Data science

The Big Data challenge

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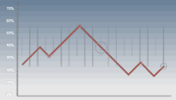
Big data hype?

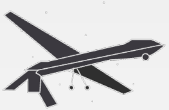
Emergency management

EARTH OBSERVATIONS

HISTORICAL DATA



SEASONAL
WEATHER FORECAST



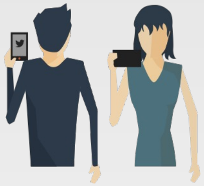
UNMANNED AERIAL VEHICLES

SOCIAL MEDIA
DATA STREAMS

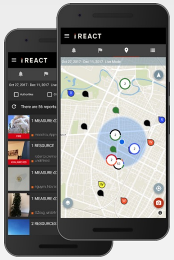
Improving Resilience to Emergencies
Through Advanced Cyber Technologies

I REACT

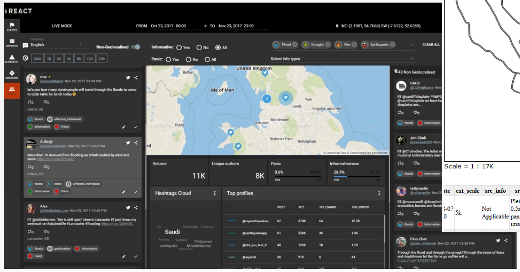
Emergency management

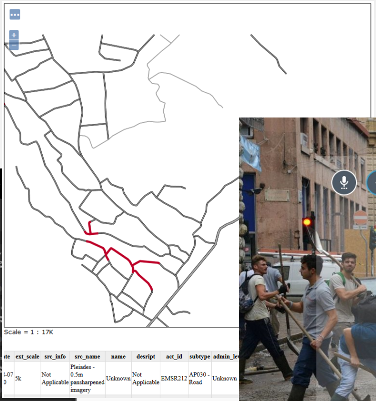


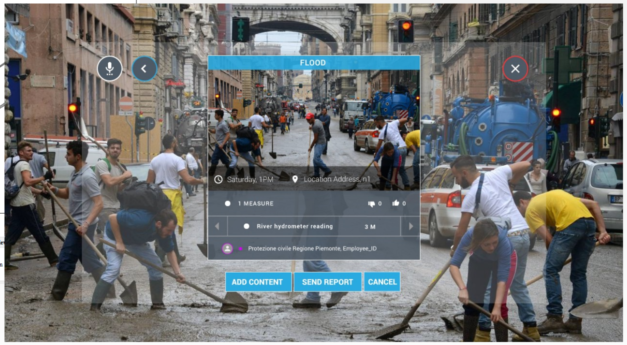
CITIZENS



FIRST RESPONDERS AND DECISION MAKERS







Improving Resilience to Emergencies Through Advanced Cyber Technologies

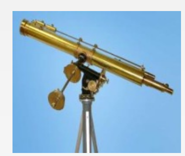
i REACT

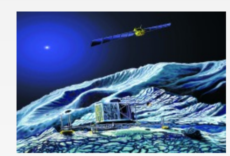
User engagement

Who generates big data?

- User Generated Content (Web & Mobile)
  - E.g., Facebook, Instagram, Yelp, TripAdvisor, Twitter, YouTube

