


loops and functions in



Berry Boessenkool, berry-b@gmx.de
Jannes Breier, jbreier@gfz-potsdam.de

These slides and tasks are a subset of Berry's teaching material at
github.com/brry/course

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R installation instructions: github.com/brry/course#install

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Outline

Conditions

For loops

lapply




Functions

Writing R packages

Debugging

Feedback

```
print("Hello world!")
```

- Berry Boessenkool → Geoecology @ Potsdam University
- R Fanatic since 2010
- Developer of [rdwd](#), Freelance trainer & consultant 
- Jannes Breier → Geoecology @ Potsdam University
- Berry taught me R in 2013 😊
-  Research Software Engineer at GFZ,  Sec.4.4: Hydrology
- If we're proceeding too fast, please interrupt!

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Conditional execution I

Syntax for a single logical value:

```
if(this_is_true) {do_something} else {do_other_thing}
```

Syntax for a vector with several T/F values:

```
ifelse(condition, expression1, expression2)
```

If condition == TRUE, then expression1 is evaluated, if condition == FALSE, then expression2 is evaluated.

7-3 > 2	TRUE
class(7-3 > 2)	logical = truth value, boolean
if(7-3 > 2) 18	Condition is TRUE, so 18 is returned
if(7-3 > 5) 18	Condition is FALSE, so nothing happens
if(7-3 > 5) 18 else 17	Condition FALSE, so 17 is returned.

Conditional execution II

Several commands must be held together with curly braces:

```
if(TRUE)
{
  plot(1:10, main="TRUE in code")
  box("figure", col=4, lwd=3)
} else
# do something else: plot random numbers
{
  plot(rnorm(500), main="FALSE in code")
}
```

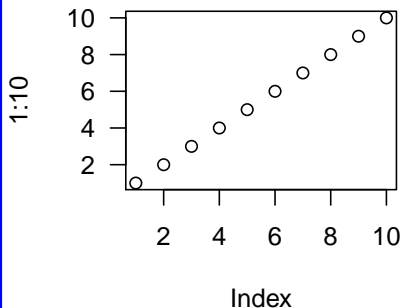
these last brackets can (but should not) be left away

indenting code makes it readable for humans

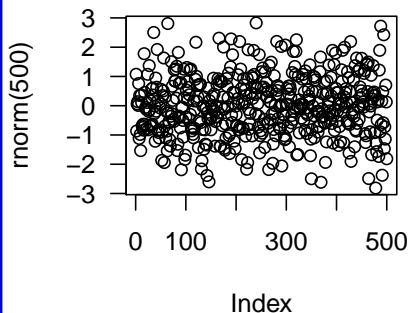
```
par(mfrow=c(1,2), cex=1, las=1)
```

Conditional execution III

TRUE in code



FALSE in code



Vectorising: `if(c) e1 else e2` vs `ifelse(c, e1, e2)`

```
v <- c(13, 14, 15, 16, 17)
```

```
v>14
```

```
## [1] FALSE FALSE TRUE TRUE TRUE
```

```
ifelse(v>14, v+10, NA) # can handle vector of input
```

```
## [1] NA NA 25 26 27
```

```
if(v>14) v+10 else NA
```

```
## Warning in if (v > 14) v + 10 else NA: the condition has  
length > 1 and only the first element will be used
```

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


Time to practice

Exercise 1: if else - Conditional code execution

- 1 `sqrt` returns NaN for the negative values in `v <- -3:5` and warns about it. With a conditional expression, pass 0 instead of negative values to `sqrt`.
- 2 Construct a statement that checks whether the variable `input <- 4` is a number smaller than 3. Let it write a useful `message` to the console (for both cases). Now test it with `input <- 1.8` and `input <- -17`.
- 3 Now restrict the correct value of input to *positive* numbers <3 , i.e. the number must be <3 AND ≥ 0 .
- 4 BONUS 1: What happens if `input <- "2"` or if `input <- "b"`?
- 5 BONUS 2: Create a character variable that, depending on the result of `rnorm(1)`, is initiated with `probable` or `unlikely`.
- 6 BONUS 3: `replicate` this experiment 1000 times and examine the result with `table`.
- 7 BONUS 4: How could you do this with `ifelse`?

Solution for exercise 1.1: if else

```
v <- -3:5
```

```
sqrt(v)
```

```
## Warning in sqrt(v): NaNs produced
```

```
## [1]      NaN      NaN      NaN 0.0000 1.0000 1.4142 1.7321 2.0000 2.2361
```

```
ifelse( v >= 0, sqrt(v), 0)
```

```
## Warning in sqrt(v): NaNs produced
```

```
## [1] 0.0000 0.0000 0.0000 0.0000 1.0000 1.4142 1.7321 2.0000 2.2361
```

```
sqrt(ifelse( v >= 0, v, 0))
```

```
## [1] 0.0000 0.0000 0.0000 0.0000 1.0000 1.4142 1.7321 2.0000 2.2361
```

Solution for exercise 1.2: if else

```
input <- 4
if( input >= 3 ) message("Input was wrong.
                        It should be <3") else
  message("Input OK")
```

Input was wrong.

It should be <3

run it again after

```
input <- 1.8
```

```
input <- -17
```

Solution for exercise 1.3: if else

three different solutions:

```
if( input >= 3 ) message("Input is > 3") else
if( input < 0 )  message("Input is < 0") else
                  message("Input OK")
```

```
if( input >= 3 | input < 0)
  message("Input outside 0...3") else
  message("Input OK")
```

```
if( input > 0 & input <= 3 )  message("Input OK") else
  message("Input (",input,") outside 0...3")
```

Solution for exercise 1.3: if else BONUS

```
result <- if(rnorm(1)>2) "unlikely" else "probable"
```

```
result <- replicate(n=1000, expr=  
  if(rnorm(1)>2) "unlikely" else "probable")  
table(result)
```

```
result <- ifelse(rnorm(1000)>2, "unlikely", "probable")  
table(result)
```

Notes on logical values

- as you might have seen in `read.table(header=T)`, logical values (TRUE, FALSE) can be abbreviated.
- If you want to play a mean prank on someone, write `T <- FALSE; F <- TRUE` in their [Rprofile](#) (see `?Startup`).
- Logical (boolean) values F and T internally are often converted to integers 0 and 1, thus `sum(c(T,F,F,T,T,T,F,F,T))` is the number of TRUEs in a vector, `mean` yields the proportion of TRUEs.
- `which(logicalVec)` gives the indices (positions) of TRUE values.
- `Vec[logicalVec]` returns only the values of vec corresponding to TRUE in logicalVec (No need to wrap it into `which`).
- Logical operators: `!`, `&`, `|`, `xor()` (not, and, or, exclusive or)

Notes on conditional code execution

- `if(c){ex1}` is valid code, thus R doesn't expect `else` anymore.
- If you execute code line by line (in a script, for example), `}` and `else` must be on the same line.
- Many people consider it good practice to do this in functions as well, but for machine-readability, it is technically fine to write

```
if(cond)
{
  ex1a
  ex1b
}
else
  ex2
```

- `if(logicalValue==TRUE) ...` is usually unnecessary, you can write `if(logicalValue) ...`, but sometimes, `if(isTRUE(logicalValue)) ...` helps to deal with NAs.

Actual usage of if else statements

See the `hist` source code:

github.com/wch/r-source -> `src / library / graphics / R / hist.R`

```
mad
```

Multiple nested conditionals

```
if(a) b else if(c) d else e
```

can be avoided with `switch`.

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For loops

Execute a block of code several times, with different input values.

Syntax: `for(aRunningVariable in aSequence){ doSomething }`

Often, `i` (for index) is used, thus `for(i in 1:n) doThis(i)`

```
help("for") # needs quotation marks!
```

```
print(1:2)
print(1:5)
print(1:9)
```

This is easier and less prone to human errors with:

```
for(i in c(2,5,9) ) { print(1:i) }
```

```
## [1] 1 2
## [1] 1 2 3 4 5
## [1] 1 2 3 4 5 6 7 8 9
```

For loops: fill a vector

```
v <- vector(mode="numeric", length=20)
```

```
v
```

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

```
for(i in 3:17) { v[i] <- (i+2)^2 }
```

```
v # this code was executed once for each i
```

```
## [1] 0 0 25 36 49 64 81 100 121
```

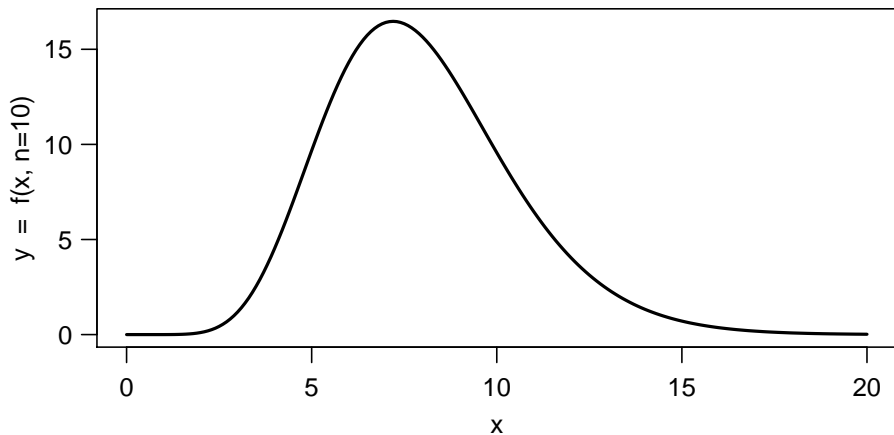
```
## [10] 144 169 196 225 256 289 324 361 0
```

```
## [19] 0 0
```

In R, `for` loops are slow. Always try to vectorize (the best option, not always possible) or use `lapply` (saves you the initiation of the empty vector, easier to parallelize).

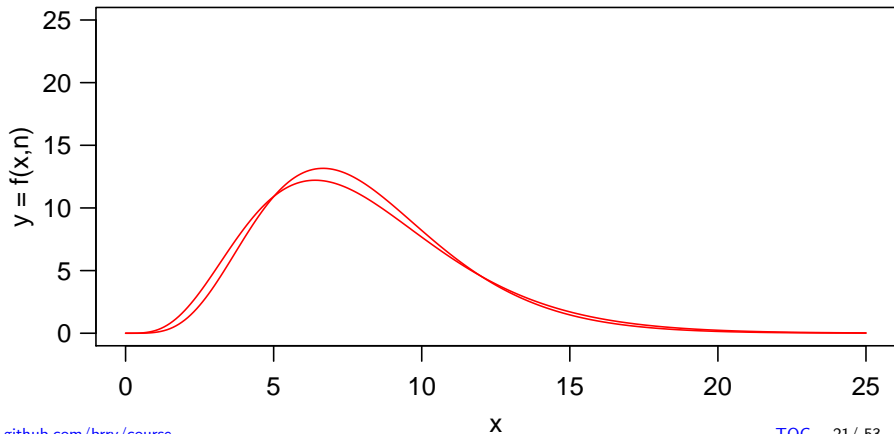
For loops: execute code multiple times I

$$y = f(x, n) = \frac{12.5 * n}{(n-1)!} * \left(\frac{nx}{8}\right)^{(n-1)} * e^{-\frac{nx}{8}}$$



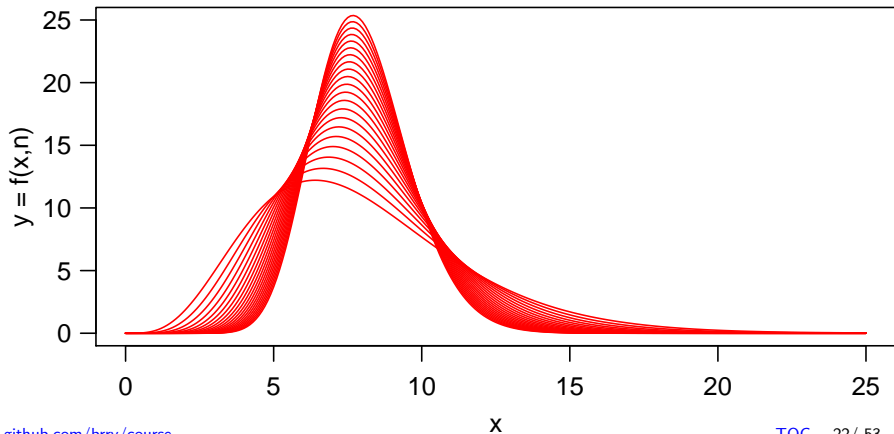
For loops: execute code multiple times II

```
x <- seq(0,25,0.1)
plot(x,x, type="n", ylab="y = f(x,n)")
lines(x, 12.5*5/factorial(5-1)*(x/8*5)^(5-1)*exp(-x/8*5), col=2)
lines(x, 12.5*6/factorial(6-1)*(x/8*6)^(6-1)*exp(-x/8*6), col=2)
```



For loops: execute code multiple times III

```
x <- seq(0,25,0.1)
plot(x,x, type="n", ylab="y = f(x,n)")
for (n in 5:25)
  lines(x, 12.5*n/factorial(n-1)*(x/8*n)^(n-1)*exp(-x/8*n), col=2)
```



for loops shouldn't grow a vector

Bad practice - R needs to recreate the vector each time:

```
output <- NA
for(column in 1:5) output[column] <- median(iris[,column])
```

This internally does the same thing as:

```
output <- vector(mode="numeric", length=0)
for(column in 1:5) output <- c(output, median(iris[,column]))
```

Good practice - first tell R how big the output will be, so it can be adequately allocated in memory:

```
output <- vector(mode="numeric", length=5)
for(column in 1:5) output[column] <- median(iris[,column])
```

for loops exercise

Exercise 2: for loops in file creation

We'll write many datasets to disc (and read them back).

- 1 With `paste0`, print a filename of the structure "mydata_123.txt" using the name, the number and the file ending as inputs. We'll be changing the number later in a loop.
- 2 Print a data.frame with two columns, each with 10 random numbers: one column from the normal, one from the exponential distribution
- 3 With `write.table`, write such a table to a file in a subfolder (remember `dir.create`), using the number of rows (e.g. 10) in the filename.
- 4 BONUS: change the arguments so that row numbers and quotation marks are not printed and tabstops are used for column separation.
- 5 With a `for`-loop, now write files for different sample sizes, e.g. 10, 20, 50, 100, 500.
- 6 Using the output of `dir()`, read all the files into a list of data.frames. Remember to first create an empty list of the right length.
- 7 BONUS: name the list elements according to the filenames.
- 8 BONUS: now replace the whole construct with an `lapply` loop. Celebrate how much nicer your code looks. Check how you can get element names with `sapply(..., simplify=FALSE)`
- 9 BONUS: With `unlink`, delete the files from this exercise. This function is vectorizable, so there's no need to do this in a for loop!

for loops exercise solution

```
dir.create("loopexercise")
for(n in c(10,20,50,100,500))
  write.table(x=data.frame(norm=rnorm(n), exp=rexp(n)),
             file=paste0("loopexercise/randomdata_", n, ".txt"),
             quote=F, row.names=F, sep="\t")

fnames <- dir("loopexercise", full=TRUE)
fcontents <- vector("list", length=length(fnames))
for(fnum in seq_along(fnames))
  fcontents[[fnum]] <- read.table(fnames[fnum], header=TRUE)

flist <- sapply(dir("loopexercise", full=TRUE), read.table, header=TRUE,
               simplify=FALSE)

unlink(paste0("loopexercise/randomdata_", c(10,20,50,100,500), ".txt"))
```

`seq_along(n)` is safer than `1:n` in `for` loops

```
do_something <- function(x) if(x<1) stop("x must be >=1, not:", x) else x
something <- 1:6
```

You'll often see the dangerous code `for(i in 1:n):`

```
for(i in 1:length(something)) do_something(i) # works with current sth
```

Imagine this:

```
something <- which(letters=="4")
for(i in 1:length(something)) do_something(i) # fails! (same code!)

## Error in do_something(i): x must be >=1, not:0
```

Safer to use is:

```
for(i in seq_along(something)) do_something(i)
```

Because:

```
1:length(something)      ; seq_along(something)

## [1] 1 0
## integer(0)
```

stocks data from finance.yahoo.com

```
# Download current datasets:
if(!requireNamespace("quantmod")) install.packages("quantmod")
if(!requireNamespace("pbapply")) install.packages("pbapply")
dummy <- pbapply::pblapply(c("F", "VLKAF", "AMZN", "AAPL", "GOOG", "MSFT"),
  function(x) zoo::write.zoo(x=quantmod::getSymbols(x, auto.assign=FALSE)[,6],
    file=paste0("data/finance/", x, ".txt"), col.names=T))

# read single files to R and merge into one file:
stocks <- lapply(dir("data/finance", full=TRUE),
  read.table, as.is=TRUE, header=TRUE)
stocks <- Reduce(function(...) merge(..., all=T), stocks)

# Get nicer column names:
names <- sapply(strsplit(colnames(stocks), "."), fix=TRUE), "[", 1)
colnames(stocks) <- c(Index="Date", F="FORD", VLKAF="VOLKSWAGEN",
  AMZN="AMAZON", AAPL="APPLE", GOOG="GOOGLE", MSFT="MICROSOFT")[names]

# Save to disc:
write.table(stocks, file="data/stocks.txt", row.names=F, quote=F)
```

For loops: multipanel graphics: the task

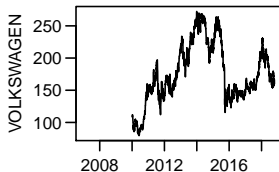
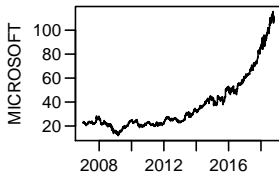
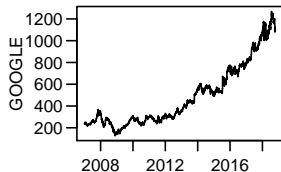
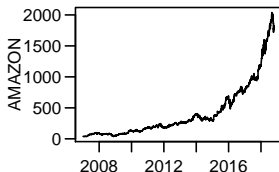
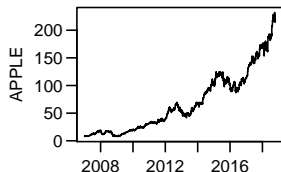
Exercise 3: for loop

- 1 Read `stocks.txt` (rightclick **Raw**, save as), so that there are no factors in the data.frame
- 2 Change the first column type from char to date with `?as.Date`
- 3 What do you get with `plot(stocks[,1:2])`? Make it a line graph.
- 4 With `par(mfrow...,` set up a two by three panel plot
- 5 With a for loop, fill those with each stock time series
- 6 BONUS 1: Make good annotations, including a main title (`par oma,` `mtext` with the outer argument)
- 7 BONUS 2: Make the plot margins smaller (`par mar`), turn y axis labels upright (`las`) and move the axis labels closer to the plots (`mgp`).
- 8 BONUS 3: Understand and comment each line of the data preparation.

For loops: multipanel graphics: the solution

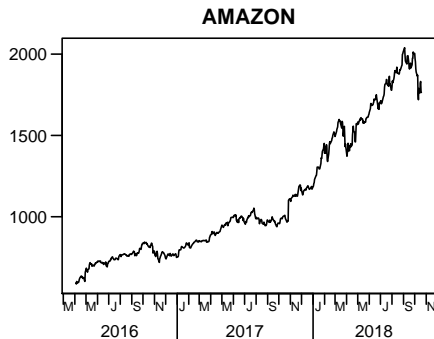
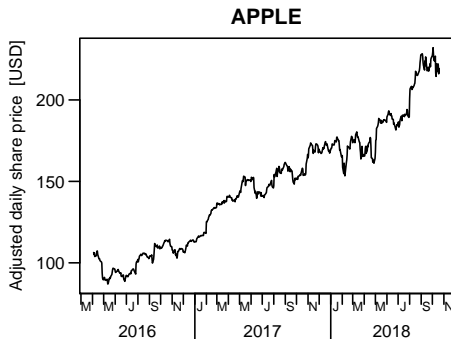
```
stocks <- read.table("data/stocks.txt", header=T, as.is=T)
stocks$Date <- as.Date(stocks$Date)
par(mfrow=c(2,3), mar=c(2,4,1,1), mgp=c(2.5,0.7,0), oma=c(0,0,2,0), las=1)
for(i in 2:7) plot(stocks[,c(1,i)], type="l")
mtext("stocks this decade", line=0, outer=TRUE)
```

stocks this decade



For loops: multipanel graphics: beautifuller

```
par(mfrow=c(1,2), mar=c(4,4,2,0.1), mgp=c(2.5,0.7,0), cex=0.7, las=1)
for(i in 2:3)
{
  plot(stocks[ stocks$Date>as.Date("2016-04-01") , c(1,i) ],
       main=colnames(stocks)[i], xaxt="n", type="l", xlab=" ",
       ylab=if(i==2) "Adjusted daily share price [USD]" else "")
  berryFunctions::monthAxis(1)
}
```



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for -> lapply l: basics

```
files <- dir("../rawdata", pattern="*.csv", full=TRUE)
```

bad and slow way:

```
ldfs <- list() # initiate empty list
```

```
for(i in 1:length(files))
```

```
  ldfs[[i]] <- read.csv(files[i], as.is=TRUE)
```

much better way: apply function to each file

```
ldfs <- lapply(X=files, FUN=read.csv, as.is=TRUE)
```

single data.frame if all files have n columns:

```
df <- do.call(rbind, ldfs)
```

PS: much faster in this example could be

```
library("data.table") # fread + rbindlist
```

```
ldfs <- lapply(X=files, FUN=fread, sep=",")
```

```
df <- rbindlist(ldfs)
```


for -> lapply II: progress bar, names, indexing etc

```
ldfs <- lapply(X=files, FUN=read.csv, as.is=TRUE)
```

```
# progress bar with remaining time
```

```
library("pbapply")
```

```
ldfs <- pblapply(X=files, FUN=read.csv, as.is=TRUE)
```

```
# nice additional stuff:
```

```
names(ldfs) <- files
```

```
str(ldfs, max.level=1)
```

```
ldfs[[2]] # second list element
```

```
# get third column / fifth row from each df:
```

```
sapply(ldfs, "[", , j=3)
```

```
sapply(ldfs, "[", 5, )
```

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Functions I

<http://r4ds.had.co.nz/functions.html>

? "function"

Syntax:

```
Functionobjectname <- function(argument1, argument2, ...)
  {"DoSomething"}
```

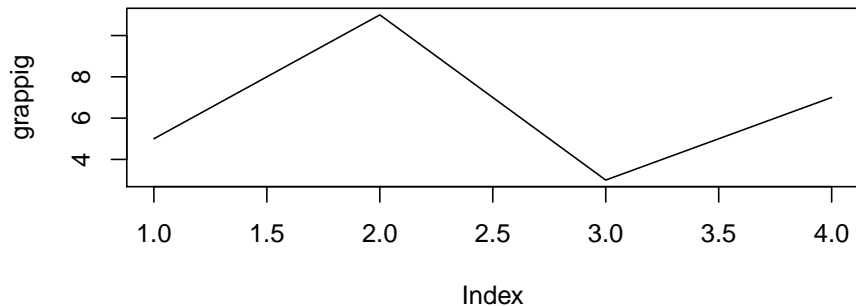
```
myfunct <- function(grappig)
  {plot(grappig, type="l"); return(grappig*7) }
```

After `return()`ing, the execution of the function is terminated, so it should only be positioned at the end. It can also be left away, the last instruction ("expression") will then be returned.

Functions II

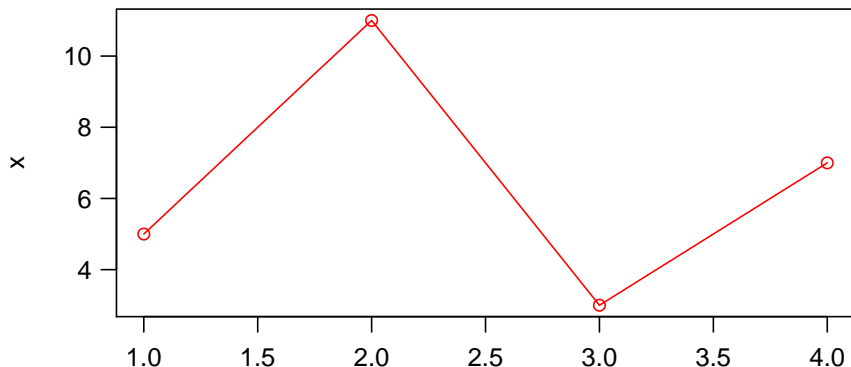
```
myfunct( c(5,11,3,7) )
```

```
## [1] 35 77 21 49
```



Functions with more arguments

```
myfunct <- function(x, type="o", ...) plot(x, type=type, ...)
# type="o" is now the default, thus used unless specified
# The ellipsis (...) passes arguments to other functions
myfunct( c(5,11,3,7) , col="red", las=1)
```



Functions: example I

If you needed to find the zeros of quadratic functions very often, you could use

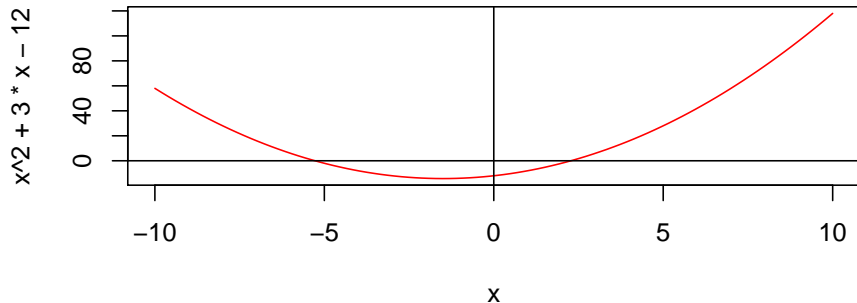
```
pq <- function(p,q) #  $y = x^2 + px + q$ 
{
  w <- sqrt( p^2 / 4 - q )
  c(-p/2-w, -p/2+w)
} # End of function
```

```
pq(3, -12)
```

```
## [1] -5.274917  2.274917
```

