An Introduction to R Graphics

Part II—ggplot2

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ggplot2 Basics

- Idea is that there are several different components that come together to produce a plot.
- These can be thought about and specified independently.
- Breaking a plot down into these components provides structure—a system—to the task of visualizing data.
- Arguably, this makes coding plots easier and more intuitive. Less arguably, it makes the software more flexible and powerful than other systems such as base graphics and lattice.
- `ggplot2` also takes care of some details automatically (like legends) and has nice defaults. These features simplify the task of coding a plot.

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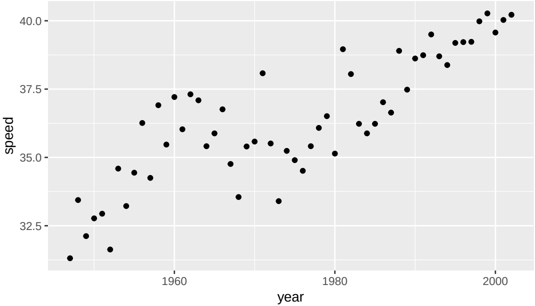
ggplot2 Basics

- There are at least eight components that can be manipulated separately in `ggplot2`, but we start with the three most important:
  - A data frame;
  - One or more geometrical representations (`geom`);
  - A mapping of the data to aesthetic (`aes`) features of the `geom`.

```r
# load ggplot2 and get some data:
require(ggplot2); data(Cars93,package="MASS"); source("https://tinyurl.com/une4s3g/getData_3.R")
# Now create a simple plot:
ggplot(tdf, mapping=aes(x=year,y=speed)) + geom_point()
```



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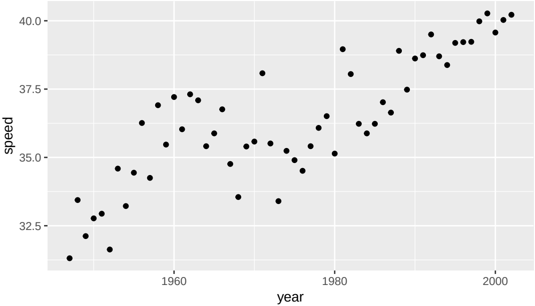

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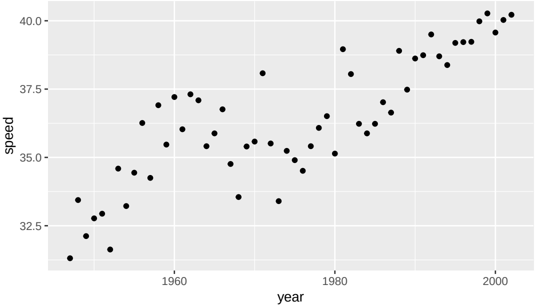

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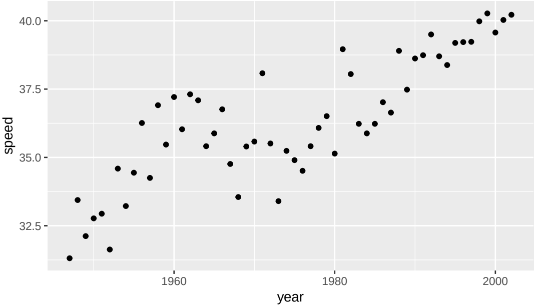
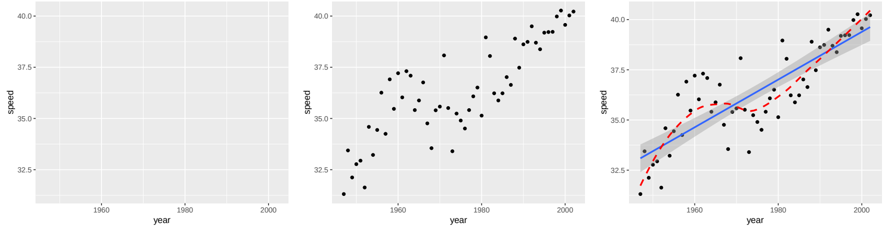


ggplot2 Basics

- Let’s re-draw the plot step-by-step and we’ll add fitted curves.
- Notice ‘`ggplot()` just draws axes where `aes()` identifies the x and y variables.
- Additional features are added (literally, with a `+` operator).
- There are many `geom` functions.
    - `geom_point()` adds points. `geom_smooth()` adds a lowess curve (the default) and a least squares fit.
    - The x and y variables are inherited from the call to `ggplot()`.