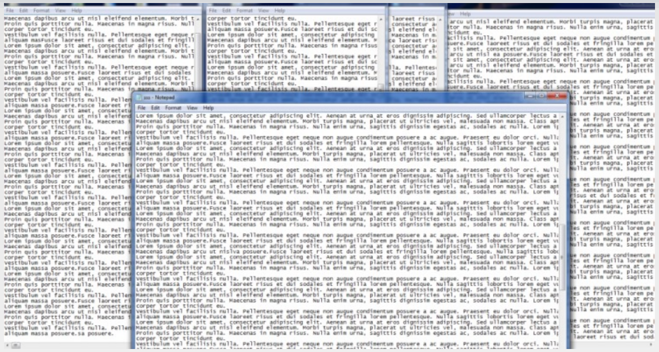
- Health and scientific computing



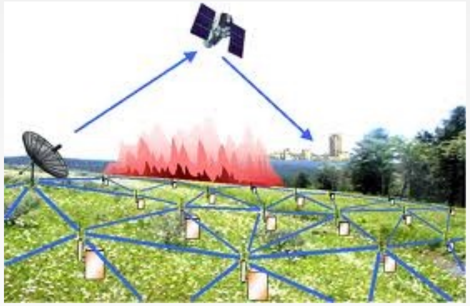


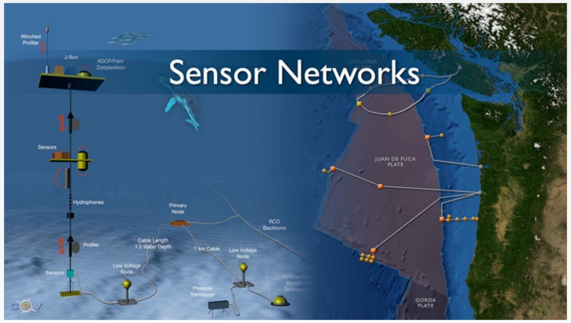
Who generates big data?

- Log files
  - Web server log files, machine syslog files



- Internet Of Things
  - Sensor networks, RFID, smart meters





What is big data?

- Many different definitions

"Data whose scale, diversity and complexity require new architectures, techniques, algorithms and analytics to manage it and extract value and hidden knowledge from it"

What is big data?

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*"Data whose **scale**, **diversity** and **complexity** require new architectures, techniques, algorithms and analytics to manage it and extract value and hidden knowledge from it"*

What is big data?

- Many different definitions

"Data whose scale, diversity and complexity require new ***architectures****,* ***techniques****,* ***algorithms*** *and* ***analytics*** *to manage it and extract value and hidden knowledge from it"*

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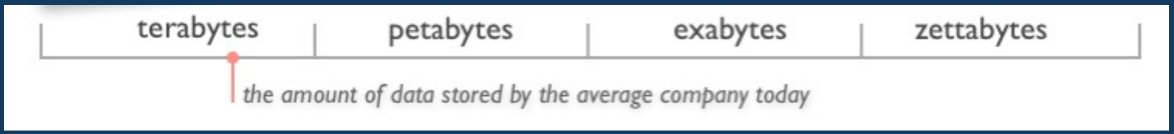
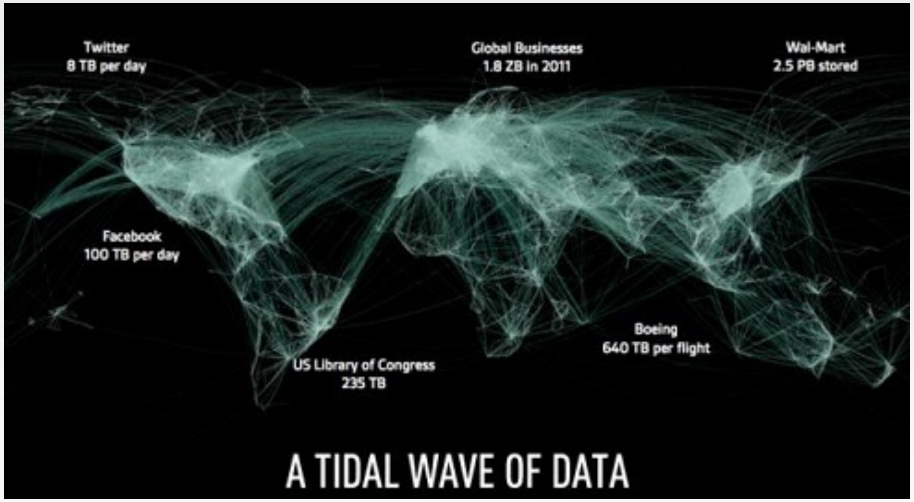
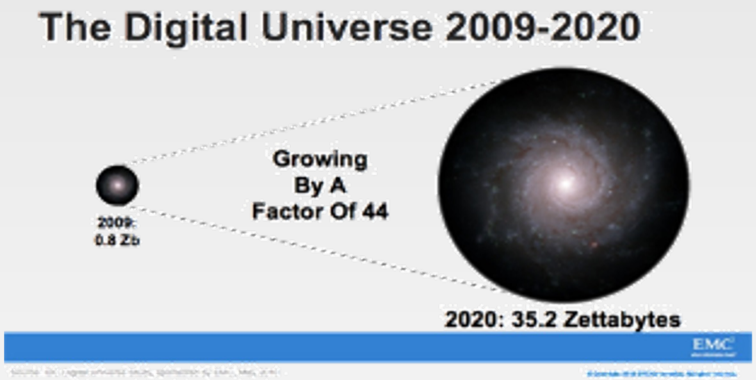
"Data whose scale, diversity and complexity require new architectures, techniques, algorithms and analytics to manage it and extract ***value*** *and hidden* ***knowledge*** *from it"*

