



Northeastern University

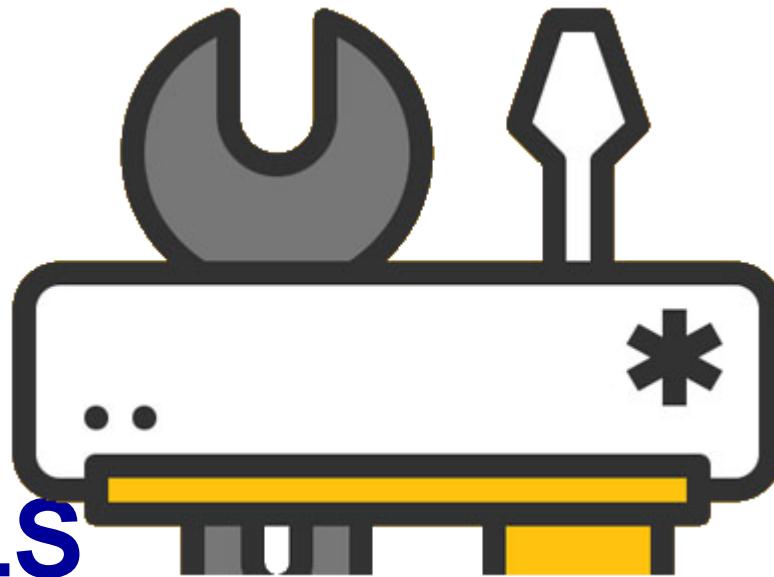
INFO 6105 Data Sci Eng Methods & Tools Lecture 1 *8 September 2022*

WELCOME

R
PYTHON



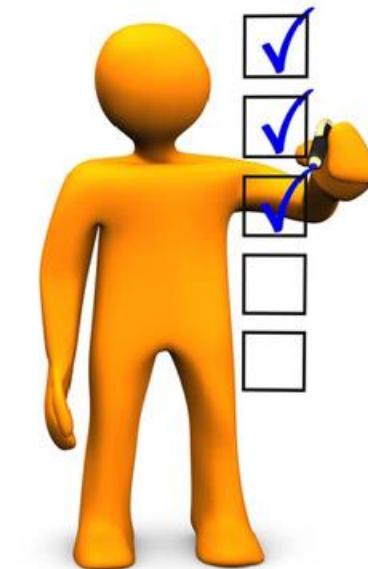
Part 1
INSTALLS





Don't do this (now or ever): Standalone R

- Install the R environment:
 - <https://cran.rstudio.com/>





Do this, but not now (do @home): RStudio IDE

- **Install *RStudio* (IDE for using R)**
 - Install for your appropriate system from the list at:
<http://www.rstudio.com/products/rstudio/download/>





Part 2

HISTORY OF STATISTICS & PROBABILITY: FROM GREECE TO FRANCE TO RUSSIA

Classical Greece



© 2005 Wadsworth - Thomson



Birth of Numbers (Pythagorean school, 6th cent. BC)

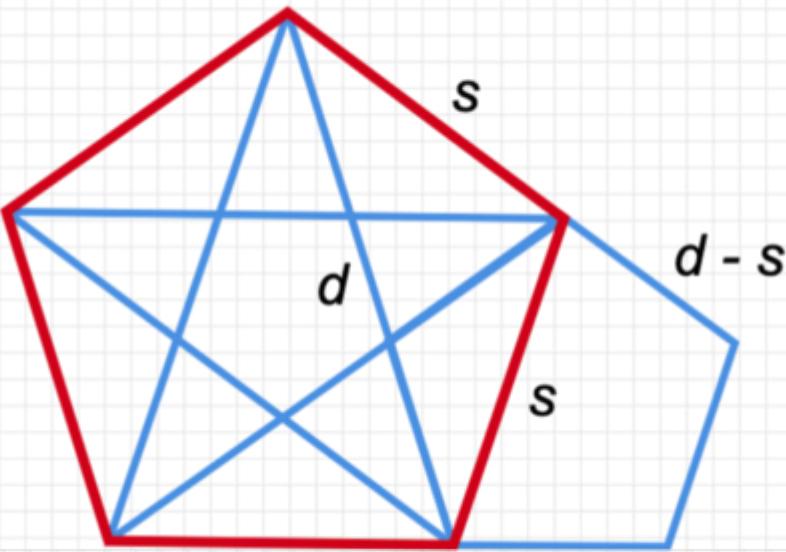
- A monochord is an ancient musical instrument. It's somewhat similar to a guitar, but it only has one string. The Pythagoreans used it for a variety of scientific experiments
- Their monochord had a moveable bridge which allowed them to set up and play all kinds of different musical intervals. At some point, the Pythagoreans realized that intervals with simpler ratios sounded significantly nicer than those with more complicated ones. For example, an interval of $1/2$ was way more pleasing to the ear then, let's say, $67/193$



- This let the Pythagoreans to believe that *absolutely everything can be quantified using a ratio of integers*. In other words, they believed that every point on the number line corresponds to a **rational number**
- The sign of the Pythagoreans was a star with five jags. Connecting all adjacent jags creates a regular pentagon. One day while playing around with such pentagons, Hippasus constructed a smaller pentagon from a bigger one...



The birth of the first irrational number



$$\frac{d}{s} = \frac{s}{d-s} \quad d, s \in \mathbb{N}$$

d: diagonal length of the larger pentagon
s: side length of the larger pentagon

- Both sides express the same ratio of diagonal length to side length. The left side does it for the larger red pentagon, the right side for the smaller blue one



Infinite descent

- Assume d and s to be natural numbers instead of integers. Makes sense because we're talking about lengths
- Assume that the ratio of diagonal length to side length is a *rational number*
- Hippasus then argued that smaller and smaller pentagons can be built...

$$\frac{d}{s} = \frac{s}{d-s} = \frac{d-s}{s-(d-s)} \quad \dots$$

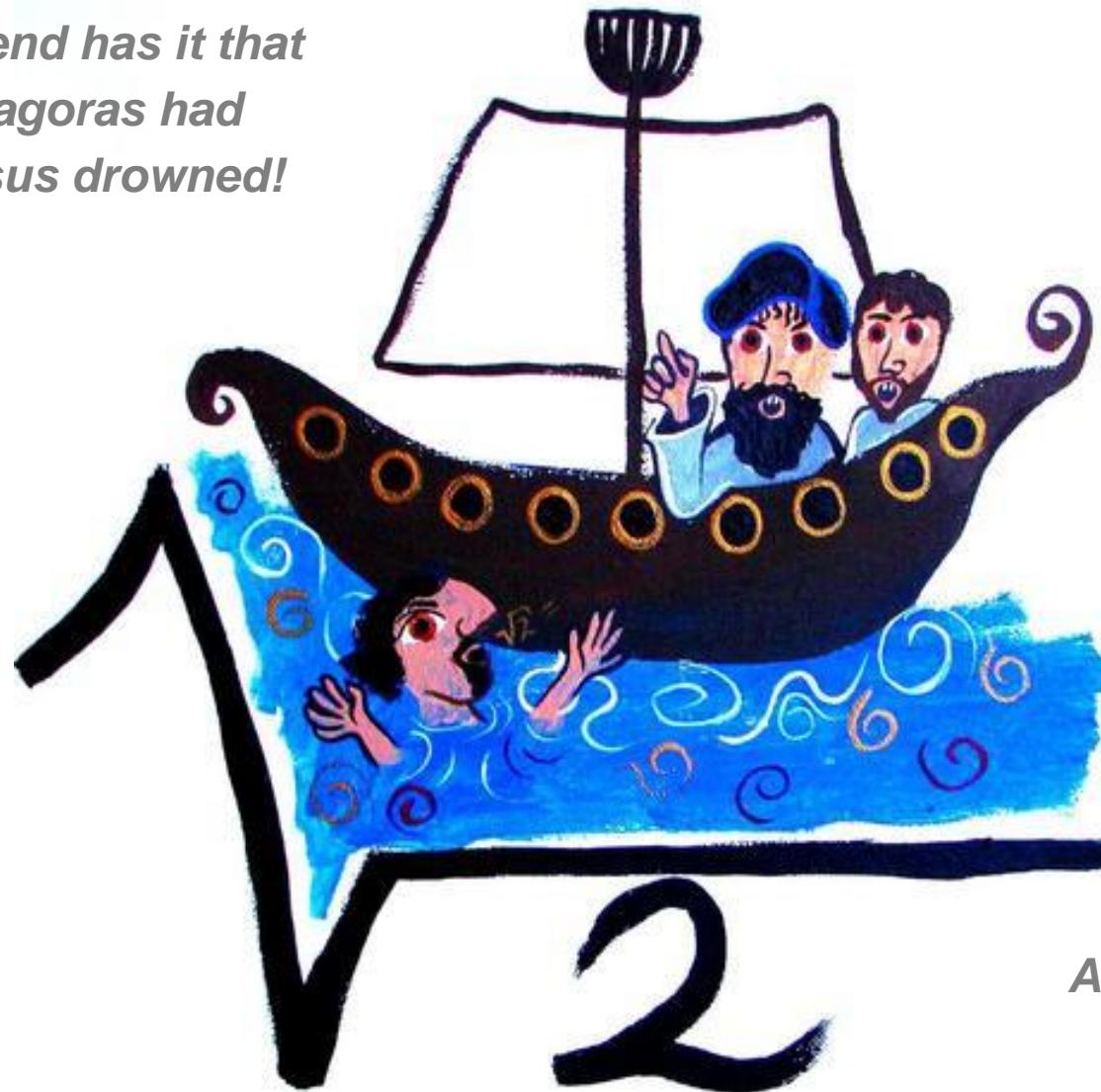
$$d < 2s \Rightarrow d - s < s \quad (\textit{triangle inequality})$$

- All pentagons' ratios of diagonal length to side length are the same, and all of these ratios can be expressed using only d and s . Because of triangle inequality, every newly constructed pentagon's ratio would have a smaller denominator than the previous one
- This will become ***impossible*** at some point because the set of natural numbers has a smallest element which happens to be zero. Therefore, the initial assumption must be wrong and the ratio of diagonal length to side length can't be a rational number





*So, legend has it that
Pythagoras had
Hippasus drowned!*



*And then $\sqrt{2}$
showed up...*



Sqrt(2)

Suppose $\sqrt{2} = \frac{a}{b}$, a simplified fraction.

$$2 = \frac{a^2}{b^2}$$

$$2b^2 = a^2.$$

Thus, a^2 is even. This only happens if a is even. So $a = 2k$.

$$2b^2 = (2k)^2 = 4k^2$$

$$b^2 = 2k^2.$$

Thus, b^2 is even. As above, $b = 2m$.

$$\text{But } \sqrt{2} = \frac{a}{b} = \frac{2k}{2m} = \frac{k}{m}.$$

This means any fraction equalling $\sqrt{2}$ can never be fully simplified, which is impossible.

$\sqrt{2}$ is not rational.



More numbers: Peloponnesian War

- In the 5th century BC. The historian *Thucydides* in his History of the Peloponnesian War describes how the Athenians calculated the height of the wall of Platea by counting the number of bricks in an unplastered section of the wall sufficiently near them to be able to count them
- The count was repeated several times by a number of soldiers. The most frequent value so determined was taken to be the most likely value of the number of bricks
- Multiplying this value by the height of the bricks used in the wall allowed the Athenians to determine the height of the ladders necessary to scale the walls
- *The Mean*





Birth of Probabilities: A Gambler's dilemma

- A gambler's dispute in 1654 led to the creation of a mathematical theory of probability by two famous French mathematicians, [Blaise Pascal](https://en.wikipedia.org/wiki/Blaise_Pascal) (https://en.wikipedia.org/wiki/Blaise_Pascal), and [Pierre de Fermat](https://en.wikipedia.org/wiki/Pierre_de_Fermat) (https://en.wikipedia.org/wiki/Pierre_de_Fermat)
- A game consisted in throwing a pair of dice 24 times:
Decide whether or not to bet even money on the occurrence of at least one "double six" during the 24 throws
- A seemingly well-established gambling rule led [Antoine Gombaud, Chevalier de Méré](https://en.wikipedia.org/wiki/Antoine_Gombaud,_Chevalier_de_Méré), a French nobleman with an interest in gaming (https://en.wikipedia.org/wiki/Antoine_Gombaud,_Chevalier_de_Méré), to believe that betting on a double six in 24 throws would be profitable, but his own calculations indicated just the opposite
- Suppose two players agree to play a certain number of games, say a best-of-seven series, and are interrupted before they can finish. How should the stake be divided among them if, say, one has won three games and the other has won one?
- [Blaise Pascal](#) and [Pierre de Fermat](#), took up the challenge. In a series of letters they laid the foundation for the ***modern theory of probability***





Textbooks

- The Dutch scientist [Christian Huygens](#), a teacher of [Leibniz](#), learned of this correspondence and shortly thereafter (in 1657) published the first book on probability; entitled *De Ratiociniis in Ludo Aleae*, it was a treatise on problems associated with gambling
- In 1812 [Pierre de Laplace](#) (1749-1827) introduced new ideas and mathematical techniques in his book, *Théorie Analytique des Probabilités*. Before Laplace, probability theory was solely concerned with developing a mathematical analysis of games of chance. Laplace applied probabilistic ideas to many scientific and practical problems.
- One of the difficulties in developing a mathematical theory of probability has been to arrive at a definition of probability that is precise enough for use in mathematics. The matter was finally resolved in the 20th century by treating probability theory on an axiomatic basis. In 1933 a monograph by a Russian mathematician [A. Kolmogorov](#) outlined an axiomatic approach that forms the basis for the modern theory. Kolmogorov's monograph is available in English translation as *Foundations of Probability Theory*



The game

- Now suppose the game is interrupted before either player has won. How does one then divide the pot fairly?
- Say, each player puts in \$6, so the total pot is \$12. Suppose they have to stop early and at that point A has won two tosses and B has won one. Should each get \$6, or should A get more since A was ahead when they stopped? What is ***fair***?
- Fermat's method was based on analyzing the remaining portion of the game that would have been played and to lay out ***all possible paths*** to the needed number of wins and count how many went to each player.





