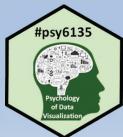


# Introduction to ggplot2



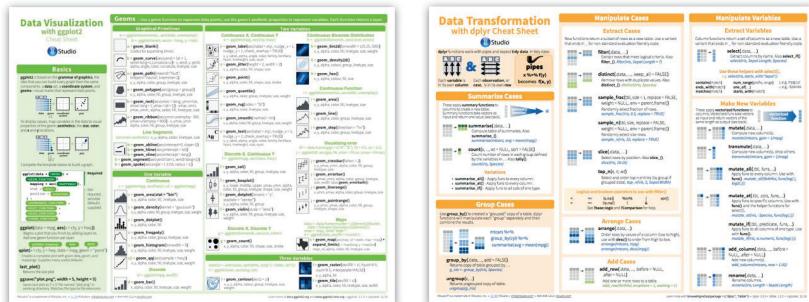
Michael Friendly  
Psych 6135

<https://friendly.github.io/6135>



## Resources: Cheat sheets

- R Studio maintains a large number of cheat sheets, <https://www.rstudio.com/resources/cheatsheets/>
- Topics:
  - R Studio IDE, Data import, Data transformation (dplyr), Data visualization (ggplot2), R Markdown, ...
  - My collection: [R Studio Cheat Sheets](#)



## Resources: Books

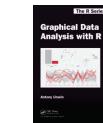


Hadley Wickham, *ggplot2: Elegant graphics for data analysis*, 2nd Ed.  
1st Ed: Online, <http://ggplot2.org/book/>  
ggplot2 Quick Reference: <http://r-statistics.co/ggplot2-cheatsheet.html>  
Complete ggplot2 documentation: <http://docs.ggplot2.org/current/>



Kieran Healy, *Data Visualization, a Practical Introduction*

A hands-on introduction to data visualization using ggplot2, with a wide range of topics.  
The online version: <https://socviz.co/> is a great example of R bookdown publishing.



Antony Unwin, *Graphical Data Analysis with R*

A gentle introduction to doing visual data analysis, mainly with ggplot2.  
R code: <http://www.gradaanwr.net/>



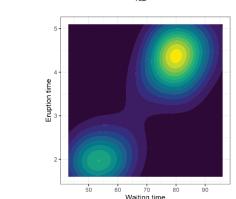
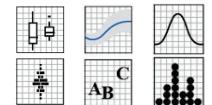
Robert Kabakoff, *Modern Data Visualization with R*

A comprehensive guide to creating data visualizations using R, mainly ggplot2, but also base R, and other tools  
Online book: <https://rkabakoff.github.io/datavis/>  
R code & data: [https://github.com/rkabakoff/datavis\\_support](https://github.com/rkabakoff/datavis_support)

2

## Topics for today

- ggplot overview
  - components: geoms, stats, scales, ...
  - getting stylish: themes
  - Using NICE fonts
- Revisioning old masters
  - Playfair, balance of trade
  - Arbuthnot's birth ratios
  - Guerry's enhanced scatterplots
- Beyond 2D
- Animation



# What is ggplot2?

- ggplot2 is Hadley Wickham's R package for producing “elegant graphics for data analysis”
  - An implementation of the ideas for graphics introduced in Lee Wilkinson's *Grammar of Graphics*
  - Ideas and the syntax of ggplot2 help to think of graphs in a new and more general way
  - → pleasing plots, taking care of many fiddly details (legends, axes, colors, ...)
  - Built on the “grid” graphics system: consistency
  - Open software, with a large number of gg\_ extensions. See: <https://exts.ggplot2.tidyverse.org/gallery/>

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# Now there's tinyplot()



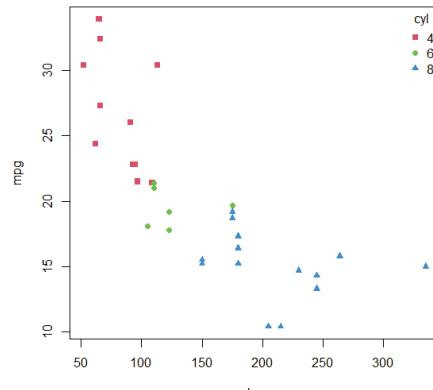
tinyplot: A lightweight, drop-in replacement for base R plot() with many conveniences.

- Formula interface: `y ~ x | group`
- Legend handled automatically
- Allows facets & themes
- Standard plot types: “p” (points), “l” (lines), “b” (both), ...
- New plot types:
  - “lm” (regression lines)
  - “loess” (smooth)
  - “jitter”, “boxplot”, “density”

R script:  
<https://friendly.github.io/6135/R/tinyplot.R>

Tutorial:  
<https://grantmcdermott.com/tinyplot/vignettes/introTutorial.html>

```
library(tinyplot)
tinyplot(mpg ~ hp | cyl, data = mtcars,
         legend = "topright",
         col = palette()[2:4],
         pch = 15:17)
```

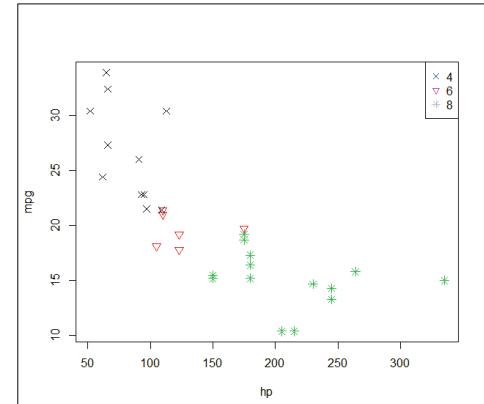


# ggplot vs base graphics

Some things that should be simple are harder than you'd like in base graphics

Here, I'm plotting gas mileage (mpg) vs. horsepower and want to use color and shape for different # of cylinders.

But I don't quite get it right!



```
mtcars$cyl <- as.factor(mtcars$cyl)
plot(mpg ~ hp, data=mtcars,
     col=cyl, pch=c(4,6,8)[mtcars$cyl], cex=1.2)
legend("topright", legend=levels(mtcars$cyl),
       pch = c(4,6,8),
       col=levels(mtcars$cyl))
```

colors and point symbols work differently in plot() and legend()

goal of ggplot2: this should “just work”

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# ggplot vs base R graphics

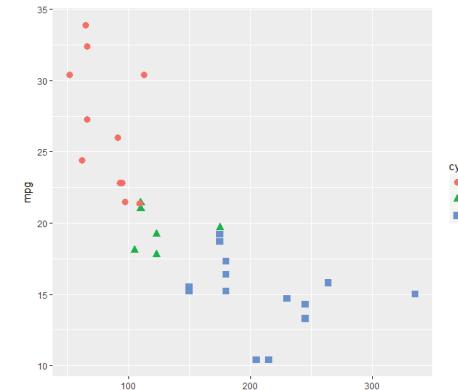
In ggplot2, just map the data variables to aesthetic attributes

`aes(x, y, shape, color, size, ...)`

ggplot() takes care of the rest

`aes()` mappings set in the call to ggplot() are passed to geom\_point() here

```
library(ggplot2)
ggplot(mtcars, aes(x=hp, y=mpg, color=cyl, shape=cyl)) +
  geom_point(size=3)
```



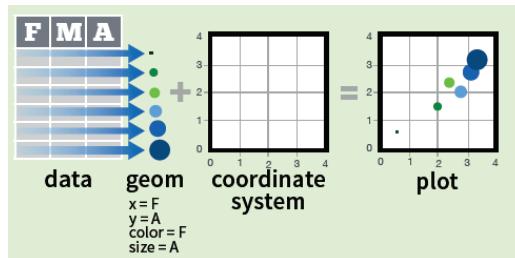
Color & shape vars must be factors

Follow along: R script for this example is at: <https://friendly.github.io/6135/R/gg-cars.R>

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# ggplot components

- Every graph can be described as a combination of independent building blocks:
  - data**: a data frame: quantitative, categorical; local or data base query
  - aesthetic mapping of variables into visual properties: size, color, x, y
  - geometric objects ("geom"): points, lines, areas, arrows, ...
  - coordinate system ("coord"): Cartesian, log, polar, map,

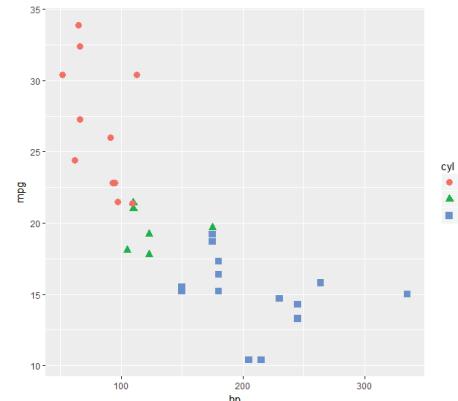


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## ggplot: data + geom -> graph

```
ggplot(data=mtcars,
       aes(x=hp, y=mpg,
           color=cyl, shape=cyl)) +
  geom_point(size=3)
```

1  
2  
3  
4



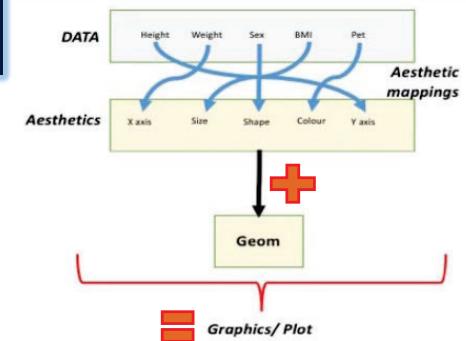
- In this call,
1. data=mtcars: data frame
  2. aes(x=hp, y=mpg): plot variables
  3. aes(color, shape): attributes
  4. geom\_point(): what to plot
  - the coordinate system is taken to be the standard Cartesian (x,y)

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## Aesthetic mapping

aes() maps **data** variables into **visual** properties

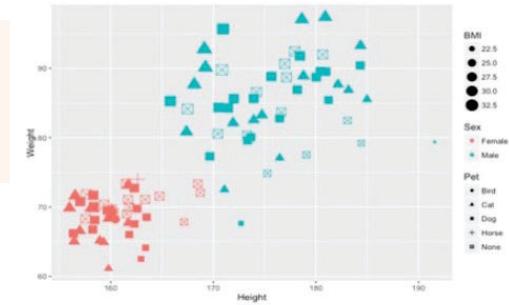
- Axes: x, y
- size, color, shape, fill
- Lines: linetype, linewidth



```
ggplot(data = patients,
       aes(y = Weight, x = Height,
           color = Sex, size = BMI,
           shape = Pet)) +
  geom_point()
```

From:

