UCLA QCBio Collaboratory

# Advanced data visualization with ggplot2

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2024 Fall

# Notation of the slides

- `Code` or `Pseudo-Code` chunk starts with " ➢ ", e.g.
  - `print("Hello world!")`

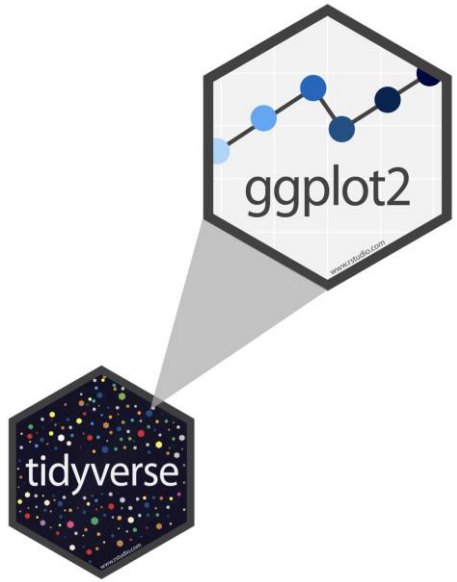
- Link is underlined

- Important terminology is in **bold** font

- Practice comes with

# Agenda

- Day 1: Data visualization basics
  - Getting started with ggplot2
  - Recap of data wrangling functions
- Day 2: Building a plot layer by layer
  - Exploring different plot types
  - Getting more control on the plots
- Day 3: Examples and useful packages
  - Practical examples and principles
  - Introducing some useful packages

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# Day 2: Building a plot layer by layer

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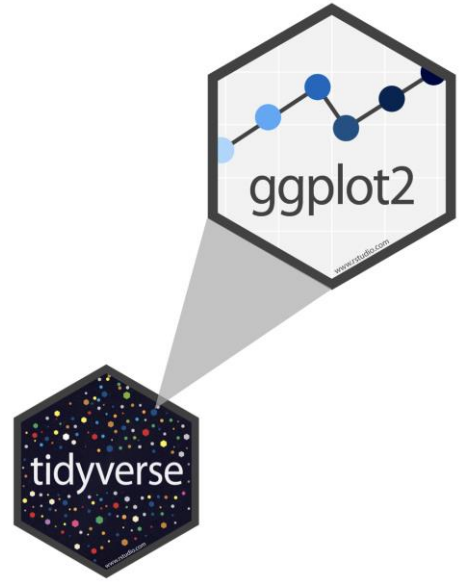
# Overview

## Time

- 3-hour workshop (45min + 45min + 30min + practice/Q&A)

## Topics

- ❑ Layers
  - ❑ Geometry
  - ❑ Statistical transformation
  - ❑ Position adjustment
- ❑ Scale
- ❑ Facet
- ❑ Coordinate system



# Summary – Day1

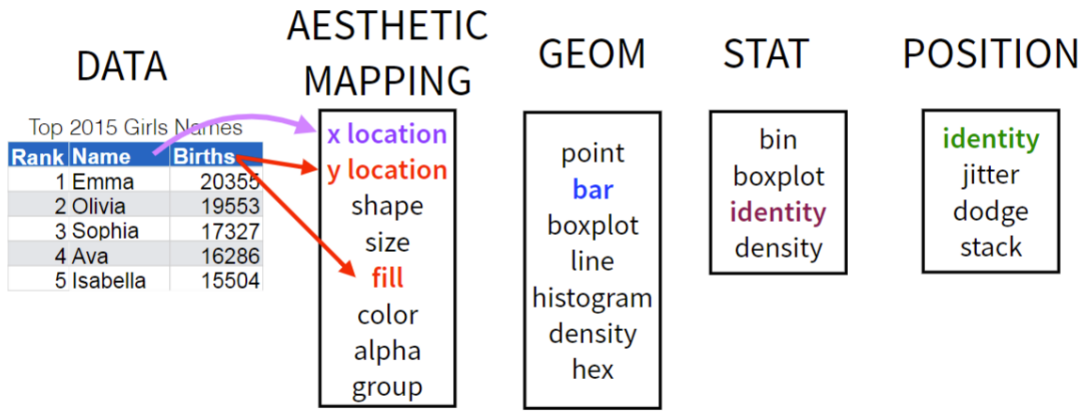
Key components of a ggplot2 object:

- ❑ **Data**
- ❑ A set of **aesthetic mappings** between variables and visual properties
- ❑ At least one **layer** describing how to render the observations

```
ggplot (data = <DATA>) +                                   ] required
<GEOM_FUNCTION>(mapping = aes(<MAPPINGS>),
 stat =<STAT>, position =<POSITION>) +                     ] Not required, sensible defaults supplied
<COORDINATE_FUNCTION> +
<FACET_FUNCTION> +
<SCALE_FUNCTION> +
<THEME_FUNCTION>
```

Syntax of ggplot2

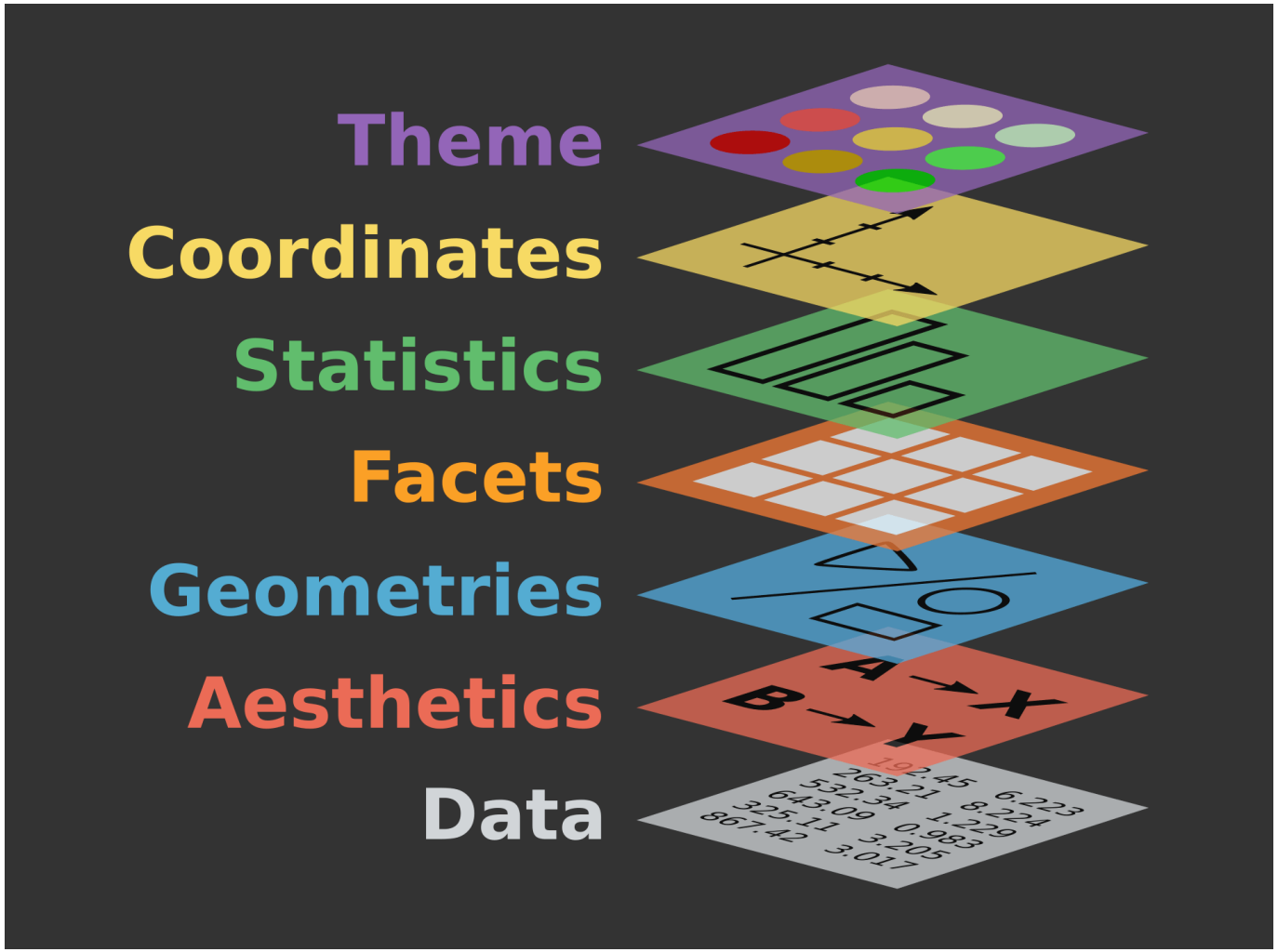
## Layers






https://edav.info/learning-ggplot2.html

# Summary – Day1




**Describes all the non-data ink**

**Plotting space for the data**

**Statistical models and summaries**

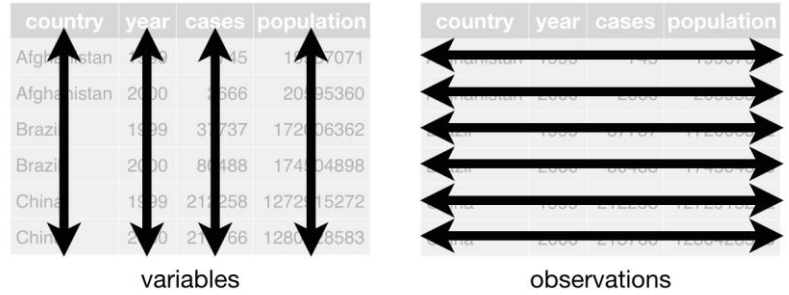
**Rows and columns of sub-plots**

**Shapes used to represent the data**

**Scales onto which data is mapped**

**The actual variables to be plotted**

# Summary – Day1



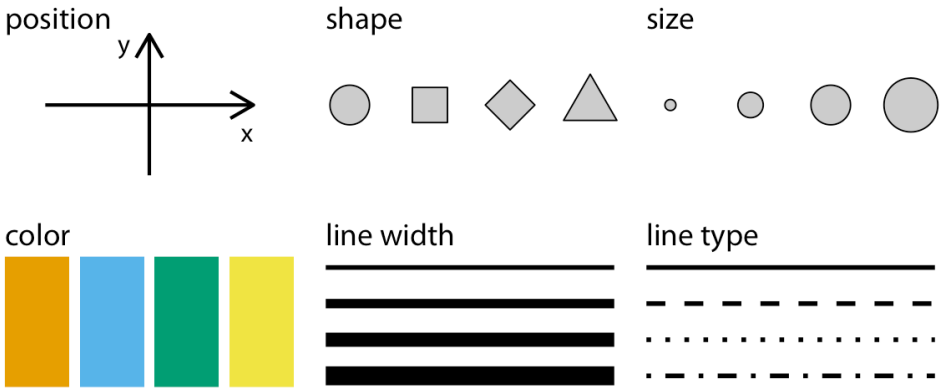

- Variable types, factors and data frame
- Data wrangling functions

| Category | Function | Usage |
|---|---|---|
| Manipulate observations | `filter()` | keep rows that meet criterions |
| | `arrange()` | orders observations according to variables |
| | `bind_rows()` | bind any number of data frames by row |
| Manipulate variables | `select()` | keep variables using their names or types |
| | `mutate()` | create new variables |
| | `*_join()` | merge data frames by columns |
| Reshape data | `pivot_longer()` | convert data frame from wide to long format |
| | `pivot_wider()` | convert data frame from long to wide format |
| Summarize data | `group_by()` | group data frame by variable |
| | `summarize()` | summarize the grouped data frame |
| pipe | `%>%` | chain operations together |

