An Introduction to R Graphics

Part I—Base Graphics

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Graphics Devices

- Plots are sent to a graphics device, typically a window or file.
- Screen device functions:
  - Mac-OS: `quartz()`. Also allows output to files of different formats.
  - Unix/Linux: `x11()`.
  - Windows OS: `windows()` (or `x11()` or `X11()`).
    - Use `windows(record=TRUE)` to record the plots so you can page through them.
- In RStudio, built-in device is `RStudioGD`. Plots can be copied and pasted or saved to files of different formats from it.
- There are also file devices such as `pdf` and `postscript`.
- Multiple devices can be open simultaneously, but only one is the *current device*.
  - Switching devices, turning them off, etc. with functions such as `dev.off()`, `dev.cur()`, `dev.next()`, etc.
- Each device has its own graphical parameters. Setting parameters (e.g., with `par()`) affects those of the current device.

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Many aspects of a plot are controlled by a large number of graphical parameters.

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  - See `?par` for a list of graphical parameters.
  - The command `par("param")` queries the value of parameter `param`.
  - E.g., below we set the `col` and `lty` parameters, add a dotted red horizontal line at 0, and then reset the parameters to their previous values.

```
par(c("col","lty"))                         # query the current values ("black" and "solid")
oldParms <- par(col="red",lty="dotted") # set to new values and save the old ones
par(c("col","lty"))                         # ("red" and "dotted")
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par(c("col","lty"))                        # ("black" and "solid")
```

Graphical Parameters

- Graphical parameters can be changed with `par()` and the new value will persist.
- Most plotting functions also accept graphical parameters optionally.
  - These settings will be temporary to the function being executed. E.g.:

```
plot(residuals(m1)~fitted(m1),col="black",pch="x")
abline(h=0,lty="dotted",col="red")
```

Graphical Parameters

Some important graphical parameters:

`col`: the plotting color
`lty`: the line type
`lwd`: the line width
`pch`: the point marker
`pty`: plotting region shape
`main, sub`: title, subtitle
`new`: wipe/retain previous plot

`mfrow/mfcol`: plots/page
`ask`: hit return for next plot?
`cex`: text expansion factor
`mar/mai`: margin dimensions
`oma/omi`: outer margin dimensions
`xlim/ylim`: axis limits
`xlab/ylab`: axis labels

- Click here for a handy cheatsheet on graphical parameters.

Graphical Parameters

`col`, `lty`, `pch` can take numeric values or character strings.

- Colors 1–8 for `col` and some of the 657 color names that R knows:

```
palette() # default mapping of colors 1-8
```

```
[1] "black"   "red"     "green3"  "blue"    "cyan"    "magenta" "yellow"
[8] "gray"
```

```
cl <- colors(); length(cl)
```

```
[1] 657
```

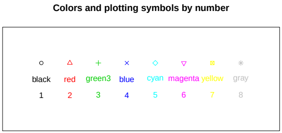
```
cl[1:12]
```

```
 [1] "white"         "aliceblue"     "antiquewhite"  "antiquewhite1"
 [5] "antiquewhite2" "antiquewhite3" "antiquewhite4" "aquamarine"
 [9] "aquamarine1"   "aquamarine2"   "aquamarine3"   "aquamarine4"
```

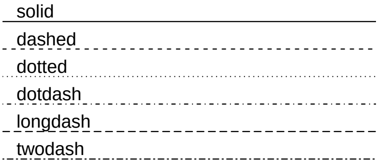
- In R, colors can also be specified with hexadecimal codes representing concentrations of red, green and blue (#rrggbb).
- See this cheatsheet for an explanation, all color names, and more on color in R.