[https://rockefelleruniversity.github.io/Plotting\\_In\\_R/presentations/slides/ggplot2.html](https://rockefelleruniversity.github.io/Plotting_In_R/presentations/slides/ggplot2.html)



## ggplot geoms: basic

### Graphical Primitives

```
a <- ggplot(economics, aes(date, unemploy))
b <- ggplot(seals, aes(x = long, y = lat))
a + geom_blank()
#(Useful for expanding limits)
b + geom_curve(aes(yend = lat + 1,
                    xend = long + 1, curvature = z)) - x, xend, y, yend,
alpha, angle, color, curvature, linetype, size
a + geom_path(lineend = "butt",
              linejoin = "round", linemetre = 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,
ymin, ymax, 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
c2 + geom_qq(aes(sample = hwy))
x, y, alpha, color, fill, linetype, size, weight
```

### Discrete

```
d <- ggplot(mpg, aes(fl))
d + geom_bar()
x, alpha, color, fill, linetype, size, weight
```

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## ggplot geoms: two variables

### Continuous X, Continuous Y

```
e <- ggplot(mpg, aes(cty, hwy))
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
```

**AB**

```
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

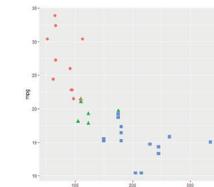
```
f <- ggplot(mpg, aes(class, hwy))
f + geom_col()
x, y, alpha, color, fill, group, linetype, size
f + geom_boxplot()
x, y, lower, middle, upper, ymax, ymin, alpha,
color, fill, group, linetype, shape, size, weight
f + geom_dotplot(binaxis = "y",
stackdir = "center")
x, y, alpha, color, fill, group
f + geom_violin(scale = "area")
x, y, alpha, color, fill, group, linetype, size,
weight
```

### Continuous Bivariate Distribution

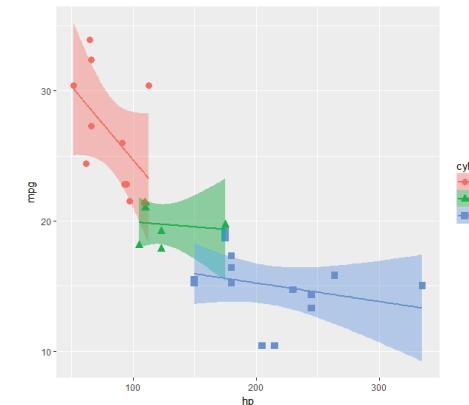
```
h <- ggplot(diamonds, aes(carat, price))
h + geom_bin2d(binwidth = c(0.25, 500))
x, y, alpha, color, fill, linetype, size, weight
h + geom_density2d()
x, y, alpha, colour, group, linetype, size
h + geom_hex()
x, y, alpha, colour, fill, size
```

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## ggplot: geoms



Basic plot



How can I enhance this visualization?

Easy: add a `geom_smooth()` to fit linear regressions for **each** level of cyl

It is clear that horsepower and # of cylinders are highly related (Duh!)

```
ggplot(mtcars, aes(x=hp, y=mpg, color=cyl, shape=cyl)) +
  geom_point(size=3) +
  geom_smooth(method="lm", aes(fill=cyl))
```

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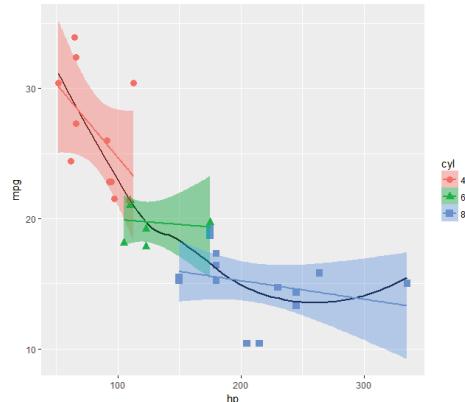
## ggplot: Inheritance in layers & aes()

Aesthetic attributes in the `ggplot()` call are **inherited** in `geom_()` layers

Attributes can also be passed as **constants** (`size=3, color="black"`) or with `aes(color=...)` in different layers

This plot adds an **overall** loess smooth to the previous plot.

`color="black"` overrides the `aes(color=cyl)`



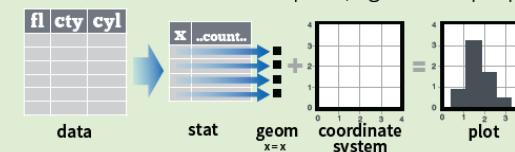
```
ggplot(mtcars, aes(x=hp, y=mpg)) +
  geom_point(size=3, aes(color=cyl, shape=cyl)) +
  geom_smooth(method="lm", aes(color=cyl, fill=cyl)) +
  geom_smooth(method="loess", color="black", se=FALSE)
```

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## ggplot: stats

- **statistical calculations ("stat")** -- data summaries: mean, sd, binning & counting, ...
- stats have a default geom and geoms have a default stat
  - `geom_bar(stat = "count") ← → stat_count(geom = "bar")`
- computed variables (eg, `..count..`, `..level..`) can be mapped to aesthetics
  - `ggplot(aes(x=, y=)) + stat_density_2d(aes(fill = ..level..), geom="polygon")`

A stat builds new variables to plot (e.g., count, prop).



some stats:

- `stat_count()`
- `stat_bin()`
- `stat_density()`
- `stat_boxplot()`
- `stat_density_2d()`
- `stat_ellipse()`

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# scales



Scales map **data** values to the visual **values** of an aesthetic.

- axis labels, legends, colors
- formatting of values (currencies: \$100, €2.50; percents: 2.5%, 50%, ...)

## General Purpose scales

Use with most aesthetics

`scale_*`**continuous()** - map cont' values to visual ones  
`scale_*`**discrete()** - map discrete values to visual ones  
`scale_*`**identity()** - use data values as visual ones  
`scale_*`**manual**(values = c()) - map discrete values to manually chosen visual ones  
`scale_*`**date**(date\_labels = "%m/%d", date\_breaks = "2 weeks") - treat data values as dates.  
`scale_*`**datetime()** - treat data x values as date times. Use same arguments as `scale_x_date()`. See ?strptime for label formats.

## X and Y location scales

Use with x or y aesthetics (x shown here)

`scale_x_log10()` - Plot x on log10 scale  
`scale_x_reverse()` - Reverse direction of x axis  
`scale_x_sqrt()` - Plot x on square root scale

## Color and fill scales (Discrete)

n <- d + geom\_bar(aes(fill = fl))

`n + scale_fill_brewer(palette = "Blues")`  
For palette choices: RColorBrewer::display.brewer.all()  
 `n + scale_fill_grey(start = 0.2, end = 0.8, na.value = "red")`

## Color and fill scales (Continuous)

`o <- c + geom_dotplot(aes(fill = ..x..))`  
`o + scale_fill_distiller(palette = "Blues")`  
`o + scale_fill_gradient(low = "red", high = "yellow")`  
`o + scale_fill_gradient2(low = "red", high = "blue", mid = "white", midpoint = 25)`  
`o + scale_fill_gradientn(colours = topo.colors(6))`  
Also: rainbow(), heat.colors(), terrain.colors(), cm.colors(), RColorBrewer::brewer.pal()

NB: diff scales for discrete vs continuous

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# ggplot themes

ggplot themes set the general style for **all** graphic elements

Designed to provide a pleasing **coherent** design – simply!

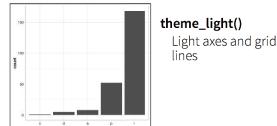
Yet, all the details can be customized

One theme can rule them all!

## Themes

Theme functions change the appearance of your plot.

`theme_bw()`  
White background with grid lines



`theme_light()`  
Light axes and grid lines



`theme_linedraw()`  
Only black lines



`theme_minimal()`  
Minimal theme, no background



`theme_gray()`  
Grey background (default theme)

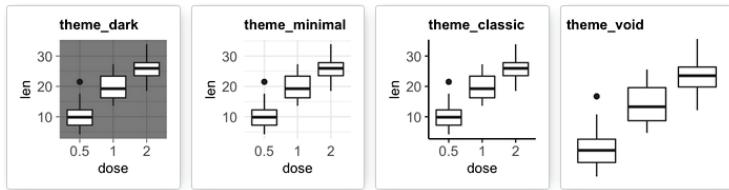


`theme_void()`  
Empty theme, only geoms are visible

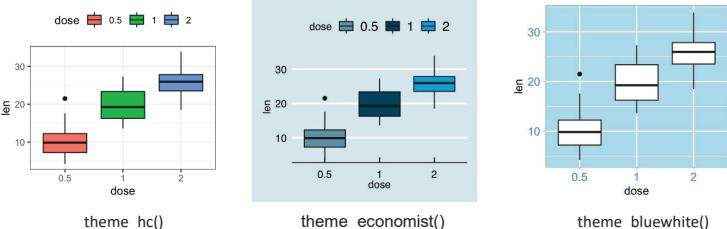


# ggplot2: themes

Built-in ggplot themes provide a wide variety of basic graph styles



Other packages provide custom themes, or you can easily define your own



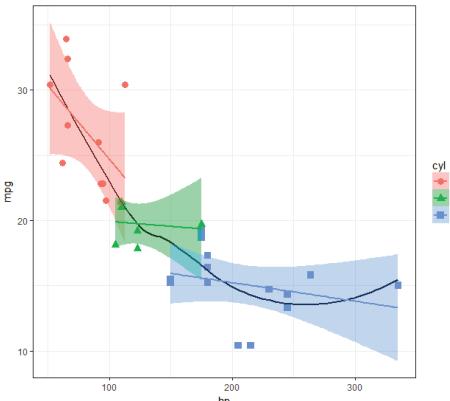
19

# ggplot2: themes

All the graphical attributes of ggplot2 are governed by themes – settings for all aspects of a plot

A given plot can be rendered quite differently just by changing the theme

If you haven't saved the ggplot object, `last_plot()` gives you something to work with further



`last_plot() + theme_bw()`



Tip: set `base_size` = here to control all text size

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# Other ggplot features

## Coordinate Systems

	<pre>r &lt;- d + geom_bar()</pre>
	<pre>r + coord_cartesian(xlim = c(0, 5))</pre>
	<pre>xlim, ylim The default cartesian coordinate system</pre>
	<pre>r + coord_fixed(ratio = 1/2) ratio, xlim, ylim Cartesian coordinates with fixed aspect ratio between x and y units</pre>
	<pre>r + coord_flip() xlim, ylim Flipped Cartesian coordinates</pre>
	<pre>r + coord_polar(theta = "x", direction=1) theta, start, direction Polar coordinates</pre>
	<pre>r + coord_trans(ytrans = "sqrt") xtrans, ytrans, limx, limy Transformed cartesian coordinates. Set xtrans and ytrans to the name of a window function.</pre>

Zoom / clip : use xlim, ylim = c(lo,hi)

## Faceting

Facets divide a plot into subplots based on the values of one or more discrete variables.

