# Simulation and Performance Evaluation

## Basic R Usage

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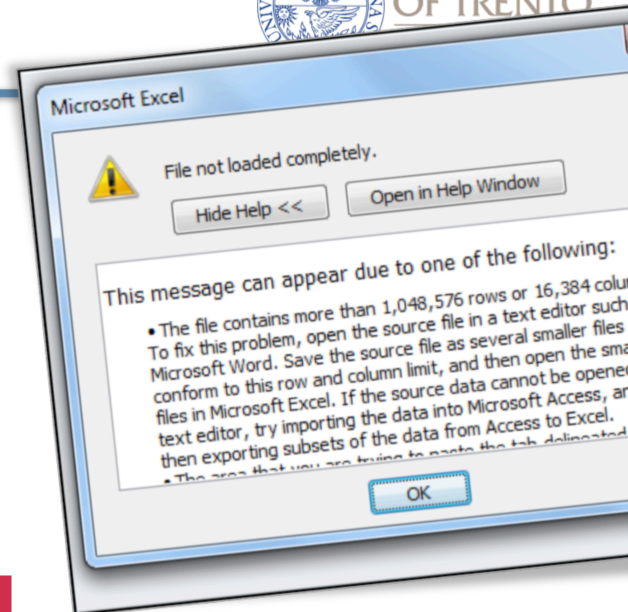
Original version taken from the Network Simulation course held at the University of Paderborn, Germany
Special thanks to Falko Dressler and Christoph Sommer

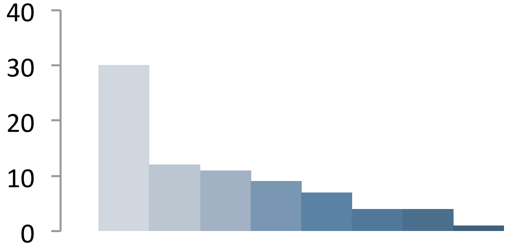
# Motivation




- How to analyze large amounts of data?
  - SAS
  - SPSS
  - Stata
  - Matlab
  - SciPy (or Pandas, or …)
  - SQL
  - Excel
  - …
  - R

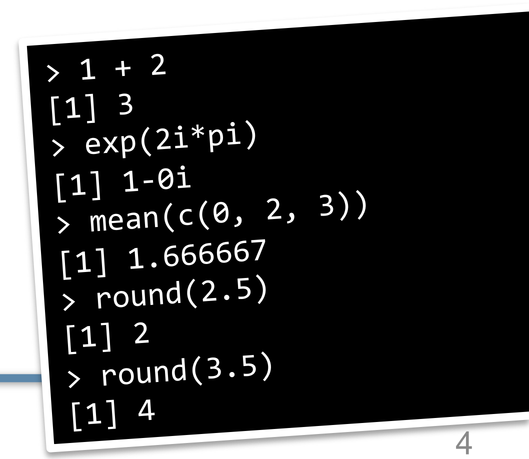
# Motivation

- Why R?
  - Oldest
    - Implementation of S, designed at Bell Labs starting 1975
  - Newest
    - Actively maintained by international team
    - Official release twice a year (Version 3 released in April 2013)
    - Version 3.2 scheduled for April 16th, 2015
  - Open Source
    - Available for every major OS
  - Popular
    - Consistently ranks among top 3 software tools for data analysis



# About

- What is R?
  - the computer language R
  - an interpreter of code written in R
  - a execution environment that contains the R interpreter
- From Wikipedia:
  - “R is an implementation of the S programming language combined with lexical scoping semantics inspired by Scheme. S was created by John Chambers while at Bell Labs. R was created by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand, and is currently developed by the R Development Core Team, of which Chambers is a member. R is named partly after the first names of the first two R authors and partly as a play on the name of S.”
- R is a (kind of) scripting language
  - Automatic variables, garbage collection
  - Lots of “smart” shortcuts (for better or worse)



# Installing R

- To install R, you can do the following depending on your OS:
  - **Linux:** Just open your terminal and type
    - sudo apt-get install r-base
  - **Mac OS X:** If you have MacPorts installed, open your terminal and type
    - sudo port install R
  - **Mac OS X:** If you don't have MacPorts, you can download R binaries from the official R website (http://www.r-project.org/)
  - **Windows:** Download the binaries from the official R website

# Running R

- Frontend
  - Official frontend: www.r-project.org
    - R
    - Rscript
  - Or any of
    - RStudio, Revolutions, Tinn-R, Deducer, RKward, R Commander, Vim R, …

- Packages
  - Extend R functionality
  - Written in C, Java, Fortran, or R
  - Official repository: cran.r-project.org
    - Comprehensive R Archive Network (CRAN)
  - Or any of
    - Bioconductor, Crantastic, R-Forge, …

- Assigning data
  - x <- 1
  - x = 1 also works
  - x <- (1+2)*NA*3 ➪ x <- NA
- Creating data of specific type and class
  - v <- c(10, 20, 30, 40, 50, 60)
  - l <- list(a="apple", b="balloon", c="crayons")
  - m <- matrix(v, nrow=3)
  - d <- data.frame(student=c("alice", "bob", "carol"), grade=c(1,2,3))

| | x |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 | 50 |
| 6 | 60 |

| a | b | c |
|---|---|---|
| apple | balloon | crayons |

| | V1 | V2 |
|---|---|---|
| 1 | 10 | 40 |
| 2 | 20 | 50 |
| 3 | 30 | 60 |

| | student | grade |
|---|---|---|
| 1 | alice | 1 |
| 2 | bob | 2 |
| 3 | carol | 3 |

- Printing
  - print(v) ➪ [1] 10 20 30 40 50 60
  - summary(v) ➪ Minimum: 10.0   1st Quartile: 32.5   Median: 45.0 …
  - …

| | x |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 | 50 |
| 6 | 60 |

| a | b | c |
|---|---|---|
| apple | balloon | crayons |

| | V1 | V2 |
|---|---|---|
| 1 | 10 | 40 |
| 2 | 20 | 50 |
| 3 | 30 | 60 |

| | student | grade |
|---|---|---|
| 1 | alice | 1 |
| 2 | bob | 2 |
| 3 | carol | 3 |

- At its core, an R object is defined by three properties
  - Type
    - homogeneous vector types (logical, integer, double, …)
    - heterogeneous list type (list)
    - miscellaneous types (function, expression, …)
  - Length
    - Only really sensible for vectors and lists
  - Attributes
    - class (matrix, factor, data.frame, …)
      - determines how generic functions interoperate
    - dim (dimensions of matrix)
    - levels (possible values of factor)
    - names, dimnames, rownames, colnames, …
    - comment
    - …

- Subset operator (attn: R is one-based, not zero-based)
  - print(v[  c(2, 3, 4)  ]) ➪ [1] 20 30 40
  - print(v[2:4]) ➪ [1] 20 30 40
  - print(v[c(T,F,F,F,F,T)]) ➪ [1] 10 60
  - print(v[-2]) ➪ [1] 10 30 40 50 60
  - v[2] <- 99; print(v) ➪ [1] 10 99 30 40 50 60
  - print(m[1,2]) ➪ [1] 40
  - print(m[1,]) ➪ [1] 10 40
  - print(m[,2]) ➪ [1] 40 50 60

| | x |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 | 50 |
| 6 | 60 |

| a | b | c |
|---|---|---|
| apple | balloon | crayons |

| | V1 | V2 |
|---|---|---|
| 1 | 10 | 40 |
| 2 | 20 | 50 |
| 3 | 30 | 60 |

| | student | grade |
|---|---|---|
| 1 | alice | 1 |
| 2 | bob | 2 |
| 3 | carol | 3 |

# Interacting with Data

- Element operator
  - print(l[["a"]]) ➪ [1] "apple"
  - print(d[["grade"]]) ➪ [1] 1 2 3
- CAREFUL: d[[”grade”]] IS DIFFERENT FROM d[”grade”]

- Name operator
  - print(l$a) ➪ [1] "apple"
  - print(d$grade) ➪ [1] 1 2 3

| | x |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 | 50 |
| 6 | 60 |

| a | b | c |
|---|---|---|
| apple | balloon | crayons |

| | V1 | V2 |
|---|---|---|
| 1 | 10 | 40 |
| 2 | 20 | 50 |
| 3 | 30 | 60 |

| | student | grade |
|---|---|---|
| 1 | alice | 1 |
| 2 | bob | 2 |
| 3 | carol | 3 |

- Defining functions
  - f <- function(x, y=1, offset=0) { offset + x * y }
  - print(f) ➪ function (x, y = 1, offset = 0) { offset + x * y }

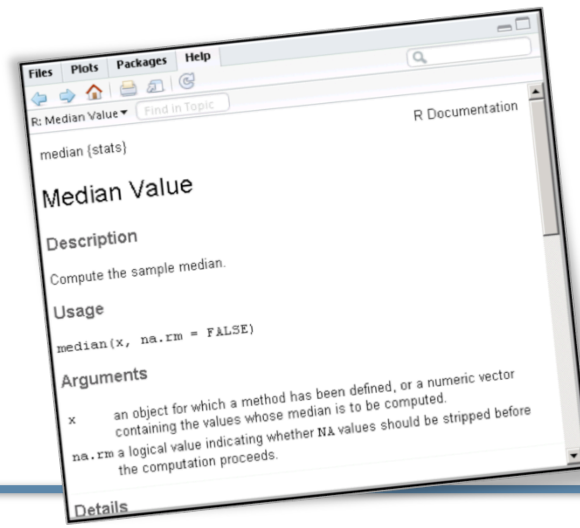
- Calling functions
  - f(3, 7, 1000) ➪ [1] 1021
  - f(3, 7) ➪ [1] 21
  - f(offset=1000, x=3, y=7) ➪ [1] 1021
  - f(3, offset=1000) ➪ [1] 1003

- Basic statistics
  - X <- c(5, 20, 40, 50, 55, 70, 80, 80, 900)
  - Y <- c(10, 20, 30, 40, 50, 60, 70, 80, 90)

  - mean(X) ➪ 144.4444
  - median(X) ➪ 55
  - quantile(X, 0.25) ➪ 40
  - glm.fit(1:9, Y, intercept=F)$coefficients ➪ 10
  - wilcox.test(X, Y)$p.value ➪ 0.72

| | X | Y |
|---|---|---|
| 1 | 5 | 10 |
| 2 | 20 | 20 |
| 3 | 40 | 30 |
| 4 | 50 | 40 |
| 5 | 55 | 50 |
| 6 | 70 | 60 |
| 7 | 80 | 70 |
| 8 | 80 | 80 |
| 9 | 900 | 90 |

- Help and more information
  - help('mean')
  - ?mean
  - citation('vioplot')



# Working with Data Frames

- Creating
  - d <- data.frame(
    student=rep(c("alice", "bob", "carol"),4),
    points=rep(c(90,30,70,50,40,10), 2)
    )

| | student | points |
|---|---|---|
| 1 | alice | 90 |
| 2 | bob | 30 |
| 3 | carol | 70 |
| 4 | alice | 50 |
| 5 | bob | 40 |
| 6 | carol | 10 |
| 7 | alice | 90 |
| 8 | bob | 30 |
| 9 | carol | 70 |
| 10 | alice | 50 |
| 11 | bob | 40 |
| 12 | carol | 10 |

- Grouping averages
  - a <- aggregate(
    d$points,
    by=list(who=d$student),
    FUN=mean
    )
  - or use ddply by plyr (see example)

| | who | x |
|---|---|---|
| 1 | alice | 70 |
| 2 | bob | 35 |
| 3 | carol | 40 |

- Adding a new column
  - a$grade <- ifelse(a$x >= 50, "pass", "fail")

| | who | x | grade |
|---|---|---|---|
| 1 | alice | 70 | pass |
| 2 | bob | 35 | fail |
| 3 | carol | 40 | fail |

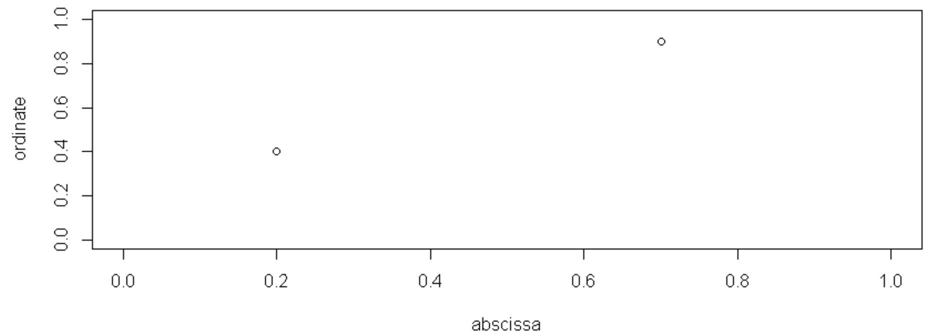
# Installing External Packages

- Syntax:
  - install.packages(“package name”) or
  - install.packages(vector of packages names)
  - e.g.: install.packages(c(“plyr”, “moments”))
- R will ask you which mirror to use, download, and install the packages
  - with dependencies
- To load your library:
  - library(“plyr”) or require(“plyr”)

- Read data frame from text file
  - d <- read.csv('data.csv’)
  - d will be a data.frame where column names matches csv column names

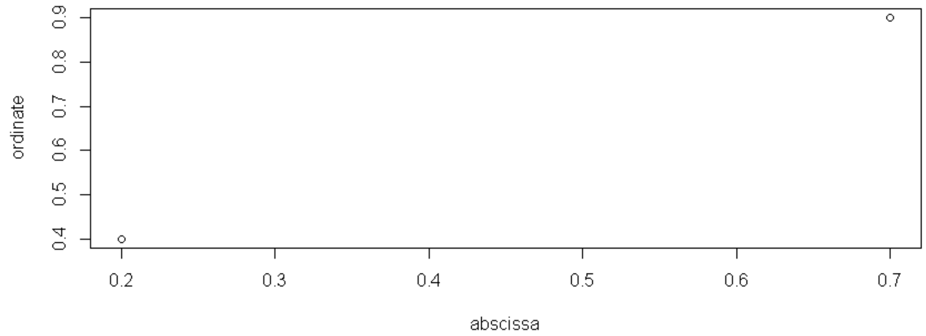
| | student | points |
|---|---|---|
| 1 | alice | 90 |
| 2 | bob | 30 |
| 3 | carol | 70 |
| 4 | alice | 50 |
| 5 | bob | 40 |
| 6 | carol | 10 |
| 7 | alice | 90 |
| 8 | bob | 30 |
| 9 | carol | 70 |
| 10 | alice | 50 |
| 11 | bob | 40 |
| 12 | carol | 10 |

- R can do plots, too
- Low level plotting commands
  - plot.new()
  - plot.window(xlim=c(0,1), ylim=c(0,1))
  - points(c(0.2, 0.7), c(0.4, 0.9))
  - box()
  - axis(1)
  - axis(2)
  - title(xlab="abscissa", ylab="ordinate")



# Plotting Data

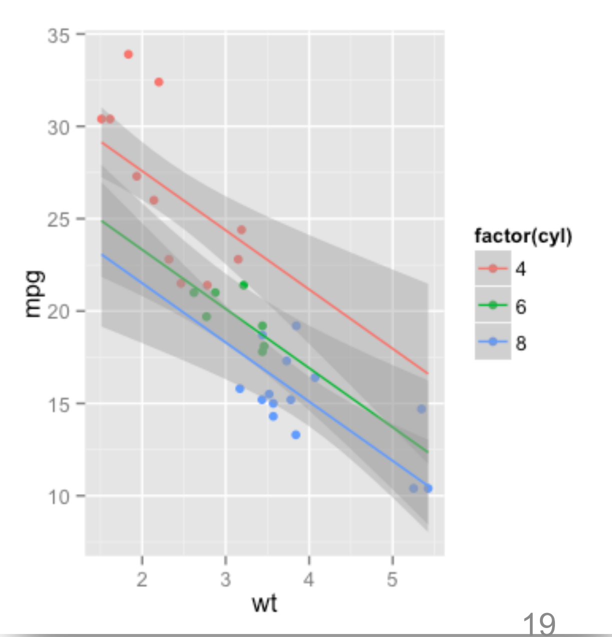
- High level plotting commands
  - generic “plot” command guesses good plot type
  - plot(c(0.2, 0.7), c(0.4, 0.9), xlab="abscissa", ylab="ordinate")
- Can mix high level and low level plotting commands
  - e.g., annotations, lines, points, abline, …



# Add-on Packages

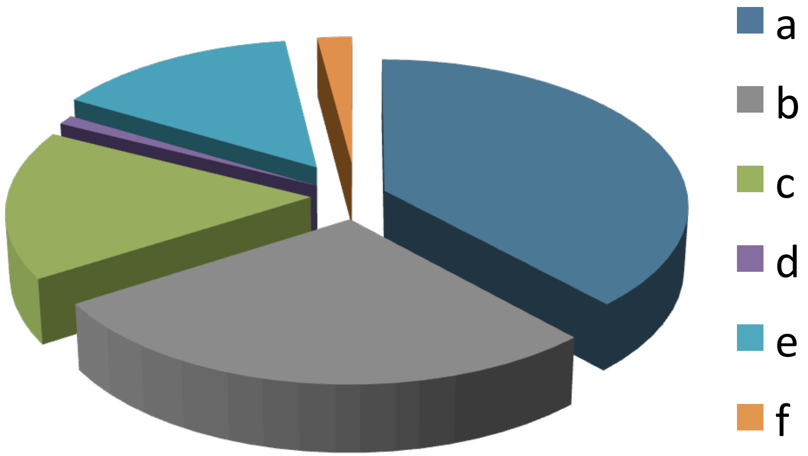
- Tons of packages for basically EVERYTHING
- **Lattice**
  - Good for *conditioning* types of plots (a vs. b depending on c…)
  - Good for assembling many plots into one
- **ggplot2**
  - Grammar-based approach
  - Good for data exploration

```
ggplot(d, aes(x=wt, y=mpg, colour=cyl))
+ geom_line()
+ geom_point(…)
+ geom_smooth(…)
+ facet_grid(model ~ make)
+ …
```

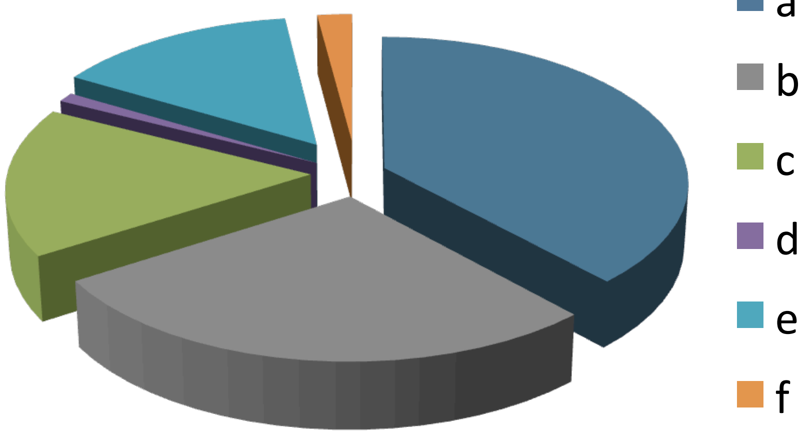


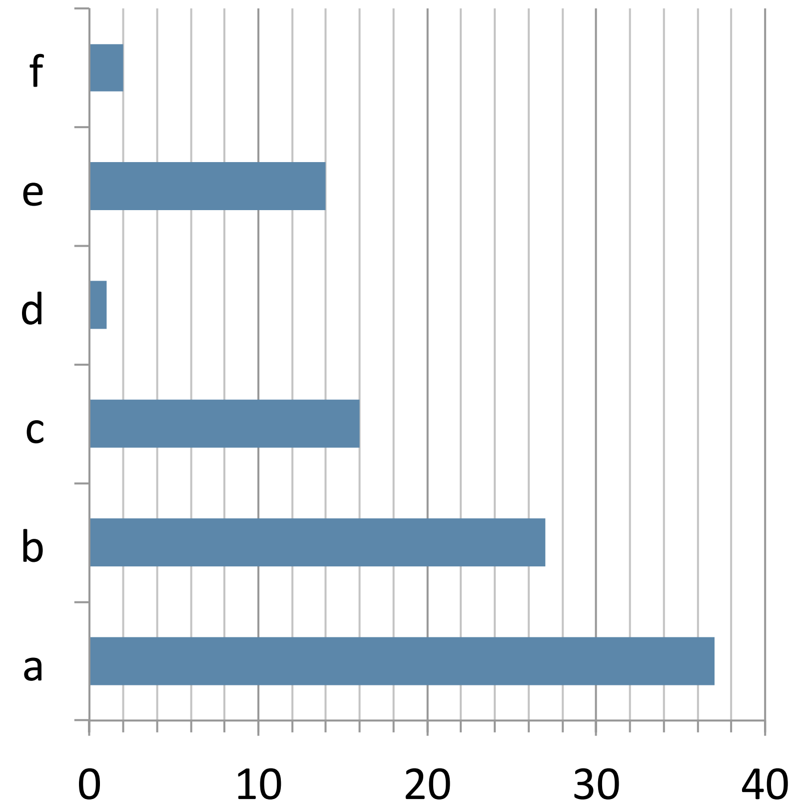
# Plotting Data

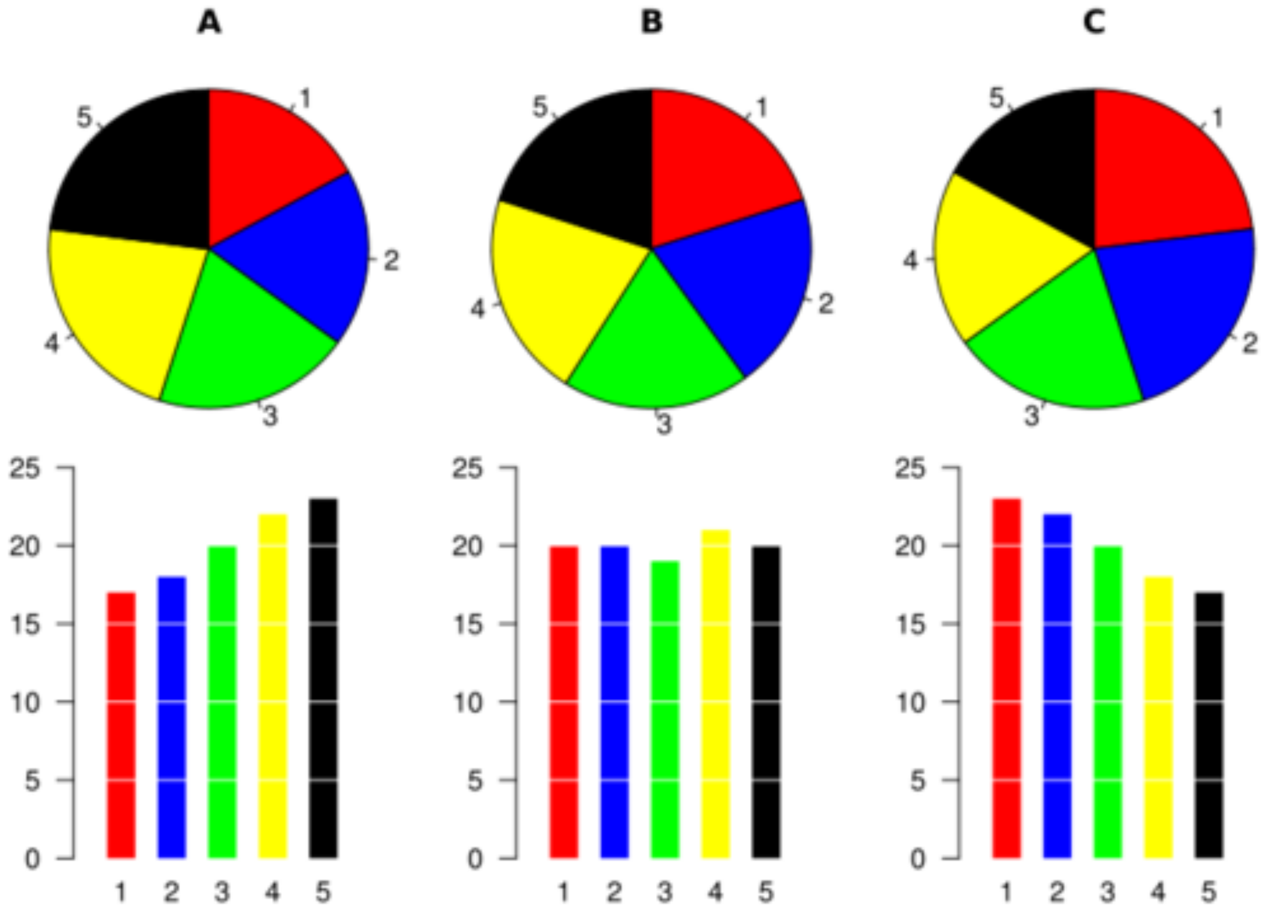
- Pie charts are almost never a good idea
  - Humans cannot perceive area, angle or perimeter properly
  - Hence comparison of quantities is difficult



