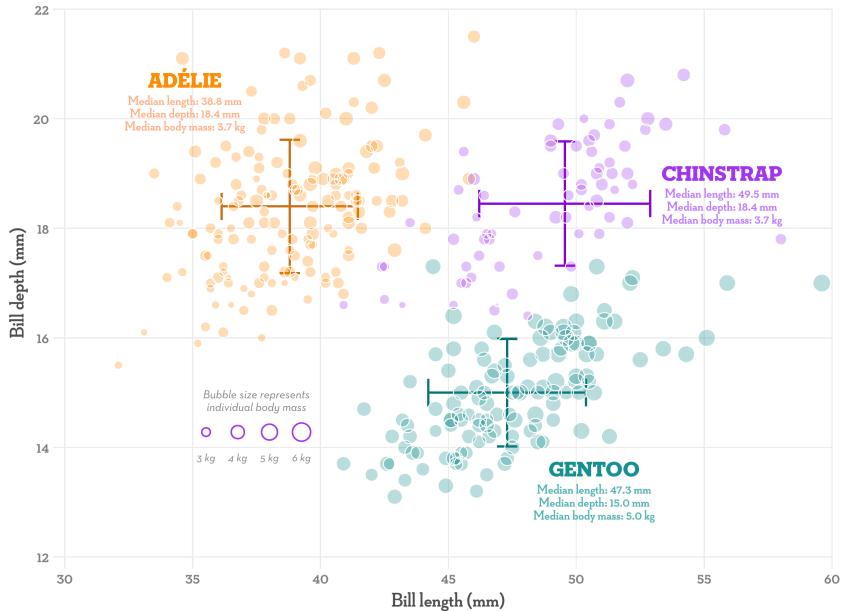


BILL DIMENSIONS OF BRUSH-TAILED PENGUINS

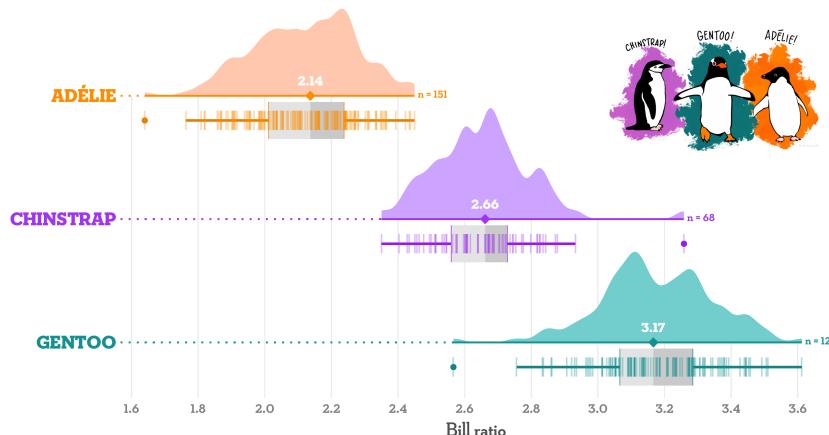
Pygoscelis adeliae (Adélie penguin) • *P. antarctica* (Chinstrap penguin) • *P. papua* (Gentoo penguin)



A. Scatterplot of bill length versus bill depth (error bars show median +/- sd)



B. Distribution of the bill ratio, estimated as bill length divided by bill depth



Note: In the original data, bill dimensions are recorded as "culmen length" and "culmen depth". The culmen is the dorsal (upper) ridge of a bird's bill.
Visualization: Cédric Scherer • Data: Gorman, Williams & Fraser (2014) DOI: 10.1371/journal.pone.0099081 • Illustrations: Allison Horst

Visualization by Cédric Scherer,
code available on [Github](#)

Advantages of ggplot

- Consistent grammar/structure
- Flexible structure allows you to produce any type of plots
- Highly customizable appearance (themes)
- Many extension packages that provide
 - Additional plot types
 - Additional themes
 - Color palettes
 - Animation
 - Composition of multiple plots
 - ...
- Active community that provides help and inspiration

Basic idea of ggplot

Shorten the distance from mind to page

(Hadley Wickham)

`ggplot2` is an implementation of the grammar of graphics by Leland Wilkinson

- Basic idea: stack distinct **layers of graphical elements** to create a plot

Layers of a ggplot

Layer	Function	Details
Data	<code>ggplot(data)</code>	The data that you want to plot.
Mapping	<code>aes()</code>	Aesthetic mappings of the geometric and statistical objects.
Geometries	<code>geom_*</code> ()	Graphical representation of aesthetics as point, line, polygon, ...
Scales	<code>scale_*</code> ()	Translate between variable values and properties (e.g. categories -> colour)
Coordinates	<code>coord_*</code> ()	Interprets and maps the position values of the data.
Facets	<code>facet_*</code> ()	Split your plot into multiples.
Themes	<code>theme()</code> and <code>theme_*</code> ()	Visual look of the plot not related to the data.

The data

The `ggplot` package has a built-in data set called `msleep` about the sleep times of 83 mammals.

Data variables (among others):

- `vore`: carnivore, omnivore, herbivore?
- `conservation`: conservation status of the animal
- `sleep_total`: total amount of sleep [h]
- `brainwt`: brain weight [kg]
- `bodywt`: body weight [kg]

If you want to know more about the data set:

```
library(ggplot2)
str(msleep)
?msleep
```

ggplot(data)

The `ggplot()` function initializes a ggplot object. Every ggplot needs this function.

```
library(ggplot2) # or library(tidyverse)  
ggplot(data = msleep)
```

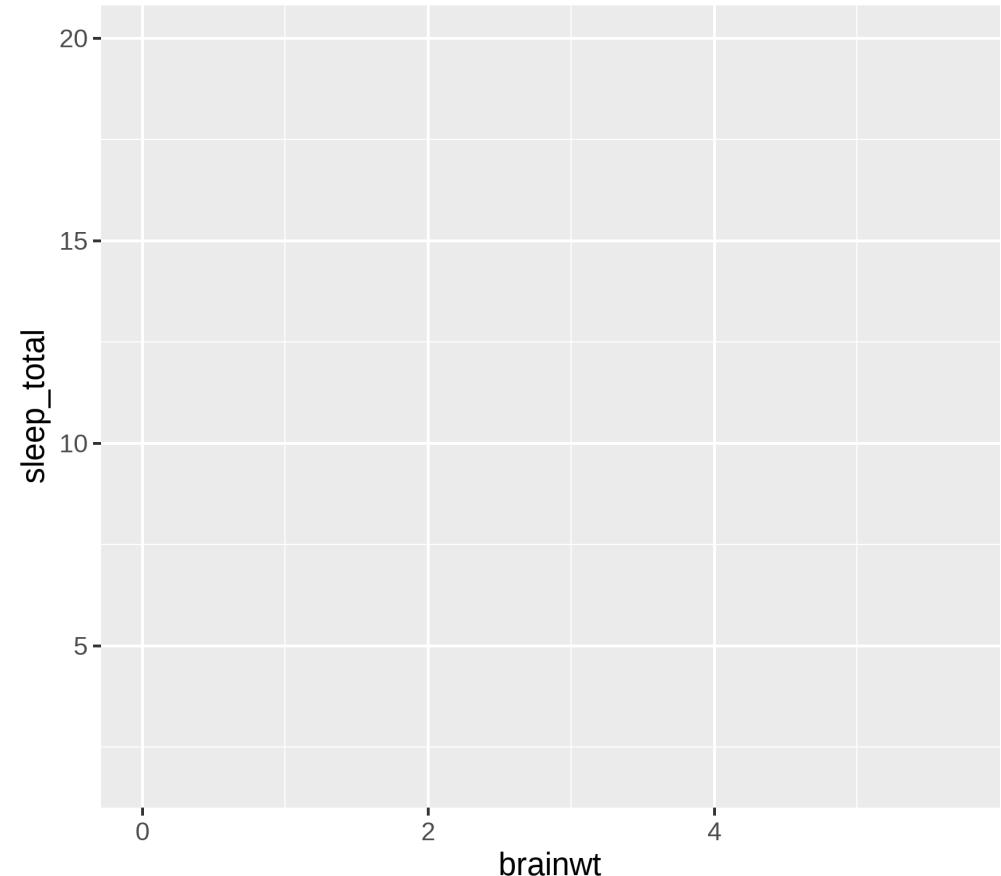
- Empty plot because we did not specify the mapping of data variables

aes(x, y)

The `aesthetic` mapping defines how variables are mapped to aesthetic properties of the plot.

```
ggplot(data = msleep,  
       mapping = aes(  
           x = brainwt,  
           y = sleep_total))
```

- Map variable `brainwt` to x-axis and `sleep_total` to y-axis
- Default scales are automatically adapted to range of data



aes(x, y)

The `aesthetic` mapping defines how variables are mapped to aesthetic properties of the plot.

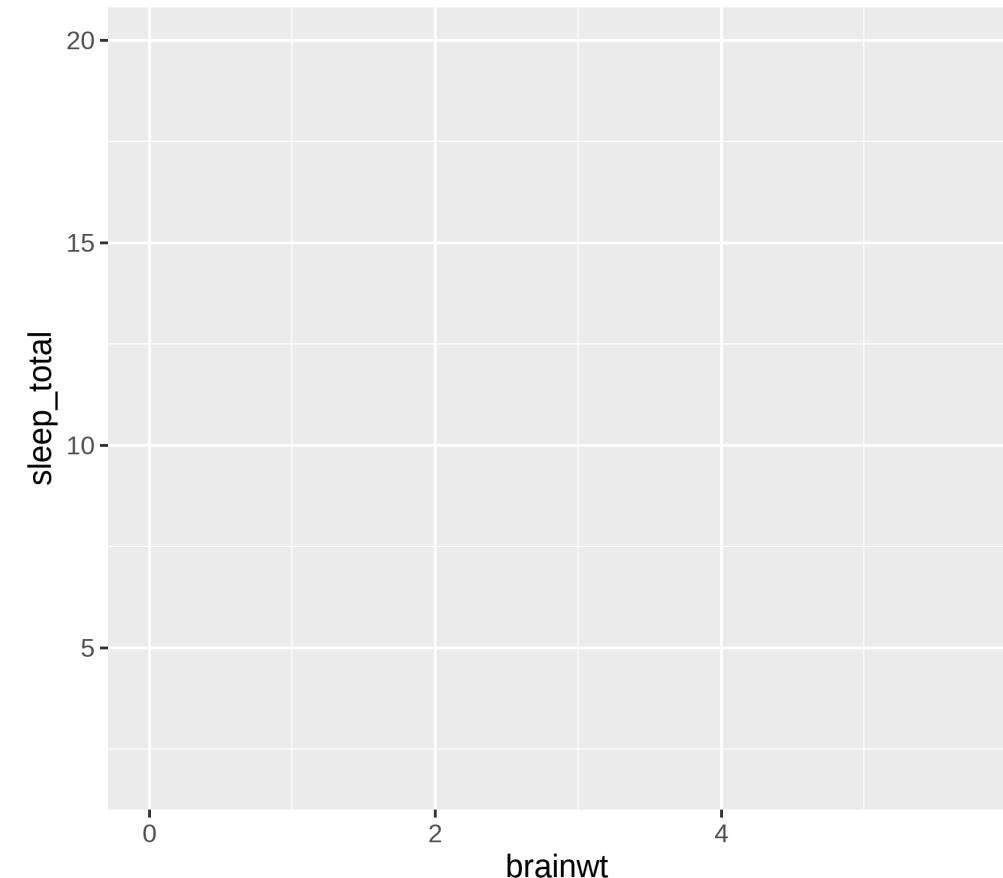
```
ggplot(data = msleep,  
       mapping = aes(  
           x = brainwt,  
           y = sleep_total))
```

- map variable `brainwt` to x-axis and `sleep_total` to y-axis
- default scales are automatically adapted to range of data

This is the same but shorter:

```
ggplot(msleep, aes(brainwt, sleep_total))
```

Remember argument matching by position?



Remember argument matching by position?