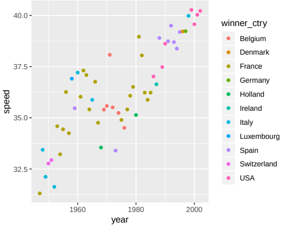
```
p1 <- ggplot(tdf, mapping=aes(x=year,y=speed)); p1
p2 <- p1 + geom_point(); p2
p3 <- p2 + geom_smooth(method=lm) + geom_smooth(color="red", linetype="dashed", se=FALSE); p3
```

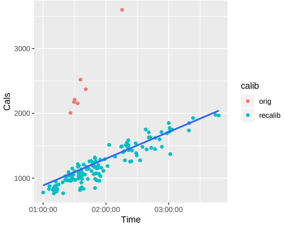


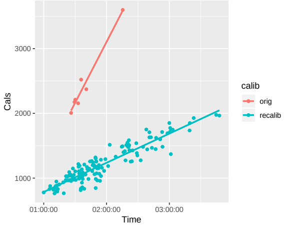
Aesthetics

- Aesthetic mappings always involve data. They determine how data influences the features of the plot.
- In many plots a single aesthetic mapping will be made in the initial call to ‘`ggplot()`. Subsequent functions (such as `geom` functions) **inherit** the mapping by default, but can also have their own `aes()` mappings to accomplish certain effects.

```r
ggplot(tdf, mapping=aes(x=year,y=speed,color=winner_ctry)) + geom_point()
ggplot(fred, mapping=aes(x=Time,y=Cals)) +
  geom_point(mapping=aes(color=calib)) + geom_smooth(method=lm,se=FALSE)
ggplot(fred, mapping=aes(x=Time,y=Cals,color=calib)) +
  geom_point() + geom_smooth(method=lm,se=FALSE)
```







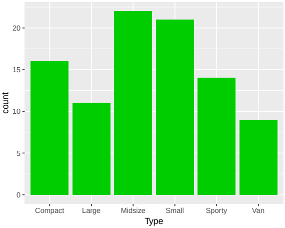
Aesthetics

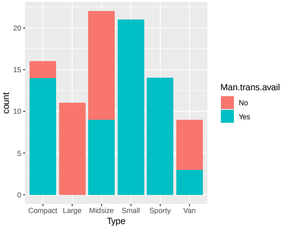
- There are several aesthetic features that can be mapped or set.
- Some roughly correspond to graphical parameters in base, but they differ and graphical parameters are not used in `ggplot2`.
    - `colour` (or `color`) and `fill`: Can take numbers or names with same values as used in base graphics.
    - `linetype`: Corresponds to and takes same values as `lty` in base graphics.
    - `size`: Width in mm. Corresponds to `lwd` in base.
    - `linejoin` and `lineend`: affect appearance of line joins (corners) and ends. Hard to see these effects unless you're using wide lines.
    - `shape`: Controls plotting symbols. Corresponds to and takes same values as `pch` in base graphics.
    - `family`: Controls font. Choices are `"sans"`, `"serif"`, or `"mono"`. Others can be implemented via secondary packages.
    - `fontface`: Controls font appearance. Choices are `"plain"`, `"bold"`, `"italic"`, `"bold.italic"`.
    - `hjust`, `vjust`: Control justification. Each take a number $\in [0, 1]$ or a string (`"top"`, `"middle"`, `"bottom"`, `"left"`, `"center"`, `"right"`).

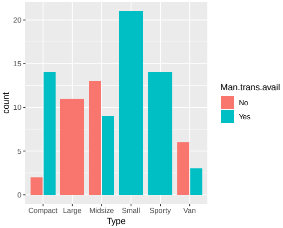
Mapping vs Setting Aesthetic Features

- Specifying a feature inside `aes()` *maps* the feature to a variable. To *set* the feature to a constant value, use it outside `aes()`.
- Bar charts are implemented with `geom_bar()`.
    - The 1st plot shows a univariate distribution, with `fill` set to a constant.
    - In the 2nd and 3rd plots, it is mapped to show a joint distribution.
    - Notice only `x` is specified in `aes()` for these plots.

```
ggplot(Cars93, aes(x=Type)) + geom_bar(fill="green3") # color and fill are set to constant values here (not in aes() function)
ggplot(Cars93, aes(x=Type,fill=Man.trans.avail)) + geom_bar() # stacked bars
# Previous line gives same result as next one (comented out):
# ggplot(Cars93, aes(x=Type)) + geom_bar(aes(fill=Man.trans.avail)) # stacked bars
ggplot(Cars93, aes(x=Type,fill=Man.trans.avail)) + geom_bar(position="dodge2") # clustered bars
```







geom Functions

- There are many functions that add geometric features (layers) to a plot.
- The ones below are part of ggplot2. Others are available in secondary packages.