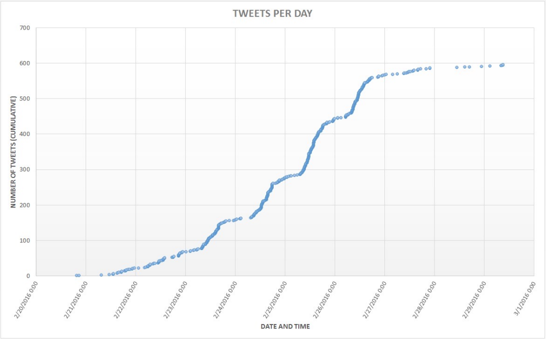


The Vs of big data: Volume

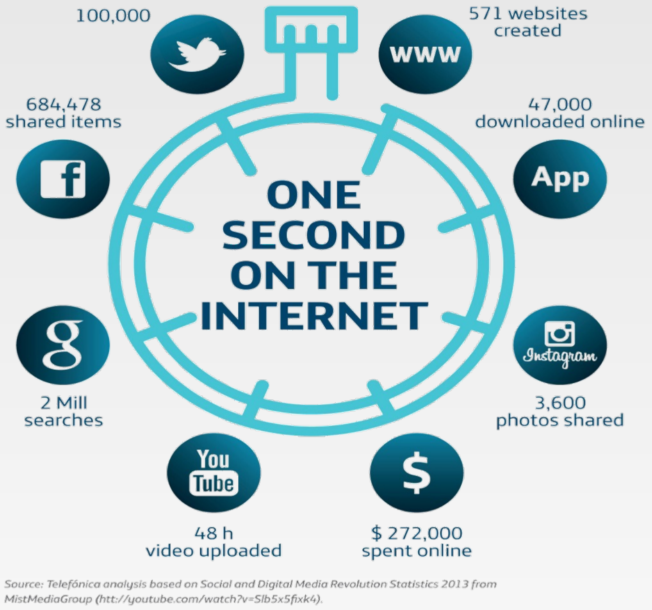
- Data volume increases exponentially over time
- 44x increase from 2009 to 2020
  - Digital data 35 ZB in 2020







