Statistics Environment R

Introduction, Overview, Applications

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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, ...)

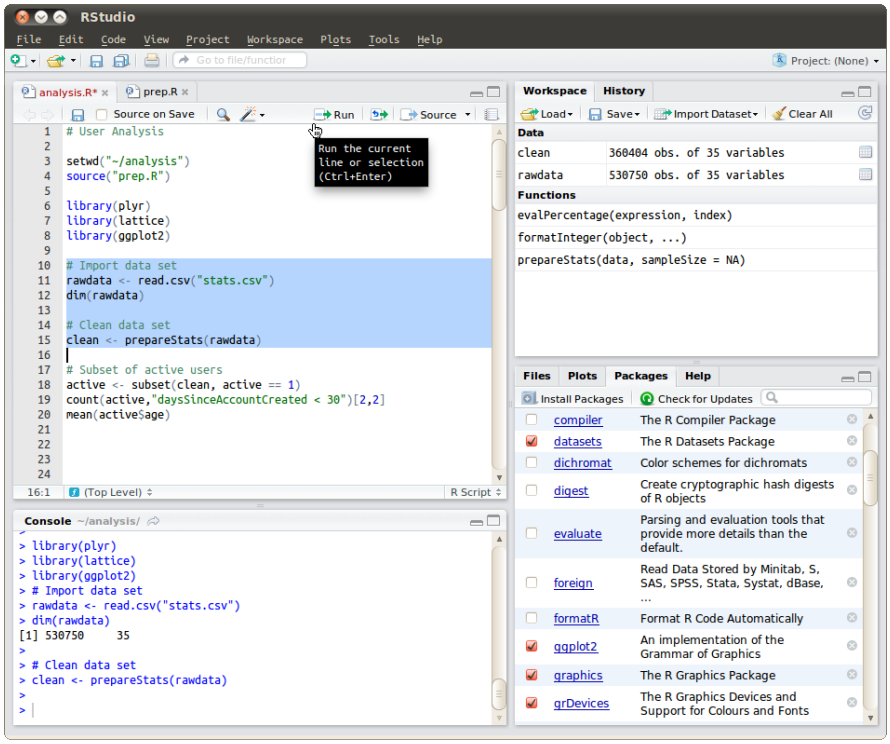
History of R (as Open Source project)

- 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



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

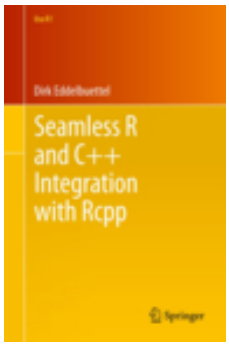
- Getting help for functions and operators
  `?lm, ?"[[", ??solve, help.start()`
- **Extended/-able help system** for package authors
  - structured help templates (Rd format)
  - automatic tests for correctness, checking examples
  - formatted inline help
  - automatic conversion to other formats: HTML, 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 ($\leftrightarrow$ 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
- 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

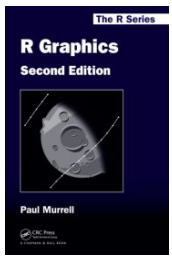
- Packages are 'bundles' of functions, data files, help files, source files (Fortran, C, C++), vignettes, and additional information such as DESCRIPTION, NAMESPACE, NEWS
- **R builds and checks packages** with 50(!) different checks
- Source files are compiled and added as dynamically linked libraries
- 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)

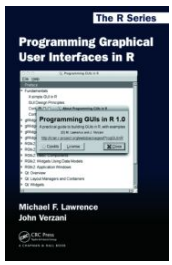
Data Sources

- 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

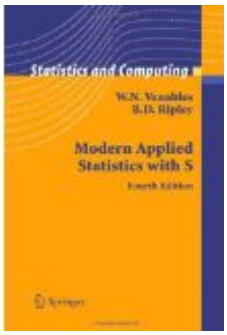




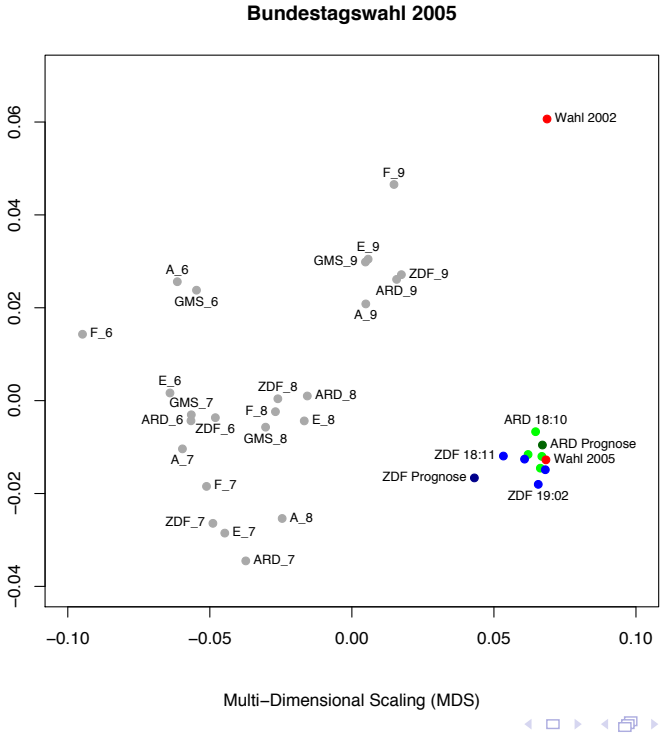
- Building Graphical User Interfaces
  Packages: '**gWidgets**', 'RGtk2', 'qtbase', 'tkltk'

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



Example: Multidimensional Scaling



Example: R code for MDS

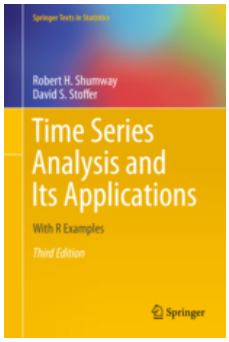
```
umf <- read.table("umfragen.txt", sep="\t", header=T, row.names=1)
umf <- umf[,-6]

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)
```

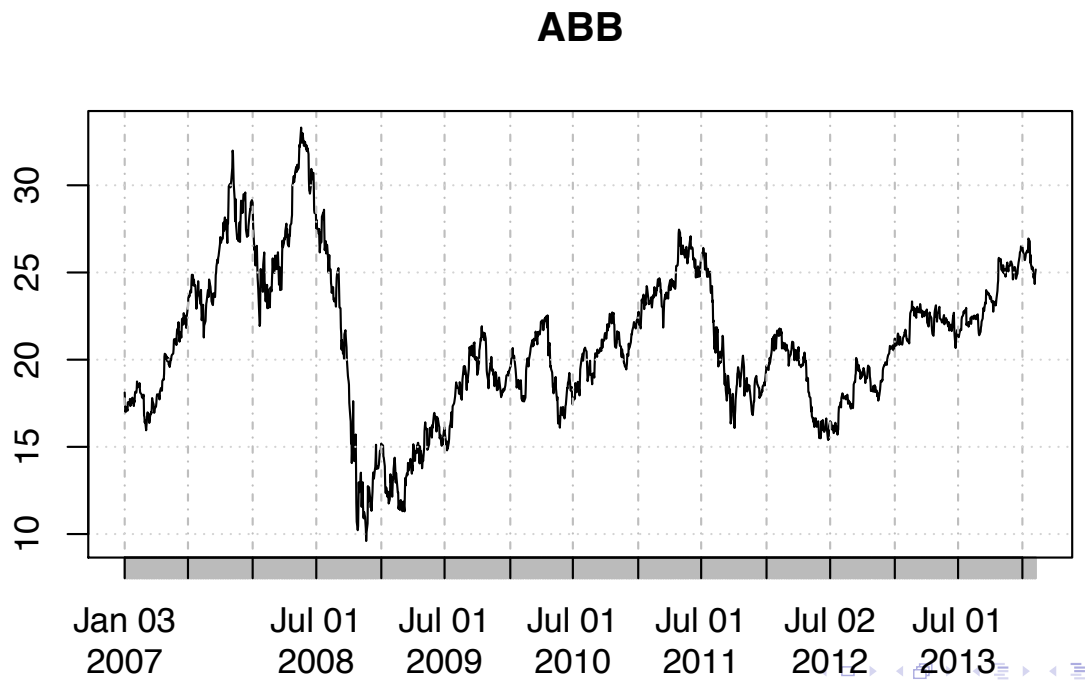

Time Series

- 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)