`geom_*`()

geoms define how data points are represented. There are many different geoms to chose from

 **a + geom_blank()**
(Useful for expanding limits)

 **b + geom_curve(aes(yend = lat + 1, xend = long + 1), curvature = 1)** - x, yend, alpha, angle, color, curvature, linetype, size

 **a + geom_path(lineend = "butt", linejoin = "round", linemitre = 1)**
x, y, alpha, color, group, linetype, size

 **a + geom_polygon(aes(group = group))**
x, y, alpha, color, fill, group, linetype, size

 **b + geom_rect(aes(xmin = long, ymin = lat, xmax = long + 1, ymax = lat + 1))** - xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size

 **a + geom_ribbon(aes(ymin = unemploy - 900, ymax = unemploy + 900))** - x, ymax, ymin, alpha, color, fill, group, linetype, size

LINE SEGMENTS

common aesthetics: x, y, alpha, color, linetype, size

 **b + geom_abline(aes(intercept = 0, slope = 1))**
 **b + geom_hline(aes(yintercept = lat))**
 **b + geom_vline(aes(xintercept = long))**

b + geom_segment(aes(yend = lat + 1, xend = long + 1))
b + geom_spoke(aes(angle = 1:1155, radius = 1))

ONE VARIABLE continuous

c <- ggplot(mpg, aes(hwy)); c2 <- ggplot(mpg)

 **c + geom_area(stat = "bin")**
x, y, alpha, color, fill, linetype, size

 **c + geom_density(kernel = "gaussian")**
x, y, alpha, color, fill, group, linetype, size, weight

 **c + geom_dotplot()**
x, y, alpha, color, fill

 **c + geom_freqpoly()** x, y, alpha, color, group, linetype, size

 **c + geom_histogram(binwidth = 5)** x, y, alpha, color, fill, linetype, size, weight

c + geom_sf(sf::st_as_sf(USArrests) %>% st_as_sf)

 **e + geom_label(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE)** x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

 **e + geom_jitter(height = 2, width = 2)**
x, y, alpha, color, fill, shape, size

 **e + geom_point()**, x, y, alpha, color, fill, shape, size, stroke

 **e + geom_quantile()**, x, y, alpha, color, group, linetype, size, weight

 **e + geom_rug(sides = "bl")**, x, y, alpha, color, linetype, size

 **e + geom_smooth(method = lm)**, x, y, alpha, color, fill, group, linetype, size, weight

 **e + geom_text(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE)**, x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

discrete x , continuous y

f <- ggplot(mpg, aes(class, hwy))

 **f + geom_col()**, x, y, alpha, color, fill, group, linetype, size

 **f + geom_boxplot()**, x, y, lower, middle, upper, ymax, ymin, alpha, color, fill, group, linetype, shape, size, weight

 **f + geom_dotplot(binaxis = "y", stackdir = "center")**, x, y, alpha, color, fill, group

 **f + geom_violin(scale = "area")**, x, y, alpha, color, fill, group, linetype, size, weight

discrete x , discrete y

g <- ggplot(diamonds, aes(cut, color))

 **g + geom_count()**, x, y, alpha, color, fill, shape, size, stroke

 **h + geom_bin2d(binwidth = c(0.25, 500))**
x, y, alpha, color, fill, linetype, size, weight

 **h + geom_density2d()**
x, y, alpha, colour, group, linetype, size

 **h + geom_hex()**
x, y, alpha, colour, fill, size

continuous function

i <- ggplot(economics, aes(date, unemploy))

 **i + geom_area()**
x, y, alpha, color, fill, linetype, size

 **i + geom_line()**
x, y, alpha, color, group, linetype, size

 **i + geom_step(direction = "hv")**
x, y, alpha, color, group, linetype, size

visualizing error

df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
j <- ggplot(df, aes(grp, fit, ymin = fit - se, ymax = fit + se))

 **j + geom_crossbar(fatten = 2)**
x, y, ymax, ymin, alpha, color, fill, group, linetype, size

 **j + geom_errorbar()**, x, ymax, ymin, alpha, color, group, linetype, size, width (also **geom_errorbarh()**)

 **j + geom_linerange()**
x, ymin, ymax, alpha, color, group, linetype, size

 **j + geom_pointrange()**
x, y, ymin, ymax, alpha, color, fill, group, linetype, shape, size

maps

data <- data.frame(murder = USArrests\$Murder, state = tolower(rownames(USArrests)))
map <- map_data("state")
k <- ggplot(data, aes(fill = murder))

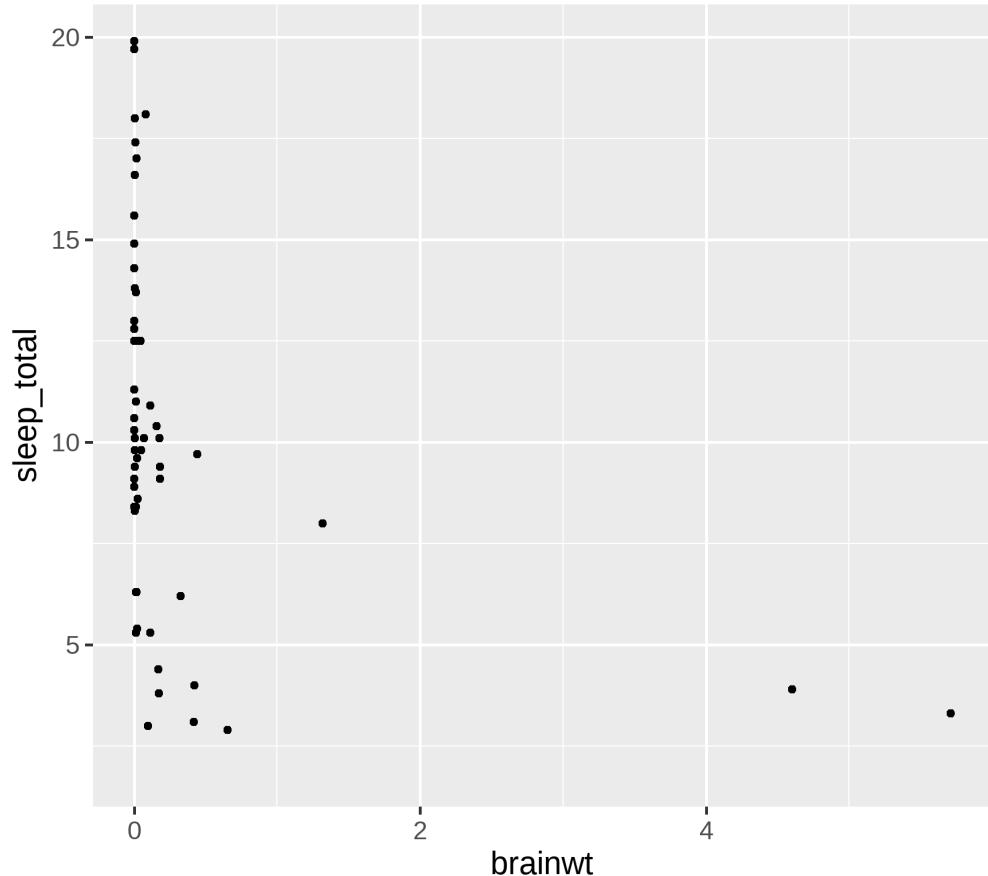
 **k + geom_map(aes(map_id = state), map = map) + expand_limits(x = map\$long, y = map\$lat)**, map_id, alpha, color, fill, linetype, size

geom_point()

```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point()
```

```
## Warning: Removed 27 rows containing missing  
values (geom_point).
```

- New plot layers are added with `+`
- Warning that 27 points can not be plotted due to missing values
- `data` and `aes` defined in `ggplot` call are inherited to all plot layers



geom_point()

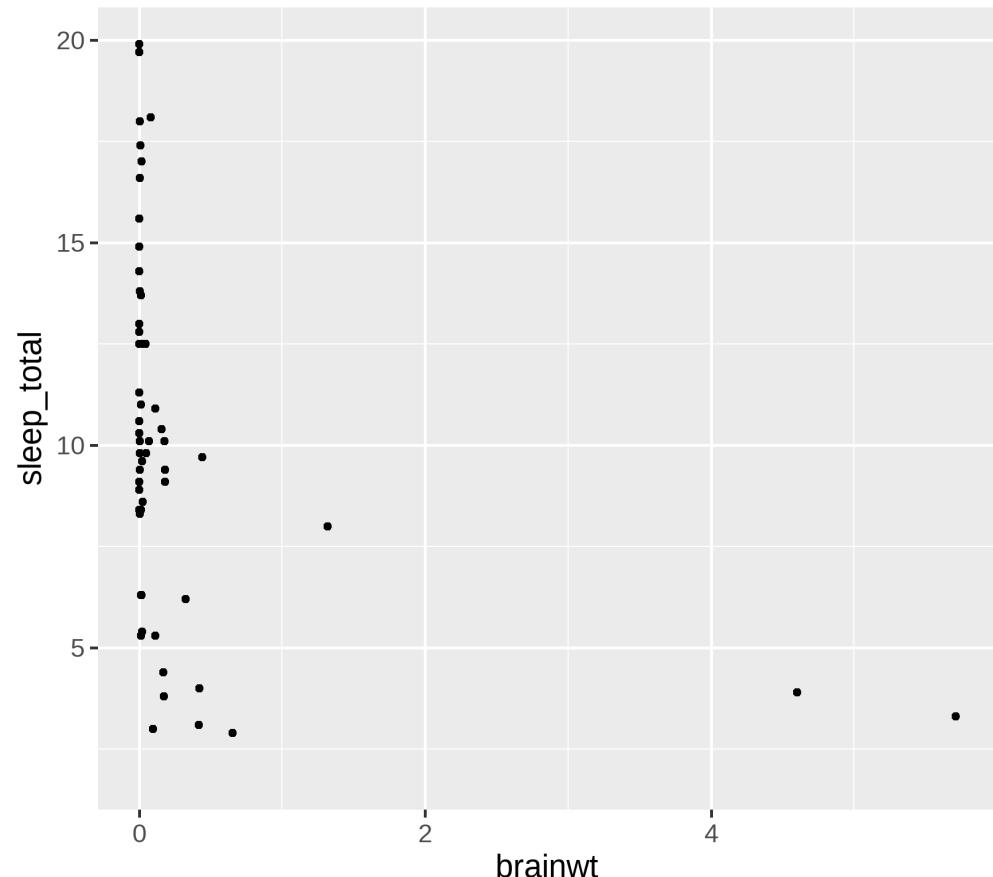
```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point()
```

- New plot layers are added with `+`
- Warning that 27 points can not be plotted due to missing values
- `data` and `aes` defined in `ggplot` call are inherited to all plot layers
- `data` and `aes` can be local to a layer:

```
ggplot(msleep) +  
  geom_point(aes(brainwt, sleep_total))
```

Here, it does not make a difference.

```
## Warning: Removed 27 rows containing missing  
values (geom_point).
```

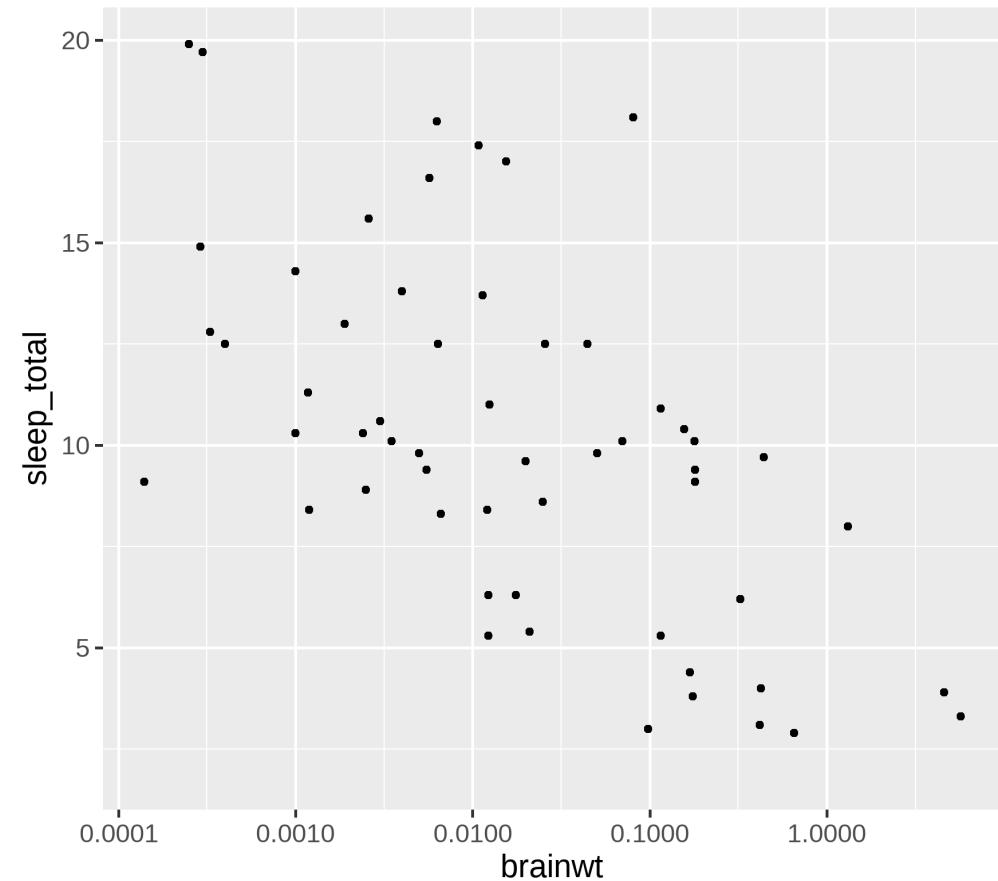


scale_x_log10()