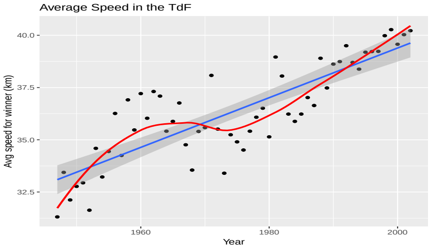
```
  geom_abline geom_density_2d  geom_linerange      geom_rug
    geom_area  geom_density2d        geom_map  geom_segment
     geom_bar    geom_dotplot       geom_path       geom_sf
   geom_bin2d   geom_errorbar      geom_point geom_sf_label
   geom_blank  geom_errorbarh geom_pointrange  geom_sf_text
 geom_boxplot    geom_freqpoly    geom_polygon   geom_smooth
     geom_col        geom_hex         geom_qq    geom_spoke
 geom_contour  geom_histogram    geom_qq_line     geom_step
   geom_count      geom_hline   geom_quantile     geom_text
geom_crossbar     geom_jitter     geom_raster     geom_tile
   geom_curve      geom_label       geom_rect   geom_violin
 geom_density       geom_line     geom_ribbon    geom_vline
```

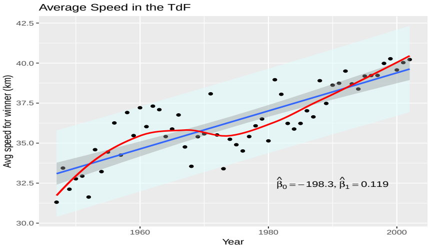
geom Functions

- geoms will use the data set specified in the ggplot() function or can use a different data set.

```
frame <- ggplot(tdf, aes(x=year,y=speed)) +
  xlab("Year") + ylab("Avg speed for winner (km)") + ggtitle("Average Speed in the TdF")
frame + geom_point() + geom_smooth(method="lm") + geom_smooth(se=FALSE,color="red")

# Here we add more features using geoms that use data from other data frames:
tdf.lm1.pi <- predict( lm(speed~year,data=tdf), interval="prediction") #don't worry about warning
pi.df <- data.frame(year=tdf$year, l.plim=tdf.lm1.pi[,2], u.plim=tdf.lm1.pi[,3])
txt.df <- data.frame(x=1990, y=32.5, txt = "list(hat(beta)[0]==-198.3,hat(beta)[1]==0.119 )" )
frame + geom_ribbon(data=pi.df, mapping=aes(x=year,ymin=l.plim,ymax=u.plim),
                    inherit.aes=F, fill="lightcyan", alpha=.5) + # alpha controls transparancy
  geom_point() + geom_smooth(method="lm") + geom_smooth(se=FALSE,color="red") +
  geom_text(data=txt.df,mapping=aes(x,y,label=txt),parse=T) # can avoid making txt.df with annotate() fn commented out below
#  annotate(geom="text", x=1990, y=32.5, label = "list(hat(beta)[0]==-198.3,hat(beta)[1]==0.119 )",parse=T )
```

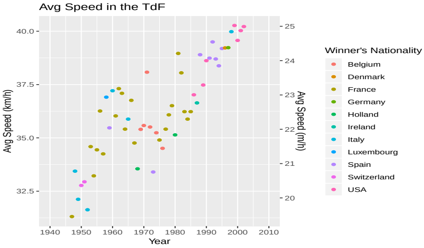




Modifying Axes and Scales

- In the previous example I used `ggtitle()` for a title and `xlab()` and `ylab()` for axis labels.
    - A more general function, `labs()`, can add title, subtitle, figure caption, and labels for aesthetics, which are useful because they appear in the legend.
- There are `xlim()` and `ylim()` functions to control the ranges of the axes.
- Functions like `xlab()` and `xlim()` are convenient, but can be replaced by a `scale` function.

```
ggplot(tdf, mapping=aes(year, speed, color=winner_ctry)) + geom_point() + labs(color="Winner's Nationality",title="Avg Speed in the TdF") +
  scale_x_continuous(name="Year", limits=c(1940,2010), breaks=seq(1940,2010,by=10), labels=as.character(seq(1940,2010,by=10))) +
  scale_y_continuous("Avg Speed (km/h)", sec.axis=sec_axis(~.*.6214,name="Avg Speed (m/h)"))
```



Scales

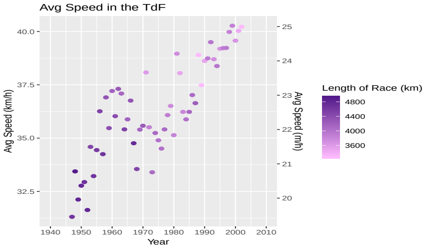
- As mentioned previously, `ggplot2` builds plots by combining components that can be manipulated separately. Scales are one of these components.
- The plot components are
  - data frames,
  - geometrical representations,
  - aesthetic mappings,
  - scales,
  - statistics from the data to be mapped,
  - position adjustments,
  - a coordinate system,
  - a faceting scheme.
- In addition, the overall appearance and some specific features are controlled by a `theme`.