Graphical Parameters

- Color and plotting symbol types 1–8 for `col` and `pch` and the corresponding color names:

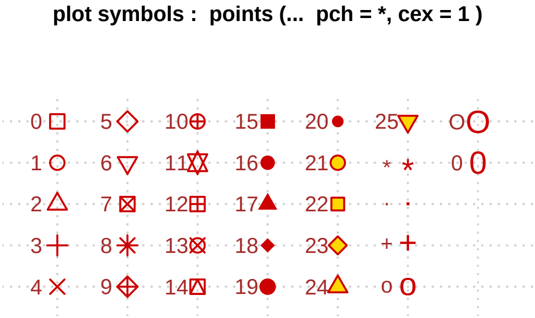


- Line types 1–8 for `lty` and the corresponding names:



Graphical Parameters

- More choices for `pch` (using `col`="red" and `bg`="gold"):



The `plot()` Function

- R is an object-oriented language and `plot()` is a generic function. That means it looks at its argument, and determines what to do with it based on its class.
  - E.g., `plot(Nile)` checks to see that `Nile` is of class `ts` (a time series object) and passes the job on to the `plot.ts()` function.
  - E.g., if `tab` is a contingency table object (class `table`) then `plot(tab)` passes the job on to the `plot.table()` function, which creates a mosaic plot.
- Thus, `plot()` can produce many different kinds of plots depending on what argument(s) you pass it.

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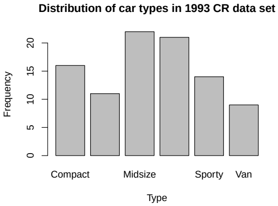
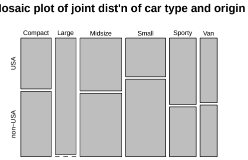
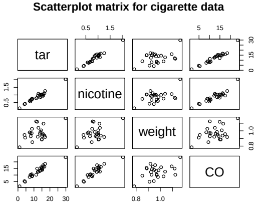
The `plot()` Function—Examples

- The generic nature of `plot()`.

```
# Get some data sets:
source("https://tinyurl.com/une4s3g/getData_3.R"); data(Cars93,package="MASS")
# plotting a factor gives a bar chart of freq distribution:
plot(Cars93$Type,main="Distribution of car types in 1993 CR data set",xlab="Type",ylab="Frequency")
# plotting a table gives a mosaic plot:
plot(table(Cars93$Type,Cars93$Origin),main="Mosaic plot of joint dist'n of car type and origin")
# plotting a data frame gives a matrix of pairwise plots (a scatterplot matrix in this case):
plot(cigData,main="Scatterplot matrix for cigarette data")
```





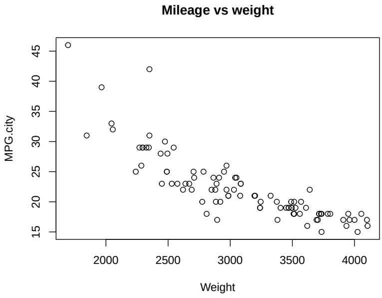


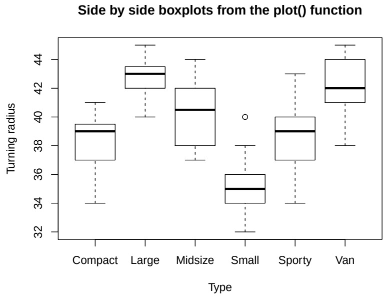
The `plot()` Function—Examples

Plotting `y` vs `x`:

- `plot(y~x,data=myDFrame)` and `plot(myDFrame$x,myDFrame$y)` produce same result.
- Gives a scatterplot if `x, y` both continuous.
- Gives side-by-side boxplots if `y` is continuous and `x` is a factor.

```
plot(MPG.city ~ Weight,data=Cars93,main="Mileage vs weight") # a scatter plot
plot(Turn.circle~Type,data=Cars93,xlab="Type",ylab="Turning radius",
     main="Side by side boxplots from the plot() function") # side-by side box plots
```

