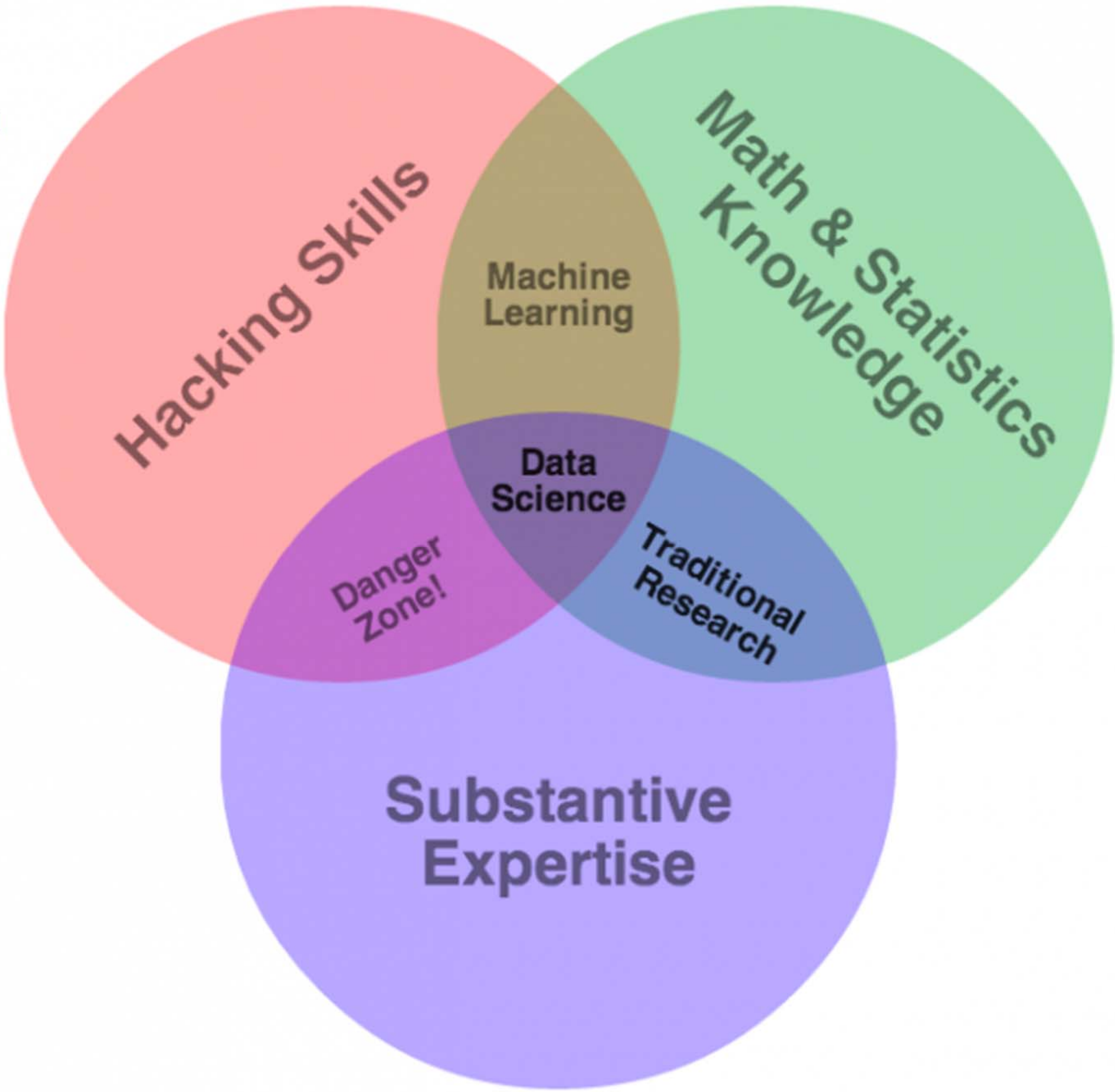
UNIVERSITY *of* WASHINGTON

Data Science UW
Methods for Data Analysis

Introduction and Data Exploration
Lecture 1
Stephen Elston


Hacking Skills
Math & Statistics Knowledge
Machine Learning
Data Science
Danger Zone!
Traditional Research
Substantive Expertise

Course Purpose

- This course focuses on essential concepts
- We are building foundations for your data science skills
- Course Objectives:
  - Learn methods to explore and understand data.
  - Understand the core concepts of statistics.
  - Understand and implement various statistical procedures in R.
  - Describe and interpret analytical results from common statistical methods.
  - Expand R programming skills to be able to write/test/log code from scratch.
  - Work with structured and unstructured data.
- See syllabus for more information:
  - https://canvas.uw.edu/courses/1087732/pages/course-abbrev-course-syllabus

Course Requirements and Grading

This course will be graded by attendance, homework, and an individual project.

- Attendance: You MUST attend at least 8 out of 10 classes. **This is a non-negotiable UW requirement**.
- Homework must be completed by the start of the next class. (Assigned weeks 1-8).
  - Returned as a 0,1, or 2.
    - 0 = Not done or a major part wrong/missing.
    - 1 = Completed, but missing or got wrong 1 or 2 parts.
    - 2 = Completed with at most minor issues. Demonstrates full understanding of subject.
- Individual Project: Due at the start of the last class.
  - Counts as 8 points.

Course Requirements and Grading

There is a total of 24 possible points. (16 pts for hmk + 8 project)

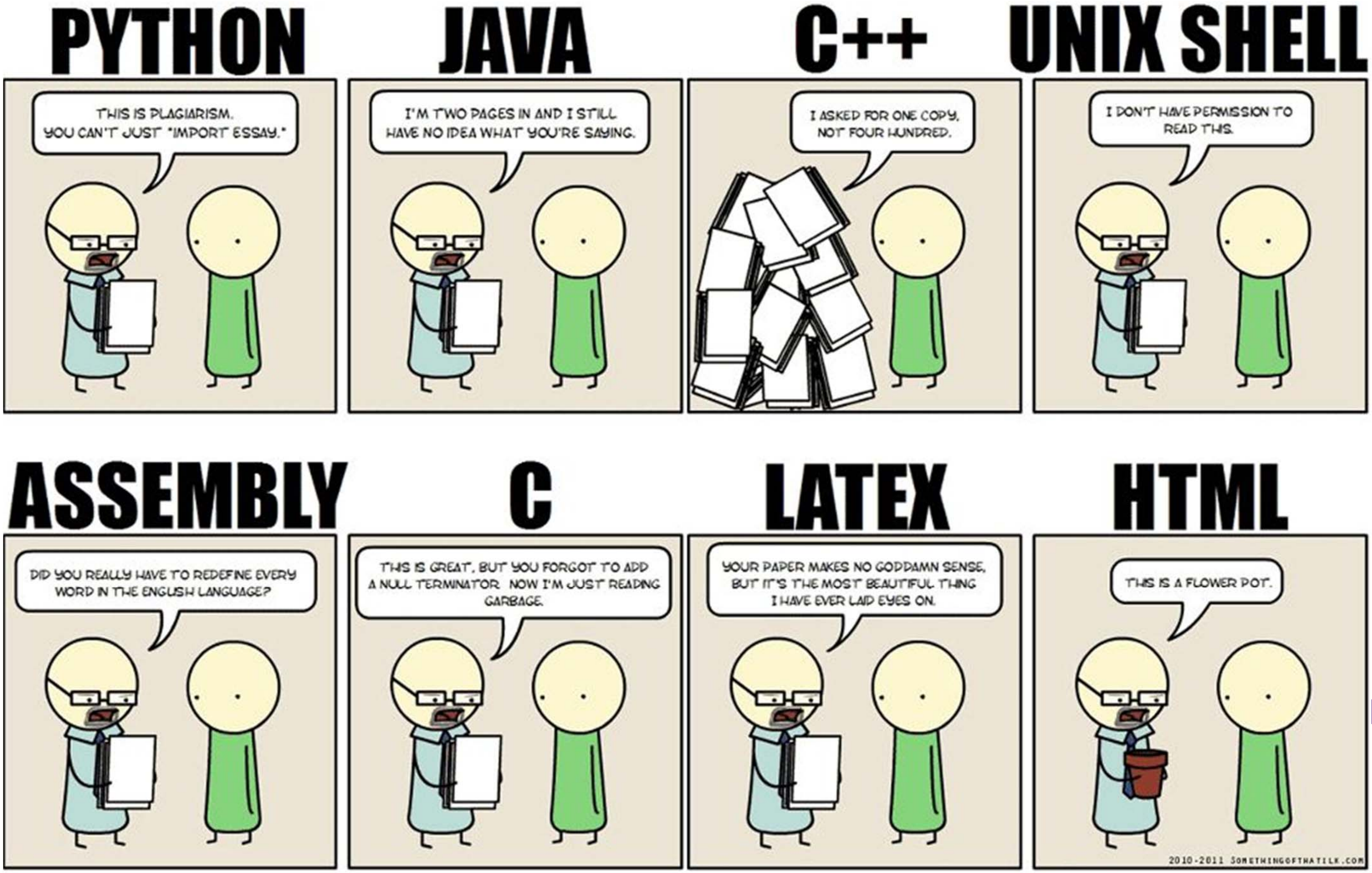
- Must get 18 total points to pass.
- All homework assignments must use good R coding technique
- The individual project must be production level code.

Office Hours and Contact Information

> Contact me at:
  - stephen.elston@quantia.com
> When I'm *usually* available:
  - Off/on for simple things during work. (M-F 8am-5pm PST)
  - Sunday various afternoon/evening times.

Emergency contact: 402-980-3192

Review


PYTHON
THIS IS PLAGIARISM. YOU CAN'T JUST "IMPORT ESSAY."
JAVA
I'M TWO PAGES IN AND I STILL HAVE NO IDEA WHAT YOU'RE SAYING.
C++
I ASKED FOR ONE COPY, NOT FOUR HUNDRED.
UNIX SHELL
I DON'T HAVE PERMISSION TO READ THIS.
ASSEMBLY
DID YOU REALLY HAVE TO REDEFINE EVERY WORD IN THE ENGLISH LANGUAGE?
C
THIS IS GREAT, BUT YOU FORGOT TO ADD A NULL TERMINATOR. NOW I'M JUST READING GARBAGE.
LATEX
YOUR PAPER MAKES NO GODDAMN SENSE, BUT IT'S THE MOST BEAUTIFUL THING I HAVE EVER LAID EYES ON.
HTML
THIS IS A FLOWER POT.
2010-2011 SOMETHINGOFTHATILK.COM

SQL Review

- SQL is the 'Linqua Franka' of data access
- SQL (to know):
  - *Create tables*
  - *Drop tables*
  - Select, where, groupby
  - Joins (Inner, outer, right, left)
  - Temp tables
  - Coalesce, Cast, Case

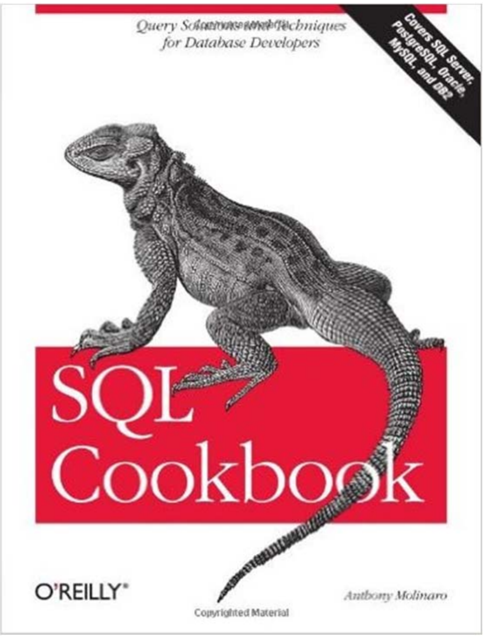
SQL Resources

SQL Tutorial and Resources

http://www.w3schools.com/sql/

Querying with Transact SQL Course, Graeme Malcom

https://www.edx.org/course/querying-transact-sql-microsoft-dat201x-3



Prepare for R Demos

> Install R

https://cran.r-project.org/

-or-

https://mran.revolutionanalytics.com/download/

> Install RStudio

https://www.rstudio.com/products/rstudio/download/

GitHub

> Code, data and slides for this course are in a GitHub repository

https://github.com/StephenElston/DataScience350

> Install GitHub for desk top

https://help.github.com/desktop/guides/getting-started/installing-github-desktop/

- Or, just download the zip files

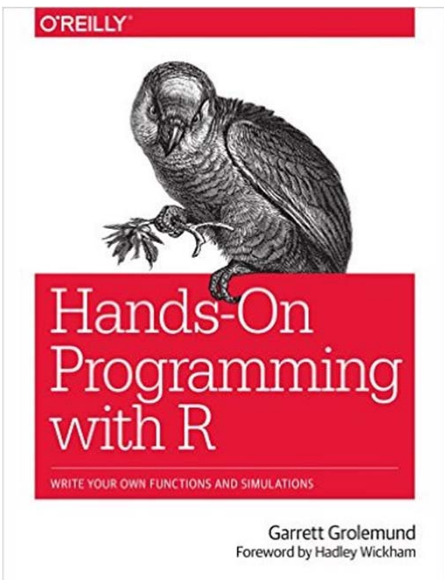
R Review

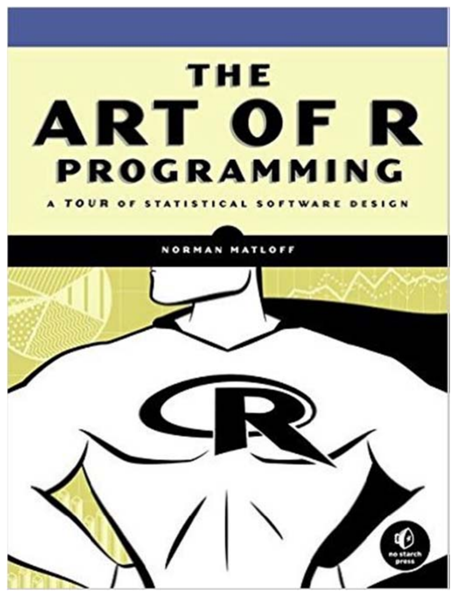
- R resources:
  - R page:
    - http://www.r-project.org/other-docs.html
  - Stackoverflow:
    - http://www.stackoverflow.com
  - ‘Little’ R intro:
    - http://cran.r-project.org/doc/contrib/Rossiter-RIntro-ITC.pdf
  - Quick R:
    - http://statmethods.net/
  - There are many tutorials available online, e.g.,
    - http://cyclismo.org/tutorial/R/
  - Google’s Style Guide:
    - http://google-styleguide.googlecode.com/svn/trunk/google-r-style.html

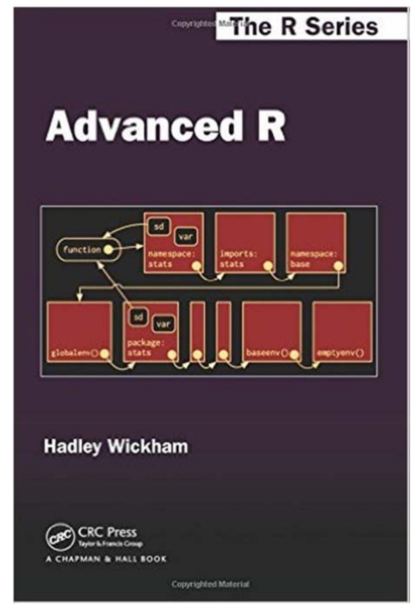
More R Resources

R Inferno, Pat Burns

http://www.burns-stat.com/pages/Tutor/R_inferno.pdf







Statistics Review

> Familiar Concepts:
  - Discrete vs. Continuous Distributions
  - Probability
  - Statistics
  - y = mx + b   vs $\bar{Y} = \mathbf{M} \cdot \bar{X} + \mathbf{B}$

> These concepts are the focus of this course.

Counting Review

- > Factorials
  - – Count # ways to order N things = N!
- > Permutations
  - – Count # of ways to **order** R things from N things = N!/(N-R)!
  - – Ordering matters
  - – P(N,R)
- > Combinations
  - – Count # of ways to **group** R things from N things = N!/(R!(N-R!))
  - – Ordering doesn't matter
  - – C(N,R) or $\binom{N}{R}$
- > We will talk about this in depth next class.

Data Distributions (Discrete)

> Discrete Distribution Properties

- Sum of probability of all possible events must equal 1.
- Probability of event equal to value of distribution at point.
- All values strictly in range 0-1.

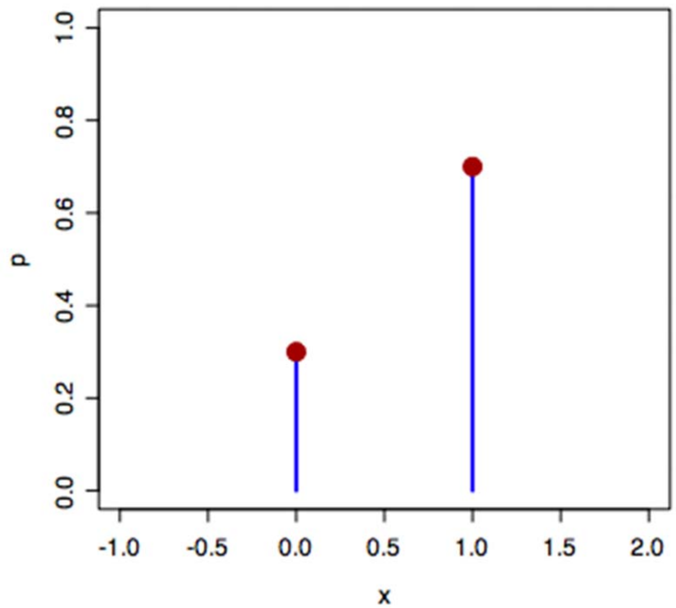
Data Distributions (Discrete)

> Bernoulli (1 event, e.g.: coin flip)

$$P(x) = \begin{cases} p \; if \; x = 1 \\ (1-p) \; if \; x = 0 \end{cases}$$

$$P(x) = p^x (1-p)^{(1-x)} \quad x \in \{0,1\}$$

- Mean = p
- Variance = p(1-p)



Data Distributions (Discrete)

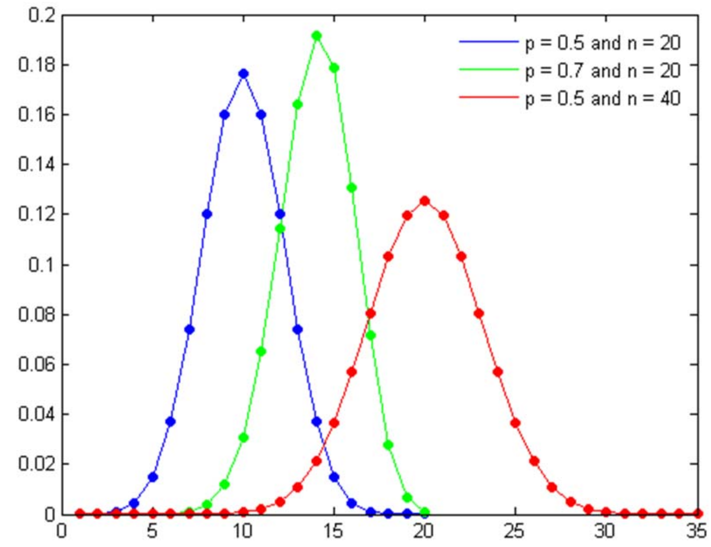
> Binomial (Multiple Bernoulli's Events)

– Multiple Independent events = Product of Bernoulli Probabilities

$$P(x|N,p) = \binom{N}{x} p^x (1-p)^{(N-x)}$$

– Mean = np

– Variance = np(1-p)



Note: for larger n, we approximate this by a normal distribution.

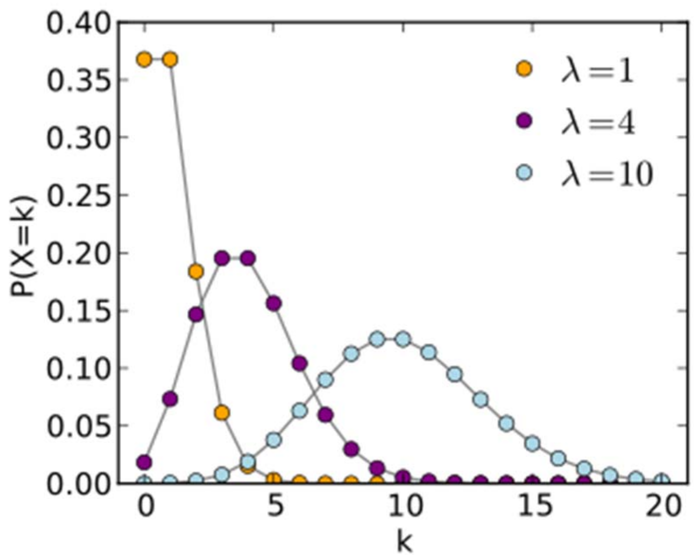
Data Distributions (Discrete)

> Poisson (Count of number of events in a time span)

$$P(x|\lambda) = \frac{\lambda^x}{x!} e^{-\lambda}$$

– Mean = λ
– Variance = λ

Interpret as the rate of occurrence of an event is equal to lambda in a finite period of time.



R Demo

Discrete distributions

Data Distributions (Continuous)

> Continuous Distribution Properties

- Area under the curve must be equal to 1.
- Probability a range of values of an event equal to AREA under curve.
- No negative values.
- Probability of a single, exact value is 0.

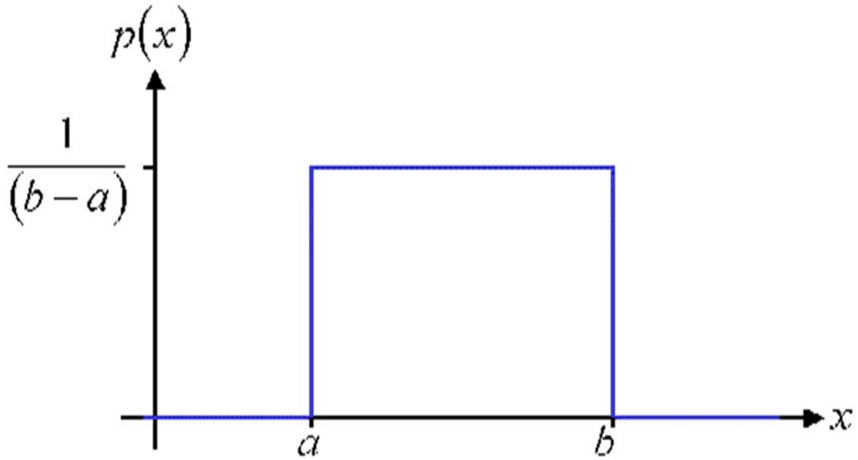
Data Distributions (Continuous)

> Uniform (flat, bounded)

$$P(x) = \begin{cases} \dfrac{1}{(b-a)} \; if \; a \le x \le b \\ 0 \; if \; x < a \; or \; x > b \end{cases}$$

> Used for parameter priors. (future discussion)

- Mean=(a+b)/2
- Variance=(1/12)(b-a)^2

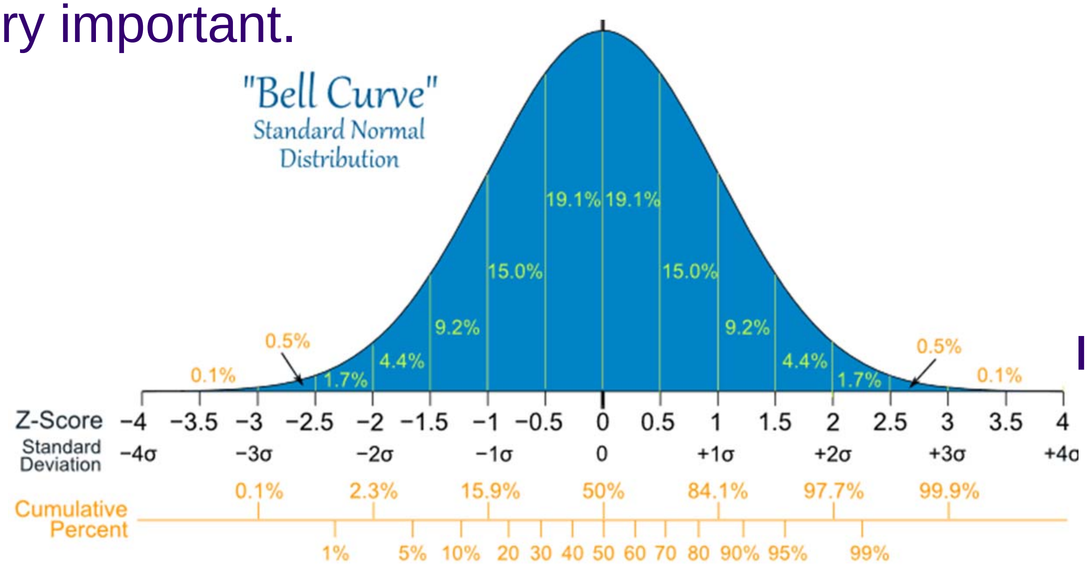


Data Distributions (Continuous)

> Normal (Gaussian) distribution
  - Most common and occurs naturally.
  - Defined by a mean and variance only. (standard = N(0,1))

$$P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

  - Has very nice properties.
  - Tests for normality are very important.



Data Distributions (Continuous)

- Student's T (normal for small samples)
  - Important for hypothesis testing smaller sample sizes.
  - Used for:
    - Testing of mean value when st. dev. is unknown.
    - Testing difference between two distribution means.
  - Looks very similar to the normal distribution.

R Demo

Continuous distributions

R review and summary statistics

> Purpose: To gain a clear understanding of your data.
  - How large is it?
  - What columns are of interest?
  - Missing data?
  - Outliers?

R Vectors, Arrays and Lists

- Vectors have one dimension, one data type
- Vectors are the atomic object in R
- R is optimized for vector operations
- Array has multiple dimensions, all data of one type
- Matrix is a 2D array
- Lists are comprised of other R object
- Elements of a list can be of any type and dimension

Data frames

- > Rectangular tables: cannot be ragged
- > List with special attributes
- > Each column is vector of single type
- > Columns can have names
- > Rows can have names
- > Subsetting function []
- > Column function $

Functional Programming with R
Definition from Wikipedia

In computer science, **functional programming** is a programming paradigm—a style of building the structure and elements of computer programs—that treats computation as the evaluation of **mathematical functions** and **avoids changing-state** and mutable data. It is a declarative programming paradigm, which means **programming is done with expressions or declarations**[instead of statements. In functional code, the **output value of a function depends only on the argument**s that are input to the function, so calling a function *f* twice with the same value for an argument *x* will produce the same result *f(x)* each time. **Eliminating side effects**, i.e. changes in state that do not depend on the function inputs, can make it much easier to understand and predict the behavior of a program, which is one of the key motivations for the development of functional programming.

Functional programming in R

- R is a functional language
- Expressions and function are objects
- Functions can be named or anonymous
- Use functional operators rather than loops

R programming practice

> Vectorize for performance
> Use functions; **avoid repetitive code!**
> Make use of functional operators
> Comment your code
> Names should mean something

R Demo

Basic data wrangling and functional programming

Data Exploration (Descriptive Statistics)

- Purpose: To gain a clear understanding of your data.
  - How large is it?
  - What columns are of interest?
  - Missing data?
  - Outliers?

Numerical Exploration

> str(): structure of the data frame

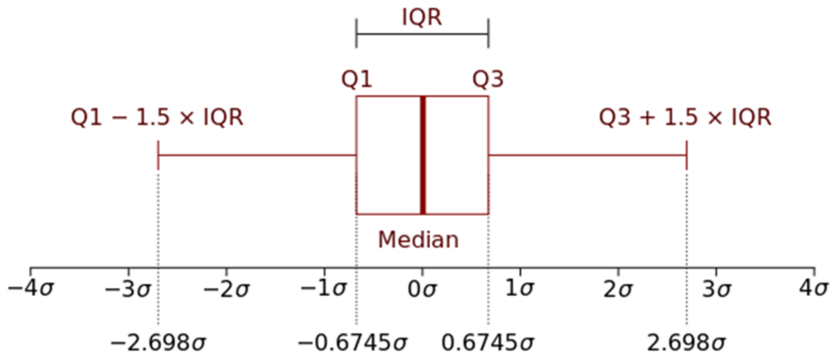
> summary(): summary of each of the columns

> head() / tail(): top / bottom of data frame

> table(): frequency table

Numerical Exploration

- > Quartile == ¼ values
- > IQR(): inner quartile range (Q3 – Q1)



Numerical Exploration

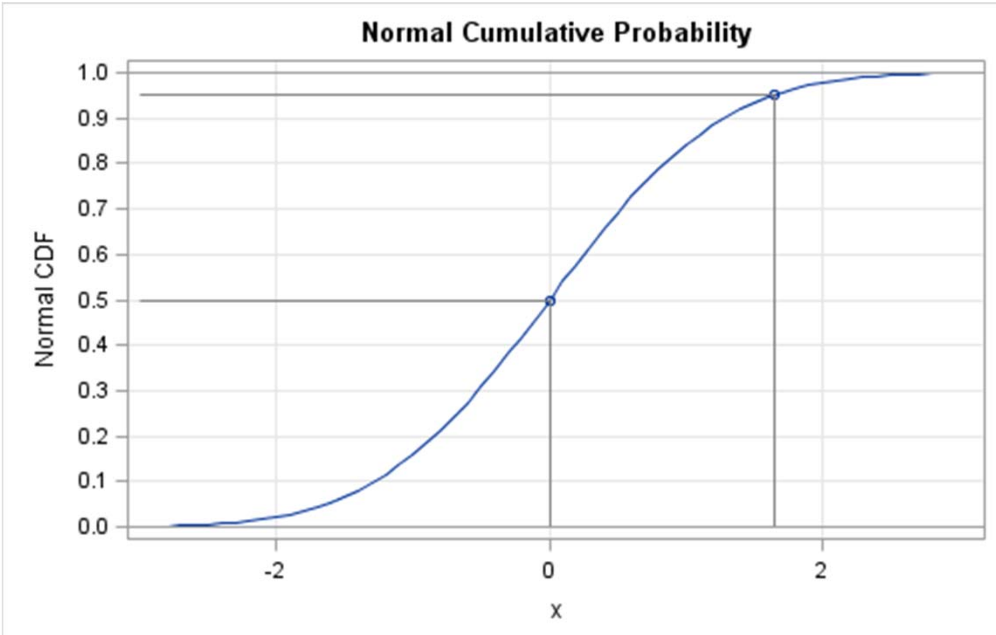
> quantile(): quantiles of numerical vectors

– Quantiles are inverse values of the CDF (cumulative distribution function).

– Standard Normal: (shown in figure)

> Quantile(0.5) = 0, means at x=0, 50% of the distribution lies to the left. (This is also the median)

> Quantile(0.95) = 1.65



Numerical Exploration

> Relationships:
  - cov(): covariances

$$cov(x, y) = E\big((x - \mu_x)(y - \mu_y)\big)$$

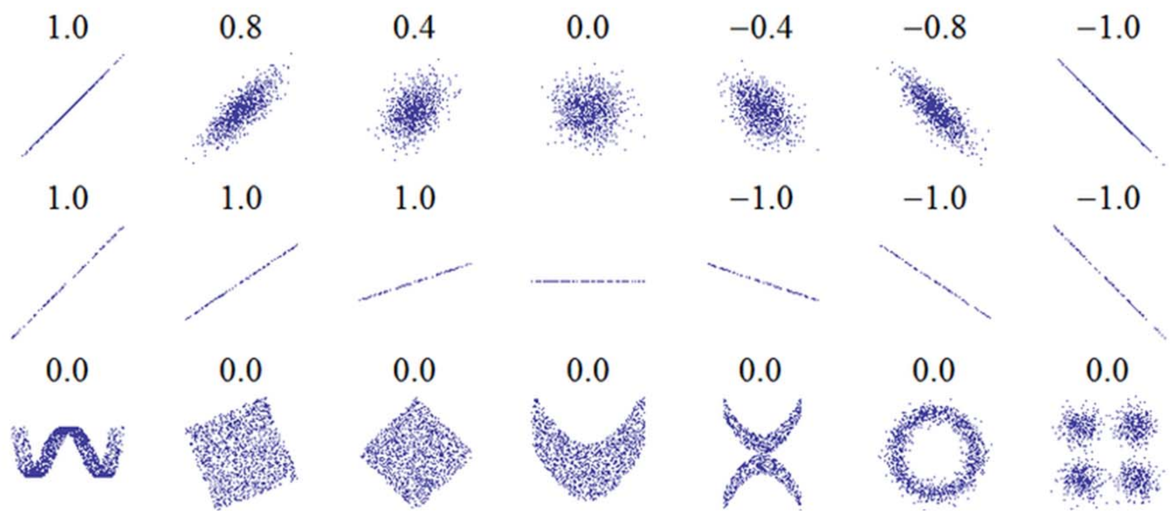
  - Interpretation: Expected value of the differences between x and y and their corresponding mean.
  - E.g. if x is above it's mean when y is also above it's mean, then they will have a high covariance.
  - Not bounded.