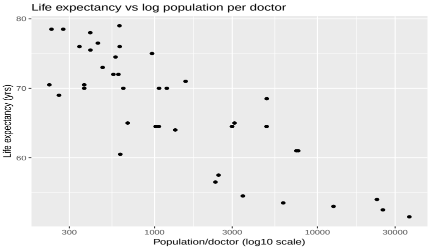
Scales

- Scales are functions that control the mapping from data to an aesthetic.
    - Every aesthetic has one; default scales are used but can be overridden/modified by using a `scale` function or functions like `xlab()` and `xlim()`.

```
ggplot(tdf, mapping=aes(year, speed, color=distance)) + geom_point(shape=19,size=2) + ggtitle("Avg Speed in the TdF") +
  scale_x_continuous(name="Year", limits=c(1940,2010), breaks=seq(1940,2010,by=10), labels=as.character(seq(1940,2010,by=10))) +
  scale_y_continuous("Avg Speed (km/h)", sec.axis=sec_axis(~.*.6214,name="Avg Speed (m/h)")) +
  scale_color_gradient("Length of Race (km)",low="Plum1",high="purple4")

ggplot(tvData, mapping=aes(x=popPerMD,y=lifeExpect)) + geom_point() +
  labs(title="Life expectancy vs log population per doctor",y="Life expectancy (yrs)") +
  scale_x_log10("Population/doctor (log10 scale)")
```





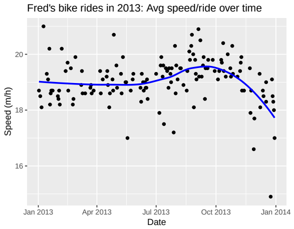
Scales

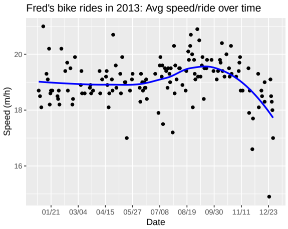
- Below we see the default scale for a variable of class `"Date"` (left).
- Next we modify that scale with the `scale_x_date()` function (middle).
- Finally, legends are generated only for mapped aesthetic features, so if we want to identify different `geoms` we have to map their aesthetics and create a suitable scale for those mappings (right).

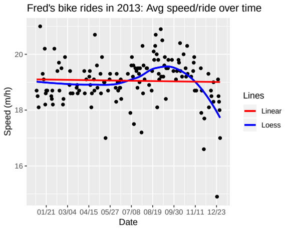
```
fred1 <-  ggplot(fred, mapping=aes(x=date,y=AvgSpd)) + geom_point() + geom_smooth(se=F,color="blue") +
  labs(title="Fred's bike rides in 2013: Avg speed/ride over time",y="Speed (m/h)",x="Date"); fred1

fred2 <- fred1 + scale_x_date(date_labels="%m/%d",date_breaks="6 weeks",limits=as.Date(c("2013-01-01","2013-12-31"))); fred2

fred2 + geom_smooth(se=F,mapping=aes(color="blue")) + geom_smooth(method="lm",se=F,mapping=aes(color="red")) +
  scale_colour_identity(name="Lines", breaks=c("red","blue"), labels=c("Linear","Loess"), guide="legend")
```







Coordinate Systems

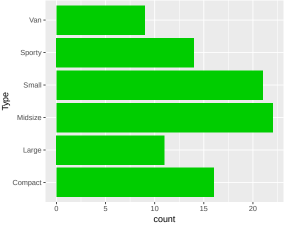
- The default and most common coordinate system is implemented in the `coord_cartesian()` function.
    - That is, in all our plots so far, there has been an implicit `+coord_cartesian()` added to our code.
- Other useful coordinate functions are
    - `coord_fixed()`, `coord_equal()`: implement fixed aspect ratio Cartesion coordinates.
    - `coord_flip()`: reverses the x and y variables.
    - `coord_map()`: for maps.
    - `coord_polar()`: polar coordinates.
    - `coord_trans()`: implements transformed Cartesian coordinates.