- Compare to bar charts:

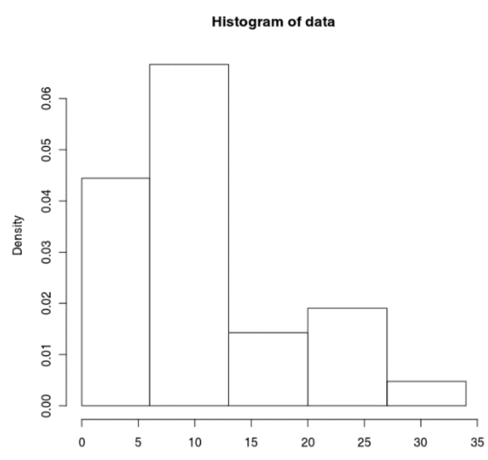


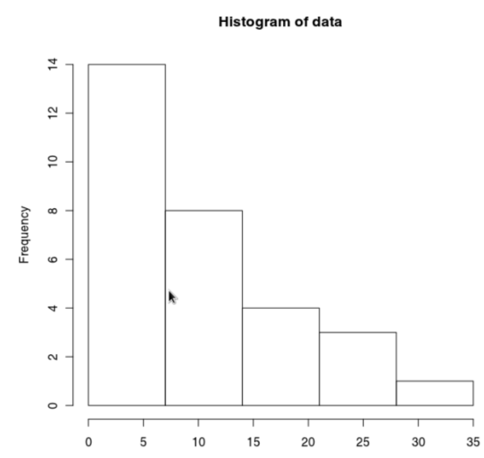






http://blog.revolutionanalytics.com/2009/08/how-pie-charts-fail.html

- Illustrates frequencies of discrete intervals (bins)
- Used to plot density of data
- Bin size important
  - May hide data when using inappropriate bin sizes
- data <- c(25, 11, 2, 13, 1, 22, 15, 3, 1, 7, 8, 10, 32, 7, 4, 9, 18, 21, 7, 7, 16, 6, 4, 12, 5, 27, 7, 9, 10, 7)



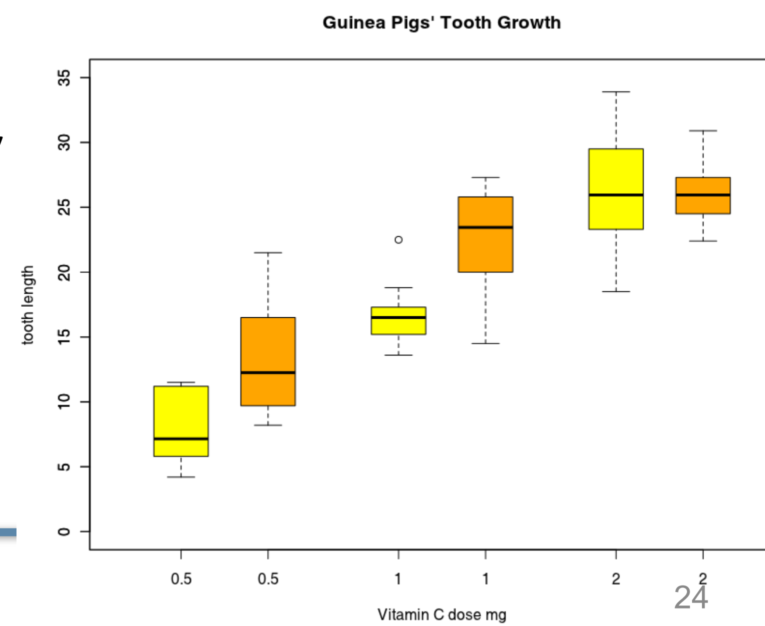

  - hist(data, breaks=c(0,6,13,20,27,34)) hist(data, breaks=c(0,7,14,21,28,35))

# Boxplot

- Give a quick overview of the following values:
  - Min, 1st quantile, median, 3rd quantile, max
  - Whiskers:
    - extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box
    - absolute minimum and maximum
- Outliers are displayed separately
  - if the minimum or maximum are not within the 1.5 IQR

- Advantages:
  - Allows to compare different result sets quickly by using multiple box plots

- Disadvantages:
  - Bimodal distributions cannot be spotted

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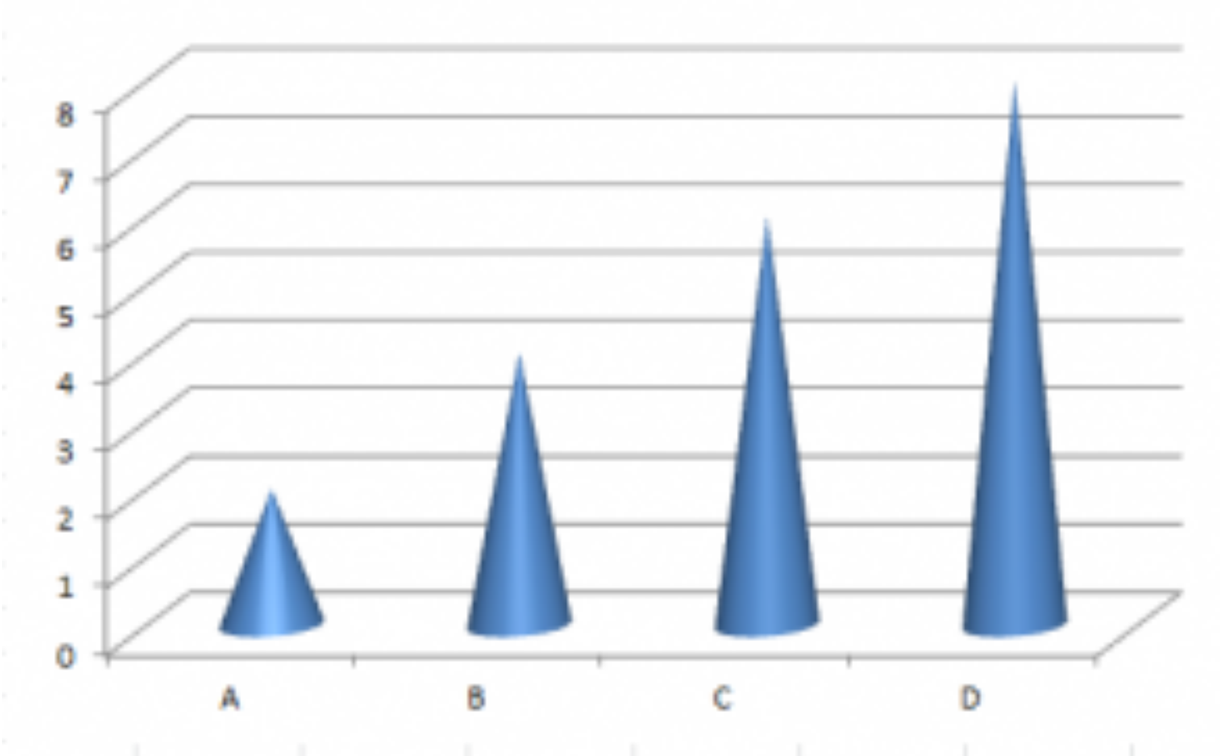
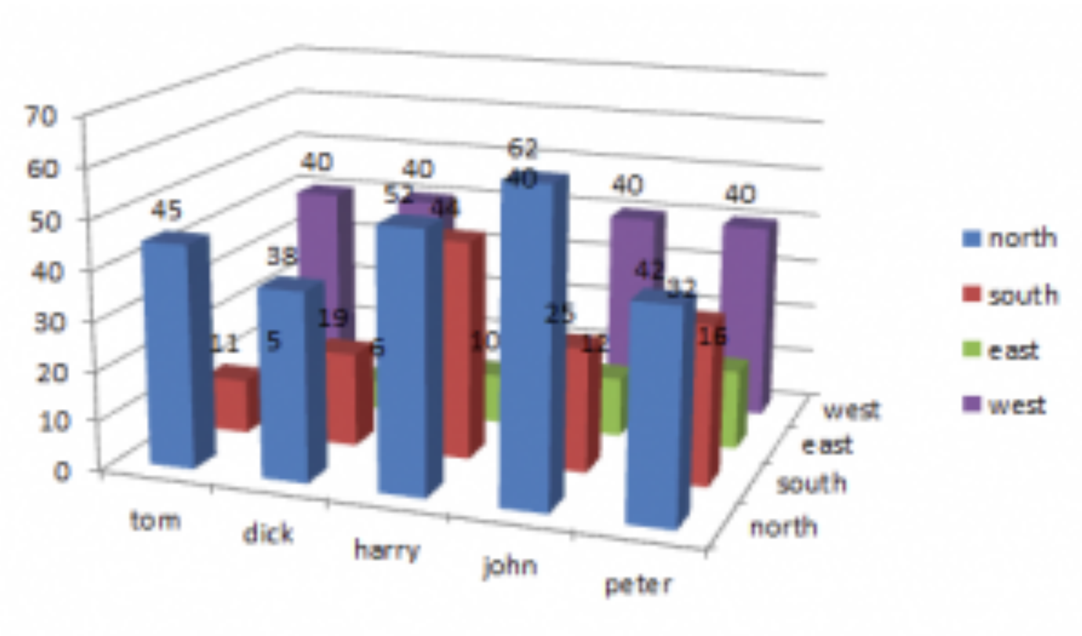
1,579 people like R Graph Gallery.
Facebook social plugin
R Project
R is a system for statistical computation and graphics. It consists of a language plus a run-time environment with graphics, a debugger, access to certain system functions, and the ability to run programs stored in script files.
R Graphic Engine
One of R's strengths is the ease with which well-designed publication-quality plots can be produced, including mathematical symbols and formulae where needed. Great care has been taken over the defaults for the minor design choices in graphics, but the user retains full control.

# Bad Graphs

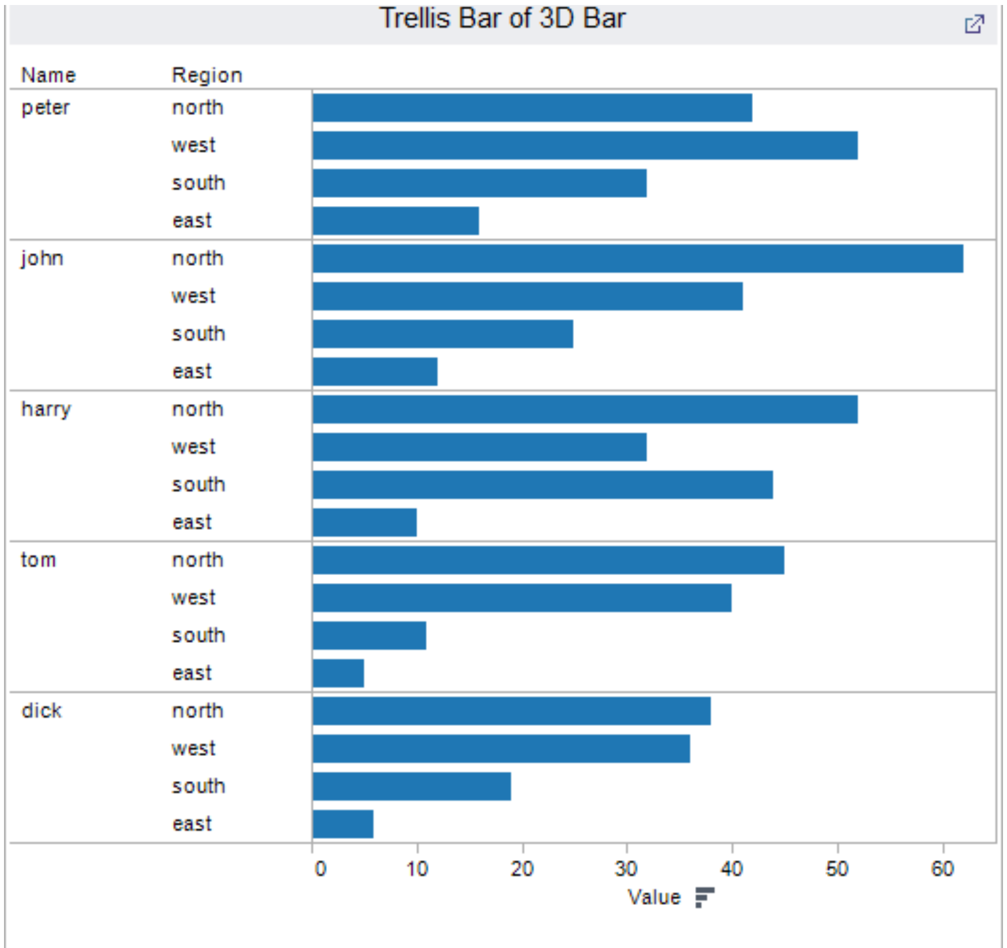



http://www.forbes.com/sites/naomirobbins/2012/05/30/winner-of-the-bad-graph-contest-announced-2/




http://www.forbes.com/sites/naomirobbins/2012/05/30/winner-of-the-bad-graph-contest-announced-2/

# Bad Graphs




http://www.forbes.com/sites/naomirobbins/2012/06/07/trellis-plot-alternative-to-three-dimensional-bar-charts/

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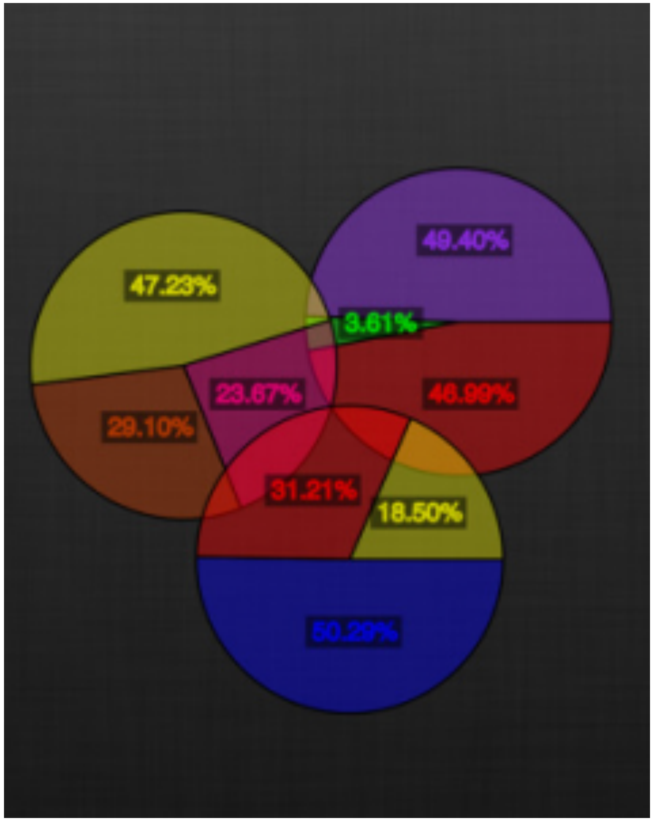


http://www.forbes.com/sites/naomirobbins/2012/05/30/winner-of-the-bad-graph-contest-announced-2/

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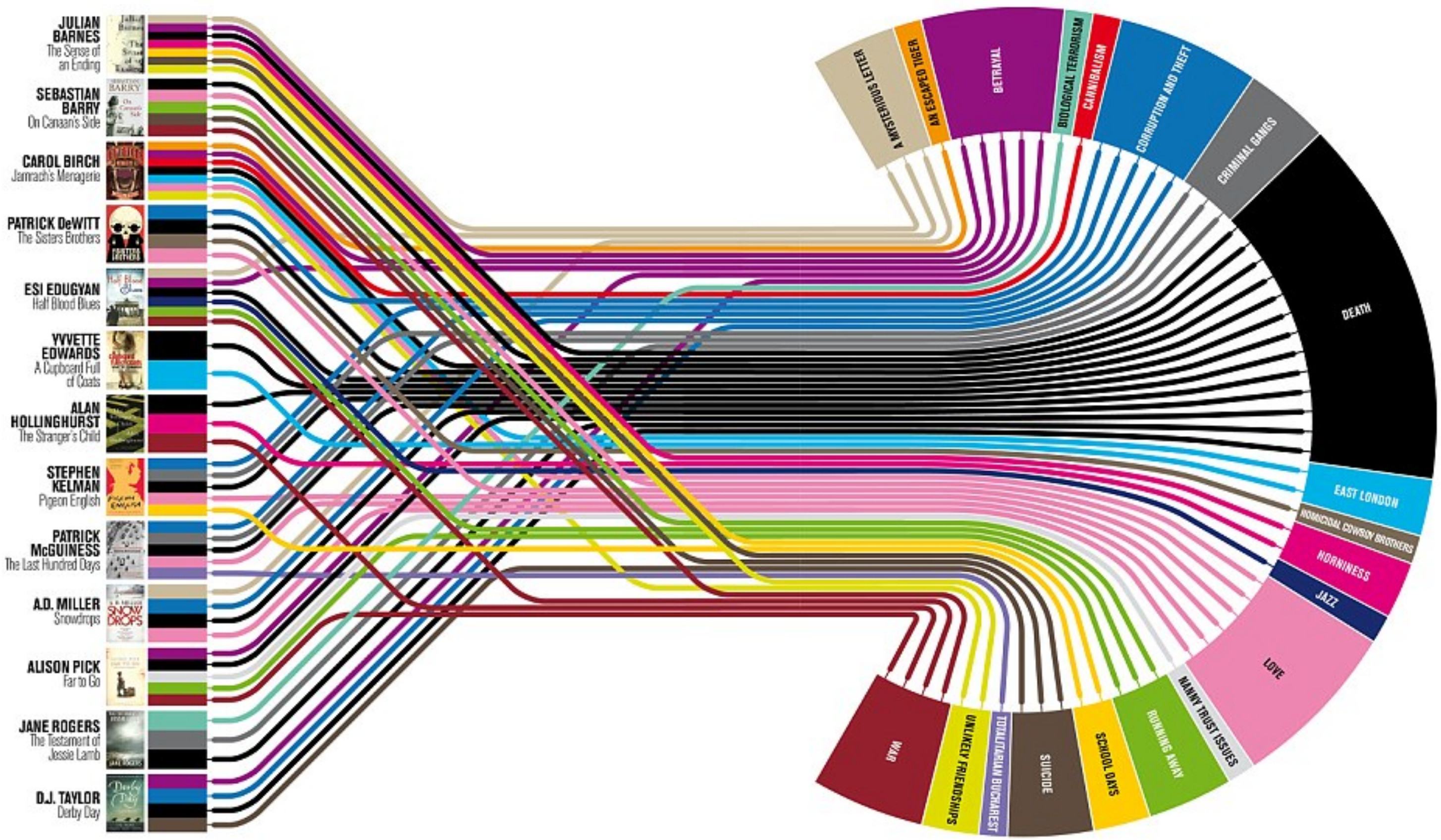
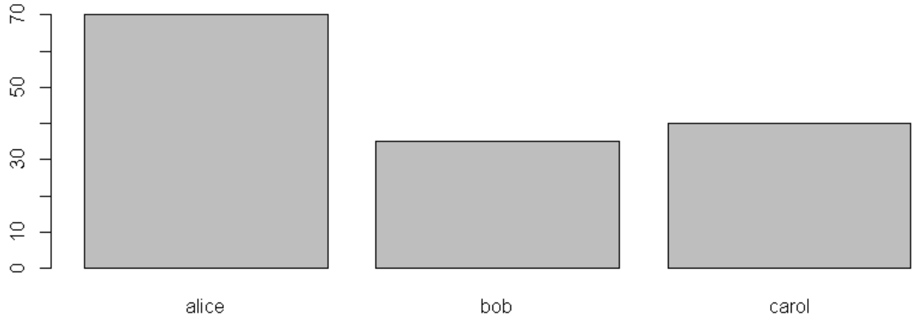
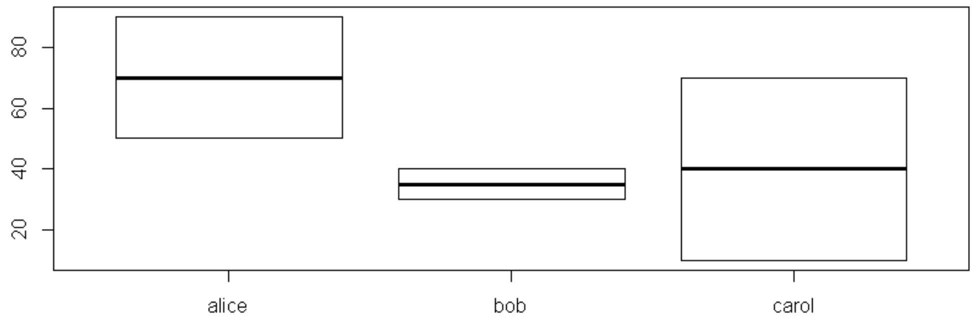



http://junkcharts.typepad.com/junk_charts/2012/10/can-information-be-beautiful-when-information-doesnt-exist.html

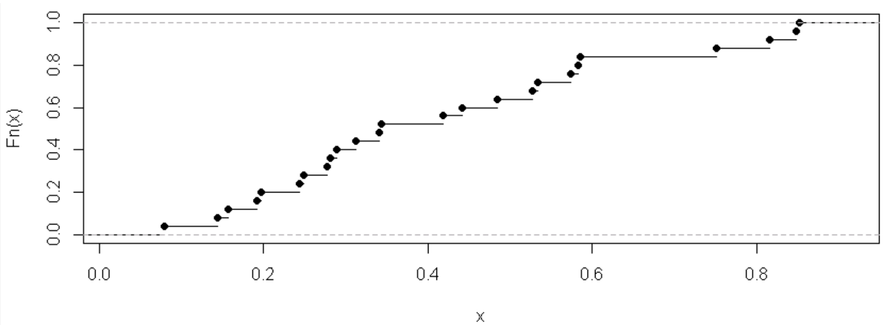
- Barplot
  - barplot(a$x, names.arg=a$who)

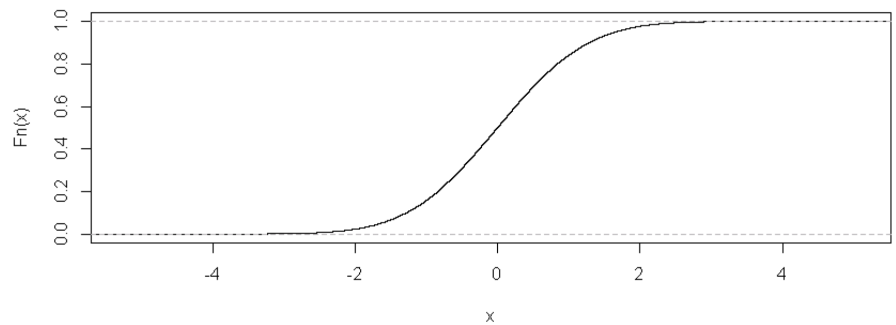



- Boxplot
  - boxplot(d$points ~ d$student)

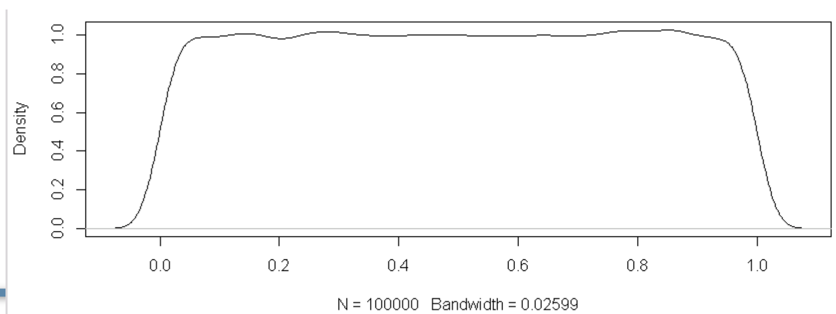


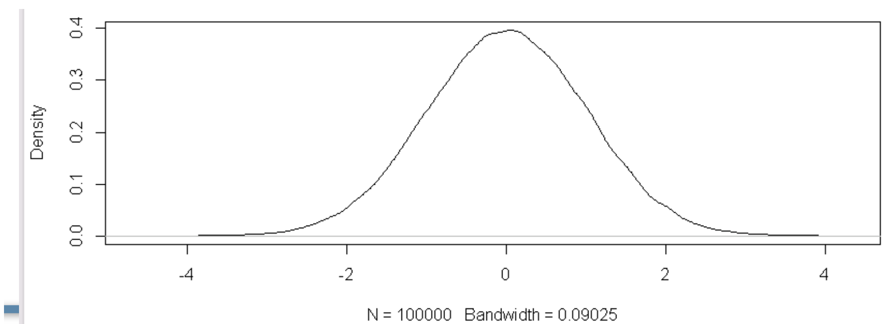
- eCDF
  - plot(ecdf(runif(25, min=0, max=1)))
  - plot(ecdf(rnorm(1e5)))