```
t <- ggplot(mpg, aes(cty, hwy)) + geom_point()
```



Set **scales** to let axis limits vary across facets

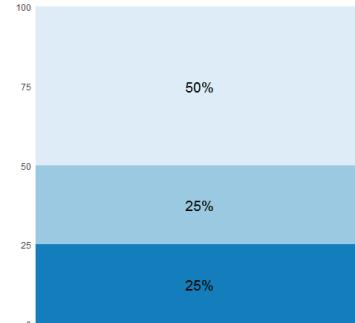
```
t + facet_grid(drv ~ fl, scales = "free")  
x and y axis limits adjust to individual facets  
• "free_x" - x axis limits adjust  
• "free_y" - y axis limits adjust
```

# ggplot2: coords

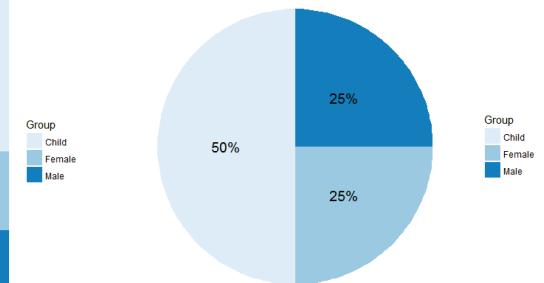
Coordinate systems, coord\_\*( ) functions, handle conversion from geometric objects to what you see on a 2D plot.

- A simple bar chart, standard coordinates
- A pie chart is just a bar chart in polar coordinates!

```
p <- ggplot(df, aes(x = "", y = value, fill = group)) +  
  geom_bar(stat = "identity")
```



```
p + coord_polar("y", start = 0)
```



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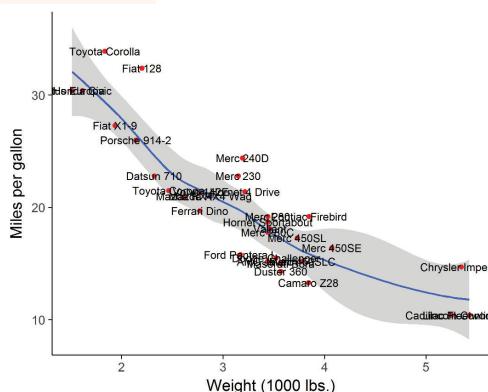
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# labeling points: geom\_text()

```
plt2 <- ggplot(mtcars, aes(x=wt, y=mpg)) +  
  geom_point(color = 'red', size=2) +  
  geom_smooth(method="loess") +  
  labs(y="Miles per gallon", x="Weight (1000 lbs.)") +  
  theme_classic(base_size = 16)  
  
plt2 + geom_text(aes(label = rownames(mtcars)))
```

Note use of theme\_classic(), better axis labels & increased font size.

But this is too messy: wouldn't want to publish this.



Sometimes it is useful to label points to show their identities.

geom\_text() often gives messy, overlapping text

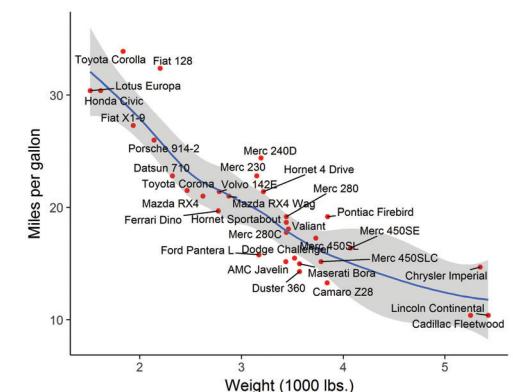
# labeling points: geom\_text\_repel()

```
library(ggrepel)  
plt2 +  
  geom_text_repel(aes(label = rownames(mtcars)))
```



geom\_text\_repel() assigns repulsive forces among points and labels to assure no overlap

Some lines are drawn to make the assignment clearer



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## labeling points: selection

It is easy to label points **selectively**, using some criterion to assign labels to points

```
mod <- loess( mpg ~ wt, data=mtcars)
resids <- residuals(mod)
mtcars$label <- ifelse(abs(resids) > 2.5,
                      rownames(mtcars), "")
```

plt2 + geom\_text\_repel(aes(label = mtcars\$label))

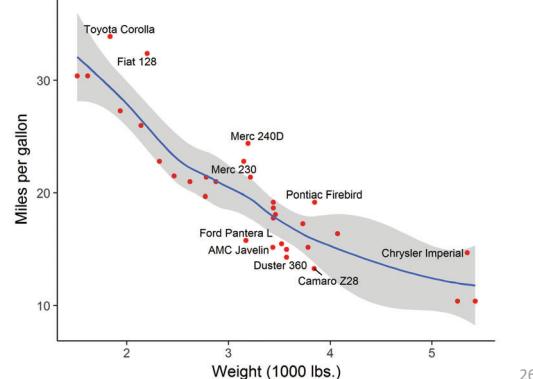
1  
2  
3

Easiest if you add such variables to the dataset

4

Here, I:

1. fit the smoothed loess curve,
2. extract residuals,  $r_i$
3. assign labels where  $|r_i| > 2.5$
4. add the text layer



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## ggplot objects

💡 `summary()` is a handy way to see what is inside a ggplot object

```
> summary(plt)
data: mpg, cyl, disp, hp, drat, wt, qsec, vs, am, gear, carb [32x11]          Basic plot
mapping: x = ~hp, y = ~mpg, colour = ~cyl, shape = ~cyl
faceting: <ggproto object: Class FacetNull, Facet, gg>
  compute_layout: function
  draw_back: function
...
super: <ggproto object: Class FacetNull, Facet, gg>
```

-----

```
geom_point: na.rm = FALSE                                Geom layers
stat_identity: na.rm = FALSE
position_identity

mapping: fill = ~cyl
geom_smooth: na.rm = FALSE, orientation = NA, se = TRUE
stat_smooth: na.rm = FALSE, orientation = NA, se = TRUE, method = lm
position_identity
```

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## ggplot objects

Traditional R graphics just produce graphical output on a device

However, `ggplot()` produces a “ggplot” object, a list of elements

```
> names(plt)
[1] "data"      "layers"    "scales"    "guides"    "mapping"   "theme"     "coordinates"
[8] "facet"     "plot_env"  "layout"    "labels"
> class(plt)
[1] "gg"        "ggplot"
```

What methods are available?

```
> methods(class="gg")
[1] +
> methods(class="ggplot")
[1] grid.draw  plot   print  summary
```

The “gg” class provides the “+” method

The “ggplot” class provides other, standard methods

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## Saving plots: `ggsave()`

- If the plot is on the screen:

```
ggsave("path/filename.png") # height=, width=, dpi=
```

- If you have a plot object:

```
ggsave(myplot, file="path/filename.png")
```

- Specify size:

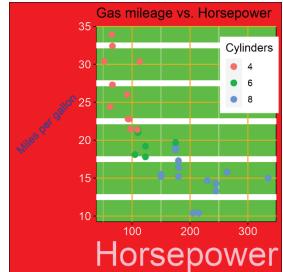
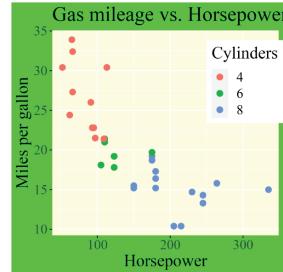
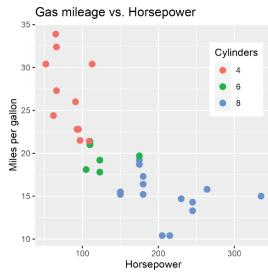
```
ggsave(myplot, "path/filename.png", width=6, height=4)
```

- any plot format (pdf, png, eps, svg, jpg, ...)

```
ggsave(myplot, file="path/filename.jpg")
```

```
ggsave(myplot, file="path/filename.pdf")
```

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## STYLING WITH THEMES

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## Moving the legend

Move the legend inside the plot region

```
p1 + theme(
  legend.position = "inside",
  legend.position.inside = c(0.85, 0.75))
```

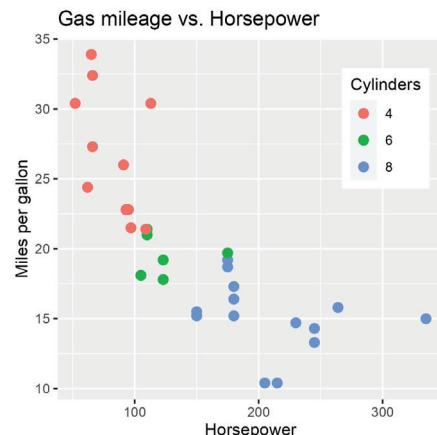
This gives more room for the data

Legend position is a theme attribute

Might also want to control:

- legend title: font, size, label...
- legend background, margin, ...

Need to know their names & properties



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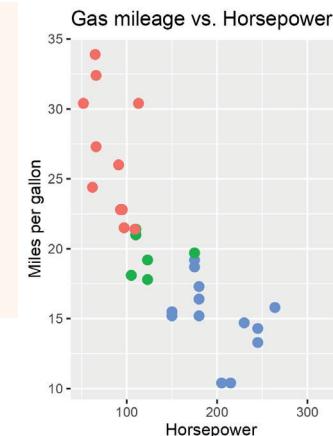
## Options vs. themes

```
p1 <-  
  ggplot(mtcars, aes(x = hp, y=mpg)) +  
  geom_point(aes(color=factor(cyl)),  
             size=3, pch=16) +  
  labs(color = "Cylinders",  
       x = "Horsepower",  
       y = "Miles per gallon") +  
  ggtitle("Gas mileage vs. Horsepower")
```

p1

Some graphic attributes (size, symbol)  
are controlled as options of geoms

Others must be controlled by theme  
elements



ggplot default: theme\_gray()

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### ggplot2 Theme Elements

```
theme(element_name = element_function())  
- element_text()  
- element_line()  
- element_rect()  
- element_blank()
```

### Plot elements:

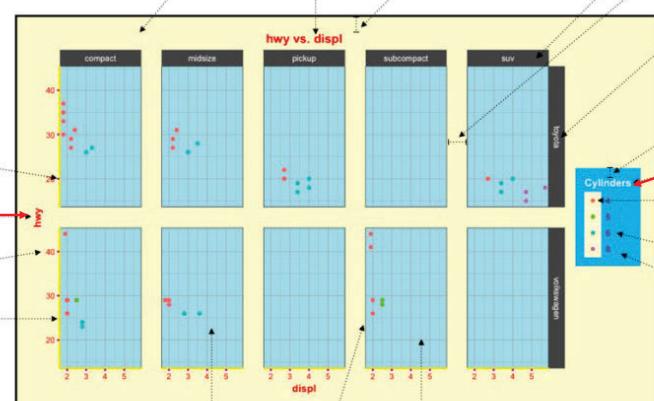
```
plot.background  
element_rect()  
  
plot.title  
element_text()  
  
plot.margin  
margin()
```

### Facetting elements:

```
strip.background  
element_rect()  
  
panel.spacing  
unit()  
  
strip.text  
element_text()
```

### Axis elements:

```
axis.ticks  
element_line()  
  
axis.title  
element_text()  
  
axis.text  
element_text()  
  
axis.line  
element_line()
```



```
Legend elements:  
legend.margin  
margin()  
  
legend.title  
element_text()  
  
legend.key  
element_rect()  
  
legend.text  
element_text()  
  
legend.background  
element_rect()
```

Panel elements:

```
panel.background  
element_rect()  
  
panel.border  
element_rect(fill = NA)  
  
panel.grid  
element_line()
```

[henrywang.nl](http://henrywang.nl)

Derived from "ggplot2: Elegant Graphics for Data Analysis"

# Styling with themes: text

## ggplot2 theme elements reference

Set `minimal` as the baseline theme:

```
theme_minimal() +  
  theme(element_type())
```

Use `element_blank()` to remove an element

Axis titles, text, ticks, and lines can be specified per axis using theme inheritance by putting `.x/.y` at the end of the theme element.

`axis.line.y = element_line()`

`axis.title.y = element_text()`

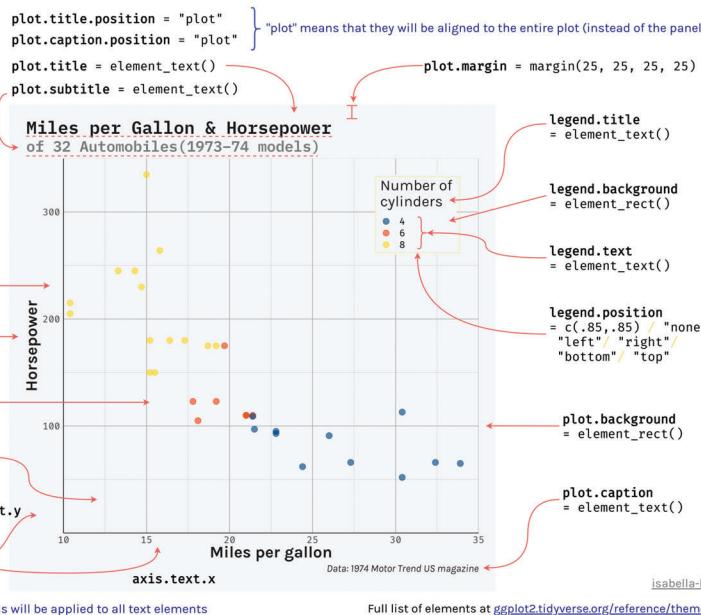
`panel.grid.major = element_line()`

`panel.grid.minor = element_line()`

`axis.text = element_text()`

`axis.text.y`

`axis.text.x`



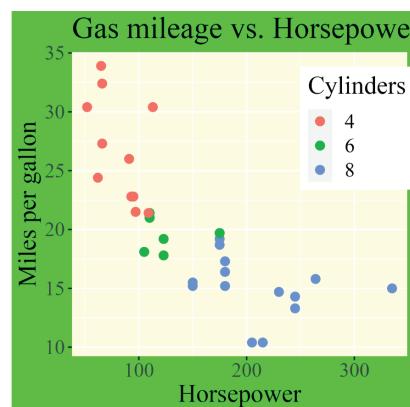
`text = element_text() ← modifications will be applied to all text elements`

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# Styling with themes: backgrounds

Change the backgrounds

```
p1 + theme(  
  legend.position = "inside",  
  legend.position = c(0.85, 0.75),  
  text = element_text(size=18, family = "serif"),  
  plot.background = element_rect(fill="green"),  
  panel.background =  
    element_rect(fill="lightyellow")  
)
```



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Gas mileage vs. Horsepower

## Gas mileage vs. Horsepower

Change the font family

`p1 + theme(`

`legend.position = "inside",`

`legend.position = c(0.85, 0.75),`

`text = element_text(size=18, family = "serif"))`

Change the font family & size for all text.

OR

Change specific text items:

- `axis.title = element_text()`

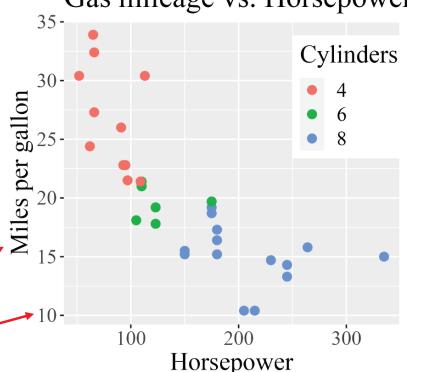
- `axis.text = element_text()`

- `legend.title =`

- `legend.text =`

- `...`

NB: could also use  
`theme_gray(base_size=, base_family=, ...)`



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# Custom themes

You can define & save your own theme and then use to style all plots consistently

```
theme_ugly <- function (base_size = 12, base_family = "") {  
  theme_gray(base_size = base_size, base_family = base_family)  
  %+replace%  
  theme(  
    axis.text = element_text(colour = "white"),  
    axis.title.x = element_text(colour = "pink", size=rel(3)),  
    axis.title.y = element_text(colour = "blue", angle=45),  
    panel.background = element_rect(fill="green"),  
    panel.grid.minor.y = element_line(size=3),  
    panel.grid.major = element_line(colour = "orange"),  
    plot.background = element_rect(fill="red")  
)  
}
```

Start with a base theme

override these properties

💡 Use `theme_update()` to change just a few elements in the **current** theme

```
theme_update(panel.grid.minor = element_line(colour = "red"))
```

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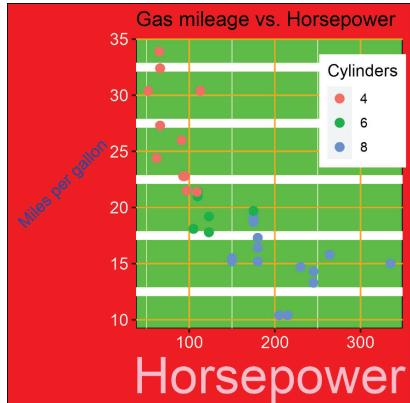
## Styling with themes

Use your theme:

```
p1 + theme_ugly() +  
  theme(legend.position = c(0.85, 0.75))
```

To set a theme as the default for all subsequent graphics:

- `theme_set(theme_bw())`
- `theme_set(theme_ugly())`



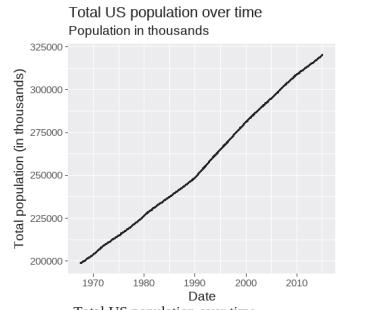
Recall Wilkinson: *GoG can produce hideous graphics ... but cannot produce a meaningful one*

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## Basic font manipulations

A simple plot

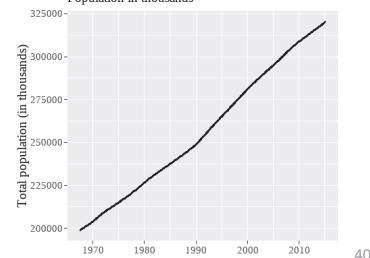
```
library(ggplot2)  
theme_set(theme_gray(base_size = 14))  
base_fig <- ggplot(data = economics, aes(date, pop)) +  
  geom_line(linewidth = 1.3) +  
  labs(title = "Total US population over time",  
       subtitle = "Population in thousands",  
       x = "Date",  
       y = "Total population (in thousands)")  
  
base_fig
```



To change **all** text in the figure to serif, update the `text` option of the theme

```
base_fig +  
  theme(text = element_text(family = "serif"))
```

You can also change fonts for any component, e.g., `plot.title`, `axis.title`, ...



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## Gimme nicer FONTS, please

Base R has access to a limited number of font families

R family	Font (Win)
sans	Arial
serif	Times New Roman
mono	Courier
symbol	Σψμβθλ

These can be rendered in plain face, **bold**, *italic*, or **bold italic**

Google fonts has ~1600 font families



The `showtext` package is among the easiest for using custom fonts  
<https://cran.rstudio.com/web/packages/showtext/vignettes/introduction.html>

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## showtext package

Setup:

```
library(showtext)  
## Load some Google fonts (https://fonts.google.com/)  
# args: Google name, R name  
font_add_google("Gochi Hand", "gochi")  
font_add_google("Schoolbell", "bell")  
  
## Automatically use showtext to render text  
showtext_auto()
```

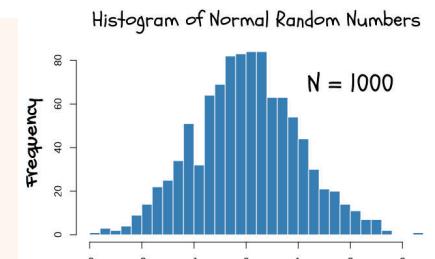
Fonts are actually registered with the `sysfonts` package

Any local font can be registered with `font_add()`

```
font_add("Times New Roman")
```

Use in a histogram (base R):

```
set.seed(123)  
hist(rnorm(1000), breaks = 30,  
     col = "steelblue", border = "white",  
     main = "", xlab = "", ylab = "")  
title("Histogram of Normal Random Numbers",  
      family = "bell", cex.main = 2)  
title(ylab = "Frequency",  
      family = "gochi", cex.lab = 2)  
text(2, 70, "N = 1000", family = "bell", cex = 2.5)
```



## showtext demo

```
library(showtext); library(glue)
font_add_google('Lora', 'lora')
font_add_google('Lobster', 'lobster')
font_add_google('Anton', 'anton')
font_add_google('Fira Sans', 'firasans')
font_add_google('Syne Mono', 'syne')
# Enable showtext font rendering!
showtext_auto()

tib <- tibble(
  family = c('firasans', 'lora', 'lobster', 'anton', 'syne'),
  x = 0,
  y = seq(.9, .1, length.out = 5),
  label = glue('Showtext {family}. What a font!'))