# Summary – Day1

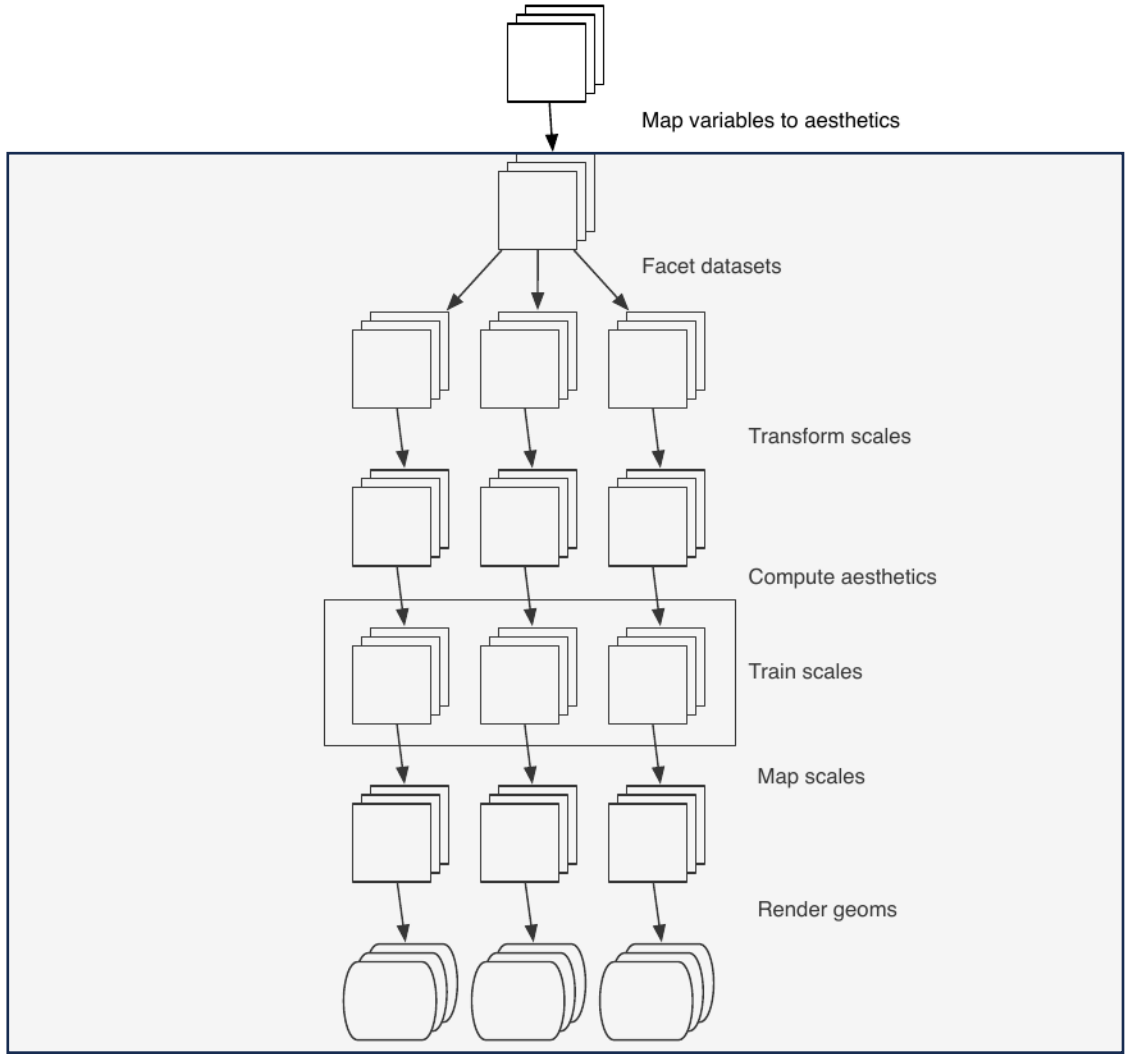
- Aesthetic mappings `aes()`
  - takes aesthetic-variable pairs (variable's type matters!)
  - describes how variables are mapped to visual properties of the geometric objects

➢ `aes(x = log(displ), y = hwy, colour = class)`




| Aesthetic | Description |
|---|---|
| x | x-axis position |
| y | y-axis position |
| colour | Color of points or outlines of other shapes |
| fill | Fill color |
| size | size of the point or thickness of line |
| alpha | Transparency of the shape |
| linetype | Line type such a solid, dashed, dotted |
| labels | Text on the plot |
| shape | Shape of the geometry |

# Plot generation process



# Geometry

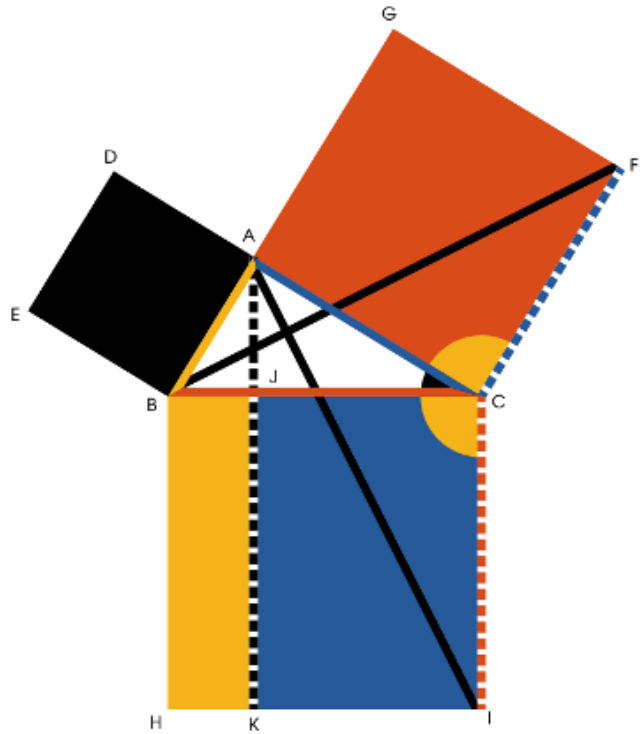


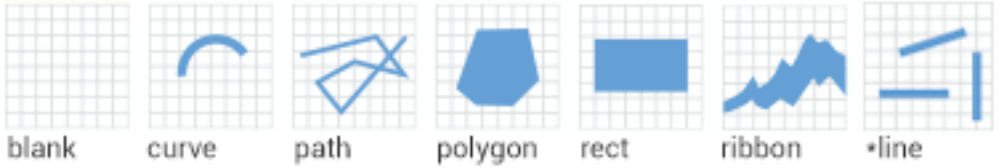



Image from book *The Elements of Euclid*

# Geometric objects

Geometric objects **geom**s perform the rendering of the layer, and control plot type

| Function | Usgae |
|---|---|
| `geom_blank()` | display nothing. |
| `geom_curve()` | draw a curved line |
| `geom_segment()` | draw a line segment, specified by start and end position |
| `geom_abline()` | draw a straight line, specified by slope and intercept |
| `geom_path()` | connect observations in order of the data |
| `geom_line()` | connect observation in order of the variables on x axis |
| `geom_rect()` | draw rectangles |
| `geom_polygon()` | draw filled polygons |
| `geom_ribbon()` | draw ribbons, a path with vertical thickness |



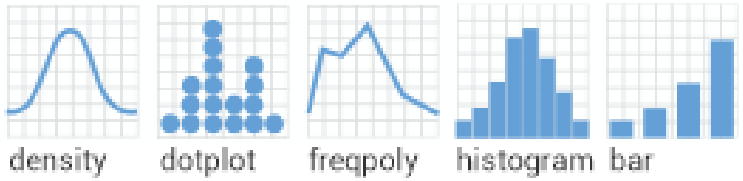
# Let’s do some practice!

- `git clone https://github.com/wbvguo/qcbio-DataViz_w_ggplot2.git`

# One variable

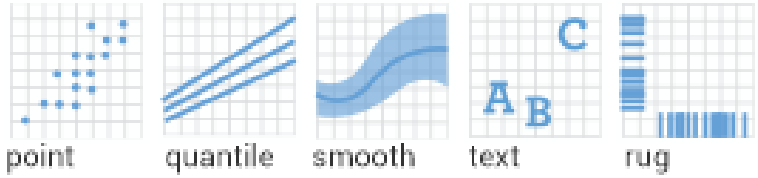
- Discrete:
  - `geom_bar()`: display count distribution of discrete variable

- Continuous:
  - `geom_histogram()`: bin and count continuous variable, display with bars
  - `geom_freqpoly()`: bin and count continuous variable, display with lines
  - `geom_density()`: smoothed density estimate
  - `geom_dotplot()`: stack individual points into a dot plot

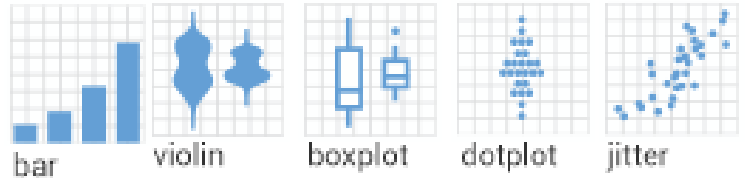


# Two variables

- Both continuous:
  - `geom_point()`: scatterplot
  - `geom_smooth()`: smoothed line of best fit
  - `geom_quantile()`: smoothed quantile regression
  - `geom_rug()`: marginal rug plots




- One continuous, one discrete:
  - `geom_bar(stat = "identity")`: a bar chart of precomputed summaries
  - `geom_boxplot()`: boxplots
  - `geom_violin()`: show density of values in each group
  - `geom_jitter()`: randomly jitter overlapping points

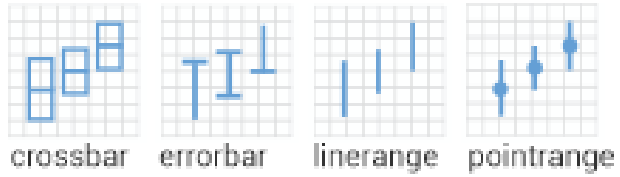



- Both discrete?