- Kernel Density Estimate
  - plot(density(runif(1e5, min=0, max=1)))
  - plot(density(rnorm(1e5)))



# Saving you plots

- With R you can quickly plot a graph: good

- Result is satisfying, how do I save it?
  - Open a graphic driver with pdf(), png(), svg(), jpeg(), …, even LaTeX

  - n <- rnorm(1000)
  - pdf('myplot.pdf')
  - plot(n, type='l')
  - dev.off()

# Plotting hints

- Make plots readable by
  - Not showing too much data, plot should be readable in seconds!
  - Using the “right” plot for visualization purpose
  - Do not rely on color alone
    - plot *will* be printed out in greyscale, or black-and-white
  - Make it easy to compare the quantities
  - Axis: what’s on abscissa? what’s on ordinate?
  - Units: without units values makes no sense
    - meters? millimeters? light years? bananas? potatoes?
  - Check your plot in the final document
    - a document on your screen might not be as good in a double column document

# Bonus! System Analysis

- Problem
  - Your virtual machine performance are terrible
  - You want to understand where the problem might be
- How:
  - You want to analyze the performance of your virtual machine
  - Indicators: CPU utilization, RAM, swap, …
  - Every 5 minutes, the indicators are logged into a csv file
  - By taking this dataset and analyzing its content, we'll try to get to a conclusion

# Steps

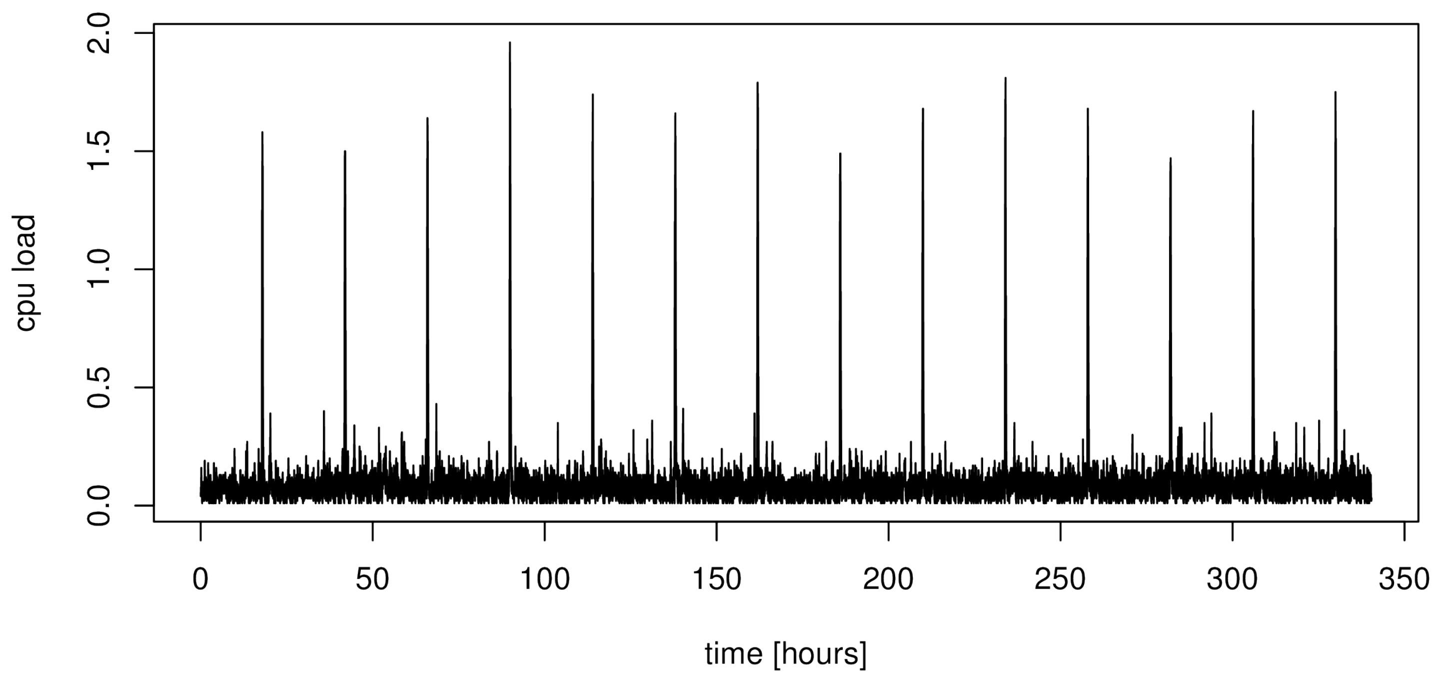
- Load your data into R:

```
d <- read.csv("measures.csv")
print(names(d))
[1] "timestamp" "tcpconnections" "swapload" "ramload" "rtodisk" "cpuload"
d$hours <- (d$timestamp - min(d$timestamp)) / 3600
```

# Steps

- Let's see if the CPU is overloaded:

```
pdf('cpuload.pdf', width=16/2, height=9/2)
plot(d$hours, d$cpuload, type='l', xlab="time [hours]", ylab="cpu load")
dev.off()
```



- When do the CPU load peaks happen?
  - peaks <- d[ d$cpuload>0.5, ]$timestamp
  - print(as.POSIXlt(peaks, origin="1970-01-01”))

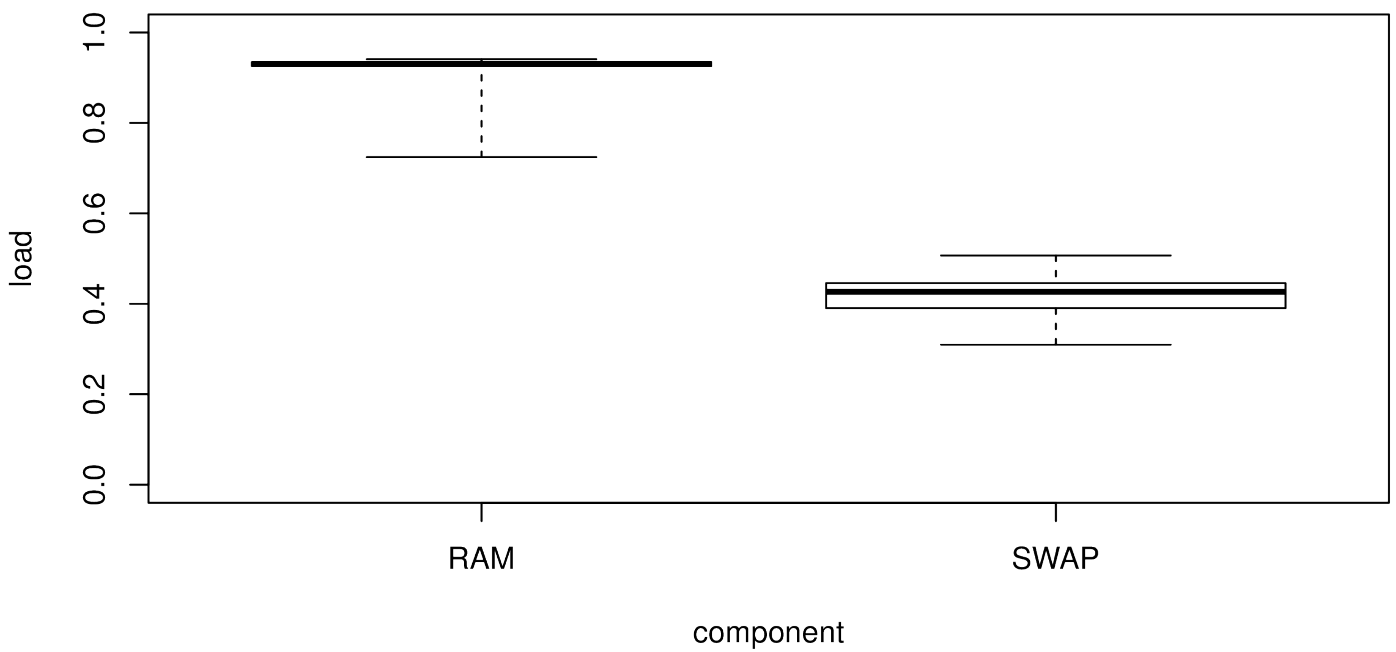
```
 [1] "2015-03-31 04:05:01 CEST" "2015-03-31 04:10:01 CEST" "2015-03-31 04:15:01 CEST" "2015-03-31 04:20:01 CEST" "2015-04-01 04:05:02 CEST"
 [6] "2015-04-01 04:10:01 CEST" "2015-04-01 04:15:01 CEST" "2015-04-01 04:20:01 CEST" "2015-04-02 04:05:01 CEST" "2015-04-02 04:10:02 CEST"
[11] "2015-04-02 04:15:01 CEST" "2015-04-02 04:20:01 CEST" "2015-04-03 04:05:01 CEST" "2015-04-03 04:10:02 CEST" "2015-04-03 04:15:01 CEST"
[16] "2015-04-03 04:20:01 CEST" "2015-04-04 04:05:01 CEST" "2015-04-04 04:10:01 CEST" "2015-04-04 04:15:01 CEST" "2015-04-04 04:20:01 CEST"
[21] "2015-04-05 04:05:02 CEST" "2015-04-05 04:10:01 CEST" "2015-04-05 04:15:01 CEST" "2015-04-05 04:20:01 CEST" "2015-04-05 04:25:01 CEST"
[26] "2015-04-06 04:05:01 CEST" "2015-04-06 04:10:01 CEST" "2015-04-06 04:15:01 CEST" "2015-04-06 04:20:01 CEST" "2015-04-07 04:05:01 CEST"
[31] "2015-04-07 04:10:02 CEST" "2015-04-07 04:15:01 CEST" "2015-04-07 04:20:01 CEST" "2015-04-08 04:05:01 CEST" "2015-04-08 04:10:01 CEST"
[36] "2015-04-08 04:15:01 CEST" "2015-04-08 04:20:01 CEST" "2015-04-09 04:05:02 CEST" "2015-04-09 04:10:01 CEST" "2015-04-09 04:15:01 CEST"
[41] "2015-04-09 04:20:02 CEST" "2015-04-10 04:05:02 CEST" "2015-04-10 04:10:01 CEST" "2015-04-10 04:15:02 CEST" "2015-04-10 04:20:01 CEST"
[46] "2015-04-11 04:05:01 CEST" "2015-04-11 04:10:01 CEST" "2015-04-11 04:15:01 CEST" "2015-04-11 04:20:01 CEST" "2015-04-12 04:05:01 CEST"
[51] "2015-04-12 04:10:02 CEST" "2015-04-12 04:15:01 CEST" "2015-04-12 04:20:01 CEST" "2015-04-12 04:25:01 CEST" "2015-04-13 04:05:01 CEST"
[56] "2015-04-13 04:10:01 CEST" "2015-04-13 04:15:01 CEST" "2015-04-13 04:20:01 CEST"
```

  - CPU load due to backups

# Steps

- Is it a memory problem?

```
pdf('memload.pdf', width=16/2, height=9/2)
boxplot(list("RAM"=d$ramload, "SWAP" = d$swapload), range=0,
          ylim=c(0, 1), xlab="component", ylab="load")
dev.off()
```




  - Is this because we don't have enough memory?

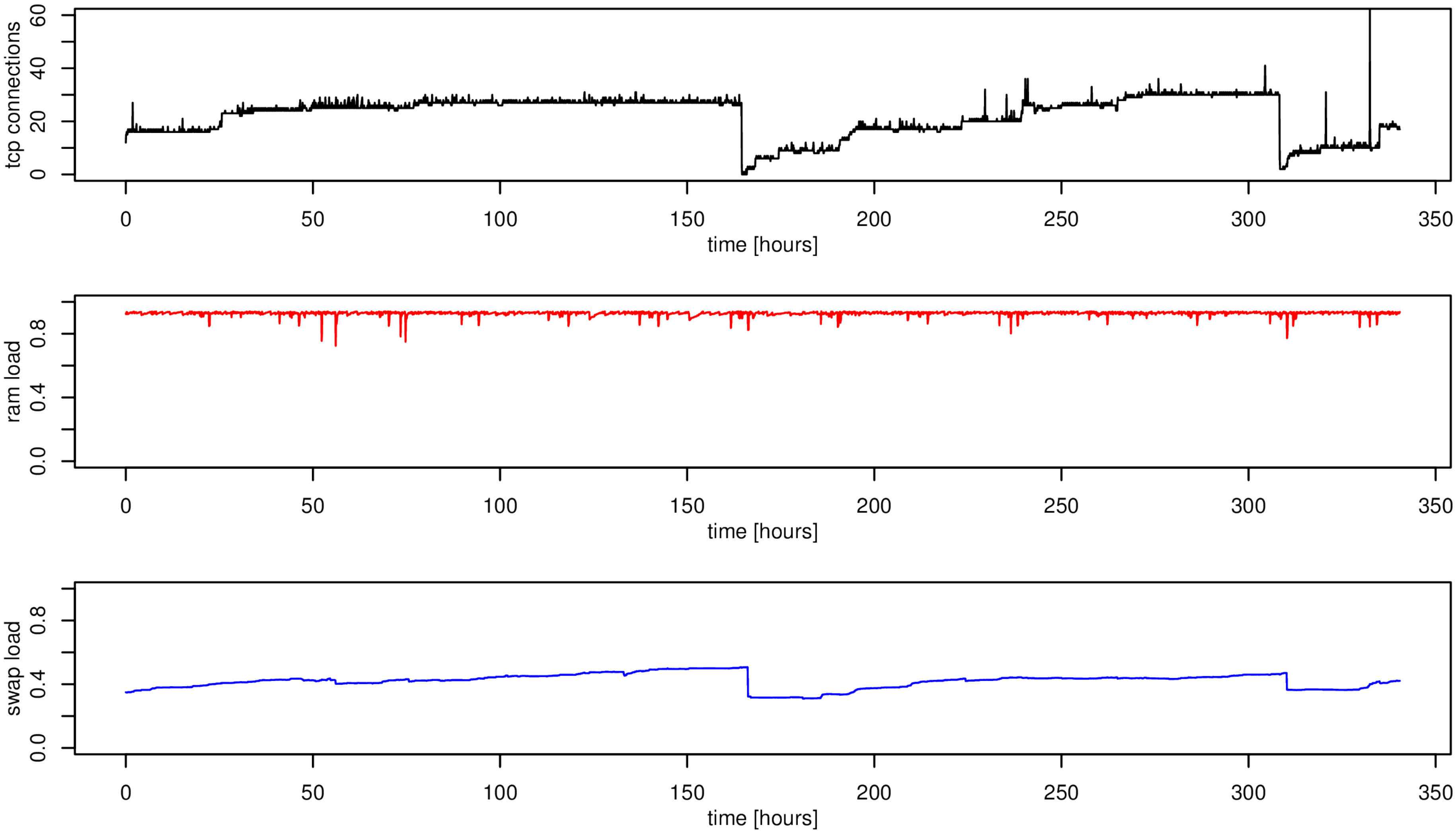
- Is there a problem with the webserver?

```
time.plot <- function(x, y, col, xlim, ylim, xlab, ylab) {
    plot.new()
    plot.window(xlim=xlim, ylim=ylim)

    lines(x, y, col=col)
    axis(1)
    axis(2)
    title(xlab=xlab, ylab=ylab, line=2)
    box()
}

pdf('tcpload.pdf', width=16/2, height=9/2)
old <- par(mfrow=c(3,1), mai = c(0.5, 0.5, 0.1, 0.3))
xlim <- c(min(d$hours), max(d$hours))
time.plot(d$hours, d$tcpconnections, 'black', xlim, ylim=c(0, 60), xlab="time [hours]", ylab="tcp connections")
time.plot(d$hours, d$ramload       , 'red'  , xlim, ylim=c(0, 1) , xlab="time [hours]", ylab="ram load")
time.plot(d$hours, d$swapload      , 'blue' , xlim, ylim=c(0, 1) , xlab="time [hours]", ylab="swap load")
par(old)
dev.off()
```

# Steps


tcp connections
0
20
40
60
ram load
0.0
0.4
0.8
swap load
0.0
0.4
0.8
0
50
100
150
200
250
300
350
time [hours]