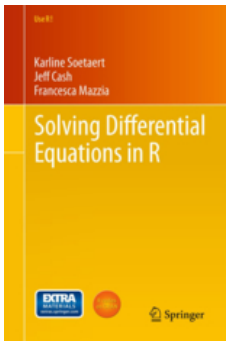
Example: Financial Time Series

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



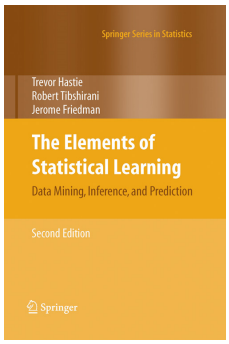
Differential Equations

- 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



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

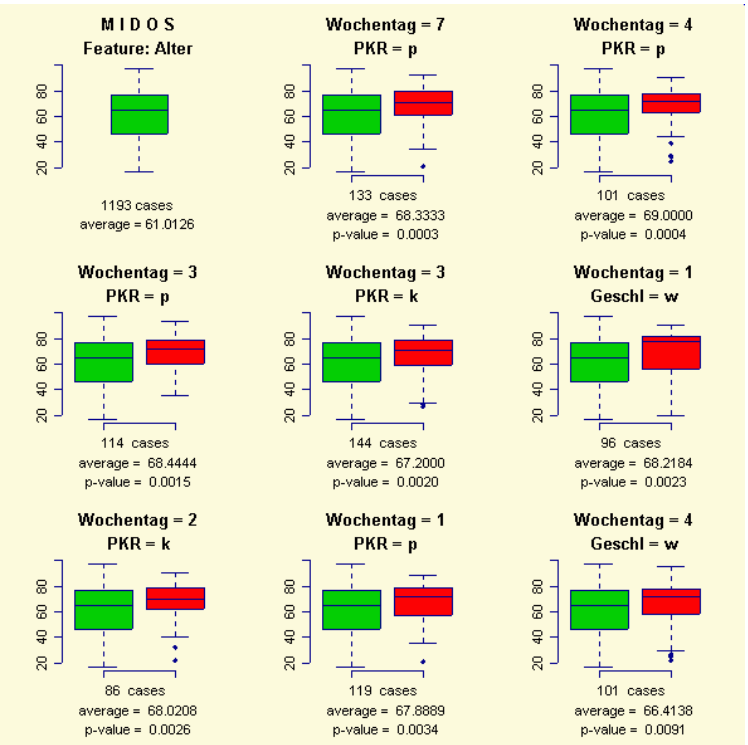
Cousera Course on "Statistical Learning" online since Jan 21, 2014

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

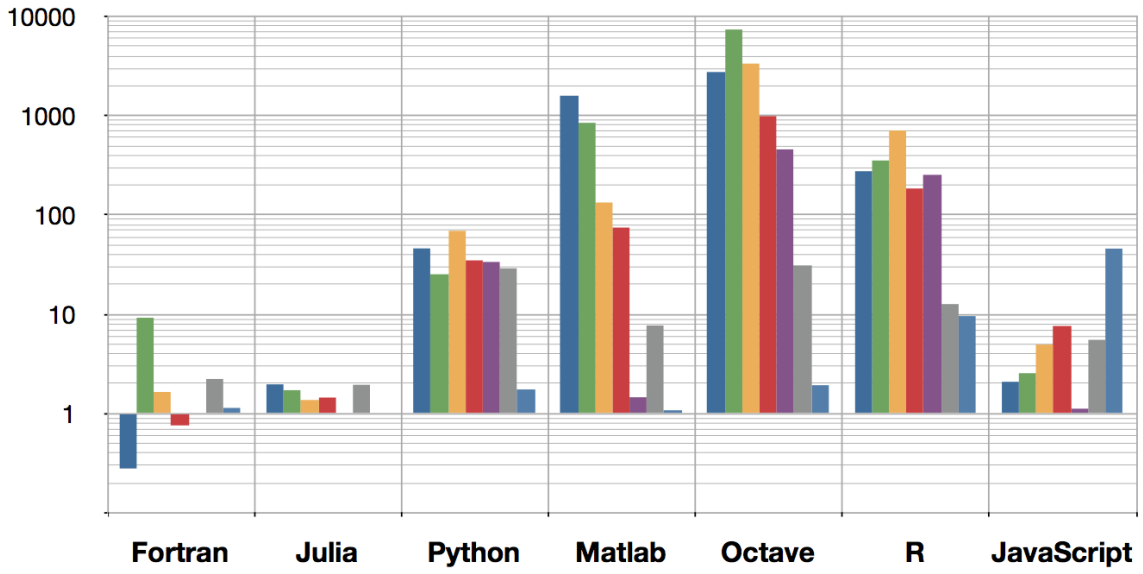
- High Performance Computing
  'Rcpp' family of packages, e.g., RcppArmadillo, RcppEigen
  'RcppOctave' – interface to Octave *and* Matlab

- **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
}
```