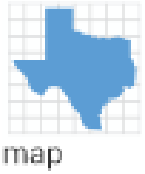
# Two variables

- Show 2D distribution:
  - `geom_bin2d()`: bin into rectangles and count
  - `geom_hex()`: bin into hexagons and count
  - `geom_density2d()`: smoothed 2d density estimate


- Display uncertainty:
  - `geom_crossbar()`: vertical bar with center
  - `geom_errorbar()`: error bars
  - `geom_linerange()`: vertical line
  - `geom_pointrange()`:vertical line with center

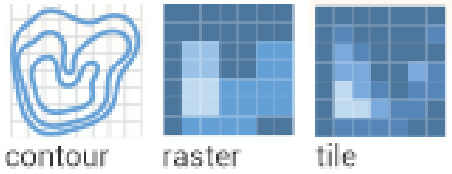


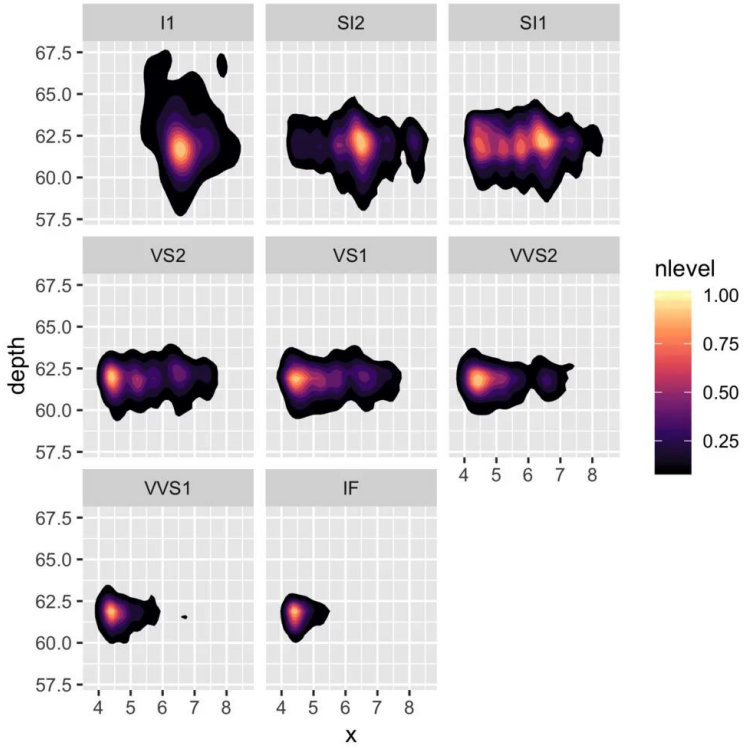

- Spatial:
  - `geom_map()`: fast version of `geom_polygon()` for map data

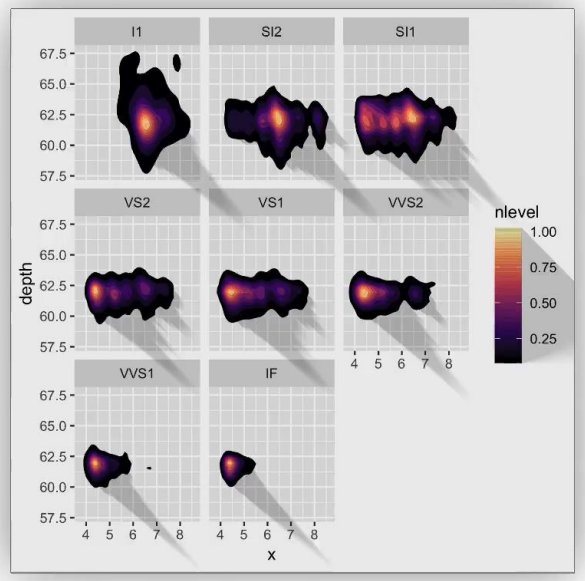


# Three variables

- `geom_contour()`: contours
- `geom_tile()`: tile the plane with rectangles
- `geom_raster()`: fast version of `geom_tile()` for equal sized tiles




# Choose geometry based on visualization goal

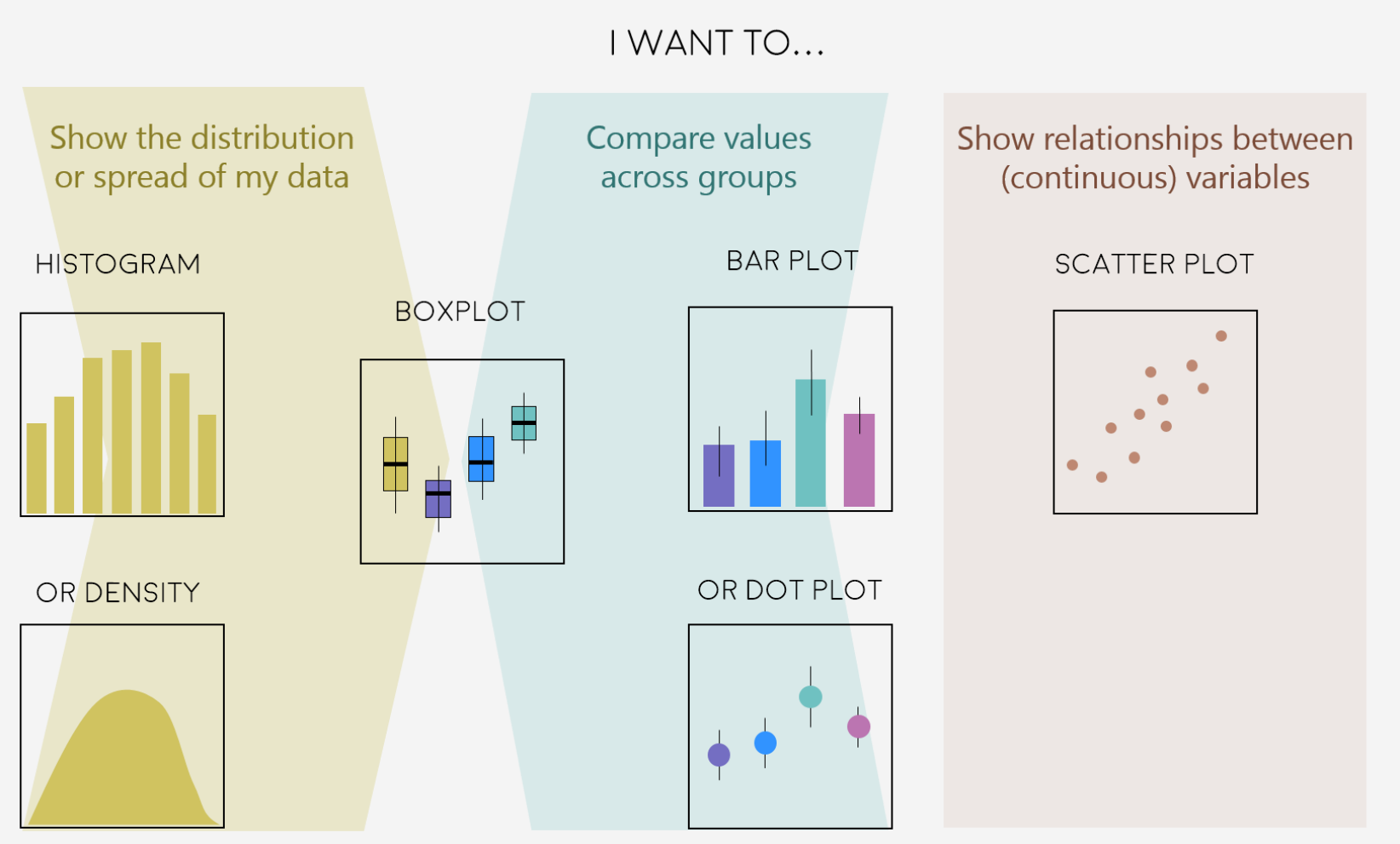
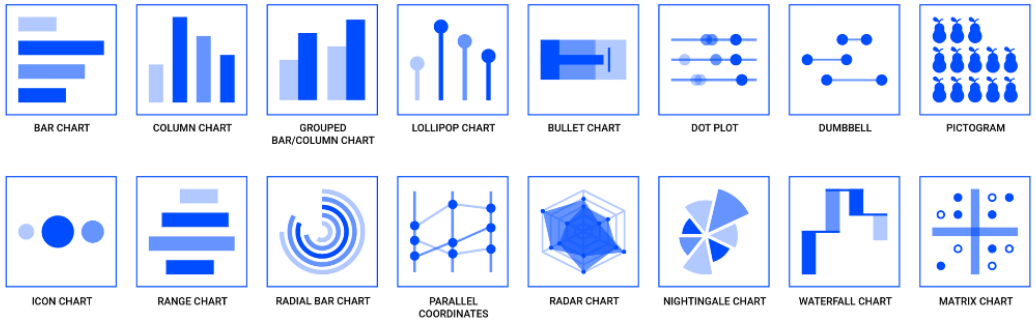




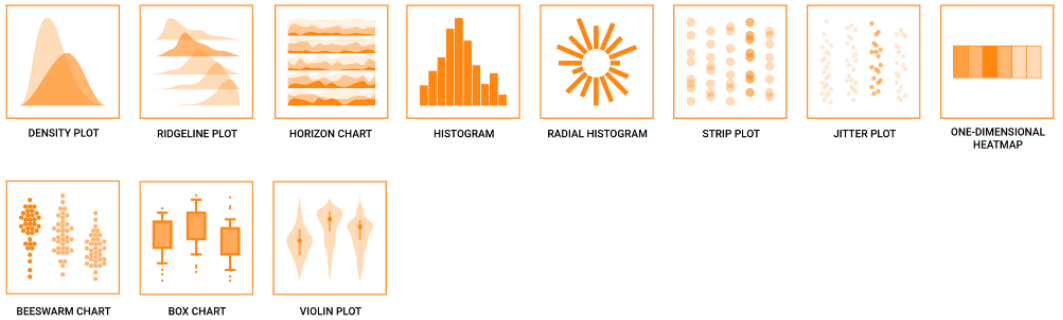

Image from Internet

# Choose geometry based on visualization goal

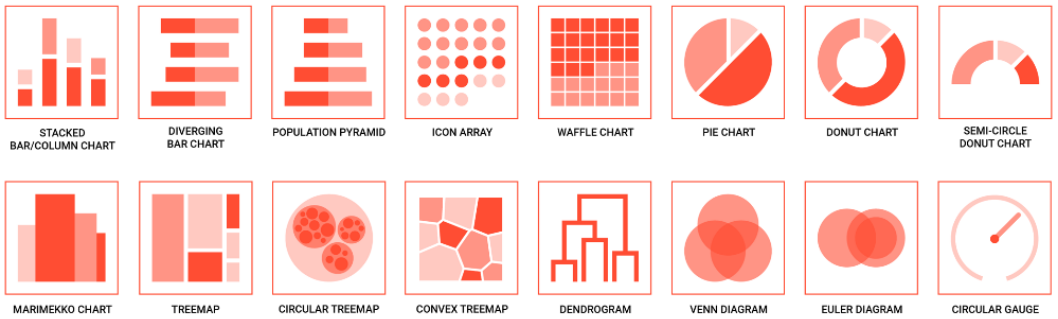
## COMPARISON



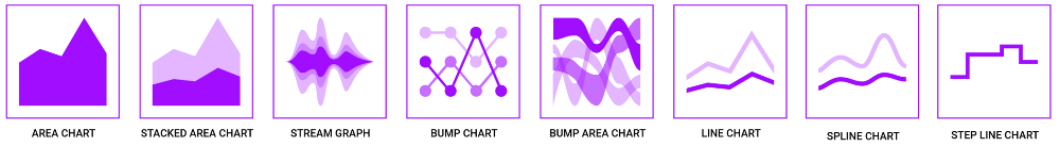

## DISTRIBUTION




## PART-TO-WHOLE & HIERARCHICAL



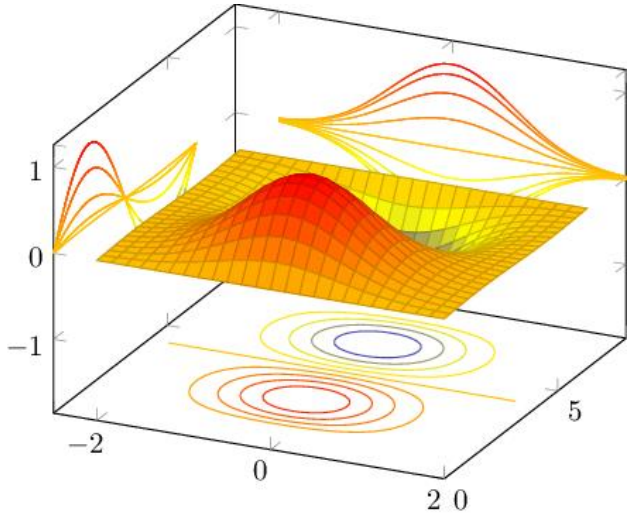

## DATA OVER TIME (TEMPORAL)




## CORRELATION




https://r-graph-gallery.com/




# Statistical transformation



Image from book Internet

# Statistical transformation

A statistical transformation (**stat)**, transforms the data, typically by summarizing the input data in some manner