tib |>
  ggplot(aes(x, y, label = label)) +
  geom_text(family = tib$family,
            size = 12, hjust = 0, col = 'dodgerblue4') +
  coord_cartesian(xlim = c(0, 1), ylim = c(0, 1)) +
  theme_void() +
  theme(plot.background = element_rect(fill = grey(.90)))
```

Add a bunch of fonts

Showtext firasans. What a  
Showtext lora. What a fo  
**Showtext lobster. What a font!**  
**Showtext anton. What a font!**  
Showtext syne. What a

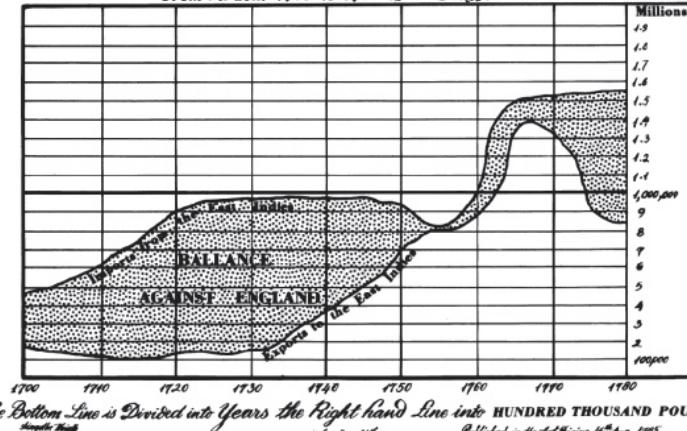
Example from: [https://albert-rapp.de/posts/ggplot2-tips/08\\_fonts\\_and\\_icons/08\\_fonts\\_and\\_icons.html](https://albert-rapp.de/posts/ggplot2-tips/08_fonts_and_icons/08_fonts_and_icons.html)

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## Re-visioning old masters in ggplot2

In the *Commercial and Political Atlas*, William Playfair used charts of imports and exports from England to its trading partners to ask “How are we doing”?

CHART of EXPORTS and IMPORTS to and from the EAST INDIES  
From the Year 1700 to 1780 by W. Playfair



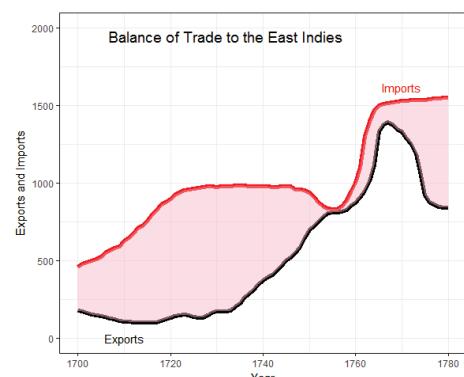
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## Playfair: Balance of trade charts

In the *Commercial and Political Atlas*, William Playfair used charts of imports and exports from England to its trading partners to ask “How are we doing”?

Here is a re-creation of one example, using ggplot2. How was it done?

```
> data(EastIndiesTrade, package="GDATaR")
> head(EastIndiesTrade)
Year Exports Imports
1 1700 180 460
2 1701 170 480
3 1702 160 490
4 1703 150 500
5 1704 145 510
6 1705 140 525
... ... ...
```



Code for this example: <https://friendly.github.io/6135/R/playfair-east-indies.R>

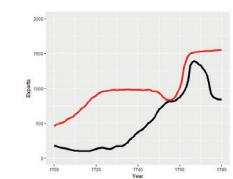
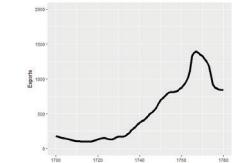
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## ggplot thinking

I want to plot two time series, & fill the area between them

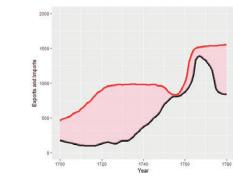
Start with a line plot of Exports vs. Year: **geom\_line()**  
Add a layer for the line plot of Imports vs. Year

```
c1 <-
ggplot(EastIndiesTrade, aes(x=Year, y=Exports)) +
  ylim(0,2000) +
  geom_line(colour="black", linewidth=2) +
  geom_line(aes(x=Year, y=Imports), colour="red", linewidth=2)
```



Fill the area between the curves: **geom\_ribbon()**  
change the Y label

```
c1 <- c1 +
  geom_ribbon(aes(ymin=Exports, ymax=Imports), fill="pink") +
  ylab("Exports and Imports")
```



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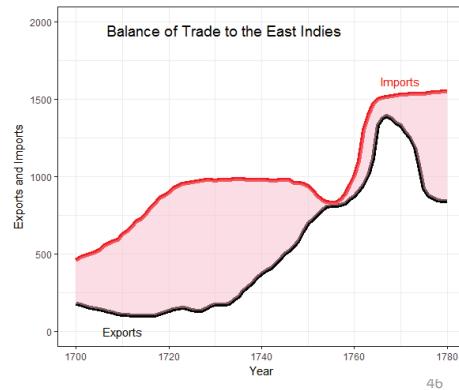
## Plot what you want to show

That looks pretty good. Add some text labels using `annotate()`

```
c1 <- c1 +  
  annotate("text", x = 1710, y = 0, label = "Exports", size=4) +  
  annotate("text", x = 1770, y = 1620, label = "Imports", color="red", size=4) +  
  annotate("text", x = 1732, y = 1950, label = "Balance of Trade to the East Indies", color="black", size=5)
```

Finally, change the theme to b/w

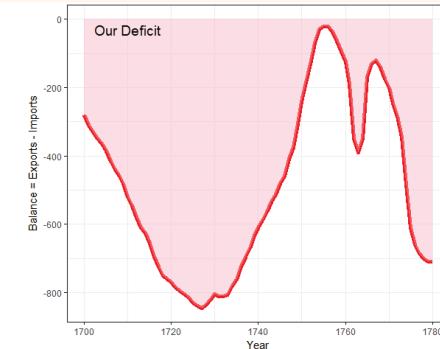
```
c1 <- c1 + theme_bw()
```



Playfair's goal was to show the **balance** of trade with different countries.  
Why not plot Exports – Imports directly?

```
c2 <-  
  ggplot(EastIndiesTrade, aes(x = Year, y = Exports - Imports)) +  
  geom_line(colour="red", linewidth=2) +  
  ylab("Balance = Exports - Imports") +  
  geom_ribbon(aes(ymin=Exports-Imports, ymax=0), fill="pink", alpha=0.5) +  
  annotate("text", x = 1710, y = -30, label = "Our Deficit", color="black", size=5) +  
  theme_bw()
```

`aes(x=, y=)` can use expressions calculated from data variables



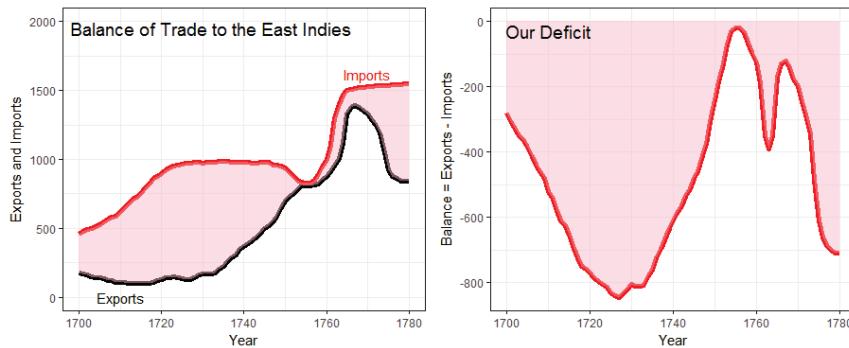
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## Composing several plots

ggplot objects use grid graphics for rendering

The `gridExtra` package has functions for combining or manipulating grid-based graphs

```
library(gridExtra)  
grid.arrange(c1, c2, nrow=1)
```



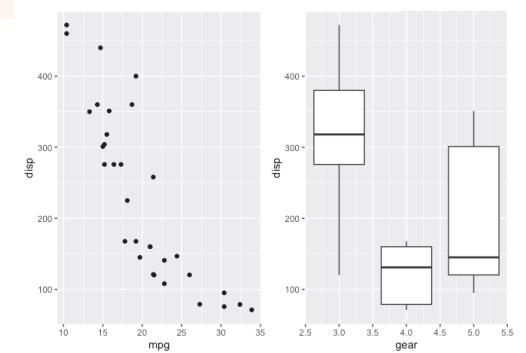
## General composing: patchwork



The `patchwork` package provides a new, complete syntax for plot compositions

```
library(patchwork)  
p1 <- ggplot(mtcars) + geom_point(aes(mpg, disp))  
p2 <- ggplot(mtcars) + geom_boxplot(aes(gear, disp, group = gear))
```

```
p1 + p2
```



Details at: <https://patchwork.data-imaginist.com/>

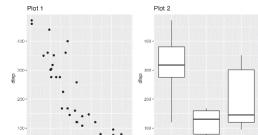
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# General composing: patchwork

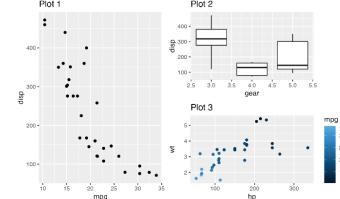


The **patchwork** package provides a new, complete syntax for plot compositions

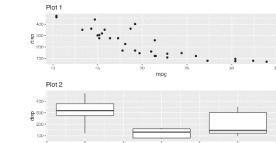
p1 + p2  
side-by-side



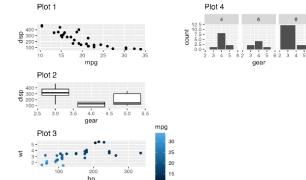
p1 + (p2 / p3)  
grouping



p1 / p2  
up/down



p1 + p2 + p3 + p4 +  
plot\_layout(nrow=3)  
fancy layouts



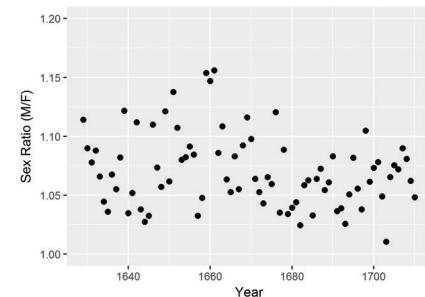
Details at: <https://patchwork.data-imaginist.com/>

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## Building a custom graph