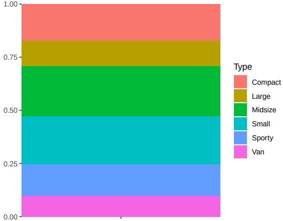
Coordinate Systems—Examples

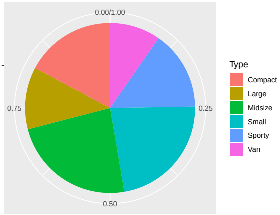
- Examples of `coord_flip()` and `coord_polar()`:

```
ggplot(Cars93, aes(x=Type)) + geom_bar(fill="green3") + coord_flip()

g <- ggplot(Cars93, aes(x="", fill=Type)) + geom_bar(width=1,position="fill") +
  scale_x_discrete(NULL, expand = c(0, 0)) + scale_y_continuous(NULL, expand = c(0, 0)); g
g + coord_polar(theta="y",start=0)
```





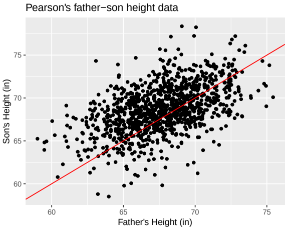


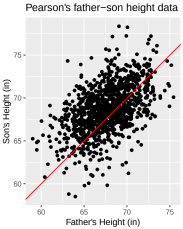
Coordinate Systems—Examples

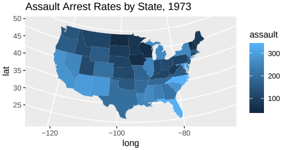
- Examples of `coord_equal()` and `coord_map()`. Note that the aspect ratio in these presentation slides is distorted.

```r
fs <- UsingR::father.son # Pearson's father-son height data
fs1 <- ggplot(fs,aes(x=fheight,y=sheight)) + geom_point() + geom_abline(slope=1,intercept=0,color="red")  +
  labs(x="Father's Height (in)",y="Son's Height (in)",title="Pearson's father-son height data"); fs1
fs1 + coord_equal()

# Example from help page for map_data() function from ggplot2 package:
states <- map_data("state"); arrests <- USArrests
names(arrests) <- tolower(names(arrests)); arrests$region <- tolower(rownames(USArrests))
choro <- merge(states, arrests, sort = FALSE, by = "region"); choro <- choro[order(choro$order), ]
ggplot(choro, aes(long, lat)) + geom_polygon(aes(group = group, fill = assault)) +
  coord_map("albers",  lat0 = 45.5, lat1 = 29.5) + ggtitle("Assault Arrest Rates by State, 1973")
```


Pearson's father−son height data


Pearson's father−son height data

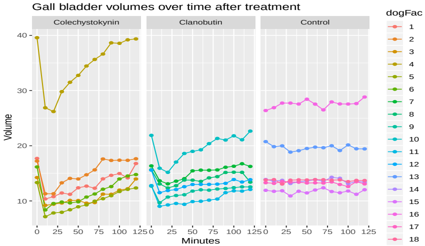

Assault Arrest Rates by State, 1973

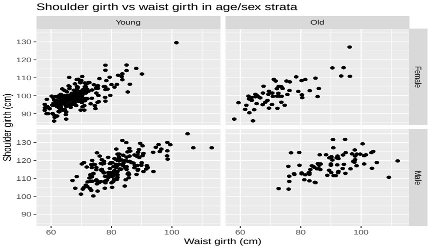
Facetting

- Facetting shows conditional relationships in paneled plots.
  - **facet_wrap()** builds plots at the level(s) of the conditioning variable(s) and adds them row-wise (**dir=h**) or column-wise (**dir=v**) to an array of plots.
  - With **facet_grid()**, plots in the grid are conditioned on a row value and a column value. These can each be values of a single variable or of combinations of variables.

```
gall$dogFac <- factor(gall$dogno); gall$trtfac <- factor(gall$trt,labels=c("Colechystokynin","Clanobutin","Control"))
ggplot(gall, aes(min,volume,group=dogFac,color=dogFac)) + geom_line() +  geom_point() +
  xlab("Minutes") + ylab("Volume") +  ggtitle("Gall bladder volumes over time after treatment") + facet_wrap(~trtfac, ncol = 3)

bodyDat$over34 <- factor(as.numeric(bodyDat$age>34),labels=c("Young","Old"))
ggplot(bodyDat,aes(x=waist_girth,y=should_girth)) + ggtitle("Shoulder girth vs waist girth in age/sex strata") +
  ylab("Shoulder girth (cm)") + xlab("Waist girth (cm)") +  geom_point() +  facet_grid(genderFac~over34)
```