| Function | Alternative form |
|---|---|
| `stat_bin()` | `geom_bar(stat="bin")` |
| `stat_bin2d()` | `geom_bin2d(stat="bin2d")` |
| `stat_binhex()` | `geom_hex(stat="binhex")` |
| `stat_contour()` | `geom_contour(stat="contour")` |
| `stat_smooth()` | `geom_smooth(stat="smooth")` |
| `stat_count()` | `geom_bar(stat="count")` |
| `stat_identity()` | `geom_point(stat="identity")` |

# Position adjustments



Image created from film *The Matrix*

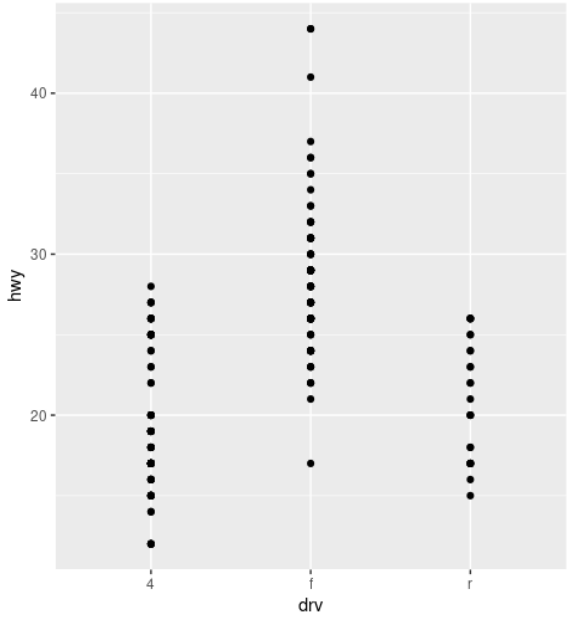
# Position adjustments

Position adjustments apply minor tweaks to the elements' position

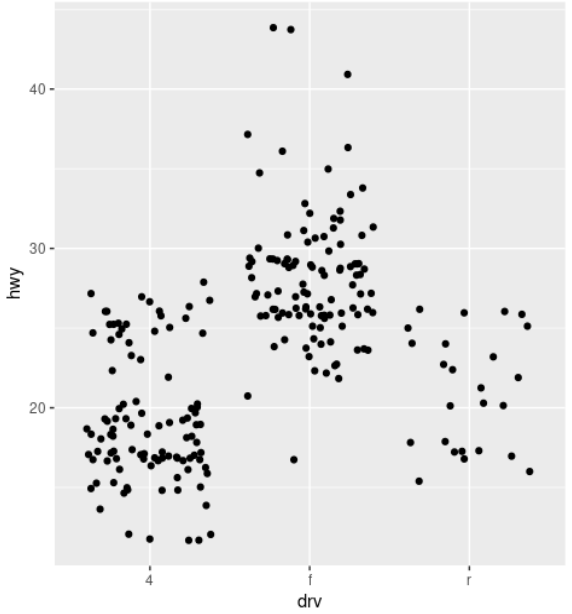
For points:

- `position_nudge()`: move points by a fixed offset
- `position_jitter()`: add a little random noise to every position
- `position_jitterdodge()`: dodge points within groups, then add a little random noise

geom_point()




geom_point(position = "jitter")



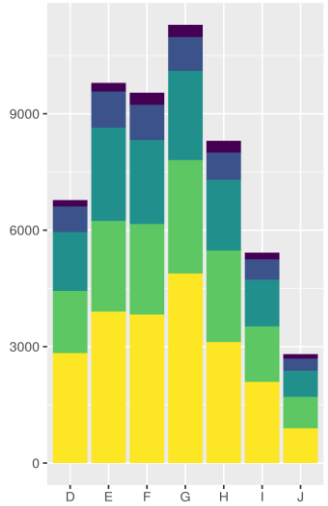
# Position adjustments

Position adjustments apply minor tweaks to the elements' position

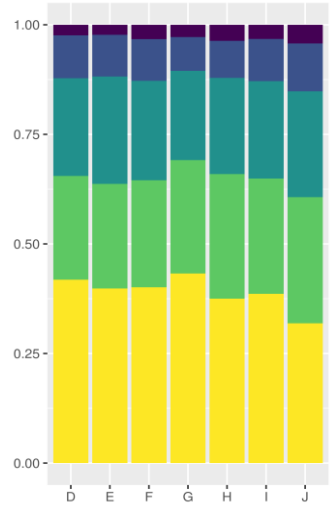
For bars:

- `position_stack()`:stack overlapping bars (or areas) on top of each other
- `position_fill()`: stack overlapping bars, scaling so the top is always at 1
- `position_dodge()`:place overlapping bars (or boxplots) side-by-side
- `position_identity()`:does nothing

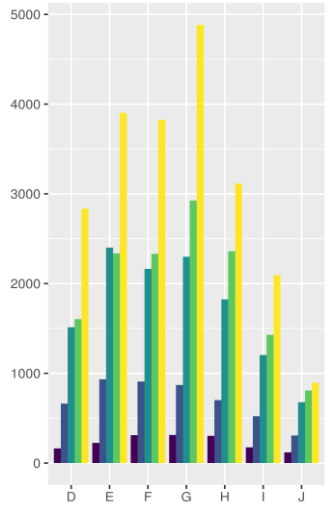
geom_bar()



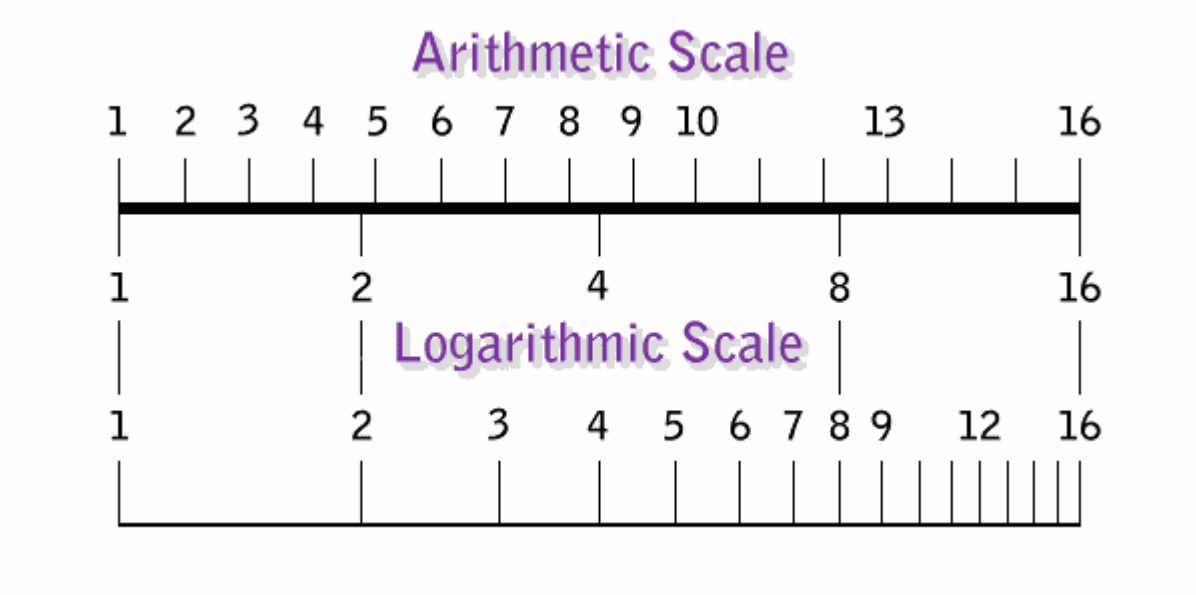

geom_bar(position = "fill")




geom_bar(position = "dodge")



# Scales



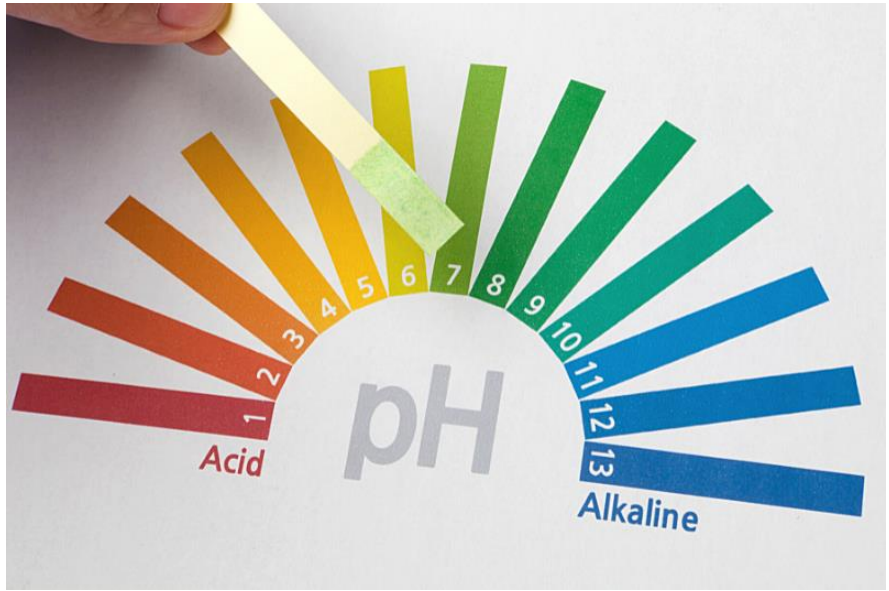






Image from Internet

# Scale settings

Syntax: `scale_<aesthetic>_<type>`

Aesthetics:

- `position`,
- `color`
- `fill`
- `size`
- `shape`
- `alpha`
- `linetype`

Type:

- `continuous`
- `discrete`

# Position scales

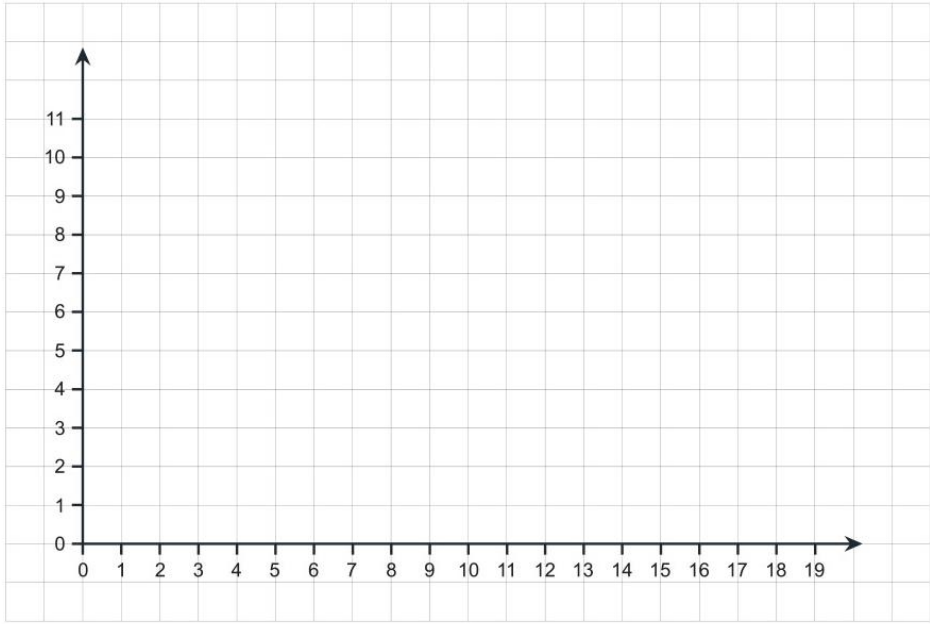
syntax: `scale_<axis>_<type>`

axis: `x`, `y`

type: `discrete`, `continuous`

arguments:

- `name`
- `limits`
- `expansion`
- `breaks`
- `labels`



# Position scales

Name:

- `scale_x_continuous(names = "x")`

Limits:

- `scale_x_continuous(limits=c(1,7))`

Breaks:

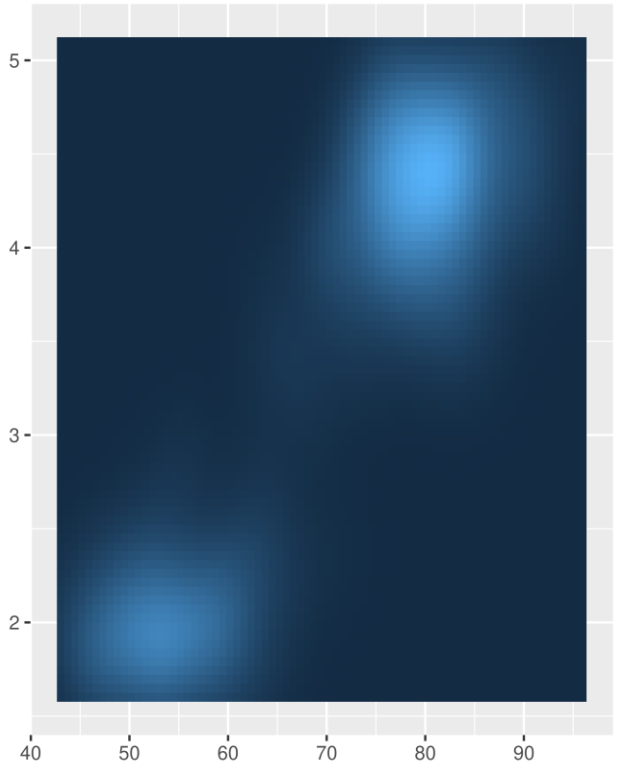
- `scale_x_continuous(breaks = NULL)`
- `scale_x_continuous(breaks = c(50, 75, 100))`

Labels:

- `scale_x_continuous(labels = c(1/2, 3/4, 1))`

Expansion:

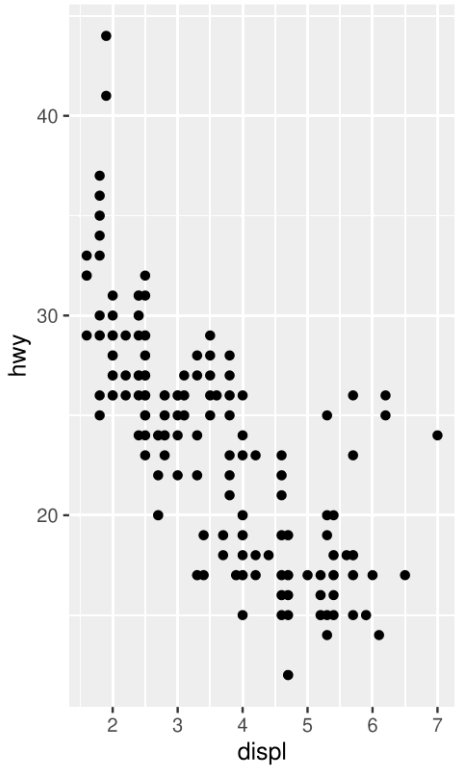
- `scale_x_continuous(expand = expansion(0))`
- `scale_x_continuous(expand = expansion(mult = c(.05, .2)))`
- `scale_x_continuous(expand = c(.05, 0, .2, 0))`

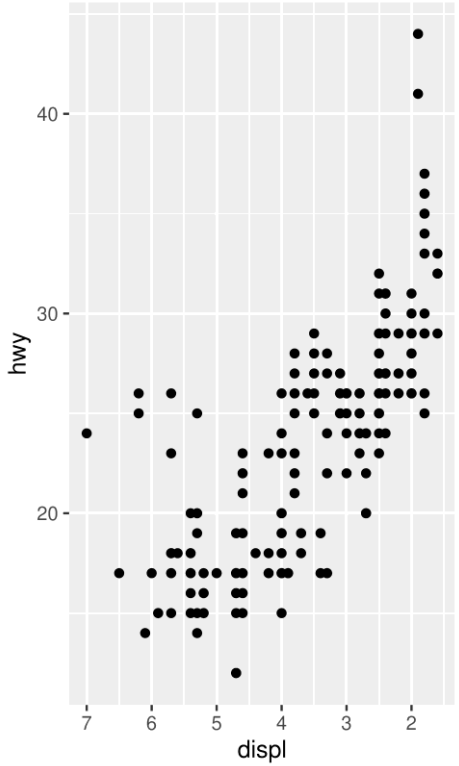


# Position scales

## Transformation:

- `scale_x_reverse()`
- `scale_x_log10()`
- `scale_x_continuous(trans = "log10")`




| Name | Transformer | Function $f(x)$ | Inverse $f^{-1}(x)$ |
|---|---|---|---|
| `"asn"` | `scales::asn_trans()` | $\tanh^{-1}(x)$ | $\tanh(y)$ |
| `"exp"` | `scales::exp_trans()` | $e^x$ | $\log(y)$ |
| `"identity"` | `scales::identity_trans()` | $x$ | $y$ |
| `"log"` | `scales::log_trans()` | $\log(x)$ | $e^y$ |
| `"log10"` | `scales::log10_trans()` | $\log_{10}(x)$ | $10^y$ |
| `"log2"` | `scales::log2_trans()` | $\log_2(x)$ | $2^y$ |
| `"logit"` | `scales::logit_trans()` | $\log(\frac{x}{1-x})$ | $\frac{1}{1+e(y)}$ |
| `"probit"` | `scales::probit_trans()` | $\Phi(x)$ | $\Phi^{-1}(y)$ |
| `"reciprocal"` | `scales::reciprocal_trans()` | $x^{-1}$ | $y^{-1}$ |
| `"reverse"` | `scales::reverse_trans()` | $-x$ | $-y$ |
| `"sqrt"` | `scales::scale_x_sqrt()` | $x^{1/2}$ | $y^2$ |

More transformations

# Color scales

syntax: `scale_<aes>_<type>`

aes: `fill`, `color`

type:

- `discrete`,
- `continuous`,
- `gradient`,
- `manual`
- ...

use `fill` as an example

# Color scales (continuous)

## Set color palettes

- `scale_fill_gradient()`: produces a 2 colour gradient
  - `scale_fill_gradient(low = "grey", high = "brown")`
- `scale_fill_gradient2()`: produces a 3 colour gradient with specified midpoint
  - `scale_fill_gradient2(low = "grey", mid = "white", high = "brown", midpoint = .02 )`
- `scale_fill_gradientn()`: produces an n-colour gradient

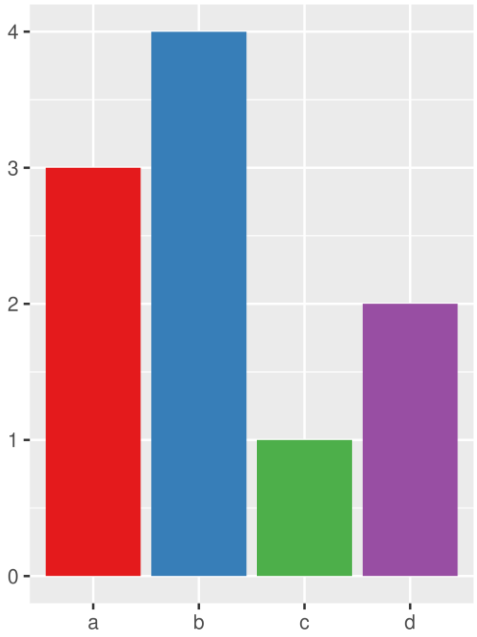
## Set color for missing values

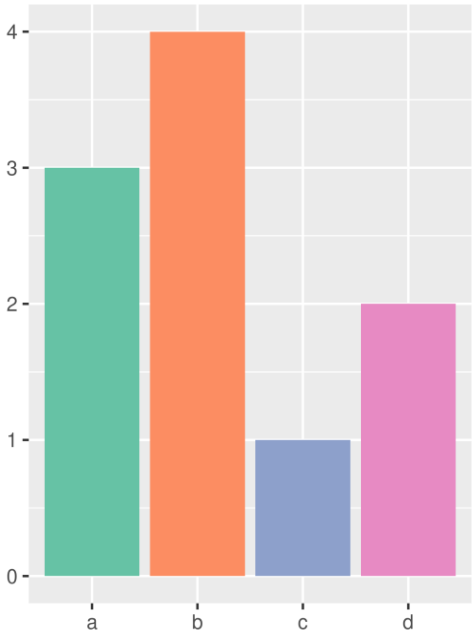
- `scale_fill_gradient(na.value = NA)`
- `scale_fill_gradient(na.value = "red")`