The scales onto which the aesthetic elements are mapped can be changed.

```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point() +  
  scale_x_log10()
```

- Scales can be changed for all elements of `aes`



scale_x_log10()

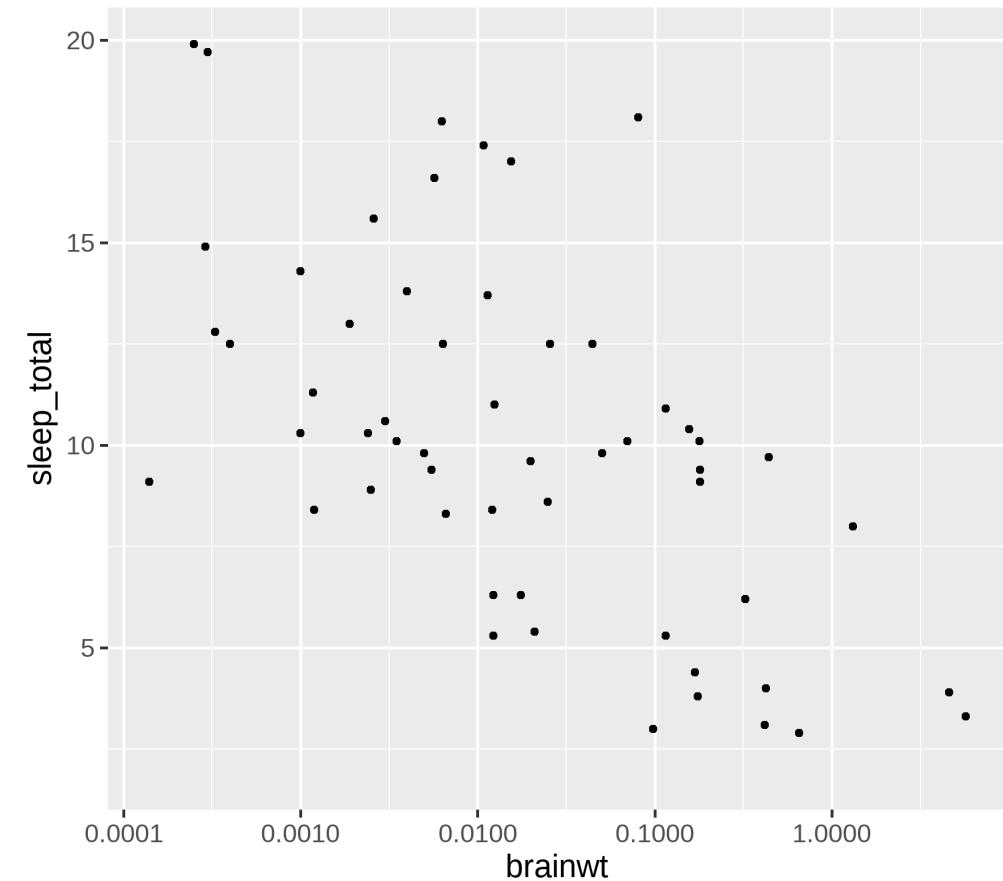
The scales onto which the aesthetic elements are mapped can be changed.

```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point() +  
  scale_x_log10()
```

- Scales can be changed for all elements of `aes`
- The general format of scale functions are:

`scale_aes-name_scale-type`

In this example we scale the `x` aesthetic to `log10`.

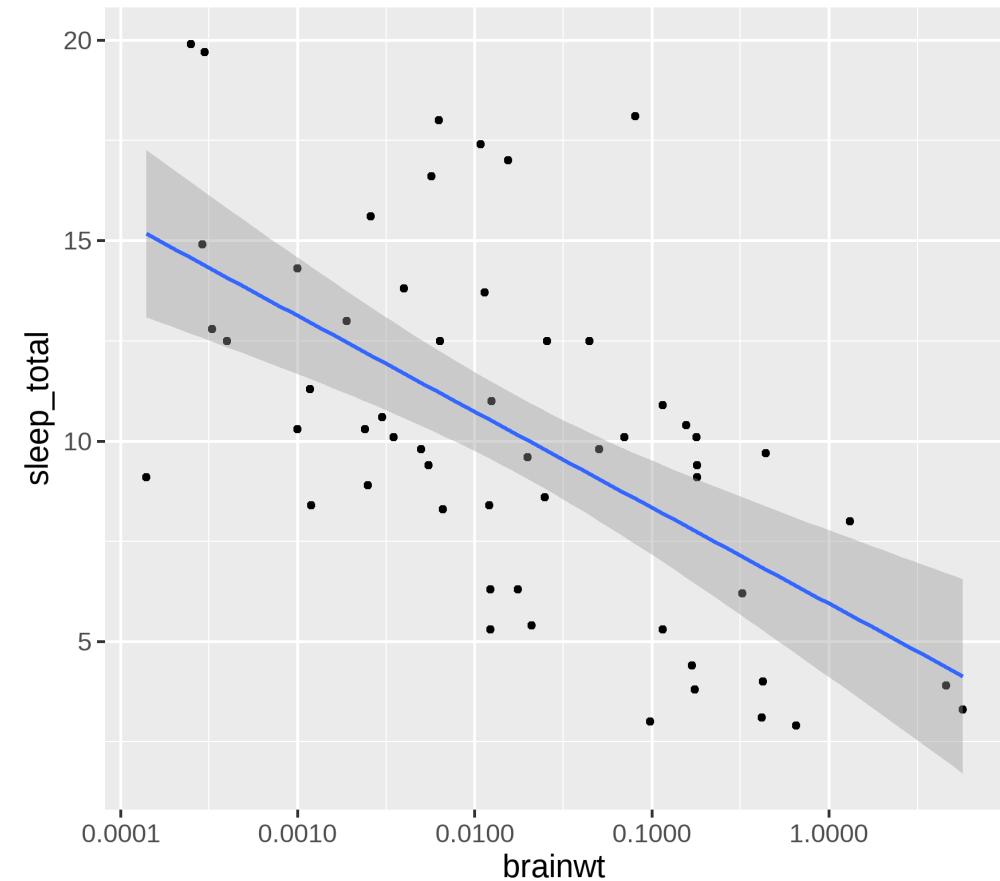


geom_smooth()

Add a smoothing line that helps see patterns in the data

```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point() +  
  geom_smooth(method = "lm") +  
  scale_x_log10()
```

- With `method = "lm"`, a linear regression line is added
- The ribbon represents confidence interval around the regression
 - Turn ribbon off with `se = FALSE` argument

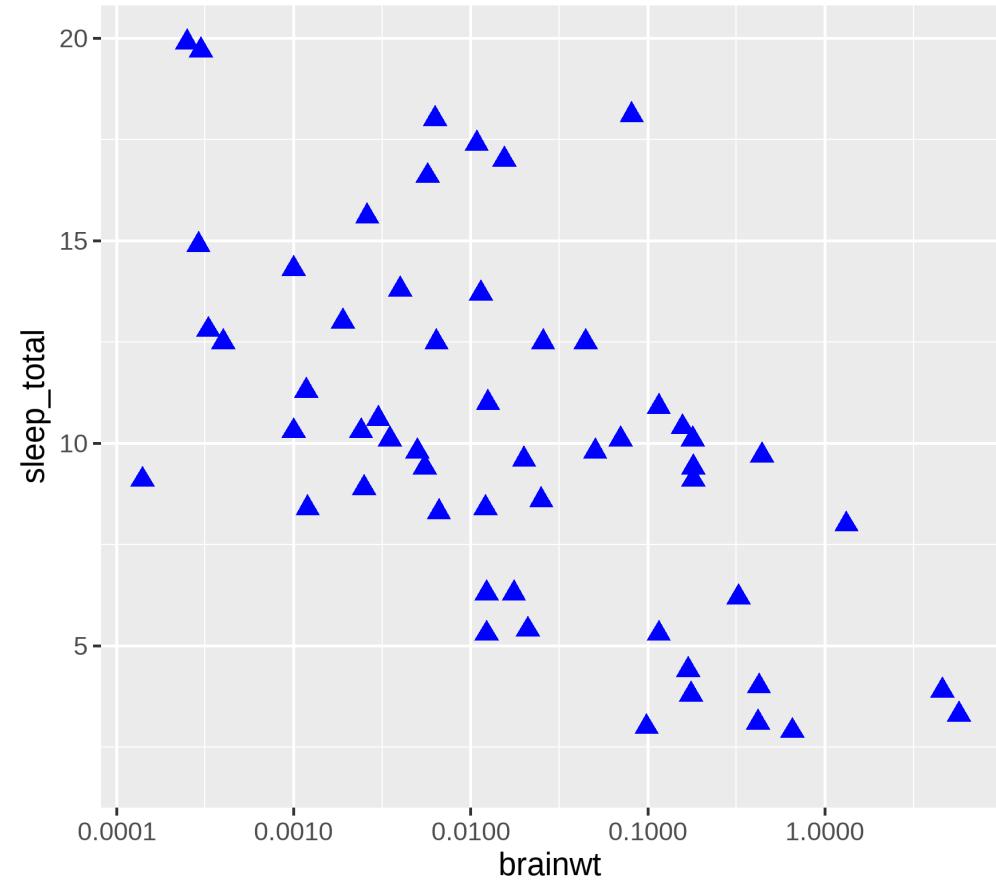
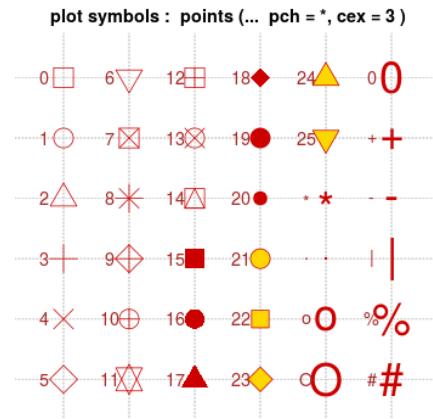


Change appearance of points

The basic things we can change about points are their **size**, **shape** and **color**:

```
ggplot(data = msleep,  
       aes(x = brainwt,  
            y = sleep_total)) +  
  geom_point(size = 4,  
             shape = 17,  
             color = "blue") +  
  scale_x_log10()
```

- Have a look [here](#) for the point shape codes:

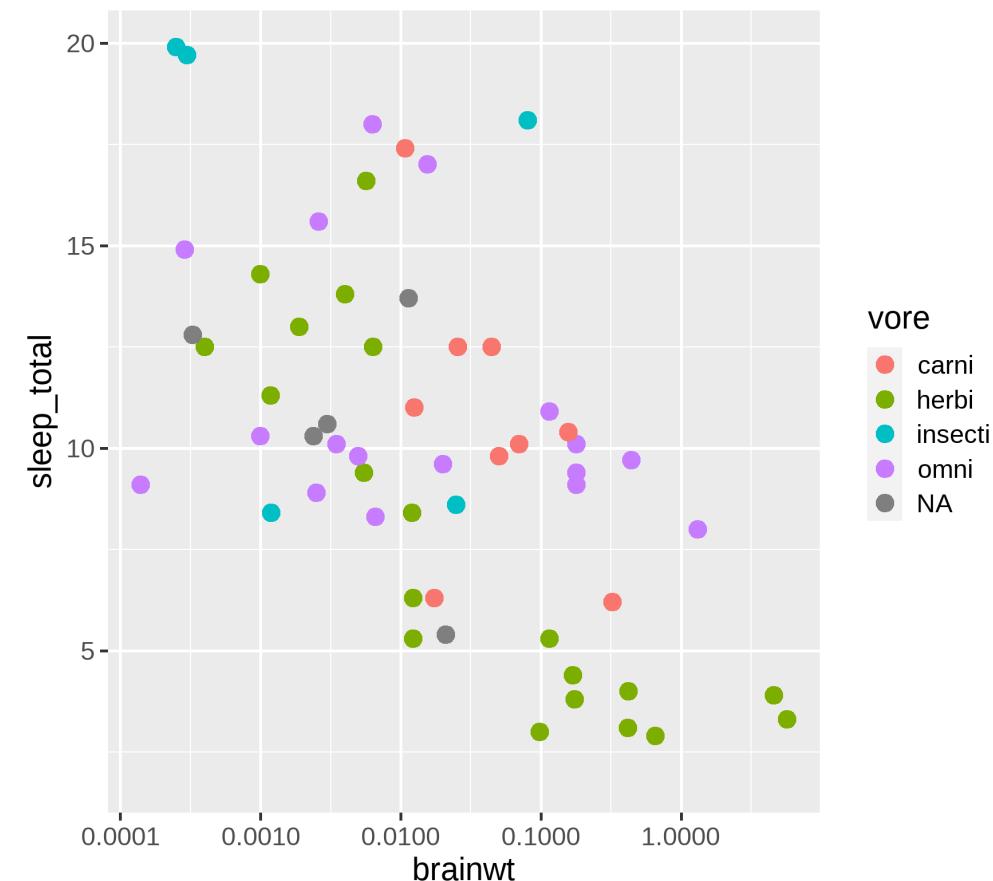


aes (color): mapping color to a variable

Instead of changing color of all points, **map color to a variable** by adding it to aesthetics:

```
g <- ggplot(  
  data = msleep,  
  aes(  
    x = brainwt,  
    y = sleep_total,  
    color = vore  
)  
) +  
  geom_point(size = 4) +  
  scale_x_log10()  
g
```

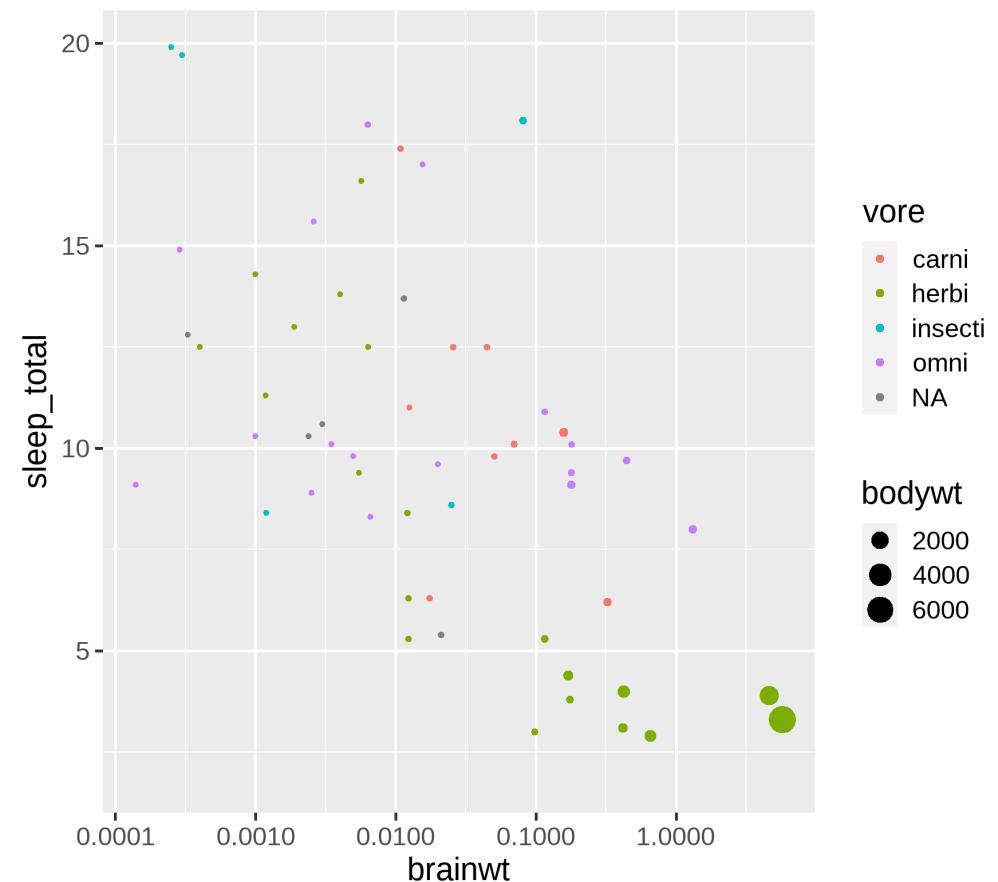
- Map the `vore` variable to the color aesthetic of the plot
- Plots can be saved in variables



aes (size): mapping size to a variable

We can do the same with size:

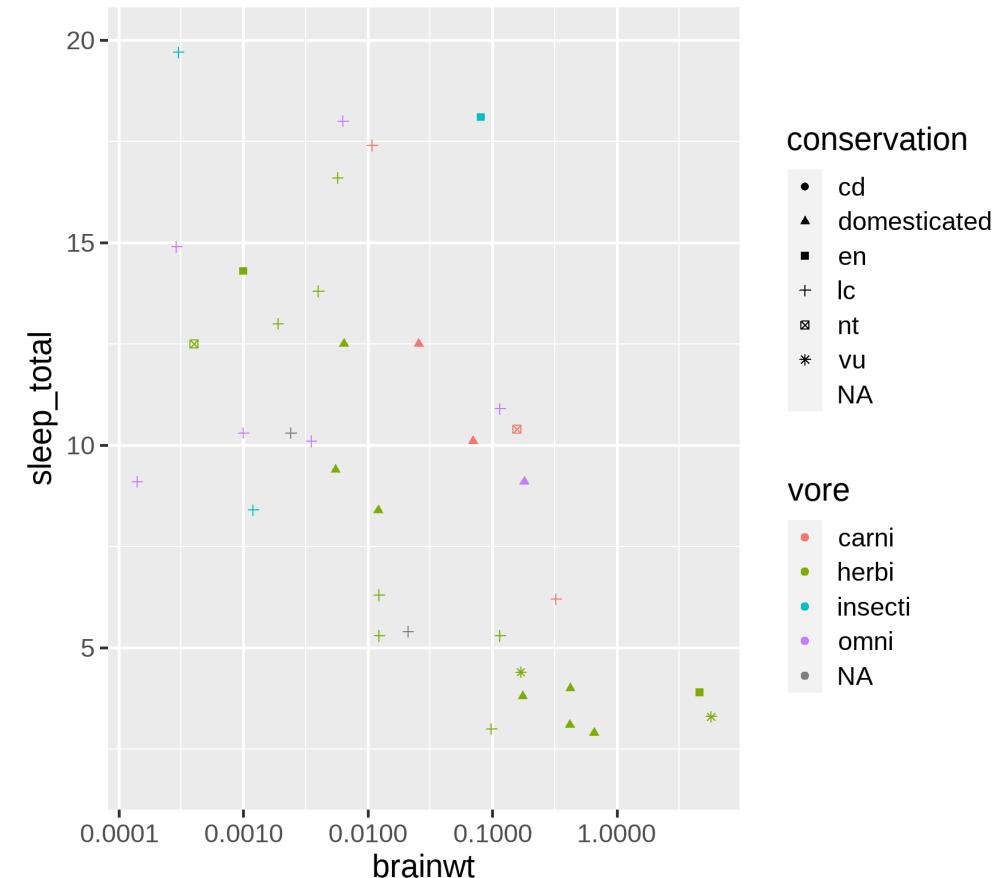
```
ggplot(  
  data = msleep,  
  aes(  
    x = brainwt,  
    y = sleep_total,  
    color = vore,  
    size = bodywt  
  )  
) +  
  geom_point() +  
  scale_x_log10()
```



aes (shape) : mapping shape to a variable

We can do the same with shape:

```
ggplot(  
  data = msleep,  
  aes(  
    x = brainwt,  
    y = sleep_total,  
    color = vore,  
    shape = conservation  
  )  
) +  
  geom_point() +  
  scale_x_log10()
```

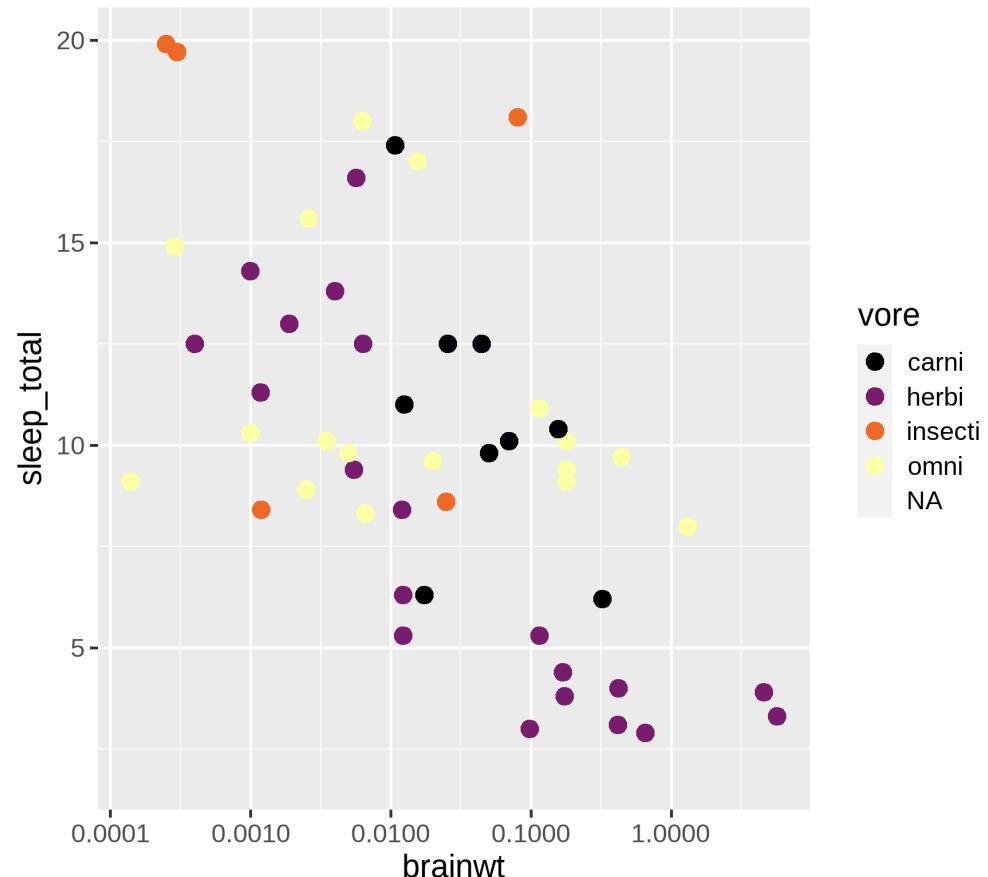


`scale_color_viridis_d()`

Back to our plot `g` with color as additional aesthetic. We can change the color scale:

```
g +  
  scale_color_viridis_d(option = "inferno")
```

- The viridis color palette is designed for viewers with common forms of color blindness
- Different options of viridis color palettes are are:
 - "magma", "inferno", "plasma", "viridis", "cividis"

