CSSS 569: Visualizing Data

Graphical Programming, Part I. Using R graphics functions

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Today’s outline: Using \texttt{R} graphics functions

Review of \texttt{R} basics

Overview of available high-level plots

Modifying traditional graphics

\texttt{R} graphic devices
Next week: Writing R graphics functions

Philosophy: Start from scratch

Line & color

Annotation

Coordinate systems

General purpose graphics packages to replace base:

The lattice graphics package

The grid graphics package

The ggplot graphics package*
Strategy for today

Review basics quickly

Stop and ask for clarification, elaboration, examples
Why R?

Real question: Why programming?

Non-programmers stuck with package defaults

For your substantive problem, defaults may be

- inappropriate (not quite the right model, but “close”)
- unintelligible (reams of non-linear coefficients and stars)

Programming allows you to match the methods to the data & question

Get better, more easily explained results.
Why R?

Many side benefits:

1. Never forget what you did: The code can be re-run.

2. Repeating an analysis $n$ times? Write a loop!

3. Programming makes data processing/reshaping easy.

4. Programming makes replication easy.
Why R?

R is

• free

• open source

• growing fast

• widely used

• the future for most fields

But once you learn one language, the others are much easier
Introduction to R

R is a calculator that can store lots of information in memory.

R stores information as “objects”

> x <- 2
> print(x)
[1] 2

> y <- "hello"
> print(y)
[1] "hello"

> z <- c(15, -3, 8.2)
> print(z)
[1] 15.0 -3.0 8.2
Introduction to R

```r
> w <- c("gdp", "pop", "income")
> print(w)
[1] "gdp"  "pop"  "income"
>
Note the assignment operator, <-, not =

An object in memory can be called to make new objects

> a <- x^2
> print(x)
[1] 2
> print(a)
[1] 4

> b <- z + 10
> print(z)
[1] 15.0 -3.0 8.2
> print(b)
[1] 25.0  7.0 18.2
```
Introduction to R

> c <- c(w,y)
> print(w)
[1] "gdp" "pop" "income"
> print(y)
[1] "hello"
> print(c)
[1] "gdp" "pop" "income" "hello"

Commands (or “functions”) in R are always written `command()`.

The usual way to use a command is:

output <- command(input)

We’ve already seen that `c()` pastes together variables.

A simple example:

> z <- c(15, -3, 8.2)
> mz <- mean(z)
> print(mz)
[1] 6.733333
Some commands have multiple inputs. Separate them by commas:

```r
plot(var1, var2) plots var1 against var2
```

Some commands have optional inputs. If omitted, they have default values.

```r
plot(var1) plots var1 against the sequence \{1, 2, 3, \ldots \}
```

Inputs can be identified by their position or by name.

```r
plot(x=var1, y=var2) plots var2 against var1
```
Entering code

You can enter code by typing at the prompt, by cutting or pasting, or from a file.

If you haven’t closed the parenthesis, and hit enter, R let’s you continue with this prompt +

You can copy and paste multiple commands at once.

You can run a text file containing a program using `source()`, with the name of the file as input (ie, in """")

I prefer the `source()` approach. Leads to good habits of retaining code.
Data types

R has three important data types to learn now

Numeric y <- 4.3
Character y <- "hello"
Logical y <- TRUE

We can always check a variable’s type, and sometimes change it:

population <- c("1276", "562", "8903")
print(population)
is.numeric(population)
is.character(population)

Oops! The data have been read in as characters, or “strings”. R does not know they are numbers.

population <- as.numeric(population)
### Some special values

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing data</td>
<td>NA</td>
</tr>
<tr>
<td>A “blank”</td>
<td>NULL</td>
</tr>
<tr>
<td>Infinity</td>
<td>Inf</td>
</tr>
<tr>
<td>Not a number</td>
<td>NaN</td>
</tr>
</tbody>
</table>
Data structures

All R objects have a data type and a data structure or class

Data structures can contain numeric, character, or logical entries

Important structures:

Vector
Matrix
Dataframe
List
Vectors in R

Vector is R are simply 1-dimensional lists of numbers or strings

Let’s make a vector of random numbers:

```r
x <- rnorm(1000)
```

x contains 1000 random normal variates drawn from a Normal distribution with mean 0 and standard deviation 1.