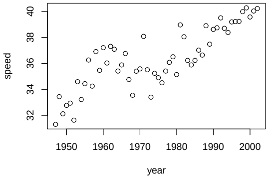


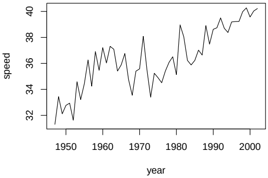


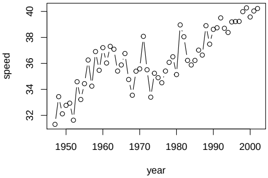
The `plot()` Function—Examples

- `plot()` takes a `type=` argument with several choices. Most important are `p`=points, `l`=lines, `b`=both (see also type `o`), or `n`=neither are plotted. Lines are useful for time series, but data should be sorted by the x-variable.
- Here, are data on the average speed of Tour de France winners over time.

```
plot(speed~year,data=tdf,type="p") # just plot points. This is the default
plot(speed~year,data=tdf,type="l") # plot lines connecting the data values.
plot(speed~year,data=tdf,type="b") # plot both points and lines.
```





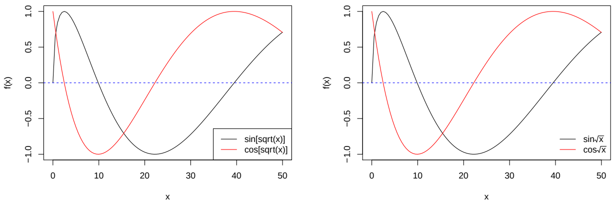


The `plot()` Function—Examples

- Plotting a function is easy with `plot()`.
- Here we also see how to add a curve, a reference line, a legend, and how to render math notation (type `?plotmath` at console for more).

```
sinRoot <- function(x){ sin(sqrt(x))}; cosRoot <- function(x){ cos(sqrt(x))}
plot(sinRoot,0,50,ylab="f(x)",xlab="x") # plots a function between (in this case) 0 and 50
curve(cosRoot,0,50,add=TRUE,col="red") ; abline(h=0,col="blue",lty="dashed")
legend("bottomright",col=c("black","red"),lty=c(1,1),legend=c("sin[sqrt(x)]","cos[sqrt(x)]"  ))

# try again with mathematical notation in legend
plot(sinRoot,0,50,ylab="f(x)",xlab="x") # plots a function between (in this case) 0 and 50
curve(cosRoot,0,50,add=TRUE,col="red") ; abline(h=0,col="blue",lty="dashed")
legend("bottomright",col=c("black","red"),lty=c(1,1),bty="n",
       legend=c(expression(plain(sin)*sqrt(x)),expression(plain(cos)*sqrt(x))))
```



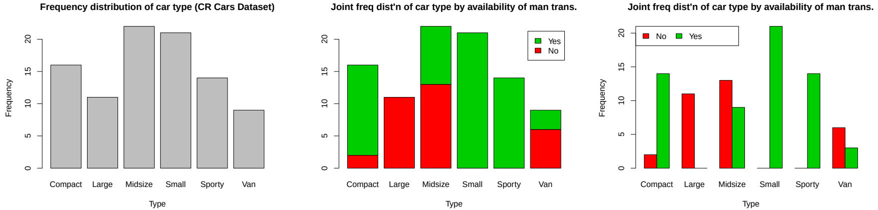
Bar charts with `barplot()`—Freq Distributions

- Bar charts are used both for plotting (joint) frequency distributions and summary statistics for multiple groups.
- `barplot()` can do both. First, frequency distributions:

```
barplot(table(Cars93$Type),ylab="Frequency",xlab="Type")
title(main="Frequency distribution of car type (CR Cars Dataset)")

# Now a two-way freq distribution with stacked bars:
carTab <- table(Cars93$Man.trans.avail,Cars93$Type)
barplot(carTab,legend.text=TRUE,col=2:3,xlab="Type")
title(main="Joint freq dist'n of car type by availability of man trans.")

# Now a two-way freq distribution with clustered bars:
barplot(carTab,legend.text=TRUE,col=2:3,xlab="Type",ylab="Frequency",
        args.legend=list(x="topleft",ncol=3),beside=TRUE)
title(main="Joint freq dist'n of car type by availability of man trans.")
```



Bar charts with barplot()—Group Statistics

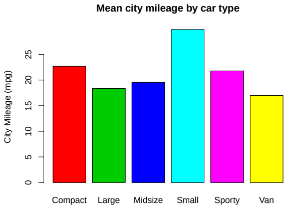
- Example: mean city mileage by car type. Error bars are hard(ish) with barplot() so use barplot2() from gplots package.