Simplify..

- Let's simplify with a simple coin flipping game
- Heads: 1 point to Fermat, Tails: 1 point to Pascal
- First to 10 points wins 100 Francs
- At 8-7 for Fermat, they stop the game
- How to *fairly* split the prize?





Solution

- At 8-7, the game will end in 4 coin flips for sure
- There are 16 possible 4-coin flips:

hhhh	tttt
hhht	ttth
hhth	ttht
hthh	thtt
thhh	httt
thhh	
tthh	
thth	
thht	
htth	
htht	
hhtt	

- Fermat wins in $11/16 = 69\%$ outcomes, so Fermat should get 69% of the prize money





Another approach..

- Imagine game 9-9: Then 50% for each winning
- Imagine game F9-8: F has 50% chance of winning this round.
If he loses, it's 9-9, and he has 50% chance of winning. So,
total probability for F winning is $50\% * 1 + 50\% * 50\% = 75\%$
 - Notice that I *multiply* probabilities when it involves successive rounds and I *add* probabilities when it involves all possible paths in a round
- Imagine game F9-7: By above, total probability for F winning is $50\% * 1 + 50\% * 75\% = 87.5\%$
- Imagine game F8-7: By above, contingency H is 50% → score 9-7, contingency T is 50% → score probability for F winning is $50\% * 87.5\% + 68.75\%$





That is *Data Science*

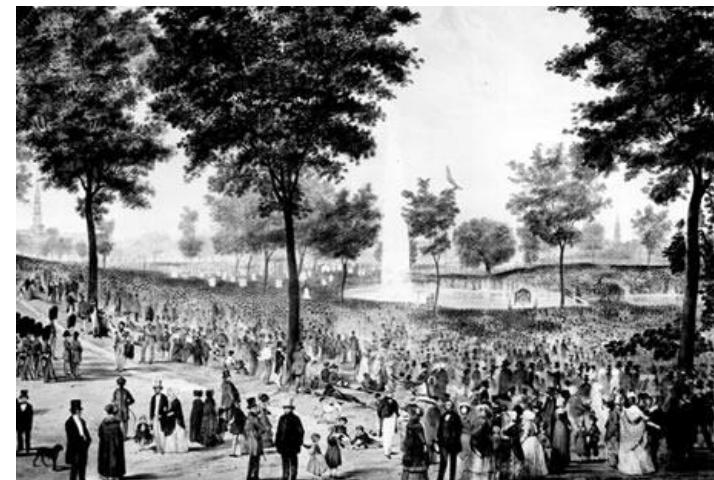
- ***Counting* to come up with a solution**
- In this case, we counted all possible *futures*





Statistics

- By the 18th century, the term **statistics** designated the systematic collection of demographic and economic data by states
 - The [German Statistik](#), first introduced by [Gottfried Achenwall](#) (1749), originally designated the analysis of [data](#) about the [state](#), signifying the "science of state"
- The birth of statistics is often dated to beginning 18th century when statistical and census methods provided a framework for modern demography that involved giving probabilities of survival to each age





Modern Statistics

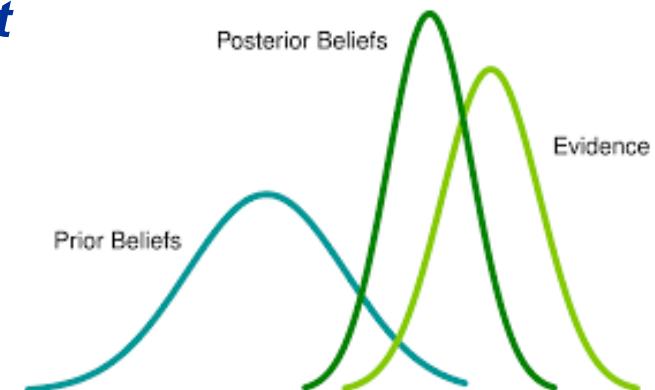
- The *modern* field of statistics only emerged in the early-20th century in three stages
- The first wave, at the turn of the century, was led by the work of *Karl Pearson*, who transformed statistics into a rigorous mathematical discipline used for analysis, not just in science, but in industry and politics as well
- The second wave reached its culmination in the insights of *Ronald Fisher*. This involved the development of better design of experiments models and techniques for use with *small data samples*
- The final wave, which mainly saw the refinement and expansion of earlier developments, emerged from work by the son of Karl Pearson, with modern concepts of the *confidence interval*, *statistical hypothesis testing*, and the *null hypothesis*
- *By the way, these great mathematicians were not very nice people...*





Bayesian Statistics

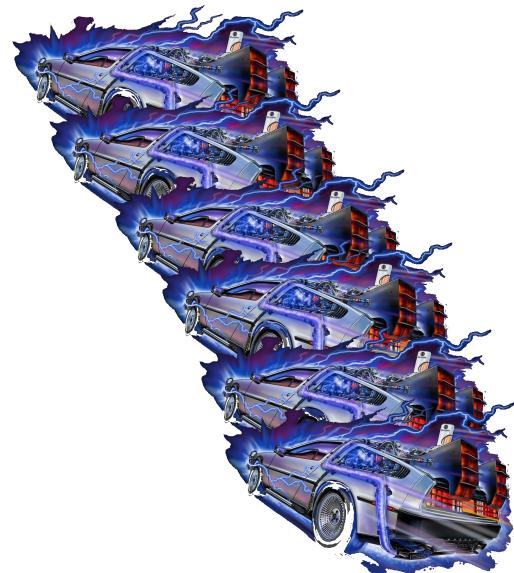
- The term Bayesian refers to **Thomas Bayes** (1702–1761), who proved that *probabilistic limits* could be placed on an unknown event
- Later on, **Pierre-Simon Laplace** (1749–1827) introduced what is now called *Bayes' theorem* and applied it to celestial mechanics, medical statistics, reliability, and law
- In the 1980s, there was a dramatic growth in research and applications of Bayesian methods, mostly attributed to the discovery of *Markov chain Monte Carlo (MCMC)* methods, which removed many of the computational problems
- Despite growth of Bayesian research, most undergraduate teaching is still based on *frequentist statistics*. Nonetheless, **Bayesian methods** are widely accepted and used in the field of *machine learning (ML)*





The essence of Bayes..

- ..is to not do one big trip to the future with the DeLorean car, but to do *many* mini-trips, *modifying your beliefs every time*





Today

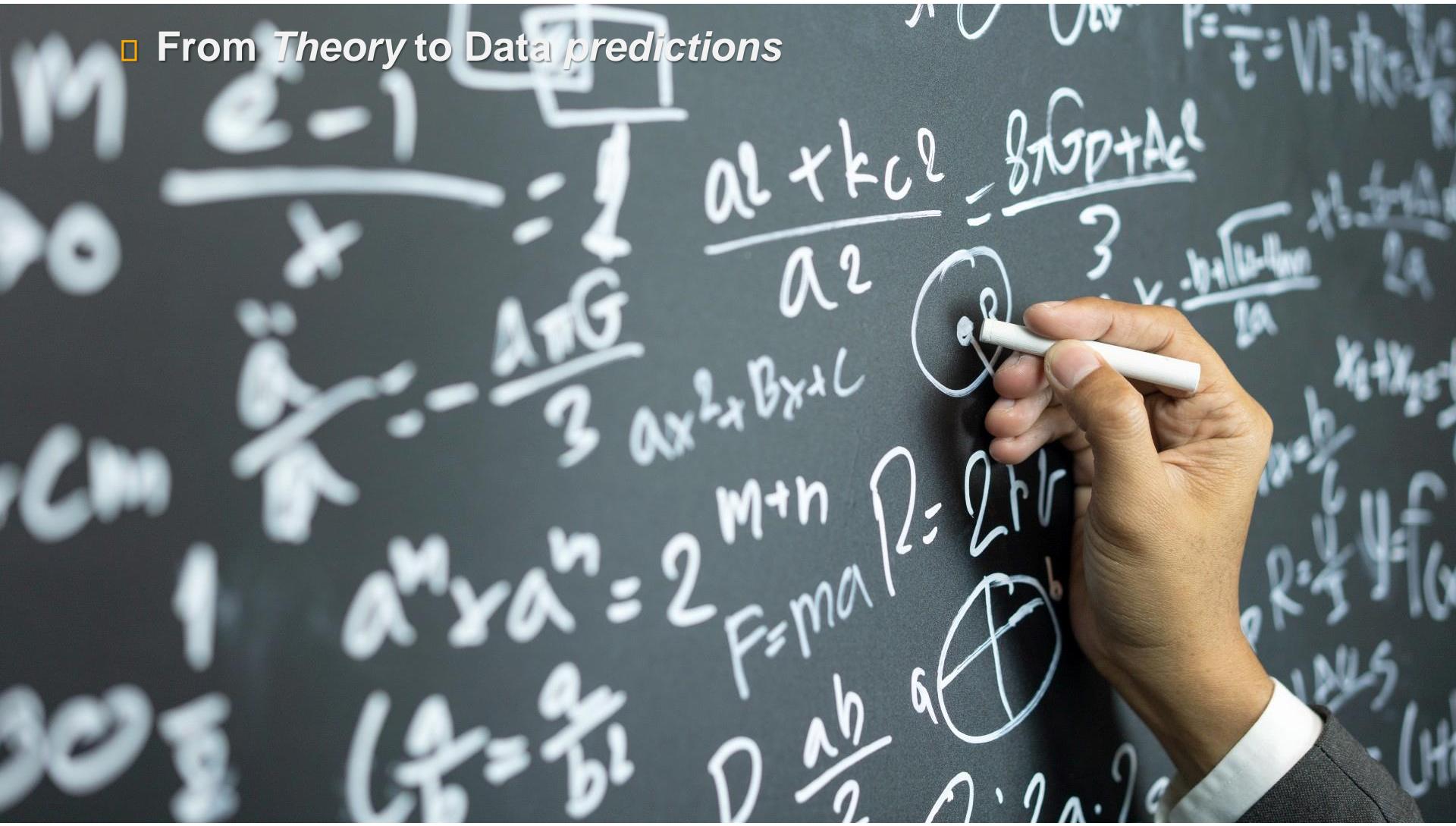


SAR OPS



Science

- From Theory to Data predictions



Statistics



- From Data *observations* to Data *predictions*
 - Most often *absent* a Theory!





Today

- Statistical methods are applied in **all** fields that involve decision making in the face of uncertainty
- For example, should I ask this person out on a date because i'm not sure if they like me?
- And in Machine Learning (ML)..





Foundations

- Machine Learning is built on top of **Statistics & Linear Algebra**
- You can study ML without a foundation in statistics and Linear Algebra, but that would be a little bit like learning how to fly a plane in a flight simulator
- You never develop the quality of airworthiness, and over time, this will show and hinder your professional development
- This semester you will learn this airworthiness with a solid foundation in statistics and linear algebra, then you can apply it to the field of Machine Learning





Class

- This class has no *prerequisites*, and it's a great class to learn python, but you will be competing with other students who may already know python, so having some experience in a managed programming language like java, C#, or Python is almost necessary
- There will be homework every week in order to better learn the week's lecture material, a midterm, a final, *and* a final project
- You will have TAs to help you, and an instructor to motivate you





Part 3

DATA SCIENCE IS SEXY



Data Scientist: The Sexiest Job of the 21st Century

by Thomas H. Davenport and D.J. Patil

FROM THE OCTOBER 2012 ISSUE

SUMMARY SAVE SHARE COMMENT 12 TEXT SIZE PRINT \$8.95 BUY COPIES



When Jonathan Goldman arrived for work in June 2006 at LinkedIn, the business networking site, the place still felt like a start-up. The company had just under 8 million accounts, and the number was growing quickly as existing members invited their friends and colleagues to join. But users weren't seeking out connections with the people who were already on the site at the rate executives had expected. Something was apparently missing in the social experience. As one LinkedIn manager put it, "It was like arriving at a conference reception and realizing you don't know anyone. So you just stand in the corner sipping your drink—and you probably leave early."



Goldman, a PhD in physics from Stanford, was intrigued by the linking he did see going on and by the richness of the user profiles. It all made for messy data and unwieldy analysis, but as he began exploring people's connections, he started to see possibilities. He began forming theories, testing hunches, and finding patterns that allowed him to predict whose networks a given profile would

<https://hbr.org/2012/10/data-scientist-the-sexiest-job-of-the-21st-century>



The sexiest job of the 21st Century

- George Roumeliotis, the head of a data science team at Intuit in Silicon Valley, holds a doctorate in astrophysics
- Roumeliotis begins his search for data scientists by asking candidates if they can develop prototypes in a mainstream programming language. Roumeliotis seeks both a skill set—a solid foundation in, statistics, probability, linear algebra, and computer science—and certain habits of mind. He wants people with a feel for business issues and empathy for customers.
- Pay will of course be a factor. A good data scientist will have many doors open to him or her, and salaries will be bid upward
- Survey of the priorities of data scientists revealed something more fundamentally important. They want to be “on the bridge.” The reference is to the 1960s television show Star Trek, in which the starship captain James Kirk relies heavily on data supplied by Mr. Spock. Data scientists want to be in the thick of a developing situation



On the bridge





The sexiest job of the 21st Century

- Data scientists say they want to build things, not just give advice to a decision maker. One described being a consultant as “the dead zone — all you get to do is tell someone else what the analyses say they should do”. By creating solutions that work, they can have more impact and leave their marks as pioneers of their profession
- Hal Varian, the chief economist at Google, is known to have said, “*The sexy job in the next 10 years will be statisticians. People think I'm joking, but who would've guessed that computer engineers would've been the sexy job of the 1990s?*”
- The advance of big data shows no signs of slowing. The more data we have, the more we need data scientists to analyze it





The tools..

- Foundations in **probability & statistics**, **linear algebra**, and **computer science**
 - **Programming**



- Not apps you can download
 - **Using**





After you take this class..

- ..you will date the partner of your dreams ☺





Also..

- ***My Experience Interviewing with Google, Meta, Amazon by Federico Mannucci, Aug, 2022***

- <https://towardsdatascience.com/my-experience-interviewing-with-google-meta-amazon-2f0c8c9a2772>
 - Once you get your foot through the door your knowledge and skills are all that matter, regardless of your years of experience, degree, or bootcamp





Also

- Why you should not be a data scientist by Rijul Singh Malik
Jul 28
 - <https://medium.com/geekculture/why-you-should-not-be-a-data-scientist-b5c2cadde6a3>





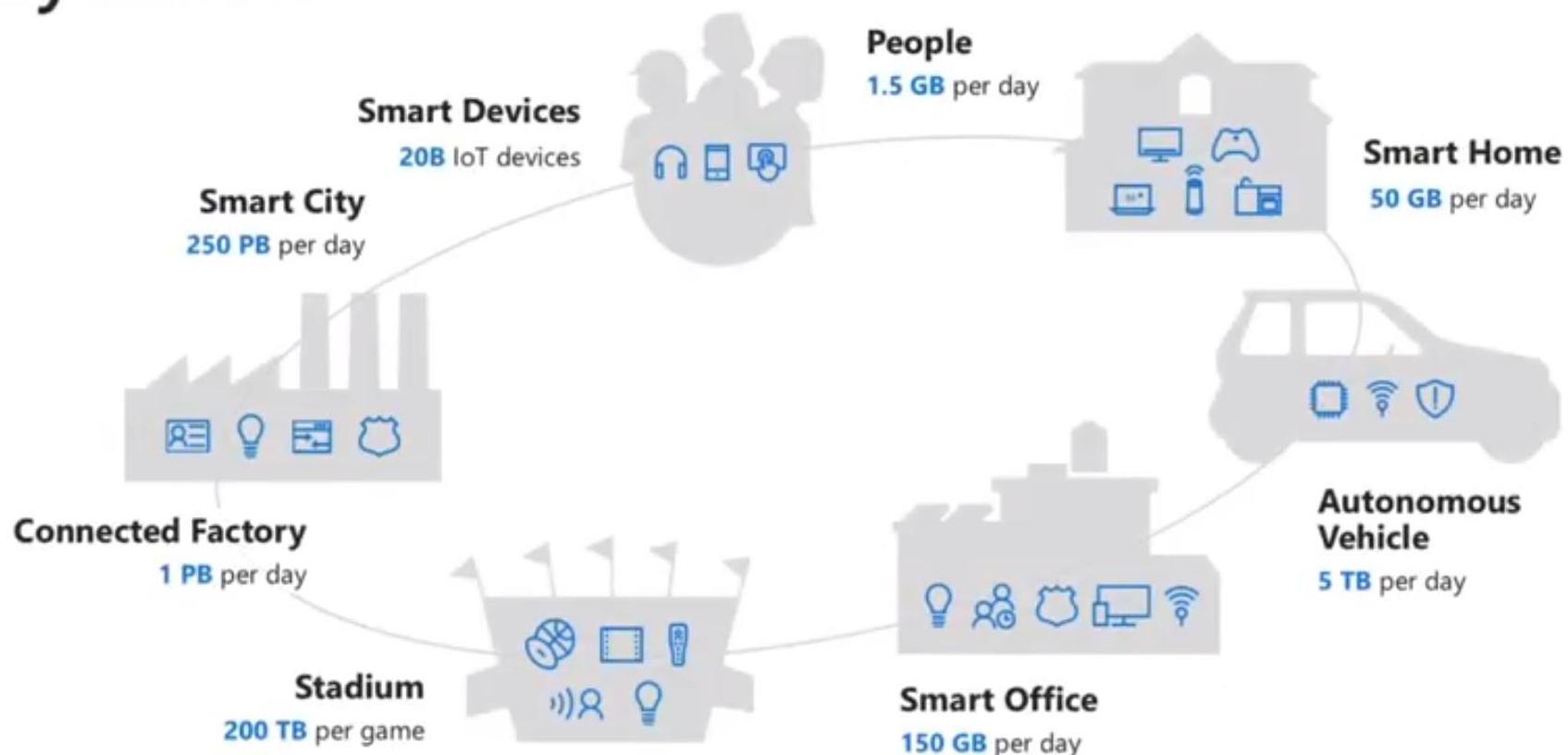
But first..

- 1. **Linear Algebra**- Vector Spaces and Norms, Basis, Tensors, Vector and Tensor Operations, Singular Value Decomposition (SVD), Eigendecomposition of a matrix, LU Decomposition, QR Decomposition/Factorization, Symmetric Matrices, Orthogonalization/Orthonormalization, Matrix Operations, Projections, Eigenvalues & Eigenvectors
- 2. **Probability & Statistics** - Probability Rules & Axioms, Bayes' Theorem, Random Variables, Variance and Expectation, Conditional and Joint Distributions, Standard Distributions (Bernoulli, Binomial, Multinomial, Uniform and Gaussian), Moment Generating Functions, Maximum Likelihood Estimation (MLE), Prior and Posterior, Maximum a Posteriori Estimation (MAP) and Sampling Methods
- 3. **Multivariate Calculus**- Differential and Integral Calculus, Partial Derivatives, Vector-Values Functions, Directional Gradient, Hessian, Jacobian, Laplacian and Lagrangian Distribution
- 4. **Algorithms and Complex Optimizations**- Complexity theory, data structures (Binary Trees, Hashing, Heap, Stack etc.), Dynamic Programming, Randomized & Sublinear Algorithm, Graphs, Gradient/Stochastic Descents



Data Science Because... Data!

By 2020...





Machine Learning is... different opinions

□ = **Statistics!**

- **Finding patterns in data**
- Covariates become **features**, non-linear regression becomes **neural networks**, transformations of random variables becomes **normalizing flow**, placing a gaussian prior on parameters becomes **L2 regularization**, etc.

□ For the opposing viewpoint, read here:

- <https://towardsdatascience.com/no-machine-learning-is-not-just-glorified-statistics-26d3952234e3>





Data Science with Machine Learning..

- Before **Tensorflow, Keras, and Torch..**
- You will become familiar with **NumPy, Pandas, SciPy, and SciKit-learn**
- Along with knowledge of **probability & statistics, and linear algebra**
 - Not simple, but *necessary*
- And you will learn
black-belt python along the way





Why Python?

- Part of Python's success is ease of integration with C, C++, and Fortran code, the other part is that it *hides* its OO heritage
- As a result, Python has inherited Fortran legacy
 - Fortran used to solve ODEs and PDEs
 - Terse, functional and not very Object Oriented
 - All legacy Fortran code now in Python
- Python has become the de-facto language of scientists



FORTRAN
.f90



Also, *quality!*

□ What is quality?





Prime Numbers in Python

- # Python program to display all the prime numbers within an interval
- lower = 900
- upper = 1000

- print("Prime numbers between", lower, "and", upper, "are:")

- # Note: all prime numbers are greater than 1





We'll start with R!



- Easier than Python
- Lots of libraries written for R
- An overview of class today
 - Today's class we learn how to program with *rows* and *columns*
- **Start working with vectors and matrices**
- R first appeared in 1995 and served as an implementation of the S statistical programming language
- Roger Peng, an 18-year R programming veteran who teaches R both at the university and on Coursera notes: "**R** is the most popular language used in the field of statistics"
 - "I like **R** because it's very easy to program"
 - R's advantages include its package ecosystem. "The vastness of package ecosystem is definitely one of R's strongest qualities -- if a statistical technique exists, odds are there's already an **R** package out there for it"
 - "There's a lot of functionality built in that's built for statisticians"

Class Policy



- Grade: 30% homework, 30% mid-term, 30% final project, 10% final exam
 - Why do universities have grades? To separate the good from the bad?
 - No, to improve your **skills**
- Do your homework, ask your TA how to deliver, due before **first class of the week**





Questions, Slides

- Ask questions: email TAs or dino.k@northeastern.edu
- Lecture slide-decks on Canvas, right before lecture
- Submit homework on time on Canvas. TAs will create assignments



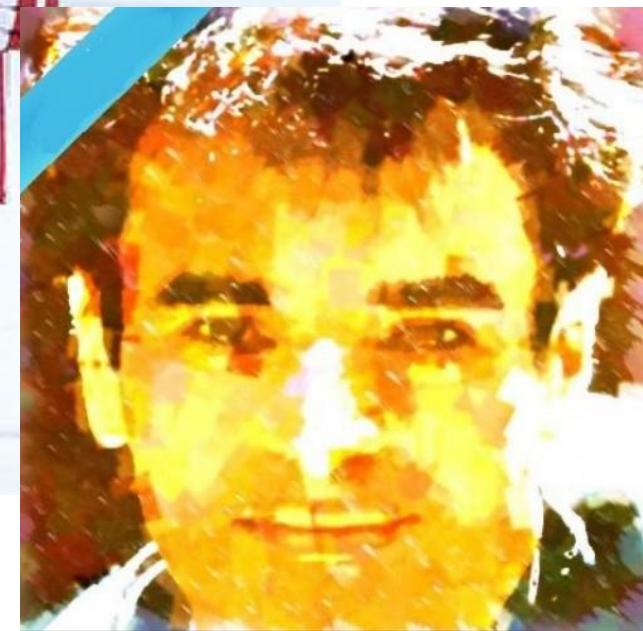


Part 4

ABOUT ME



Me





Industry

- Xerox, Operating System research (headless)

xerox





Government

JMPs-Combat1 - Limited Distribution - [View 1]

File Edit View Map Overlay Tools Options Test Window Help

UNCLAS

Active View

Graphical Tabular Document 3-D Viewer

Configured Data

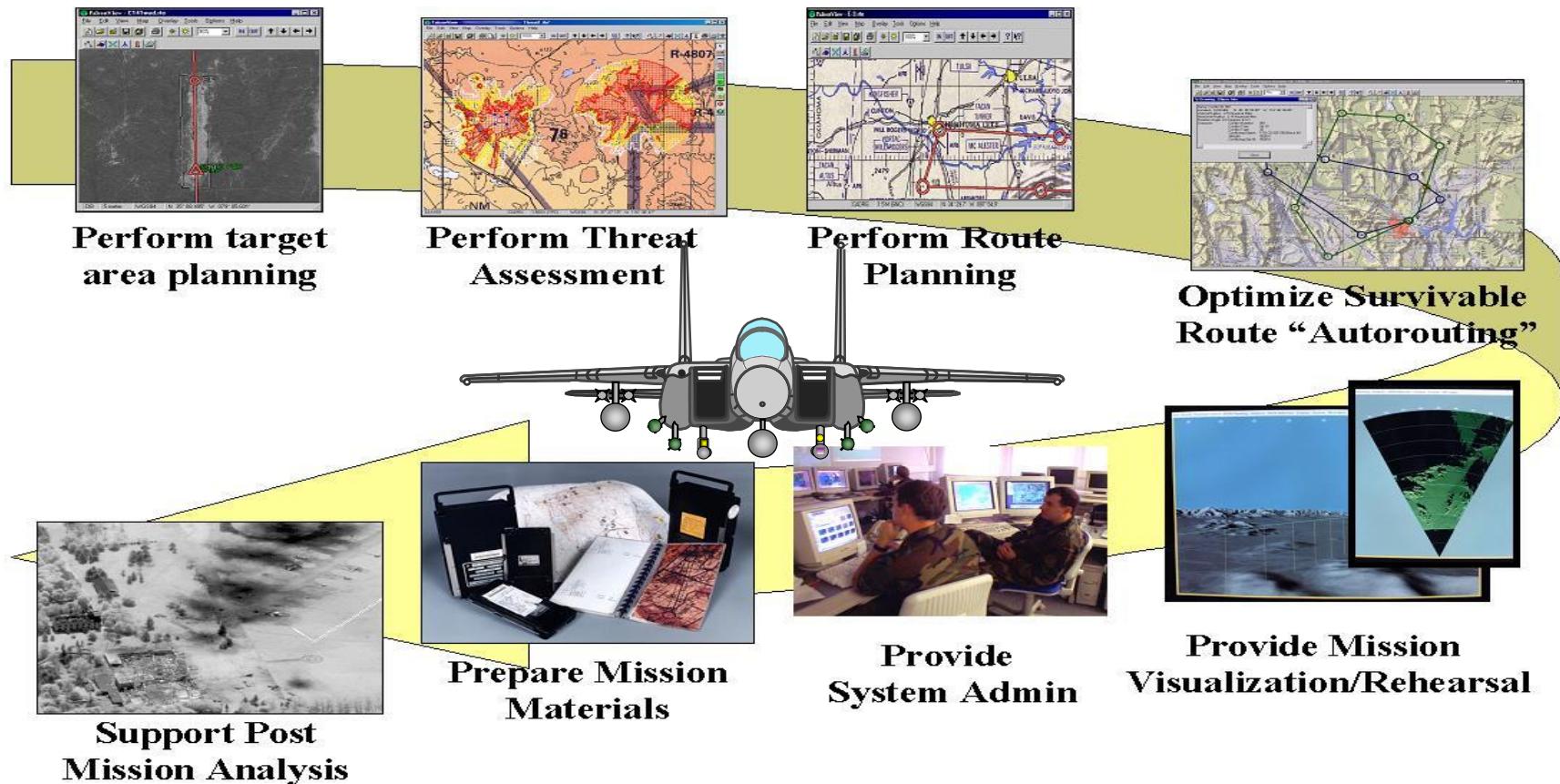
- ACDs
 - Aimpoints
 - Airports
 - Airways
- ATOs
 - CMF Tool
 - CollabNavAids
 - CollabRoutes
 - CollabTargets
 - CollabThreats
- Drawing
 - Electronic Chum
- GPS Trail
 - Grid Lines
 - Helipots
 - Local Points
 - Local Routes
 - Manual Chum
- MTR Military Training Routes
 - Mission Binders
 - NavAids
 - Order Of Battle
 - Parachute Jump Areas
 - PTW
 - Refueling Routes
 - ShapeFile
 - Threat Parametrics
 - UnitLandingZones
 - ValidLandingZones
 - WaterPages
 - Waypoints
 - Weather
- Connected Servers
- Downloaded Data
 - Mission Binders
- Current Session
 - Open Data Items
 - View 1

Equal Rectangular | Earth | World | WGE | N 39° 06' 22.7





Mission Planning

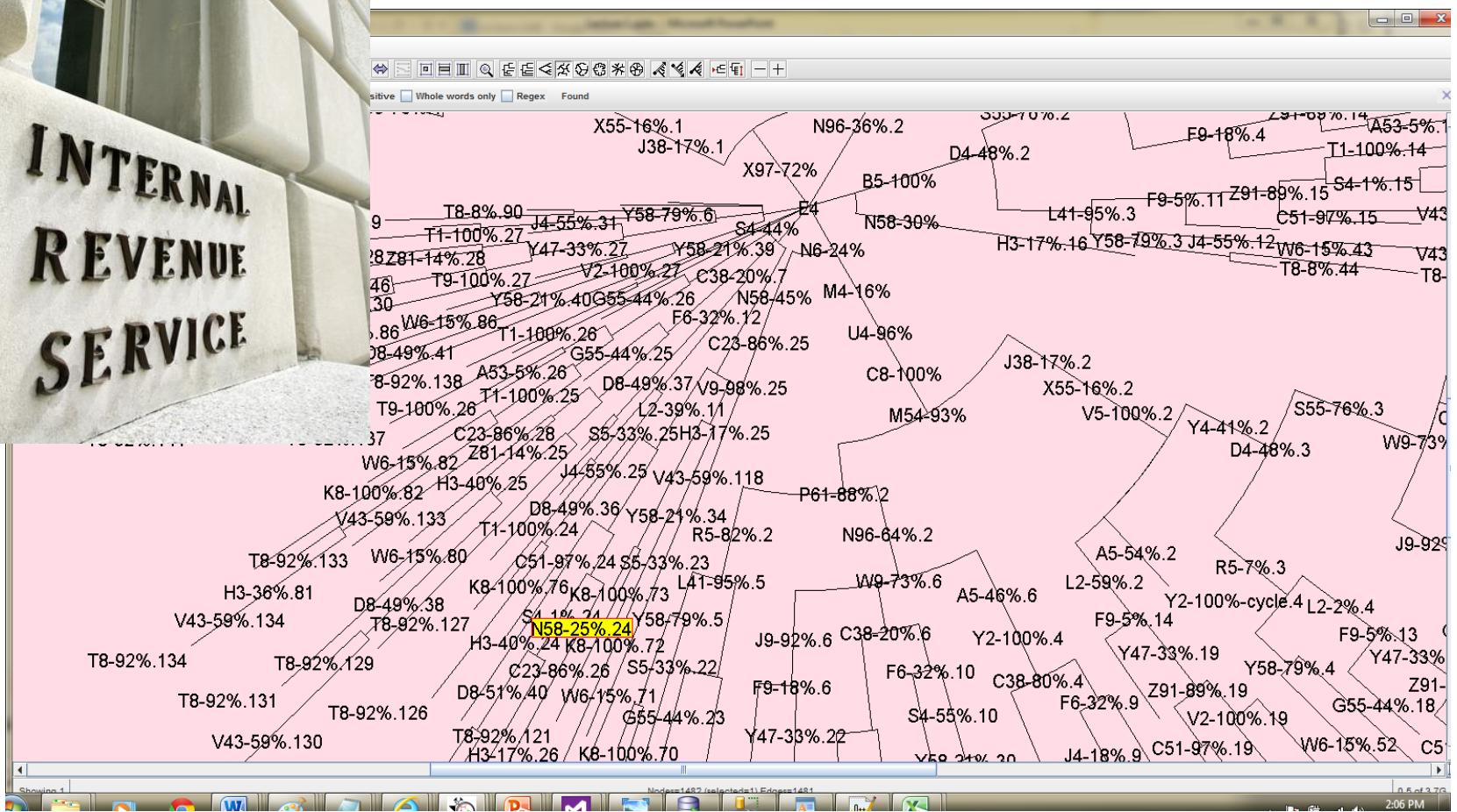
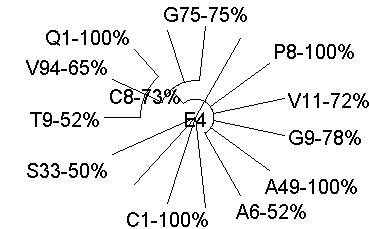
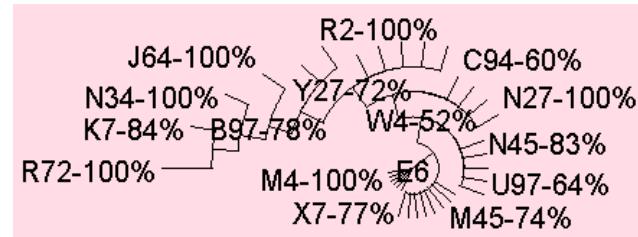




Army

- Use of microwave sensors for imaging continues to grow for applications such as target detection, airport screening, soil moisture estimation, etc.
- Hence, the need for indoor/small theater microwave imaging facilities
- A multi-static system is one where multiple transmit sites or multiple receive sites, or both, are used to construct the radar picture

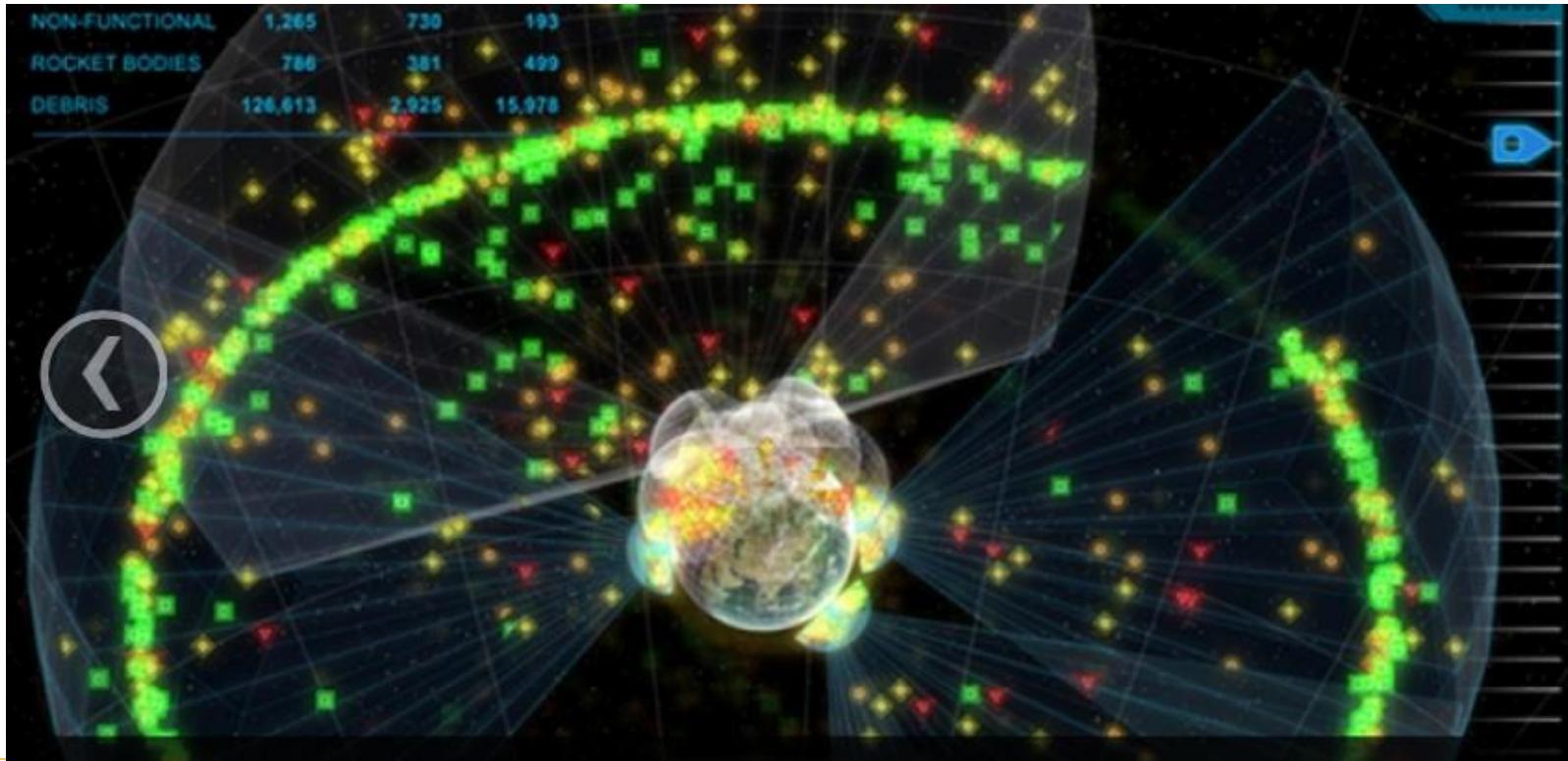






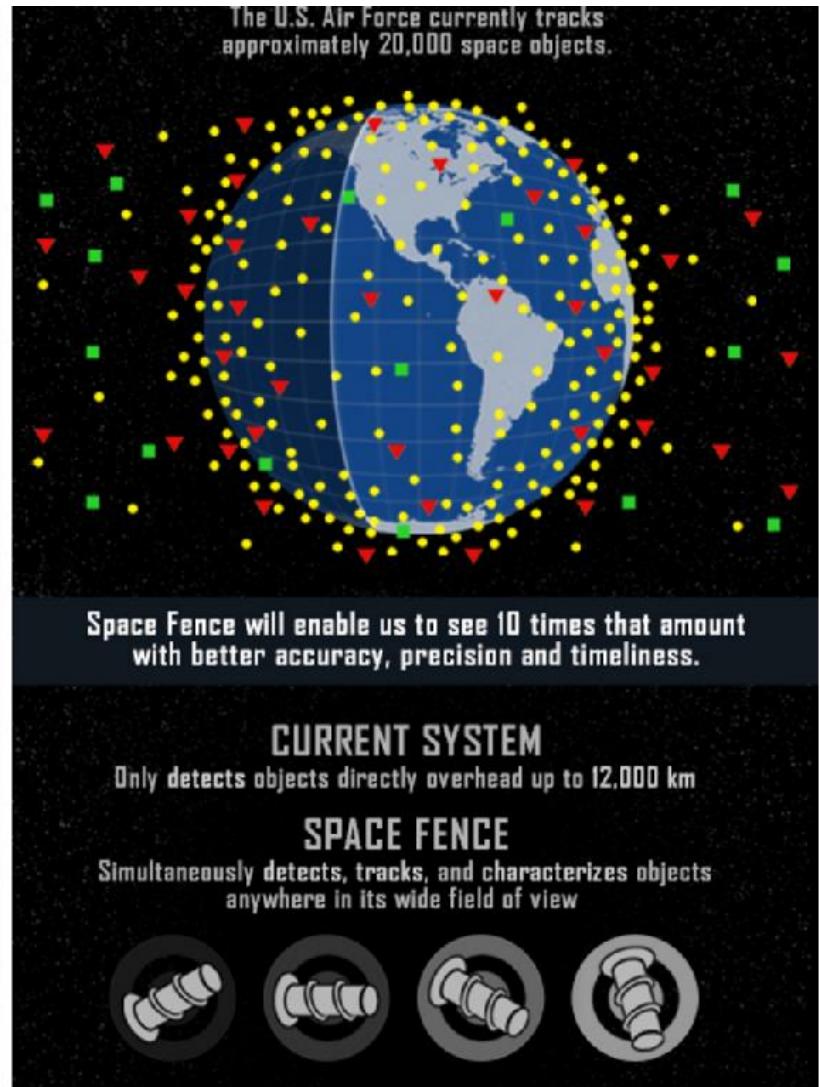
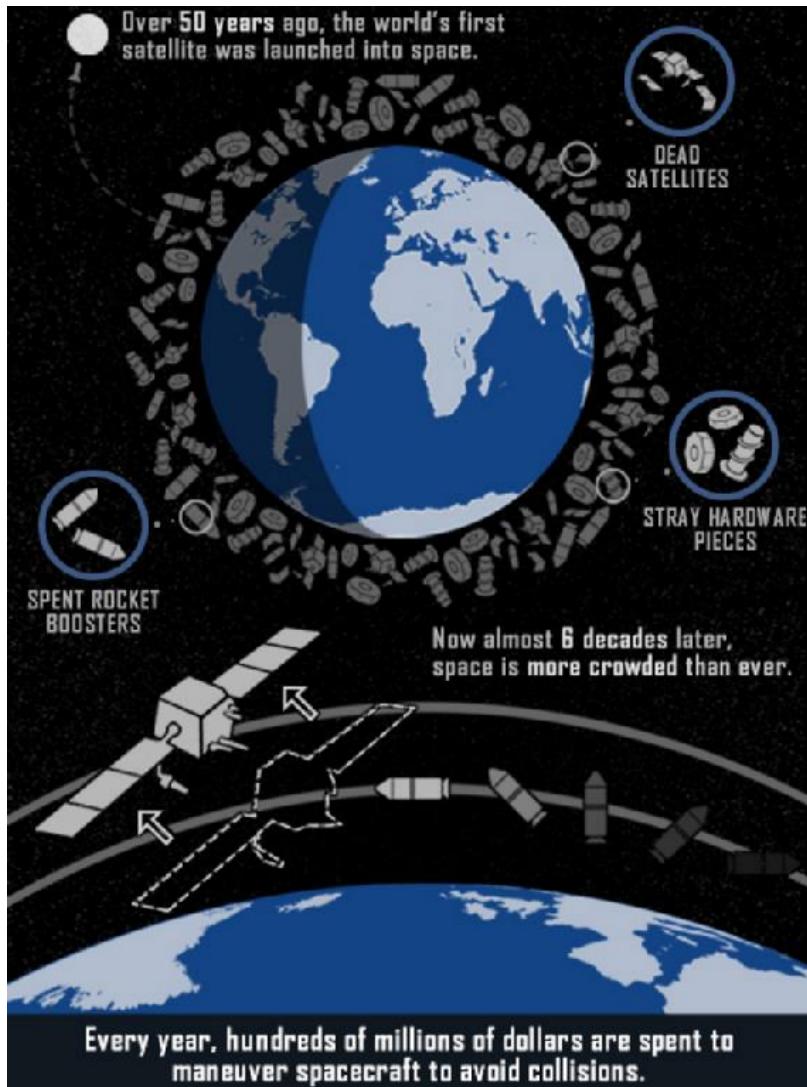
USAF Space Fence

- <http://www.lockheedmartin.com/us/products/space-fence.html>
- Kwajalein Atoll in the Marshall Islands: Space Fence, the most powerful radar ever built, to identify and tracks objects in space. Initial operational capability 2018





USAF Space Fence







Also





Part 5

INSTALLING ANACONDA PYTHON (NOT NOW, IT'S YOUR *HOMEWORK!*)



Anaconda

- Enterprise-ready Python distribution with packages for Big Data processing, predictive analytics, and scientific computing
- <https://www.continuum.io/anaconda>

ANACONDA
Powered by Continuum Analytics®



Install Anaconda

- Install anaconda, from:
 - <https://www.continuum.io/downloads>
 - <https://repo.continuum.io/archive/index.html>
- Option: You may install miniconda instead, *if you don't have enough disk space*
 - Pick Python 3.x distro
 - Please, no Python 2.x! (`python -v`)
- Test drive anaconda by running all steps in:
 - <http://conda.pydata.org/docs/test-drive.html>
 - Learn to play with different python environments and manage packages



To create new conda environments

- We are going to create new environments in this class:
 - `conda create --name theano python=3.4`
 - Because theano does not support python 3.5!
- Activate it:
 - Windows: `activate theano`
 - OSX/Linux: `source activate theano`
- List all & default (*) environment:
 - `conda info -envs`
- Python version?
 - `conda version`



Python IDEs

- Anaconda *spyder*
- Visual Studio with *Python Tools for Visual Studio (PVTS)*
- Visual Studio Code
- PyCharm
- PyDev (on top of Eclipse)
- Wing IDE
- Ninja IDE
- https://docs.continuum.io/anaconda/ide_integration



Python notebook

- **Install jupyter notebook (for miniconda):**
 - `conda install notebook` or `pip install jupyter`
 - That will install a number of dependencies (incl. ipython and jupyter)
 - It will allow us to do python in class like we did R in RStudio..
- **Full anaconda should already have jupyter notebook installed**



Anaconda IDE

- `conda install spyder`
- At a command prompt: `spyder`
- (like code) ☺
- Full anaconda should already have `spyder` installed, but probably old version
 - Update with:
 - `conda update spyder`
 - Windows: Administrator privileges console
 - OSX/Linux: `sudo`



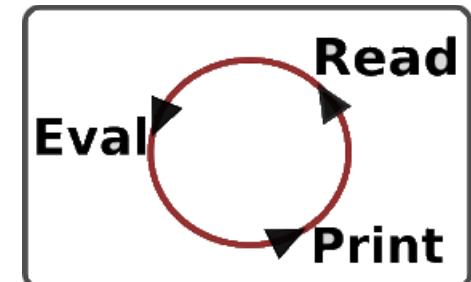
Google Colab

- Free Jupyter notebook environment that requires no setup and runs entirely on the Cloud
- <https://colab.research.google.com/notebooks/welcome.ipynb>
- Free GPU support
 - Able to cut down training time from few hours to well below 5 mins
 - Direct integration with Google drive, where you can download a lot of data or just upload your own
 - Share the link for the notebook and anyone can import it and run it for themselves
-



How to run ipython notebook in a browser

- In a command shell: `jupyter notebook`
- That will pop up a browser
- You cut and paste code in the `In[]` cells on the iPython page, and then click on the 'Play' button to run each cell
- The great part about the seamless integration of text and code in IPython Notebook is that it's entirely conducive to the process:
 1. Form hypothesis
 2. Evaluate data
 3. Form conclusion
- It's a REPL loop, and we'll use that to do ML





To load a notebook..

- .. That you downloaded from the Web:
 - Open up a command shell
 - Go to the folder where you downloaded your notebook
 - `jupyter notebook mynotebook.ipynb`
- You can only run one notebook server at a time..
 - ..unless you change the port for ipython, because the default port for conda is 8888



An important URL

- Unofficial Windows Binaries for Python Extension Packages
 - <https://www.lfd.uci.edu/~gohlke/pythonlibs>
 - E.g. <https://www.lfd.uci.edu/~gohlke/pythonlibs/#python-ldap>



Part 6

ABOUT R



R Introduction

- Ross Ihaka and Robert Gentleman created the open-source language R in 1995 as an implementation of the **S programming language**
 - Purpose was to develop a language that focused on delivering a better and more user-friendly way to do data analysis, statistics and graphical models
 - CRAN is a huge repository of curated R packages to which users can easily contribute
 - Comprehensive R archival network
 - <https://cran.r-project.org/>



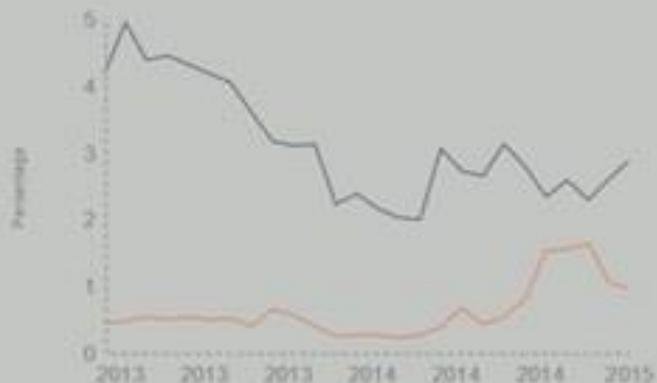


R vs Python

R and Python: The Numbers

Popularity Rankings

R and Python's popularity between 2013 and February 2015 (TIOBE Index)



Jobs And Salary?

2014 Dice Tech Salary Survey:
Average Salary For High Paying Skills and Experience



\$115,531

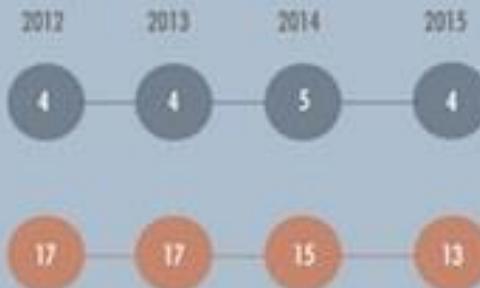


\$94,139

Redmonk ranking, comparing the relative performance of programming languages on GitHub and Stack Overflow
(September 2012 and January 2013, 2014, 2015)

Python

R



Source www.kdnuggets.com



What is R

- **R is a free software environment for statistical computing, data mining, and graphics**
 - Hopefully replace **Matlab**, the crack-cocaine of scientists-engineers-turned-programmers
- **R is one of the major languages for data science**
 - It provides excellent visualization features, which is essential to explore the data before submitting it to any automated learning, as well as assessing the results of the learning algorithm
 - Many R packages for **machine learning** are available off the shelf and many modern methods in statistical learning are implemented in R as part of their development
- **We use statistical analysis for:**
 - **inference - making conclusions based on data**
 - **prediction - what will happen when I observe new data?**
 - **and we create models to do both of those things**



To install R and RStudio, *Prerequisites*

□ Install it with Anaconda!

The screenshot shows the Anaconda Navigator application window. On the left is a sidebar with navigation links: Home, Environments, Projects (beta), Learning, Community, Documentation, Developer Blog, and Feedback. At the bottom are social media icons for Twitter, YouTube, and GitHub. The main area is titled "Anaconda Navigator" and shows a grid of application icons. The applications listed are:

- jupyterlab (0.27.0): An extensible environment for interactive and reproducible computing, based on the Jupyter Notebook and Architecture. Includes a "Launch" button.
- jupyter notebook (5.0.0): Web-based, interactive computing notebook environment. Edit and run human-readable docs while describing the data analysis. Includes a "Launch" button.
- qtconsole (4.3.1): PyQt GUI that supports inline figures, proper multiline editing with syntax highlighting, graphical calltips, and more. Includes a "Launch" button.
- spyder (3.2.3): Scientific Python Development Environment. Powerful Python IDE with advanced editing, interactive testing, debugging and introspection features. Includes a "Launch" button.
- glueviz (0.10.4): Multidimensional data visualization across files. Explore relationships within and among related datasets. Includes an "Install" button.
- orange3 (3.4.1): Component based data mining framework. Data visualization and data analysis for novice and expert. Interactive workflows with a large toolbox. Includes an "Install" button.
- rstudio (1.0.153): A set of integrated tools designed to help you be more productive with R. Includes R essentials and notebooks. Includes an "Install" button.



R = or ← ?

In R, both statements `x = 3` and `x <- 3` have the effect of assigning the value 3 to the variable x. So if they have the same effect, does it matter which you use? When R (and S before it) was first created, `<-` **was the only choice for the assignment operator**. Old AT&T keyboards had arrow as a key!

But R uses `=` for yet another purpose: associating function arguments with values (as in `pnorm(1, sd=2)`, **to set sd to 2**)

To make things easier for new users, R added the capability in 2001 to also allow `=` be used as an assignment operator, on the basis that the intent (assignment or association) is usually clear by context. So,

`x = 3`

clearly means "assign 3 to `x`", **whereas**

`f(x = 3)`

clearly means "call function `f`, setting the argument `x` to 3".

There is one case where ambiguity might occur: if you wanted to assign a variable *during* a function call. The only way to do this in modern versions of R is:

`f(x <- 3)`

which means "assign 3 to `x`, **and call f with the first argument set to the value 3**



APL Character Set



IBM 2741 keyboard layout



Part 7

INTRODUCTION TO STATISTICAL LEARNING AND FIRST CONCEPTS



A.I.

- Today's "A.I." may be *artificial*, but it's not *intelligent*
- It is mostly *statistics*, and *invented centuries ago*
- The new part is mostly to handle lots of data with new methods based on using algebra to create geometry (graphs to join point clouds into surfaces): ML
- So, what is AI, *really?*
 - To me, AI implies a certain amount of *independence* of the machine, to the programmer
 - The machine decides, to a certain extent, what to learn
 - It also implies a certain amount of *deductive power*
 - In other words, the machine can reason
 - *Not just statistical learning, even though it often can be reduced to statistical learning through genetic algorithms..*
 - *And a certain amount of free will*
 - *We feel something is intelligent when it does something unexpected. If we program it, it is not unexpected*





Statistics

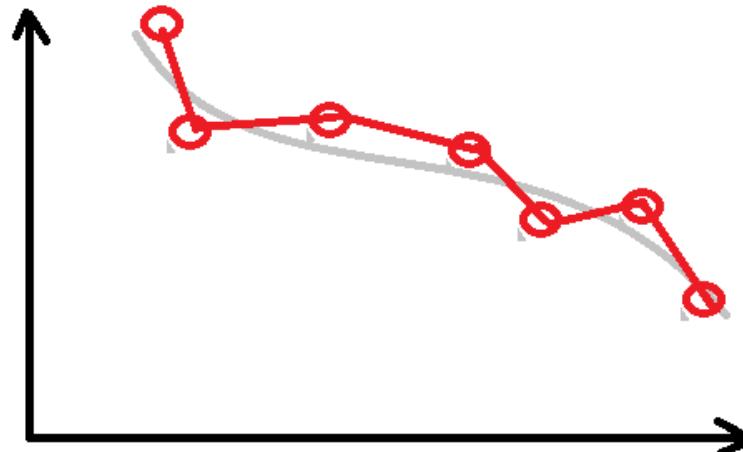
- From Data *observations* to Data *predictions*
- Most often *absent* a Theory!





A.I. according to your instructor, and ML

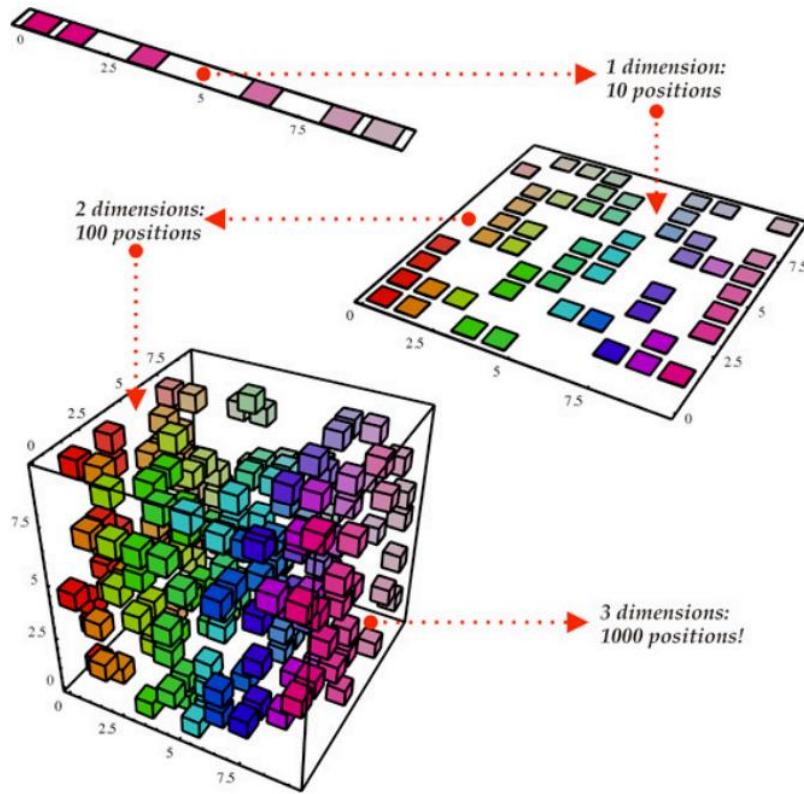
- An **artificial intelligence** is not entirely *preprogrammed*, can *reason*, and is somewhat *free* to act
- **Machine Learning** uses artificial neural networks or other methods to build surfaces in many dimensions that represent an *interpolation* of data points in order to approximate the science behind a mechanism: That really *is* Data Science'



- Before we learn how to use machines to do that, we need to do that ourselves, with math and computer science
- <https://towardsdatascience.com/a-deep-dive-into-curve-fitting-for-ml-7aeef64755d2>

State of the Art of ML

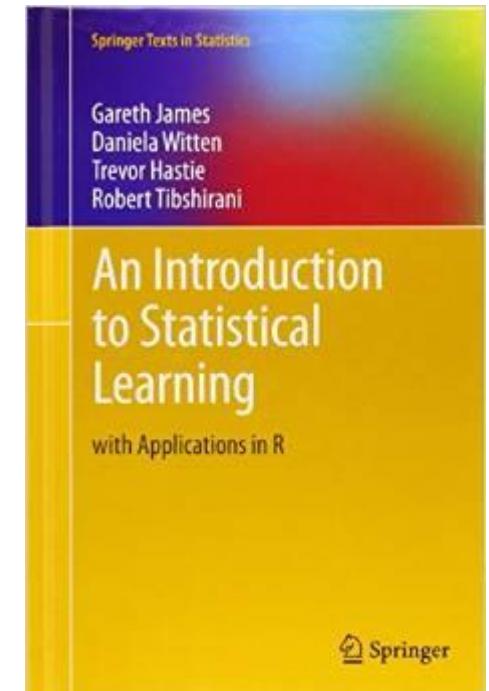
- ... How to go from *Data models* to *Theory*





Intro to Statistical Learning

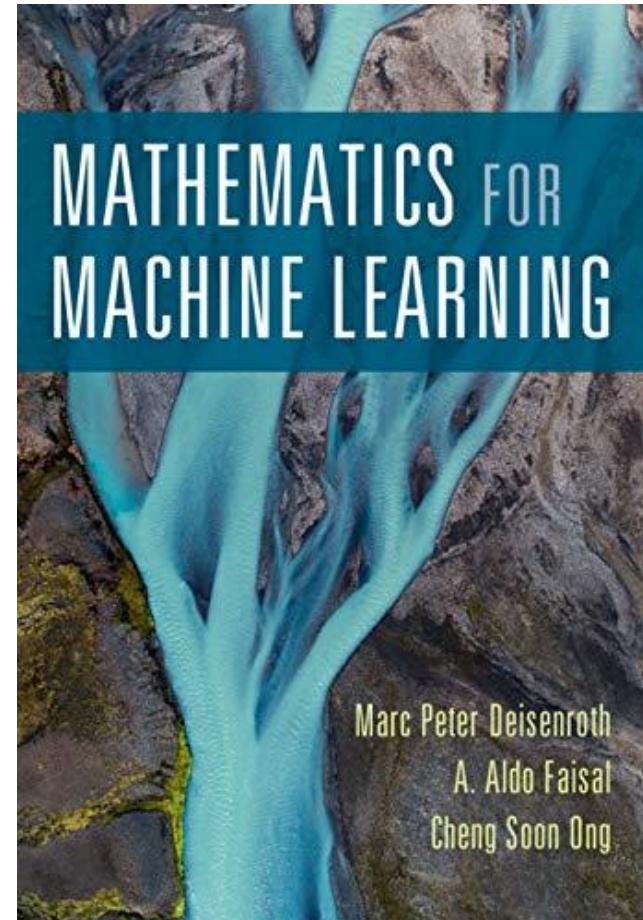
- An Introduction to Statistical Learning with Applications in R, by James et al:
- https://www.amazon.com/Introduction-Statistical-Learning-Applications-Statistics/dp/1461471370/ref=sr_1_2?crid=2F1CWLTDU33EG&keywords=An+Introduction+to+Statistical+Learning+with+Applications+in+R%2C+by+James+et+al
- <http://www-bcf.usc.edu/~gareth/ISL/>





Mathematics of Machine Learning

- <https://www.amazon.com/Mathematics-Machine-Learning-Peter-Deisenroth/dp/110845514X>
- <https://mml-book.github.io/>





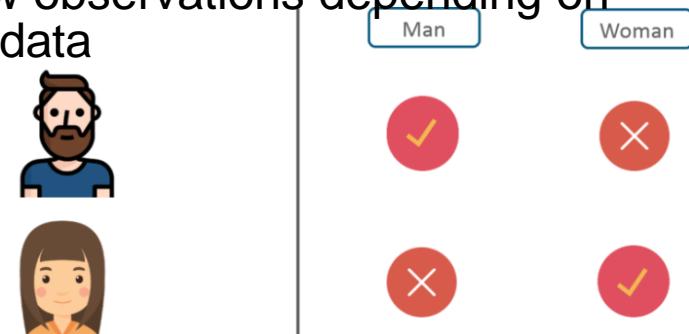
Overview of Machine Learning (ML)

- In **supervised learning** (SL), the learning algorithm is presented with labelled example inputs, where the labels indicate the desired output
 - SML itself is composed of **classification**, where the output is categorical, and **regression**, where the output is numerical
- In **unsupervised learning** (UL), no labels are provided, and the learning algorithm focuses solely on detecting structure in unlabeled input data
- Note that there are also **semi-supervised learning** approaches that use labelled data to inform unsupervised learning on the unlabeled data to identify and annotate new classes in the dataset (also called *novelty detection*)
- **Reinforcement learning** (RL), the learning algorithm performs a task using feedback from operating in a real or synthetic environment, with rewards over actions



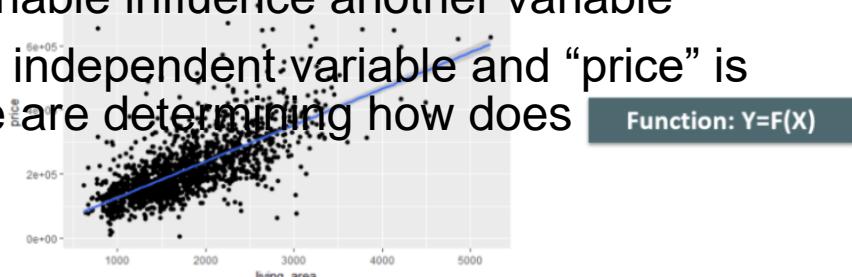
Supervised Learning = Classification or Regression

- Supervised Learning algorithm learns from a known data-set(Training Data) which has labels to make predictions
- **Classification:**
 - Classification determines to which set of categories does a new observation belongs i.e. a classification algorithm learns all the features and labels of the training data and when new data is given to it, it has to assign labels to the new observations depending on what it has learned from the training data



- **Regression:**

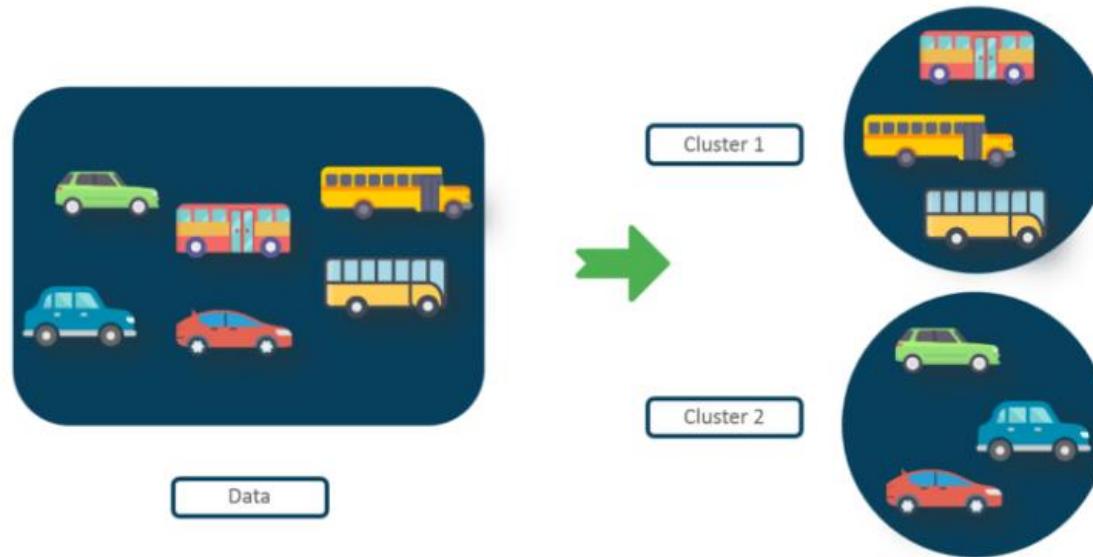
- Regression is a supervised learning algorithm which helps in determining how does one variable influence another variable
 - Over here, “living_area” is the independent variable and “price” is the dependent variable i.e. we are determining how does “price” vary wrt “living_area”





Unsupervised Learning is much more difficult

- Unsupervised learning algorithm draws inferences from data which does not have labels



- In this example, the set of observations is divided into two clusters. Clustering is done on the basis of similarity between the observations. There is a high intra-cluster similarity and low inter-cluster similarity i.e. there is a very high similarity between all the buses but low similarity between the buses and cars.



Reinforcement Learning

- Reinforcement Learning is a type of machine learning algorithm where the *machine/agent* in an *environment* learns ideal behavior in order to maximize its performance. Simple reward feedback is required for the agent to learn its behavior, this is known as the *reinforcement signal*



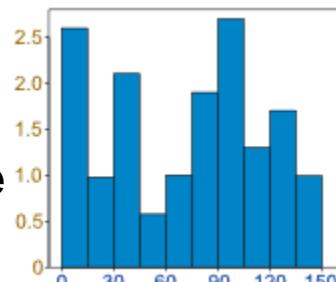
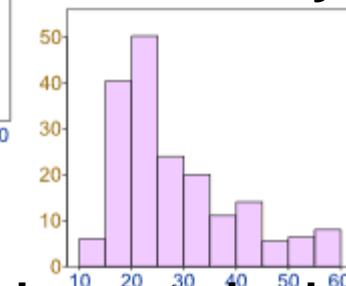
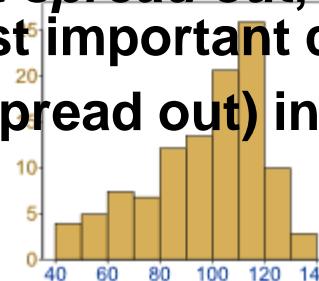
- pacman* for example. As long as pacman keeps eating food, it earns points but when it crashes against a monster it loses its life. Thus pacman learns that it needs to eat more food and avoid monsters so as to improve its performance



Most important concept in statistics: *Data distribution*

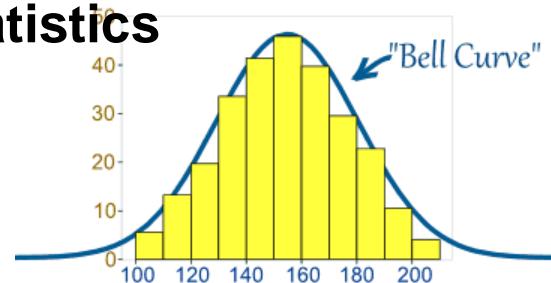
- How data is distributed (is it *spread out*, is it *scrunched together*) is one of the most important concepts in statistics
- Data can be "distributed" (spread out) in different ways

- It can be spread out more on the left
 - Or more on the right
 - Or it can be all jumbled up
 - In many cases, the data tends to be around a central value bias left or right
 - It is often called a "Bell Curve" because it looks like a bell



- How data is distributed is the foundation of statistics

- Histogram
<https://en.wikipedia.org/wiki/Histogram>





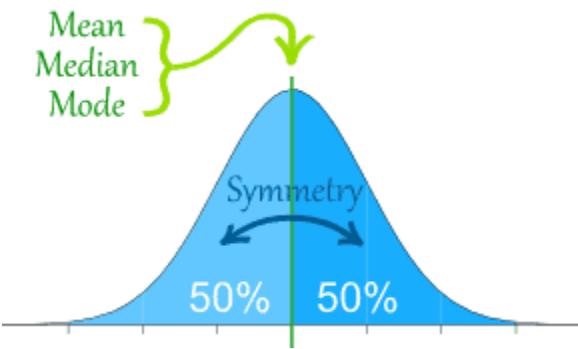
Normal distribution (rnorm)

- We say the data is normally distributed when:

- The probability density of the normal distribution is:

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

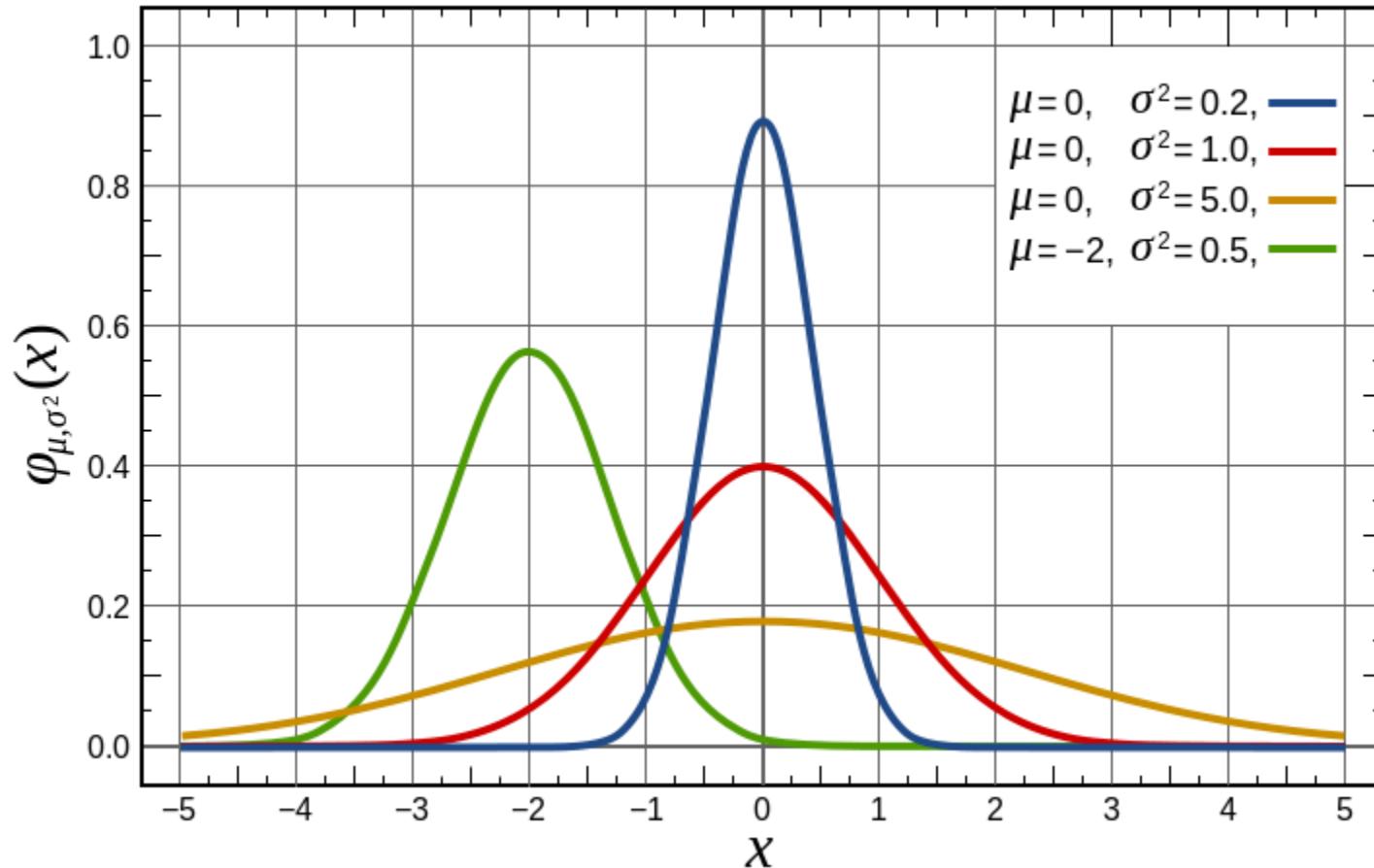
- Here, μ is the mean or expectation of the distribution (and also its median and mode). The parameter σ is its standard deviation; its variance is then σ^2
 - If $\mu = 0$ and $\sigma = 1$ the distribution is called the *standard normal distribution* or the *unit normal distribution*



symmetry about the center
50% of values less
than the
mean and 50% greater
than
the mean



Normal (a.k.a. Gaussian) Distributions





Central Limit Theorem

- In probability theory, the central limit theorem (CLT) states that, given certain conditions, the arithmetic mean of a sufficiently large number of iterates of independent random variables, each with a well-defined expected value and well-defined variance, will be approximately *normally distributed, regardless of the underlying distribution*
- When **independent random variables** are summed up, their properly **normalized** sum tends toward a **normal distribution** even if the original variables themselves are not *normally distributed*
- **Example:** if one **flips a coin many times**, the probability of getting a given number of heads will approach a normal distribution, with the mean equal to half the total number of flips. At the limit of an infinite number of flips, it will equal a normal distribution
- **Example:** <https://www.mathsisfun.com/data/quincunx.html>



Correlation

- In statistics, **dependence** is any statistical relationship between two random variables or two sets of data
 - Correlation refers to any of a broad class of statistical relationships involving dependence
 - Familiar examples of dependent phenomena include the correlation between the demand for a product and its price
 - Correlations are useful because they can indicate a *predictive* relationship that can be exploited
- Statistical learning, or learning-by-experience, is all about correlation
 - *When I see my mum, I get good food*
 - *If I climb high on a tree, I can fall and hurt myself*
 - *When the girl winks at me, it means she likes me ☺*



Linear relationships

- The Pearson correlation coefficient indicates the strength of a *linear relationship* between two variables
 - The *Pearson correlation coefficient*, which is sensitive *only* to a *linear relationship* between two variables
 - If we have a series of n measurements of X and Y written as x_i and y_i where $i = 1, 2, \dots, n$

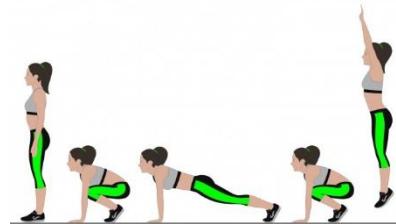
$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}},$$

where x and y are the sample means of X and Y , and s_x and s_y are the sample standard deviations of X and Y



Causation

- **Correlation does not imply causation!**
- A correlation between age and height in children is fairly causally transparent (age → height), but a correlation between mood and health in people is less so
 - Does improved mood lead to improved health (mood → health), or does good health lead to good mood (health → mood), or both (mood ↔ health)? Or does some other factor underlie both (factor x ↔ mood + health) ?
 - E.g.:



- Culture
 - Is local Culture in Crete, which includes a great diet and lots of music, responsible for elevated measures of both health and mood?





Statistical Analysis

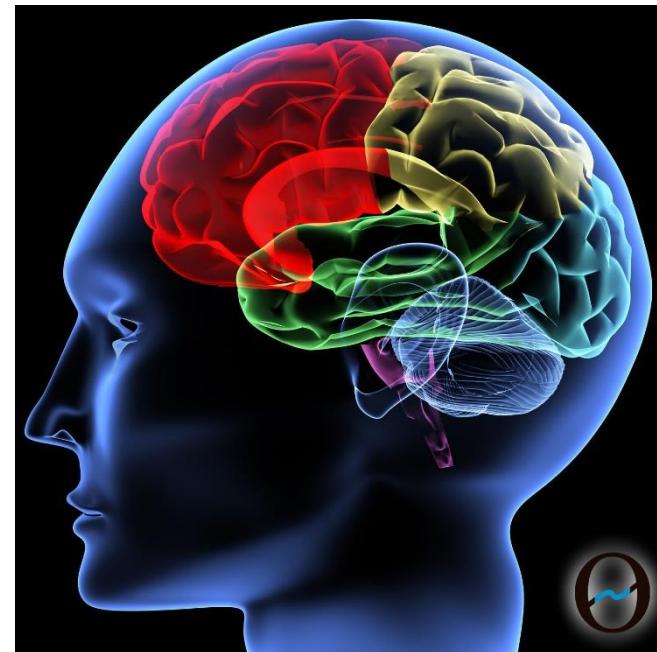
- We use statistical analysis for:
 - *Inference* - making conclusions based on data
 - *Prediction* - what will happen when I observe new data?
 - And we create *models* to do both of those things
- "*All models are wrong - some are useful*" - George E. P. Box





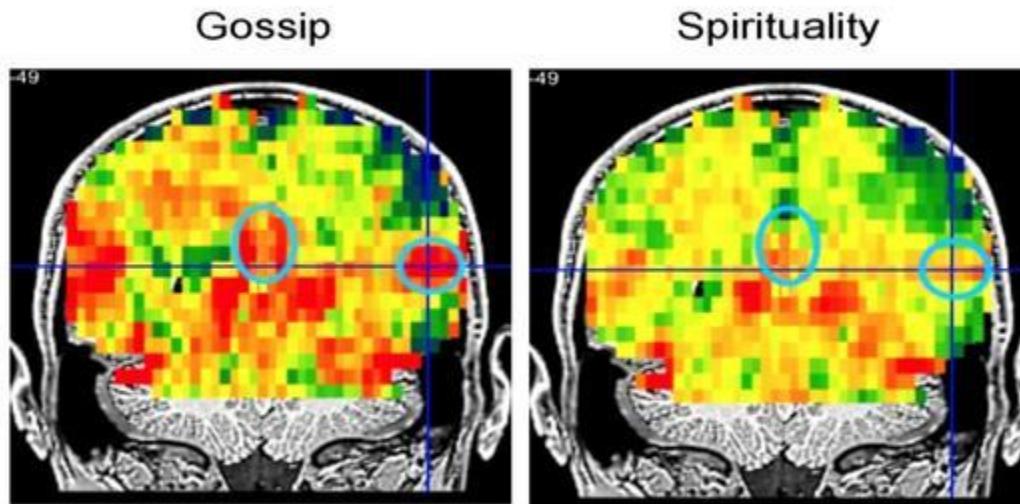
Ghost in the shell

- Our brain simply consists of a bunch of *predictors*, based on *models* we build for ourselves in our lifetimes..
- In the last 20 years, we got very excited trying to find the ghost in the shell, learning how to use a machine to learn, only to uncover that ML is nothing more than plotting high-dimensional graphs using algebraic methods
- Then we realized that we too, we are just machines, with graphs in our brains, and there is no real ghost in the shell



fMRI

- We can put your brain in a machine, and it *can* figure out what you are thinking about!
- Please view this video *after class*:
<https://www.cbsnews.com/video/can-fmri-brain-scans-spot-suicidal-thoughts/>





Variables

- The decision as to which variable in a data set is modeled as the ***dependent variable*** and which are modeled as the ***independent variables*** may be based on a presumption that the value of one of the variables is caused by, or directly influenced by the other variables
- Independent variables (the x 's) are also called ***regressors, exogenous variables, explanatory variables, covariates, input variables, and predictor variables***
- Dependent variables (the y 's) are also called ***output variables***



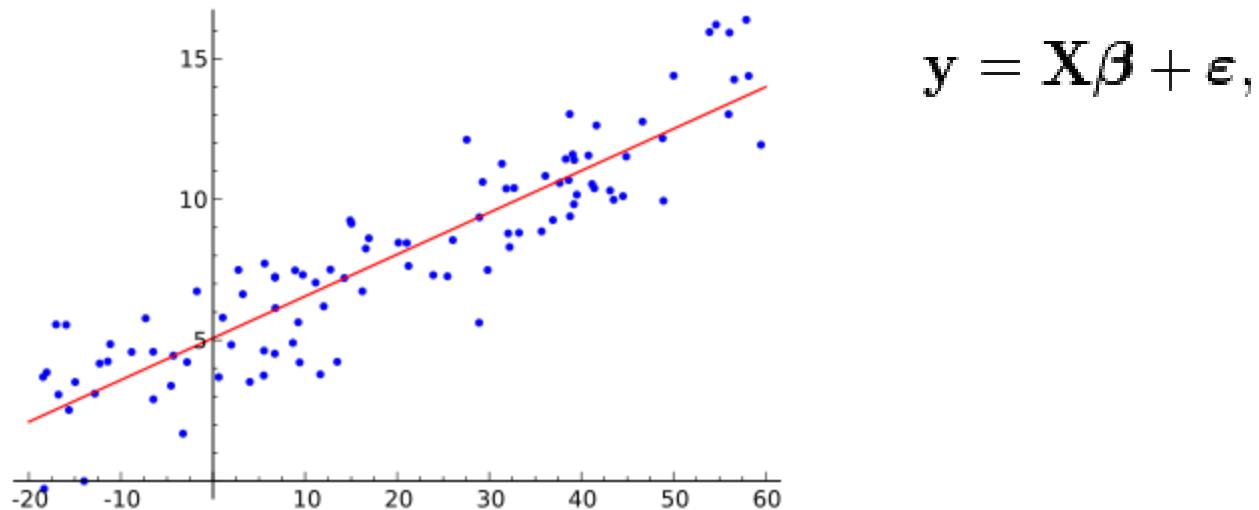
Statistical Models

- The two kinds of Models we build in statistics/ML are:
 - *Regression*
 - *Classification*



Linear Regression

- Regression is an approach for modeling the relationship between a **dependent variable** y and one or more explanatory variable (**independent variable**) x
 - In linear regression, data are modeled using linear predictor functions
 - Linear regression models are often fitted using the least squares approach, but they may also be fitted in other ways..





Logistic Regression

- Logistic regression describes a kind of classification model in which predictor variables are combined with linear weights and then passed through a soft-limit function that limits the output to the range [0, 1]
- Logistic regression is closely related to other models such as:
 - *Perceptron* (where the soft limit is replaced by a hard limit)
 - *Neural networks* (where multiple layers of linear combination and soft limiting are used)
 - *Naive Bayes* (where linear weights are determined strictly by feature frequencies assuming independence)
- Logistic regression can't separate all possible classes, but in very high dimensional problems or where you can introduce new variables by combining other predictors, this is less of a problem
- Mathematical simplicity of logistic regression allows very efficient and effective learning algorithms to be derived



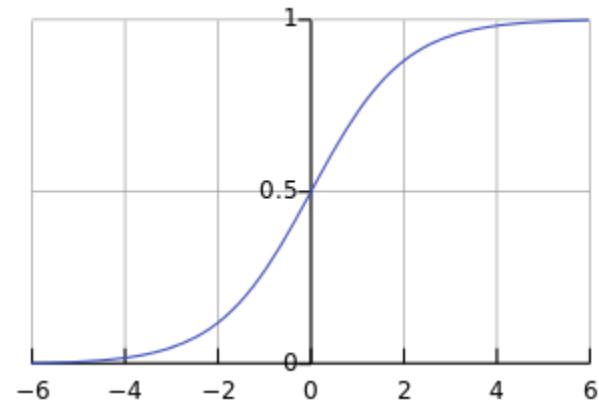
Logistic Regression

- The probabilities describing the possible outcomes of a single trial are modeled, as a function of the explanatory (predictor) variables, using a logistic function

- A logistic function is a common "S" shape (sigmoid curve), with equation:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}}$$

- Population growth: The initial stage of growth is approximately exponential, then, as saturation begins, the growth slows, and at maturity, growth stops



The logistic function is useful because it can take an input with any value from negative to positive infinity, whereas the output always takes values between zero and one and hence is interpretable as a probability



Classification Example

- A good grade in this class (the *dependent variable*) is directly influenced by how many hours per week (the *predictor* or *independent variable*) you review the slides and do the homework
 - For example:
 - 1 or less hours per week → F
 - 2 – 3 hours per week → C
 - 4 – 5 hours per week → B
 - 8 – 9 hours per week → A



Understanding Machine Learning

- How do you know all of these are cats?
- As a kid, you might have come across a picture of a cat and you would have been told by your kindergarten teachers or parents that this is a cat and it has some specific features associated with it like it has fluffy ears, a pair of cute eyes, a tail and so on
- Now, whenever your brain comes across an image with those set of features, it automatically registers it as a cat because your brain has *learned* that it is a cat





Machine Learning

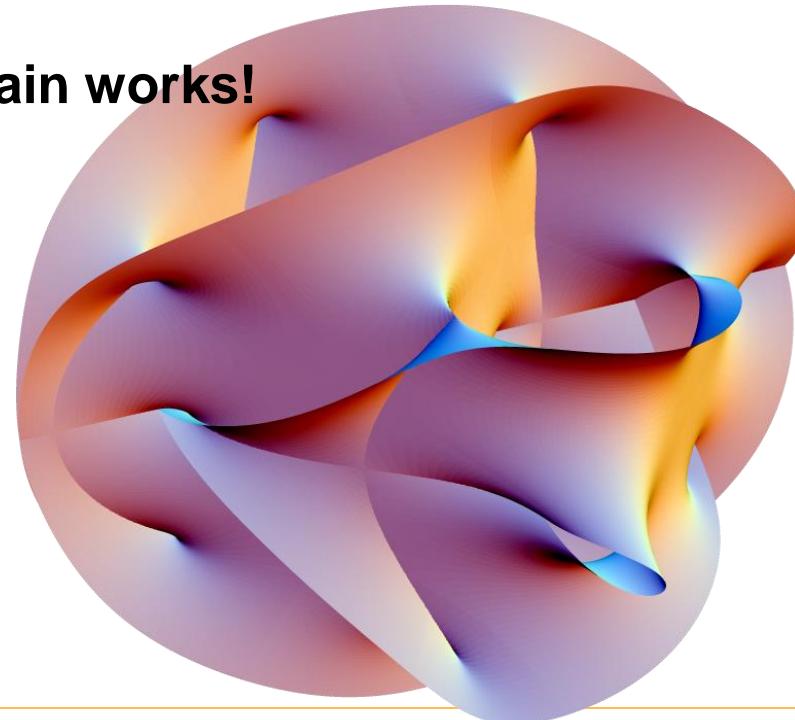
- If the same image is fed to a machine, how will the machine identify it to be a cat?
- This is where *Machine Learning* comes in. We'll keep on feeding images of a cat to a computer with the tag "cat" until the *machine learns all the features associated with a cat*
 - We'll also feed it images of things that are not a cat, like a dog for example, with the tag "not a cat"
- Once the machine learns all the features associated with a cat, we will feed it new data to determine how much has it learned
- In other words, *Raw Data/Training Data* is given to the machine, so that it *learns* all the features associated with the *Training Data*. Once, the learning is done, it is given *New Data/Test Data* to determine how well the machine has learned





The graph in the Machine

- The machine decides how many features it will examine, say n , and then it will draw a cat graph in n -dimensional space, and a non-cat graph
- Given a new image, it will look at the n features, and plot them in n -dimensional space and look at the intersect with the cat graph, and the non-cat graph, and decide which is the best intersect
- That, is also how your brain works!





Part 8

INTRO TO PROGRAMMING WITH R



Why?

- To learn to operate on vectors (lists) and matrices (spreadsheets) *all at the same time*
- Programming =
 1. Learn how to use a calculator
 2. Calculate with many numbers at the same time (e.g. spreadsheets)
 3. Work with variables in order to memorize intermediate computations





Next week: Learning R

- Run Anaconda
- Click on RStudio

The screenshot shows the Anaconda Navigator interface. On the left, there's a sidebar with links for Home, Environments, Projects (beta), Learning, and Community. The main area is titled "Applications on root" and shows several icons for different tools:

- lab**: An extensible environment for interactive and reproducible computing, based on the Jupyter Notebook and Architecture. Version 0.2.0. Includes "Launch" and "Install" buttons.
- jupyter**: Web-based, interactive computing notebook environment. Edit and run human-readable docs while describing the data analysis. Version 5.0.0. Includes "Launch" and "Install" buttons.
- ipy**: IPython Qt console. Version 4.3.1. Includes "Launch" and "Install" buttons.
- notebook**: A web-based, interactive computing notebook environment. Version 3.3. Includes "Launch" and "Install" buttons.
- qtconsole**: A Qt GUI that supports inline figures, proper multiline editing with syntax highlighting, graphical calltips, and more. Version 3.3. Includes "Launch" and "Install" buttons.
- spyder**: Scientific Python Development Environment. Powerful Python IDE with advanced editing, interactive testing, debugging and introspection features. Version 3.2.3. Includes "Launch" and "Install" buttons.
- glueviz**: Multidimensional visualization across files. Explore relationships within and among related datasets. Version 0.10.4. Includes "Install" button.
- orange3**: Components based on machine learning framework. Data visualization and data analysis for novice and expert. Interactive workflows with a large toolbox. Version 3.4.1. Includes "Install" button.
- rstudio**: A set of integrated tools designed to help you be more productive with R. Includes R essentials and notebooks. Version 1.0.153. Includes "Install" button.



120



After installing R, install R packages:

□ Install *dplyr* and *ggplot2* packages

- `install.packages("dplyr")`
- `install.packages("ggplot2")`

□ Load the libraries

- `library(dplyr); library(ggplot2)`

□ a) MAC OS X and Linux:

- Open Rstudio, in Menu, go to Packages and Data → Package Installer
- Search for and install the above two packages (may need to choose a “mirror” - click on something in the USA):
 - Type in the name of one package, click “get list”, check “Install Dependencies” and then “Install Selected”
 - Do the same for the other package

□ b) Windows:

- Open Rstudio, in Menu, go to "Packages" → "Install package(s) . . ." and select each of the packages at top to install



Homework (due next week)



West

- Research the history of numbers, probabilities, and statistics in non-western civilizations, like *yours*. Write one-page report.



East