What if we wanted the mean of this vector?

```r
mean(x)
```

What if we wanted the standard deviation?

```r
sd(x)
```
Vectors in R

What if we wanted just the first element?

\[ x[1] \]

or the 10th through 20th elements?

\[ x[10:20] \]

what if we wanted the 10th percentile?

\[ \text{sort}(x)[100] \]

Indexing a vector can be very powerful. Can apply to any vector object.

What if we want a histogram?

\[ \text{hist}(x) \]
Vectors in R

Useful commands for vectors:

- `seq(from, to, by)` generates a sequence
- `rep(x, times)` repeats x
- `sort()` sorts a vector from least to greatest
- `rev()` reverses the order of a vector
- `rev(sort())` sorts a vector from greatest to least
Matrices in R

Vector are the standard way to store and manipulate variables in R.

But usually our datasets have several variables measured on the same observations.

Several variables collected together form a matrix with one row for each observation and one column for each variable.
Matrices in R

Many ways to make a matrix in R

```r
a <- matrix(data=NA, nrow, ncol, byrow=FALSE)
```

This makes a matrix of $nrow \times ncol$, and fills it with missing values.

To fill it with data, substitute a vector of data for NA in the command. It will fill up the matrix column by column.

We could also paste together vectors, binding them by column or by row:

```r
b <- cbind(var1, var2, var3)
c <- rbind(obs1, obs2)
```
Matrices in R

Optionally, R can remember names of the rows and columns of a matrix

To assign names, use the commands:

```r
colnames(a) <- c("Var1", "Var2")
rownames(a) <- c("Case1", "Case2")
```

Substituting the actual names of your variables and observations (and making sure there is one name for each variable & observation)
Matrices in R

Matrices are indexed by row and column.

We can subset matrices into vectors or smaller matrices

- `a[1,1]` Gets the first element of a
- `a[1:10,1]` Gets the first ten rows of the first column
- `a[,]5` Gets every row of the fifth column
- `a[4:6,]` Gets every column of the 4th through 6th rows

To make a vector into a matrix, use `as.matrix()`

R defaults to treating one-dimensional arrays as vectors, not matrices

Useful matrix commands:

- `nrow()` Gives the number of rows of the matrix
- `ncol()` Gives the number of columns
- `t()` Transposes the matrix
Dataframes in R

Dataframes are a special kind of matrix used to store datasets

To turn a matrix into a dataframe (note the extra .):

```r
a <- as.data.frame(a)
```

Dataframes always have columns names, and these are set or retrieved using the `names()` command

```r
names(a) <- c("Var1","Var2")
```

Dataframes can be “attached”, which makes each column into a vector with the appropriate name

```r
attach(a)
```
Loading data

There are many ways to load data to R. I prefer using comma-separated variable files, which can be loaded with `read.csv`

You can also check the `foreign` library for other data file types

If your data have variable names, you can attach the dataset like so:

```r
data <- read.csv("mydata.csv")
attach(data)
```

to access the variables directly
Missing data

When loading a dataset, you can often tell R what symbol that file uses for missing data using the option `na.strings=`

So if your dataset codes missings as ., set `na.strings="."`

If your dataset codes missings as a blank, set `na.strings=""`

If your dataset codes missings in multiple ways, you could set, e.g.,
`na.strings=c("."","","NA")`
Missing data

Many R commands will not work properly on vectors, matrices, or dataframes containing missing data (NAs)

To check if a variable contains missings, use `is.na(x)`

To create a new variable with missings listwise deleted, use `na.omit`

If we have a dataset `data` with NAs at `data[15,5]` and `data[17,3]`

```r
dataomitted <- na.omit(data)
```

will create a new dataset with the 15th and 17th rows left out

Be careful! If you have a variable with lots of NAs you are not using in your analysis, remove it from the dataset `before` using `na.omit()`
Mathematical Operations

R can do all the basic math you need

Binary operators:

+  -  *  /  ^

Binary comparisons:

<  <=  >  >=  ==  !=

Logical operators (and, or, and not; use parentheses!):

&&  ||  !