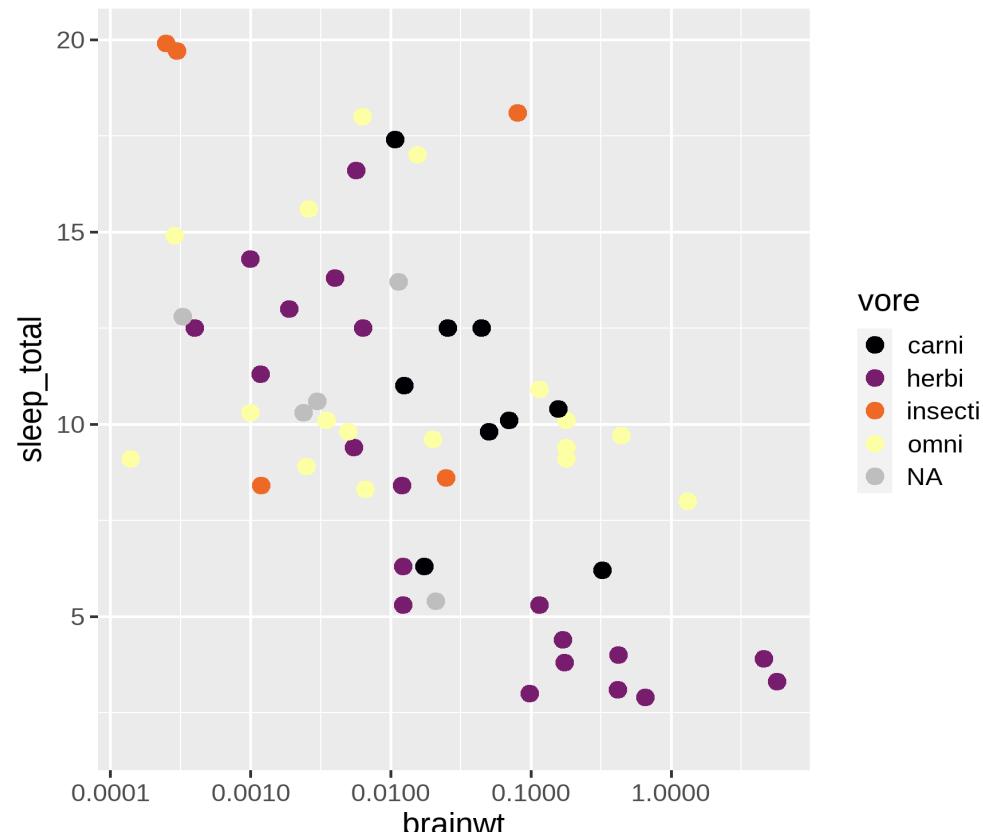


`scale_color_viridis_d()`

The `scale_color_viridis_d` function by default does not map color to missing data points (`NA` values). We have to explicitly state the color for `NA`:

```
g +
  scale_color_viridis_d(
    option = "inferno",
    na.value = "grey")
```

- Whether or not you have to do this, depends on the default of the `na.value` argument of the color scale that you use
- You can also remove missing values from your data set before plotting (we will learn that later)



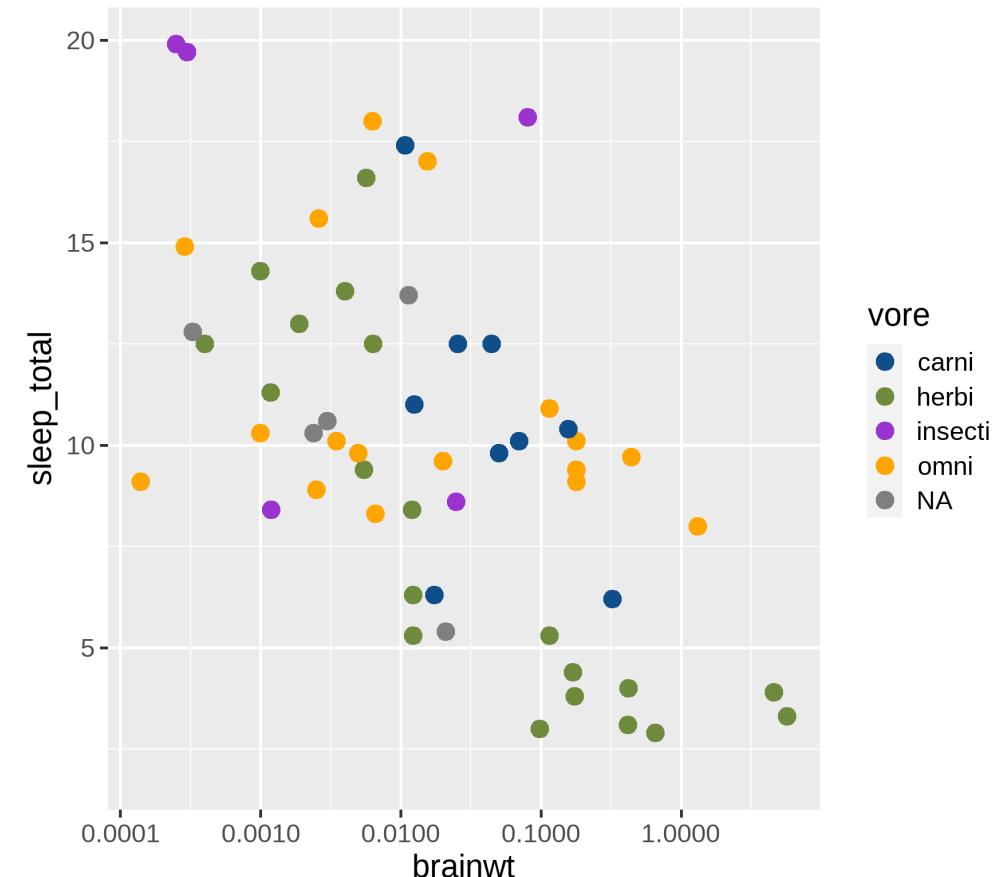
scale_color_manual()

We can also manually specify colors:

```
g <- g +  
  scale_color_manual(  
    values = c("dodgerblue4",  
              "darkolivegreen4",  
              "darkorchid3",  
              "orange",  
              "grey"))
```

g

- Length of color vector has to match number of levels in your aesthetic
- Specify colors
 - Via their name (see [here](#) for all color names)
 - Via their Hex color codes (use websites to generate your own color palettes, e.g. [here](#))



Other color scales

There are many packages with preset color palettes, e.g.:

ggsci: scientific journal and sci-fi themed palettes

```
install.packages("ggsci")
# Examples
ggsci::scale_color_npg() # nature publishing group
ggsci::scale_color_rickandmorty()
```

ggthemes: software and publisher themed palettes:

```
install.packages("ggthemes")
# Examples
ggthemes::scale_color_excel_new() # colors from new Excel version
ggthemes::scale_color_economist() # color palette from Economist graphs
```

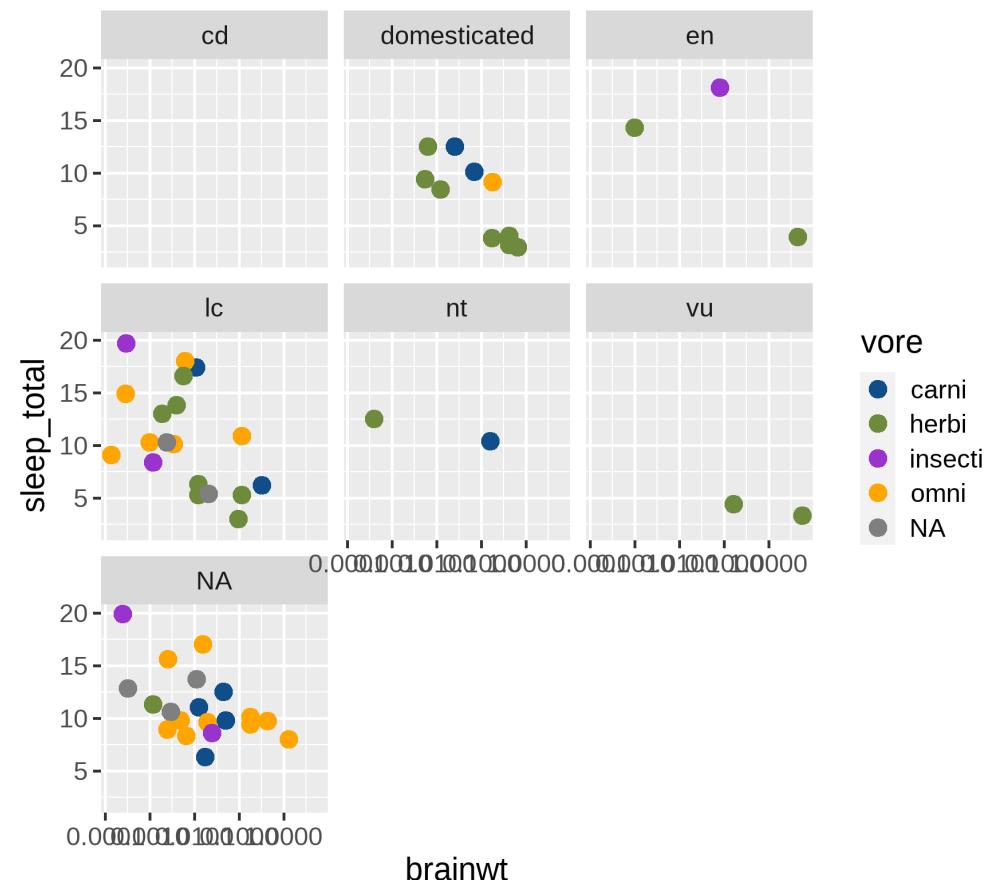
For a comprehensive list of color palettes available, check out [this repository](#) by Emil Hvitfeldt.

`facet_wrap()` and `facet_grid()`

Facets split a plot into small multiples along values of a variable from the data.

```
g +  
  facet_wrap(~conservation)
```

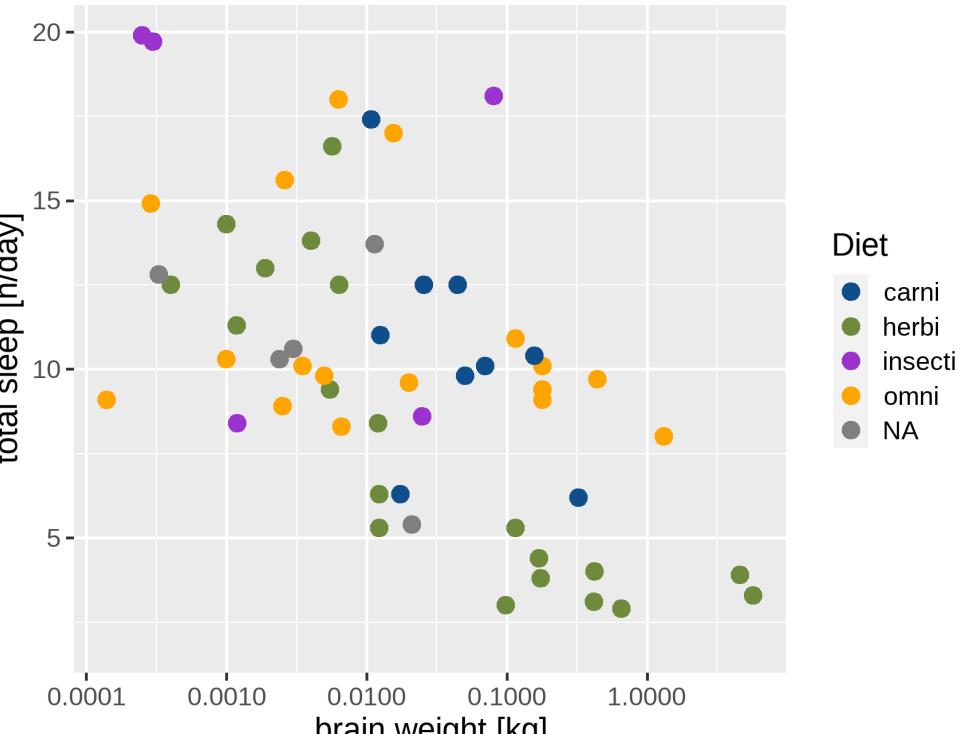
- You can even split plots along two variables using `facet_grid()` instead of `facet_wrap()`
- The basic functioning is `facet_grid(yvar ~ xvar)`
 - `yvar` will be displayed as columns
 - `xvar` will be displayed as rows



labs(): change axis and legend titles and add plot title

```
g <- g +  
  labs (  
    x = "brain weight [kg]",  
    y = "total sleep [h/day]",  
    color = "Diet",  
    title = "Brain weight and sleep time in  
mammals",  
    subtitle = "Larger brains seem to sleep  
less",  
    caption = "Data from the ggplot2 package")  
g
```