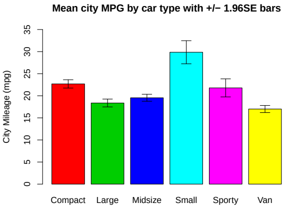
```
# First compute the means for each car Type:
(mean.arr <- tapply(Cars93$MPG.city,Cars93$Type,mean))
```

```
 Compact    Large  Midsize    Small   Sporty      Van
22.68750 18.36364 19.54545 29.85714 21.78571 17.00000
```

```
# Then plot them:
barplot(mean.arr, legend.text=FALSE, col=2:7, main="Mean city mileage by car type",
        xlab="Type", ylab="City Mileage (mpg)")

# To add error bars, must compute SEs:
se.arr <- tapply(Cars93$MPG.city,Cars93$Type,function(x) sqrt(var(x)/length(x)))
gplots::barplot2(mean.arr, legend.text=FALSE, col=2:7, ylim=c(0,35), plot.ci=TRUE, xlab="Type",
  ci.l=mean.arr-1.96*se.arr, ci.u=mean.arr+1.96*se.arr, ci.width=0.3, ylab="City Mileage (mpg)")
title(main="Mean city MPG by car type with +/- 1.96SE bars")
```



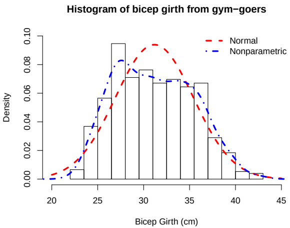


Histograms with hist()

- Histograms can be plotted with `hist()`. Binning scheme matters (a lot) and trial and error is necessary.
- Use density scale rather than counts to compare to a fitted density. Here we overlay a normal and a kernel density estimate.

```
hist(bodyData$bicep_girth,xlab="Bicep Girth (cm)", main="Histogram of bicep girth from gym-goers")

# Now use different bins, switch to a probability density scale, and overlay densities
hist(bodyData$bicep_girth,xlab="Bicep Girth (cm)",breaks=seq(from=22,to=43,by=1.5),
     main="Histogram of bicep girth from gym-goers",freq=FALSE,ylim=c(0,.1),xlim=c(20,45))
curve(dnorm(x, mean=mean(bodyData$bicep_girth),sd=sd(bodyData$bicep_girth)),
      col = 2, lty = 2, lwd = 3, add = TRUE)
lines(density(bodyData$bicep_girth), col = 4, lty = 4, lwd = 3)
legend("topright",lty=c(2,4),col=c(2,4),lwd=3,legend=c("Normal","Nonparametric"),bty="n")
```