Math/stat fns:

log  exp  mean  median  mode  min  max  sd  var  cov  cor

Set functions (see help(sets)), Trigonometry (see help(Trig)),

R follows the usual order of operations; if it doubt, use parentheses
An R list is a basket containing many other variables

```r
> x <- list(a=1, b=c(2,15), giraffe="hello")

> x$a
[1] 1

> x$b
[1] 2 15

> x$b[2]
[1] 15

> x$giraffe
[1] "hello"

> x[3]
$giraffe
[1] "hello"

> x[["giraffe"]]
[1] "hello"
```
R lists

Things to remember about lists

• Lists can contain any number of variables of any type

• Lists can contain other lists

• Contents of a list can be accessed by name or by position

• Allow us to move lots of variables in and out of functions

• Functions often return lists (only way to have multiple outputs)
# To run a regression
res <- lm(y~x1+x2+x3, data, na.action="")

# To print a summary
summary(res)

# To get the coefficients
res$coefficients

# or
dcoef(res)

# To get residuals
res$residuals

# or
resid(res)
lm() basics

# To get the variance-covariance matrix of the regressors
vcov(res)

# To get the standard errors
sqrt(diag(vcov(res)))

# To get the fitted values
predict(res)

# To get expected values for a new observation or dataset
predict(res,
        newdata,           # a dataframe with same x vars
        interval = "confidence",  # alternative: "prediction"
        level = 0.95
    )
R lists & Object Oriented Programming

A list object in R can be given a special “class” using the `class()` function.

This is just a metatag telling other R functions that this list object conforms to a certain format.

For example, suppose we run a linear regression:

```r
resLS <- lm(y~x, data=exampledata)
```

The result `resLS` is a list object of class `'lm'`.

Other functions like `plot()` and `predict()` will react to `resLS` in a special way because of this class designation.

Specifically, they will run functions called `plot.lm()` and `predict.lm()`.

OOP: functions respond to class of objects.
What’s a high-level graphics command?

Most of you probably make \texttt{R} graphics by calling a “high-level” command (HLC) in \texttt{R}, HLCs:

- produce a standard graphic type
- fill in lots of details (axes, titles, annotation)
- have many configurable parameters
- have varied flexibility
- may respond to object class

You don’t need to use HLCs to make \texttt{R} graphics.

Could do from scratch
Some major high-level graphics commands

The two key places to find HLCs:
the base graphics package, and the lattice package

Use different graphical primitives

Have distinctive “looks”

Lattice is really good at conditioning and EDA (coplots)

Besides these, there are many HLCs strewn through other packages

Easiest way to find them: help.search()

I did help.search('plot') on a full install of R packages

Found lots of neat plotting functions in packages I’d never heard of.
## Some major high-level graphics commands

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<td><code>barchart()</code></td>
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<td><code>wireframe()</code></td>
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<td>3D scatter</td>
<td><code>scatterplot3d()</code>*</td>
<td><code>cloud()</code></td>
</tr>
<tr>
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<td></td>
</tr>
</tbody>
</table>
Scatterplot: `plot()`

```
x <- sort(rnorm(47))
plot(x, type = "p")
```
Line plot: `plot(..., type="l")`

```
x <- sort(rnorm(47))
plot(x, type = "l")
```

Index

![Graph showing a line plot with indices and values ranging from -2 to 1 on the y-axis and from 0 to 40 on the x-axis. The plot is generated by `plot(x, type = "l")` where `x` is the sorted random normal distribution of 47 elements.](image-url)
(Smoothed) Histograms: `densityplot()` & others

![Histograms of Height (inches) for Different Voice Types](image)

- **Bass 2**
- **Bass 1**
- **Tenor 2**
- **Alto 2**
- **Alto 1**
- **Soprano 2**
- **Soprano 1**
Dot plot is sensitive to device size
Dot plot has a layout option

Barley Yield (bushels/acre)

- Svansota
- Manchuria
- Velvet
- Peatland
- Glabron
- Wisconsin No. 38
- Wisconsin No. 457
- No. 462
- No. 475
- Trebi

20 30 40 50 60

- Crookston
- Waseca
- University Farm
- Morris
- Grand Rapids
- Duluth

1932 1931
Contour plot: `contour()`

Maunga Whau Volcano
Image plot: `image()`

Maunga Whau Volcano
Image plot with contours: contour(..., add=TRUE)
3D surface: \texttt{persp()}

3D surface: wireframe()
Conditional plots: coplot()
3D scatter: scatterplot3d() in own library
**Scatterplot matrix:** splom()