Brain weight and sleep time in mammals
Larger brains seem to sleep less

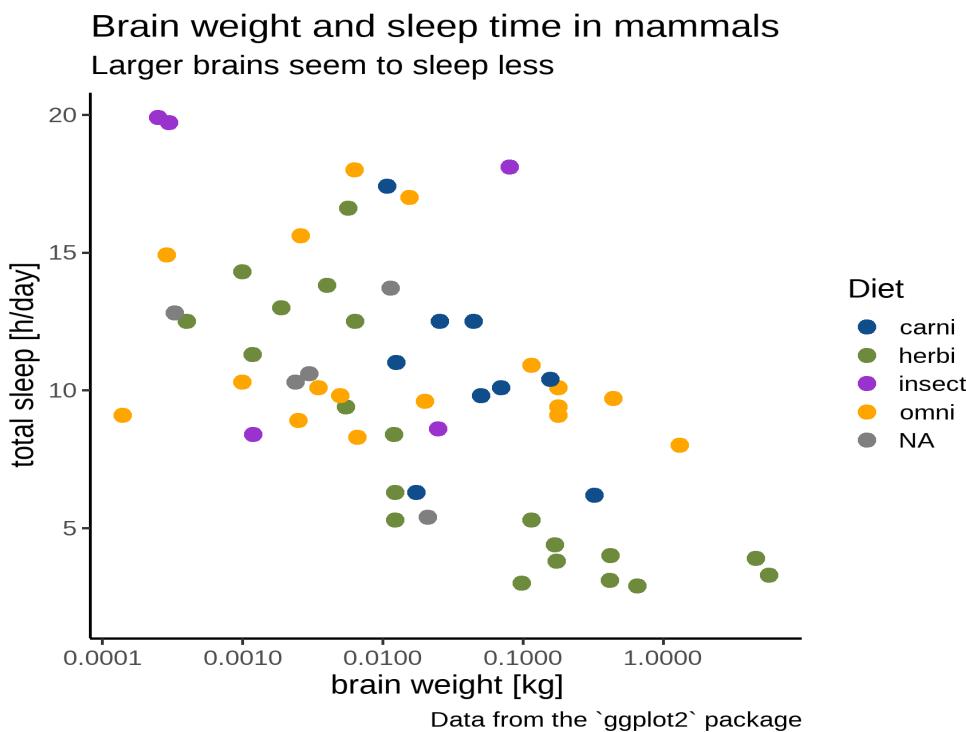


Data from the `ggplot2` package

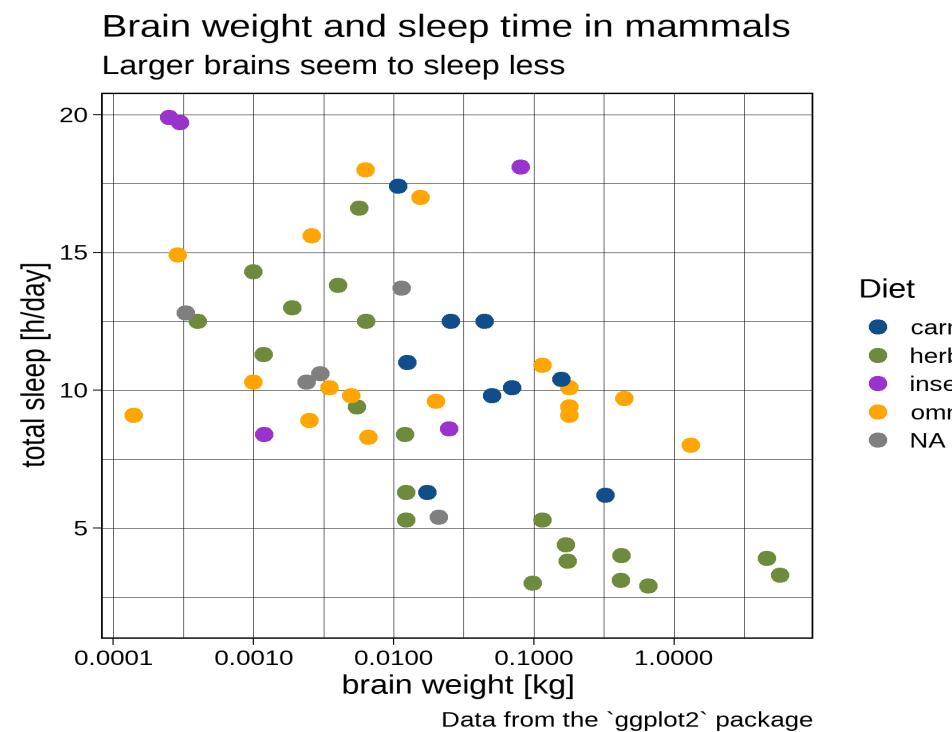
theme_*(): change appearance

ggplot2 offers many pre-defined themes that we can apply to change the appearance of a plot.

```
g +  
  theme_classic()
```



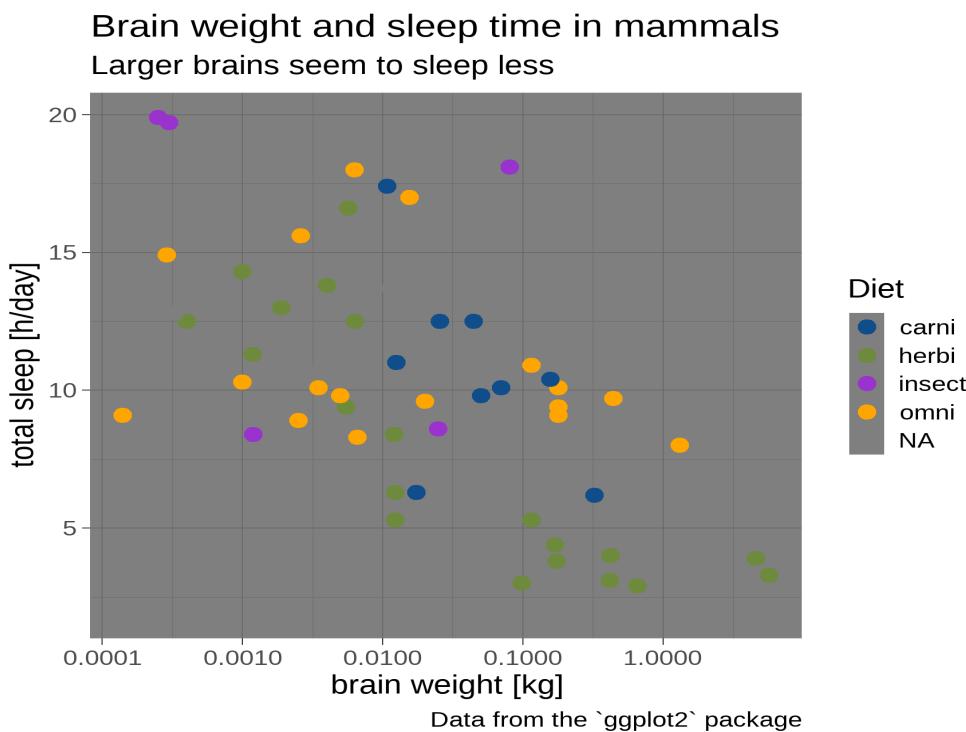
```
g +  
  theme_linedraw()
```



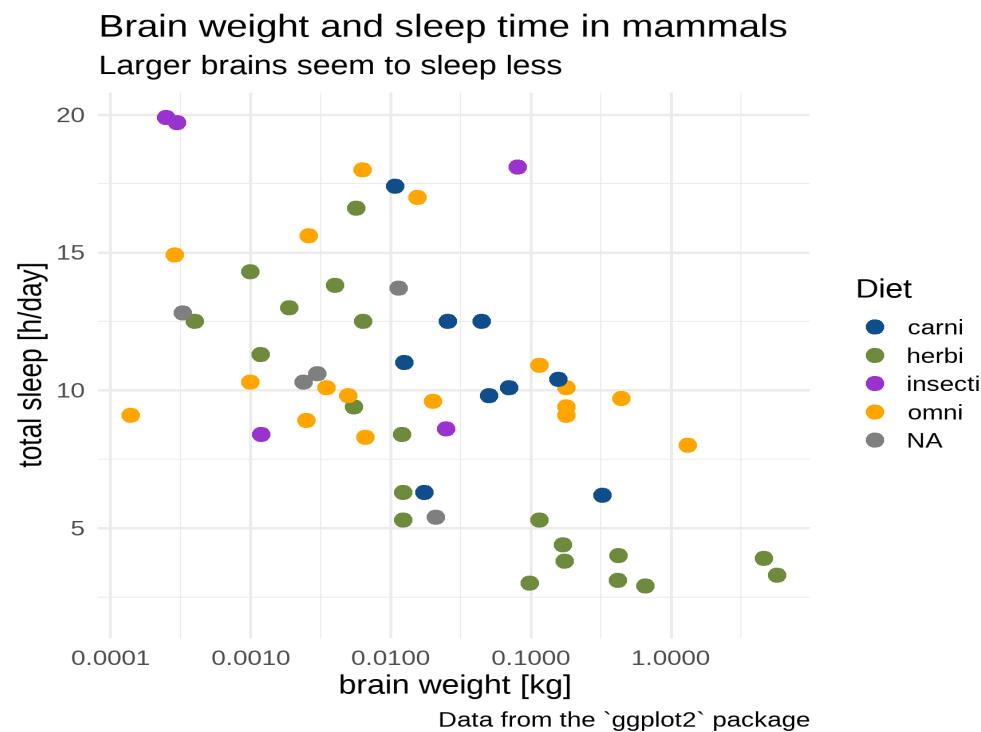
theme_*(): change appearance

ggplot2 offers several pre-defined themes that we can apply to change the appearance of our plot.

```
g +  
  theme_dark()
```



```
g +  
  theme_minimal()
```



theme(): customize theme

You can manually change a theme or even create an entire theme yourself. The elements you can control in the theme are:

- titles (plot, axis, legend, ...)
- labels
- background
- borders
- grid lines
- legends

If you want a full list of what you can customize, have a look at

```
?theme
```

theme(): customize theme

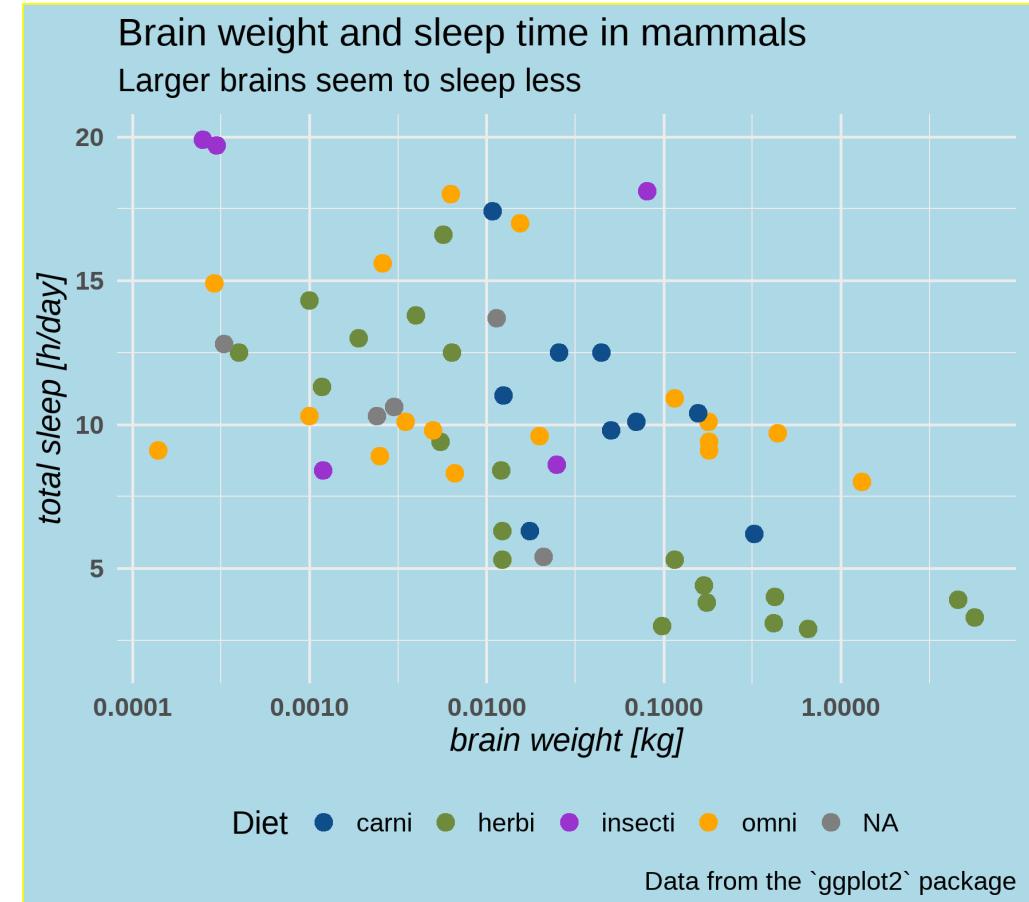
To edit a theme, just add another `theme()` layer to your plot.

```
g +
  theme_minimal() +
  theme(
    axis.text = element_text(face = "bold"),
    axis.title = element_text(face = "italic"),
    legend.position = "bottom",
    plot.background = element_rect(
      fill = "lightblue",
      color = "yellow")
  )
```

- The basic functioning is:

```
theme(
  element_name = element_function()
)
```

- Look [here](#) for an overview of the elements that you can change and the corresponding



theme_set(): set global theme

You can set a global theme that will be applied to all ggplot objects in the current R session.

```
# Globally set theme_minimal as the default theme  
theme_set(theme_minimal())
```

Add this to the beginning of your script.