On the Internet…

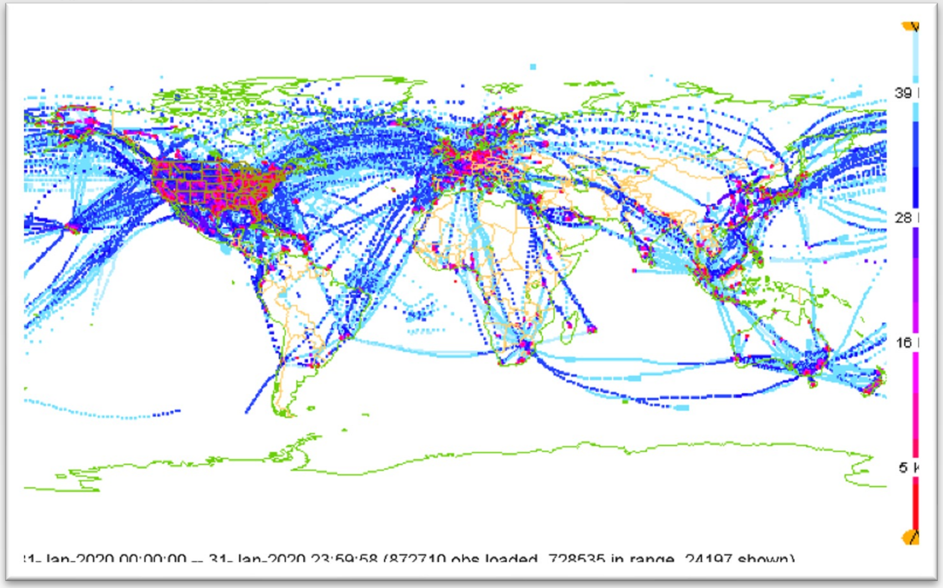


- http://www.internetlivestats.com/

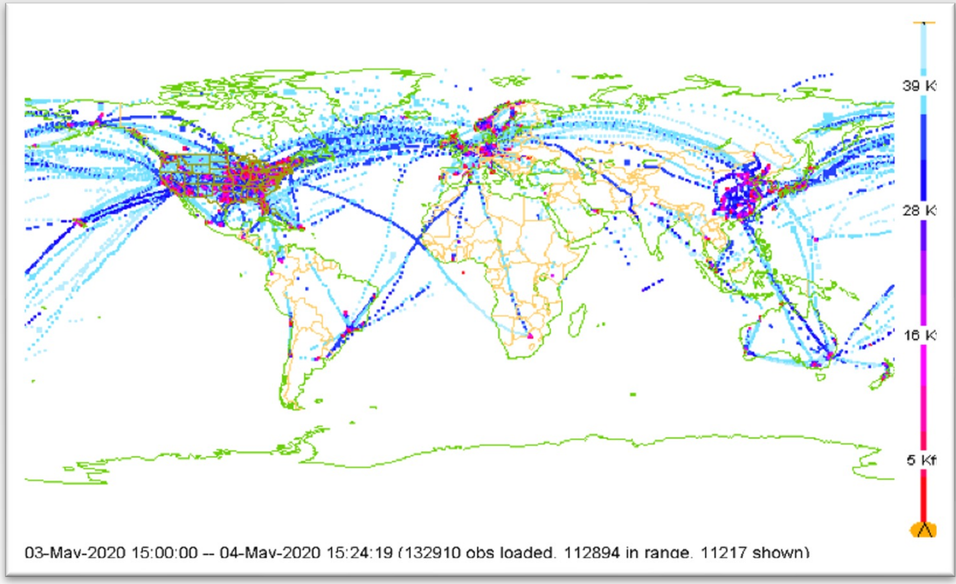
Weather forecast

WORLD METEOROLOGICAL ORGANIZATION

January 2020

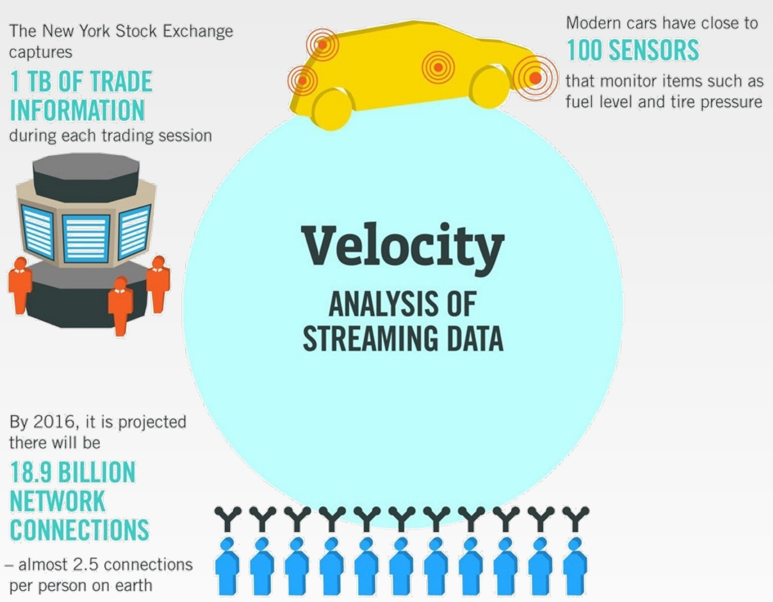


May 2020

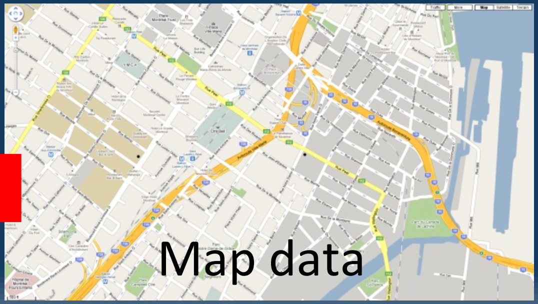


The Vs of big data: Velocity