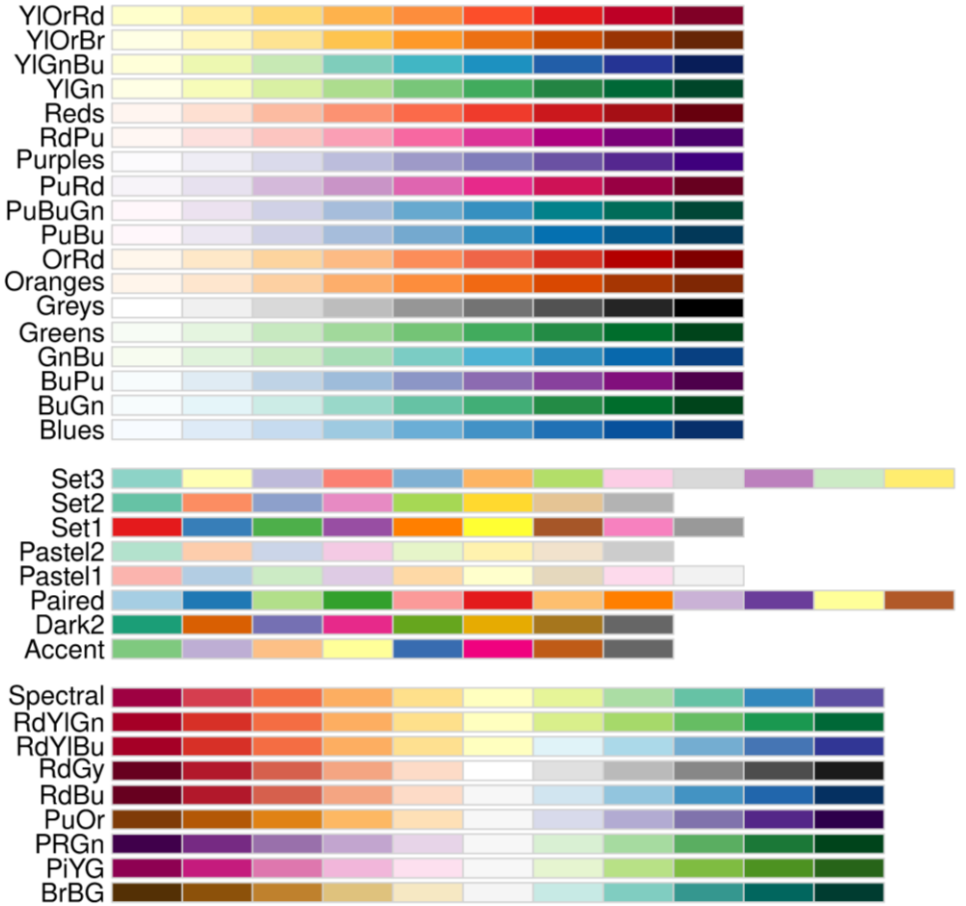
# Color scales (discrete)

## Brewer scales

- `RColorBrewer::display.brewer.all()`
- `scale_fill_brewer(palette="Set1")`
- `scale_fill_brewer(palette="Set2")`



# Color scales (discrete)

## Manually set color

### Use a vector

- `scale_fill_manual(values = c("grey", "black", "grey", "grey"))`

### Use a named vector

- 
```
scale_fill_manual(values = c( "d" = "grey", "c" = "grey",
                              "b" = "black", "a" = "grey" ))
```

# Facet

"Perspectives are projections"

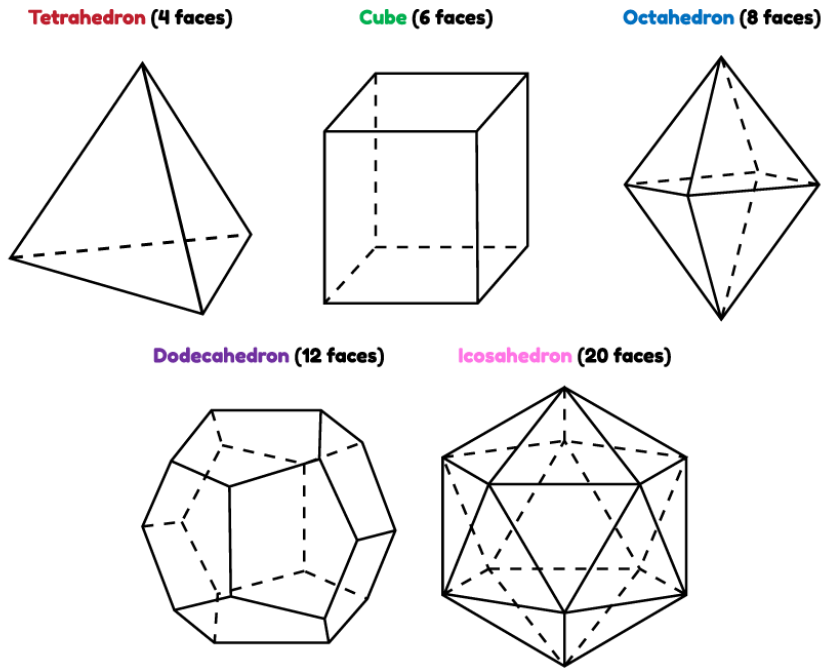
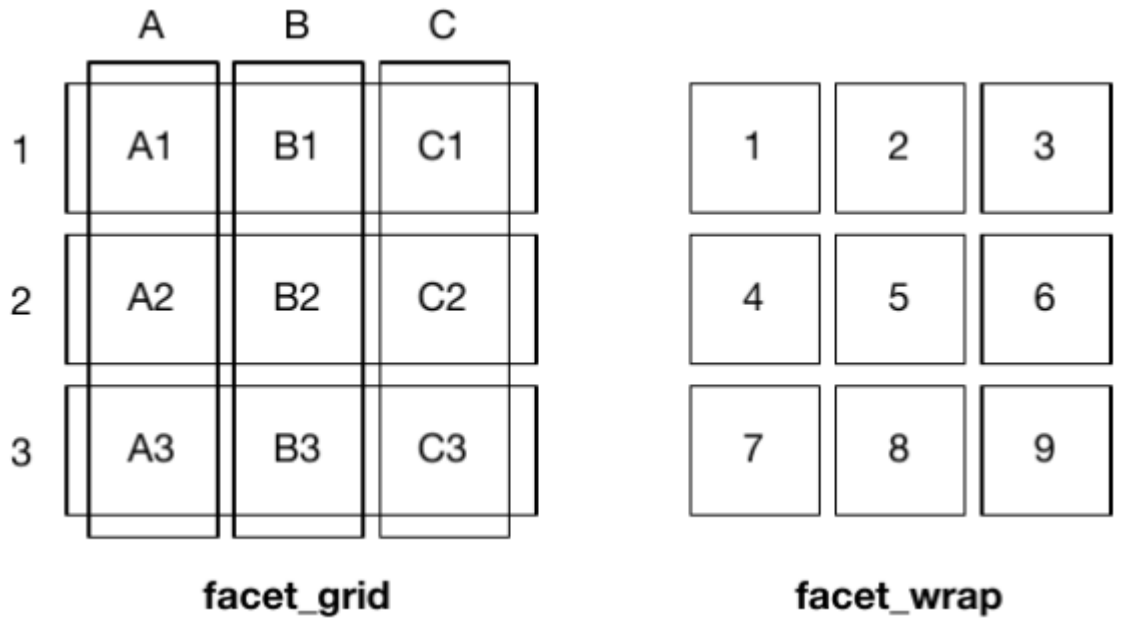





Image from book Internet

# 3 types of facet

- `facet_null()`: a single plot, the default.
- `facet_wrap()`: “wraps” a 1d ribbon of panels into 2d.
- `facet_grid()`: produces a 2d grid of panels defined by variables which form the rows and columns.



# Facet wrap

`facet_wrap()` makes a long ribbon of panels (generated by any number of variables) and wraps it into 2d

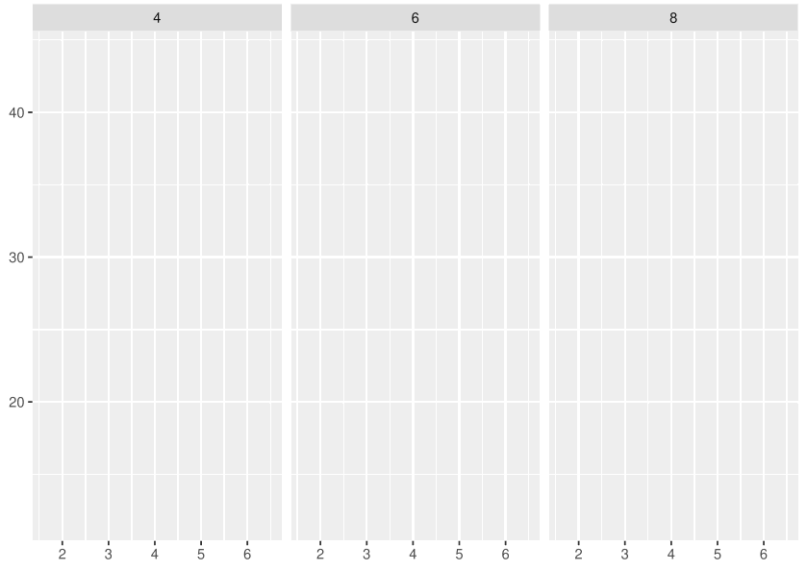
- `facet_wrap(~a, …)`

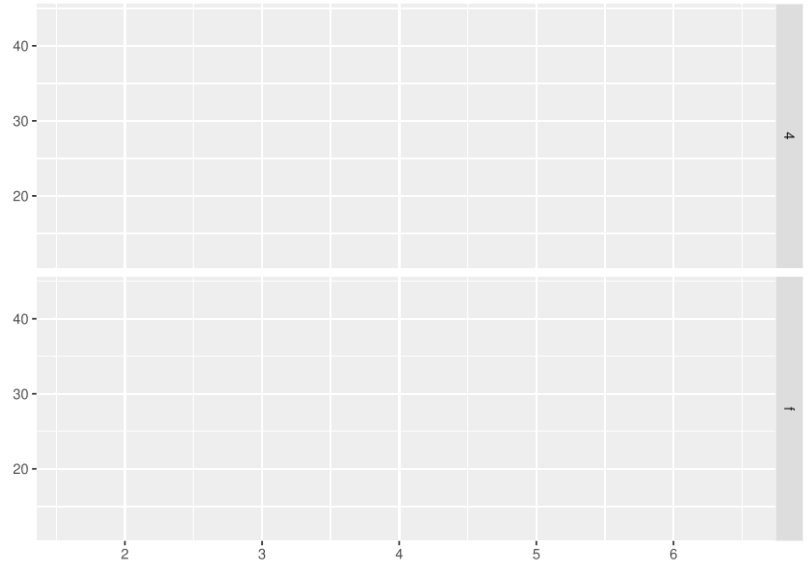
## Parameters

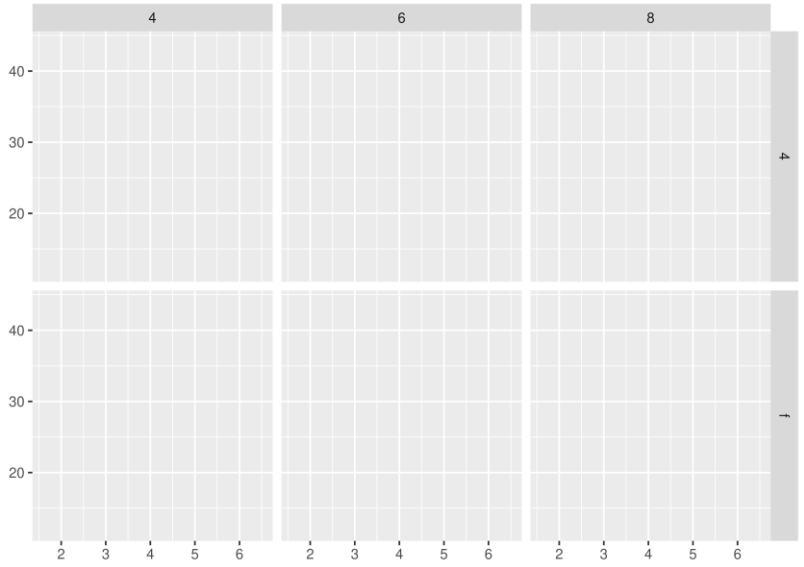
- `ncol`, `nrow`: controls how many rows/columns in the 2d panel
- `dir`: controls the direction of wrap: horizontal or vertical.