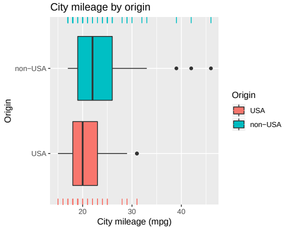


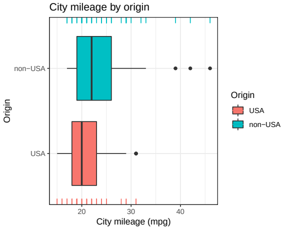


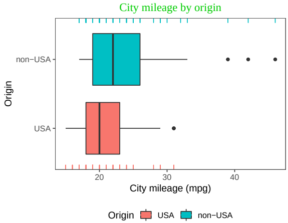
Themes

- The overall appearance of a plot is controlled by a theme. Themes control background color, font size and color, legend position, and much more.
- There are several complete themes in `ggplot2` with more in `ggthemes`.
    - The default theme is `theme_grey()`, but switching themes is easy by using other theme functions.
    - Alternatively, change specific elements in the current theme with `theme()`.

```
bp <- ggplot(Cars93) + geom_boxplot(aes(x = Origin, y = MPG.city, fill = Origin)) +
  ggtitle("City mileage by origin") + ylab("City mileage (mpg)") + coord_flip() +
  geom_rug(data=Cars93[Cars93$Origin!="USA",],mapping=aes(x=NULL,y=MPG.city,color=Origin), sides="t") +
  geom_rug(data=Cars93[Cars93$Origin=="USA",],mapping=aes(x=NULL,y=MPG.city,color=Origin), sides="b") +
  scale_colour_discrete(drop=FALSE) ; bp
bp + theme_bw()
bp + ggthemes::theme_few() + theme(legend.position="bottom", plot.title=element_text(family="serif",color="green3",hjust=.5))
```



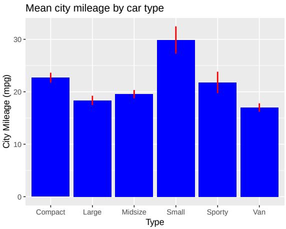


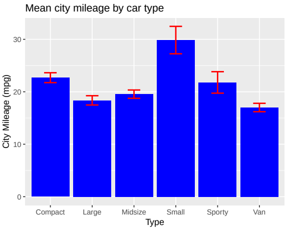


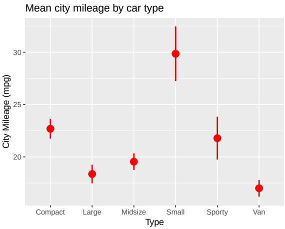
Examples—Bar Plots Showing Statistics by Group

- We've seen examples of bar plots showing (joint) distributions. For that we used `geom_bar()`.
- Here we use `geom_col()` for bar plots showing statistics by group (with error bars).

```r
mean.arr <- tapply(Cars93$MPG.city,Cars93$Type,mean); se.arr <- tapply(Cars93$MPG.city,Cars93$Type,function(x) sqrt(var(x)/length(x)))
df <- data.frame(Type=names(mean.arr),mn=mean.arr,se=se.arr)
p1 <- ggplot(df, aes(Type,mn,ymin = mean.arr-1.96*se.arr, ymax = mean.arr+1.96*se.arr)) +
  geom_col(fill="blue") + labs(title="Mean city mileage by car type",x="Type",y="City Mileage (mpg)")
p1 + geom_linerange(color="red",size=.8) # one style of error bar
p1 + geom_errorbar(color="red",width=.3,size=.8) # another style of error bar
# A better choice is to omit the bars entirely:
ggplot(df, aes(Type,mn,ymin = mean.arr-1.96*se.arr, ymax = mean.arr+1.96*se.arr)) +
  labs(title="Mean city mileage by car type",x="Type",y="City Mileage (mpg)") + geom_pointrange(color="red",size=.8)
```