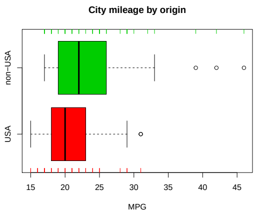


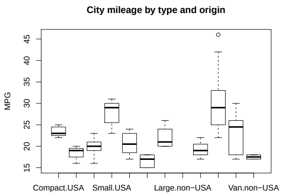
Boxplots with `boxplot()`

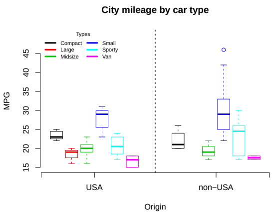
- Formula syntax in `boxplot()` is convenient for grouped boxplots, but labels can get crowded.
- `boxplot(y ~ f)` for boxplots of `y` at each level of `f` or `boxplot(y ~ f + g)` at each combination of `f` and `g`.

```r
boxplot(MPG.city~Origin, data=Cars93, main="City mileage by origin", xlab="MPG", horizontal=T, col=2:3)
rug(Cars93$MPG.city[Cars93$Origin=="USA"],side=1,col=2); rug(Cars93$MPG.city[Cars93$Origin!="USA"],side=3,col=3)
boxplot(MPG.city~Type+Origin, data=Cars93, main="City mileage by type and origin", ylab="MPG")

# fixing crowding of x-axis labels can be challenging
boxplot(MPG.city~Type+Origin,data=Cars93, main="City mileage by car type",
        ylab="MPG", border=1:6, pars=list(axes=F, ylim=c(15,50)), xlab="Origin", at=c(1:6,9:14))
abline(v=7.5,lty=2); axis(2,at=seq(from=15,to=45,by=5))
axis(1,at=c(0,3.5,11.5,15), labels=c("",levels(Cars93$Origin),""))
legend("topleft", bty="n", col=1:6, legend=levels(Cars93$Type), cex=.70, ncol=2, lty=rep(1,6), lwd=3, title="Types")
```



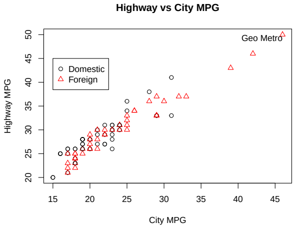


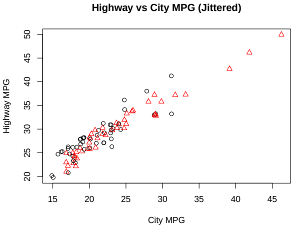


Labelling Points

- Groups can be distinguished with graphical parameters. E.g., give `col` or `pch` a vector of values of same length as the data.
- Labels for points can be done with `text()` function.

```
plot(MPG.highway~MPG.city, data=Cars93, pch= as.integer(Origin), col=as.integer(Origin),
     xlab="City MPG",ylab="Highway MPG",main="Highway vs City MPG")
with(Cars93,text(x=MPG.city[MPG.city>45], y=MPG.highway[MPG.city>45], labels=Make[MPG.city>45], adj=c(1,1))) # adj offsets labels
legend(x=15, y=45, legend=c("Domestic","Foreign"), pch=1:2, col=1:2)
# Many values overplotted. Better to jitter the points:
plot(jitter(MPG.highway,1.5) ~ jitter(MPG.city,1.5), data=Cars93, pch= as.integer(Origin), col=as.integer(Origin),
     xlab="City MPG",ylab="Highway MPG",main="Highway vs City MPG (Jittered)")
```





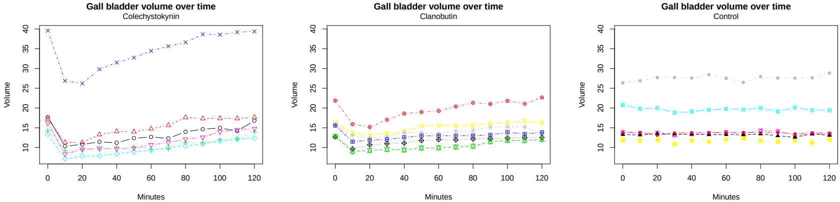
Profile Plots for Longitudinal Data

- Longitudinal studies involve data over time for multiple individuals, possibly in different (treatment) groups.
- Task is much better handled by functions in `lattice` or `ggplot2`.

```
gall$trtfac <- factor(gall$trt,labels=c("Colechystokynin","Clanobutin","Control")); head(gall,3)
```

```
  trt dogno min volume          trtfac
1   1     1   0  17.70 Colechystokynin
2   1     1  10  10.35 Colechystokynin
3   1     1  20  10.78 Colechystokynin
```