You can also specify some defaults, e.g. the text size:

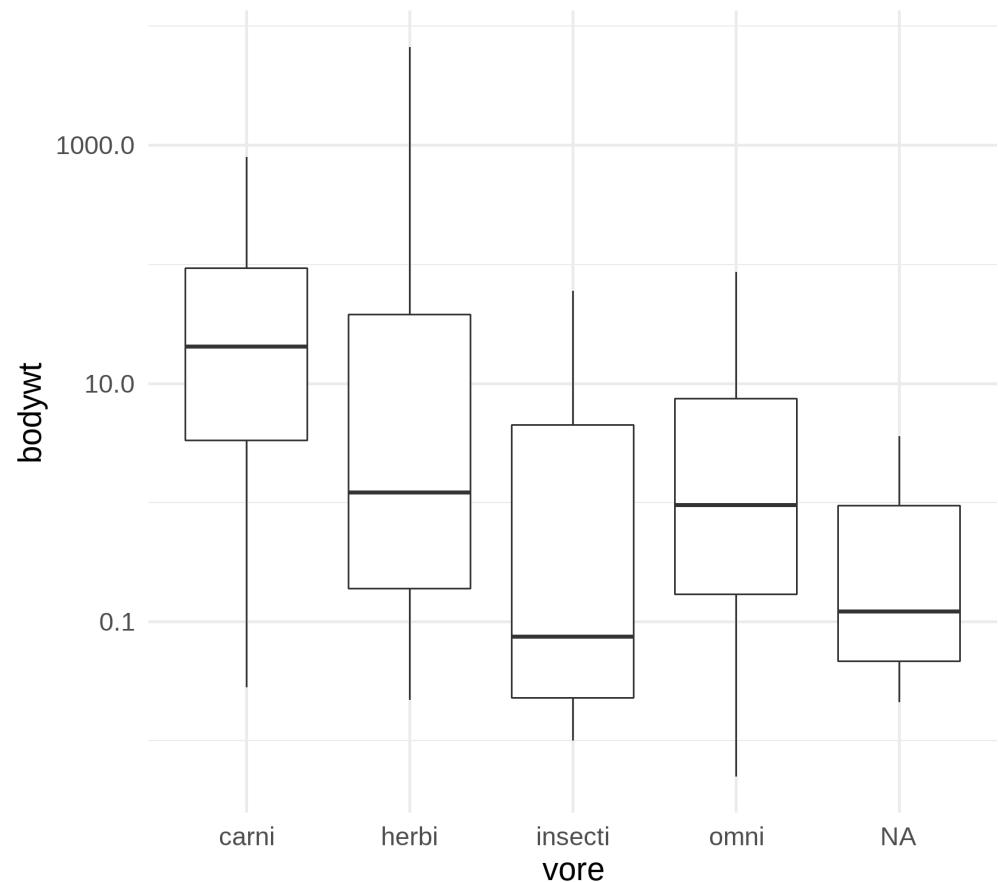
```
theme_set(theme_minimal(base_size = 16))
```

This is very practical if you want to achieve a consistent look, e.g. for a scientific journal.

geom_boxplot()

A boxplot can be created with `geom_boxplot`:

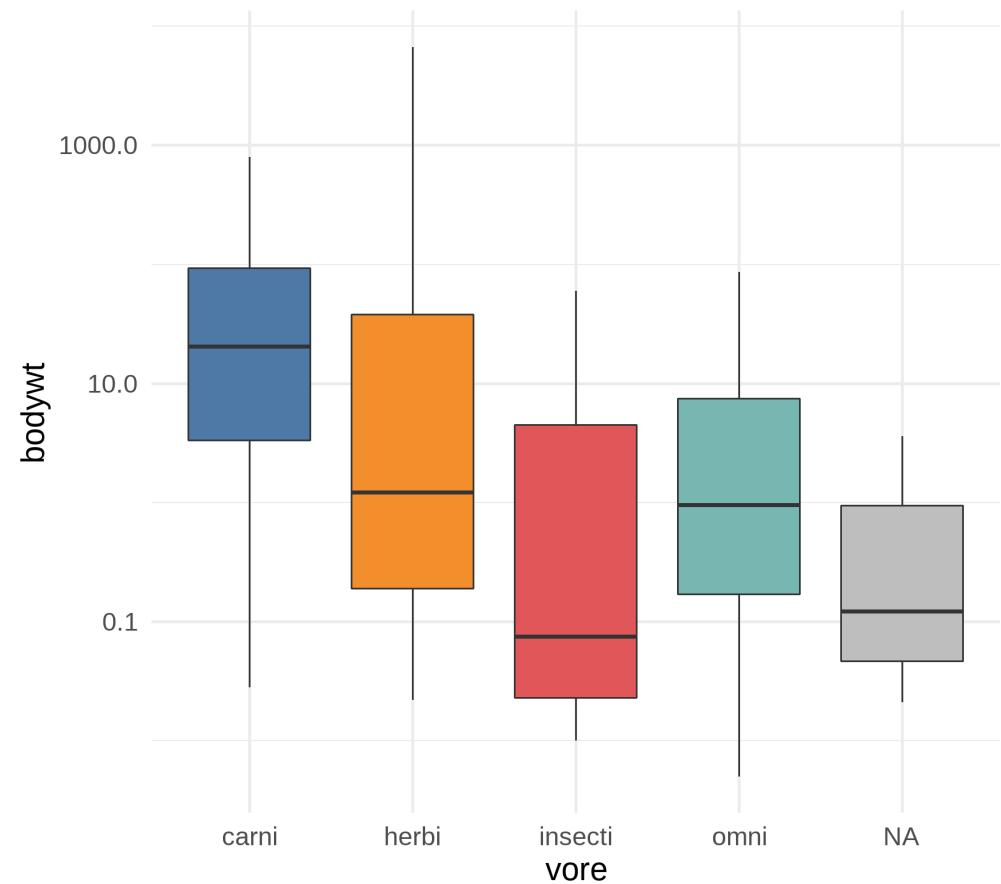
```
ggplot(msleep, aes(x = vore, y = bodywt)) +  
  geom_boxplot() +  
  scale_y_log10()
```



aes(fill) and scale_fill_*

Pay attention to fill vs. color aesthetic

```
ggplot(msleep, aes(x = vore, y = bodywt)) +  
  geom_boxplot(  
    aes(fill = vore)  
  ) +  
  scale_y_log10() +  
  ggthemes::scale_fill_tableau(  
    na.value = "gray",  
    guide = "none")
```

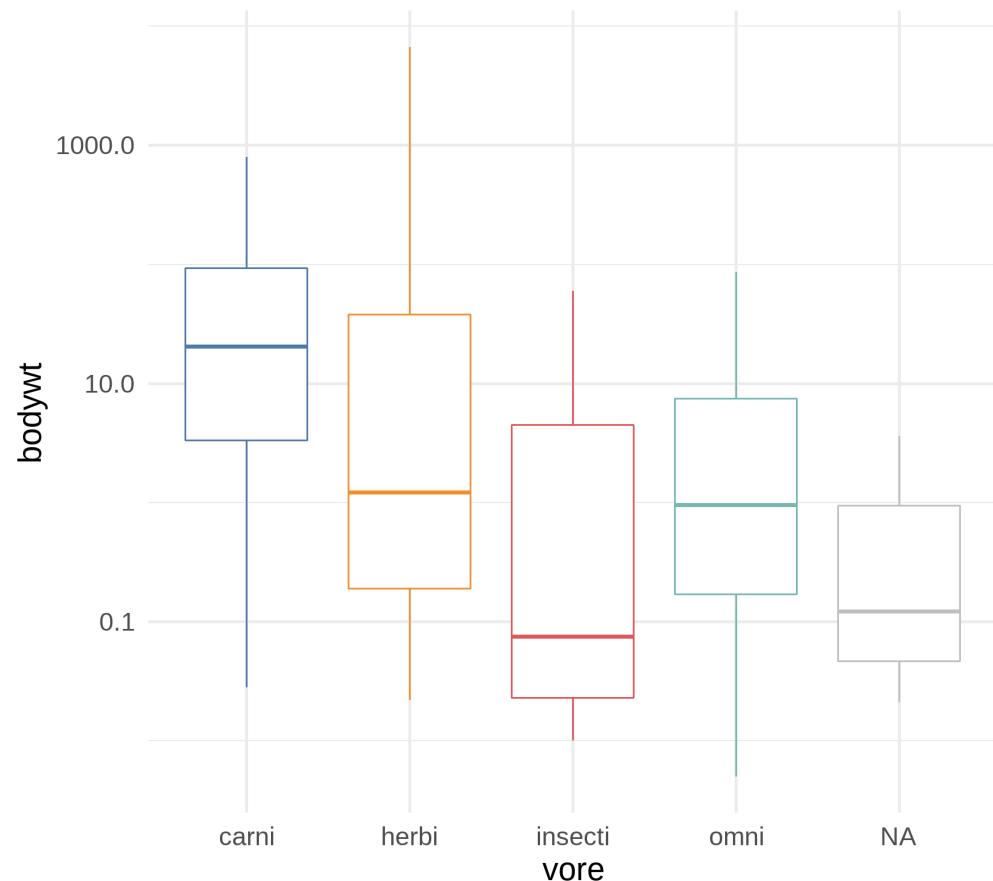


aes(color) and scale_color_*

Pay attention to fill vs. color aesthetic

```
ggplot(msleep, aes(x = vore, y = bodywt)) +  
  geom_boxplot(  
    aes(color = vore)  
  ) +  
  scale_y_log10() +  
  ggthemes::scale_color_tableau(  
    na.value = "gray",  
    guide = "none")
```

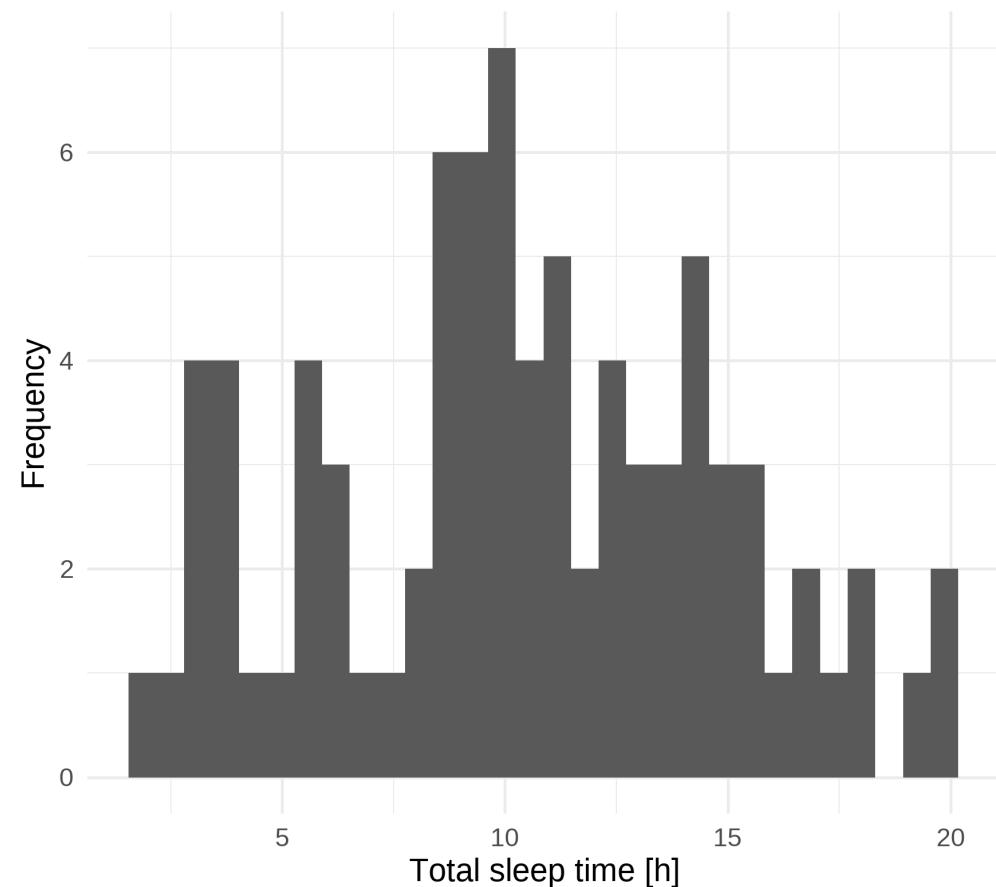
- `color` means the border color or the color of points and lines
- `fill` means the fill color of boxes, bars, ...