Mean city mileage by car type


Mean city mileage by car type

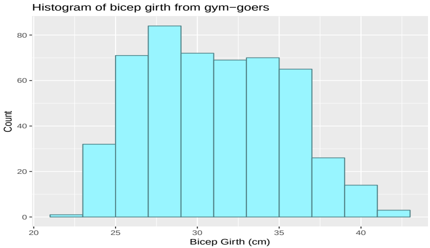

Mean city mileage by car type

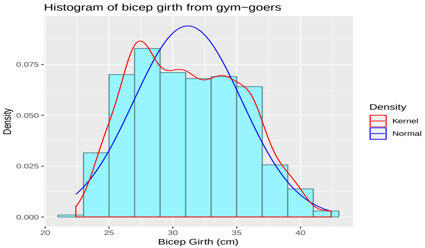
Examples—Histograms

- By default, `geom_histogram()` uses too many bins so always choose a binning scheme with one or more of the arguments `binwidth`, `bins`, `center`, `boundary`, `breaks`, and `closed`.

```
ggplot(bodyDat, aes(bicep_girth)) + geom_histogram(binwidth=2,color="cadetblue4",fill="cadetblue1") +
  xlab("Bicep Girth (cm)") +  ylab("Count") + ggtitle("Histogram of bicep girth from gym-goers")

ggplot(bodyDat, aes(x = bicep_girth)) +
  geom_histogram(aes(y =..density..),binwidth=2,color="cadetblue4",fill="cadetblue1") +
  xlab("Bicep Girth (cm)") + ylab("Density") + ggtitle("Histogram of bicep girth from gym-goers") +
  stat_function(aes(color="blue"),fun = dnorm,
                args = list(mean = mean(bodyDat$bicep_girth), sd = sd(bodyDat$bicep_girth))) +
  geom_density(aes(color="red"),adjust=.8) + # adjust value multiplies the default bandwidth
  scale_colour_identity(name="Density", breaks=c("red","blue"), labels=c("Kernel","Normal"), guide="legend")
```

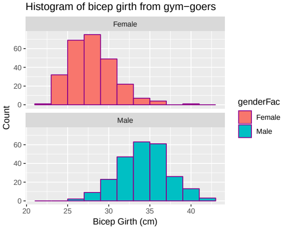

Histogram of bicep girth from gym−goers

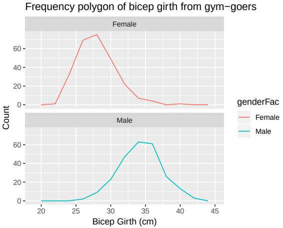

Histogram of bicep girth from gym−goers

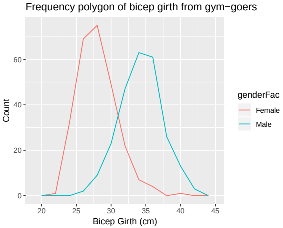
Examples—Histograms vs Frequency Polygons

- Recall that the bicep data are from men and women. Best to examine distribution by sex.

```
ggplot(bodyDat, aes(bicep_girth,fill=genderFac)) + geom_histogram(binwidth=2,color="darkmagenta") +
  xlab("Bicep Girth (cm)") +  ylab("Count") + ggtitle("Histogram of bicep girth from gym-goers") +
  facet_wrap(~genderFac, ncol = 1)
# Now use frequency polygon instead of histogram
fp1 <- ggplot(bodyDat, aes(bicep_girth,color=genderFac)) + geom_freqpoly(binwidth=2) +
  xlab("Bicep Girth (cm)") +  ylab("Count") + ggtitle("Frequency polygon of bicep girth from gym-goers")
fp1 + facet_wrap(~genderFac, ncol = 1)
# No need to use panels. Polygons look good when superimposed in the same panel
fp1
```


Histogram of bicep girth from gym−goers

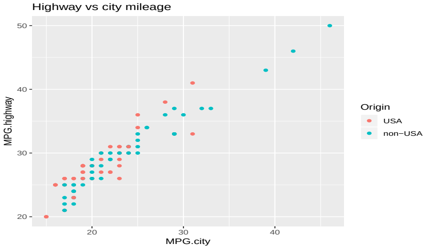

Frequency polygon of bicep girth from gym−goers

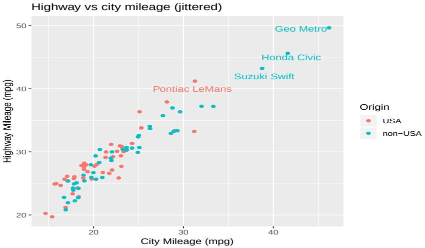

Frequency polygon of bicep girth from gym−goers

Examples—Scatterplots with Jittering and Labels

- To avoid overplotting it is useful to *jitter* the points.
- Points can be labeled with `geom_text()`. Need to adjust position of labels slightly. Adjustment can be done (and often must be done) in multiple ways.

```
ggplot(Cars93, aes(x=MPG.city,y=MPG.highway,color=Origin)) + geom_point() + ggtitle("Highway vs city mileage")
ggplot(Cars93, aes(x=MPG.city,y=MPG.highway,color=Origin)) +
  geom_jitter() + labs(x="City Mileage (mpg)",y="Highway Mileage (mpg)", title="Highway vs city mileage (jittered)") +
  geom_text(aes(label = Make),show.legend=F, data=Cars93[Cars93$MPG.city>45,], vjust = "inward", hjust = "inward") +
  geom_text(aes(label = Make),show.legend=F, data=Cars93[Cars93$MPG.highway>40 & Cars93$MPG.city<45,],
          nudge_y = -1)
```