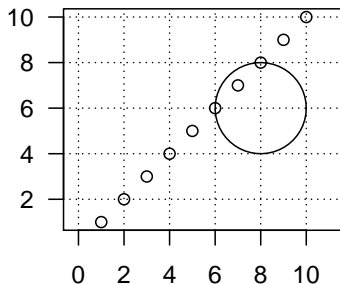
Functions: example II

```
x <- seq(-10, 10, len=100)
plot(x, x^2 + 3*x - 12, type="l", col=2)
abline(h=0, v=0)
```



Exercise: add circles with given radius

```
plot(1:10, asp=1) # aspect ratio y/x of graph range  
grid(col=1) # the next part should go into a function:  
x <- 8 ; y <- 6 ; r <- 2  
p <- seq(0, 2*pi, len=50)  
cx <- x+r*cos(p) ; cy <- y+r*sin(p)  
polygon(cx, cy)
```



Time to practice programming

Exercise 4: Writing functions

Write a function that

- 1 - draws a circle with a certain radius at user-specified locations of an existing plot (see last slide).
- 2 - uses ellipsis to allow the user to customize the appearance
- 3 - checks all the arguments and gives useful warnings if the wrong type of input is provided
- 4 - has useful explanations for each argument (documentation)
- 5 - has readable indentation, spacing and comments explaining the code
- 6 Now let your neighbor use it without explaining how it is to be used (this should be inferred from the code and comments!)
- 7 Use your neighbor's function with a vector to draw several circles at once. (unintended use?) What happens?

```

# Small helper function drawing circles into existing graphics
# Berry Boessenkool, berry-b@gmx.de, 2012
circle <- function(
  x, # x-coordinate of points, numeric value of length 1
  y, # ditto for y
  r, # radius of the circle, in the graphic's units
  locnum=100, # number of points on circle (more means smoother but slower)
  ...) # Further Arguments passed to polygon, like col, border, lwd
{
  # input checking - only one circle can be drawn:
  if(length(x) >1 | length(y) >1 | length(r) >1 | length(locnum) >1)
  {
    warning("Only the first element of the vectors is used.")
    x <- x[1]; y <- y[1]; r <- r[1]; locnum <- locnum[1]
  }

  # input checking - is every value numeric?
  if(!is.numeric(x)) stop("x must be numeric, not ", class(x))
  if(!is.numeric(y)) stop("y must be numeric, not ", class(y))
  if(!is.numeric(r)) stop("r must be numeric, not ", class(r))

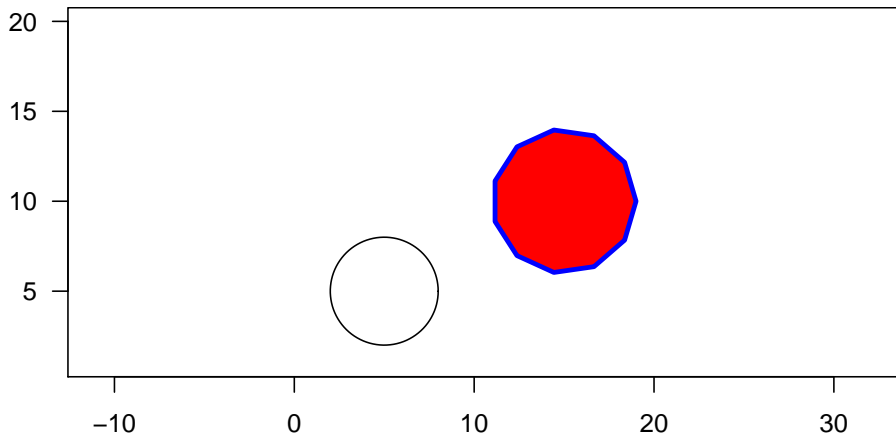
  # prepare circle line coordinates:
  cx <- x+r*cos( seq(0,2*pi,len=locnum) )
  cy <- y+r*sin( seq(0,2*pi,len=locnum) )
  polygon(cx, cy, ...) # actually draw it
}

# Note: if circles look like ellipsis, use plot(... asp=1)

```

Solution for exercise 4 II: functions

```
plot(1:20, type="n", asp=1, cex=2)  
circle(5,5, r=3)  
circle(15,10, r=4, locnum=12, col=2, border=4, lwd=3)
```



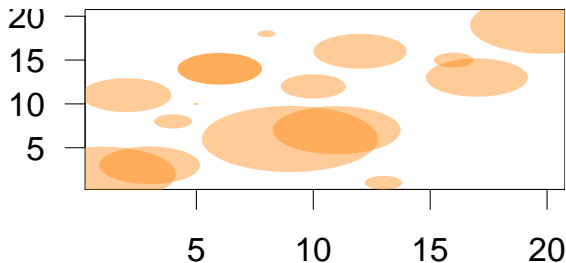
Solution for exercise 4 III: functions

can not be vectorized:

```
x <- sample(1:20, 15) ; y <- sample(1:20, 15) ; r <- runif(20)*4  
circle(x,y,r, col=rgb(1,0.5,0,alpha=0.4), border=NA)
```

Warning in circle(x, y, r, col = rgb(1, 0.5, 0, alpha = 0.4), border = NA):
Only the first element of the vectors is used.

```
for(i in 1:15) circle(x[i],y[i],r[i], col=rgb(1,0.5,0,alpha=0.4), border=NA)
```



Outline

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Why you should write R packages

- Collect your own functions in one place
- Combine functions and documentation in the right way
- Share code with others
- Make your research reproducible !

Good introduction at [packdev.R](#) (rightclick **Raw**, save as)

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- Your code throws an error. You didn't call the mentioned function. Obviously, your code calls some function calling some function calling some function calling [you get the idea] which in the end creates an error. To trace back this path, you can use `traceback()`.
- Now that you know where the error originates from, you set `options(error=recover)`. You run your code again, but this time R waits at the level creating an error. You examine the environment within the function, play around with the objects and internal function code, until the bug has been fixed. You have just debugged a function.
- You want to step into the function you are developing at a specific point. You add `browser()` at that point of the code. You want to go line by line in one specific function. You set `debug(thatFunction)`.
- You want to learn about lexical scoping (Where does R find variables?).
<http://trestletech.com/2013/04/package-wide-variablescache-in-r-package/>
<http://adv-r.had.co.nz/Environments.html>

Debugging: useful functions

<code>source("projectFuns.R")</code>	execute complete file
<code>traceback()</code>	find error source in sequence of function calls
<code>options(warn=2)</code>	warnings to error. default 0
<code>browser()</code>	go into function environment: <code>n</code> , <code>s</code> , <code>f</code> , <code>c</code> , <code>Q</code>
<code>options(error=recover)</code>	open interactive session where error occurred
<code>debug(func)</code>	toggle linewise function execution
<code>undebug(func)</code>	after calling and fixing func

```
if(length(input)>1) stop("length must be 1, not ", length(input))
```

`stop`: Interrupts function execution and gives error

`warning`: continues but gives warning

`message`: to inform instead of worry the user

R. Peng (2002): Interactive Debugging Tools in R

D. Murdoch (2010): Debugging in R

H. Wickham (2015): Advanced R: debugging

Example: Pete Werner Blog Post (2013)

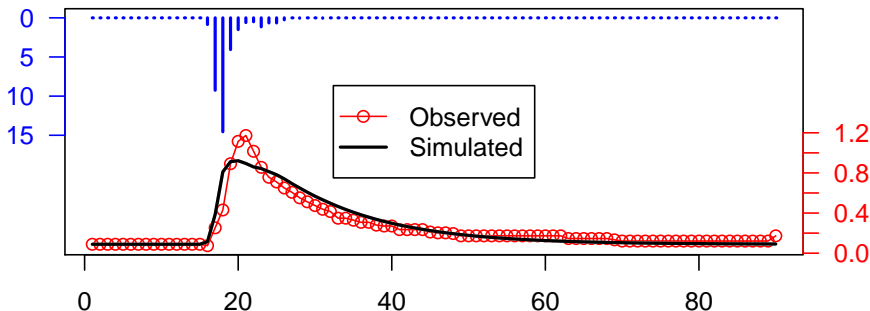
Exercise 5: Debugging

- 1 Load your package and the datasets. Correct the functions until `lsc(calib$P, calib$Q, area=1.6)` returns the result below.
- 2 BONUS: commit each change to git.

P [mm]

Precipitation and discharge

Q [m³/s]



Solution for exercise 5: Debugging

- `stupid error you can easily remove` - traceback - find location of error - `lsc#73` - just comment it out
- `harder to find but still stupid` - traceback - `nse#11` - ditto
- `Error in plot: need finite 'ylim' value` - `debug/browser/options(error=recover)` - `lsc#105` - NAs in `Q` - `range(Q, na.rm=TRUE)` - also in other applicable locations
- `There were 50 or more warnings` - come from `rmse` being called in optimization - add argument `quietNA` (or similar) to `lsc` that is passed to `rmse` in `lsc#79`

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Please fill out the feedback form at

bit.ly/feedbackR

(it only takes a few minutes and helps to improve the course)

Thanks!