<table>
<thead>
<tr>
<th>virginica</th>
<th>Petal Length</th>
<th>Sepal Width</th>
<th>Sepal Length</th>
</tr>
</thead>
<tbody>
<tr>
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<table>
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<th>Sepal Width</th>
<th>Sepal Length</th>
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<th>Petal Length</th>
<th>Sepal Width</th>
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Three Varieties of Iris

Scatter Plot Matrix
Ternary plot: `ternaryplot()` in vcd
Mosaic plot: `mosaic()` in vcd

Titanic Survival Proportions: Deaths vs Survivors
Star plot: stars()

Motor Trend Cars: full stars()

Mazda RX4  Mazda RX4 Wag  Datsun 710  Hornet 4 Drive  Hornet Sportabout  Valiant
Duster 360  Merc 240D  Merc 230  Merc 280  Merc 280C  Merc 450SE
Merc 450SL  Merc 450SLC  Cadillac Fleetwood  Lincoln Continental  Chrysler Imperial  Fiat 128
Honda Civic  Toyota Corolla  Toyota Corona  Dodge Challenger  AMC Javelin  Camaro Z28
Pontiac Firebird  Fiat X1–9  Porsche 914–2  Lotus Europa  Ford Pantera L  Ferrari Dino
Maserati Bora  Volvo 142E
Fourfold plot: `fourfoldplot()` in `vcd`
Fourfold plot: `fourfoldplot()` in `vcd`
Some major high-level graphics commands

stem> stem(log10(islands))

The decimal point is at the |

1 | 1111112222233444
1 | 5555556666667899999
2 | 3344
2 | 59
3 |
3 | 5678
4 | 012
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Basic customization

For any given high-level plotting command, there are many options listed in help

```
barplot(height, width = 1, space = NULL,
   names.arg = NULL, legend.text = NULL, beside = FALSE,
   horiz = FALSE, density = NULL, angle = 45,
   col = NULL, border = par("fg"),
   main = NULL, sub = NULL, xlab = NULL, ylab = NULL,
   xlim = NULL, ylim = NULL, xpd = TRUE,
   axes = TRUE, axisnames = TRUE,
   cex.axis = par("cex.axis"), cex.names = par("cex.axis"),
   inside = TRUE, plot = TRUE, axis.lty = 0, offset = 0, ...)
```

Just the tip of the iceberg: notice the ...

This means you can pass other, unspecified commands through `barplot`
Basic customization

The most important (semi-) documented parameters to send through . . . are settings to \texttt{par()}

Most base (traditional) graphics options are set through \texttt{par()}

\texttt{par()} has no effect on grid graphics (e.g., lattice, tile)

If you never have, consult \texttt{help(par)} now!

Some key examples, grouped functionally
par() settings

Customizing text size:

- `cex`  Text size (a multiplier)
- `cex.axis`  Text size of tick numbers
- `cex.lab`  Text size of axes labels
- `cex.main`  Text size of plot title
- `cex.sub`  Text size of plot subtitle

note the latter will multiply off the basic `cex`
par() settings

More text specific formatting

font          Font face (bold, italic)
font.axis     etc

srt           Rotation of text in plot (degrees)
las           Rotation of text in margin (degrees)

Note the distinction between text in the plot and outside.

Text in the plot is plotted with text()

Text outside the plot is plotted with mtext(), which was designed to put on titles, etc.
Aside on margins

`mtext()` expects to be told which side of the plot & how many margin lines away the text is

This is kind of hopeless

A work-around to get stuff in the margins:

1. Turn off “clipping”, the function that keeps data outside the plotting region from showing up in the margin.
   
   We do this by setting `par(xpd=TRUE)` for the current plot

2. Then plot your text using the usual `text()` command, but with coordinates outside the plot region

3. Now, if you want to rotate, use `par(srt)` as normal

4. You could turn clipping on and off to get only certain marginal data plotted.

`grid` offers a much better way
More `par()` settings

Formatting for most any object

- `bg` background color
- `col` Color of lines, symbols in plot
- `col.axis` Color of tick numbers, etc

Want to color the axes? You’ll need to draw them yourself (next time)
Aside: Colors in R

Three ways to specify a color to an R function (for all R graphics tools):