```
ggplot(Arbuthnot, aes(x=Year, y=Ratio)) +
  ylim(1, 1.20) +
  ylab("Sex Ratio (M/F)") +
  geom_point(pch=16, size=2)
```

Start with a basic scatterplot,  
Ratio vs. Year



R script for this example:  
<https://friendly.github.io/6135/R/arbuthnot-gg.R>

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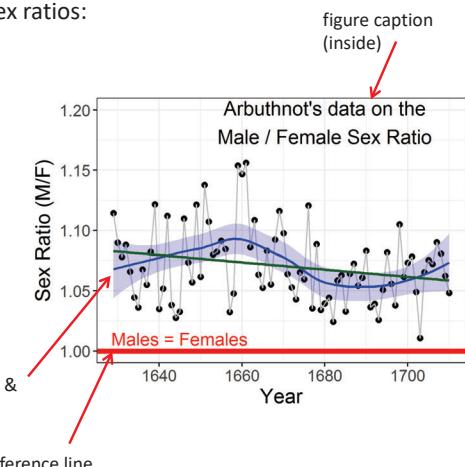
## Arbuthnot's data on birth ratios

Custom graphs can be constructed by adding graphical elements (points, lines, text, arrows, etc.) to a basic ggplot()

John Arbuthnot: data on male/female sex ratios:

```
> data(Arbuthnot, package="HistData")
> head(Arbuthnot[,c(1:3,6,7)])
  Year Males Females Ratio Total
1 1629  5218   4683 1.114 9.901
2 1630  4858   4457 1.090 9.315
3 1631  4422   4102 1.078 8.524
4 1632  4994   4590 1.088 9.584
5 1633  5158   4839 1.066 9.997
6 1634  5035   4820 1.045 9.855
...
...
```

Arbuthnot didn't make a graph. He simply calculated the probability that in 81 years from 1629–1710, the sex ratio would **always** be > 1  
The first significance test!

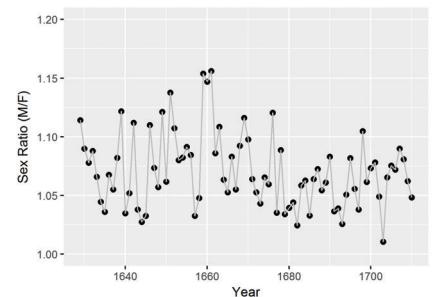


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## Building a custom graph

```
ggplot(Arbuthnot, aes(x=Year, y=Ratio)) +
  ylim(1, 1.20) +
  ylab("Sex Ratio (M/F)") +
  geom_point(pch=16, size=2) +
  geom_line(color="gray")
```

Connect points with a line



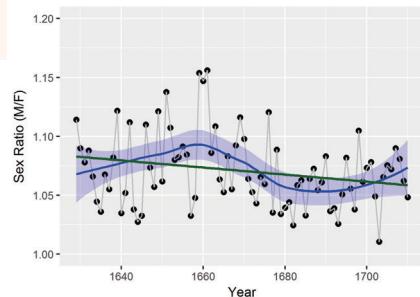
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## Building a custom graph

```
ggplot(Arbuthnot, aes(x=Year, y=Ratio)) +  
  ylim(1, 1.20) +  
  ylab("Sex Ratio (M/F)") +  
  geom_point(pch=16, size=2) +  
  geom_line(color="gray") +  
  geom_smooth(method="loess", color="blue",  
    fill="blue", alpha=0.2) +  
  geom_smooth(method="lm", color="darkgreen",  
    se=FALSE)
```

```
# save what we have so far  
arbuth <- last_plot()
```

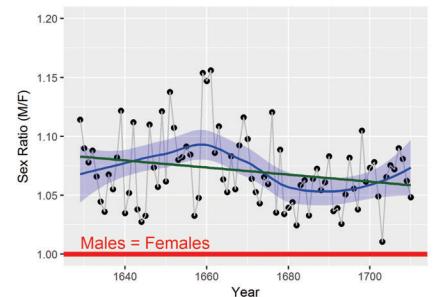
- Add smooths:
- loess curve
  - linear regression line



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```
arbuth +  
  geom_hline(yintercept=1, color="red", linewidth=2) +  
  annotate("text", x=1645, y=1.01, label="Males = Females", color="red", size=5)
```

- Add horizontal reference line & text label

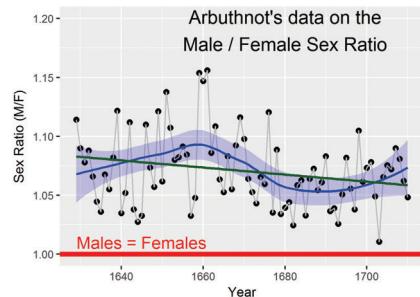


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## Building a custom graph

```
arbuth +  
  geom_hline(yintercept=1, color="red", linewidth=2) +  
  annotate("text", x=1645, y=1.01, label="Males = Females", color="red", size=5) +  
  annotate("text", x=1680, y=1.19,  
    label="Arbuthnot's data on the\nMale / Female Sex Ratio", size=5.5)
```

Add figure title (but inside!)

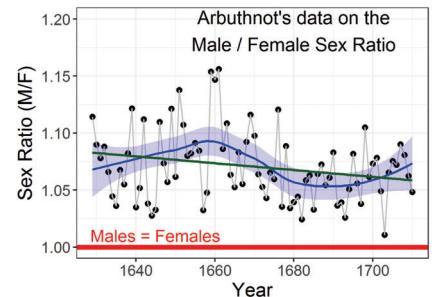


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```
arbuth +  
  geom_hline(yintercept=1, color="red", linewidth=2) +  
  annotate("text", x=1645, y=1.01, label="Males = Females", color="red", size=5) +  
  annotate("text", x=1680, y=1.19,  
    label="Arbuthnot's data on the\nMale / Female Sex Ratio", size=5.5) +  
  theme_bw() + theme(text = element_text(size = 16))
```

## Building a custom graph

Change the theme and font size

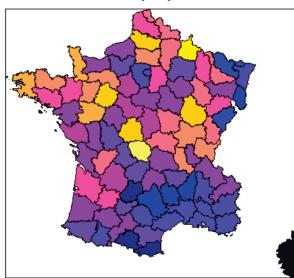


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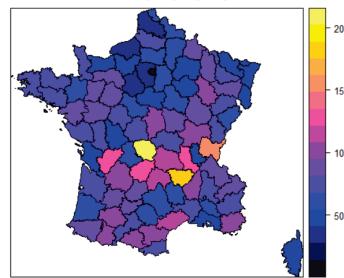
# Guerry: Moral statistics of France



Persons per personal crime



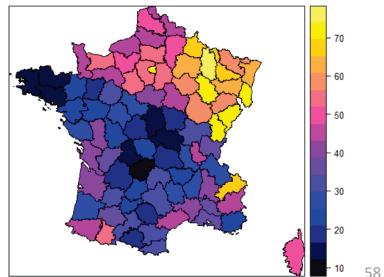
Persons per property crime



Guerry (1833) made shaded maps of France to determine if crime was related to literacy & other factors

```
library(Guerry)
library(sp)
spplot(gfrance, "Crime_pers")
spplot(gfrance, "Crime_prop")
spplot(gfrance, "Literacy")
```

Literacy (% Read & Write)



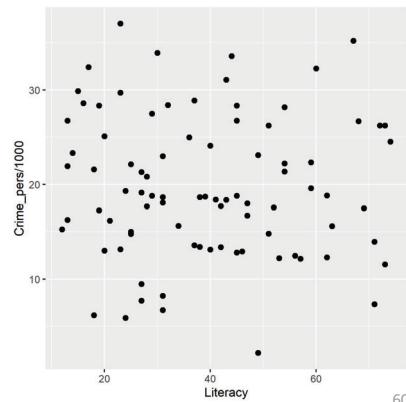
## Building Guerry's plots

```
data(Guerry, package = "Guerry")
ggplot(aes(x=Literacy, y=Crime_pers/1000), data=Guerry) +
  geom_point(size=2)
```

Start with a basic scatterplot

(Crime\_pers = # of persons per crime against persons.  
I divide by 1000 to keep the axis labels short)

Could also use scales::unit\_format("k", 1e-3) to get  
10k, 20k, 30k



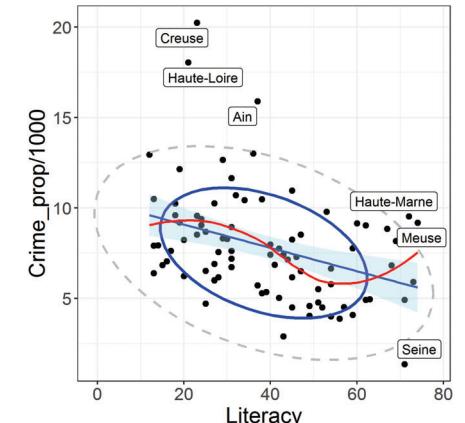
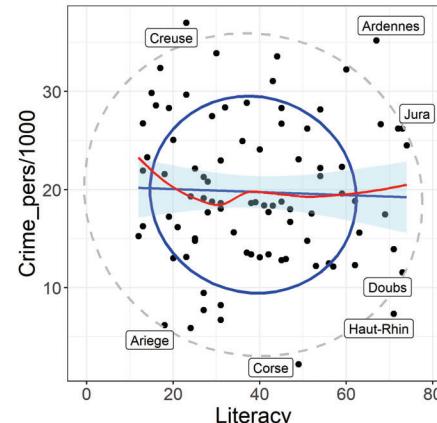
R script:  
<https://friendly.github.io/6135/R/ggGuerry.R>

# Consulting for Guerry



Guerry: Mes cartes sont très jolies, non? But how can I go further?

MF: Make scatterplots! Add smooths & data ellipses. See you next week at Café Lillas  
Guerry: Les boissons sont pour moi, mon ami!



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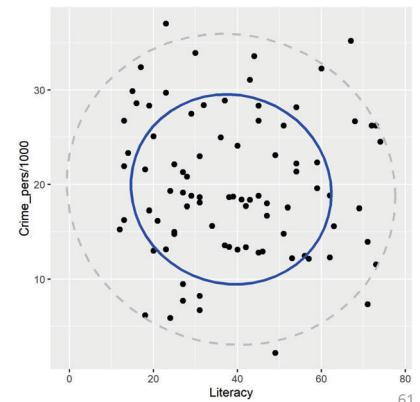
## Building Guerry's plots