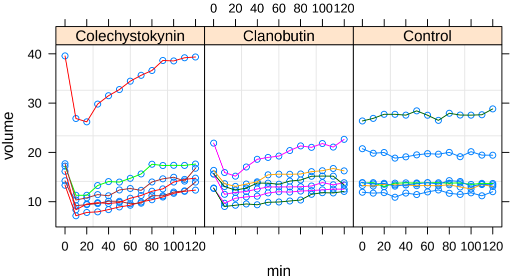
```
for (i in levels(gall$trtfac)){
  galli <- gall[gall$trtfac==i,]
  plot(volume ~ min, data=gall, type="n", xlab="Minutes", ylab="Volume", main="Gall bladder volume over time")
  mtext(i,side=3,line=0.5)
  for (j in unique(galli$dogno)){
    lines(galli$min[galli$dogno==j], galli$volume[galli$dogno==j], lty=j, pch=j, col=j, type="b") }}
```



Profile Plots for Longitudinal Data

- The `nlme` package implements profile plots via the `plot()` function applied to a `groupedData` object.
- The work is done by the `xyplot()` function of the `lattice` package.
- Later we'll see how to use `ggplot2` for this task.

```
library(nlme)
gall2 <- groupedData(volume~min|dogno,data=gall) # a data frame with a formula attached
plot(gall2,outer= ~trtfac,aspect="fill",key=FALSE)
```



Adding Fitted Lines/Curves to a Plot

- Here we add a linear fit with 95% CI and PI and a lowess fitted curve.
- Important to add features in the proper order to avoid overplotting.

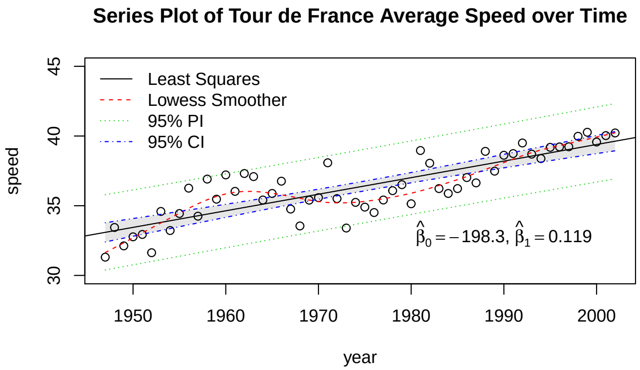
```
# Create a plot of the data but omit the points initially by setting type="n":
plot(speed~year, data=tdf, type="n", ylim=c(30,45), main="Series Plot of Tour de France Average Speed over Time")

# Fit a simple linear regression to get least squares fitted line, and 95% CI and PI limits
tdf.lm1 <- lm(speed~year,data=tdf)
tdf.lm1.pi <- predict(tdf.lm1, interval="prediction")
tdf.lm1.ci <- predict(tdf.lm1, interval="confidence")

# Now add a 95% prediction interval with a shaded region to the plot:
polygon(c(tdf$year,rev(tdf$year)), c(tdf.lm1.ci[,2],rev(tdf.lm1.ci[,3])), border=NA, col=gray(.9))
# Then add other features:
lines(speed ~ year, data=tdf, type="p") ; abline(tdf.lm1) # adds points and a straight line fit
lines(lowess(tdf$year,tdf$speed, f=1/3), col=2, lty=2)    # adds a lowess fit
lines(tdf$year, tdf.lm1.pi[,2], lty=3, col=3); lines(tdf$year, tdf.lm1.pi[,3], lty=3, col=3) #PI limits
lines(tdf$year, tdf.lm1.ci[,2], lty=4, col=4); lines(tdf$year, tdf.lm1.ci[,3], lty=4, col=4) #CI limits
legend("topleft", c("Least Squares","Lowess Smoother","95% PI","95% CI"), col=1:4, lty=1:4, bty="n") # a legend
text(1990,33,expression(paste(hat(beta)[0]==-198.3,", ", hat(beta)[1]==0.119))) # parm estimates
```

