An Introduction to R Graphics

Part I—Base Graphics

Dan Hall, Director of the SCC
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Resources for Graphics in R
Introduction

Having powerful and flexible systems for graphics is one of R’s biggest strengths.

- **Base Graphics.** Contained in the `graphics` package distributed in base R.
  
- Grid graphics. `grid` package is distributed in base R.
  - Contains low-level graphics functions.
  - Useful as a platform for developing and implementing higher-level graphics functions and systems.

- **Lattice Graphics.** `lattice` package also distributed in base R.
  - Mimics and extends trellis graphics from S and S-PLUS.
  - Characteristic feature is plots with multiple panels.
  - Built on grid.

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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(recording=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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  • 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.
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Graphical Parameters

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

- These parameters can be queried or reset with `par()`.
  - 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")
abline(h=0)            # line will be dotted and red
par(oldParms)          # reset to the original values
par(c("col","lty"))  # ("black" and "solid")
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par(oldParms)  # reset to the original values
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.:

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

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

[1] "black" "red" "green3" "blue" "cyan" "magenta" "yellow"

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:

```
  Colors and plotting symbols by number

  symbol  meaning
  --------  --------
    ●      black
    △      red
    +      green3
    x      blue
    ◆      cyan
    ▼      magenta
    ○      yellow
    □      gray

  1      2      3      4      5      6      7      8
```

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

```
  solid
  dashed
  dotted
  dotdash
  longdash
  twodash
```
Graphical Parameters

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

plot symbols: points (... pch = *, cex = 1)
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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- Thus, `plot()` can produce many different kinds of plots depending on what argument(s) you pass it.
The `plot()` Function—Examples

- The generic nature of `plot()`.

```r
# 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")
```

---

**Distribution of car types in 1993 CR data set**

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact</td>
<td>0</td>
</tr>
<tr>
<td>Midsize</td>
<td>5</td>
</tr>
<tr>
<td>Sporty</td>
<td>10</td>
</tr>
<tr>
<td>Van</td>
<td>20</td>
</tr>
</tbody>
</table>

**Mosaic plot of joint dist'n of car type and origin**

<table>
<thead>
<tr>
<th>Type</th>
<th>Compact</th>
<th>Large</th>
<th>Midsize</th>
<th>Small</th>
<th>Sporty</th>
<th>Van</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>non-USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Scatterplot matrix for cigarette data**

- tar
- nicotine
- weight
- CO
The `plot()` Function—Examples

Plotting $y$ vs $x$:

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

```r
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.

```r
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).

```r
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),legend=c("plain(sin)*sqrt(x)","plain(cos)*sqrt(x)"))
```

![Graphs showing plots of sin(sqrt(x)) and cos(sqrt(x))](image)
Bar charts with \texttt{barplot()}—Freq Distributions

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

```r
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.")
```

Frequency distribution of car type (CR Cars Dataset)

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.

```r
# 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")
```

![Mean city mileage by car type](image1)

![Mean city MPG by car type with +/- 1.96SE bars](image2)
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.

```r
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.

```r
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)"
```

![Highway vs City MPG](image1.png)  ![Highway vs City MPG (Jittered)](image2.png)
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 \texttt{lattice} or \texttt{ggplot2}.

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

<table>
<thead>
<tr>
<th>trt</th>
<th>dogno</th>
<th>min</th>
<th>volume</th>
<th>trtfac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>17.70 Colechystokynin</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10.35 Colechystokynin</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>20</td>
<td>10.78 Colechystokynin</td>
</tr>
</tbody>
</table>

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.

```r
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.

```r
# 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:

```
\[ \hat{\beta}_0 = -198.3, \hat{\beta}_1 = 0.119 \]
```
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.

```r
# 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 matrix for country-level data on life expectancy, access to healthcare, and access to technology.](image)
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.

```r
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 plotted with pairs()"
```

Variables from the TV Dataset plotted 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.
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.

```r
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.

```r
(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.

```r
(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


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


- 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:

```r
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()
```