- Fast data generation rate
  - Streaming data
- Very fast data processing to ensure timeliness

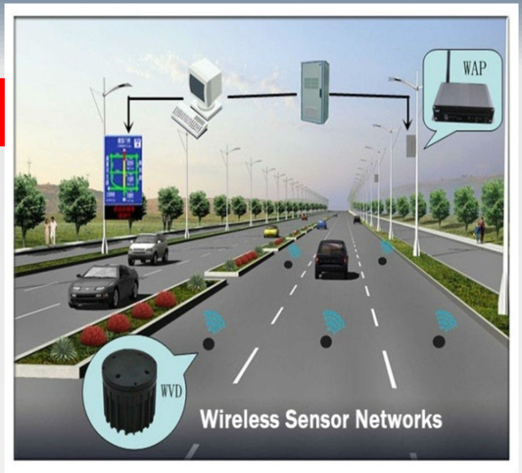


(Near) Real time processing

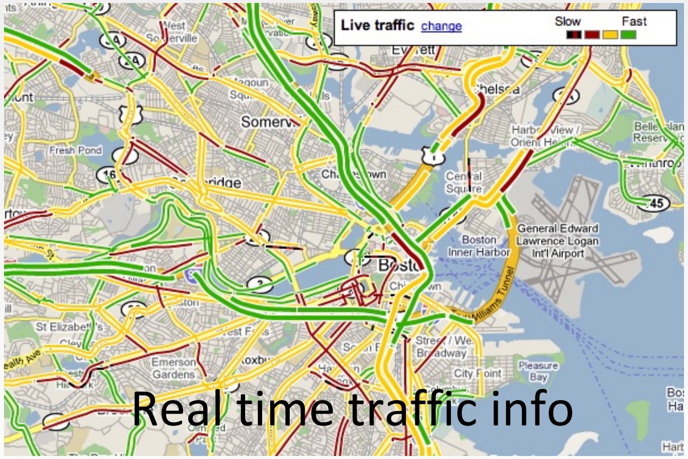


Crowdsourcing

Computing

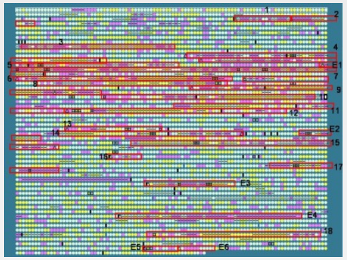
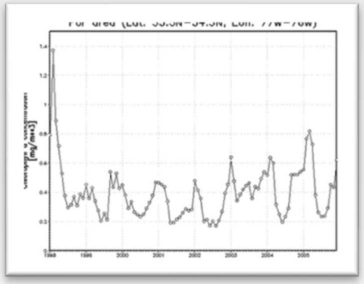