Histograms: `geom_histogram()`

Basic histogram of total sleep time:

```
ggplot(msleep, aes(x=sleep_total)) +  
  geom_histogram() +  
  labs(x = "Total sleep time [h]",  
       y = "Frequency")
```



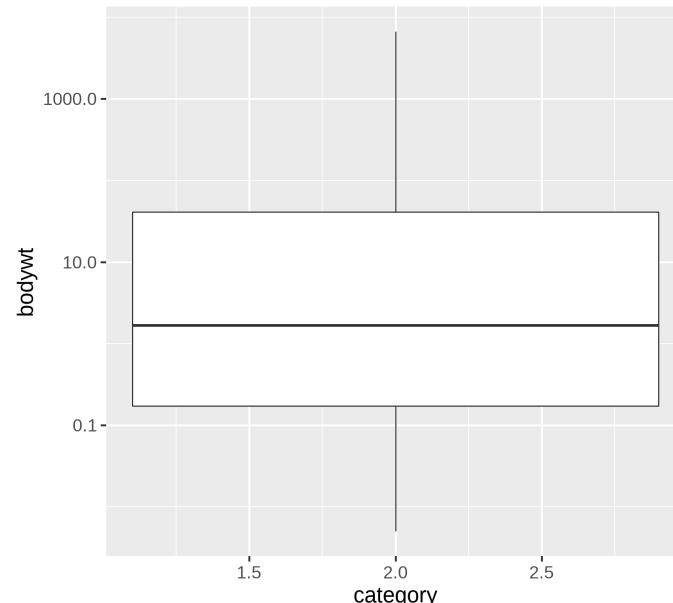
Discrete vs. continuous variables

Let's add a sleep category to the data set depending on the hours of sleep an animal gets in total:

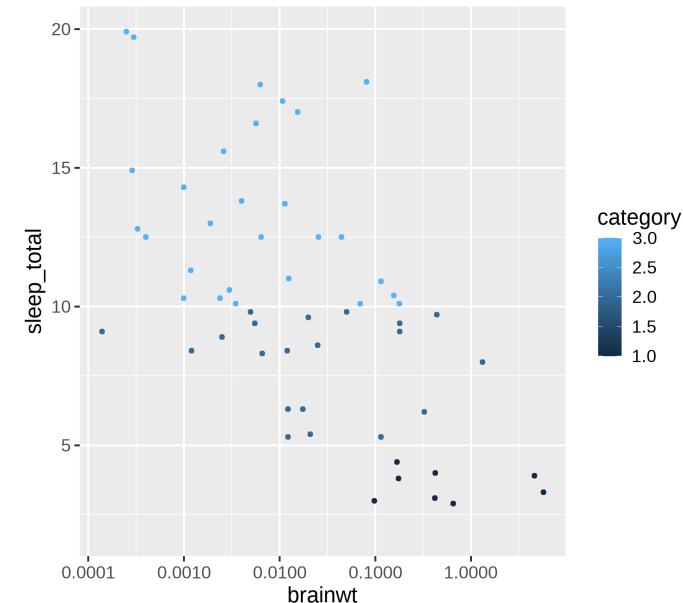
Discrete vs. continuous variables

What's happening here?

```
ggplot(msleep,  
       aes(x = category,  
            y = bodywt)) +  
  geom_boxplot() +  
  scale_y_log10()
```



```
ggplot(msleep,  
       aes(x = brainwt,  
            y = sleep_total,  
            color = category)) +  
  geom_point() +  scale_x_log10()
```



Discrete vs. continuous variables

CONTINUOUS

measured data, can have ∞ values within possible range.



I AM 3.1" TALL

I WEIGH 34.16 grams

DISCRETE

OBSERVATIONS can only exist at limited values, often COUNTS.



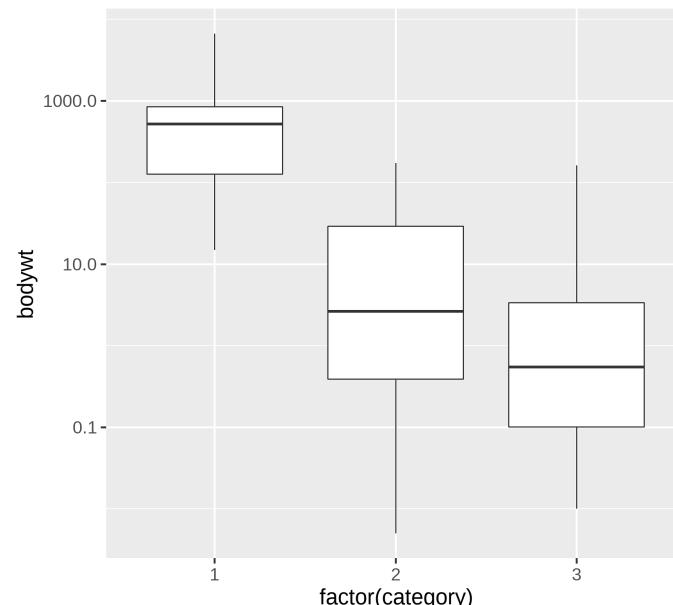
I HAVE 8 LEGS
and
4 SPOTS!

@allison_horst

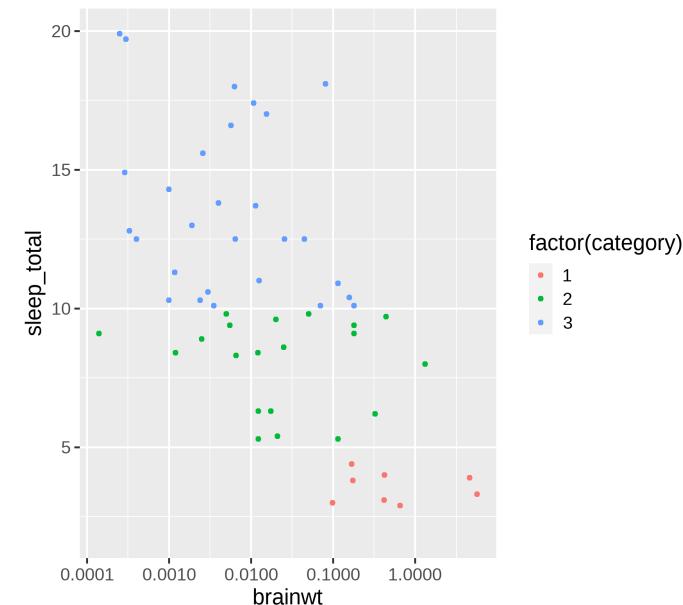
Discrete vs. continuous variables

Solution: Turn continuous variable into a factor before plotting

```
ggplot(msleep,  
       aes(x = factor(category),  
            y = bodywt)) +  
  geom_boxplot() +  
  scale_y_log10()
```



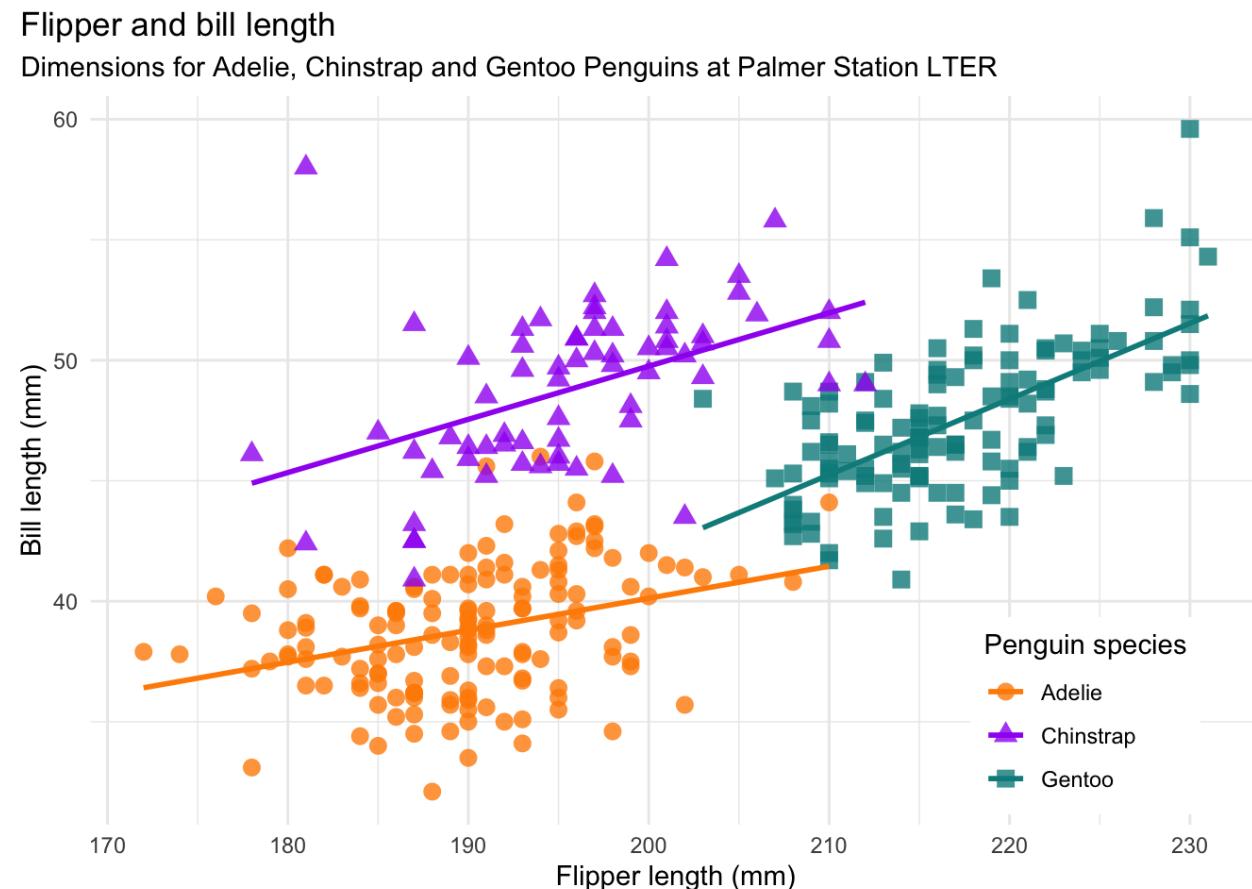
```
ggplot(msleep,  
       aes(x = brainwt,  
            y = sleep_total,  
            color = factor(category))) +  
  geom_point() + scale_x_log10()
```



Let's look at an example

What are the layers in this plot?

- data
- aesthetic mapping
- geoms
- themes



ggsave()

A ggplot object can be saved on disk in different formats.

Without specifications:

```
# save plot g in img as my_plot.pdf  
ggsave(filename = "./img/my_plot.pdf", plot = g)  
# save plot g in img as my_plot.png  
ggsave(filename = "./img/my_plot.png", plot = g)
```

Or with specifications:

```
# save a plot named g in the img directory under the name my_plot.png with width 16 cm and height  
9 cm  
ggsave(filename = "./img/my_plot.png",  
       plot = g,  
       width = 16,  
       height = 9,  
       units = "cm")
```

Have a look at `?ggsave` to see all options.

Summary I

Tidyverse and ggplot

- The tidyverse is a collections of R packages for data analysis, including `ggplot2`, `readr`, `tidyverse`, `dplyr`, `tibble`
- All tidyverse packages are designed to work together seamlessly
- basic idea of `ggplot` is to stack distinct layers of graphical elements to create a plot
- Check out the [ggplot cheatsheet](#) for an overview of how to create a ggplot

Now you

Task 1: Create your own penguin ggplots (90 min)

Find the task description [here](#)