Adding Fitted Lines/Curves to a Plot

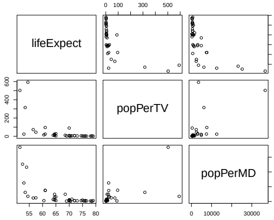
- Results from the code on the previous slide:

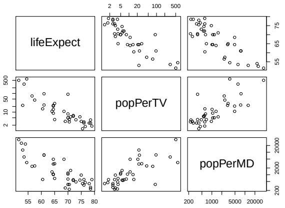


Scatterplot Matrices

- The `pairs()` function produces scatterplot matrices. It is illustrated below on some country-level data on life expectancy, access to healthcare, and access to technology.

```
# basic illustration of pairs():
pairs(~lifeExpect+popPerTV+popPerMD,data=tvData)
# log scaling of axes:
pairs(~lifeExpect+popPerTV+popPerMD,data=tvData,log=2:3,
      main="Log scale for popPerTV and popPerMD")
```

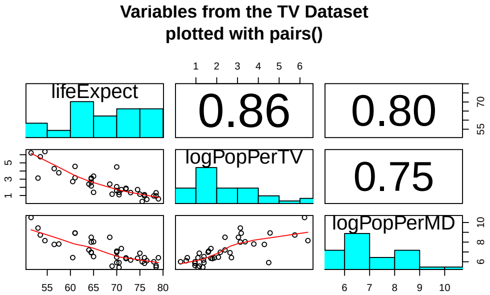




Scatterplot Matrices

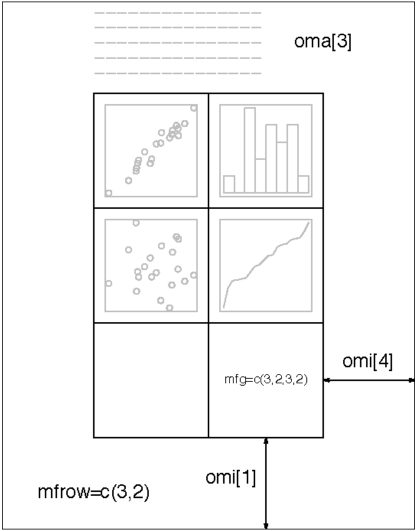
- Can make better use of the space in a scatterplot matrix by using the diagonal cells and the upper or lower triangle to display other information.
- Can be done with `lower.panel`, `upper.panel`, `diag.panel` arguments.
- The `panel.cor()` and `panel.hist()` functions used below are from the `pairs()` help page; `panel.smooth()` is built-in.

```
tvData$logPopPerTV <- log(tvData$popPerTV); tvData$logPopPerMD <- log(tvData$popPerMD)
pairs(~lifeExpect+logPopPerTV+logPopPerMD, data=na.omit(tvData),
      lower.panel=panel.smooth, upper.panel=panel.cor, diag.panel=panel.hist,
      main="Variables from the TV Dataset\nplotted with pairs()")
```



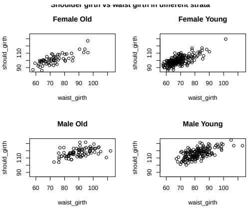
Multiple Plots per Page

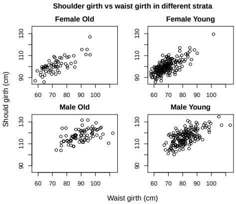
- Placing multiple plots in an $R \times C$ grid on a page can be done with `par(mfrow=c(R,C))` (see also `mfcol`).
- The page layout is displayed to the right. For multiple plots/page, usually must adjust the margins (`mar`) and outer margins (`oma`). This can be tricky.



