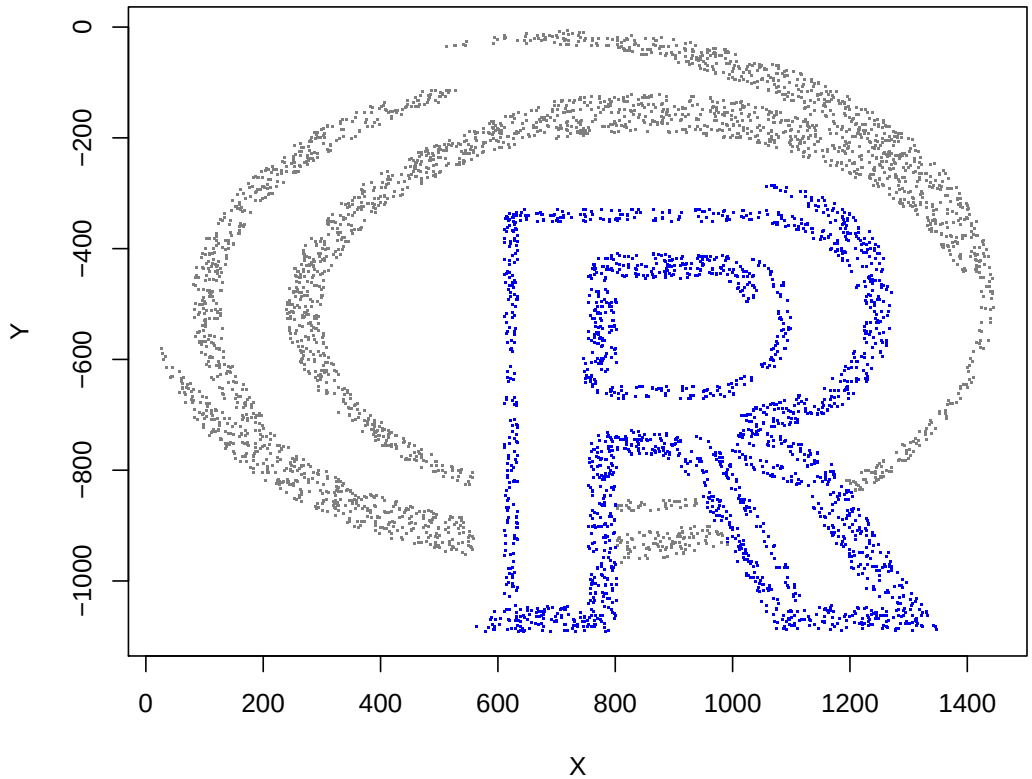
# Basic Graphics




Lecture 5

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# Outline

1. Overview of R Graphics
2. High-Level Plot Functions
3. Low-Level Plot Functions
4. Saving Graphs

# R Graphics

- R is capable of creating high quality graphics
- Graphs are typically created using a series of high-level and low-level plotting commands. High-level functions create new plots and low-level functions add information to an existing plot.
- Customize graphs (line style, symbols, color, etc) by specifying graphical parameters
  - Specify graphic options using the `par()` function.
  - Can also include graphic options as additional arguments to plotting functions

# Graphic Parameters, `par()`

- The function `par()` is used to set or get graphical parameters.
- This function contains 70 possible settings and allows you to adjust almost any feature of a graph.
- Graphic parameters are reset to the defaults with each new graphic device.
- To extract a graphic parameter, `par("`*tag*`")` or `par()$`*tag*.
- To set a graphic parameter, `par(`*tag*`=`*value*`)`.
- Most elements of `par()` can be set as additional arguments to a plot command, however there are some that can only be set by a call to `par()`, `mar, oma, mfrow, mfcol` see the documentation for others.

# High-Level Plot Functions

| | |
|---|---|
| `plot()` | Scatterplot |
| `hist()` | Histogram |
| `boxplot()` | Boxplot |
| `qqplot()`, `qqnorm()`, `qqline()` | Quantile plots |
| `interaction.plot()` | Interaction plot |
| `sunflowerplot()` | Sunflower scatterplot |
| `pairs()` | Scatter plot matrix |
| `symbols()` | Draw symbols on a plot |
| `dotchart()`, `barplot()`, `pie()` | Dot chart, bar chart, pie chart |
| `curve()` | Draw a curve from a given function |
| `image()` | Create a grid of colored rectangles with colors based on the values of a third variable |
| `contour()`, `filled.contour()` | Contour plot |
| `persp()` | Plot 3-D surface |

# Low-Level Plot Functions

| | |
|---|---|
| `points()` | Add points to a figure |
| `lines()` | Add lines to a figure |
| `text()` | Insert text in the plot region |
| `mtext()` | Insert text in the figure and outer margins |
| `title()` | Add figure title or outer title |
| `legend()` | Insert legend |
| `axis(), axis.Date()` | Customize axes |
| `abline()` | Add horizontal and vertical lines or a single line |
| `box()` | Draw a box around the current plot |
| `rug()` | Add a 1-D plot of the data to the figure |
| `polygon()` | Draw a polygon |
| `rect()` | Draw a rectangle |
| `arrows()` | Draw arrows |
| `segments()` | Draw line segments |
| `trans3d()` | Add 2-D components to a 3-D plot |

# Scatterplot and Line Graphs

- The `plot()` function is used for producing scatterplots and line graphs
- Common arguments for `plot()`, see `par()` for a complete list

| | |
|---|---|
| `type` | 1-character string denoting the plot type |
| `xlim` | x limits, c(x1, x2) |
| `ylim` | y limits, c(y1, y2) |
| `log` | Character string that contains "x" if x-axis is log-scale, "y" if y-axis is log scale, and "xy" if both axes are log scale |
| `main` | Main title for the plot |
| `sub` | Sub title for the plot |
| `xlab` | x-axis label |
| `ylab` | y-axis label |
| `ann` | Logical, should default annotation appear on plot |
| `axes` | Logical, should both axes be drawn |
| `col` | Color for lines and points, either a character string or a number that indexes the `palette()` |
| `pch` | Number referencing a plotting symbol or a character string |
| `cex` | A number giving the character expansion of the plot symbols |
| `lty` | Number referencing a line type |
| `lwd` | Line width |

# Example - Scatterplot

```
x <- rnorm(50); y <- rnorm(50)
group <- rbinom(50, size=1, prob=.5)

# Basic Scatterplot
plot(x, y)
plot(x, y, xlab="X", ylab="Y", main="Y vs X", pch=15, col="red")

# Distinguish between two separate groups
plot(x, y, xlab="X", ylab="Y", main="Y vs X",
      pch=ifelse(group==1, 5, 19),
      col=ifelse(group==1, "red", "blue"))

# The points argument can be, (1) two separate vectors where one vector
# is the x-coordinates and the other is the y-coordinates (2) a
# two-column matrix or (3) a two-element list with x and y components
plot(x, y, xlab="X", ylab="Y", main="Y vs X", type="n")
points(x[group==1], y[group==1], pch=5, col="red")
points(x[group==0], y[group==0], pch=19, col="blue")

plot(x, y, xlab="X", ylab="Y", main="Y vs X", type="n")
points(cbind(x,y)[group==1,], pch=5, col="red")
points(cbind(x,y)[group==0,], pch=19, col="blue")
```

# Example - Line Graphs

```
# Basic Line Graphs
plot(sort(x), sort(y), type="l", lty=2, lwd=2, col="blue")

# Like points, the lines argument can be, (1) two separate vectors
# where one vector is the x-coordinates and the other is the
# y-coordinates (2) a two-column matrix or (3) a two-element list
# with x and y components.
plot(x, y, type="n")
lines(sort(x), sort(y), type="b")
lines(cbind(sort(x),sort(y)), type="l", lty=1, col="blue")

# If there is only one component then the argument is plotted against
# its index (same with plot and points)
plot(sort(x), type="n")
lines(sort(x), type="b", pch=8, col="red")
lines(sort(y), type="l", lty=6, col="blue")
```

# Histograms and Boxplots

- Use `hist()` to create histograms and `boxplot()` for boxplots.

```
x <- rnorm(50); y <- rnorm(50)
group <- rbinom(50, size=1, prob=.5)

# Basic Histogram
hist(x, main="Histogram of X", col="deeppink4")

# Plot histogram along with a normal density
# Set freq=FALSE, so that the density histogram is plotted (area sums to 1)
hist(x, freq=FALSE, col="red", main="Histogram with Normal Curve")

# Uses the observed mean and standard deviation for plotting the normal curve
xpts <- seq(min(x), max(x), length=50)
ypts <- dnorm(xpts, mean=mean(x), sd=sd(x))
lines(xpts, ypts, lwd=3)

# Basic boxplot
boxplot(x, main="Boxplot of X", border="red", lwd=2)

# Side-by-Side Boxplots
boxplot(x~group, main="Boxplot of X by Group",
names=c("Group 0", "Group 1"), border=c("red", "blue"), lwd=2)
```

# curve()

- The function `curve()` draws a curve corresponding to a given function.
- If the function is written within `curve()` it needs to be a function of `x`
- If you want to use a multiple argument function, use `x` for the argument you wish to plot over.

```
# Plot a 5th order polynomial
curve(3*x^5-5*x^3+2*x, from=-1.25, to=1.25, lwd=2, col="blue")

# Plot the gamma density
curve(dgamma(x, shape=2, scale=1), from=0, to=7, lwd=2, col="red")

# Plot multiple curves, notice that the first curve determines the x-axis
curve(dnorm, from=-3, to=5, lwd=2, col="red")
curve(dnorm(x, mean=2), lwd=2, col="blue", add=TRUE)

# Add vertical lines at the means
lines(c(0, 0), c(0, dnorm(0)), lty=2, col="red")
lines(c(2, 2), c(0, dnorm(2, mean=2)), lty=2, col="blue")
```

# outer()

- The `outer()` function is very useful for contour plots and 3-D surface plots.
- `outer()` performs a general outer product of two vectors,

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} (y_1 \ y_2 \ y_3) = \begin{pmatrix} f(x_1, y_1) & f(x_1, y_2) & f(x_1, y_3) \\ f(x_2, y_1) & f(x_2, y_2) & f(x_2, y_3) \\ f(x_3, y_1) & f(x_3, y_2) & f(x_3, y_3) \end{pmatrix}$$

  Normally, $f(x_i, y_j) = x_i y_j$, with `outer()` $f$ can be any function.
- The function passed to `outer()` must be a vectorized function

```
> x <- 1:5
> y <- 1:5
> outer(x, y, FUN=function(row, col) row^col)
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    1    1    1    1
[2,]    2    4    8   16   32
[3,]    3    9   27   81  243
[4,]    4   16   64  256 1024
[5,]    5   25  125  625 3125
```

# Contour and 3-D Plots

- Contour plots are created using either `contour()` or `filled.contour()`
- `filled.contour()` accepts a color palette function that is used to assign colors in the plot
  - Built-in color palettes: `heat.colors()`, `terrain.colors()`, `topo.colors()`, `rainbow()` and `cm.colors()`
  - Create your own color palette using `colorRampPalette()`
- 3-D surface plots are created using `persp()`. Use `trans3d()` to add 2-D components to a 3-D surface plot.
- All these functions require a matrix of the $z$ values that correspond to $z = f(x, y)$ evaluated on a grid given by $x$ and $y$, the function `outer()` is very useful for creating this matrix.

# Example - Contour and 3-D Plots

```
library(TeachingDemos)     # Contains rotate.persp()

# Evaluate z on a grid given by x and y
x <- y <- seq(-1, 1, len=25)
z <- outer(x, y, FUN=function(x,y) -x*y*exp(-x^2-y^2))

# Contour plots
contour(x,y,z, main="Contour Plot")
filled.contour(x,y,z, main="Filled Contour Plot")
filled.contour(x,y,z, color.palette = heat.colors)
filled.contour(x,y,z, color.palette = colorRampPalette(c("red", "white", "blue")))

persp(x,y,z, shade=.75, col="green3") # 3-D Surface Plot
rotate.persp(x,y,z)                   # Rotate 3-D Surface Plot

# Add 2-D components to a 3-D Surface plot
# view is the "viewing transformation matrix" needed by trans3d
view <- persp(x,y,z, shade=.75, col="green3")

# Point at (x=1, y=1, z=.01)
points(trans3d(1,1,.1, view), cex=2, col="red", pch=19)
text(trans3d(1,1,.1, view), "(1,1,0.1)", pos=1, font=2)

# Line of z vs x, when y=-.5
lines(trans3d(x, y=-.5, z[7,], view), lwd=2, col="red")
```

# Example - Bivariate Normal

```
library(TeachingDemos)

# Bivariate Normal Density
# x: 2x1 vector, mu: 2x1 mean vector, Sigma: 2x2 covariance matrix
bivariate.normal <- function(x, mu, Sigma) {
     exp(-.5*t(x-mu)%*%solve(Sigma)%*%(x-mu))/sqrt(2*pi*det(Sigma))
}

mu <- c(0,0)
Sigma <- matrix(c(1,.5,.5,1), nrow=2)

x <- y <- seq(-3, 3, len=25)

# Evaluate the bivariate normal density for each value of x and y
z <- outer(x, y,
  FUN=function(x, y, ...){
     apply(cbind(x,y), 1, bivariate.normal, ...)
  }, mu=c(0,0), Sigma=Sigma)

# Filled contour and surface plot of the bivariate normal density
filled.contour(x,y,z, main="Bivariate Normal Density", color.palette=topo.colors)
persp(x, y, z, shade=.75, col="red", main="Bivariate Normal Density")
rotate.persp(x, y, z)
```

# Multiple Graphs

- To create a $n \times m$ grid of figures use `par()` with either the `mfcol` or `mfrow` settings.
  - `mfcol=c(nr, nc)` adds figures by column
  - `mfrow=c(nr, nc)` adds figures by row
- To create a more complex arrangement of multiple plots used `layout()`
  - The arguments `widths` and `heights` are vectors that specify the relative widths and heights of the columns and rows, respectively
- `split.screen()` is used to create multiple plots and allows you to switch control between plots. After a figure is created you can go back to that figure and add more information, `layout()` and `par()` do not have this capability.
  - However, the documentation warns that returning to an existing screen to add information results in unpredictable behavior and may lead to problems that are not readily visible.
- To open a new graphics device,
  - `windows()` on a Windows machine
  - `quartz()` on a Mac machine

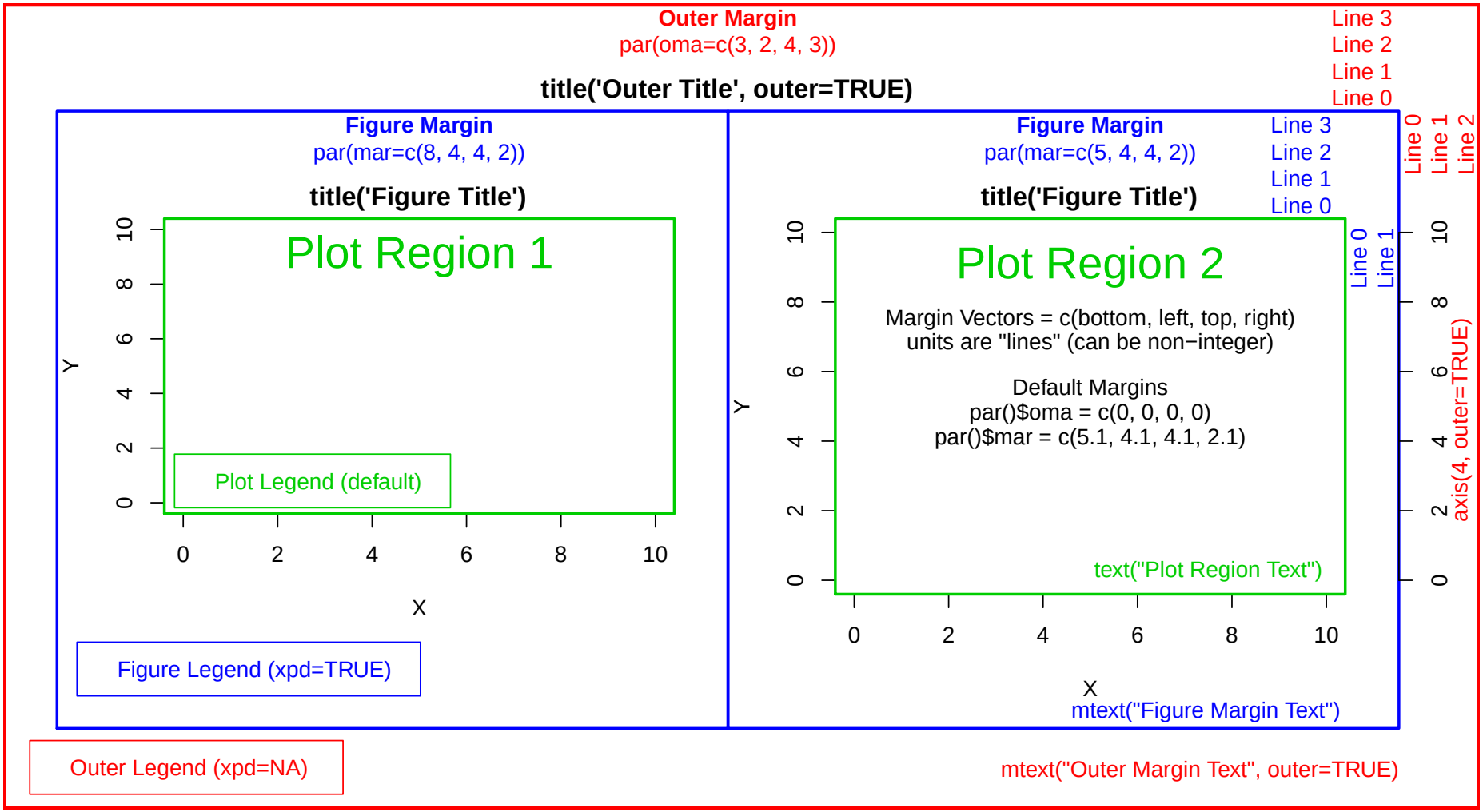
# Example - Multiple Graphs

```
# Figure with two plots side by side
par(mfrow=c(1,2))
plot(rnorm(100), main="Figure 1", pch=19, col="red")
plot(rnorm(100), main="Figure 2", pch=5, col="blue")

# Create layout
layout(matrix(c(1,1,2,3), 2, 2, byrow = TRUE), heights=c(.5,1))
layout.show(3) # View layout

# Create layout
layout(matrix(c(2,0,1,3),2,2, byrow=TRUE), widths=c(3,.5), heights=c(.5,3))
layout.show(3) # View layout

# Plot scatterplot and boxplots
x <- rnorm(100); y <- rnorm(100)

# Notice that the range of the scatterplot and boxplots have the same limits
par(mar=c(4,4,1,1),oma=c(0,0,1,0), font.axis=2, font.lab=2, cex.axis=1.5, cex.lab=1.5)
plot(x, y, xlim=c(-3,3), ylim=c(-3,3), xlab="X", ylab="Y", pch=17, col="darkgreen", cex=1.5)
box(lwd=2)
par(mar=c(0,4,0,1))
boxplot(x, horizontal=TRUE, ylim=c(-3,3), axes=FALSE, at=.75, border="red", lwd=3)
par(mar=c(4,0,1,0))
boxplot(y, ylim=c(-3,3), axes=FALSE, at=.75, border="blue", lwd=3)

# Add title in outer margin
title("Scatterplot and Boxplots of X and Y", outer=TRUE, line=-2, cex.main=2)
```

# Example - Multiple Graphs

```
# Divide the figure into 3 screens and add scatter plots to each screen
split.screen(c(2,1))                 # Split display into two screens
split.screen(c(1,2), 2)              # Split bottom half in two
screen(3)                            # Select screen 3
plot(1:10)                           # Draw plot in screen 3
erase.screen()                       # Forgot title, erase screen 3
plot(1:10, main= "Screen 3")         # Redraw screen 3
screen(1)                            # Select screen 1
plot(runif(100), main="Screen 1") # Add plot to screen 1
screen(4)                            # Select screen 4
plot(0:10, 10:0, main="Screen 4") # Add plot to screen 4
screen(1, FALSE)                     # Return to screen 1, but do not clear
abline(h=.5, lwd=2, col="red")    # Add horizontal line at y=.5 (almost)
close.screen(all = TRUE)             # Exit split-screen mode

# Proper behavior of abline()
windows()  # Start new graphics window
plot(runif(100))
abline(h=.5, lwd=2, col="red")
```

# Margins




- R Graphics consist of a plot region, a figure margin and an outer margin.
- The figure space can be divided into multiple plot regions

# Text

- To add text to the plot region use `text()` and use `mtext()` to add text to the figure and outer margins.

```
par(mfrow=c(1,2), oma=c(2,2,2,2)) # Add an outer margin to the figure

set.seed(123); x <- rnorm(10); y <- rnorm(10)

# Plot 1
plot(x, pch=19, col="red", main="Figure 1")

# Label each point with its index
text(1:10, x, label=1:10, pos=rep(c(4,2), c(2,8)), font=2, cex=1.5)

# Add fancy text to the plot region
text(1, 1, "This is Fancy Plot Text", family="HersheyScript", adj=0, cex=1.5)

# Add text to the margin
mtext("This is Margin Text for Figure 1", side=2, line=4)

# Plot 2
plot(x, pch=15, col="blue", main="Figure 2")

# Add plain text to the plot region
text(1, 1, "This is More Plot Text", family="mono", adj=0, cex=1)

# Add text to the margin
mtext("This is Margin Text for Figure 2", side=3, line=.5)

# Outer Margin, the \n can be include in character strings to add new lines
title("OUTER\nTITLE", outer=TRUE, line=-1)
mtext("This is Outer Margin Text", side=1, outer=TRUE, font=3)
```

# Math Expressions

- R is capable of adding LaTeX like expressions to R graphics
- Use `expression()` to add math expressions to a figure
- The function `bquote()` is used to add expressions and values. Terms inside `.()` are evaluated, the remaining terms are evaluated as math expressions.
- Math expressions can be used in place of almost any `text` argument (cannot be used for axis labels on `persp()` plots).
- See `?plotmath` for a complete list of the syntax used by `expression()` and `bquote()`

```
plot(1:10, type="n", xlab="X", ylab="Y")
text(5.5, 9, "expression(y==alpha[1]*x+alpha[2]*x^2)", cex=1.5)
text(5.5, 8, expression(y==alpha[1]*x+alpha[2]*x^2), cex=1.5)

theta = 3
text(5.5, 6, "theta=3; bquote(hat(theta)==.(theta))", cex=1.5)
text(5.5, 5, bquote(hat(theta)==.(theta)), cex=1.5)
```

# Legend

- Legends are added to a figure using `legend()`, legends can be added to the plot region, figure margin, or the outer margin
- You are responsible for matching plotting symbols and colors with the symbols and colors in the legend
- Legend placement is delicate, the location of the legend often changes when the figure is resized. Fixing the window size before adding legends helps.
- If you are creating one graph the `locator()` function can be useful for determining the placement

# Example - Legend

```
windows(width=9, height=6)         # Fix window size
par(mfrow=c(1,2), oma=c(3,0,2,0)) # Add an outer margin to the figure

set.seed(789)
x1 <- rnorm(10); x2 <- rnorm(10, mean=2)
y1 <- rnorm(10); y2 <- rnorm(10, mean=2)

# PLOT 1, Use range to determine a plot region that is large enough for all the points
plot(range(x1,x2), range(y1,y2), main="Figure 1", type="n", xlab="X", ylab="Y")
points(x1, y1, col="red", pch=19)  # Group 1
points(x2, y2, col="blue", pch=0)  # Group 2
legend("topleft", c("Group 1","Group 2"), pch=c(19,0), col=c("red", "blue"),
       horiz=TRUE, bty="n")
legend(locator(1), c("Group 1","Group 2"), pch=c(19,0), col=c("red", "blue"), title="Legend")

# PLOT 2
plot(range(x1,x2), range(y1,y2), main="Figure 2", type="n", xlab="X", ylab="Y")
lines(sort(x1), sort(y1), col="red", type="o", pch=19)  # Group 1
lines(sort(x2), sort(y2), col="blue", type="o", pch=0)  # Group 2
legend(-2, 2.5, c("Group 1", "Group 2"), pch=c(19,0), col=c("red", "blue"),
       horiz=TRUE, bty="n", lty=1)

# Legend in figure margin
legend(1.5, -2.25, c("Group 1", "Group 2"), pch=c(19,0), col=c("red", "blue"), lty=1,
      bty="n", xpd=TRUE)
# Legend in outer margin
legend(-5.25, -3, c("Group 1", "Group 2"), pch=c(19,0), col=c("red", "blue"), lty=1,
      horiz=TRUE, xpd=NA)
```

# Axis

- In a high-level plot function, if the argument `axes=FALSE` then the plot axes will be omitted.
- The functions `axis()` and `axis.Date()` are used create custom axes.

```
# Plot with no axes
par(mar=c(5,5,5,5))
plot(1:10, axes=FALSE, ann=FALSE)

# Add an axis on side 2 (left)
axis(2)

# Add an axis on side 3 (top), specify tick mark location, and add labels
axis(3, at=seq(1,10,by=.5), labels=format(seq(1,10,by=.5), nsmall=3))

# Add an axis on side 4 (right), specify tick mark location and rotate labels
axis(4, at=1:10, las=2)

# Add axis on side 1 (bottom), with labels rotated 45 degrees
tck <- axis(1, labels=FALSE)
text(tck, par("usr")[3]-.5, labels=paste("Label", tck), srt=45, adj=1, xpd=TRUE)

box() # Add box aroung plot region
mtext(paste("Side", 1:4), side=1:4, line=3.5, font=2) # Add axis labels
```

# Example - axis.Date()

```
dates <- seq.Date(Sys.Date(),by="3 day", length.out=25)
y <- sort(rexp(length(dates)))

plot(dates, y, xlab="Date", ylab="Y", main="Y vs Date",
      axes=FALSE, type="o", pch=18, col="darkorange4", cex=1.5)

# Y-axis
axis(2, at=seq(0, max(y), by=.5))

# X-axis
axis.Date(1, at=seq.Date(min(dates),  max(dates), "week"),
          format="%b %d\n%Y", padj=.5)
axis.Date(1, at=seq.Date(min(dates),  max(dates), "day"),
          labels=FALSE, tcl=-.25)

box()
```

# Colors

- The function `colors()` returns a vector of built-in color names.
- `grep()` can be used to help find colors
- Earl Glynn, has create a very nice PDF color chart of all the built-in colors, there is a link on the class homepage.
- To create your own color use, `rgb()`, `hsv()` or `hcl()`, depending on what method of color specification you prefer
- Create a personal color palette using, `palette()`. When the argument `col=`*number*, `R` uses the color in the palette that is indexed by *number*.

```
# Create and use a custom color
burnt.orange <- rgb(red=204, green=85, blue=0, max=255)
plot(1:10, pch=15, col=burnt.orange, cex=3)

palette()  # Current palette()
plot(1:10, pch=15, col=5, cex=3)

# Custom palette()
palette(c("red", "darkorange", "gold", "green3", "blue", "magenta3"))

plot(c(1,10), c(-3,3), type="n")
for(i in 1:length(palette())) points(rnorm(10), col=i, pch=18, cex=1.5)

palette("default") # Return to default, here "default" is a keyword
```

# Saving Graphs

- Graphs can be saved using several different formats, such as PDFs, JPEGs, and BMPs, by using `pdf()`, `jpeg()` and `bmp()`, respectively.
- Graphs are saved to the current working directory.
- In my opinion, `pdf()` produces the highest quality graphics and are easy to include in LaTeXdocuments if you use a PDF compiler.

```
# Create a single pdf of figures, with one graph on each page
pdf("SavingExample.pdf", width=7, height=5)   # Start graphics device
x <- rnorm(100)
hist(x, main="Histogram of X")
plot(x, main="Scatterplot of X")

dev.off()  # Stop graphics device


# Create multiple pdfs of figures, with one pdf per figure
pdf(width=7, height=5, onefile=FALSE)
x <- rnorm(100)
hist(x, main="Histogram of X")
plot(x, main="Scatterplot of X")

dev.off()  # Stop graphics device
```