# Facet grid

- `facet_grid()` lays out plots in a 2d grid
  - facet_grid(. ~ a): spreads the values of a across the columns
  - facet_grid(b ~ .): spreads the values of b down the rows
  - facet_grid(b ~ a): b ~ a spreads a across columns and b down rows



# Controlling scales

control whether the position scales are the same in all panels (fixed) or allowed to vary between panels (free) with the `scales` parameter:

- `scales = "fixed"`: x and y scales are fixed across all panels.
- `scales = "free_x"`: the x scale is free, and the y scale is fixed.
- `scales = "free_y"`: the y scale is free, and the x scale is fixed.
- `scales = "free"`: x and y scales vary across panels.

# Things to consider when using facet

- When multiple data frames are used, missing faceting variables are treated like they exists in every data frame

- If we want to facet on a continuous variable, discretization is needed
  - Divide data into n bins with same length `cut_interval(x, n)`
  - Divide data into bins of width `cut_width(x, width)`
  - Divide data into n bins with same number of points `cut_number(x, n = 10)`

- Grouping vs. faceting
  - When using aesthetics to differentiate groups, the groups are close together and may overlap, but small differences are easier to see
  - With faceting, each group is quite far apart in its own panel, which is beneficial to avoid overlapping, but it does make small differences harder to see

# Coordinates

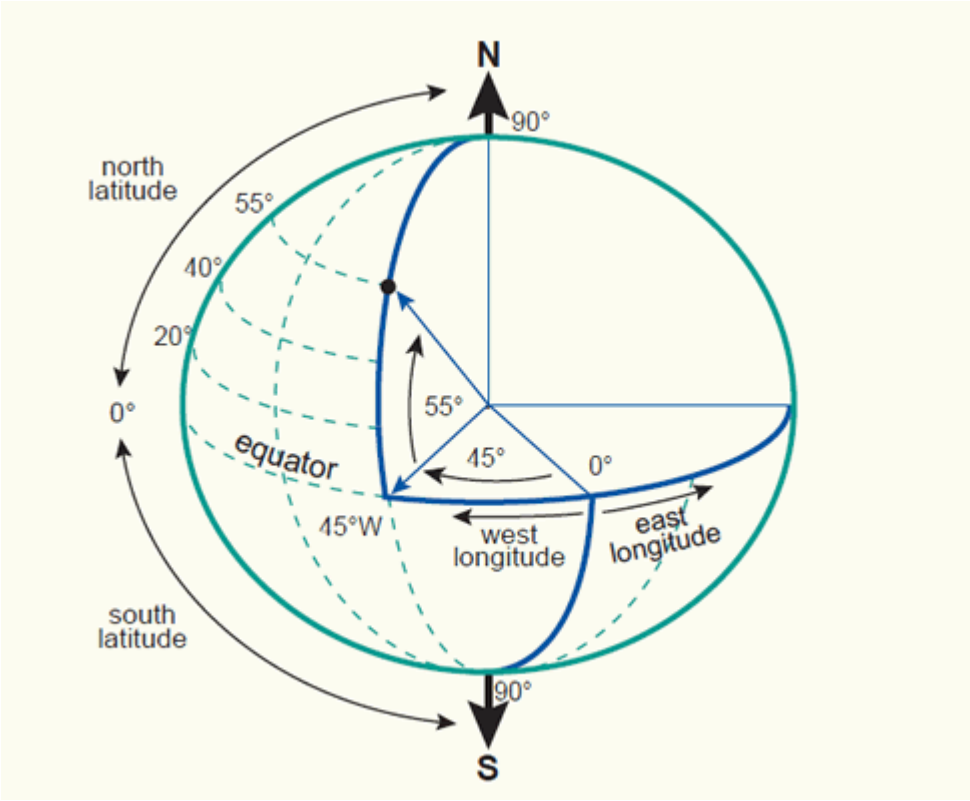
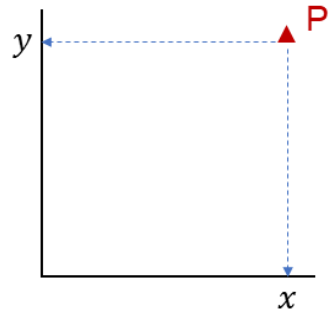





Image from book Internet

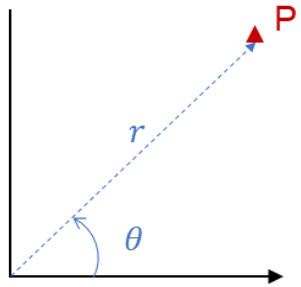
# Coordinate system: linear vs nonlinear

Cartesian coordinates




P = $(x, y)$

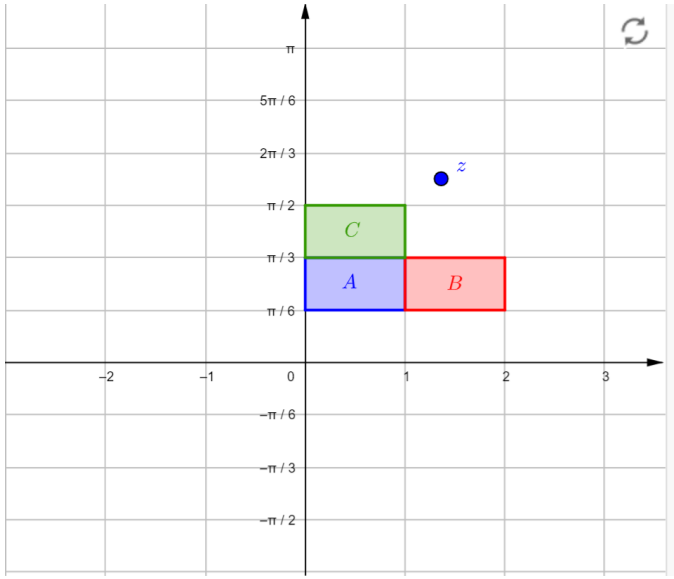
Polar coordinates




P = $(\theta, r)$

**Convert Polar to Cartesian**

$$x = r\cos\theta$$
$$y = r\sin\theta$$



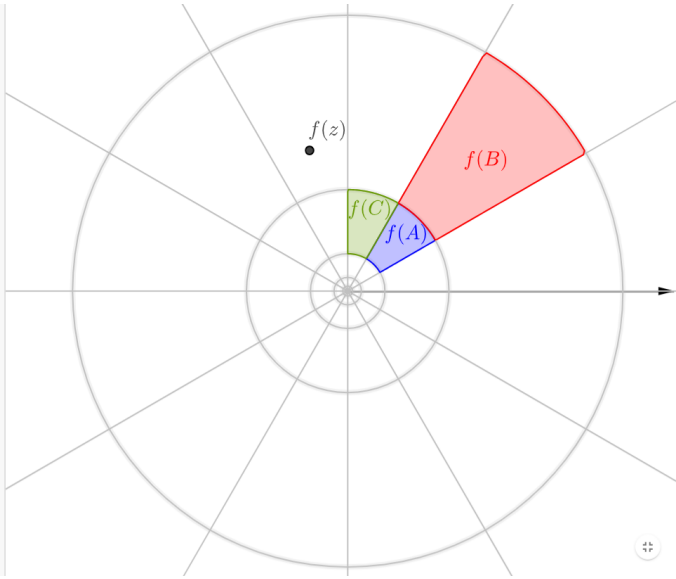
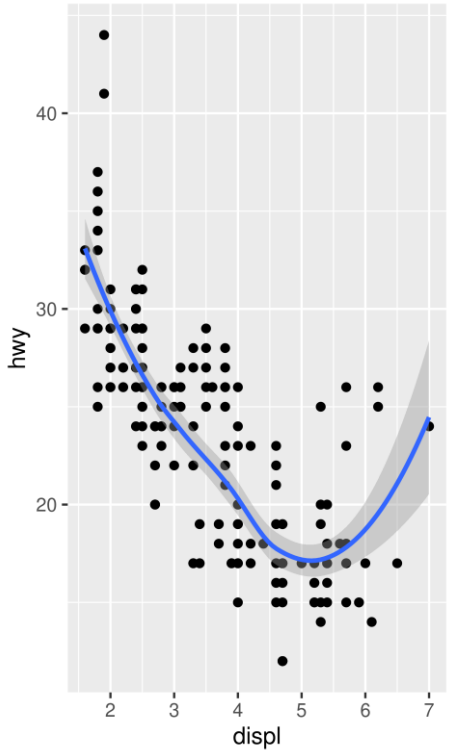



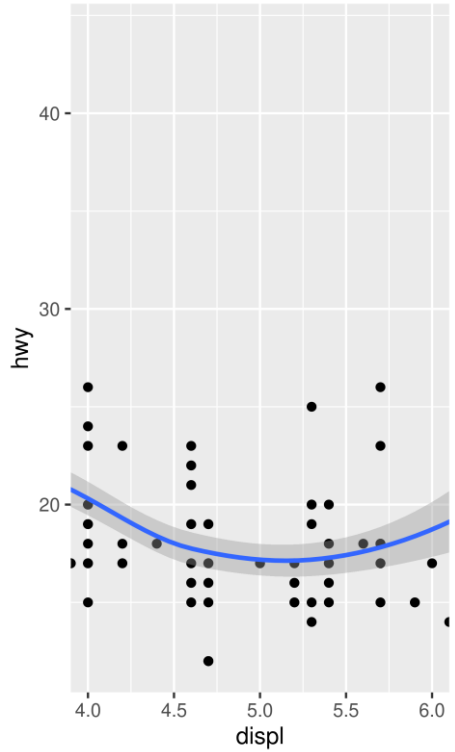



Image from book Internet

# Linear coordinate systems

- Zooming into a plot with `coord_cartesian()`
  - `coord_cartesian(xlim = c(4, 6))`