Multiple Plots per Page

- This example using `mfrow` shows the need to adjust the margins. The plot on the top is run without the adjustments to `mar` and `oma` on the third line of code.






```
bodyData$over34 <- factor(bodyData$age>34, labels=c("Young","Old"))
bodyData$sexAge <- factor(paste(bodyData$genderFac,bodyData$over34))
op <- par(mfrow=c(2,2),mar=c(2,2,2,2)+.1,oma=c(3,3,1.5,1))
for (lev in levels(bodyData$sexAge)){
  plot(should_girth~waist_girth,data=bodyData,type="n",main=lev)
  points(should_girth~waist_girth,data=bodyData[bodyData$sexAge==lev,])
}
title(main="Shoulder girth vs waist girth in different strata",outer=TRUE)
mtext("Should girth (cm)",side=2,outer=TRUE,line=1);
mtext("Waist girth (cm)",side=1,outer=TRUE,line=1)
par(op)
```

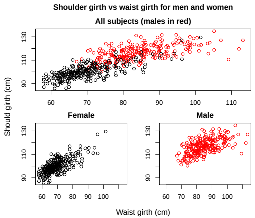
Multiple Plots per Page

- A more flexible arrangement is possible with the command `layout(mat)` where `mat` is a matrix specifying the desired arrangement.

```
(layoutMat <- rbind(c(1,1),c(2,3)))
```

```
     [,1] [,2]
[1,]    1    1
[2,]    2    3
```

```
layout(layoutMat); op <- par(mar=c(2,2,2,2)+.1,oma=c(3,3,1.5,1))
plot(should_girth~waist_girth,data=bodyData,main="All subjects (males in red)",
     col=as.integer(genderFac))
for (lev in levels(bodyData$genderFac)){
  plot(should_girth~waist_girth,data=bodyData,type="n",main=lev)
  points(should_girth~waist_girth,data=bodyData[bodyData$genderFac==lev,],
         col=as.integer(genderFac)) }
title(main="Shoulder girth vs waist girth for men and women",outer=TRUE)
mtext("Should girth (cm)",side=2,outer=TRUE,line=1)
mtext("Waist girth (cm)",side=1,outer=TRUE,line=1); par(op)
```



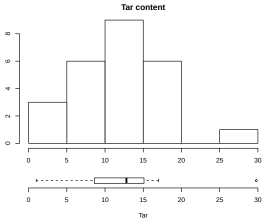
Multiple Plots per Page

- Another example. Here the top plot takes 75% of the page.

```
(layoutMat <- rbind(matrix(1,nrow=3,ncol=2),c(2,2)))
```

```
     [,1] [,2]
[1,]    1    1
[2,]    1    1
[3,]    1    1
[4,]    2    2
```

```
layout(layoutMat)
op <- par(mar=c(2,2,2,2)+.1,oma=c(1,1,1,1))
hist(cigData$tar,main="Tar content",xlim=c(0,30))
par(mar=c(4,2,1,2)+.1)
boxplot(cigData$tar,horizontal=TRUE,xlab="Tar",pars=list(bty="l"),
        frame=FALSE,ylim=c(0,30)) # ylim becomes xlim when horiz=T
par(op)
```



Resources for Graphics in R

Friendly, M. (2018). Data Visualization in R, SCS Short Course. http://www.datavis.ca/courses/RGraphics/

- Fantastic resource. Session 2 slides focus on Base Graphics. Session 1 slides point the way to many more important resources.

Tierney, L. (2019). STAT:4580 Data Visualizations and Data Technology. Course Notes.

- Another great resource on data visualization methods and the tools to implement them. Much content on R graphics systems, especially `ggplot2`.

RStudio. Data Visualization with ggplot2:: Cheat Sheet. (All RStudio cheat sheets in a single PDF at this link.)

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, shamelessly stolen from the is.R() tumblr site:

```
library(ggplot2)
Turkey <- read.csv("http://pages.iu.edu/~cdesante/turkey.csv")
ggplot(data = Turkey) + geom_tile(aes(x = Happy, y = Thanksgiving, fill=Turkey.Colors,
width=1))+ scale_fill_identity() + theme_bw()
```