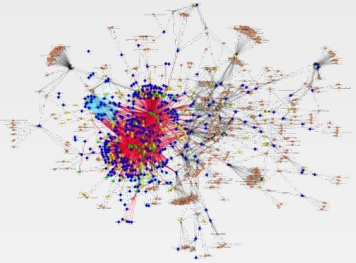
Sensing



The Vs of big data: Variety

- Various formats, types and structures
  - Numerical data, image data, audio, video, text, time series



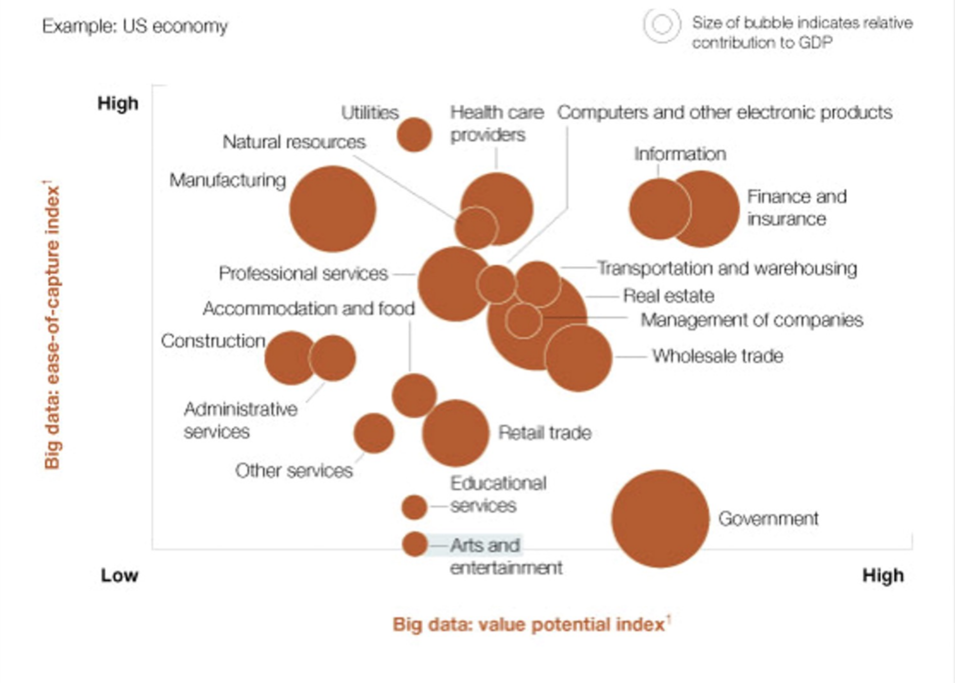
- A single application may generate many different formats

The Vs of big data: Veracity

- Data quality

The most important V: Value

- Translate data into business advantage



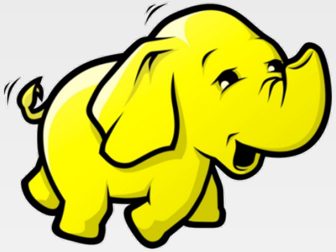
[1] For detailed explication of metrics, see appendix in McKinsey Global Institute full report *Big data: The next frontier for innovation, competition, and productivity*, available free of charge online at mckinsey.com/mgi.

Source: US Bureau of Labor Statistics; McKinsey Global Institute analysis

Big data challenges

- Technology & infrastructure
  - New architectures, programming paradigms and techniques

    Transfer the processing power to the data
  - Apache Hadoop/Spark ecosystem



- Data management & analysis
  - New emphasys on "data"

