Statistics Environment R

Introduction, Overview, Applications

Hans Werner Borchers
Duale Hochschule Mannheim

Universität Kassel
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What is R?

- R is “a **language** and **environment** for statistical computing and graphics”.
- R is Free Software under the terms of the GNU General Public License (GPL).
- **R Foundation of Statistical Computing**
- As an integrated suite for data analysis it includes:
  - well-developed high-level programming language.
  - extensible through packages and C/C++/Fortran codes
  - effective data handling and storage facilities,
  - large, integrated collection of tools for data analysis
  - graphical facilities for statistical (and other) plots
  - elaborate help system (text, PDF, HTML, LaTeX, ...)

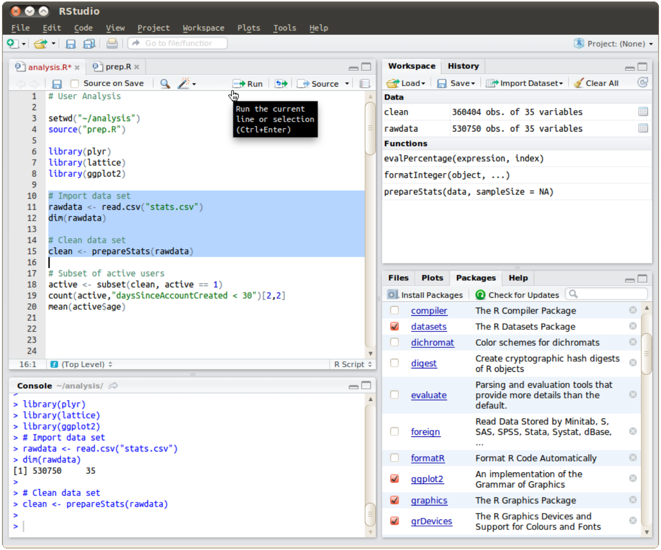
History of R (as Open Source project)

- John Chambers: “S Programming Language"(1985/88)
  ACM Software Award to J. Chambers (1998)
- *S-PLUS* – commercial implementation of S (1988–2008)
- Ross Ihaka and Robert Gentleman, Sidney (1995)
  Environment for statistical computing (Mac)
  “R: Language for Data Analysis and Graphics"(1996)
- Martin Mächler hosts R on a server at the ETH Zürich
  R Core Development Team (1998)
  R becomes an official part of the GNU project
- R version 1.0.0 stable for production use (2000)
- ... CRAN ... R-Forge ... RStudio ... Rcpp ...
- R version 3.0 (April 2013)
  $>$ 5000 user contributed packages on CRAN

R Resources

- R home and download pages (95 mirrors worldwide)
  `http://www.r-project.org`, `cran.r-project.org`
- Contributed packages (sorted by name or date of publication)
  `cran.r-project.org/web/packages/`
- Mailing lists (searchable)
  `https://stat.ethz.ch/pipermail/r-help/`,
  `stackoverflow.com/questions/tagged/r/`
- Task Views
  `cran.r-project.org/web/views/`
- R Journal and the Journal of Statistical Software
  `journal.r-project.org/`, `www.jstatsoft.org/`
- Books related to R (a.o., Springer UseR Series, CRC R Series)
  `www.R-project.org/doc/bib/R-books.html`

Graphical User Interface: RStudio



```
# User Analysis

setwd("~/analysis")
source("prep.R")

library(plyr)
library(lattice)
library(ggplot2)

# Import data set
rawdata <- read.csv("stats.csv")
dim(rawdata)

# Clean data set
clean <- prepareStats(rawdata)

# Subset of active users
active <- subset(clean, active == 1)
count(active,"daysSinceAccountCreated < 30")[2,2]
mean(active$age)
```

```
> library(plyr)
> library(lattice)
> library(ggplot2)
> # Import data set
> rawdata <- read.csv("stats.csv")
> dim(rawdata)
[1] 530750     35
>
> # Clean data set
> clean <- prepareStats(rawdata)
>
> 
```

Data	
clean	360404 obs. of 35 variables
rawdata	530750 obs. of 35 variables

Functions

```
evalPercentage(expression, index)
formatInteger(object, ...)
prepareStats(data, sampleSize = NA)
```

☐	compiler	The R Compiler Package
☑	datasets	The R Datasets Package
☐	dichromat	Color schemes for dichromats
☐	digest	Create cryptographic hash digests of R objects
☐	evaluate	Parsing and evaluation tools that provide more details than the default.
☐	foreign	Read Data Stored by Minitab, S, SAS, SPSS, Stata, Systat, dBase, ...
☐	formatR	Format R Code Automatically
☑	ggplot2	An implementation of the Grammar of Graphics
☑	graphics	The R Graphics Package
☑	grDevices	The R Graphics Devices and Support for Colours and Fonts

Reproducible Research

- “Combine technical report, data analysis, and experimental data s.t. research can be recreated, better understood and verified.”
- RStudio supports document preparation by
    - Markup languages: Markdown (HTML) or LaTeX (PDF)
    - knitr: literate programming
      Presentation + analysis + executable code
    - Unix-like shell programs, e.g., GNU make, pandoc
    - Storing data, code and text on Git/Github repositories
- Minimal requirements for reproducible research: fingerprinting of data, reproducing random numbers, identification of R and package versions, reproducing system settings, etc., are not covered in this framework!

Help System

- Getting help for functions and operators
  `?lm, ?"[[", ??solve, help.start()`
- **Extended/-able help system** for package authors
  - structured help templates (Rd format)
  - automatic tests for correctness, checking examples
  - formatted inline help
  - automatic conversion to other formats: HTML, LaTeX, ...
  - generation of package manual in PDF format
- User and reference manuals easily available
- Web-based online help
  Search facilities for package manuals and mailing lists
  Online documentation: `http://www.Rdocumentation.org/`

Object Orientation

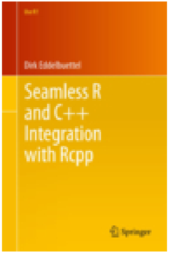
"Everything in R is an object."

- **S3 classes**
  'informal classes', using method dispatching on polymorphic functions
  e.g., generic functions summary or plot: `methods(plot)`

- S4 classes
  newer, fully object-oriented system [*seldom used*]
- OO in packages
  prototype-based: proto, R.OO; multiple inheritance: mutatr
- Reference Classes (Chambers)
  mutable objects, message-passing mechanism (↔ C++)

Integrating Fortran / C / C++

- Dynamically linked Fortran / C / C++ code can be directly used in R and is fully supported by package management and CRAN facilities
- ‘Rcpp’ provides an interface for seamlessly accessing, extending or modifying R objects at the C++ level
  ‘Rinline’: use uncompiled C++ code in R programs



Dirk Eddelbuettel

Seamless R and C++ Integration with Rcpp

Springer

- Other languages:
  - ‘rJava’: low-level R to Java interface
  - ‘rPython’: permits calls form R to Python
  - ‘R.matlab’: TCP/IP interface with the Matlab process

Package Management

- Packages are 'bundles' of functions, data files, help files, source files (Fortran, C, C++), vignettes, and additional information such as DESCRIPTION, NAMESPACE, NEWS
- **R builds and checks packages** with 50(!) different checks
- Source files are compiled and added as dynamically linked libraries
- User-contributed packages are stored on CRAN (> 5000) and are installed and updated from there:
  ```
  install.packages("pracma") ... update.packages()
  library(pracma)
  ```
- Packages can be stored and checked on R-Forge (subversion repository)

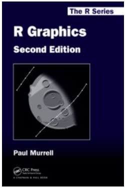
Data Sources

- Reading in data files: Text, CSV files (URL addresses)
  read.table(<file>, header=TRUE, sep='\t', ...)
- Data files from other systems: *.mat (Matlab),
  Excel, ODS, SAS, SPSS, Stata, Systat, IDL(?), ...
- Database connections: DBI, ODBC, JDBC
  Oracle, MySQL, PostgreSQL, **SQLite**
  (non-SQL:) MongoDB, ArangoDB
- Internet data sources: Statistical databases, data archives
  Finance, economics, ecological, census data, geographic, demographic, weather, medical, forensic, genomic/sequencing, ...
- Example:

Statistical Graphs

- Statistical Graphs are completely customized
  scatter plots, function graphs, density diagrams, pie charts, histograms, box and mosaic plots, spine/spinograms, ...
  advanced: grid graphics, ‘pairs’, ‘coplots’
- Dynamic graphics: ‘animation’ package, ‘rgobi’
- Importing and exporting graphics formats
- ‘**ggplot2**’ (Grammar of Graphics) for professional plots
- *Missing Links*: high-quality 3D-Graphs, interactive graphs

- Building Graphical User Interfaces
  Packages: ‘**gWidgets**’, ‘RGtk2’, ‘qtbase’, ‘tkltk’



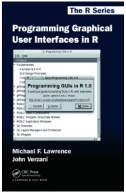
The R Series

R Graphics

Second Edition

Paul Murrell

CRC Press



The R Series

Programming Graphical User Interfaces in R

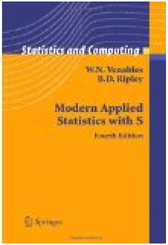
Michael F. Lawrence

John Verzani

CRC Press

Computational Statistics

- Classical univariate Statistics:
  Distributions, summaries, random data, robust methods, density estimation, hypotheses testing, ...
- **Linear regression**, generalized/additive linear models
  Formula language for linear models: `y~x1+x2-1`
- Nonlinear and smooth regression
- Multivariate Statistics:
  cluster/factor/discriminant analysis, classification
  visualization methods: PCA, MDS, SOM, ICA, etc.
- Tree-based methods, random and mixed effects
- Time series, survival analysis, spatial analysis



Statistics and Computing

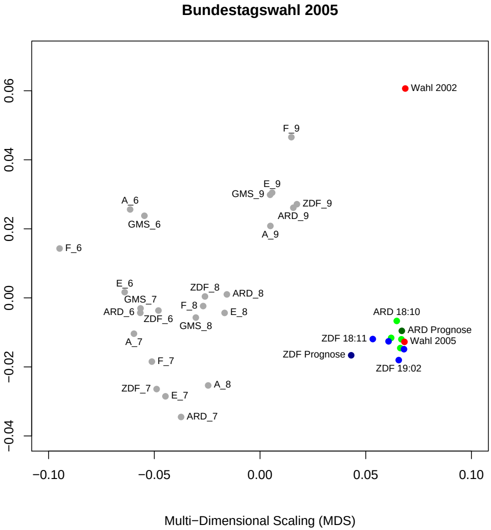
W.N. Venables
B.D. Ripley

Modern Applied Statistics with S

Fourth Edition

Springer

Example: Multidimensional Scaling



Example: R code for MDS

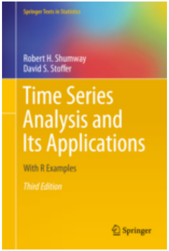
```
umf <- read.table("umfragen.txt", sep="\t", header=T, row.names=1)
umf <- umf[,-6]

dumf <- dist(umf)
cumf <- cmdscale(dumf)

# plotting
clrs <- c(rep("darkgray", 24), "darkgreen", rep("green", 4),
          "darkblue", rep("blue", 4), rep("red", 2))
plot(cumf, pch=19, col=clrs,
     xlim=c(-0.10,0.10), ylim=c(-0.04,0.07),
     xlab=, ylab=,
     main="Bundestagswahl 2005",
     sub="Multi-Dimensional Scaling (MDS)")
identify(cumf[,1], cumf[,2], labels=rownames(umf), cex=0.75)
```

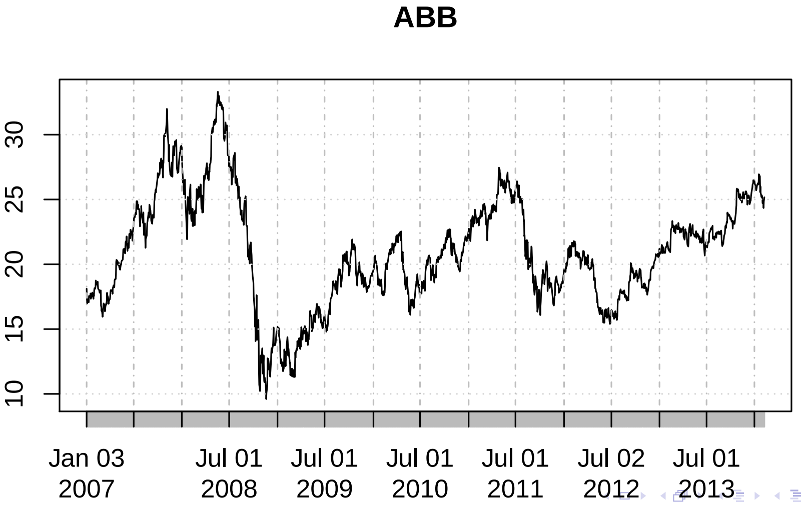
Time Series

- Reading time series from different sources
    - text files, spreadsheets
    - Internet time series databases
    - PostgreSQL time series (‘TSdbi’)
    - Handling of time and date
- **Forecasting** and Modeling
  Decomposition, seasonal trends, ARMA/ARIMA
  spectral analysis, state space identification
- ‘signal’ package, but no ‘control’ package
- **Time Series Data Mining**
    - Clustering and classification
    - Dynamic time warping
    - Functional Data Analysis (FDA)


Springer Texts in Statistics
Robert H. Shumway
David S. Stoffer
Time Series Analysis and Its Applications
With R Examples
Third Edition
Springer

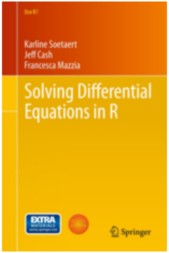
Example: Financial Time Series

```
library(quantmod); getSymbols("ABB"); plot(ABB)
```



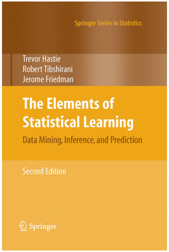
Differential Equations

- Several packages offer to solve differential equations, e.g. ‘deSolve’ or ‘bvpSolve’, mostly by integrating known free solvers written in C or Fortran:
  - Ordinary differential equations (ODEs)
  - Partial differential equations (PDEs)
  - Boundary value problems, e.g. reactive transport equations
  - Differential algebraic equations (DAEs)
  - Delay differential equations (DDEs)



Statistical Learning

- Linear regression and classification
- Kernel smoothing methods (e.g., radial basis functions)
- **CART**, Decision Trees, **MARS**, Earth
- Neural Networks, Kohonen maps
- Support Vector Machines (classification, regression)
- **Random Forests**, ensemble learning
- Graphical models [, Bayesian networks]
- Boosting, AdaBoost, JackKnife methods
- Model assessment and selection



Springer Series in Statistics

Trevor Hastie
Robert Tibshirani
Jerome Friedman

The Elements of Statistical Learning

Data Mining, Inference, and Prediction

Second Edition

Springer

T. Hastie, R. Tibshirani, J. Freedman: *The Elements of Statistical Learning*
James, Witten, Hastie & Tibshirani: *An Introduction to Statistical Learning – With Applications in R*.

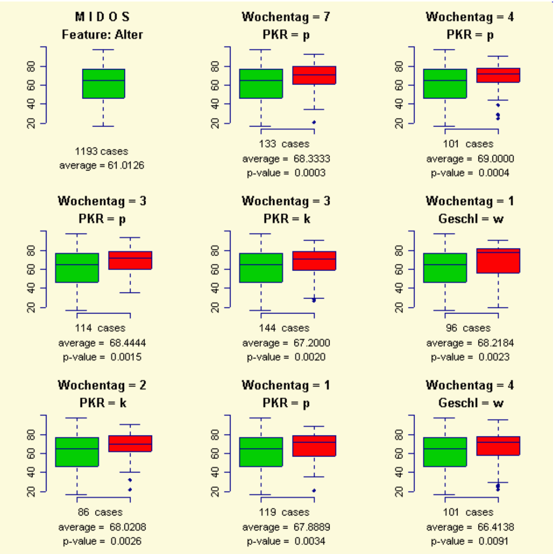
Cousera Course on “Statistical Learning” online since Jan 21, 2014

Data Mining with R

Database Mining...Data Mining...Predictive Analytics...Big Data...Data Science

- Packages providing Data Mining functionality:
  - **Weka**: open source machine learning software
  - Decision trees: Cubist, **C5.0** (Quinlan) [GritBot ?]
  - Random Forest (Breiman): ensemble learning
  - FactorMineR: sequence analysis
- Rattle: graphical user interface for data mining in R
- RODM: interface to Oracle Data Mining
- Vikamine: open source Subgroup Discovery
- Integration of R in Data Mining environments
  (free) Weka, KNIME, RapidMiner; (comm.) SAS Enterprise Miner

Example: MIDOS Graph



Optimization with R (I)

- Optimization in Base R
  `optim(par, fn, gr, lower, upper,`
  `method="Nelder-Mead", "BFGS", "CG", "L-BFGS-B", "SANN")`
- (Nonlinear) Least-Squares optimzation: ‘nls’, ‘nnls’, ‘minpack.lm’, ...
- Derivative-free optimization: ‘dfoptim’
- (Mixed-integer) Linear Programming:
  ‘lpSolve’, ‘Rglpk’, ‘Rsymphony’, ‘rneos’ (NEOS server)
- Nonlinear Optimization: ‘nloptr’ (NLopt library)
- Constraint Optimization: ‘alabama’, ‘Rsolnp‘
  (using “augmented Lagrangian”)

Optimization with R (II)

- Global Optimization: ‘GenSA’, ‘PSO’, ‘soma’, ‘cmaes’ ‘**DEoptim**’, ‘RcppDE’, ‘DEoptimR’ (differential evolution)
- Convex Optimization: ‘Rcsdp’ (semi-definite programming) CVX ?? (“disciplined convex programming”) [Matlab toolbox]
- QP-QC (w/ quadratic constraints) ?? – MIQP ??
- Non-smooth Optimization: ?? (e.g., minimax problems)
- Discrete Optimization: ‘knapsack’, ‘TSP’
- Modeling language ?? [MathProg, AMPL, GAMS, ZIMPL]

- Recommendations: See the “Optimization” task view !, or Special Issue “Optimization in R”, J. of Stat. Software, 2014

Application Areas / Related Projects

- Econometrics / Financial Engineering: **Rmetrics**
  “Financial Market Analysis w/ R” <https://www.rmetrics.org/>
- Bioinformatics: **Bioconductor** <www.bioconductor.org/>
  “Analysis and comprehension of high-throughput genomic data”
- Spatial Statistics: Rgeo <www.R-project.org/Rgeo>
- Robust Statistics: <www.statistik.tuwien.ac.at/rsr/>
- Social Network Analysis: ‘igraph’, ‘sna’
- Optimization “community”

- See the ‘R task View’s <cran.r-project.org/web/views/>

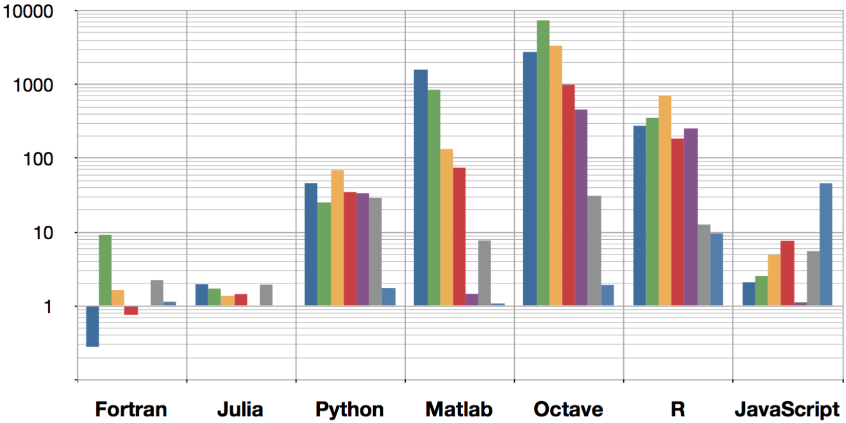
High Performance / Parallel Computing

- High Performance Computing
  'Rcpp' family of packages, e.g., RcppArmadillo, RcppEigen
  'RcppOctave' – interface to Octave *and* Matlab
- **Parallel Computing**
  - Message Passing Interface (MPI)
  - Packages for explicit / implicit parallelism
  - Grid computing, GPUs
- Apache **Hadoop** framework (HDFS, MapReduce)
- Cloud Computing, e.g., Amazon Web / EC2 services
- Large memory / big data support / profiling tools

Gang of Forty

Matlab Maple Mathematica SciPy SciLab IDL R
Octave S-PLUS SAS J APL Maxima Mathcad
Axiom Sage Lush Ch LabView O-Matrix PV-WAVE
Igor Pro OriginLab FreeMat Yorick GAUSS MuPad
Genius SciRuby Ox Stata JLab Magma Euler Rlab
Speakeasy GDL Nickle gretl ana Torch7

Obligatory Performance Slide



Execution time relative to C++

Some Examples of R and Matlab Syntax

Matlab

```
x = [1, 3, 5, 7, 9]
y = A(:, 2)

% defined in ’myfun.m’
function [a,b] = myfun(x,y,z)
...
end

if x == 1
    y = 0
else
    y = x
end
```

R

```
x <- c(1, 3, 5, 7, 9)
y <- A[, 2]

# defined interactively
myfun <- function(x,y,z=1e-0.7) {
    ...
}

if (x == 1) {
    y <- 0
} else {
    y <- x
}
```