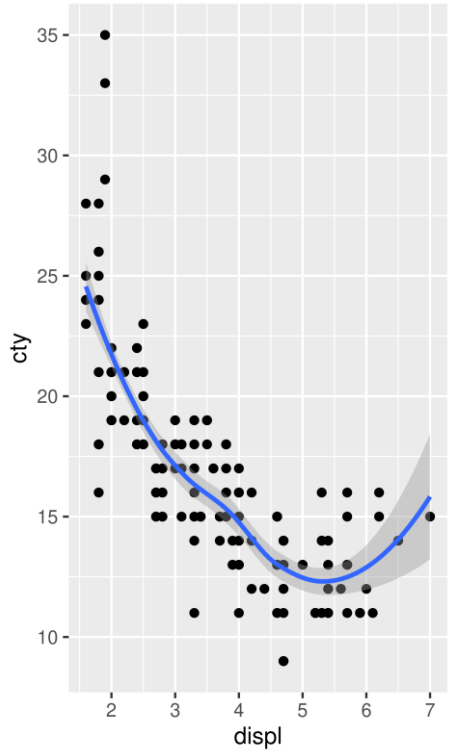


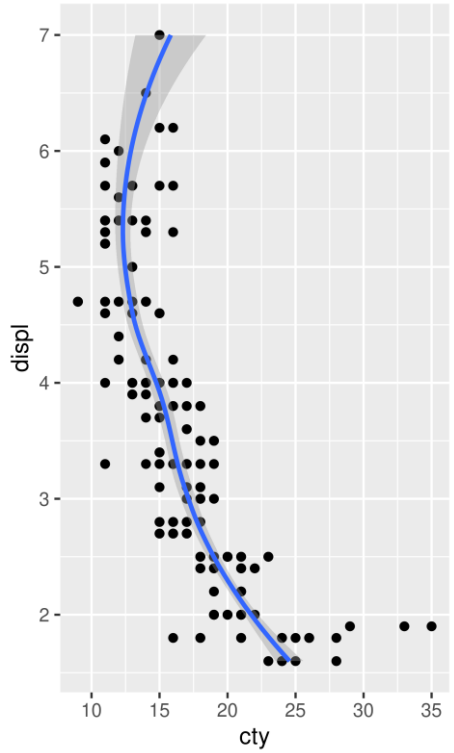




Compare it to `scale_x_continuous(limits = c(4, 6))`, what do you find?

# Linear coordinate systems

- Flipping the axes with `coord_flip()`
  - `coord_flip()`



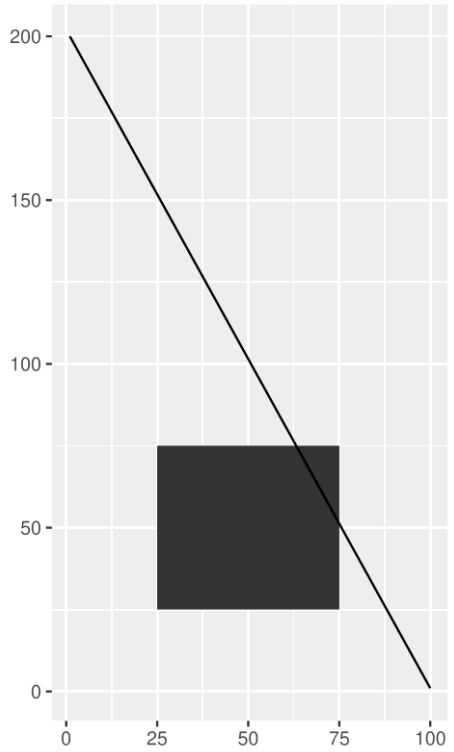

Compared to directly switch the x and y, what do you find?

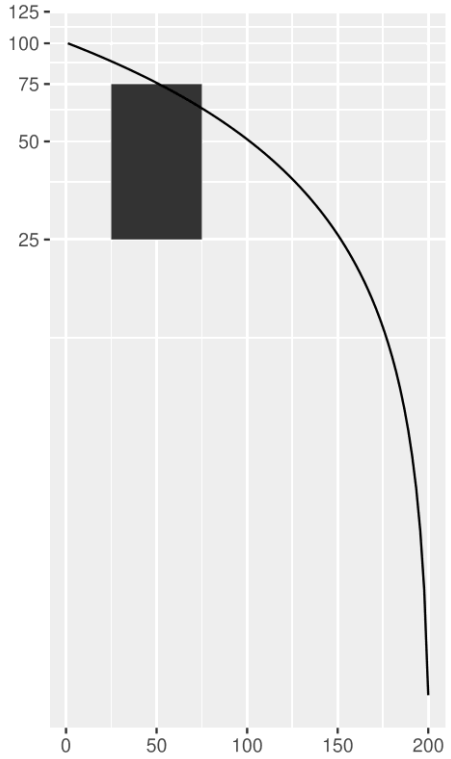
# Linear coordinate systems

- Equal scales with `coord_fixed()`
  - `coord_fixed(ratio = 1)`

# Non-linear coordinate systems

- Transformations with `coord_trans()`
  - `coord_trans(x = log10, y = log10)`

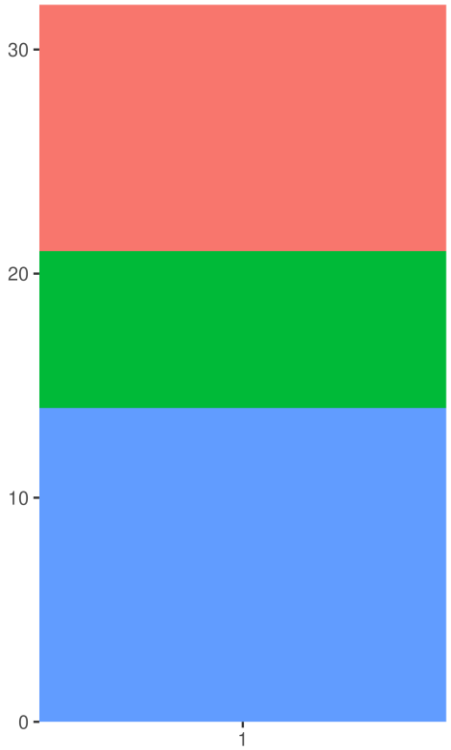


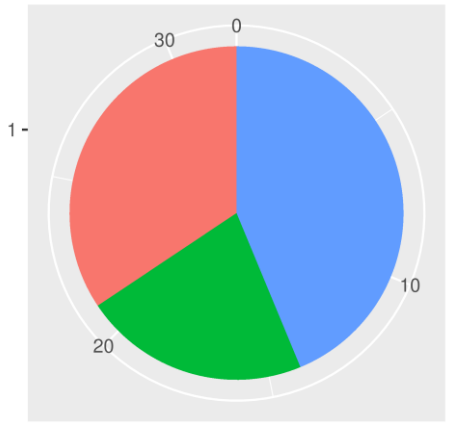



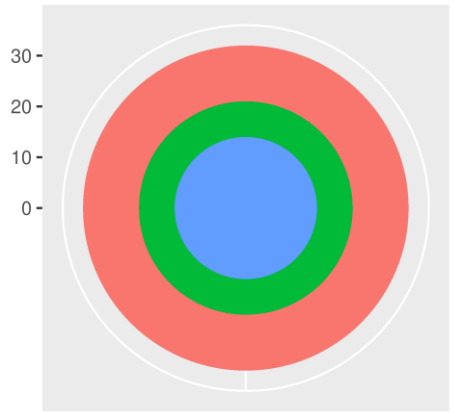
# Non-linear coordinate systems

- Polar coordinates with `coord_polar()`
  - ➢ coord_polar(theta = "x")

The theta argument determines which position variable is mapped to angle (by default, x) and which to radius



# Valentine’s special

Use what we learnt today to generate a heart curve

1. Generate the data
2. Plot the heart curve
3. Save into an image

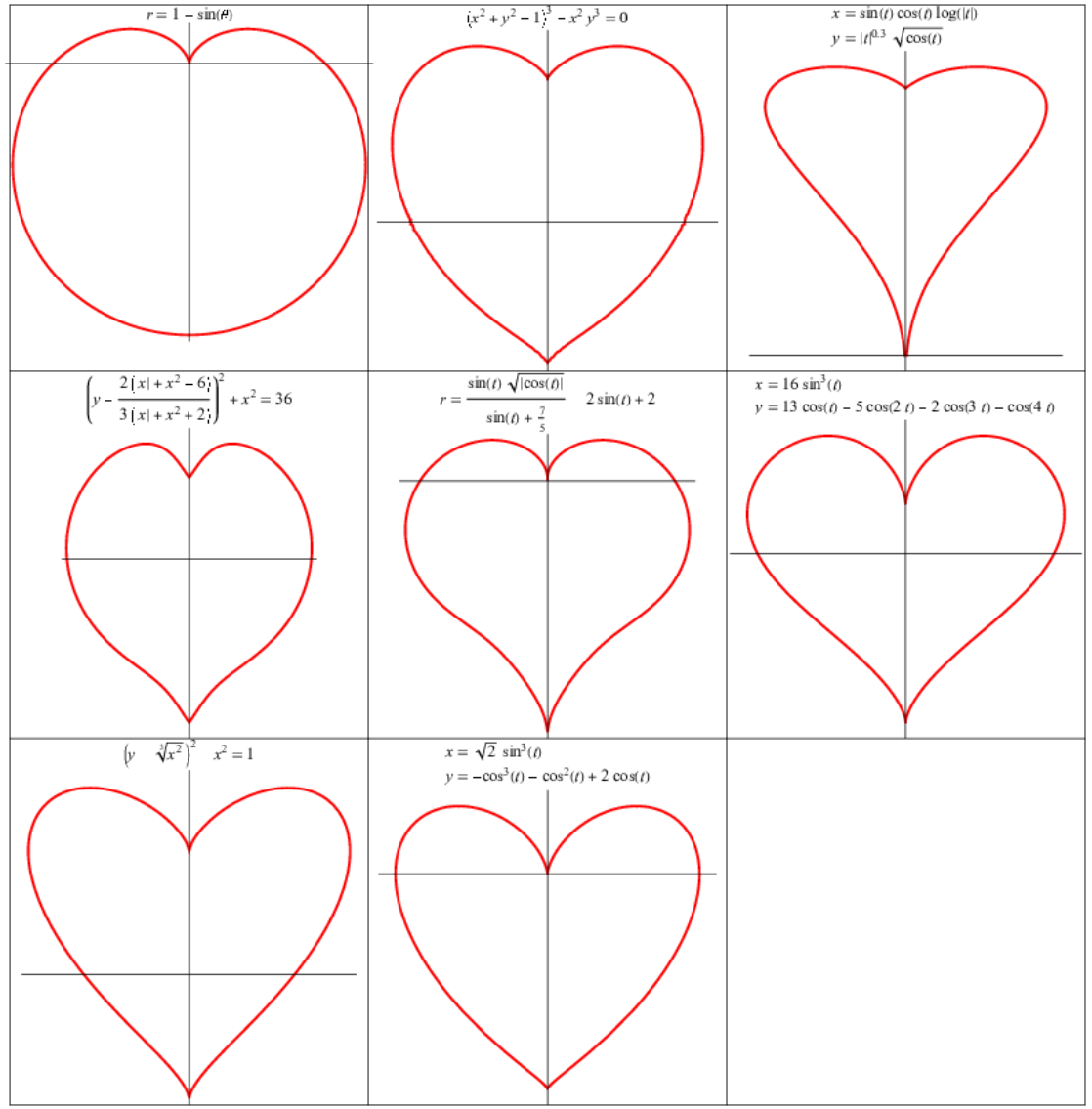





Image from book Internet