```
ggplot(aes(x=Literacy, y=Crime_pers/1000), data=Guerry) +
  geom_point(size=2) +
  stat_ellipse(level=0.68, color="blue", linewidth=1.2) +
  stat_ellipse(level=0.95, color="gray", linewidth=1, linetype=2)
```

Add data ellipses to show correlation

- 68%  $\sim$  mean  $\pm$  1 sd
- 95%  $\sim$  mean  $\pm$  2 sd

(Default: geom="path" for stat\_ellipse  
Use geom="polygon" for filled ellipses)



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## Guerry's plots: Add smooths

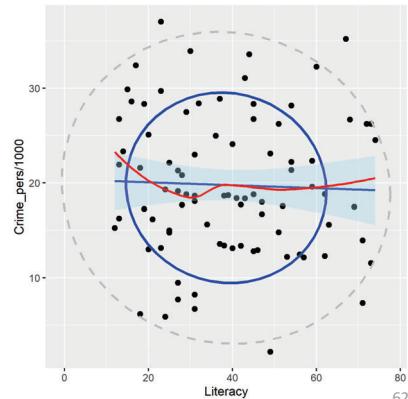
```
ggplot(aes(x=Literacy, y=Crime_pers/1000), data=Guerry) +
  geom_point(size=2) +
  stat_ellipse(level=0.68, color="blue", linewidth=1.2) +
  stat_ellipse(level=0.95, color="gray", linewidth=1, linetype=2) +
  geom_smooth(method="lm", formula=y~x, fill="lightblue") +
  geom_smooth(method="loess", formula=y~x, color="red", se=FALSE)
```

Add lm() and loess() smooths

- lm shows regression slope
- loess diagnoses possible non-linearity

Coffee break: save the current plot object

```
gplot <- last.plot()
```



## Guerry's plots: Labeling

Guerry: OK, but I see some **unusual** points. What are they?

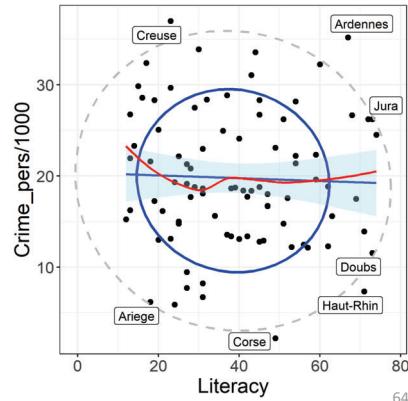
MF: Need to calculate “unusualness” – Mahalanobis  $D^2$  squared distance from centroid

```
gdf <- Guerry[, c("Literacy", "Crime_pers", "Department")]
gdf$dsq <- gdf$dsq <- heplots::Mahalanobis(gdf[, 1:2])
```

$$D^2 = (x - \bar{x})' S^{-1} (x - \bar{x})'$$

```
library(ggrepel)
gplot +
  theme_bw() +
  theme(text = element_text(size=18)) +
  geom_label_repel(aes(label=Department),
    data = gdf[gdf$dsq > 4.6,])
```

$(D^2 \sim \chi^2 \text{ w/ } 2 \text{ df, so } \Pr(D^2 > 4.6) = 0.10)$



## Guerry's plots: Styling

Guerry: I want to publish this! But ditch that grey background & make text larger

```
gplot <- last_plot()
gplot + theme_bw() +
  theme(text = element_text(size=18))
```

Could also use:

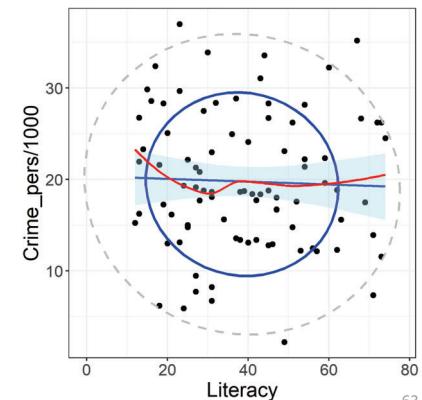
```
gplot + theme_bw(base_size=18)
```

MF:

- I'll change the basic theme to theme\_bw()
- Increase the font size for all text
- You can change the style of anything you want
- I'll create a theme\_Guerry() you can use in all your graphs

Guerry:

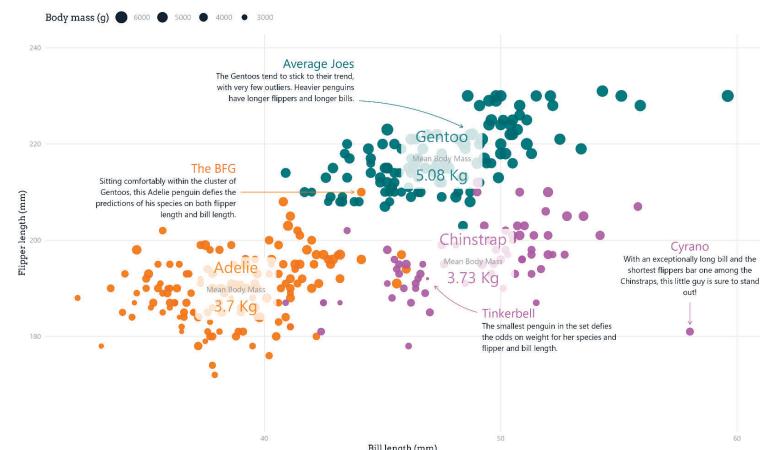
- Looking better, mon ami



## Penguin tour-de-force

Perfectly proportional penguins - with a few exceptions!

Typically, the heavier the penguin, the longer its flippers and bill. The proportions within each species are also very consistent. **Adelle** penguins tend to be the smallest penguins, with the shortest bills and flippers. **Chinstraps** have longer bills but not much longer flippers. The largest birds in this dataset, with the longest flippers, are the **Gentoo**.

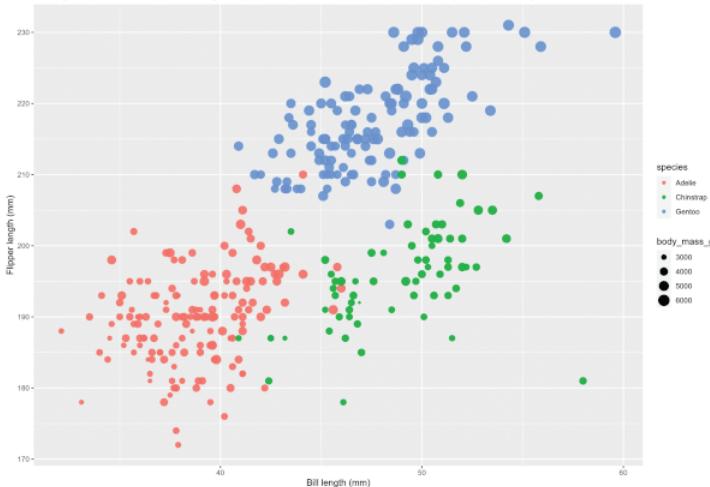


Thompson, Cara. 2022. “Level Up Your Labels: Tips and Tricks for Annotating Plots.” <https://www.cararthompson.com/talks/user2022>.

# Penguins: How this was made



Perfectly proportional penguins - with a few exceptions!  
 Typically, the heavier the penguin, the longer its flippers and bill. The proportions within each species are also very consistent!  
 Adelie penguins tend to be the lightest penguins, with the shortest bills and flippers. Chinstraps have longer bills but not much longer flippers.  
 The largest birds in this dataset, with the longest flippers, are the Gentoo. The proportions within each species are also very consistent!



**camcorder** pkg  
makes a GIF  
animation of steps  
in constructing a  
graph

Thompson, Cara. 2022. "Level Up Your Labels: Tips and Tricks for Annotating Plots."

<https://www.cararthompson.com/talks/user2022>.

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# Beyond 2D: Contour plots

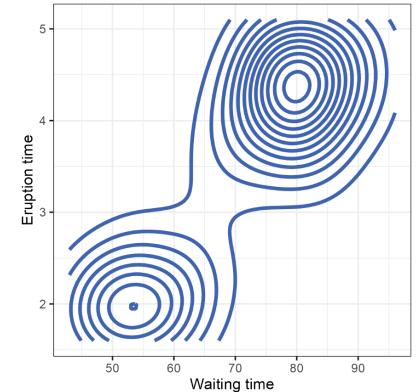
Data on eruptions of geysers at Old Faithful (Yellowstone Natl Park)

```
p <- ggplot(faithful, aes(waiting, eruptions))  
  
p + geom_density_2d(linewidth=1.2) +  
  labs(x = "Waiting time",  
       y = "Eruption time")
```

**geom\_density\_2d()** calculates  
relative frequency (density) over a grid of  
X, Y values

It plots contours of equal density

```
> str(faithful)  
'data.frame': 272 obs. of 2 variables:  
 $ eruptions: num 3.6 1.8 3.33 2.28 4.53 ...  
 $ waiting : num 79 54 74 62 85 55 88 85 51 85 ...
```

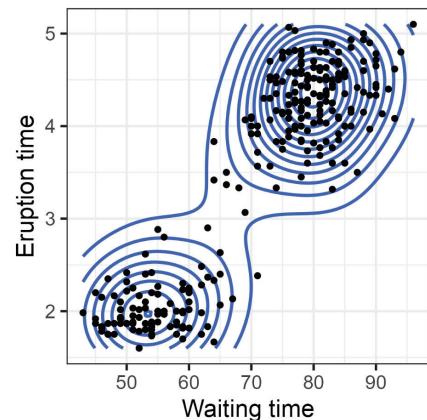


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## Contours: add another layer

We also want to see the data: add points

```
p + geom_density_2d() +  
  geom_point() +  
  labs(x = "Waiting time",  
       y = "Eruption time") +  
  theme_bw(base_size = 16)
```



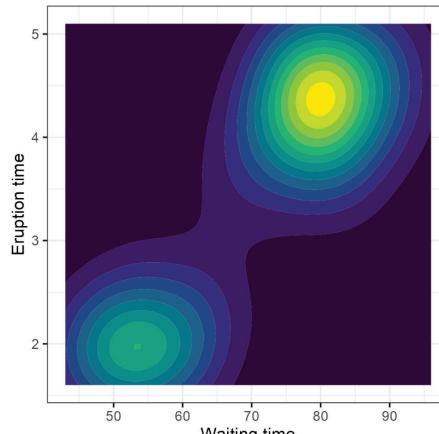
Note use of **base\_size** to  
control all size elements

Layers add "ink" so consider their  
order: I added points last

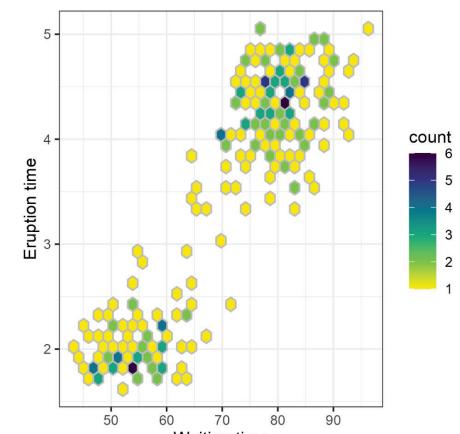
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## Other forms: Filled contours, hex bins

```
p +  
  geom_density_2d_filled(show.legend = FALSE)
```



```
p +  
  geom_hex(bins=30, color="gray") +  
  scale_fill_viridis_c(direction = -1) +
```



# Real 3D: rayshader



The rayshader package produces stunning 3D visualizations of X, Y, Z data (Z ("elevation") data above an X, Y plane)

Allows:

- photo-realistic lighting & shading
- animation
- camera motion
- cinematic depth of field



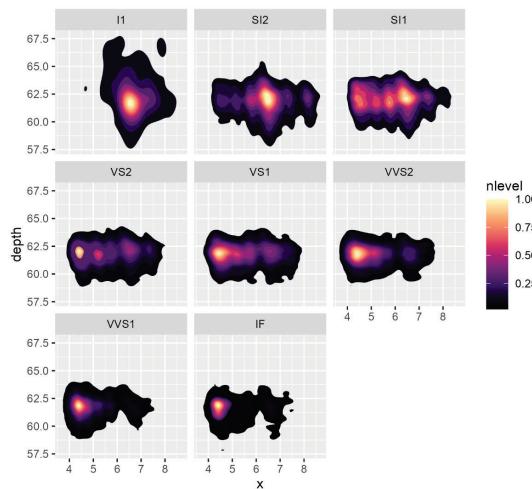
computationally intensive

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Give your data the full 3D treatment (if you dare)

```
ggdiamonds <-  
  ggplot(diamonds, aes(x, depth)) +  
  stat_2d_density(...) +  
  facet_wrap(clarity ~ .)
```

"Please Ma, can I have it in 3D?"

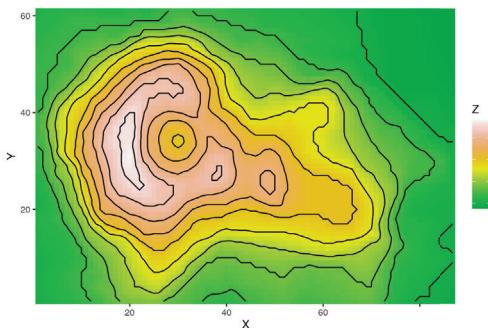


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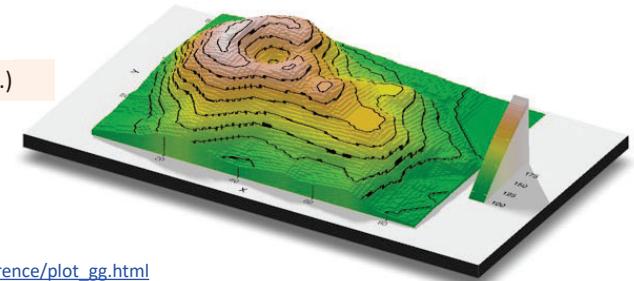
# rayshader::plot\_gg()



A volcano:



```
plot_gg(ggvolcano, ...)
```

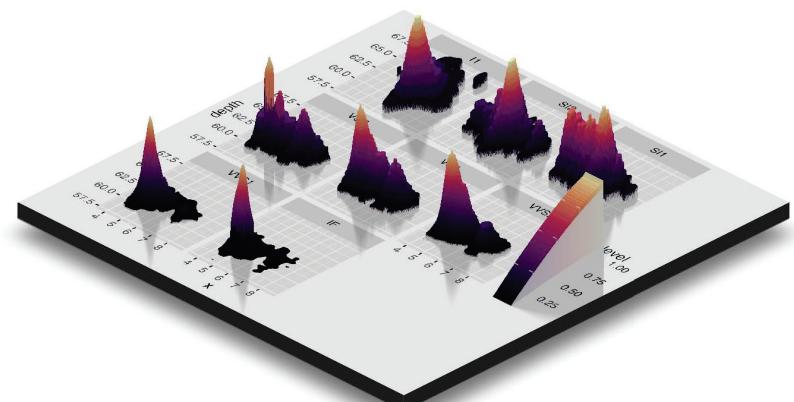


From: [https://www.rayshader.com/reference/plot\\_gg.html](https://www.rayshader.com/reference/plot_gg.html)

Give your data the full 3D treatment (if you dare)

```
ggdiamonds <-  
  ggplot(diamonds, aes(x, depth)) +  
  stat_2d_density(...) +  
  facet_wrap(clarity ~ .)
```

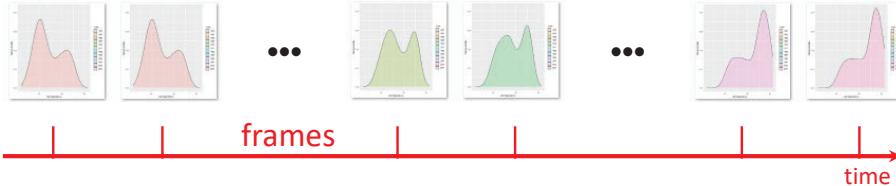
```
plot_gg(ggdiamonds, zoom = 0.55,  
        phi = 30, ...)
```



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# Animation

An animation is a sequence of frames showing a series of related images



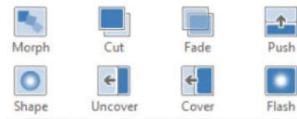
Frames can be based on:

- data subsets (year)
- plot attributes (color, shape)
- plot elements or layers
- ...

Enter / exit types:

- fade
- grow / shrink
- fly / drift

Transition effects:



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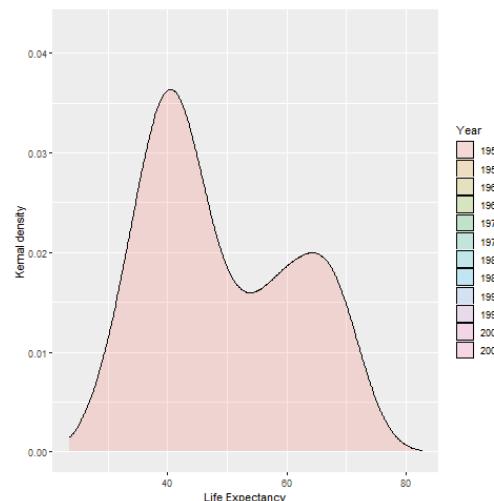
## Make it an animation

Frames are defined by `transition_*` functions

`enter_*`, `exit_*`, `ease_*` functions define the change between transition states

```
p +  
  transition_time(year) +  
  ease_aes('linear')
```

```
anim_save("gap-anim.gif",  
         nframes=20)
```



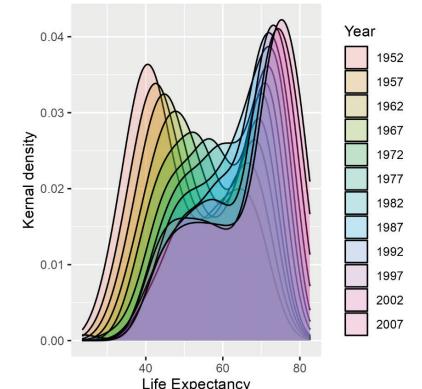
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# Animation with gganimate

Draw density curves for life expectancy over years

-- separate curve for each year

```
data(gapminder, package="gapminder")  
p <- gapminder %>%  
  ggplot(aes(lifeExp, fill = factor(year))) +  
  geom_density(alpha=.2) +  
  xlab("Life Expectancy") +  
  ylab("Kernal density") +  
  guides(fill = guide_legend(title = "Year"))  
plot(p)
```



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## Frames: `transition_*`()

`transition_*`()

We're cycling between values of `color`, ...

`transition_states()`

a + `transition_states(color, transition_length = 3, state_length = 1)`

... and spending 3 times as long going to the next cut as we do pausing there.

`transition_time()`

b + `transition_time(year, range = c(2002L, 2006L))`

...from 2002 to 2006 (range is optional; default is the whole time frame). Unlike `transition_states()`, `transition_time()` treats the data as continuous and so the transition length is based on the actual values. Using 2002L instead of 2002 because the underlying data is an integer.

`transition_reveal()`

c + `transition_reveal(date)`

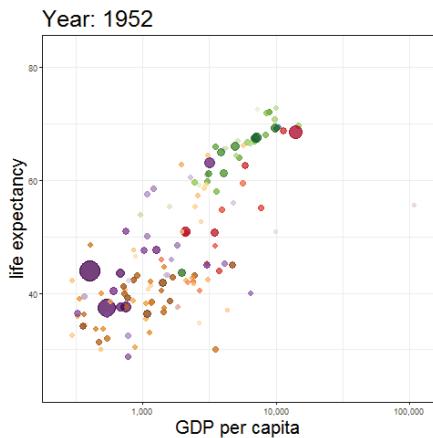
We're adding each `date` of the data on top of 'old' data

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## transition\_time()

The classic Rosling moving bubble plot

```
plt <-  
ggplot(gapminder,  
       aes(x = gdpPercap, y = lifeExp,  
            size = pop, colour = country)) +  
  geom_point(alpha = 0.7) +  
  scale_colour(values=country_colors) +  
  scale_size(range = c(2, 15)) +  
  scale_x_log10(labels = scales::comma) +  
  theme_bw() +  
  theme(legend.position = "none",  
        plot.title = element_text(size = 25),  
        axis.title = element_text(size = 20 ))  
  
plt +  
  labs(title = 'Year: {frame_time}') +  
  transition_time(year) +  
  ease_aes('linear')
```

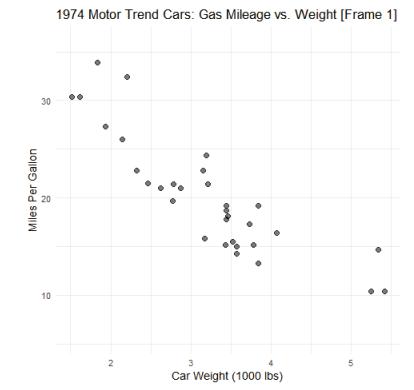


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## transition\_layers()

transition\_layers(): Add layers or geoms one at a time

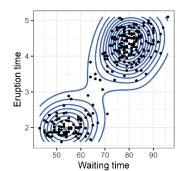
```
ggplot(mtcars, aes(y=mpg, x=wt)) +  
  geom_point(size=3, alpha=0.5) +  
  labs(x="Car Weight (1000 lbs)",  
       y="Miles Per Gallon") +  
  ggtitle("1974 Motor Trend Cars: Gas Mileage  
          vs. Weight [Frame {frame}])" +  
  theme_minimal(base_size = 14) +  
  geom_smooth(method = "lm", color="red") +  
  geom_smooth(method = "loess", color="blue") +  
  
# do the animation, by layers  
transition_layers() +  
  enter_fade() +  
  enter_grow()
```



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## Summary

- Understand ggplot components
  - aes(): map data variables to visual features
  - geoms, stats, scales, ...
  - think in terms of layers:
    - + geom\_point(), + geom\_line(), + geom\_smooth()
  - themes
    - basic themes, extension packages
    - theme components, custom themes
    - **FONTS**: use showtext
- Going beyond 2D: contour/density plots
- Animation: transitions over frames



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