MFE R Programming Workshop

Week 2

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Introduction

Questions

Any questions before we start?

Overview of Week 2

- Time Series Data in R
- Retrieving Time Series Data from the Web
- Graphics in R

Time Series Data in R (`xts`)

What is a Time Series?

- A time series is a set of observations x_t, each one being recorded at a specified time t.

Key R Time Series Packages

- `xts`: eXtensible Time Series.
- `zoo`: Z's Ordered Observations.
  - Both were created by Achim Zeileis.
- `lubridate`
  - Created by Garrett Grolemund and Hadley Wickham.

Date Classes in R

- `Date` is in `yyyy-mm-dd` format.
- `POSIXct` represents the (signed) number of seconds since the beginning of 1970 (in the UTC time zone) as a numeric vector.
- `POSIXlt` is a named list of vectors representing `sec`, `min`, `hour`, `mday`, `mon`, `year`, time zone par maters, and a few other items.

```
x <- Sys.time()  # clock time as a POSIXct object
x
```

```
## [1] "2016-11-02 18:16:27 PDT"
```

```
class(x)
```

```
## [1] "POSIXct" "POSIXt"
```

What is xts?

- xts is an extended zoo object.
- A zoo object is a matrix with a vector of times that form an index.

```
library(xts)
# xts is a matrix plus an index
x <- matrix(1:4, nrow=2, ncol=2)
idx <- seq(as.Date("2016-10-27"), length=2, by="days")
x_xts <- xts(x, order.by = idx)
x_xts
```

```
##            [,1] [,2]
## 2016-10-27    1    3
## 2016-10-28    2    4
```

Constructing `xts`

- The function `xts()` gives you a few other options as well.
  - See `?xts`.
  - `unique` forces times to be unique.
  - `tzone` sets the time zone of the series.
- The index should be of class Date, POSIX, timeDate, chron, etc.
- If the dates are not in chronological order, the `xts` constructor will automatically order the time series.
- Since `xts` is a subclass of `zoo`, `xts` gives us all the functionality of `zoo`.

Deconstructing xts

- How do we get the original index and matrix back?
  - `coredata` extracts the matrix.
  - `index` extracts the index.

```
coredata(x_xts)  # Gives us a martix
```

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

```
index(x_xts)  # Gives us a vector of dates
```

```
## [1] "2016-10-27" "2016-10-28"
```

Viewing the structure of an xts Object.

- The str() function compactly displays the internal structure of an R object.

```
str(x_xts)
```

```
## An 'xts' object on 2016-10-27/2016-10-28 containing:
##   Data: int [1:2, 1:2] 1 2 3 4
##   Indexed by objects of class: [Date] TZ: UTC
##   xts Attributes:
##  NULL
```

Importing and Exporting Time Series

- Importing:
  1. Read data into R using one of the usual functions.
     - `read.table()`, `read.xts()`, `read.zoo()`, etc.
  2. `as.xts()` converts R objects to `xts`.
- Exporting:
  - `write.zoo(x, "file")` for text files.
  - `saveRDS(x, "file")` for future use in R.

Subsetting Time Series

- xts supports one and two-sided intervals.

```
# Load fund data
data(edhec, package = "PerformanceAnalytics")
edhec["2007-01/2007-02", 1]  # interval
```

```
##            Convertible Arbitrage
## 2007-01-31                0.0130
## 2007-02-28                0.0117
```

```
head(edhec["2007-01/", 1])  # start in January 2007
```

```
##            Convertible Arbitrage
## 2007-01-31                0.0130
## 2007-02-28                0.0117
## 2007-03-31                0.0060
## 2007-04-30                0.0026
## 2007-05-31                0.0110
```

Truncated Dates

- `xts` allows you to truncate dates

```r
# January 2007 to March
edhec["200701/03", 1]  # interval
```

```
##            Convertible Arbitrage
## 2007-01-31                0.0130
## 2007-02-28                0.0117
## 2007-03-31                0.0060
```

Other Ways to Extract Values

- We can subset `xts` objects with vectors of integers, logicals, or dates.

```
edhec[c(1,2), 1]  # integers
```

```
##            Convertible Arbitrage
## 1997-01-31                0.0119
## 1997-02-28                0.0123
```

```
edhec[(index(edhec) < "1997-02-28"), 1]  # a logical vecto
```

```
##            Convertible Arbitrage
## 1997-01-31                0.0119
```

```
edhec[c("1997-01-31","1997-02-28") , 1]  # a date vector
```

```
##            Convertible Arbitrage
## 1997-01-31                0.0119
```

first() and last() Functions

- R uses head() and tail() to look at the start and end of a series.
  - i.e. “the first 3 rows” or “the last 6 rows”.
- xts has two functions first() and last().
  - i.e. “the first 6 days” or “the last 6 months”

```
first(edhec[, "Convertible Arbitrage" ], "3 months")
```

```
##            Convertible Arbitrage
## 1997-01-31                0.0119
## 1997-02-28                0.0123
## 1997-03-31                0.0078
```

Math Operations

- Math operations are on the intersection of times.

```
x <- edhec["199701/02", 1]
y <- edhec["199702/03", 1]
x + y # only the intersection
```

```
##            Convertible.Arbitrage
## 1997-02-28                0.0246
```

Operations on the Union

```r
x + merge(y, index(x), fill = 0)
```

```
##            Convertible.Arbitrage
## 1997-01-31                0.0119
## 1997-02-28                0.0246
```

```r
x + merge(y, index(x), fill = na.locf)
```

```
##            Convertible.Arbitrage
## 1997-01-31                    NA
## 1997-02-28                0.0246
```

Database Joins

- There are four main database joins: inner, outer, left and right joins.
  - inner join: intersection.
  - outer join: union.
  - left: using times from the left series.
  - right: using times from the right series.

Merging xts objects

- We can merge xts objects using the merge function.
- merge takes three arguments.
  - an arbitrary number of time series.
  - fill, which handles missing data.
  - join, the type of join we want to do.

```r
colnames(x) <- "x"; colnames(y) <- "y"
merge(x, y)
```

```
##                 x      y
## 1997-01-31 0.0119     NA
## 1997-02-28 0.0123 0.0123
## 1997-03-31     NA 0.0078
```

Merging xts Objects: Left and Right Joins

```r
merge(x, y, join='left')
```

```
##                 x      y
## 1997-01-31 0.0119     NA
## 1997-02-28 0.0123 0.0123
```

```r
merge(x, y, join='right')
```

```
##                 x      y
## 1997-02-28 0.0123 0.0123
## 1997-03-31     NA 0.0078
```

Missing Data

- locf: last observation carried forward

```
x <- c(1, NA, NA, 4)
idx <- seq(as.Date("2016-10-27"), length=4, by="days")
x <- xts(x, order.by = idx); colnames(x) <- "x"
cbind(x, na.locf(x), na.locf(x, fromLast = TRUE))
```

```
##             x x.1 x.2
## 2016-10-27  1   1   1
## 2016-10-28 NA   1   4
## 2016-10-29 NA   1   4
## 2016-10-30  4   4   4
```

Other NA Options

```r
na.fill(x, -999)
```

```
##                x
## 2016-10-27    1
## 2016-10-28 -999
## 2016-10-29 -999
## 2016-10-30    4
```

```r
na.omit(x)
```

```
##            x
## 2016-10-27 1
## 2016-10-30 4
```

Interpolate NAs

```
na.approx(x)
```

```
##            x
## 2016-10-27 1
## 2016-10-28 2
## 2016-10-29 3
## 2016-10-30 4
```

Lagging a Time Series

- `lag(x, k = 1, na.pad = TRUE)`
  - k is the number of lags (positive = forward and negative = backward)
  - k can be a vector of lags
  - 'na.pad' pads the vector back to the original size

```
x <- na.approx(x)
cbind(x, lag(x,1), lag(x,-1))
```

```
##            x x.1 x.2
## 2016-10-27 1  NA   2
## 2016-10-28 2   1   3
## 2016-10-29 3   2   4
## 2016-10-30 4   3  NA
```

Diffferencing Series

- Differencing converts levels to changes.
- see `diff.xts` for additional function arguments.

```
x <- na.approx(x)
cbind(x, diff(x))
```

```
##            x x.1
## 2016-10-27 1  NA
## 2016-10-28 2   1
## 2016-10-29 3   1
## 2016-10-30 4   1
```

Apply over Time Periods

- `period.apply()` applys a function over time intervals.
- `endpoints` gives us the row numbers of endpoints.
- `apply.monthly`, `apply.daily`, `apply.quarterly`, etc. take care of the endpoint calculation for us.

```r
edhec9701 <- edhec["1997/2001", c(1,3)]
# determine the endpoints
ep <- endpoints(edhec9701, "years")
period.apply(edhec9701, INDEX=ep, FUN=mean)
```

```
##            Convertible Arbitrage Distressed Securities
## 1997-12-31            0.01159167           0.013016667
## 1998-12-31            0.00270000          -0.001491667
## 1999-12-31            0.01251667           0.015225000
## 2000-12-31            0.01377500           0.004050000
## 2001-12-31            0.01086667           0.011525000
```

do.call: A Useful R Trick

- The do.call function allows us to specify the name of function, either as a character or an object, and provide arguments as a list.

```
do.call(mean, args= list(1:10))
```

```
## [1] 5.5
```

```
do.call("mean", args= list(1:10))
```

```
## [1] 5.5
```

Discrete Rolling Windows

- split, lapply a function (cumsum, cumprod, cummin, cummax), and recombine.

```
edhec.yrs <- split(edhec[,1], f="years")
edhec.yrs <- lapply(edhec.yrs, cumsum)
edhec.ytd <- do.call(rbind, edhec.yrs)
edhec.ytd["200209/200303", 1]
```

```
##            Convertible Arbitrage
## 2002-09-30                0.0322
## 2002-10-31                0.0426
## 2002-11-30                0.0677
## 2002-12-31                0.0834
## 2003-01-31                0.0283
## 2003-02-28                0.0416
## 2003-03-31                0.0505
```

Continuous Rolling Windows

- `rollapply(data, width, FUN, ...)`

```
rollapply(edhec["200301/06", 1], 3, mean)
```

```
##              Convertible Arbitrage
## 2003-01-31                      NA
## 2003-02-28                      NA
## 2003-03-31              0.01683333
## 2003-04-30              0.01240000
## 2003-05-31              0.01250000
## 2003-06-30              0.00760000
```

Lubridate

Lubridate

- Lubridate is an R package that makes it easier to work with dates and times.
- Lubridate was created by Garrett Grolemund and Hadley Wickham.

```r
# install.packages("lubridate")
library(lubridate)
```

```
##
## Attaching package: 'lubridate'

## The following object is masked from 'package:base':
##
##     date
```

Parse a date

- Lubridate accepts lots of formats

```r
ymd("20110604")
```

```
## [1] "2011-06-04"
```

```r
mdy("06-04-2011")
```

```
## [1] "2011-06-04"
```

```r
dmy("04/06/2011")
```

```
## [1] "2011-06-04"
```

Parse a date and time

```r
ymd_hms("2011-06-04 12:00:00", tz = "Pacific/Auckland")
```

```
## [1] "2011-06-04 12:00:00 NZST"
```

Extraction

```r
arrive <- ymd_hms("2011-06-04 12:00:00")
second(arrive)
```

```
## [1] 0
```

```r
second(arrive) <- 25
arrive
```

```
## [1] "2011-06-04 12:00:25 UTC"
```

Intervals

```r
arrive <- ymd_hms("2011-06-04 12:00:00")
leave <- ymd_hms("2011-08-10 14:00:00")
interval(arrive, leave)
```

```
## [1] 2011-06-04 12:00:00 UTC--2011-08-10 14:00:00 UTC
```

Arithmetic

```r
mydate <- ymd("20130130")
mydate + days(2)
```

```
## [1] "2013-02-01"
```

```r
mydate + months(5)
```

```
## [1] "2013-06-30"
```

Arithmetic

```r
mydate <- ymd("20130130")
mydate + days(1:5)
```

```
## [1] "2013-01-31" "2013-02-01" "2013-02-02" "2013-02-03"
```

End of (next) month

```
jan31 <- ymd("2013-01-31")
jan31 + months(1)
```

```
## [1] NA
```

```
ceiling_date(jan31, "month") - days(1)
```

```
## [1] "2013-01-31"
```

```
floor_date(jan31, "month") + months(2) - days(1)
```

```
## [1] "2013-02-28"
```

Stock Market Data in R

Data from quantmod

- With quantmod we can download stock market data into xts objects.

```
library(quantmod)
getSymbols("^GSPC", src="yahoo", from = "2008-01-01")
```

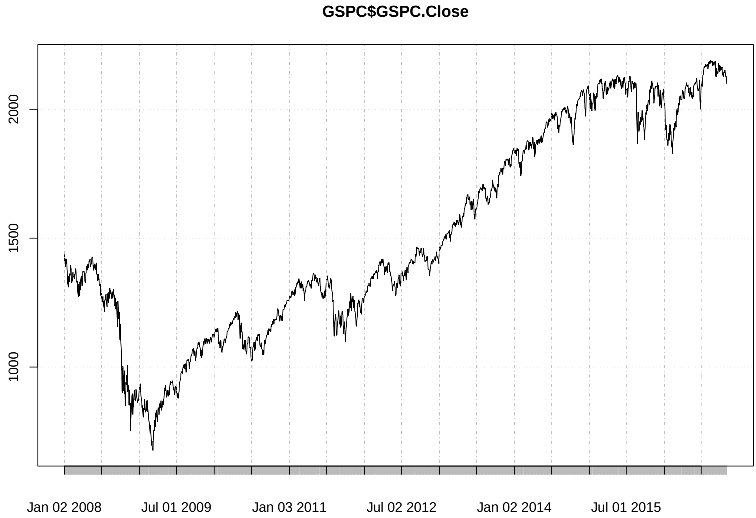
```
## [1] "GSPC"
```

```
head(GSPC,3)[, 1:4]
```

```
##            GSPC.Open GSPC.High GSPC.Low GSPC.Close
## 2008-01-02   1467.97   1471.77  1442.07    1447.16
## 2008-01-03   1447.55   1456.80  1443.73    1447.16
## 2008-01-04   1444.01   1444.01  1411.19    1411.63
```

A Basic Plot

```r
plot(GSPC$GSPC.Close)
```



Switch Period

- `to.period` changes the periodicity of a univariate or OHLC (open, high, low, close) object.

```
eom <- to.period(GSPC,'months')
head(eom,3)
```

```
##            GSPC.Open GSPC.High GSPC.Low GSPC.Close GSPC.
## 2008-01-31   1467.97   1471.77  1270.05    1378.55 98475
## 2008-02-29   1378.60   1396.02  1316.75    1330.63 78536
## 2008-03-31   1330.45   1359.68  1256.98    1322.70 93189
##            GSPC.Adjusted
## 2008-01-31       1378.55
## 2008-02-29       1330.63
## 2008-03-31       1322.70
```

Plotting in R

Motivation

One skill that isn't taught in grad school is how to make a nice chart.

- Managing Director at Citigroup

What makes a chart nice?

- The reader should look at the chart and immediately understand what data are displayed.
- This means we need:
  - A clear title.
  - Clear labels for each axis (scale and units).
  - A legend if more than one time series is displayed.
  - Different colors and line formats for different time series.
  - Grid lines.
  - Labels.

Plotting Facilities in R

- R has excellent plotting methods built-in.
- I will focus on base R.
- As a next step, I recommend learning `ggplot2`, an excellent plotting package.
- http://www.r-graph-gallery.com/

Basic Plotting

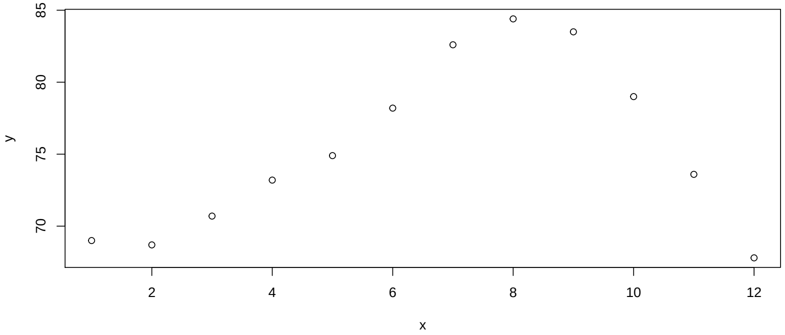
- `example(plot)`
- `example(hist)`
- `?par`
- `?plot.default`

The `plot()` Function

- `plot()` is generic function, i.e. a placeholder for a family of functions.
  - the function that is actually called depends on the class of the object on which it is called.
- `plot()` works in stages.
  - you can build up a graph in stages by issuing a series of commands.
- We will see how this works with an example.

A Basic Plot

```
x <- seq(1:12)
y <- c(69, 68.7, 70.7, 73.2, 74.9, 78.2,
       82.6, 84.4, 83.5, 79, 73.6, 67.8)
plot(x, y)
```



`xlim()` and `ylim()`

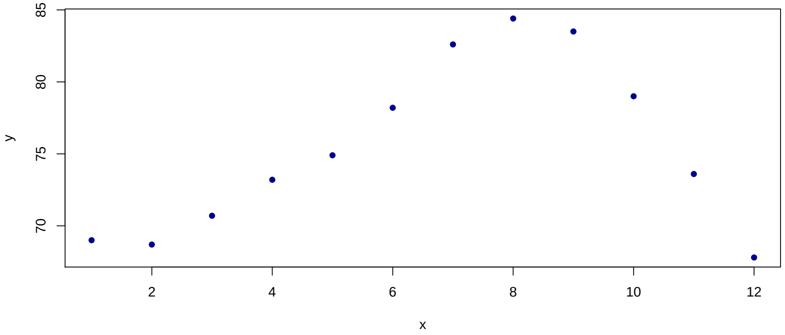
Graphical `par`amaters

- Graphical parameters can be set as arguments to the `par` function, or they can be passed to the `plot` function.
- Make sure to read through `?par`.
- Some useful parameters:
  - `cex`: sizing of text and symbols
  - `pch`: point type.
  - `lty`: line type.
    - 0=blank, 1=solid (default), 2=dashed, 3=dotted, 4=dotdash, 5=longdash, 6=twodash
  - `lwd`: line width.
  - `mar`: margins.

pch

- `pch` sets how points are displayed

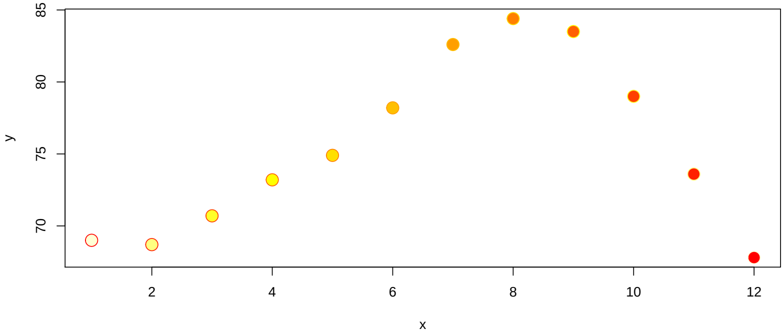

```r
plot(x,y, pch = 16, col='darkblue')
```



Colors in R

- `colors()` returns all available color names.
- `rainbow(n)`, `heat.colors(n)`, `terrain.colors(n)` and `cm.colors(n)` return a vector of `n` contiguous colors.

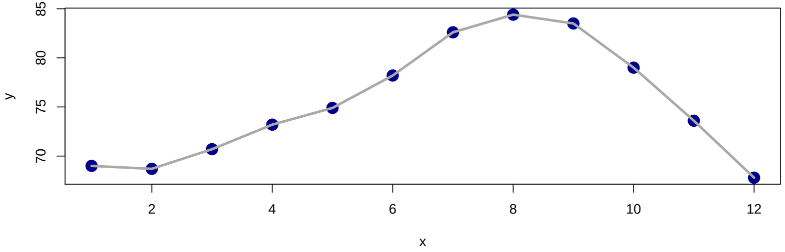
```
plot(x, y, pch = 21, col=heat.colors(12),
     cex = 2, bg = rev(heat.colors(12)))
```



lines()

- `lines()` takes coordinates and joins the corresponding points with line segments.
  - Notice, by calling `lines` after `plot` the line is on top of the points.
  - This is why we want to build the plot in stages.

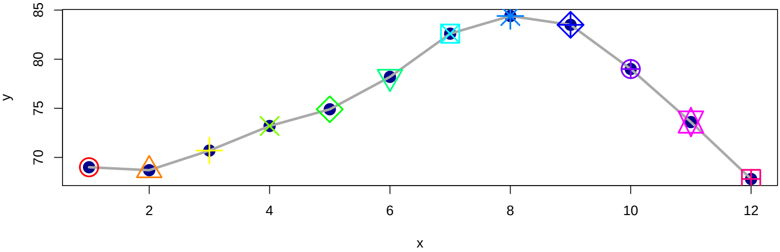
```
plot(x,y, pch = 16, col='darkblue', cex=2)
lines(x, y, col='darkgrey', lwd = 3)
```



points()

- points is a generic function to draw a sequence of points at the specified coordinates. The specified character(s) are plotted, centered at the coordinates.

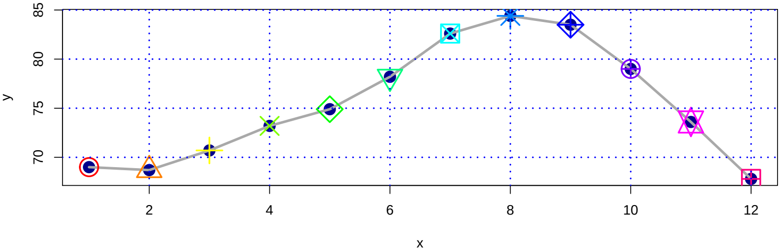
```
plot(x,y, pch = 16, col='darkblue', cex=2)
lines(x, y, col='darkgrey', lwd = 3)
points(x, y, col=rainbow(12), pch=1:12, cex=3, lwd=2)
```



grid()

- `grid` adds a rectangular grid to an existing plot.
- `?grid` for more details.

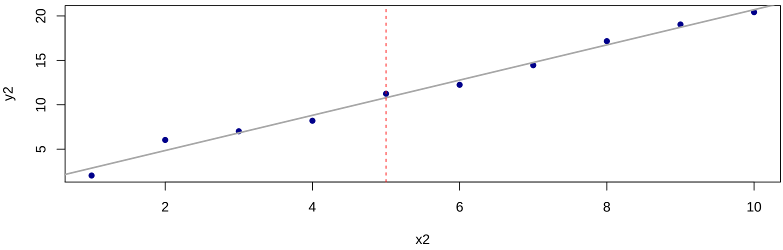
```
plot(x,y, pch = 16, col='darkblue', cex=2)
lines(x, y, col='darkgrey', lwd = 3)
points(x, y, col=rainbow(12), pch=1:12, cex=3, lwd=2)
grid(col="blue", lwd=2)
```



abline()

- abline adds one or more straight lines through the current plot.

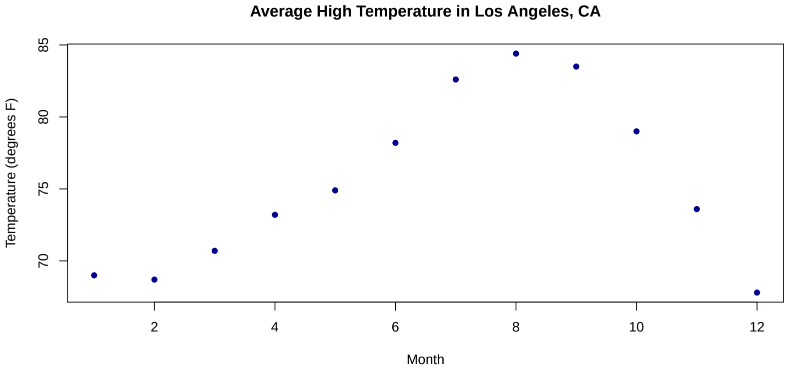
```
x2 <- 1:10; y2 <- 1 + 2*x2 + rnorm(10)
plot(x2,y2, pch = 16, col='darkblue')
model <- lm(y2 ~ x2)
abline(model, col="darkgrey", lwd=2)
abline(v = 5, col = "red", lty = 2)
```



Adding a Title in Lables

- Use the `main` argument for a title.
- Use the `xlab` and `ylab` for axis labels.

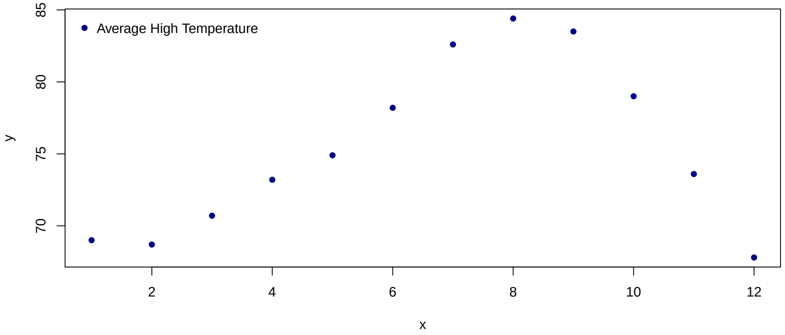
```
plot(x,y, pch = 16, col='darkblue',
     xlab = "Month", ylab = "Temperature (degrees F)",
     main = "Average High Temperature in Los Angeles, CA")
```



Adding a Legend: The legend() Function

- see ?legend and example(legend)

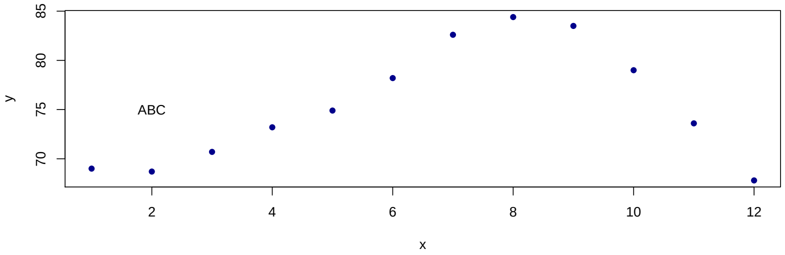
```r
plot(x,y, pch = 16, col='darkblue')
legend("topleft", inset=.01, "Average High Temperature",
  col = "darkblue", pch = 16, bg="white",box.col="white")
```



text() and locator()

- Use the text() function to add text anywhere in the current graph.
- locator() allows you to click on a point in the chart and returns the location.

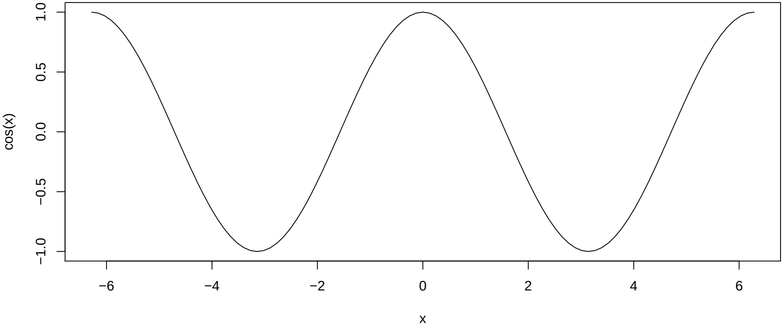
```
plot(x,y, pch = 16, col='darkblue')
text(2,75, "ABC")
```



curve()

- With `curve()`, you can plot a function.

```
curve(cos(x), -2*pi, 2*pi)
```



Saving a Plot to a File

1. Open a file: `pdf("name.pdf")`
2. Create the plot.
3. Close the device with `dev.off()`

- You can use `dev.copy()` to save the displayed graph.
- See `library(help = "grDevices")` for more information.

An Example of Plotting in R

- Let's plot the cumulative (gross) return of IBM and the S&P 500 since 1980.

```
library(quantmod)
getSymbols(c("^GSPC", "IBM"), src="yahoo", from = "1979-12-
```

```
## [1] "GSPC" "IBM"
```

```
adj_close <- merge(GSPC$GSPC.Adjusted, IBM$IBM.Adjusted)
daily_returns <- diff(adj_close)/lag(adj_close)
cum_ret <- cumprod(1+daily_returns[-1,])
ret1 <- xts(matrix(1, ncol=2), as.Date("1979-12-31"))
cum_ret <- (rbind(cum_ret, ret1) - 1)*100
colnames(cum_ret) <- c("GSPC", "IBM")
```

The Data

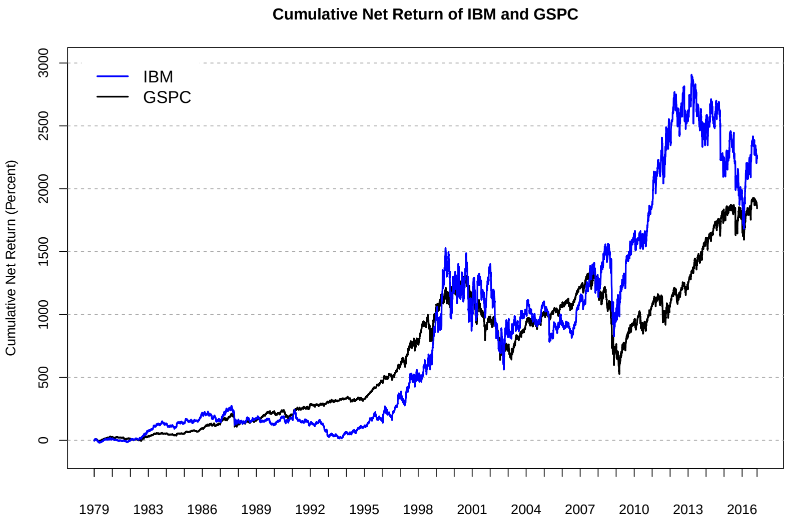
```
head(cum_ret, 9)
```

```
##                  GSPC       IBM
## 1979-12-31  0.0000000  0.000000
## 1980-01-02 -2.0196405 -2.912622
## 1980-01-03 -2.5199194 -1.359235
## 1980-01-04 -1.3155503 -1.553402
## 1980-01-07 -1.0468816 -1.941753
## 1980-01-08  0.9357004  4.660191
## 1980-01-09  1.0283500  1.553387
## 1980-01-10  1.8065564  4.854359
## 1980-01-11  1.8343487  4.077673
```

Start with a Blank Chart and Build it Up

```
plot(cum_ret$IBM, xlab="", ylab = "Cumulative Net Return (F
     main="", major.ticks="years", minor.ticks=F,
     type="n", major.format = "%Y", auto.grid=F,
     ylim = c(-500, 3000))
abline(h=seq(-500,3000,500), col="darkgrey", lty=2)
lines(cum_ret$GSPC, col="black", lwd=2)
lines(cum_ret$IBM, col="blue", lwd=2)
legend("topleft", inset=.02,
       c("IBM","GSPC"), col=c("blue", "black"),
       lwd=c(2,2),bg="white", box.col="white")
```

The Chart


Cumulative Net Return of IBM and GSPC
Cumulative Net Return (Percent)
0
500
1000
1500
2000
2500
3000
IBM
GSPC
1979
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016

Lab 2

Let's work on Lab 2.