Approaches to science & statistical inference

ZOL 851

Sept 6 2016

Goals for today

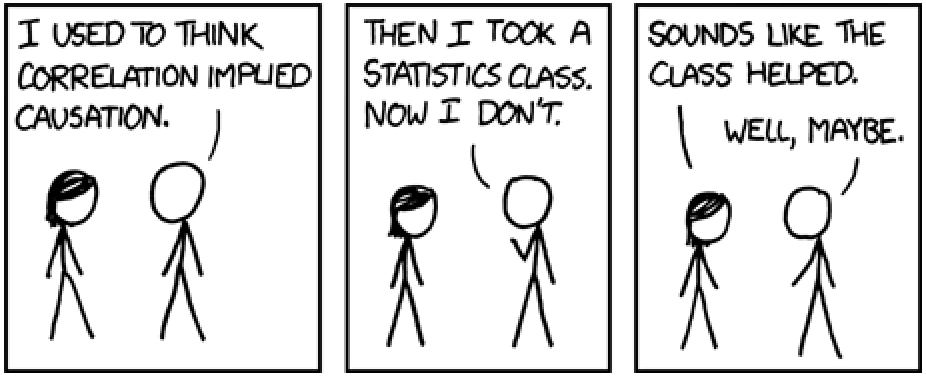
- Overview of scientific & statistical approaches
- Factors influencing experimental designs
- Different methods of categorizing data
- Introduction to R

Where does statistical inference fit into a scientific research program?

- Statistical inference is about providing a quantitative & mathematical formalism to the ideas & approaches you take to science
- Without an understanding of the approach we take to science, how can the hypotheses we generate and tests we perform be statistically useful?

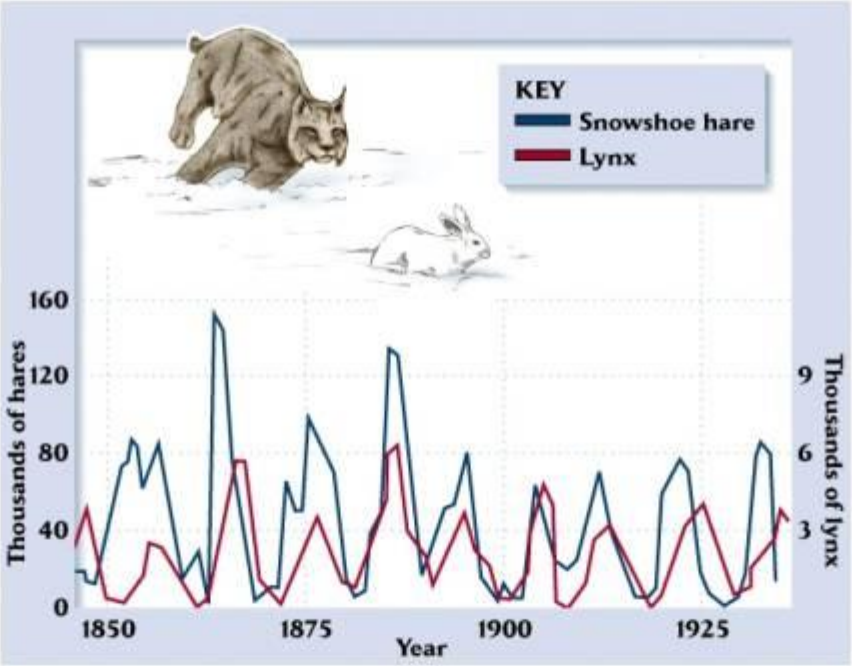
Scientific approaches

- Experimentation vs. observation
- Correlation is not causation
  - Associations can be completely unrelated
  - Due to some unmeasured 3rd variable
- Experiments as mechanism
  - Not always possible in ecology



Scientific approaches

- When experimentation is not possible, the study of natural patterns can get at mechanism



What is statistical inference?

- Attempt to evaluate a set of probabilistic hypotheses about the behavior of some data-generating mechanism
- 3 approaches
    - Bayesian
    - Likelihoodist
    - Frequentist

What is statistical inference?

- All 3 approaches use likelihood functions, where the likelihood function for a datum *E* on a set of hypotheses *H* is
  - $\Pr(E|H)$: the probability of E given H
- **Likelihoodists** use them to characterize data as evidence
  - $L = \Pr(E|H_1)/\Pr(E|H_2) > 1$
- **Bayesians** use them to update probability distributions
- **Frequentists** use them to design experiments that will generally perform well in repeated applications

Motivating example

- In 1980s, infants showing a particular pattern of respiratory problems had a ~20% survival rate until researchers developed a new therapy ECMO
    - ECMO led to 72% survival of the first 100 patients tested
- Despite early success, conventional standards (i.e. frequentist approaches) required the team to perform a randomized clinical trial using ECMO & conventional treatments side-by-side

Motivating example

- Concerned about continuing to use a seemingly inferior treatment, the team used a 'randomized play the winner' trial design
    - Result: all 11 infants given ECMO survived; 1 given conventional therapy died
- Approach still didn't meet the standard, so 2nd trail designed

Motivating example

- Still concerned about the ethics, the team designed a trail with 2 phases: it would be randomized until 4 patients died on either treatment
    - Result: 28/29 given ECMO survived; 6/10 given conventional therapy died
- This too failed to meet efficacy standards

Motivating example

- 3^{rd} randomized trail conducted by separate team
  - Had to be terminated when early results clearly indicated ECMO superiority
  - Resulted in 54 more infant deaths under conventional therapy
- Illustrates the costs of failing to reach a consensus on an approach to statistical inference
  - Rigid application of frequentist approach in this case

Bayesian vs. frequentist inference

- A simple analogy:
- You've misplaced your phone somewhere in your house. You use a friend's phone to call it & it starts ringing somewhere—where should you search?

Frequentist

- I have a mental model that helps me identify the area from which the sound is coming. So upon hearing the ring, I infer the area of my house I should search.

Bayesian

- Apart from the mental model, I also know the locations where I've misplaced the phone in the past. So, I combine inferences using the ring & my prior info to identify an area to search.

What is a p-value?

- The p-value is used throughout frequentist statistics—from t-tests to regression analyses
- You use p-values to determine statistical significance in a hypothesis test
- But it’s a slippery concept—how do you correctly interpret p-values?

What is a p-value?

1. $P(D|H_0)$: probability of observing the data given that the null hypothesis is true
2. $P(D|H_1)$: probability of observing the data given that the alternative hypothesis is true
3. $P(H_0|D)$: probability of the null hypothesis being true given the data
4. $P(H_1|D)$: probability of the alternative hypothesis being true given the data

What is a p-value?

- Need to understand null hypotheses to understand p-values
- In every experiment, there is an effect or difference between groups that are being tested
- There is always a possibility that there is no effect, or no difference between groups: null hypothesis

What is a p-value?

- Imagine an experiment for a treatment that you know is ineffective (e.g., use of tap vs. distilled water to grow a certain species of plant)
- We know the null hypothesis is true (no difference between plant growth of two groups)
- But it's possible that you will actually observe an effect just by random sampling error
- Null hypothesis should be interpreted as: the observed difference in the sample—which does not necessarily reflect a true difference between populations

What is a p-value?

- A low p-value suggests that your sample provides enough evidence that you can reject the null hypothesis for the entire population
- P-values address only 1 question: how likely are your data, assuming a true null hypothesis?
  - P-values do not measure support for the alternative hypothesis
  - P-values are not the error rate

What is a p-value?

- While a low p-value indicates that your data are unlikely assuming a true null, it cannot evaluate which of these 2 competing cases is more likely:
  - Null is true but your sample was unusual
  - Null is false

What is a p-value?

- Going back to the water/plant example, assume your experiment obtained a p-value of 0.04
- Correct interpretation: Assuming water treatment had no effect on plant growth, you'd obtain the observed difference or more in 4% of studies due to random sampling error
- Incorrect: If you reject the null hypothesis, there's a 4% chance you're making a mistake

Statistics & the scientific method

- How do we incorporate statistics into scientific reasoning?
- Fundamentally, statistics are statements of probability
- A p-value is a statement about the probability P(Data | Ho)

Experimental design

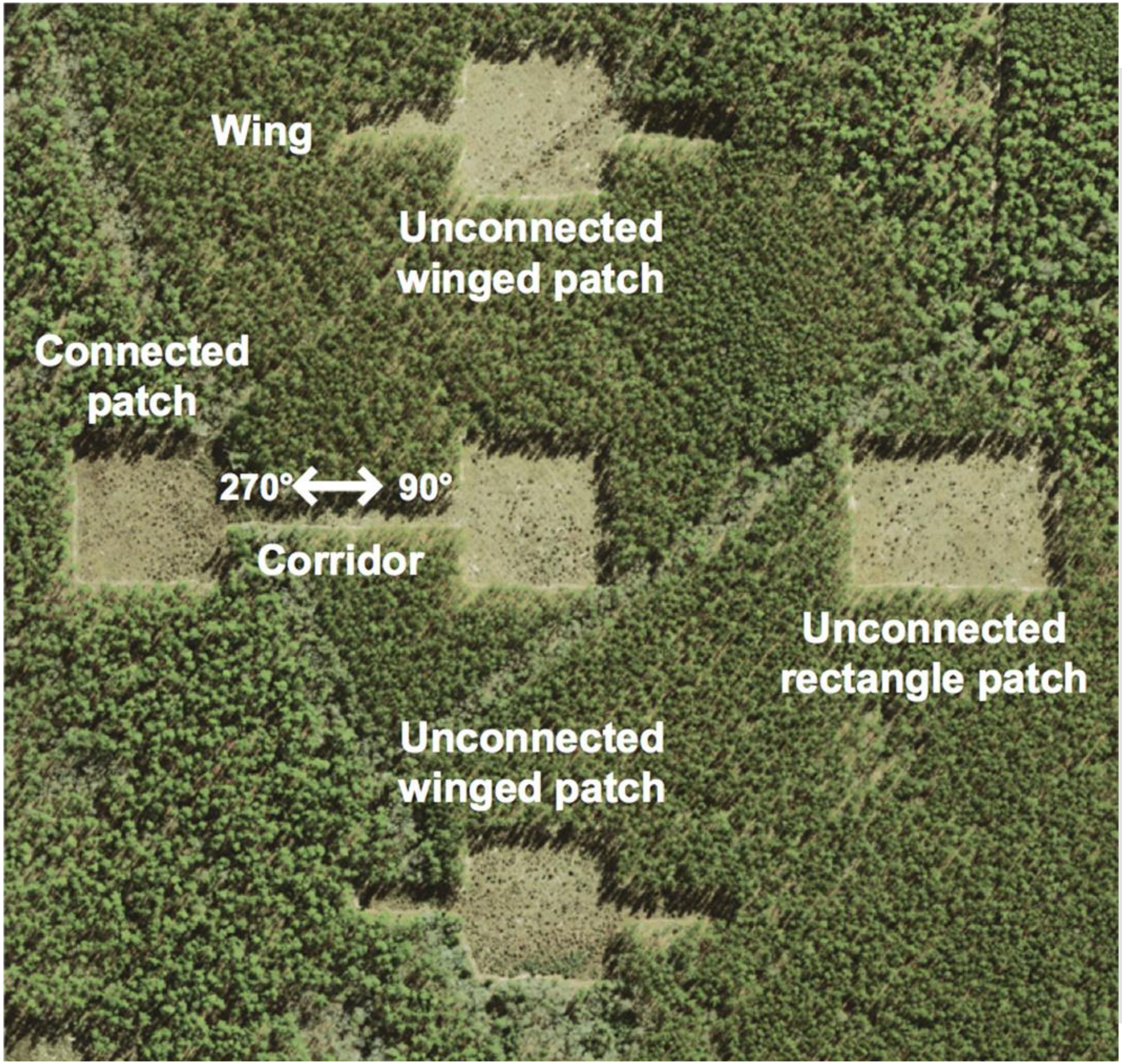
- Deliberately imposing a treatment on a group of objects/subjects in the interest of observing a response
- Need to design the experiment such that the right type of data is generated to answer the questions of interest
- Attempt to identify known sources of variability

Experimental design

- Randomization
  - Most reliable method to reduce bias by creating homogeneous treatment groups

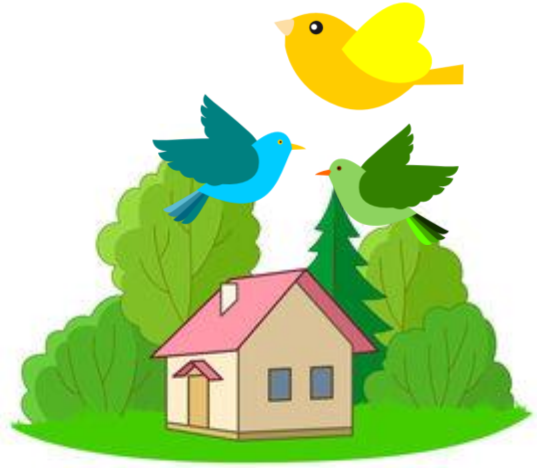
1. Completely randomized design
2. Randomized block design
   - Subjects first divided into homogeneous blocks before being randomly assigned to group

Experimental design



Experimental design

- Replication
  - Repetition of an experiment on a large group of subjects
  - Reduces variability
  - Increases significance & confidence in results

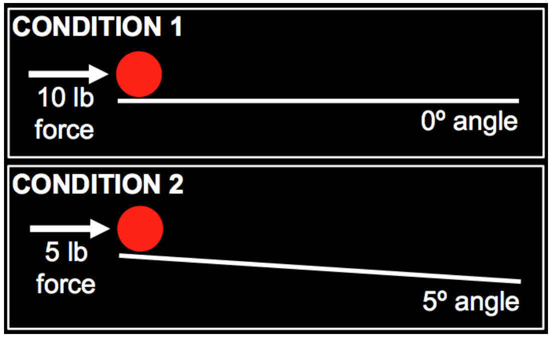


Experimental design

- Confounding factors
  - Some sources of variation are considered ‘nuisance’ factors that contribute to variability
  - Examples?
    - Age, sex, observer experience
  - Solution: sort subjects into blocks before randomization

Experimental design

- Multifactorial design
  - Testing one factor per experiment is insufficient and inefficient
  - Multiple factors allow for exploration of interactions
  - Some factors may be blocking factors or confounding variables
    - Extraneous variable that correlates with both the dependent and independent variable



Variables

- Outcome variables
  - Or dependent variables
  - The response a treatment is meant to influence
- Explanatory variables
  - Or independent variables
  - The predictors that are either manipulated or thought to affect the outcome
  - Can have interactions between predictor variables

Variables

- Quantitative: continuous vs. discrete
  - Examples?
- Categorical: nominal vs. ordinal
  - Examples?




Intro to R

Overview

1. Why R?
2. Getting started: steep learning curve
3. The basics
4. R interface
5. How to download
6. Intro to R & R Studio programming

Why R?

- It’s free!
- It runs on a variety of platforms, including Windows and MacOS
- Provides an unparalleled platform for programming new statistical methods in a straightforward way
- It has state of the art graphics capabilities

R has a steep learning curve

- Don’t feel intimidated!
- Much of the advanced functionality of R comes from hundreds of user-contributed packages
- Hunting for what you want can be time consuming
- Can be difficult to get a clear overview of what procedures are available

R has a steep learning curve

- Rather than setting up a complete analysis all at once, the process is much more interactive
- You run a command, process the results through another command, and repeat
- Because of this, R is very flexible and powerful for statistical analysis

Advantages & disadvantages

Advantages

- Fast & free
- State of the art
- Active user community
- Forces you to *think* about your analysis
- Excellent for simulation, programming, computer-intensive analyses

Advantages & disadvantages

Disadvantages

- Not user-friendly at the start
- No commercial support; figuring out correct methods on your own can be frustrating
- Working with large datasets is limited by RAM

Tutorials

- All of the following are in PDF format:
  - P. Kuhnert & B. Venables, An Introduction to R: Software for Statistical Modeling & Computing
  - J.H. Maindonald, Using R for Data Analysis and Graphics
  - W.J. Owen, The R Guide
  - W.N. Venebles & D. M. Smith, An Introduction to R
- Use rseek.org instead of google for R-related help/searching

The basics

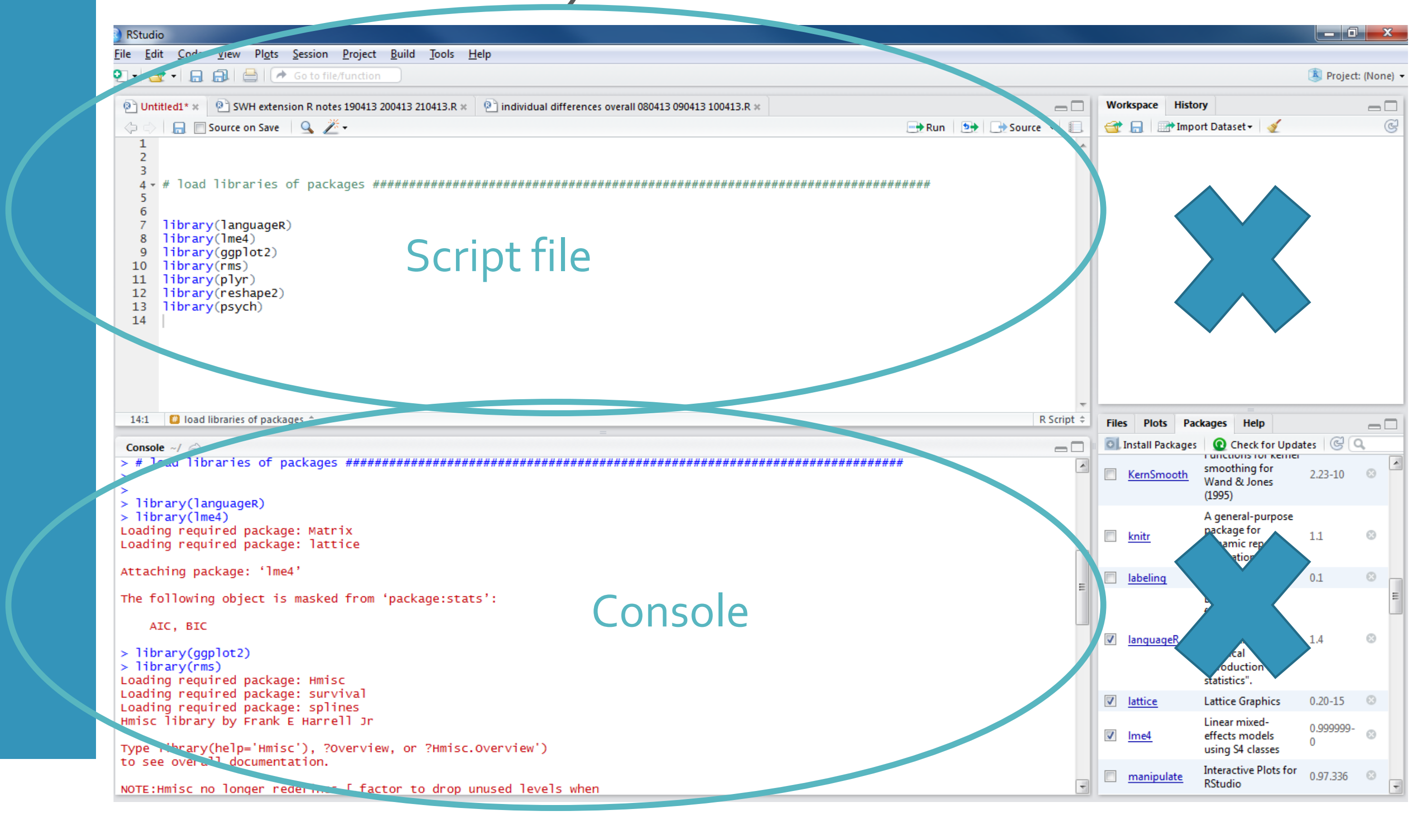
- There is a wide variety of data types, including vectors, dataframes, matrices & lists
- Most functionality is provided through built-in and user-created functions
- All data objects are kept in memory during an active session
- Basic functions available by default
- Other functions are contained in separate ‘packages’ to be attached to the current session as needed

The basics

- A key skill to using **R** effectively is learning how to use the built-in help system
  - Just type help.search or ?? followed by a command
- A fundamental design feature of **R** is that the output from most functions can be used as input to other functions

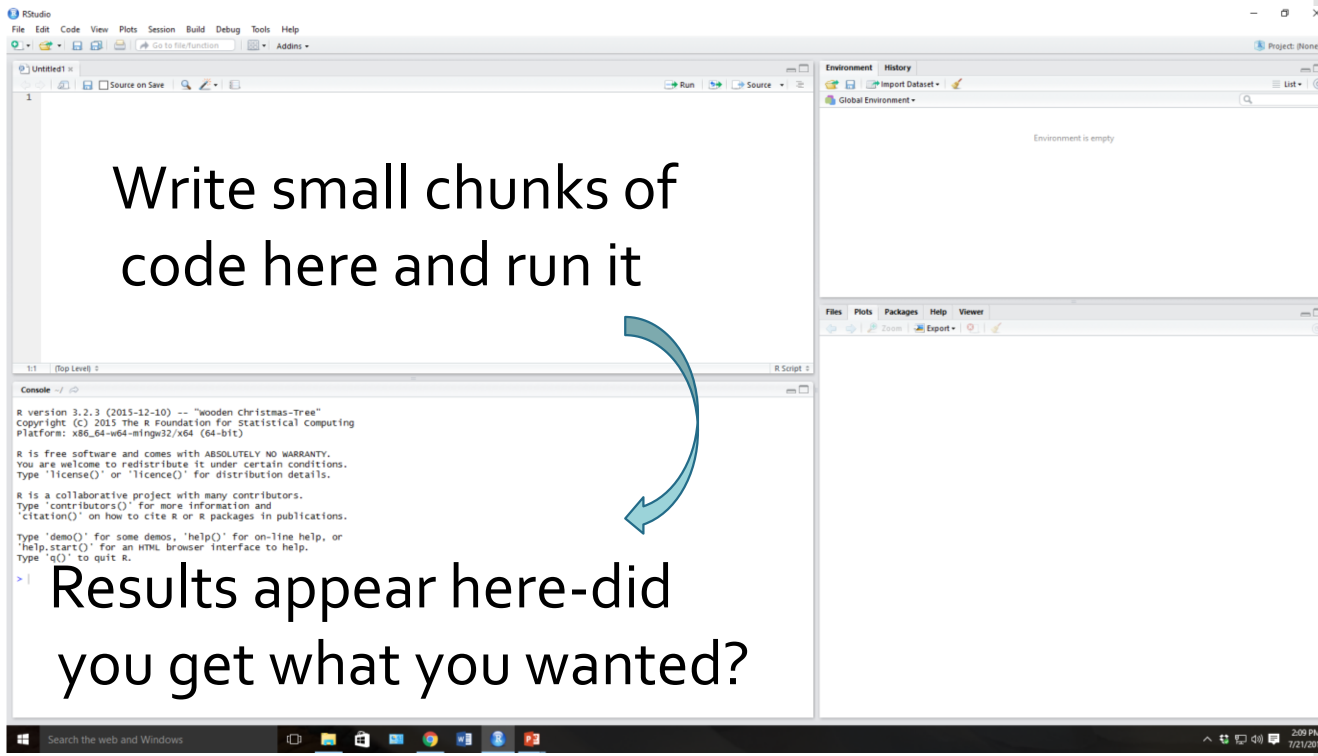
Interface: RStudio

- 2 important windows
  - Script file(s) that will be saved
  - Console that displays output and temporary input (usually unsaved)



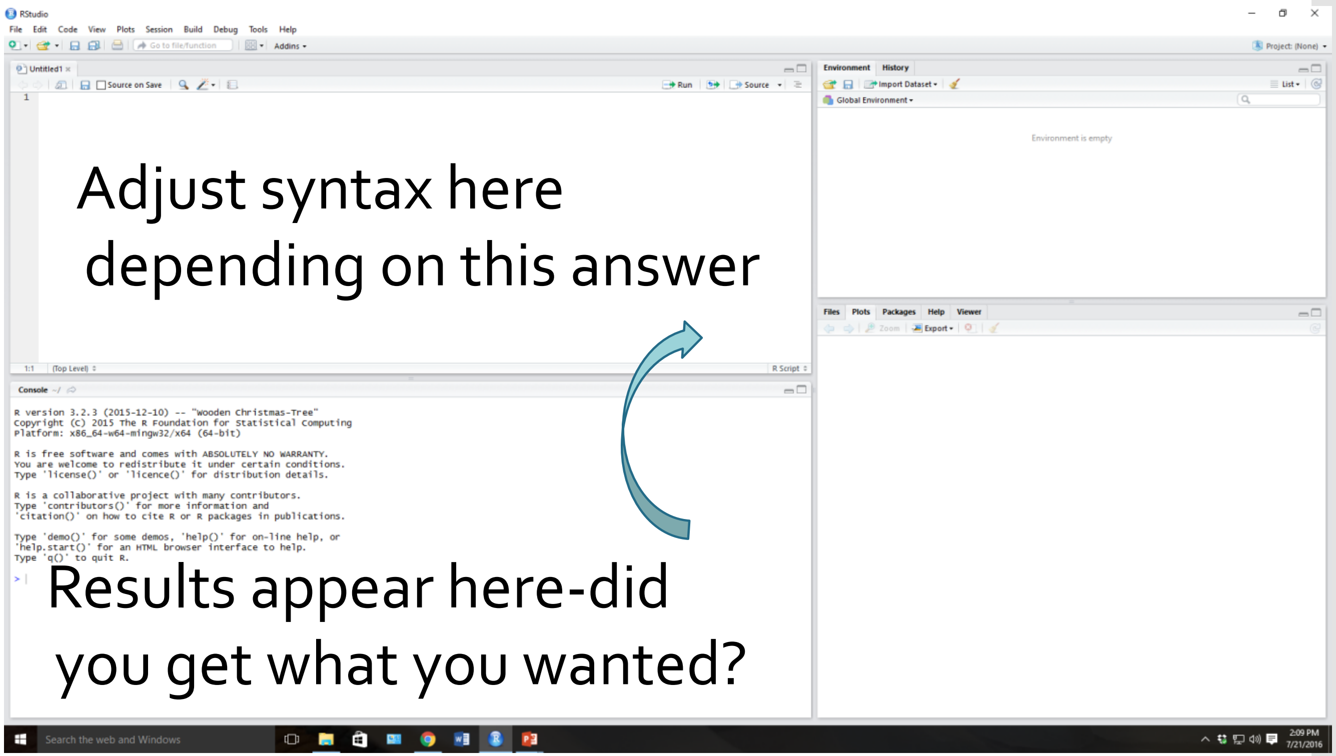
Interface: RStudio

- R sessions are interactive



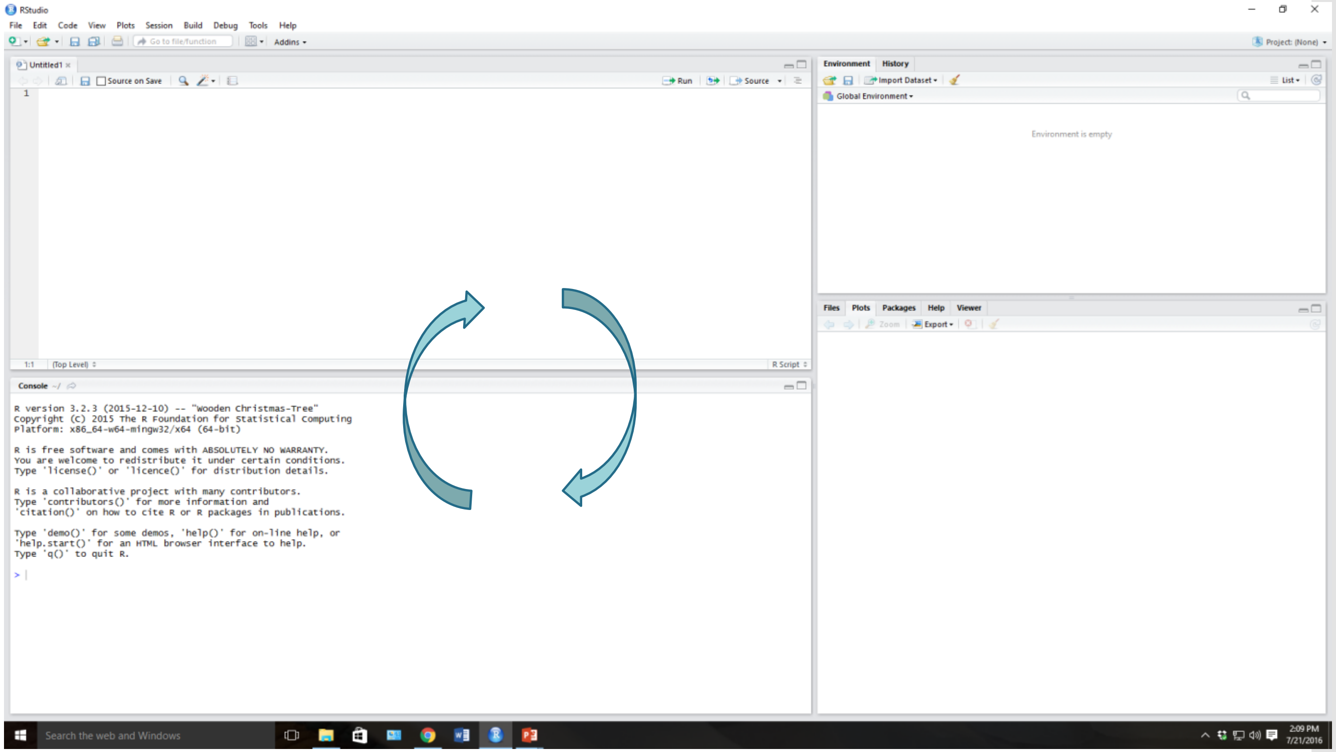
Interface: RStudio

- R sessions are interactive



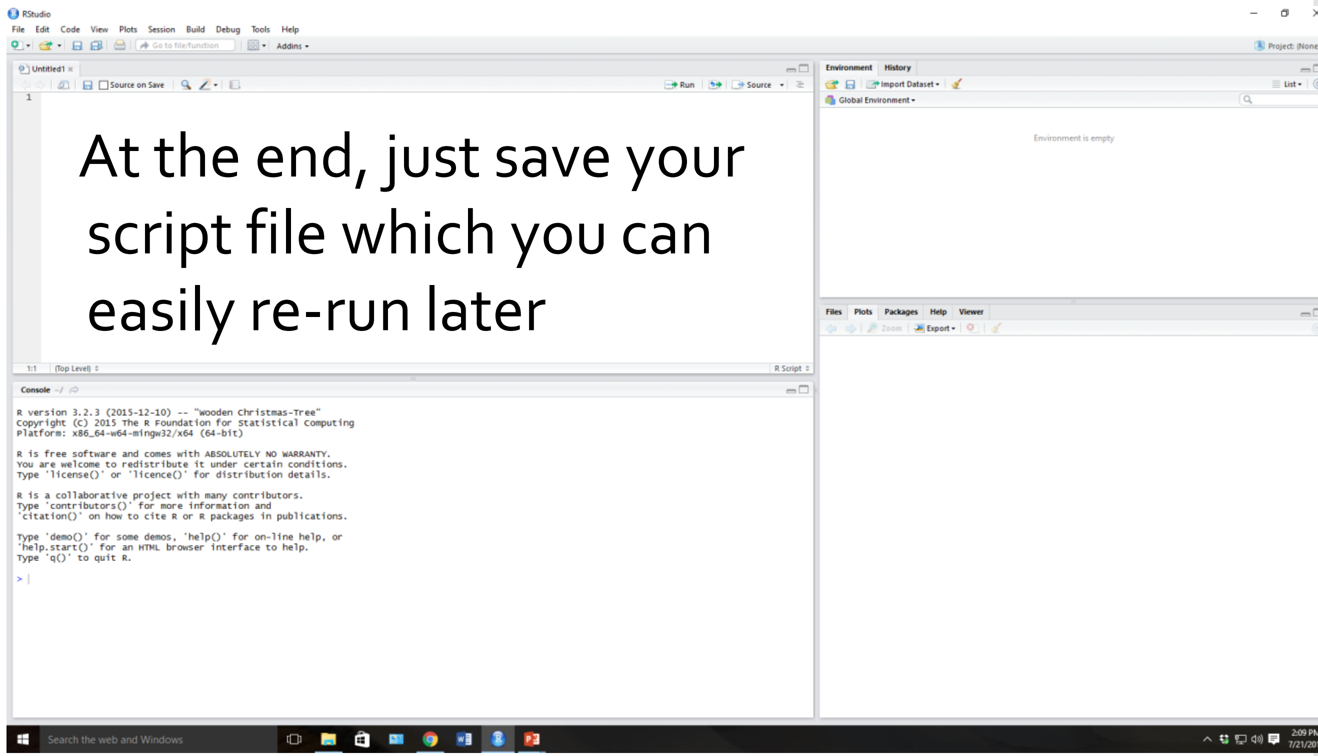
Interface: RStudio

- R sessions are interactive



Interface: RStudio

- R sessions are interactive



Interface: RStudio

- Results of calculations can be stored in objects using the assignment operators:
  - An arrow (<-) formed by a smaller than character and a hyphen without a space!
  - The equal character (=)
- Almost all things in R (functions, datasets, results) are objects

Interface: RStudio

- Script can be thought of as a way to make objects
- Your goal is usually to write a script that, by its end, has created the objects (e.g. statistical results) and graphics you need

Interface: RStudio

- These objects can then be used in other calculations
- To print the object just enter the name of the object
- There are some restrictions when giving an object a name:
  - Object names cannot contain `strange' symbols like !, +, -, #.
  - A dot (.) and an underscore (_) are allowed
  - Object names can contain a number but cannot start with a number
  - R is case sensitive, X and x are two different objects

R workspace

- Objects that you create during an R session are held in memory
- The collection of objects that you currently have is called the workspace
- This workspace is not saved on hard drive unless you tell R to do so
- This means that your objects are lost when (1) you close R and do not save the workspace or (2) your system crashes on you during a session

R workspace

- When you close the R console window, the system will ask if you want to save the workspace image
- If you select to save the workspace image, then all the objects in your current R session are saved in a file .RData
- This is a binary file located in the working directory of R, which is by default the installation directory of R

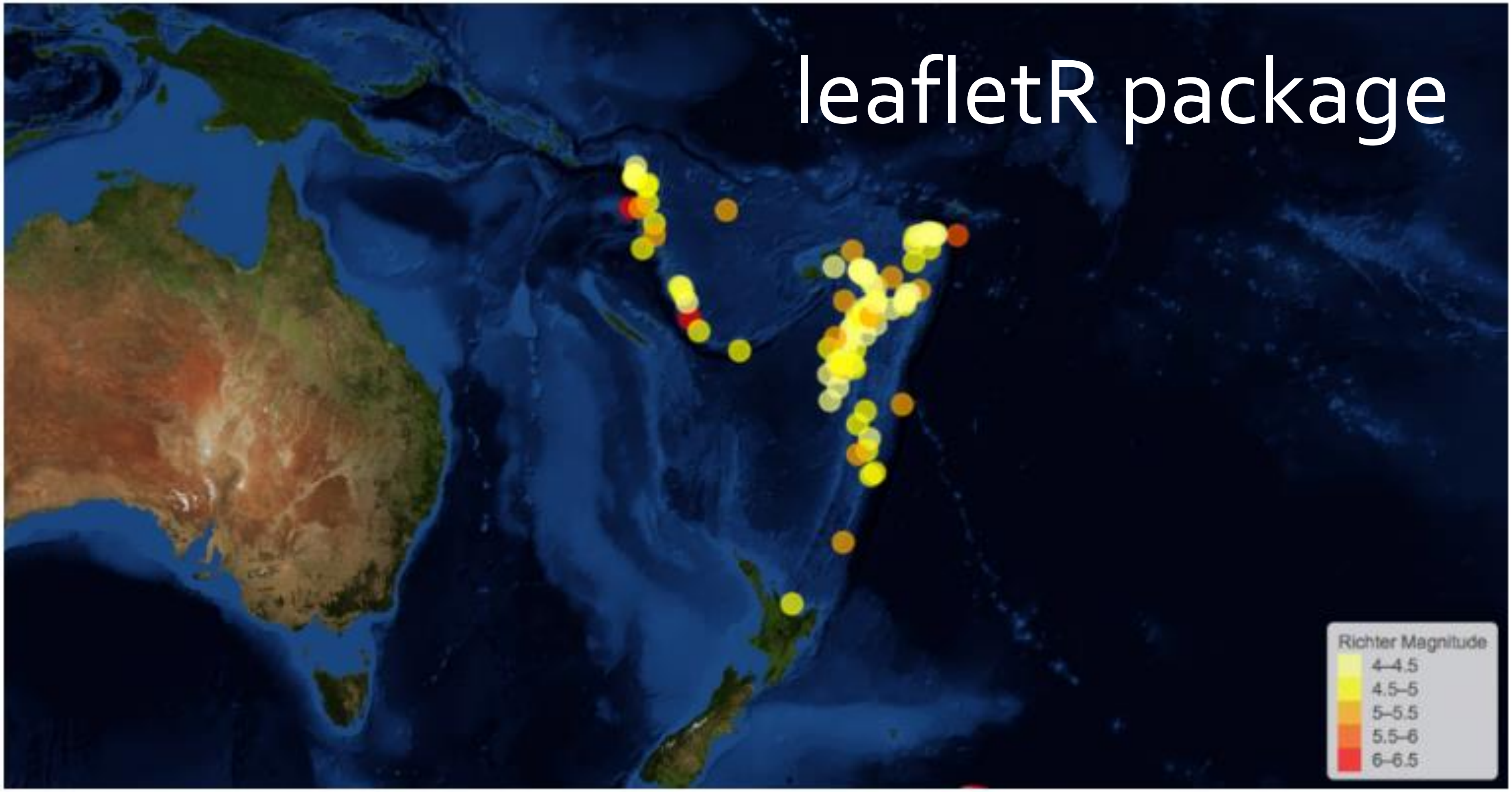
R workspace

- If you have saved a workspace image and you start R the next time, it will restore the workspace
- So all your previously saved objects are available again

R packages

- There is an active R user community and many R packages have been written and made available on CRAN for other users
- Just a few examples: there are packages for
  - Portfolio optimization, drawing maps, exporting objects to html, time series analysis, spatial statistics
  - And on and on…

leafletR package



R packages

- Some basic packages are auto downloaded when you downloaded R
- In the future, you'll find you need certain packages that aren't installed and we'll go through how to download and use them when the time comes

Built-in functions

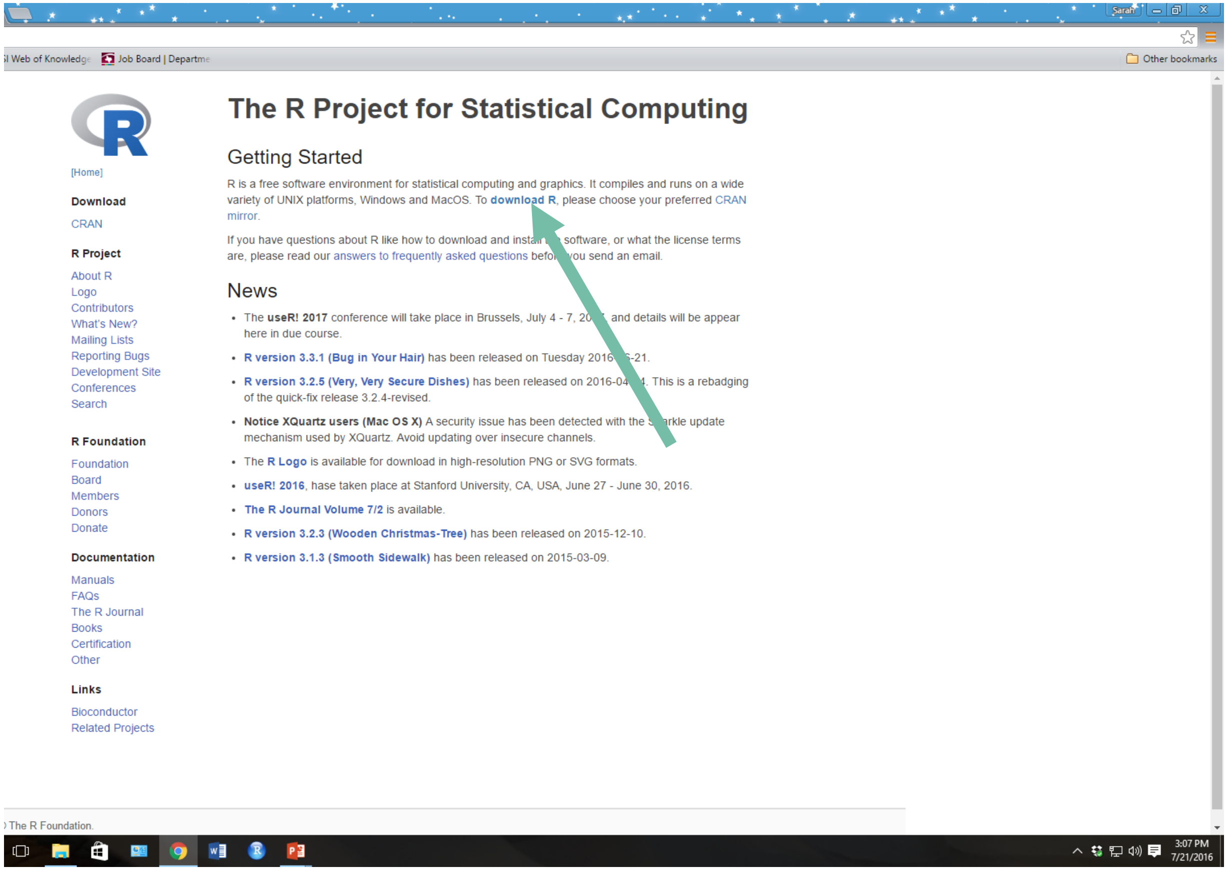
- R has many built in functions that compute different statistical procedures
- Functions in R are followed by ( )
- Inside the parenthesis we write the object (vector, matrix, array, dataframe) to which we want to apply the function

Vectors, arrays, matrices

- Vectors are variables with one or more values of the same type
- Arrays are numeric objects with dimension attributes
- A matrix is a two dimensional array

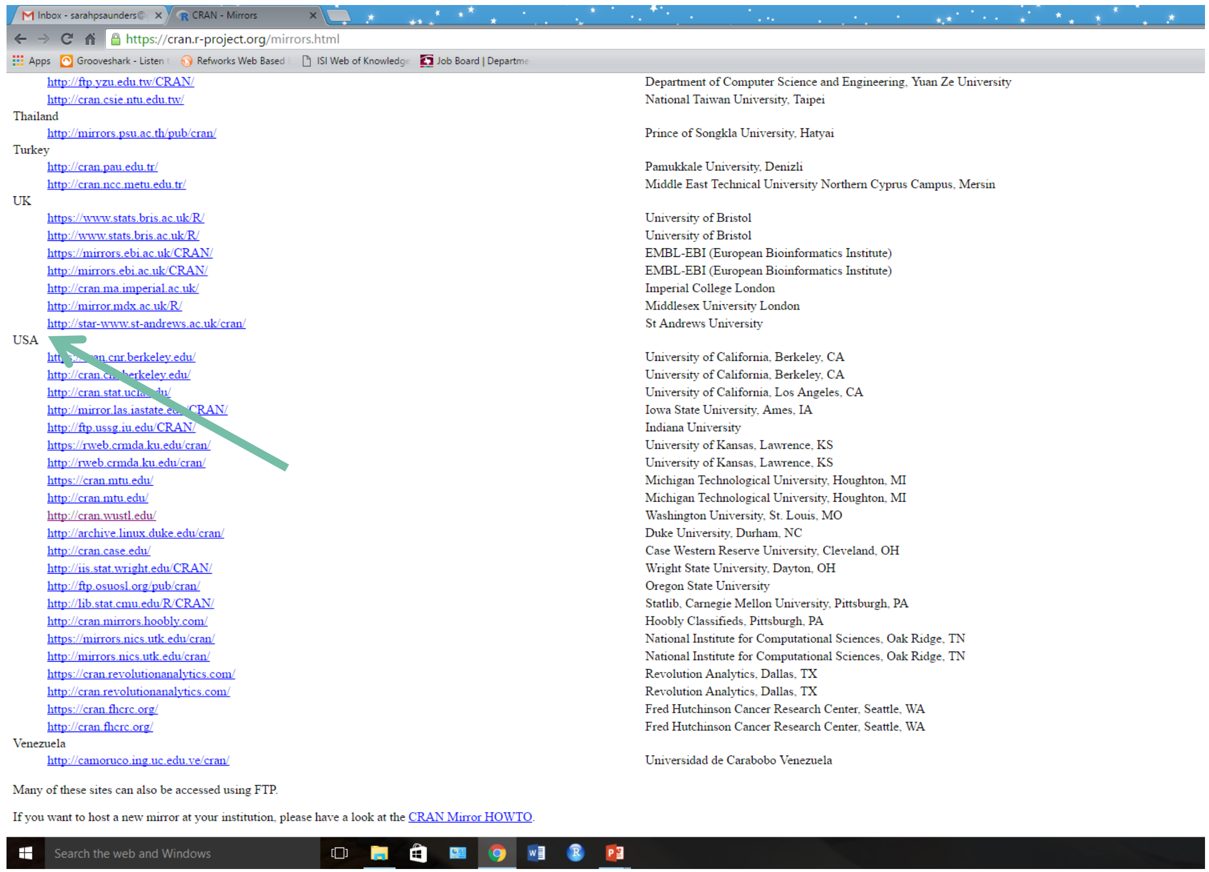
Downloading R

- To install R on your Mac or PC, go to http://www.r-project.org/



Downloading R

- Select CRAN mirror

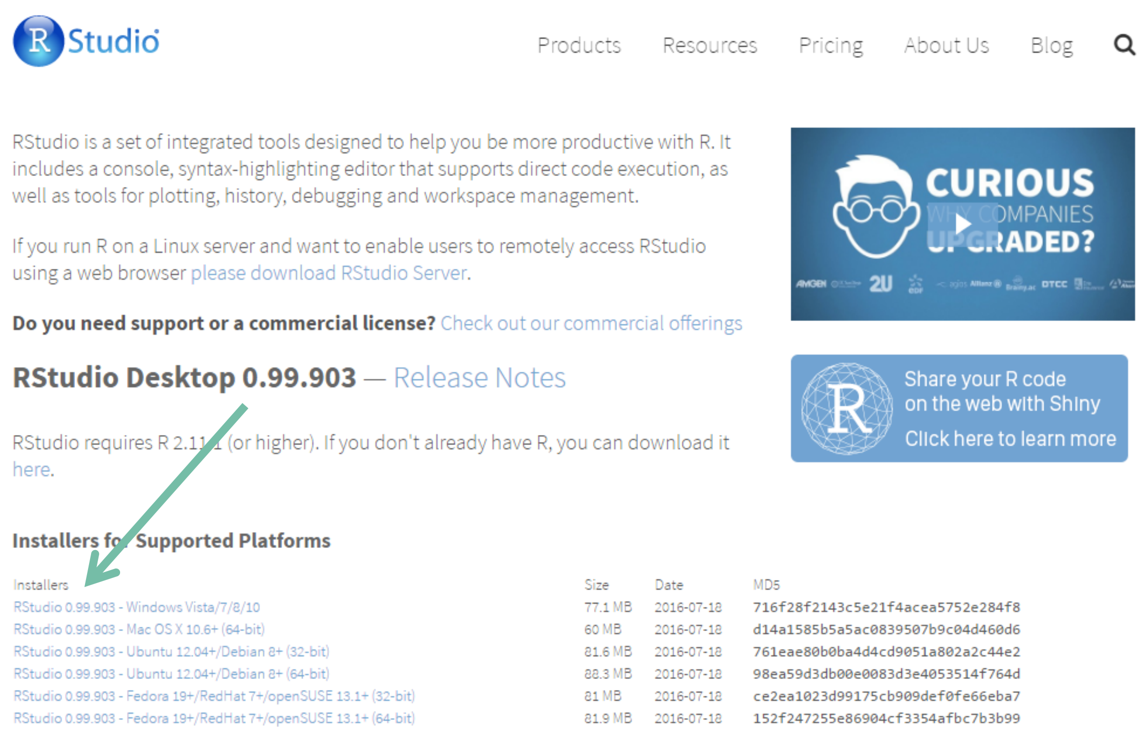


Downloading R

- Select your operating system

Downloading RStudio

- Once R is downloaded, install Rstudio (a nicer interface to use with R)
- https://www.rstudio.com/products/rstudio/download/



Studio

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RStudio is a set of integrated tools designed to help you be more productive with R. It includes a console, syntax-highlighting editor that supports direct code execution, as well as tools for plotting, history, debugging and workspace management.

If you run R on a Linux server and want to enable users to remotely access RStudio using a web browser please download RStudio Server.

Do you need support or a commercial license? Check out our commercial offerings

CURIOUS WHY COMPANIES UPGRADED?

Share your R code on the web with Shiny

Click here to learn more

RStudio Desktop 0.99.903 — Release Notes

RStudio requires R 2.11.1 (or higher). If you don't already have R, you can download it here.

Installers for Supported Platforms

Installers	Size	Date	MD5
RStudio 0.99.903 - Windows Vista/7/8/10	77.1 MB	2016-07-18	716f28f2143c5e21f4acea5752e284f8
RStudio 0.99.903 - Mac OS X 10.6+ (64-bit)	60 MB	2016-07-18	d14a1585b5a5ac0839507b9c04d460d6
RStudio 0.99.903 - Ubuntu 12.04+/Debian 8+ (32-bit)	81.6 MB	2016-07-18	761eae80b0ba4d4cd9051a802a2c44e2
RStudio 0.99.903 - Ubuntu 12.04+/Debian 8+ (64-bit)	88.3 MB	2016-07-18	98ea59d3db00e0083d3e4053514f764d
RStudio 0.99.903 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (32-bit)	81 MB	2016-07-18	ce2ea1023d99175cb909def0fe66eba7
RStudio 0.99.903 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (64-bit)	81.9 MB	2016-07-18	152f247255e86904cf3354afbc7b3b99

Intro to R programming

- Let’s go to RStudio