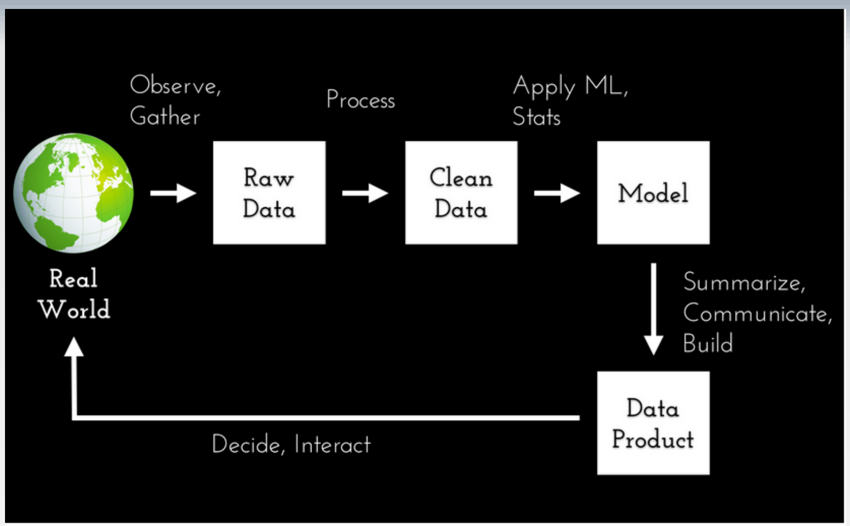
➡ ***Data science***

Data science

"Extracting meaning from very large quantities of data"

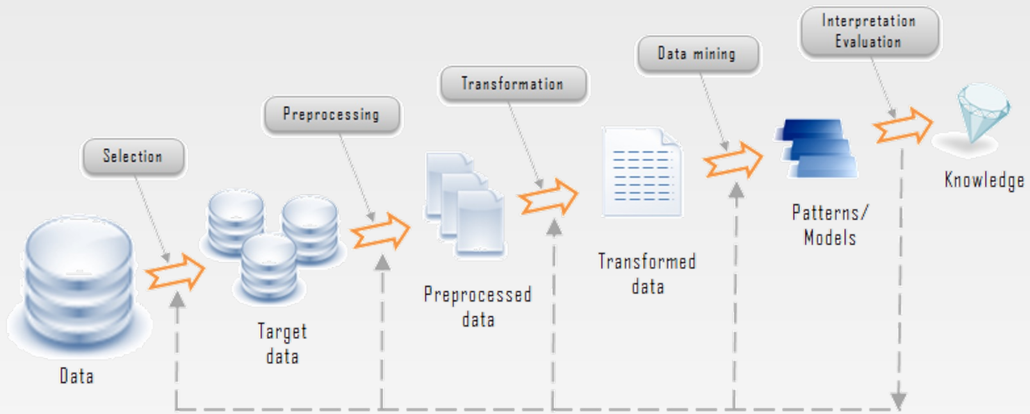
D.J. Patil coined the word *data scientist*