Numerical Exploration

> Relationships:
  - cor(): correlations (pearsons)

$$cor(x,y) = \frac{E\big((x-\mu_x)(y-\mu_y)\big)}{\sigma_x \sigma_y}$$

  - Bounded between 0 and 1.
  - **Does not indicate causeation!!**



Distribution Transformations

- The purpose of transforming a variable is to make it easier to distinguish between values.
  - Most commonly we are looking to transform a distribution to be normal.
- Common Transformations
  - Log-based:
    - Log(x), log(x+1), log(x-min(x) + 1)
  - N-th Root based:
    - X^(1/n)
  - Any combination you can think of (remembering math rules).
- We will cover normality tests in a later class.

R Demo

Summary statistics

Introduction to dplyr

Data Wrangling Cheat Sheet:

https://www.rstudio.com/wp-content/uploads/2015/02/data-wrangling-cheatsheet.pdf

> Data scientists spend most of their time on data munging or data wrangling
> dplyr package provides a regular grammar for most data wrangling
> Optimized for fast operations on data frames
> Chain verbs (operators) for fast operations

Col1	Col2	Col3
2012	14	45
2013	13	76
2013	34	65
2014	23	47

```
library(dplyr)
df <- read.csc('data.csv',
header = TRUE,
stringsAsFactors = FALSE)
```

Col1	Col2	Col3
2013	13	45
2013	34	65
2013	34	65
2014	23	47

```
df <- filter(df, Col1 ==
2013)
```

Col1	Col3	Col3
2012	14/45	45
2013	16/76	76
2013	34/65	65
2014	23/47	47

```
df <- select(df, Col1, Col3)
```

Col1	Col2		Col3		Col4
2012	14	14	45	45	59
2013	13	13	76	76	89
2013	34	34	65	65	99
2014	23	23	47	47	70

```
df <- mutate(df, Col4 = Col2 +
Col3)
```

Other useful dplyr verbs include:

```
df <- group_by(df, Col1)

df <- distinct(df, Col1)

df <- arrange(df, Col1)

df <- slice(df, 10:15)

df <- sample_frac(df, 0.5)

df <- sample_n(df, 500)

df <- summarize(df, m1 =
mean(Col1))
```

Col1		Col2	Col3		Col4
2013	13	14	76	45	89
2013	34	13	65	76	99
2013		34		65	
2014		23		47	

```
df <- df %>%
      filter(Col1 == 2013) %>%
      mutate(Col4 = Col2 + Col3)
```

```
iris %>% group_by(Species) %>%
summarise(…)
```

Simpsons Paradox

- Slicing up data in different ways can create different results.
- Generally arises in context of larger dataset with latent variable

- http://vudlab.com/simpsons/
- http://www.math.grinnell.edu/~mooret/reports/SimpsonExamples.pdf

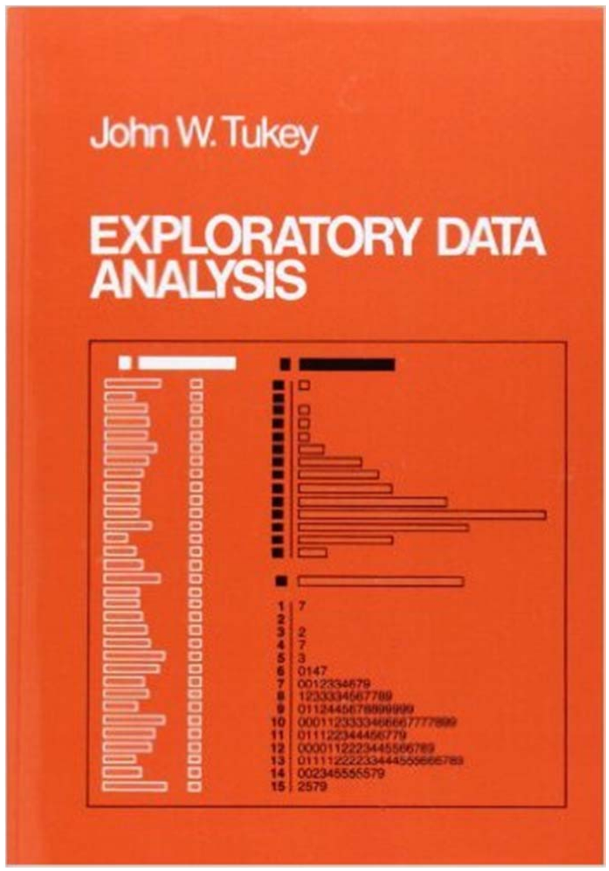
- **R Demo with dplyr**

Exploratory data analysis

- Explore the data with visualization
- Understand the relationships in the data
- Use multiple views of data
- Aesthetics to project multiple dimensions
- Conditioning to project multiple dimensions

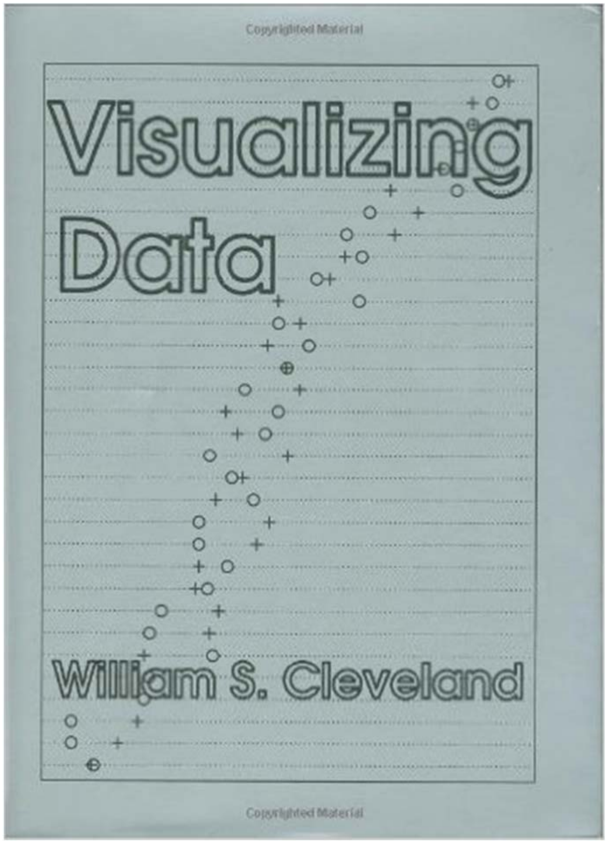
Seminal Book

John Tukey, Exploratory Data Analysis, 1977, Addison-Westley



Seminal Book

Visualizing Data, William S. Cleveland, Hobart Press 1993



Views of data

> Data contains complex relationships
> Explore data with multiple views
> Views show different aspects of the relationships
> Different plots highlight different relationships

Different plots for different views

- Scatter
- Scatter plot matrix
- Line plots
- Bar plots
- Histograms
- Box plots
- Violin plots
- Q-Q plots

Visualization Aesthetics

Aesthetics expand dimensionality of projection

- Color
- Shape
- Size
- Transparency
- Aesthetics specific to plot type
- **Don’t over do it!**

Presenting charts

Charts must inform, not confuse!

> Creating good visualization is iterative, and lots of work
> Axis labels
> Title
> Legend
> Large symbols and lines
> Be sensitive to color blindness
> No pie charts, please!
> **Simplify, simplify, simplify!**

Grammar of Graphics: ggplot2

Grammar for building charts

> Import library

```
library(ggplot2)
```

> Define basic chart data and type

```
p1 = ggplot(df, aes(x = col1, y = col2,
       by = col3)) +
     geom_plottype(aes(asthetics))
```

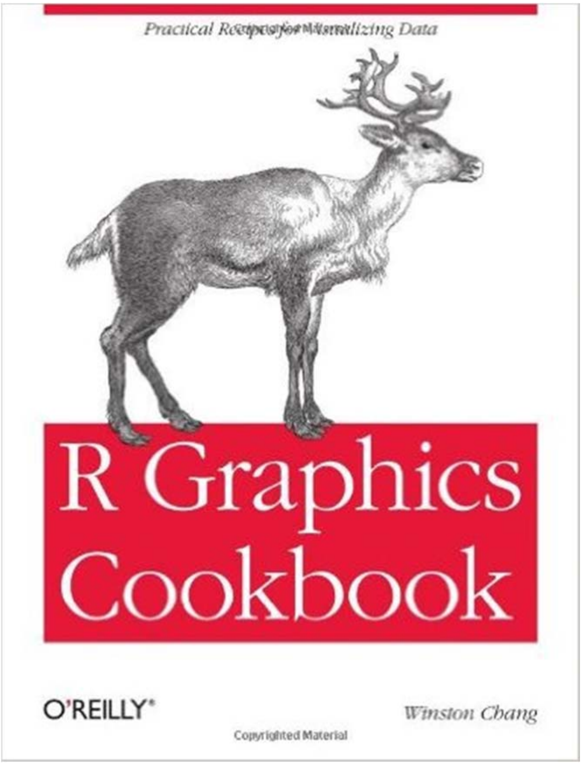
> Chain to add attributes

```
p1 + xlab('xlab') + ylab('ylab') +
    ggtitle('The Title') +
    other_attributes(…)
```

ggplot2 resources

ggplot2 cheat sheet

https://www.rstudio.com/wp-content/uploads/2015/03/ggplot2-cheatsheet.pdf



R Demo

Data Visualization

Assignment

Homework 1:

- Explore auto price data set.
- Write R program that shows/illustrates 3 key takeaways of your choosing from exploring the data.
- You should submit:
  - **ONE R-script.**
  - **One word document with 3 key points.** (example next page).

Example Takeaway

> The price of automobiles is dependent on feature x. The levels of feature x separate the following specific types of autos. Specifically these include…… The charts illustrate this relationship. Examining the chart shows………

Recommended Readings

> An Introduction to Data Science, Chapters 3 and 9
> Statistical Thinking for Programmers, Chapter 2