1. color names, like ‘’red’’ or ‘’lightblue’’
   (see `colors()` for a list of hundreds of color names)

2. numerical color codes from `rgb()`, `hsv()`, or `hcl()`
   (`hcl()` gives CIEluv equal perceptual changes for unit changes in chroma, value, or brightness)
   Also useful: `col2rgb()`, `rgb2hsv()`, etc. for conversions among these functions

3. numerical color codes offered by packages for selecting cognitively valid palattes, optimized to your required number of colors and level of measurement (categorical, ordered, interval):

<table>
<thead>
<tr>
<th>Package</th>
<th>Key function(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RColorBrewer</td>
<td><code>brewer.pal()</code></td>
</tr>
<tr>
<td>colorspace</td>
<td><code>sequential_hcl()</code> and <code>diverge_hcl()</code></td>
</tr>
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</table>

RColorBrewer is fast and easy; colorspace is very powerful
More `par()` settings

Formatting for lines and symbols

- lty  Line type (solid, dashed, etc)
- lwd  Line width (default too large; try really small, e.g., 0)
- pch  Data symbol type; see example(points)

`lty` can take complex inputs, see the help for `par()`

You will very often need to set the above
More `par()` settings

Formatting for axes

- `lab` Number of ticks
- `xaxp` Number of ticks for `xaxis`
- `tck,tcl` Length of ticks relative to plot/text
- `mgp` Axis spacing: axis title, tick labels, axis line

These may seem trivial, but affect the aesthetics of the plot & effective use of space.

R defaults to excessive `mgp`, which looks ugly & wastes space.

Most HLCs forget to rotate the y-axis labels. This is a bit harder to fix.
More par() settings

More formatting for axes

The following commands are special:
they are primitives in par() that can’t be set inside the ... of high-level commands

You must set them with par() first:

usr       Ranges of axes: c(xmin, xmax, ymin, ymax)
xlog      Log scale for x axis?
ylog      Log scale for y axis?
Getting math on plots

Getting mathematics on the plots is sometimes possible

See example(text) for ideas

The key command is expression()

For example,

- \text{expression}(\overline{x}) \quad \bar{x}
- \text{expression}(x[i]) \quad x_i
- \text{expression}(x^{-2}) \quad x^{-2}

etc

Vaguely Latex-like, but less powerful

Give up and use Illustrator and/or Latex?
R graphics devices

Everything you draw in R must be drawn on a canvas.

Must create the canvas before you draw anything.

Computer canvases are devices you draw to.

Devices save graphical input in different ways.

Most important distinction: raster vs. vector devices.
Vector vs. raster

Pointalism = raster graphics. Plot each pixel on an $n$ by $m$ grid.
Vector vs. raster

Pixel = Point = Raster

Good for pictures. Bad for drawings/graphics/cartoons.

(Puzzle: isn’t everything raster? In display, yes. Not in storage)

Advantages of vector:

• Easily manipulable/modifiable groupings of objects
• Easy to scale objects larger or smaller/ Arbitrary precision
• Much smaller file sizes
• Can always convert to raster (but not the other way round, at least not well)

Disadvantages:

• A photograph would be really hard to show (and huge file size)
• Not web accessible. Convert to PNG or PDF.
## Some common graphics file formats

<table>
<thead>
<tr>
<th>Lossy</th>
<th>Lossless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raster</td>
<td>.gif, .jpeg</td>
</tr>
<tr>
<td></td>
<td>.wmf, .png, .bmp</td>
</tr>
<tr>
<td>Vector</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>.ps, .eps, .pdf, .ai, .wmf</td>
</tr>
</tbody>
</table>

Lossy means during file compression, some data is (intentionally) lost.

Avoid lossy formats whenever possible.

Avoid copy-and-paste on PC: rasterizes vector graphics in lossy way!
Some common graphics file formats

In R, have access to several formats:

- `win.metafile()` wmf, Windows media file
- `pdf()` pdf, Adobe portable data file
- `postscript()` postscript file (printer language)
- `x11()` opens a screen; all computers
- `windows()` opens a screen; PC only
- `quartz()` opens a screen; Mac only

Latex, Mac or Unix users can’t use wmf

`windows(record=TRUE)` let’s you cycle thru old graphs with arrow keys

Best to make final graphics directly through `pdf()` or `postscript()`

Avoids rasterization