The Data Science Track

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Why do data science?

"It is not the critic who counts: not the man who points out how the strong man stumbles or where the doer of deeds could have done better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood, who strives valiantly, who errs and comes up short again and again, because there is no effort without error or shortcoming, but who knows the great enthusiasms, the great devotions, who spends himself for a worthy cause; who, at the best, knows, in the end, the triumph of high achievement, and who, at the worst, if he fails, at least he fails while daring greatly, so that his place shall never be with those cold and timid souls who knew neither victory nor defeat."

Theodore Roosevelt, 26th President of the United States

Statistics and the science game

The key challenge in data science

"Ask yourselves, what problem have you solved, ever, that was worth solving, where you knew knew all of the given information in advance? Where you didn't have a surplus of information and have to filter it out, or you didn't have insufficient information and have to go find some?"


Dan Myer, Mathematics Educator

The key word in data science is not data; it is science

About us

Data intensive statistics in biology and medicine

- Brian Caffo
  - Website http://www.bcaffo.com/
  - Twitter @bcaffo
  - Github https://github.com/bcaffo
- Jeff Leek
  - Website http://biostat.jhsph.edu/~jleek/, http://simplystatistics.org/
  - Twitter @jtleek
  - Github https://github.com/jtleek
- Roger Peng
  - Website http://www.biostat.jhsph.edu/~rpeng/,http://simplystatistics.org/
  - Twitter @rdpeng
  - Github https://github.com/rdpeng

Why data science?

http://www.economist.com/node/15579717

Why data science?

McKinsey Global Institute

June 2011

Big data: The next frontier for innovation, competition, and productivity

http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation

Why statistical data science?

The New York Times

For Today's Graduate, Just One Word: Statistics

By STEVE LOHR
Published: August 5, 2009

MOUNTAIN VIEW, Calif. — At Harvard, Carrie Grimes majored in anthropology and archaeology and ventured to places like Honduras, where she studied Mayan settlement patterns by mapping where artifacts were found. But she was drawn to what she calls "all the computer and math stuff" that was part of the job.

TWITTER
LINKEDIN
COMMENTS (58)
SIGN IN TO E-MAIL

http://www.nytimes.com/2009/08/06/technology/06stats.html?_r=0

Why are you lucky?

Why are you lucky?

Heritage Health Prize

Why R?

http://www.nytimes.com/2009/01/07/technology/business-computing/07program.html?pagewanted=all

Why R?

- It is free
- It has a comprehensive set of packages
  - Data access
  - Data cleaning
  - Analysis
  - Data reporting
- It has one of the best development enviroments - Rstudio http://www.rstudio.com/
- It has an amazing ecosystem of developers
- Packages are easy to install and "play nicely together"

Who is a data scientist?

Daryl Morey

Who is a data scientist?

Hilary Mason

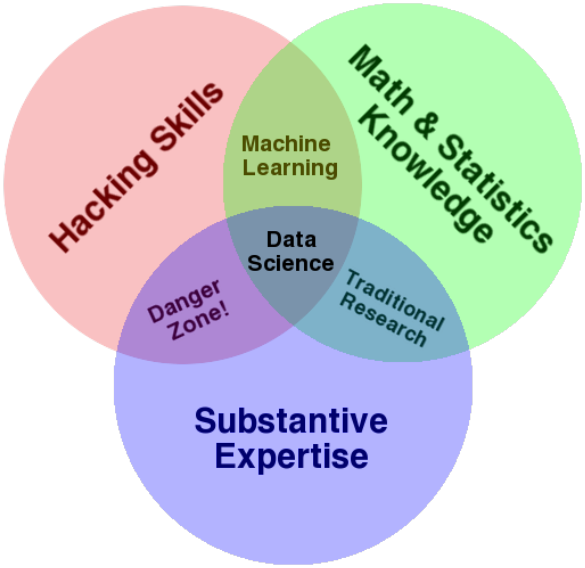
Who is a data scientist?

Daphne Koller

Who is a data scientist?

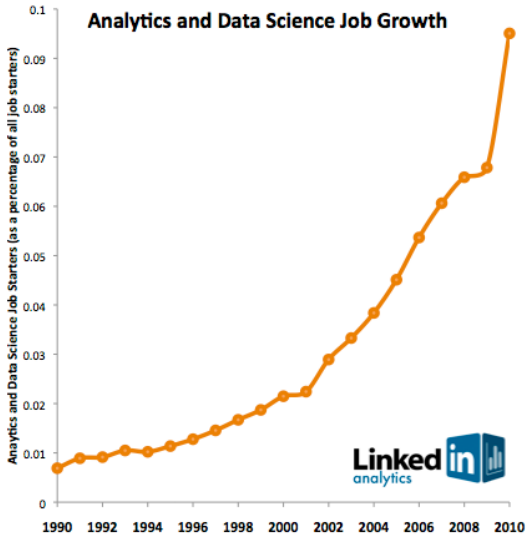
Nate Silver

Our goal



Drew Conway

Plus jobs



http://radar.oreilly.com/2011/09/building-data-science-teams.html

This course

- Introducing you to the track
- Getting tools set up
- Giving you basic background

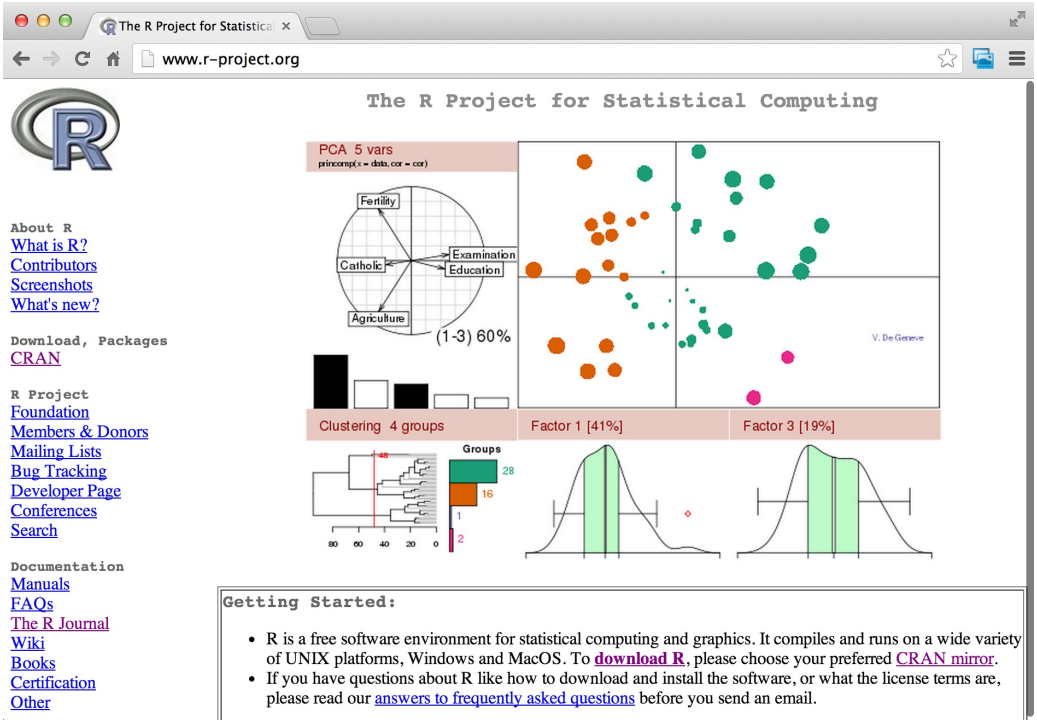
The Data Scientist's Toolbox

Johns Hopkins Bloomberg School of Public Health

What do data scientists do?

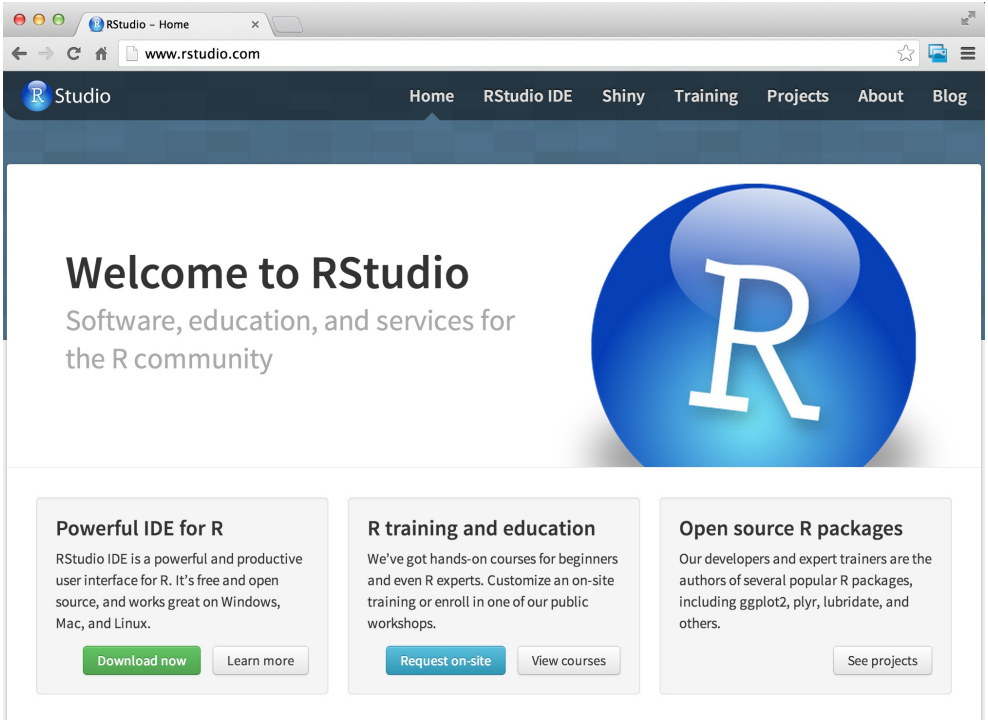
- Define the question
- Define the ideal data set
- Determine what data you can access
- Obtain the data
- Clean the data
- Exploratory data analysis
- Statistical prediction/modeling
- Interpret results
- Challenge results
- Synthesize/write up results
- Create reproducible code
- Distribute results to other people

The main workhorse of data science



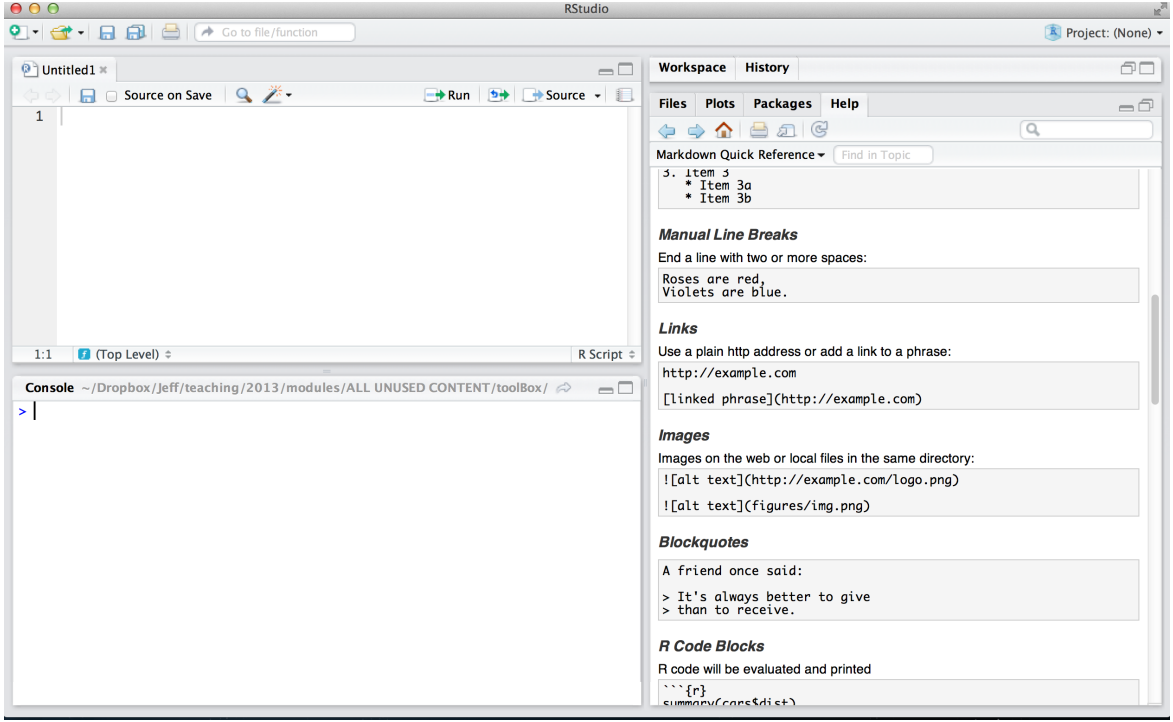
http://www.r-project.org/

Where we will work on coding



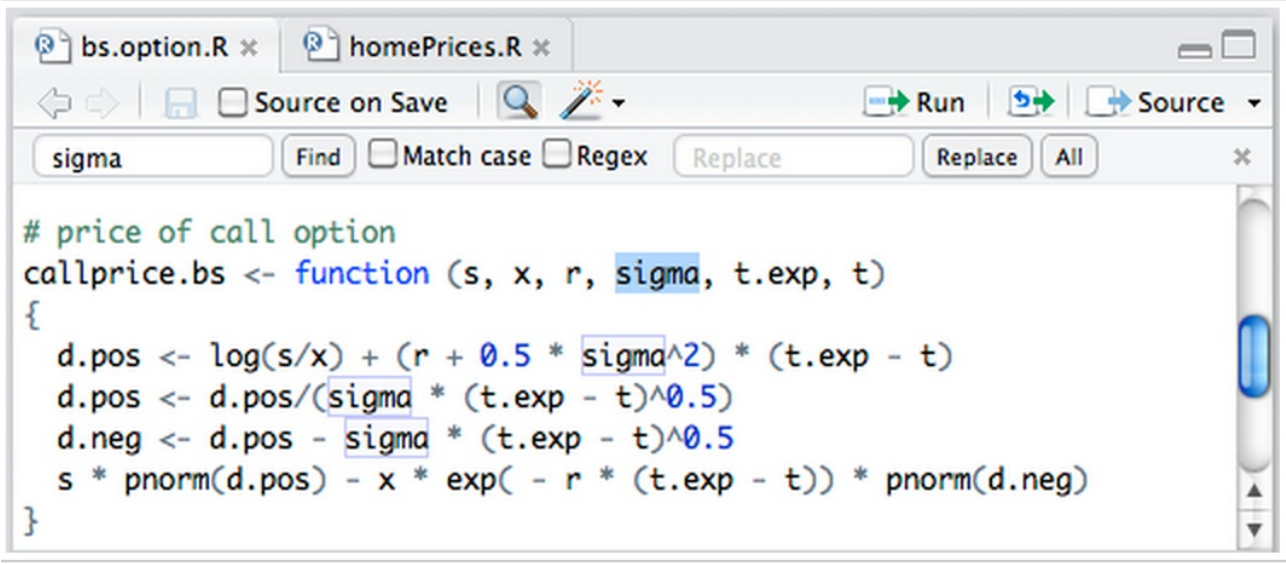
http://www.rstudio.com/

Rstudio's interface



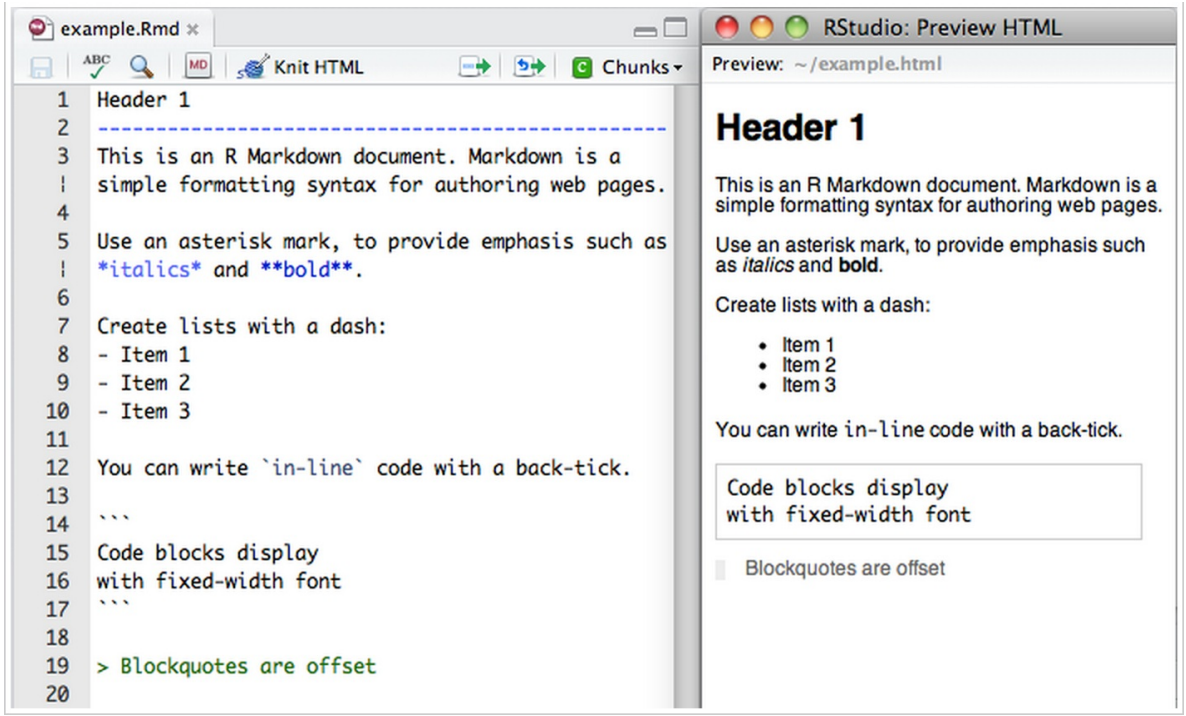
http://www.rstudio.com/

Primary file types - R script



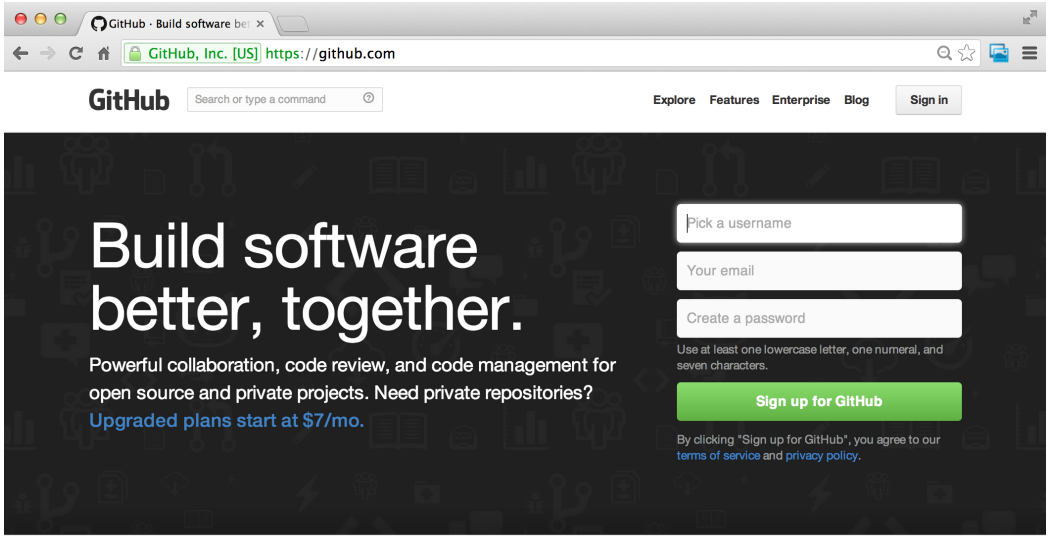
http://www.rstudio.com/ide/docs/using/source

Primary file types - R markdown document



http://www.rstudio.com/ide/docs/authoring/using_markdown

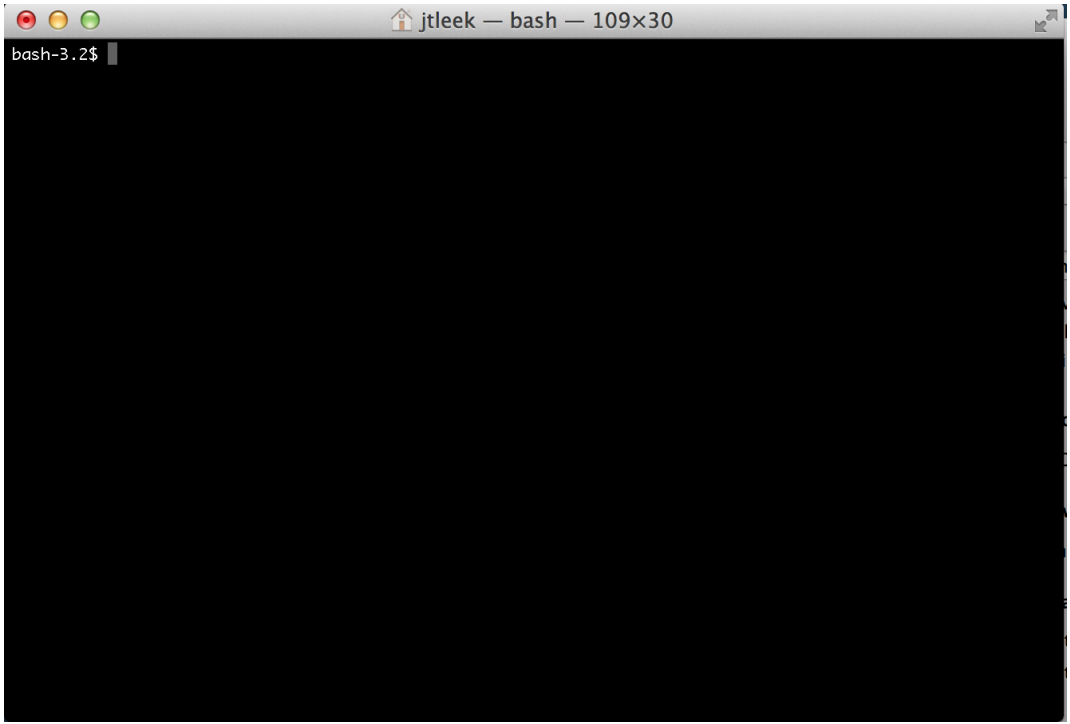
Sharing your results - Github & Git



Why you'll love GitHub.

Powerful features to make software development more collaborative.