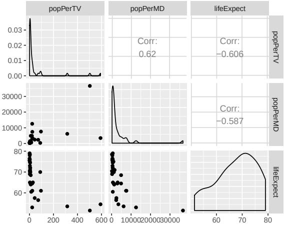


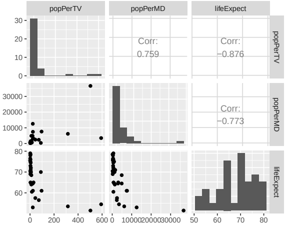


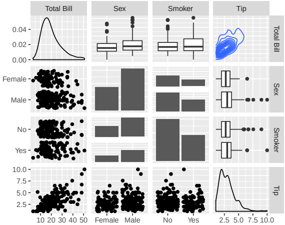
Examples—Plot Matrices

- The GGally package offers the ggpairs() function for plotting pairwise plot matrices.
- This yields scatter plot matrices when all variables are continuous (left and middle), but it works with variables of mixed scales (right).

```
require(GGally); ggpairs(na.omit(tvData), c("popPerTV","popPerMD","lifeExpect"))
# Default uses nonparametric densities on the diagonal and Pearson cors in upper tri, but these can be altered:
ggpairs(na.omit(tvData), columns=c("popPerTV","popPerMD","lifeExpect"),
        upper=list(continuous=wrap("cor",method="spearman")), diag=list(continuous=wrap("barDiag",bins=10)))
# Example from the ggpairs() help page involving the tips data set from reshape package.
data(tips, package = "reshape")
ggpairs(tips[,c("total_bill", "sex", "smoker", "tip")], columnLabels = c("Total Bill", "Sex", "Smoker", "Tip"),
  upper = list(continuous = "density", combo = "box_no_facet"),
  lower = list(continuous = "points", combo = "dot_no_facet") )
```



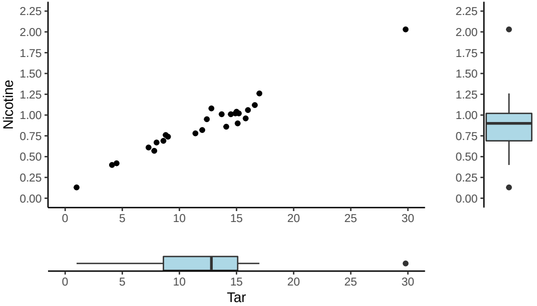




Examples—Multiple Plots per Page

- Multiple plots/page is implemented in several tools including `plot_grid()` of the `cowplot` package and `ggmatrix()` of the `GGally` package.
- Here's an example using `plot_grid()` in which alignment is important.

```
tar.nic.scatter <- ggplot(data=cigData, aes(x=tar,y=nicotine)) + geom_point() + theme_classic() +
  scale_x_continuous("",breaks=seq(0,30,by=5),limits=c(0,30)) + scale_y_continuous("Nicotine",breaks=seq(0,2.25,by=.25),limits=c(0,2.25))
tar.box <- ggplot(aes(y = tar), data = cigData) + geom_boxplot(fill = "lightblue") + theme_classic() + coord_flip() +
  scale_y_continuous("Tar",breaks=seq(0, 30, by=5),limits=c(0,30)) + scale_x_continuous(name=NULL,breaks=NULL)
nic.box <- ggplot(aes(y = nicotine), data = cigData) + geom_boxplot(fill = "lightblue") + theme_classic() +
  scale_y_continuous(name=NULL,breaks=seq(from=0, to=2.25, by=.25),limits=c(0,2.25)) + scale_x_continuous(name=NULL,breaks=NULL)
cowplot::plot_grid(tar.nic.scatter, nic.box, tar.box, align = "hv", ncol=2, nrow = 2, rel_widths = c(4, 1)/5, rel_heights = c(4, 1)/5)
```



Resources for Graphics in R

- Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis, Second Edition.* Springer.
  - Available through UGA Libraries for free.
- Friendly, M. (2018). Data Visualization in R, SCS Short Course. http://www.datavis.ca/courses/RGraphics/
  - The Session 4 slides focus on `ggplot2`.
- Tierney, L. (2019). STAT:4580 Data Visualizations and Data Technology. Course Notes.
- RStudio. Data Visualization with ggplot2:: Cheat Sheet. (All RStudio cheat sheets in a single PDF at this link.)
- `ggplot2` home page https://ggplot2.tidyverse.org/reference/

Thank You!

- If you need assistance with R or with selecting or implementing data visualizations to better understand your data, contact the SCC!
- We can help!

www.stat.uga/consulting

Finally…

- Holiday wishes, rendered with `ggplot2` and shamelessly stolen from the *Standard error* blog http://t-redactyl.io/: