

Overview of Data Science

Promises and Pitfalls, Tools and Techniques



Professor Widom's Instructional Odyssey
www.professorwidom.org



Association for
Computing Machinery



Very Large Data Bases
Endowment Inc.



Data is Everywhere

- Explosion in data-driven scientific discovery, business practices, medicine, education, politics, societal interventions, ...
- And it's just the beginning
 - Ability to collect data across many domains will continue to accelerate
 - Data analysis techniques will continue to improve

“Data is the oil of the 21st century”



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“Data is the oil fuel of the 21st century”



The Two Steps of Working with Data

(1) Collect data

Via computers, sensors, people, events ...

(2) Do something with it

Make decisions, confirm hypotheses,
gain insights, predict future ...

“Data Science” = Going from (1) to (2)



This Session

- Promises of data science
 - Applications and services
- Data tools and techniques
 - Data analysis
 - Data mining and machine learning
 - Data visualization
- Pitfalls in data science
 - Correlation and causation
 - Underfitting and overfitting
 - Privacy and a few others
- Data systems and platforms

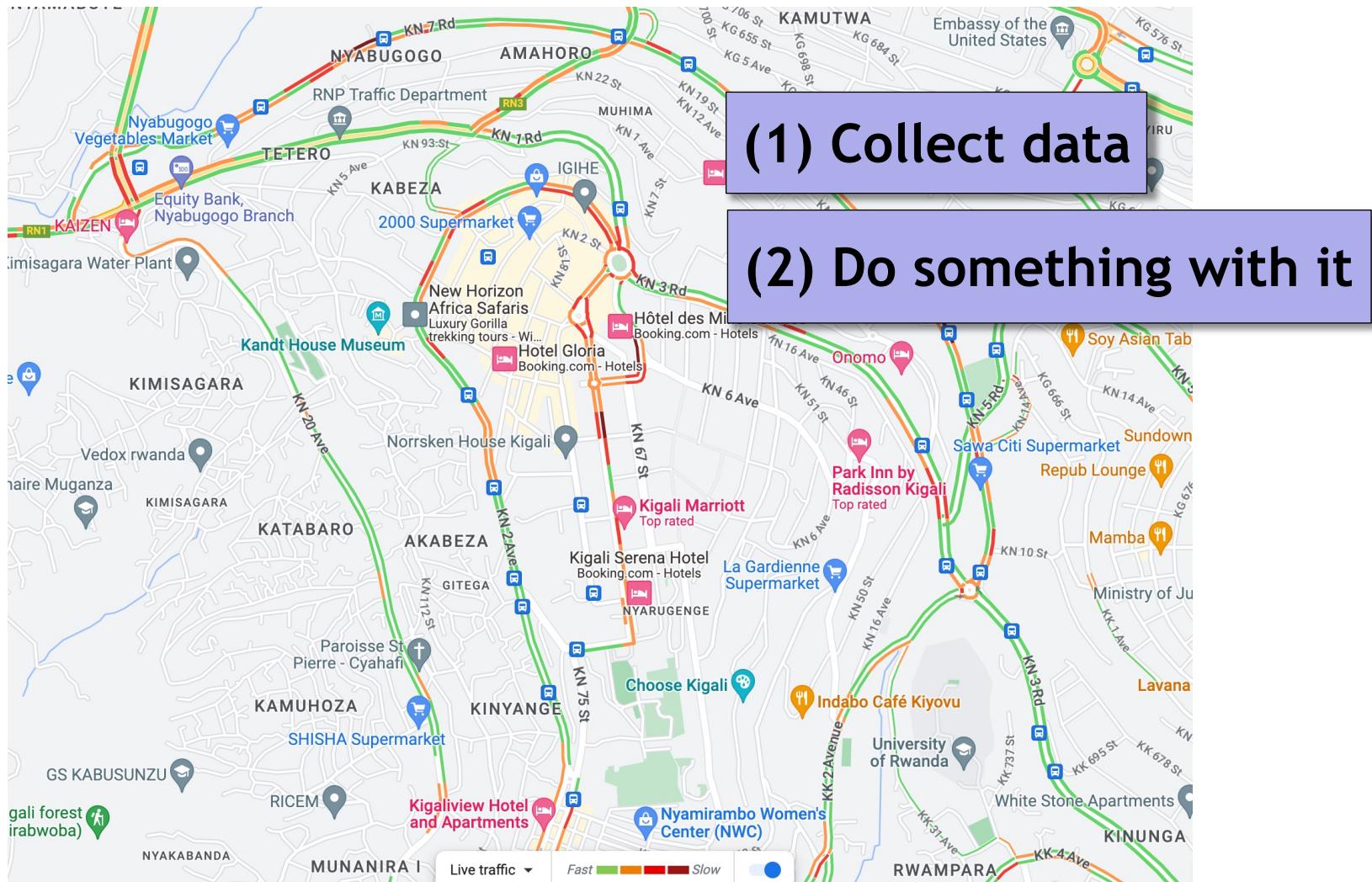


Promises of Data Science

- (1) Collect data
- (2) Do something with it

beneficial

Traffic



Recommender Systems

The image shows a composite screenshot of two websites illustrating recommender systems. The top half is the Amazon homepage, where a purple box highlights the 'Recommended for you, Jennifer' section with the text '(1) Collect data'. The bottom half is a Netflix interface, also with a purple box highlighting the 'Top Picks for Matthew' and 'Popular on Netflix' sections with the text '(2) Do something with it'.

(1) Collect data

(2) Do something with it

Recommended for you, Jennifer

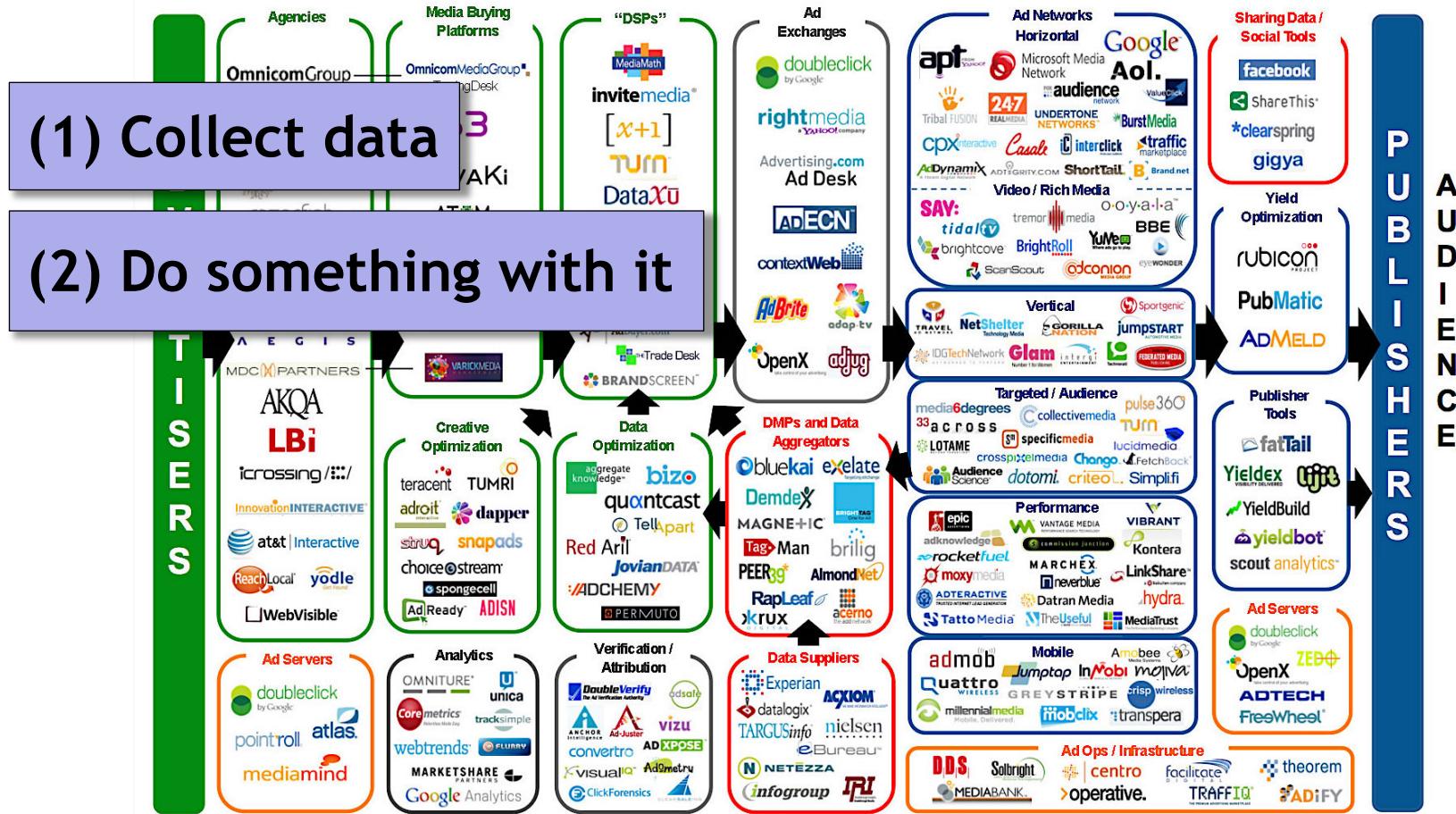
Top Picks for Matthew

Popular on Netflix

+ music, news, friends, romantic partners, and many more!

Online Advertising

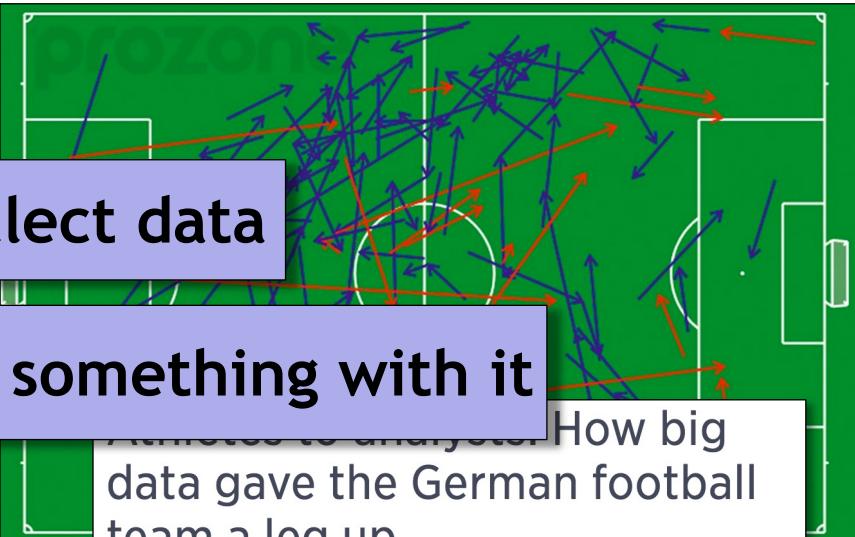
Display Advertising Technology Landscape



Sports



(1) Collect data



(2) Do something with it

"Remember, the other team is counting on Big Data insights based on previous games. So, kick the ball with your other foot."



How Big Data is Changing the World of Football

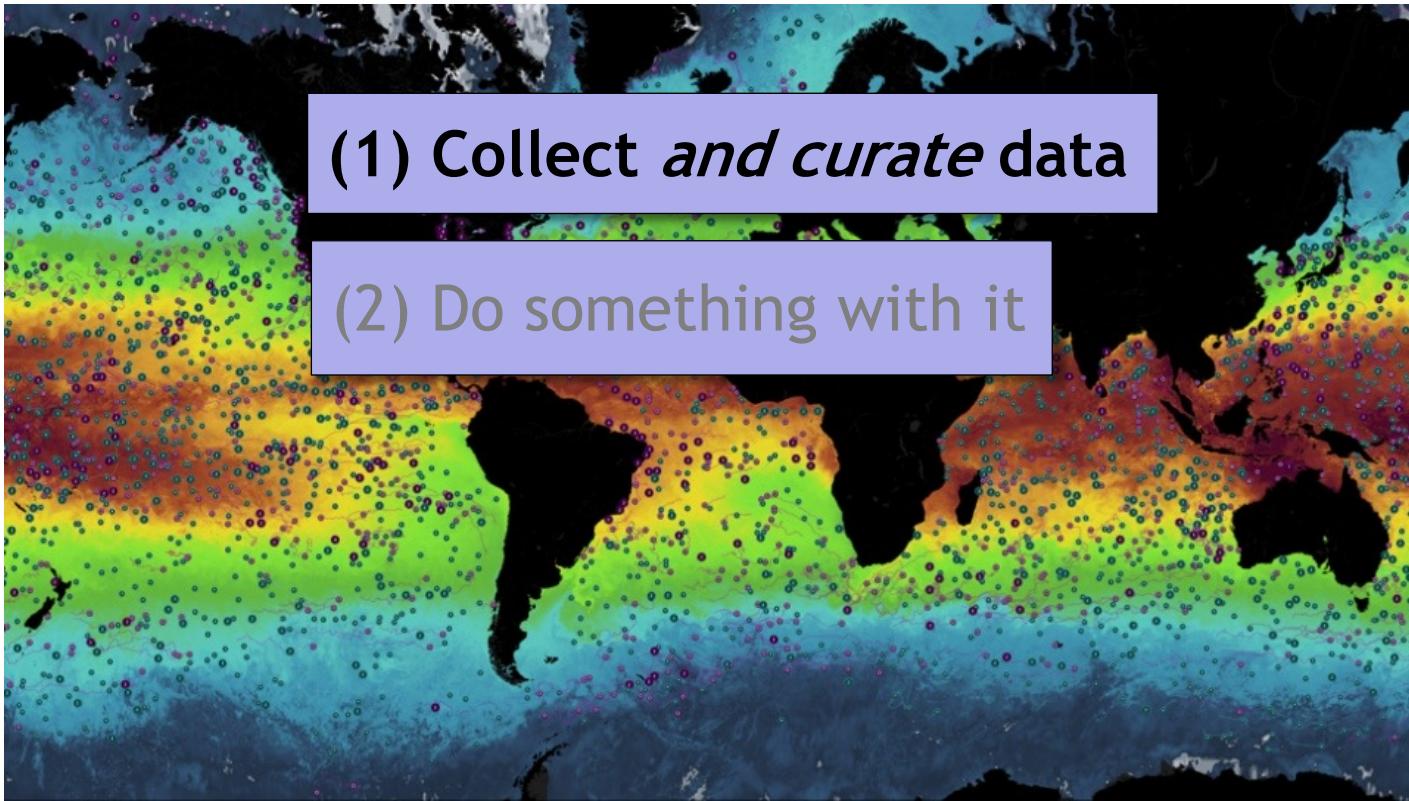
Athletes to analysts: How big data gave the German football team a leg up

Saheli Roy Choudhury | @sahelirc
Thursday, 7 Jul 2016 | 12:39 AM ET

CNBC



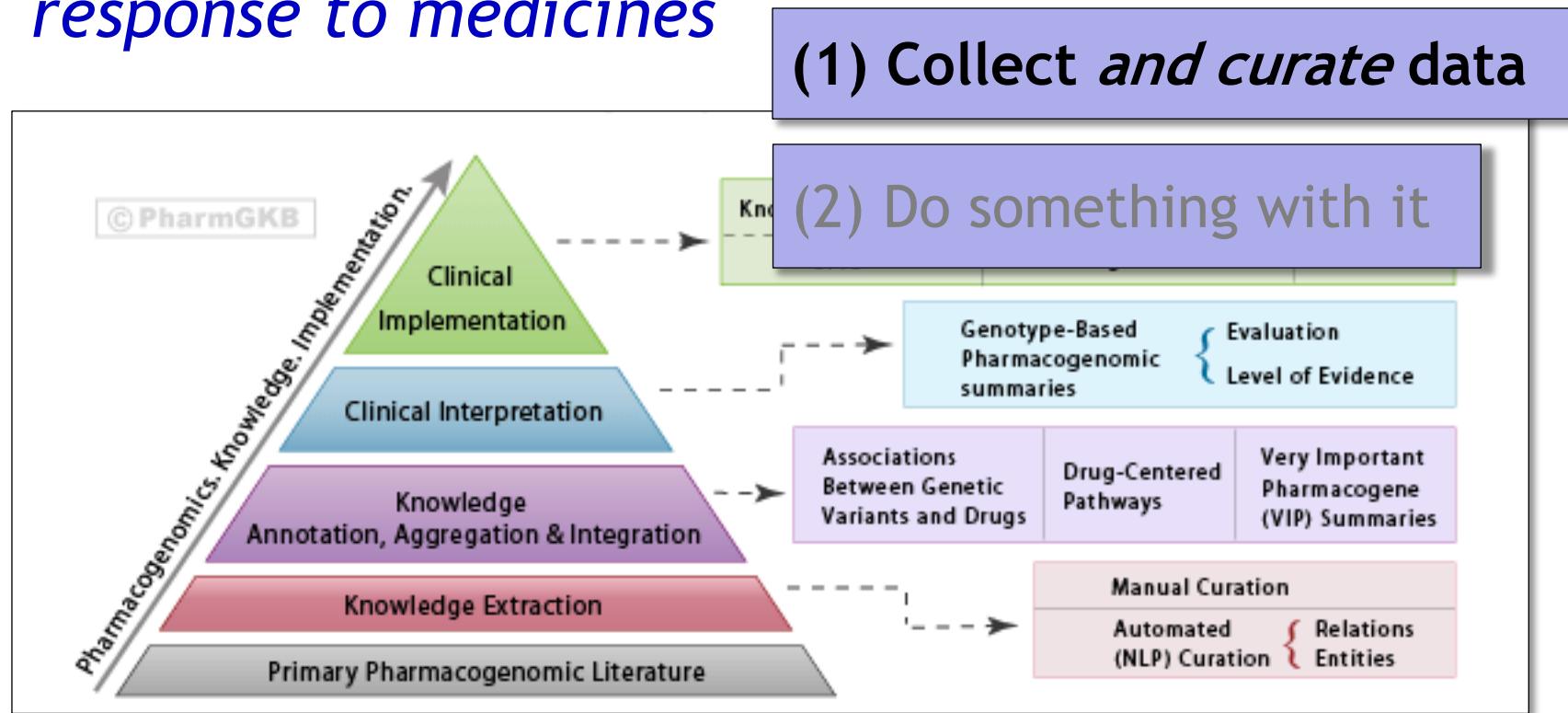
Ocean Health



44,000 sensors, over 2 billion measurements
Physical, chemical, biological ...

Genetics-Medicine Relationships

PharmGKB collects, curates, and disseminates knowledge about how human genetics affects response to medicines



And Many More

- Weather prediction
- Medical diagnosis
- Financial markets
- Resource management
- Computational social science
- Smart buildings and cities
-

The list goes on and on,
and it's still early days



Data Tools and Techniques

- Basic Data Manipulation and Analysis
Performing well-defined computations or asking well-defined questions (“queries”)
- Data Mining
Looking for patterns in data
- Machine Learning
Using data to build models and make predictions
- Data Visualization
Graphical depiction of data
- Data Collection and Preparation



Basic Data Manipulation and Analysis

Performing well-defined computations or asking well-defined questions (“queries”)

- Average January low temperature for each country over last 20 years
- Number of items over \$100 bought by females between ages 20 and 30
- Frequency of specific medicine relieving specific symptoms
- The ten stocks whose price varied the most over the past year



Basic Data Manipulation and Analysis

Performing well-defined computations or asking well-defined questions (“queries”)

- **Av** • Spreadsheets
- CO • Relational (SQL) database systems
- **Nu** • Programming languages with fe data support (e.g., Python, R)
- **Fr** • Specialized languages/platforms sp for “big data” (e.g., Spark, Hadoop)
- The ten stocks whose price varied the most over the past year



Data Mining

Looking for patterns in data

- Items X,Y,Z are bought together frequently
- People who like movie X also like movie Y
- Patients who respond well to medicines X and Y also respond well to medicine Z
- Students going to the same university are frequently online friends
- Wealthier people are moving from cities to suburbs



Data Mining

Looking for patterns in data

- Items X,Y,Z are bought together frequently
- People buy movie Y
- Patients buy movies X and Y
- Students buy books Z
- Students buy graphs, text, multimedia
- Friends are frequently online friends
- Wealthier people are moving from cities to suburbs

- Frequent item-sets
- Association rules
- Specialized techniques for



Machine Learning

Using data to build models and make predictions

- Customers who are women over age 20 are likely to respond to an advertisement
- Students with good grades are predicted to do well on entrance exams
- The temperature of a city can be estimated as the average of its nearby cities, unless some of the cities are on the coast or in the mountains



Machine Learning

Using data to build models and make predictions

- Customers who are over age 20 are likely to respond to an advertisement
 - Students who are predicted to do well on entrance exams
 - Roughly: Basic data analysis and data mining give answers from the available data, while machine learning uses the available data to make predictions about missing or future data
- Regression
 - Classification
 - Clustering



Machine Learning

The Latest in ML

Large Language Models and *Generative AI*

Machine learning models can also be used to generate new content in response to prompts, for example:

- *ChatGPT* for text
- *Copilot* for code
- *DALL-E* for images

Early days but very exciting technology



Data Visualization

“A picture is worth a thousand words”



Data Visualization

“A picture is worth a thousand words”
trillion data points



Early Data Visualization

Napoleon's Army

Carte Figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.

Dessiné par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite — Paris, le 20 Novembre 1869.

Les nombres d'hommes présents sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en travers des zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte ont été puisés dans les ouvrages de M. M. Chiers, de Ségur, de Fezensac, de Chambray et le journal médical de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davout, qui avaient été détachés sur Minsk et Mogilow et se rejoignaient vers Orsha en Witelsk, avaient toujours marché avec l'armée.

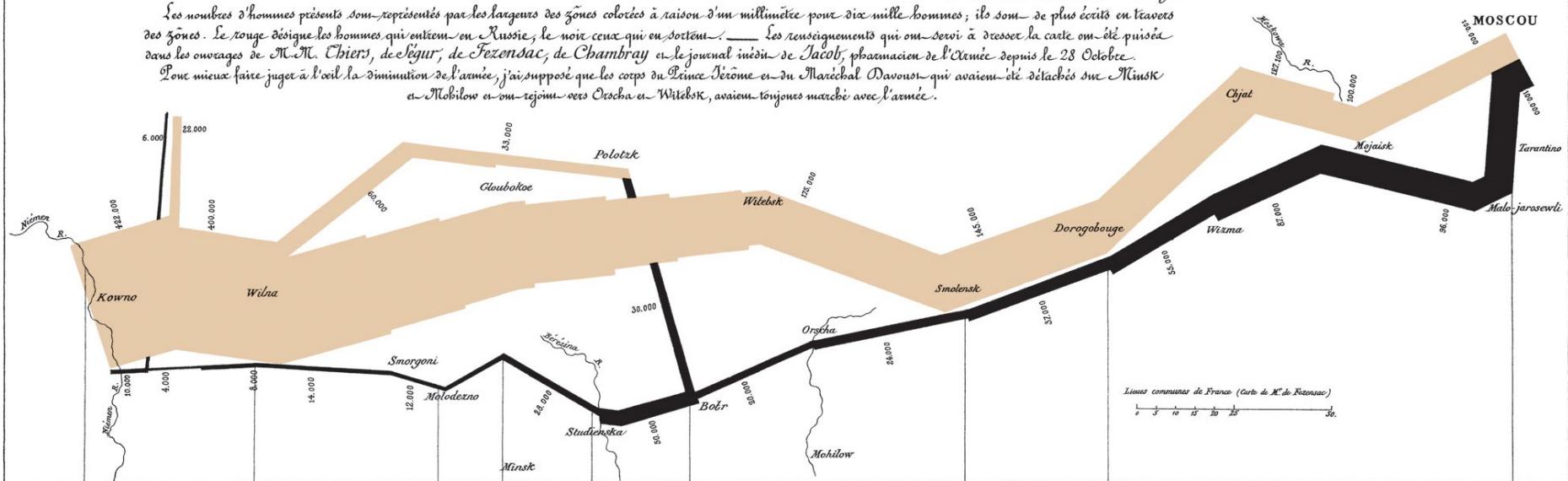
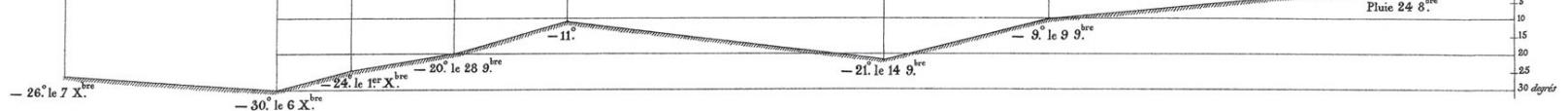
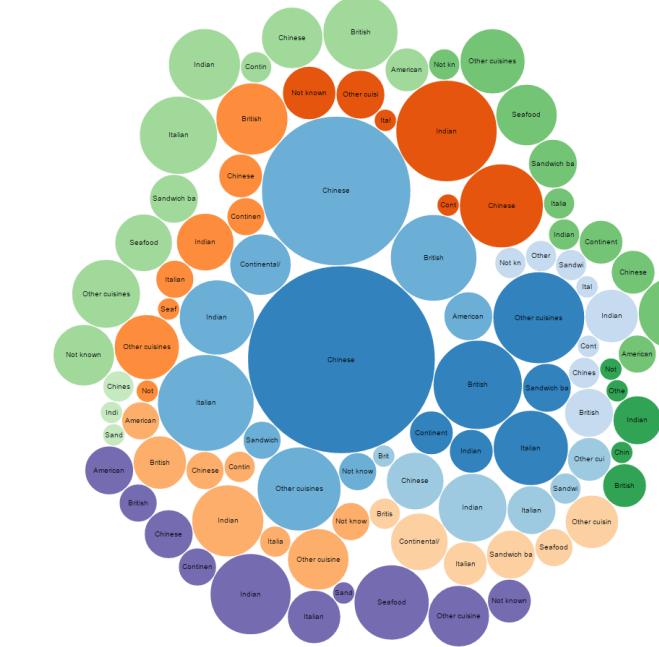
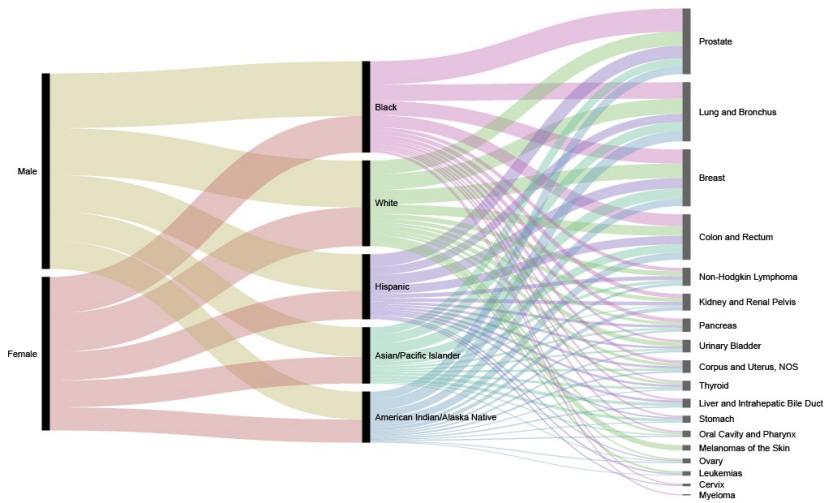
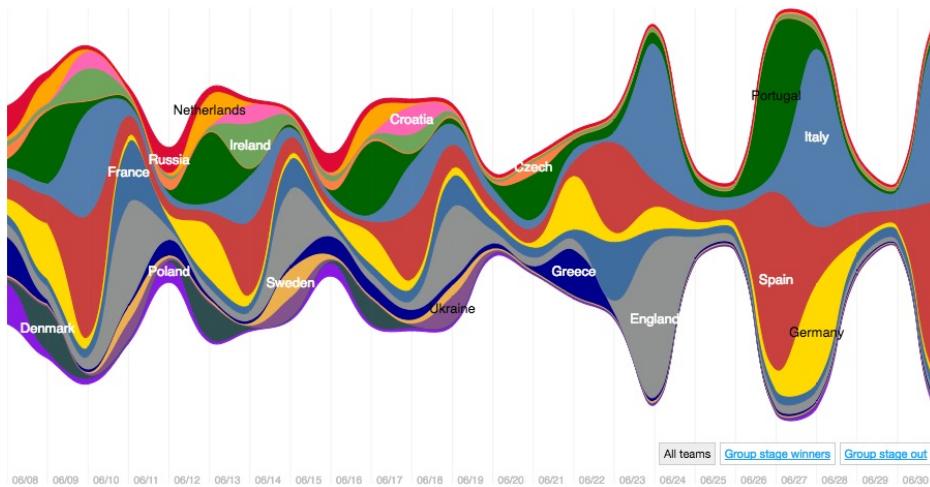


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.



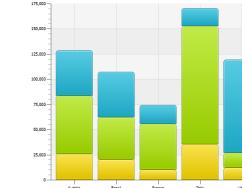
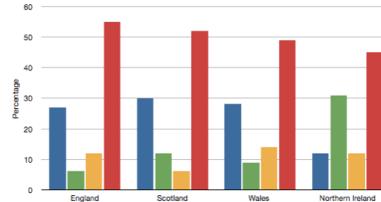
Modern Data Visualization



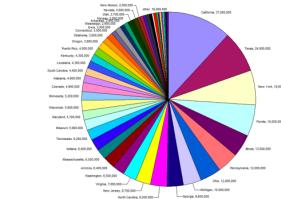
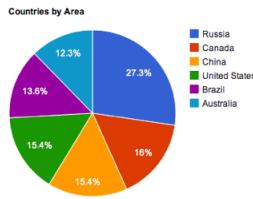
Basic Data Visualization

Don't underestimate the power of basic visualizations

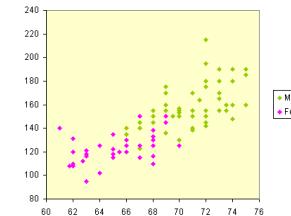
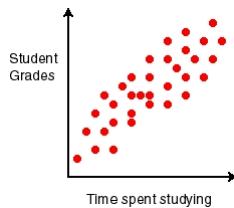
- Bar charts



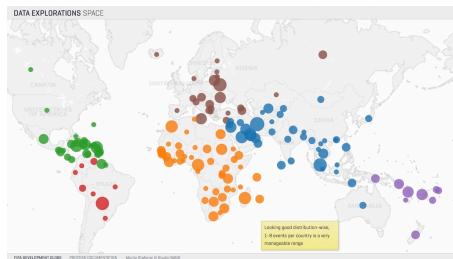
- Pie charts



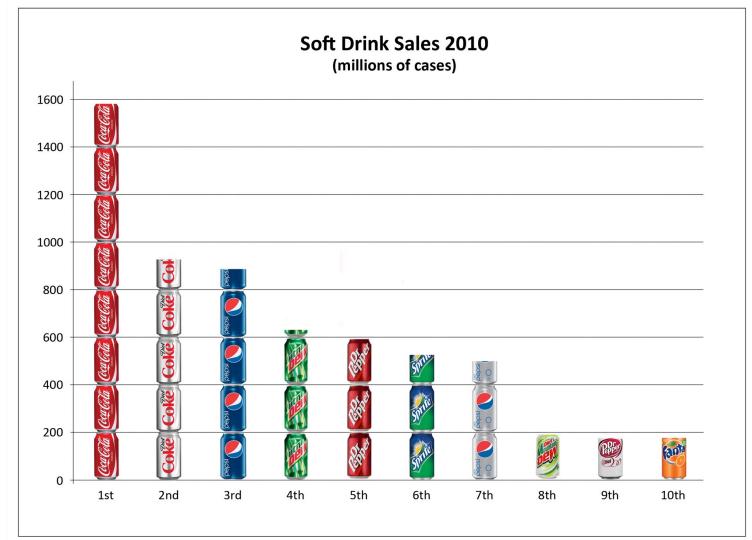
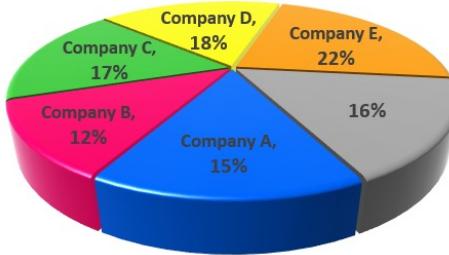
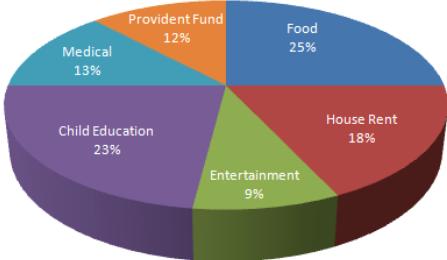
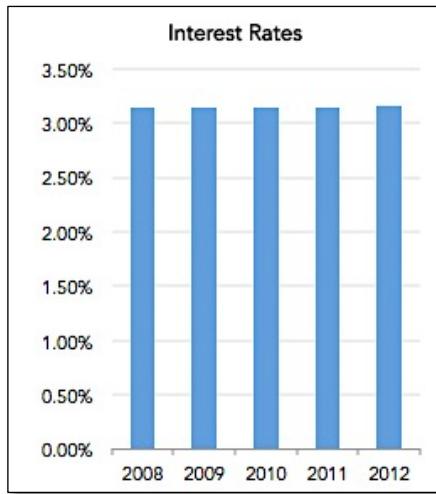
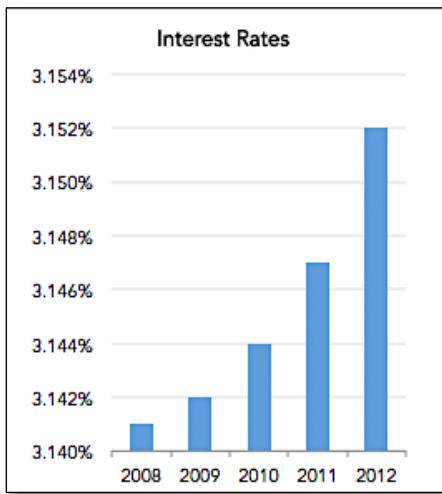
- Scatterplots



- Maps



Misleading Data Visualization



Data Collection and Preparation

The “dirty” secret of working with data

- Extracting data from difficult sources
- Filling in missing values
- Removing suspicious data
- Making formats, encoding, and units consistent
- De-duplicating and matching

Data preparation often
consumes 80% or more of the
effort in a data-driven project



Pitfalls of Data Science

- (1) Collect data
- (2) Do something with it

correct

Correlation and Causation

Data analysis, data mining, and machine learning can reveal relationships between data values

Correlation - values track each other

- Height and Shoe Size
- Grades and Entrance Exam Scores

Causation - because one value influences the other

- Education Level → Starting Salary
- Temperature → Cold Drink Sales



Correlation and Causation

“Correlation does not imply causation”

Correlation - values track each other

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Causation - because one value influences the other

- Education Level → Starting Salary
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Correlation and Causation

“Correlation does not imply causation”

- Correlation can be result of causation from a hidden “confounding variable”
- A and B are correlated because there's a hidden C such that $C \rightarrow A$ and $C \rightarrow B$
 - ❖ Homeless population and crime rate
Confounding variable: unemployment
 - ❖ Forgetfulness and poor eyesight
Confounding variable: age
 - ❖ Height and shoe size
 - ❖ Grades and entrance exam scores



Correlation and Causation

“Correlation does not imply causation”

- Correlation can be result of causation from a hidden “confounding variable”
- A and B are correlated because there's a hidden C such that $C \rightarrow A$ and $C \rightarrow B$

- Correlation is usually “easy” to test
- Causation is hard or impossible to test



Correlation and Causation



"I wish they didn't turn on that seatbelt sign so much! Every time they do, it gets bumpy."

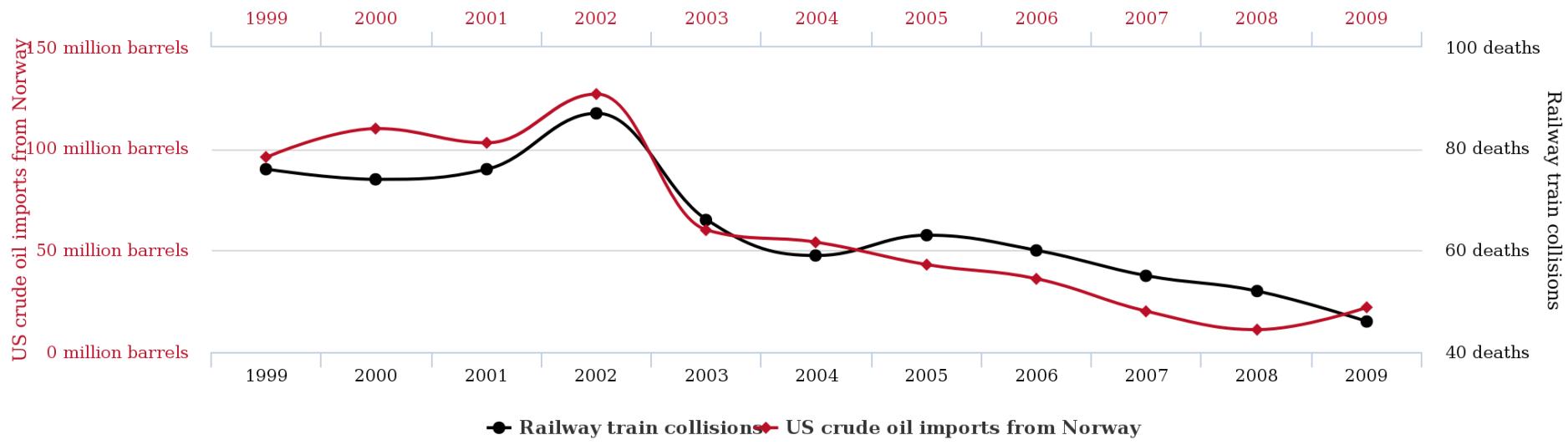


Surprising Correlation #1

US crude oil imports from Norway

correlates with

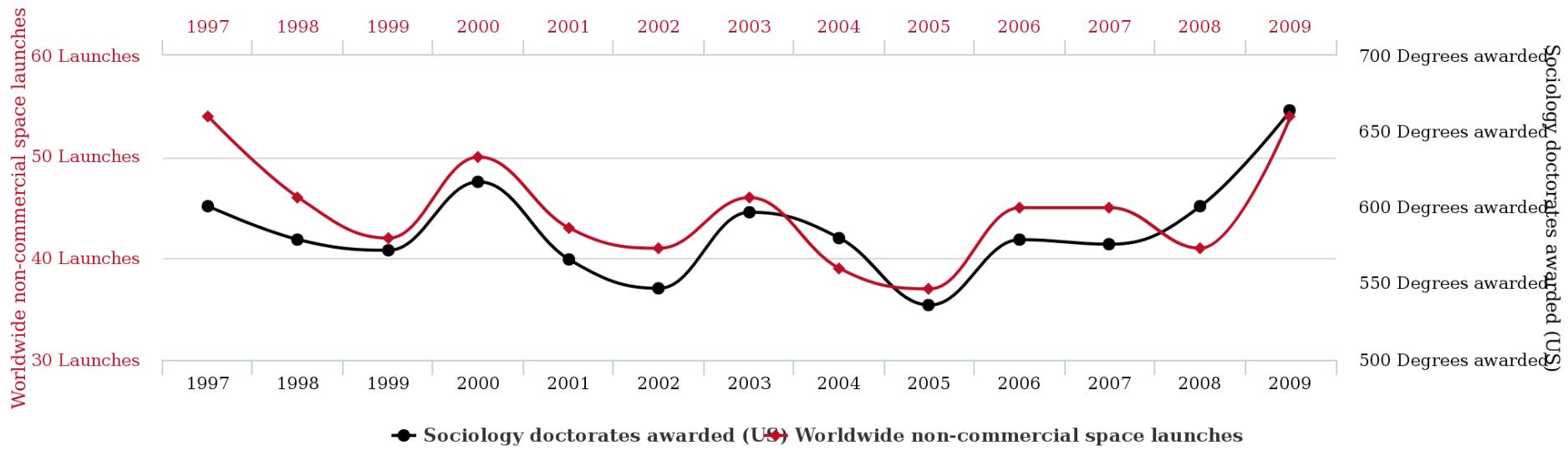
Drivers killed in collision with railway train



tylervigen.com

Surprising Correlation #2

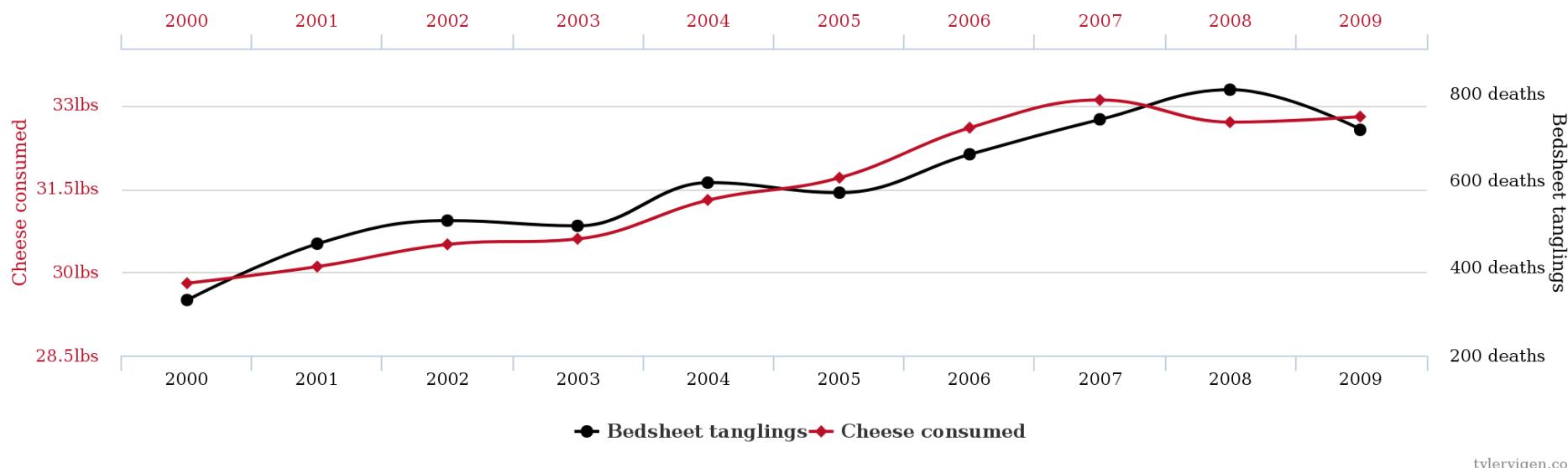
Worldwide non-commercial space launches
correlates with
Sociology doctorates awarded (US)



tylervigen.com

Surprising Correlation #3

Per capita cheese consumption
correlates with
Number of people who died by becoming tangled in their bedsheets



tylervigen.com

“Spurious Correlations” Website

<http://www.tylervigen.com/>



Stanford University

Underfitting and Overfitting

Machine learning uses data to create a “model” and uses model to make predictions

- Customers who are women over age 20 are likely to respond to an advertisement
- Students with good grades are predicted to do well on entrance exams
- The temperature of a city can be estimated as the average of its nearby cities, unless some of the cities are on the coast or in the mountains



Underfitting

Model used for predictions is too simplistic

- 60% of men and 70% of women responded to an advertisement, therefore all future ads should go to women
- If a furniture item has four legs and a flat top it is a dining room table
- The temperature of a city can be estimated as the average of its nearby cities, unless some of the cities are on the coast or in the mountains



Overfitting

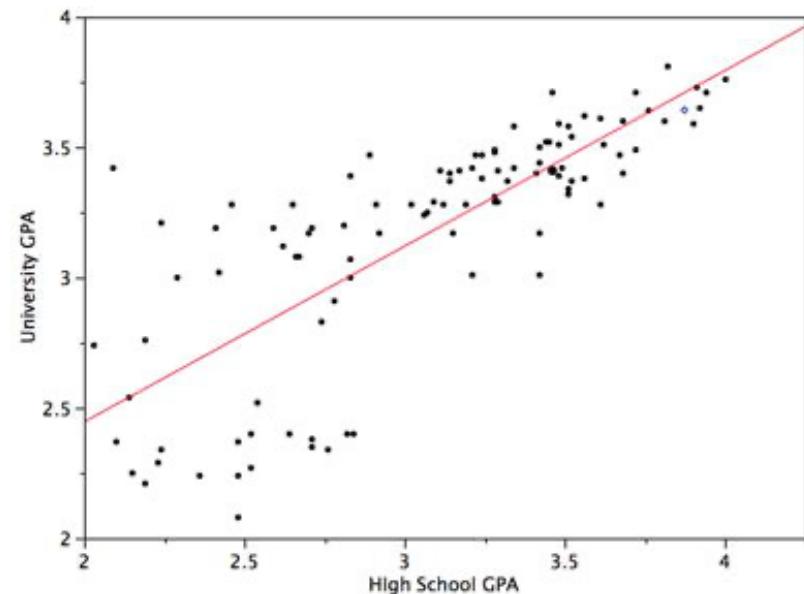
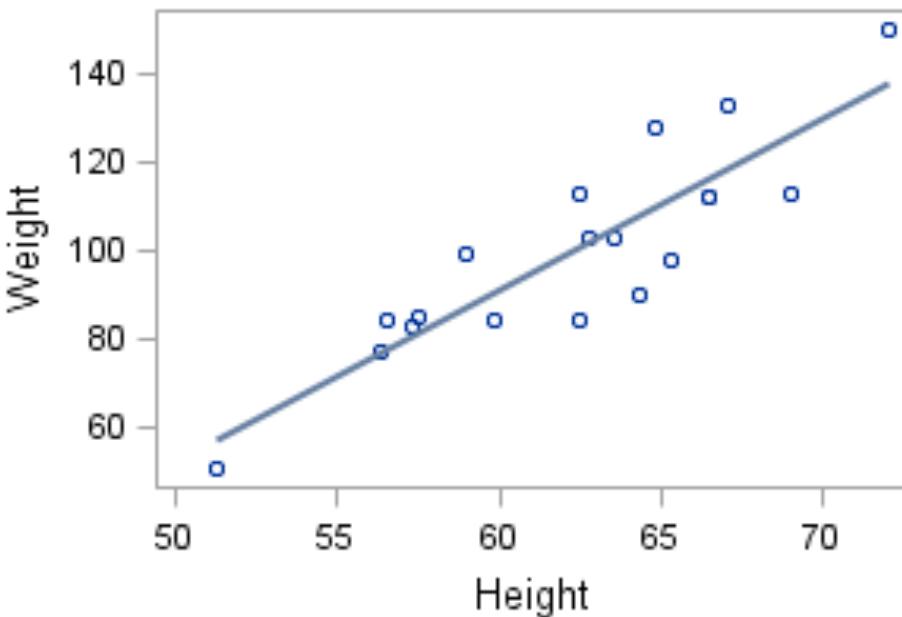
Model used for predictions is too specific

- The best targets for an advertisement are married women between 25 and 27 years with short black hair, one child, and one pet dog
- If a furniture item has four 100 cm legs with decoration and a flat polished wooden top with rounded edges then it is a dining room table



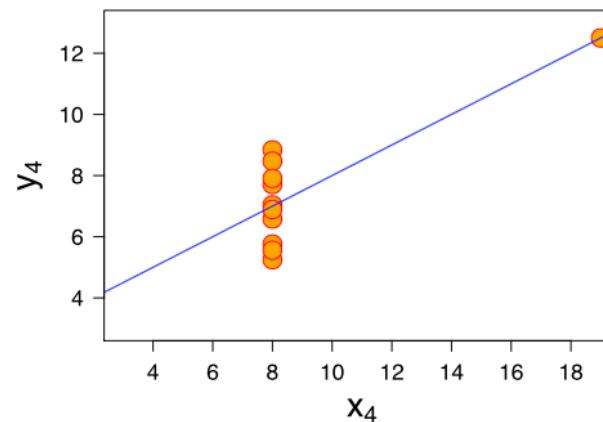
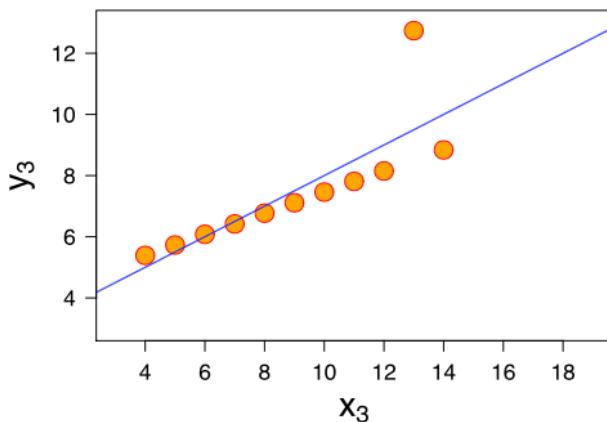
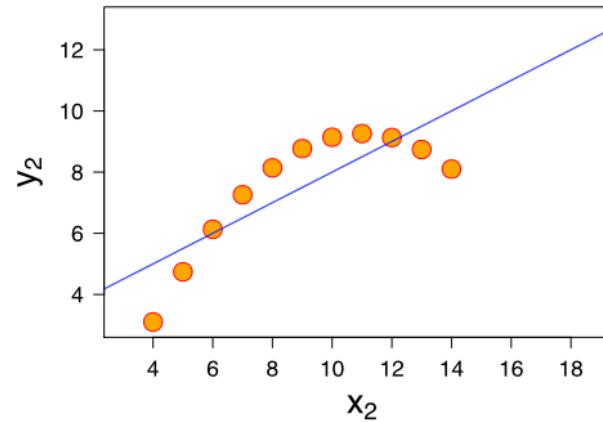
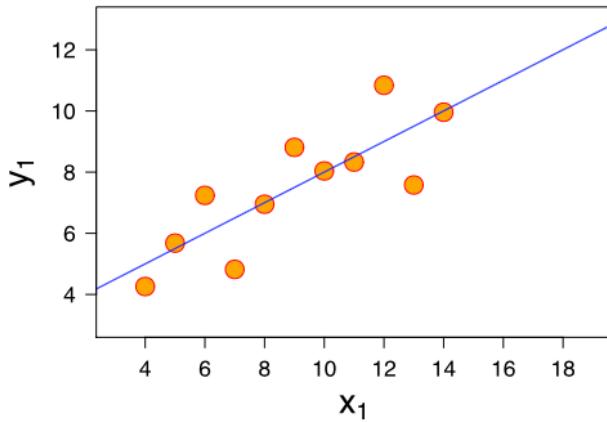
Regression

- Fit a line or curve to a set of points (model)
- Use model to predict values for new points



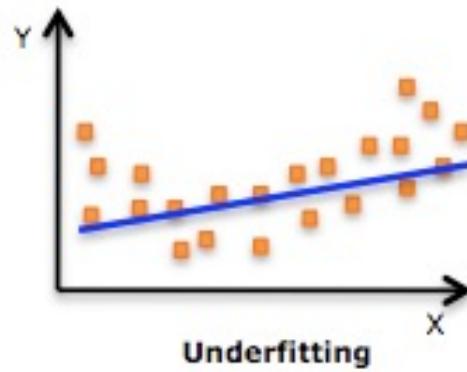
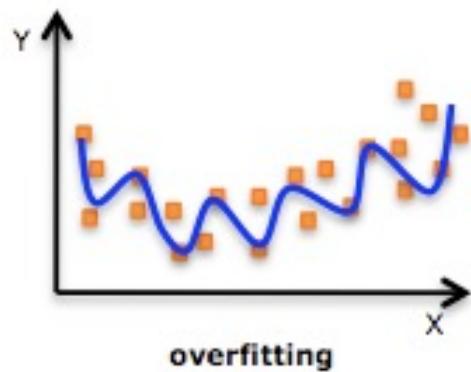
Underfitting

Model is too simplistic



Overfitting

Model is too specific



Soccer Match Prediction Scam

- Friday: receive email from “Psychic Sally” predicting which teams will be the winners in the weekend’s five soccer matches. She’s right about all of them!
- Same thing the following weekend: five games, all winners predicted correctly
- And the following one: five more correct
- Fourth Friday: Sally offers to give you her predictions for the coming weekend’s games, for a fee

Should you do it?



Soccer Match Prediction Scam

How many contacts must Sally start with on week one to ensure she has 100 potential buyers by week four, i.e., 100 people who received 15 correct predicted winners?
(Assume no draws)



Data Privacy

Of significant concern in some sectors

- Individual data collected covertly
 - Edward Snowden, “metadata” argument
- Individual data collected legally but used questionably
 - Individual “information trails” are enormous
 - Target stores pregnancy mailing
- Individual data deduced from “anonymous” public data
 - Governor of Massachusetts health record



Languages, Systems, Platforms

- Spreadsheets

Surprisingly versatile and powerful for data analysis tasks, provided data is not *too* large

- Relational Database Management Systems

- Also called RDBMS, SQL Systems
- Long-standing solution for reliability, efficiency, powerful query processing
- Works for all but truly extreme data sizes, or highly unstructured data



Languages, Systems, Platforms

- Programming languages with data support
 - R Language - powerful statistical features
 - Python - general-purpose language with R-like add-ons (Pandas, SciPy, scikit-learn)
- Specialized languages/platforms for “big data”
 - Distributed processing for extreme scalability
 - Some specifically target unstructured data (documents, graphs)
 - *Spark* and *Hadoop* widely used



Languages, Systems, Platforms

- Systems for data preparation
- Systems for data visualization
- Data processing in the cloud
 - Amazon Web Services, Google Cloud, Microsoft Azure
 - Data storage
 - Data processing: SQL, Spark, Hadoop
 - Machine learning libraries
 - Integration with visualization systems



How Much Data is There?

Complete works of William Shakespeare
5 megabytes

Average individual
50 gigabytes (10,000 Shakespeares)

USA Library of Congress
10 terabytes (2 million Shakespeares)

Uploaded to Facebook daily
1 petabyte (200 million Shakespeares)

Produced by humanity daily
2.5 exabytes (500 trillion Shakespeares)



“Big Data”

Some domains produce vast quantities of data, and some analyses require “big data” to be effective

- Most tools and techniques apply to data of all sizes
- Big insights can come from small/medium data

Sometimes twenty Spark servers
in the cloud are required.

More often a laptop with SQL, Python,
or simple spreadsheets does the job.

Rest of the Short-Course

- Data Analysis Using Spreadsheets
- Data Visualization Using Spreadsheets
- Advanced Data Visualization Using Tableau
- Relational Databases and Basic SQL
- Python for Data Analysis and Visualization
- Machine Learning - Regression, Classification, Clustering
- Using Python for Machine Learning

If more time, decide among...

- Advanced SQL
- Data Mining Algorithms
- Data Mining Using Python
- The R Language
- Network Analysis
- Unstructured Data
- Correlation and Causation



Overview of Data Science Promises and Pitfalls, Tools and Techniques



Thank You!



Association for
Computing Machinery



Very Large Data Bases
Endowment Inc.