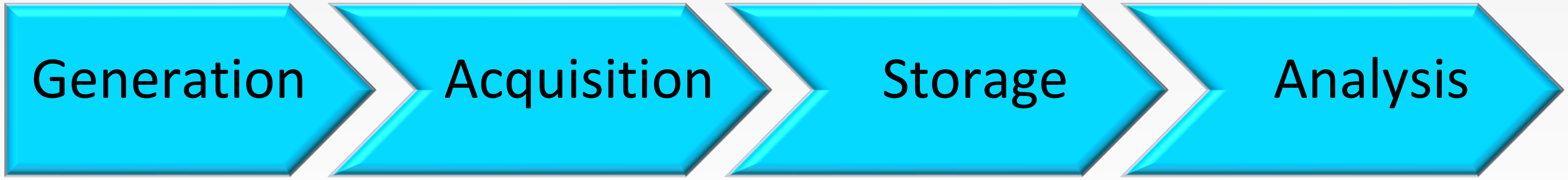
The data science process



AKA *KDD* process

Knowledge Discovery in Databases





Generation

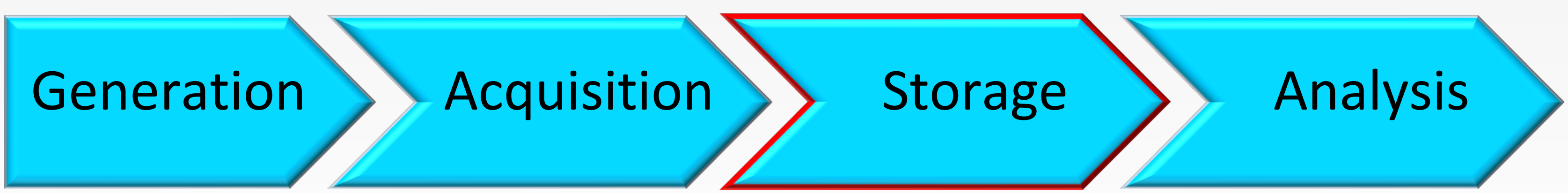
- Passive recording
  - Typically structured data
  - Bank trading transactions, shopping records, government sector archives
- Active generation
  - Semistructured or unstructured data
  - User-generated content, e.g., social networks
- Automatic production
  - Location-aware, context-dependent, highly mobile data
  - Sensor-based Internet-enabled devices (IoT)

Acquisition

- Collection
  - Pull-based, e.g., web crawler
  - Push-based, e.g., video surveillance, click stream
- Transmission
  - Transfer to data center over high capacity links
- Preprocessing
  - Integration, cleaning, redundancy elimination

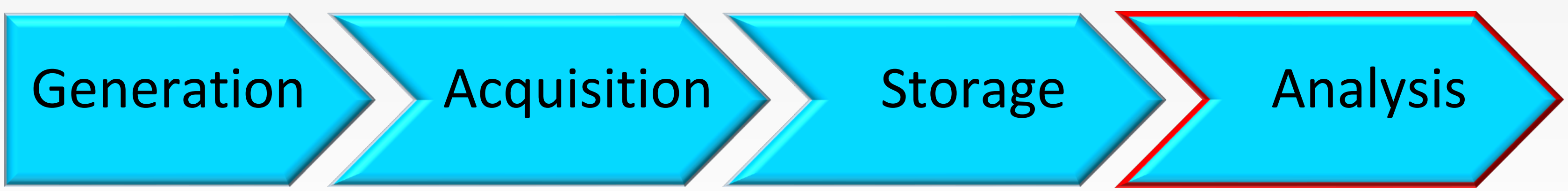
Storage

- Storage infrastructure
  - Storage technology, e.g., HDD, SSD
  - Networking architecture, e.g., DAS, NAS, SAN
- Data management
  - File systems (HDFS), key-value stores (Memcached), column-oriented databases (Cassandra), document databases (MongoDB)
- Programming models
  - Map reduce, stream processing, graph processing



Analysis

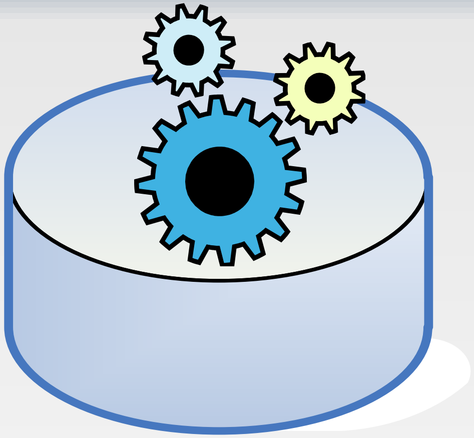
- Objectives
  - Descriptive analytics, predictive analytics, prescriptive analytics
- Methods
  - Statistical analysis, machine learning and data mining, text mining, network and graph data mining
  - Association analysis, classification and regression, clustering
- Diverse domains call for customized techniques



Machine learning and data mining

- Non trivial extraction of
  - implicit
  - previously unknown
  - potentially useful

  information from available data



- Extraction is automatic
  - performed by appropriate algorithms
- Extracted information is represented by means of abstract models
  - denoted as *pattern*

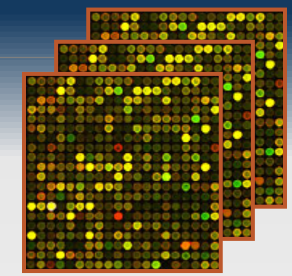
Example: profiling

- Consumer behavior in e-commerce sites
  - Selected products, requested information, …
- Search engines and portals
  - Query keywords, searched topics and objects
- