

# Statistical Inference: a Gentle Introduction for Linguists and similar creatures (SIGIL)

With practical examples in GNU R

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# Outline

## General Introduction

- Statistical inference and GNU R
- About this course

## Getting Started With R

- Installation tips
- Basic functionalities
- External files and data-frames
- A simple case study: comparing Brown and LOB

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- ▶ Managing **large data sets**
  - ▶ statistical summaries, data analysis, visualisation
  - ▶ e.g. collocations as compact summary of word usage
  - ➡ **descriptive statistics**

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  - ▶ statistical summaries, data analysis, visualisation
  - ▶ e.g. collocations as compact summary of word usage
  - ➡ **descriptive statistics**
- ▶ Discovering **latent** (hidden) **properties**
  - ▶ clustering, multivariate analysis, distributional semantics
  - ▶ advanced statistical modelling (e.g. mixed-effects models)
  - ➡ **exploratory data analysis**

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What you can do on your own:

- ▶ Learn about specific statistical tests and procedures

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  - ▶ *White Book* (version 3, 1992); *Green Book* (version 4, 1998)
  - ▶ commercial: S-Plus (Insightful Corporation, since 1987)

# R – An environment for statistical programming

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  - ▶ *White Book* (version 3, 1992); *Green Book* (version 4, 1998)
  - ▶ commercial: S-Plus (Insightful Corporation, since 1987)
- ▶ **R** is an open-source implementation of the S language
  - ▶ originally by Ross Ihaka and Robert Gentleman (Auckland)
  - ▶ open-source development since mid-1997

# R – An environment for statistical programming



- ▶ binary packages available for Linux, Mac OS X and Windows
- ▶ 64-bit support for large data sets
- ▶ extensive documentation & tutorials
- ▶ thousands of add-on packages ready to install from CRAN

<http://www.R-project.org/>

Recommended cross-platform GUI:

**RStudio** from <http://www.rstudio.com/ide/>

# More about R

- ▶ Advantages of R
  - ▶ free & open source
  - ▶ many add-on packages with state-of-the-art algorithms
  - ▶ large, enthusiastic and helpful user community
  - ▶ easy to automate and extend (every analysis is a program)
  - ▶ no point & click interface

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  - ▶ large, enthusiastic and helpful user community
  - ▶ easy to automate and extend (every analysis is a program)
  - ▶ no point & click interface
  
- ▶ Disadvantages
  - ▶ learning curve sometimes rather steep
  - ▶ not very good at manipulating non-English text
  - ▶ no built-in data editor (spreadsheet)
  - ▶ no point & click interface



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# Goals of the course

- ▶ Basic principles of statistical inference
- ▶ Elementary hypothesis tests, estimators & models
- ▶ Hands-on work with R on real-life data sets
- ▶ Data manipulation and basic R programming skills
- ▶ Get to know R implementations of statistical techniques, data analysis and visualisation methods that are useful in various areas of (computational) linguistics along the way

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What this course is *not* about:

- ▶ Deeper mathematical foundations of statistics
- ▶ Specific (advanced) statistical methods
- ▶ Cookbook recipes for particular analyses with R

# Course units

1. R Basics: installation, data manipulation, input/output (h)
2. Corpus frequency data & statistical inference (h)
3. Descriptive and inferential statistics for continuous data (f)
4. Co-occurrence, contingency tables and collocations (f)  
+ vectorised data processing, high-quality graphs
5. Word frequency distributions with the zipfR package (h)
6. Regression and linear models (f)
7. Exploratory data analysis: clustering, visualisation, ML (h)
8. The non-randomness of corpus data: a GLM approach (h)
9. Inter-annotator agreement (h)

(h) = half-day session / (f) = full-day session (optimistic)

# Introductions



Who are you?

## Recommended textbooks: introductory level

- ▶ Baroni, Marco & Evert, Stefan (2008). *Statistical methods for corpus exploitation*. In A. Lüdeling & M. Kytö (eds.), *Corpus Linguistics. An International Handbook*, Mouton de Gruyter.
- ▶ Gries, Stefan Th. (2013). *Statistics for Linguistics with R: A Practical Introduction*, 2nd ed. Mouton de Gruyter. [€29]
  - ▶ German original from Vandenhoeck & Ruprecht [€25]
- ▶ Johnson, Keith (2008). *Quantitative Methods in Linguistics*. Blackwell. [€38]
- ▶ Field, Andy; Miles, Jeremy; Field, Zoë (2012). *Discovering Statistics Using R*. SAGE Publications, Thousand Oaks. [€61]
- ▶ Peter Dalgaard (2008). *Introductory Statistics with R*, 2nd ed. Springer. [€52]

## Recommended textbooks: advanced level

- ▶ R. Harald Baayen (2008). *Analyzing Linguistic Data: A practical introduction to statistics*. CUP. [€29]
  - ▶ <http://www.sfs.uni-tuebingen.de/~hbaayen/publications/>
- ▶ Morris H. DeGroot and Mark J. Schervish (2002). *Probability and Statistics*, 4th ed. Pearson Education Ltd. [€74]
- ▶ John M. Chambers (2008). *Software for Data Analysis: Programming with R*. Springer. [€85]
- ▶ Christopher Butler (1985), *Statistics in Linguistics*. Blackwell.
  - ▶ out of print and available online for free download from <http://www.uwe.ac.uk/hlss/llas/statistics-in-linguistics/bkindex.shtml>

## Recommended textbooks: R programming

- ▶ Wickham, Hadley (2014). *Advanced R*. The R Series. Chapman & Hall/CRC. [€50]
  - ▶ free online version at <http://adv-r.had.co.nz/>
- ▶ Kabacoff, Robert I. (2011). *R in Action: Data analysis and graphics with R*. Manning. [€40]
- ▶ Teetor, Paul (2011). *R Cookbook*. O'Reilly Media. [€25]
- ▶ Chang, Winston (2012). *R Graphics Cookbook*. O'Reilly Media, Sebastopol, CA. [€25]
- ▶ Wickham, Hadley (2009). *ggplot2: Elegant Graphics for Data Analysis*. Springer, Heidelberg, New York. [€57]



## Free online resources

- ▶ Kuhnert, Petra and Venables, Bill (2005). *An introduction to R: Software for statistical modelling & computing*. Lecture notes, CSIRO Mathematical and Information Sciences.
  - ▶ <http://cran.r-project.org/other-docs.html> (ZIP archive)
- ▶ Robinson, Andrew (2013). *icebreakR*. Lecture notes, University of Melbourne, Department of Mathematics and Statistics.
  - ▶ <http://www.ms.unimelb.edu.au/~andrewpr/r-users/>
- ▶ Burns, Patrick (2011). *The R inferno*. Online publication.
  - ▶ <http://www.burns-stat.com/documents/books/the-r-inferno/>
- ▶ Cheat sheets from <http://cran.r-project.org/other-docs.html>
  - ▶ R Reference Card by Tom Short
  - ▶ R Reference Card for Data Mining by Yanchang Zao

# Course materials

- ▶ Handouts, example scripts and data sets are available on our homepage for this course:

<http://SIGIL.R-Forge.R-Project.org/>

(includes additional material, software, links, etc.)

Another interesting online course:

- ▶ Shravan Vasishth: *Introduction to statistical data analysis + Advanced data analysis*
  - ▶ <http://www.ling.uni-potsdam.de/~vasishth/>

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# Installation guide for Linux & Mac OS X

## Mac OS X

- ▶ Download binary installer from <http://www.R-project.org/>
- ▶ Start GUI application **R** (64-bit)
- ▶ Alternative: run from **TextMate** or various other text editors
- ▶ Shell command **R** available for command-line use

## Linux (Ubuntu and other popular distributions)

- ▶ Install R with standard package manager (e.g. *Synaptic*)
- ▶ Add CRAN repository to obtain up-to-date version of R
  - ▶ e.g. <http://cran.at.r-project.org/bin/linux/ubuntu/precise/>
  - ▶ pkgs: **r-base-core** **r-base-html** **r-base-dev** **r-doc-html** **r-doc-pdf**
- ▶ Various GUIs available, e.g. **Rkward** and **R Commander**
- ▶ Power users: Emacs + ESS or shell command **R** in terminal

# Installing add-on packages

## Mac OS X

- ▶ Select **Packages & Data | Package Installer** from GUI menu
- ▶ Click **Get List**, then choose packages to be installed
  - ▶ you may need to check **install dependencies**, too
  - ▶ installing for all users is only possible on the command line

## Linux (Ubuntu and other popular distributions)

- ▶ Use standard package manager with CRAN repository
  - ▶ offers choice of “difficult” binary packages named **r-cran-\***
  - ▶ make sure that you install the up-to-date CRAN versions!
- ▶ Other packages need to be installed from the command line

## All Unix platforms

- ▶ Install packages from within R (system-wide with `sudo R`)
  - ▶ e.g. `install.packages(c("languageR", "corpora"))`
  - ▶ select CRAN mirror from pop-up list (recommended: Austria)

# Installation on Windows (XP/Vista/7)

Step 1: Download R for Windows installer from [www.R-project.org](http://www.R-project.org)

- ▶ CRAN | choose mirror (Austria) | R for Windows | base
- ▶ **Download R ... for Windows**, then run the installer
- ▶ if Windows complains, allow installer to run & make changes
- ▶ select “full installation” and keep defaults for everything else
- ▶ start R, adjust GUI preferences and save to default location (make sure to select **SDI mode** if you use Tinn-R GUI)

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**Step 2:** Install some important add-on packages

- ▶ Vista/Win 7: run R as administrator to install packages for all users (right-click program icon in Start menu)
- ▶ select **Packages | Install package** from GUI menu
- ▶ choose mirror (Austria), then pick the package(s) to install
- ▶ check successful installation with these R commands:  

```
library(corpora)  
help("VSS") # should pop up Web browser with help page  
data(VSS); head(VSS, 20)
```

## Recommended add-on packages for this course

- `SIGIL` data sets and utilities for this course
- `corpora` some additional corpus-related functions
- `languageR` data sets and functions from Baayen (2008)
- `exact2x2` exact inference for  $2 \times 2$  contingency tables  
(relevant for corpus frequency comparisons)
- `zipfR` word frequency distributions & Zipf's law
- `e1071` machine learning (SVM) and many other utilities
- `MASS` lots of statistical functions (companion package  
to *Modern Applied Statistics with S and S-Plus*)

Some other useful packages:

- `rgl` animated 3D graphics with OpenGL (also: `misc3d`)
- `vcd` visualisation of categorical data (contingency tables)
- `plyr`, `doBy`, convenience functions for data manipulation
- `reshape2`



# Recommended cross-platform GUI: RStudio

<http://www.rstudio.com/ide/>

The screenshot displays the RStudio integrated development environment (IDE) with the following components:

- Source Editor (Untitled1\*):** Contains R code for loading a corpus and creating a table.
 

```
1 library(corpora)
2 ?VSS
3 table(VSS$pos)
4
```
- Console:** Shows the R startup message and the output of the executed code.
 

```
R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> library(corpora)
> table(VSS$pos)

''      (      )      ,      :      CC      CD      DT      EX      FW      IN      JJ      JJR      JJS      MD      NN
71      32      32      451      61      187      69      839      22      1      783      528      15      11      63      1101
MNS      NP      PDT      POS      PP      PPB      RB      RBR      RBS      RP      SENT      TO      UH      VB      VBD      VBG
304      194      13      23      457      167      447      13      9      64      423      206      17      238      603      149
VBN      VBP      VBZ      WDT      WP      WRB      ''
180      67      42      40      26      27      68

> ?VSS
> |
```
- Environment Pane:** Shows the 'Global Environment' with the message 'Environment is empty'.
- Files Pane:** Displays the file structure of the project, including 'VSS (corpora)' and 'R Documentation'.
- Viewer Pane:** Shows the title 'A small corpus of very short stories with linguistic annotations' and a description of the data set, which contains 8043 tokens of short stories from the collection *Very Short Stories* (VSS).

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# R as an oversized calculator

```
> 1+1
```

```
[1] 2
```

```
> a <- 2      # assignment does not print anything by default
```

```
> a * 2
```

```
[1] 4
```

```
> log(a)      # natural, i.e. base-e logarithm
```

```
[1] 0.6931472
```

```
> log(a,2)    # base-2 logarithm
```

```
[1] 1
```

# Basic session management

Some of it is not necessary if you only use the GUI

# to start R on command line, simply type "R"

setwd("path/to/data") # or use GUI menus

ls() # probably empty for now

ls # notice difference with previous line

quit() # or use GUI menus

quit(save="yes")

quit(save="no")

# NB: at least some interfaces support history recall, TAB completion, etc.

# Vectorial math

```
> a <- c(1,2,3) # c (for combine) creates vectors
```

```
> a * 2 # operators are applied to each element of a vector  
[1] 2 4 6
```

```
> log(a) # also works for most standard functions  
[1] 0.0000000 0.6931472 1.0986123
```

```
> sum(a) # basic vector operations: sum, length, product, ...  
[1] 6
```

```
> length(a)  
[1] 3
```

```
> sum(a)/length(a)  
[1] 2
```

# Initializing vectors

```
> a <- 1:100 # integer sequence
> a

> a <- 10^(1:100)

> a <- seq(from=0, to=10, by=0.1) # general sequence

> a <- rnorm(100) # 100 random numbers

> a <- runif(100, 0, 5) # what you're used to from Java etc.
```

# Summary statistics

More about these summary statistics in Unit 3

```
> length(a)
```

```
> summary(a) # statistical summary of numeric vector
```

```
  Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
0.02717 0.51770 1.05200 1.74300 2.32600 9.11100
```

```
> mean(a)
```

```
> median(a)
```

```
> sd(a) # standard deviation is not included in summary
```

```
> quantile(a)
```

```
   0%   25%   50%   75%  100%
0.0272 0.5177 1.0518 2.3261 9.1107
```

## Basic plotting

```
> a <- 2^(1:100) # don't forget the parentheses!
```

```
> plot(a)
```

```
> x <- 1:100 # most often: plot x against y
```

```
> y <- sqrt(x)
```

```
> plot(x, y)
```

```
> plot(x, a)
```

```
> plot(x, a, log="y") # various logarithmic plots
```

```
> plot(x, a, log="x")
```

```
> plot(x, a, log="xy")
```

```
> plot(log(x), log(a))
```

```
> hist(rnorm(100)) # histogram and density estimation
```

```
> hist(rnorm(1000))
```

```
> plot(density(rnorm(100000)))
```



## (Slightly less) basic plotting

```
> a <- rbinom(10000,100,.5)
> hist(a)

> hist(a, probability=TRUE)
> lines(density(a))

> hist(a, probability=TRUE)
> lines(density(a), col="red", lwd=3)

> hist(a, probability=TRUE,
  main="Some Distribution", xlab="value",
  ylab="probability") # better to type command on a single line!
> lines(density(a), col="red", lwd=3)
```

# Help!

```
> help("hist")    # R has excellent online documentation
> ?hist           # short, convenient form of the help command

> help.search("histogram")

> ?help.search

> help.start()    # searchable HTML documentation

# or use GUI menus to access & search documentation
```

# Your first R script

- ▶ Simply type R commands into a text file & save it
- ▶ Use built-in GUI functionality or external text editor
  - ▶ Microsoft Word is *not* a text editor!
  - ▶ nor is Apple's TextEdit application ...
- ▶ Execute R script from GUI editor or by typing
  - > `source("my_script.R")` # more about files later
  - > `source(file.choose())` # select with file dialog box
- ▶ Many GUI editors can execute scripts line by line
  - ▶ check your editor's documentation for keyboard shortcuts
- ▶ Just typing an expression will not automatically print the result in a script: use `print(sd(a))` instead of `sd(a)`

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# Input from an external file

- ▶ We like to keep our data in space- or TAB-delimited text files with a first row (“header”) labeling the fields:

word	frequency	cat
dog	15	noun
bark	10	verb

- ▶ This is an easy format to import into R, and it is easy to convert to/from other tabular formats using standard tools
- ▶ We assume that external input is always in this format (or can easily be converted to it)
  - ▶ spreadsheet applications prefer CSV (comma-separated values), which R also reads and writes quite well
  - ▶ Microsoft Excel is a nice table editor, but beware of localised number formats

## Reading a TAB-delimited file with header

```
> brown <- read.table("brown.stats.txt",  
  header=TRUE)  
# if file is not in working directory, you must specify the full path  
# (or use setwd() function we introduced before)  
  
# exact behaviour of file.choose() depends on operating system  
> brown <- read.table(file.choose(), header=TRUE)  
  
# more robust if you are sure file is in tab-delimited format  
> brown <- read.delim("brown.stats.txt")  
  
# this data set is also included in the SIGIL package  
> library(SIGIL)  
> brown <- BrownStats
```

## Reading and writing CSV files

```
# R can also read and write files in CSV format
> write.csv(brown, "brown.stats.csv",
  row.names=FALSE)

# this is convenient for exchanging data with database and
# spreadsheet software (or using Excel as a data editor)

# NB: comma-separated values are not always separated by commas
# (e.g. in German; use write.csv2 if Excel doesn't recognise columns)
> write.csv2(brown, "brown.stats.csv",
  row.names=FALSE)

# TASK: load brown.stats.csv into Excel or OpenOffice.org

# check generated CSV file (use read.csv2 with write.csv2 above)
> brown.csv <- read.csv("brown.stats.csv")
> all.equal(brown.csv, brown)
```

# Data frames

- ▶ The commands above create a **data frame**
- ▶ This is the basic data structure (object) used to represent statistical tables in R
  - ▶ rows = objects or “observations”
  - ▶ columns = variables, i.e. measured quantities
- ▶ Different types of variables
  - ▶ numerical variables (what we’ve used so far)
  - ▶ Boolean variables
  - ▶ factor variables (nominal or ordinal classification)
  - ▶ string variables
- ▶ Technically, data frames are collections of column vectors (of the same length), and we will think of them as such



# Data frames

```
> summary(brown)
```

```
> colnames(brown)
```

```
> dim(brown)           # number of rows and columns
```

```
> head(brown)
```

```
> plot(brown)
```

# Type/token counts and word lengths for Brown & LOB texts

Data files in TAB-delimited format:

- ▶ `brown.stats.txt`: information for Brown corpus (AmE)
- ▶ `lob.stats.txt`: information for LOB corpus (BrE)

Variables:

- `to` Token count
- `ty` Type count (*distinct* words)
- `se` Sentence count
- `towl` Average word length  
(averaged across tokens in document)
- `tywl` Average word length  
(averaged across distinct types in document)

## Access vectors inside a data frame

```
> brown$to  
> head(brown$to)
```

# TASK: compute summary statistics (length, mean, max, etc.)  
# for vectors in the Brown data frame

# what does the following do?  
> summary(brown\$ty / brown\$to)

```
> attach(brown)      # attach data frame for convenient access  
> summary(ty/to)  
> detach()           # detach from search path
```

```
> with(brown, summary(ty/to)) # a better approach
```

## More data access

```
> brown$ty[1]      # vector indexing starts with 1
> brown[1,2]       # row, column

> brown$ty[1:10]   # use arbitrary vectors as indices
> brown[1:10,2]

> brown[1,]
> brown[,2]
```

# Conditional selection

```
> brown[brown$to < 2200, ] # index with Boolean vector
> brown$ty[brown$to >= 2200]
> sum(brown$to >= 2200)    # standard way to count matches

> subset(brown, to < 2200) # syntactic sugar (similar to with)
> lessdata <- subset(brown, to < 2200)

> a <- brown$ty[brown$to >= 2200]

# equality: == (also works for strings)
# inequality: !=
# complex constraints: and &, or |, not !
# NB: always use single characters, not && or ||
```

# Outline

## General Introduction

Statistical inference and GNU R

About this course

## Getting Started With R

Installation tips

Basic functionalities

External files and data-frames

A simple case study: comparing Brown and LOB

# Procedure

The methods used here will be explained in Units 3 and 6

- ▶ Collect basic summary statistics for the two corpora
- ▶ Check if there is a significant difference in the token counts (since document length was controlled by corpus builders)
- ▶ If difference is significant (we will see that it is), then type counts are not directly comparable, and sentence counts should be normalized (divide by token count)
- ▶ Is word length correlated to document length? (corpus comparison would also not be appropriate in this case)

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- ▶ Is word length correlated to document length? (corpus comparison would also not be appropriate in this case)
- ▶ Please read the LOB data set into a data frame named `lob` now, and take a look at its basic statistics
  - ▶ file `lob.stats.txt`, or `LOBStats` in SIGIL package
- ▶ Also, plot the data frame for a first impression of correlations between the variables



## Comparing token counts

```
> boxplot(brown$to,lob$to)
> boxplot(brown$to,lob$to,names=c("brown","lob"))
> boxplot(brown$to,lob$to,names=c("brown","lob"),
  ylim=c(1500,3000))
> ?boxplot

> t.test(brown$to, lob$to)
> wilcox.test(brown$to, lob$to)

> brown.to.center <-
  with(brown, to[to > 2200 & to < 2400])
> lob.to.center <-
  with(lob, to[to > 2200 & to < 2400])

> t.test(brown.to.center, lob.to.center)
```

# Is word length correlated with token count?

# average word length by tokens and types is almost the same:

```
> plot(brown$towl, brown$tywl)
> cor.test(brown$towl, brown$tywl)
> cor.test(brown$towl, brown$tywl, method="spearman")
```

# correlation with token count

```
> plot(brown$to, brown$towl)
> cor.test(brown$to, brown$towl)
```