Where to run Github commands - the shell



Getting help

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Asking questions

- In a standard class
  - There are 30-100 people
  - You raise your hand and ask a question
  - The instructor responds
- In a MOOC
  - There are almost 100,000 people
  - You post a question to the message board
  - Others vote on your questions
  - Your instructor responds (as often as possible)
  - Your peers respond (as often as possible)

Often the fastest answer is the one you find yourself

- It's important to try to answer your own questions first
- If the answer to your question is in the help file or the top hit on Google, the answer to your question will be, "Read the documentation" or "Google it" (http://lmgtfy.com/)
- If you figure out the answer and see the same questions on the forum, post the solution you found

Some important R functions

Access help file

```
?rnorm
```

Search help files

```
help.search("rnorm")
```

Get arguments

```
args("rnorm")
```

```
function (n, mean = 0, sd = 1)
NULL
```

Some important R functions

See code

```
rnorm
```

```
function (n, mean = 0, sd = 1)
.External(C_rnorm, n, mean, sd)
<bytecode: 0x7f9173a9f630>
<environment: namespace:stats>
```

R reference card

http://cran.r-project.org/doc/contrib/Short-refcard.pdf

How to ask an R question

- What steps will reproduce the problem?
- What is the expected output?
- What do you see instead?
- What version of the product (e.g. R, packages, etc.) are you using?
- What operating system?

How to ask a data analysis question

- What is the question you are trying to answer?
- What steps/tools did you use to answer it?
- What did you expect to see?
- What do you see instead?
- What other solutions have you thought about?

Be specific in the title of your questions

- Bad:
  - HELP! Can't fit linear model!
  - HELP! Don't understand PCA!
- Better
  - R 2.15.0 lm() function produces seg fault with large data frame, Mac OS X 10.6.3
  - Applied principal component analysis to a matrix - what are U, D, and V^T?
- Even better
  - R 2.15.0 lm() function on Mac OS X 10.6.3 -- seg fault on large data frame
  - Using principal components to discover common variation in rows of a matrix, should I use U, D or V^T?

Etiquette for forums/help sites: DOs

- Describe the goal
- Be explicit
- Provide the minimum information
- Be courteous (never hurts)
- Follow up and post solutions
- Use the forums rather than email

Etiquette for forums/help sites: DON'Ts

- Immediately assume you found a bug
- Grovel as a substitute for doing your work
- Post homework questions on mailing lists (people don't like doing your homework)
- Email multiple mailing lists at once/the wrong mailing list
- Ask others to fix your code without explaining the problem
- Ask about general data analysis questions on R forums.

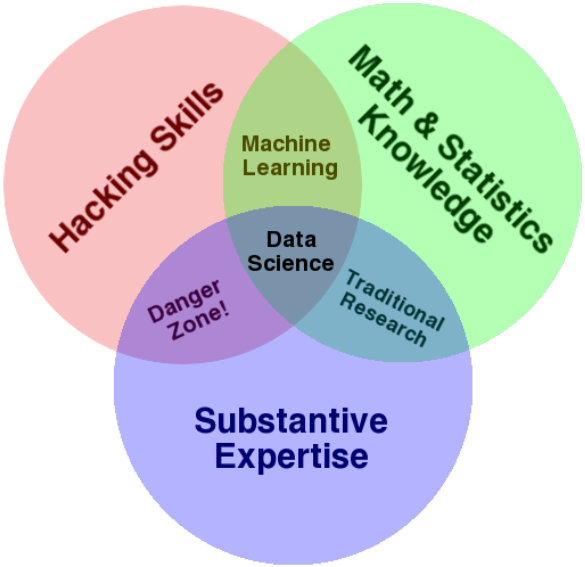
Credits

- Roger's Getting Help Video
- Inspired by Eric Raymond's "How to ask questions the smart way"

Finding answers

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

One of the key data science traits



Drew Conway

Key characteristics of hackers

- Willing to find answers on their own
- Knowledgeable about where to find answers on their own
- Unintimidated by new data types or packages
- Unafriad to say they don't know the answer
- *Polite but relentless*

Google knows it too

Where to look for different types of questions

- R programming (see also: http://bit.ly/Ufaadn)
  - Search the archive of the class forums
  - Read the manual/help files
  - Search on the web
  - Ask a skilled friend
  - Post to the class forums
  - Post to the R mailing list or Stackoverflow
- Data Analysis/Statistics
  - Search the archive of the class forums
  - Search on the web
  - Ask a skilled friend
  - Post to the class forums

A note on Googling data science questions

- The best place to start for general questions is the forums
- Stackoverflow (use the tag "[r]"),R mailing list for software questions, CrossValidated for more general questions
- Otherwise Google "[data type] data analysis" or "[data type] R package"
- Try to identify what data analysis is called for your data type
  - Biostatistics for medical data
  - Data Science for data from web analytics
  - Machine learning for data in computer science/computer vision
  - Natural language processing for data from texts
  - Signal processing for data from electrical signals
  - Business analytics for data on customers
  - Econometrics for economic data
  - Statistical process control for data about industrial processes

Credits

- Roger's Getting Help Video
- Inspired by Eric Raymond's "How to ask questions the smart way"

R Programming Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

R programming content

- Data types
- Subsetting
- Reading and writing data
- Control structures
- Functions
- Scoping
- Vectorized operations
- Dates and times
- Debugging
- Simulation
- Optimization

Reading Lines of a Text File

`readLines` can be useful for reading in lines of webpages

```
## This might take time
con <- url("http://www.jhsph.edu", "r")
x <- readLines(con)
> head(x)
[1] "<!DOCTYPE HTML PUBLIC \"-//W3C//DTD HTML 4.0 Transitional//EN\">"
[2] ""
[3] "<html>"
[4] "<head>"
[5] "\t<meta http-equiv=\"Content-Type\" content=\"text/html;charset=utf-8
```

Something's Wrong!

How do you know that something is wrong with your function?

- What was your input? How did you call the function?
- What were you expecting? Output, messages, other results?
- What did you get?
- How does what you get differ from what you were expecting?
- Were your expectations correct in the first place?
- Can you reproduce the problem (exactly)?

lapply

`lapply` takes three arguments: a list `X`, a function (or the name of a function) `FUN`, and other arguments via its ... argument. If `X` is not a list, it will be coerced to a list using `as.list`.

```
> lapply
function (X, FUN, ...)
{
    FUN <- match.fun(FUN)
    if (!is.vector(X) || is.object(X))
        X <- as.list(X)
    .Internal(lapply(X, FUN))
}
```

The actual looping is done internally in C code.

Getting and Cleaning Data Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Getting and Cleaning Data Content

- Raw vs. tidy data
- Downloading files
- Reading data
  - Excel, XML, JSON, MySQL, HDF5, Web, ...
- Merging data
- Reshaping data
- Summarizing data
- Finding and replacing
- Data resources

Connecting and listing databases

```
ucscDb <- dbConnect(MySQL(), user = "genome", host = "genome-mysql.cse.ucsc.edu")
result <- dbGetQuery(ucscDb, "show databases;")
dbDisconnect(ucscDb)
result
```

Merging data - merge()

```
mergedData2 <- merge(reviews, solutions, by.x = "solution_id", by.y = "id",
    all = TRUE)
head(mergedData2[, 1:6], 3)
reviews[1, 1:6]
```

Raw versus processed data

Raw data

- The original source of the data
- Often hard to use for data analyses
- Data analysis *includes* processing
- Raw data may only need to be processed once

http://en.wikipedia.org/wiki/Raw_data

Processed data

- Data that is ready for analysis
- Processing can include merging, subsetting, transforming, etc.
- There may be standards for processing
- All steps should be recorded

http://en.wikipedia.org/wiki/Computer_data_processing

Exploratory Analysis Overview

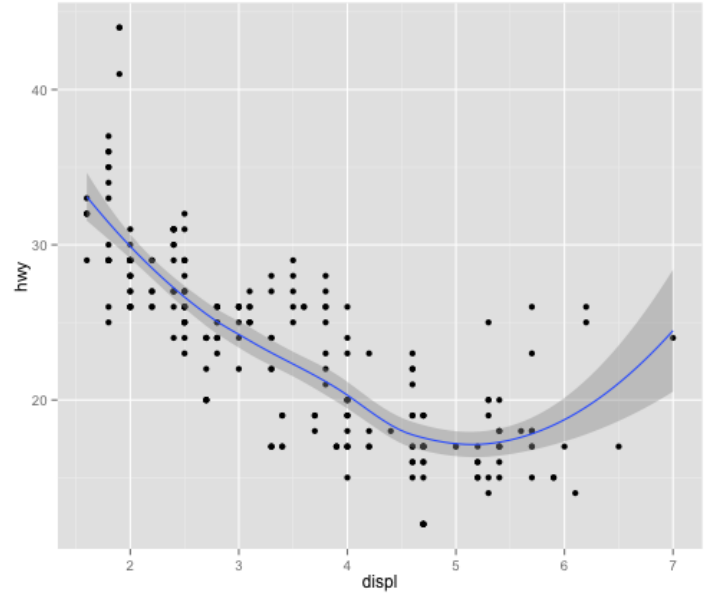
Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Exploratory Analysis Content

- Principles of Analytic Graphics
- Exploratory graphs
- Plotting Systems in R
  - base
  - lattice
  - ggplot2
- Hierarchical clustering
- K-Means clustering
- Dimension reduction

Adding a geom

```
qplot(displ, hwy, data = mpg, geom = c("point", "smooth"))
```

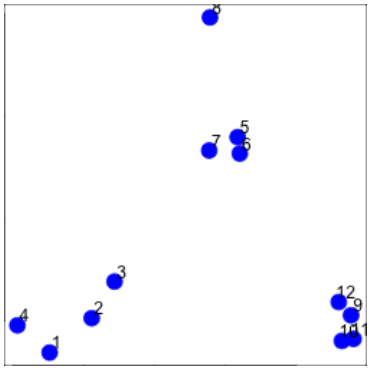


Principles of Analytic Graphics

- Principle 1: Show comparisons
- Principle 2: Show causality, mechanism, explanation
- Principle 3: Show multivariate data
- Principle 4: Integrate multiple modes of evidence
- Principle 5: Describe and document the evidence
- Principle 6: Content is king

K-means clustering - example

```
set.seed(1234)
par(mar = c(0, 0, 0, 0))
x <- rnorm(12, mean = rep(1:3, each = 4), sd = 0.2)
y <- rnorm(12, mean = rep(c(1, 2, 1), each = 4), sd = 0.2)
plot(x, y, col = "blue", pch = 19, cex = 2)
text(x + 0.05, y + 0.05, labels = as.character(1:12))
```



Reproducible Research Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Reproducible Research Content

- Structure of a Data Analysis
- Organizing a Data Analysis
- Markdown
- LaTeX
- R Markdown
- Evidence-based data analysis
- RPubs

Steps in a data analysis

- Define the question
- Define the ideal data set
- Determine what data you can access
- Obtain the data
- Clean the data
- Exploratory data analysis
- Statistical prediction/modeling
- Interpret results
- Challenge results
- Synthesize/write up results
- Create reproducible code

Data analysis files

- Data
  - Raw data
  - Processed data
- Figures
  - Exploratory figures
  - Final figures
- R code
  - Raw scripts
  - Final scripts
  - R Markdown files (optional)
- Text
  - Readme files
  - Text of analysis

Statistical Inference Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Statistical Inference Content

- Basic probability
- Likelihood
- Common distributions
- Asymptotics
- Confidence intervals
- Hypothesis tests
- Power
- Bootstrapping
- Non-parametric tests
- Basic bayesian statistics

Example

Suppose that the proportion of help calls that get addressed in a random day by a help line is given by

$$f(x) = \begin{cases} 2x & \text{for } 1 > x > 0 \\ 0 & \text{otherwise} \end{cases}$$

Is this a mathematically valid density?

The normal distribution

- A random variable is said to follow a **normal** or **Gaussian** distribution with mean μ and variance σ^2 if the associated density is

$$(2\pi\sigma^2)^{-1/2}e^{-(x-\mu)^2/2\sigma^2}$$

  If X a RV with this density then $E[X] = \mu$ and $Var(X) = \sigma^2$

- We write $X \sim N(\mu, \sigma^2)$
- When $\mu = 0$ and $\sigma = 1$ the resulting distribution is called **the standard normal distribution**
- The standard normal density function is labeled ϕ
- Standard normal RVs are often labeled Z

Example bootstrap code

```
B <- 1000
n <- length(gmVol)
resamples <- matrix(sample(gmVol,
                           n * B,
                           replace = TRUE),
                    B, n)
medians <- apply(resamples, 1, median)
sd(medians)
[1] 3.148706
quantile(medians, c(.025, .975))
    2.5%    97.5%
582.6384 595.3553
```

Regression Models Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Regression Models Content

- Linear regression
- Multiple Regression
- Confounding
- Residuals and diagnostics
- Prediction using linear models
- Model misspecification
- Scatterplot smoothing/splines
- Machine learning via regression
- Resampling inference in regression, bootstrapping, permutation tests
- Weighted regression
- Mixed models (random intercepts)

A historically famous idea, Regression to the Mean

- Why is it that the children of tall parents tend to be tall, but not as tall as their parents?
- Why do children of short parents tend to be short, but not as short as their parents?
- Why do parents of very short children, tend to be short, but not a short as their child? And the same with parents of very tall children?
- Why do the best performing athletes this year tend to do a little worse the following?

Basic regression model with additive Gaussian errors

- Least squares is an estimation tool, how do we do inference?
- Consider developing a probabilistic model for linear regression

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i$$

- Here the ϵ_i are assumed iid $N(0, \sigma^2)$.
- Note, $E[Y_i \mid X_i = x_i] = \mu_i = \beta_0 + \beta_1 x_i$
- Note, $Var(Y_i \mid X_i = x_i) = \sigma^2$.
- Likelihood equivalent model specification is that the Y_i are independent $N(\mu_i, \sigma^2)$.

Multivariable regression analyses

- An insurance company is interested in how last year's claims can predict a person's time in the hospital this year.
  - They want to use an enormous amount of data contained in claims to predict a single number. Simple linear regression is not equipped to handle more than one predictor.
- How can one generalize SLR to incoporate lots of regressors for the purpose of prediction?
- What are the consequences of adding lots of regressors?
  - Surely there must be consequences to throwing variables in that aren't related to Y?
  - Surely there must be consequences to omitting variables that are?

Practical Machine Learning Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Practical Machine Learning Content

- Prediction study design
- Types of Errors
- Cross validation
- The caret package
- Plotting for prediction
- Preprocessing
- Predicting with regression
- Predicting with trees
- Boosting
- Bagging
- Model blending
- Forecasting

Basic terms

In general, **Positive** = identified and **negative** = rejected. Therefore:

- **True positive** = correctly identified
- **False positive** = incorrectly identified
- **True negative** = correctly rejected
- **False negative** = incorrectly rejected

Medical testing example:

- **True positive** = Sick people correctly diagnosed as sick
- **False positive**= Healthy people incorrectly identified as sick
- **True negative** = Healthy people correctly identified as healthy
- **False negative** = Sick people incorrectly identified as healthy.

http://en.wikipedia.org/wiki/Sensitivity_and_specificity

Correlated predictors

```
library(caret)
library(kernlab)
data(spam)
inTrain <- createDataPartition(y = spam$type, p = 0.75, list = FALSE)
training <- spam[inTrain, ]
testing <- spam[-inTrain, ]

M <- abs(cor(training[, -58]))
diag(M) <- 0
which(M > 0.8, arr.ind = T)
```

```
##        row col
## num415  34  32
## direct  40  32
## num857  32  34
## num857  32  40
```

Basic idea behind boosting

1. Start with a set of classifiers $h_1, \ldots, h_k$
   - Examples: All possible trees, all possible regression models, all possible cutoffs.
2. Create a classifier that combines classification functions: $f(x) = \text{sgn}\left(\sum_{t=1}^{T} \alpha_t h_t(x)\right)$.
   - Goal is to minimize error (on training set)
   - Iterative, select one h at each step
   - Calculate weights based on errors
   - Upweight missed classifications and select next h

Adaboost on Wikipedia

http://webee.technion.ac.il/people/rmeir/BoostingTutorial.pdf

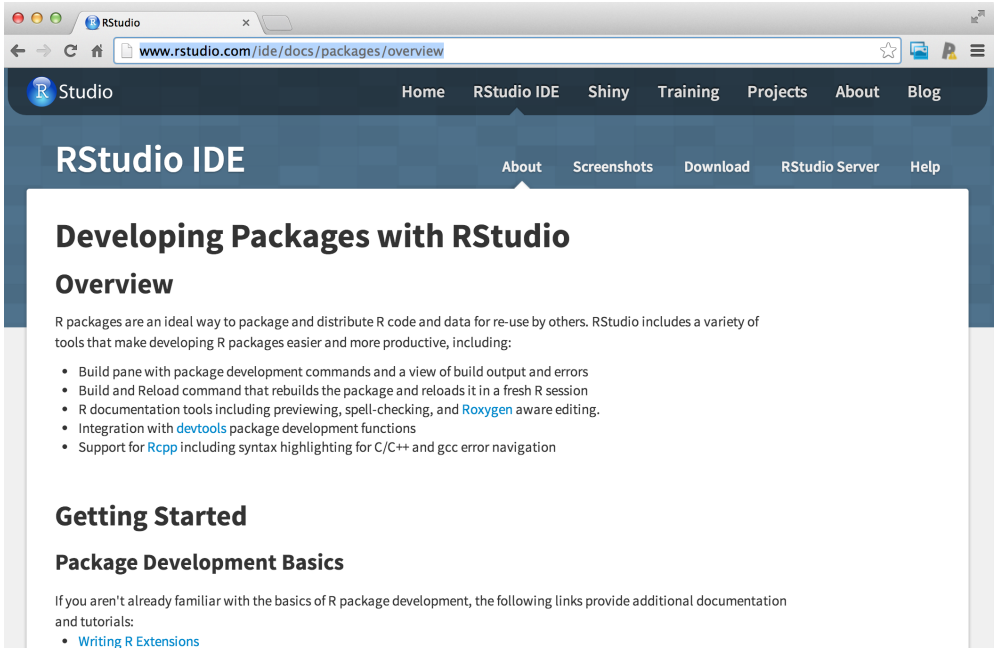
Building Data Products Overview

Jeffrey Leek
Johns Hopkins Bloomberg School of Public Health

Building Data Products Content

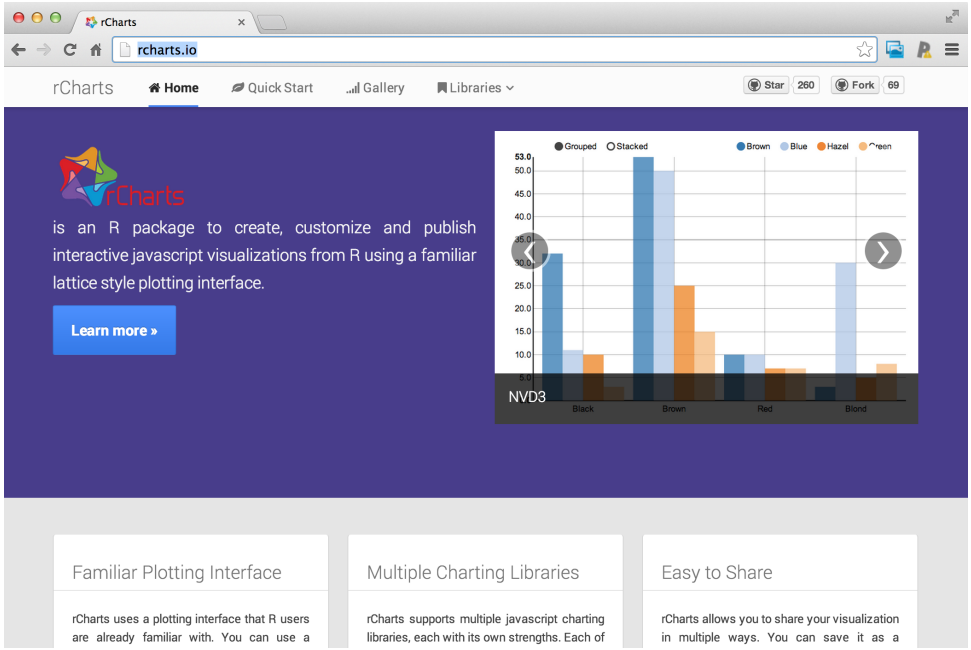
- R packages
  - devtools
  - roxygen
  - testthat
- rCharts
- Slidify
- Shiny

R packages - for the engineers



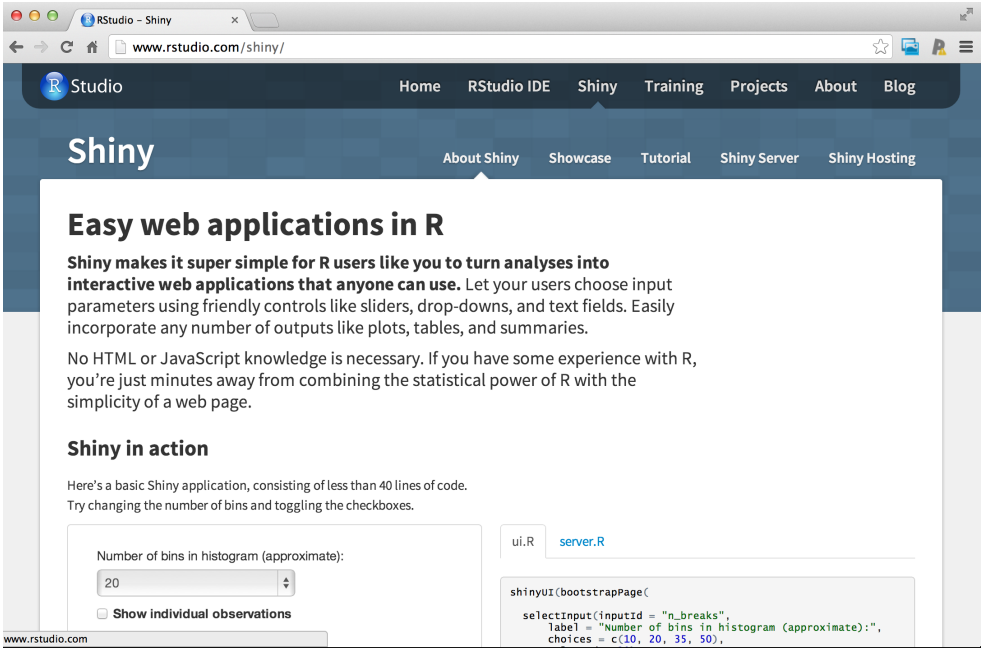
http://cran.r-project.org/web/packages/ http://www.rstudio.com/ide/docs/packages/overview

rCharts - for marketing



http://rcharts.io/ http://ramnathv.github.io/rChartsNYT/

Shiny - for your users



http://www.rstudio.com/shiny/ http://www.rstudio.com/shiny/showcase/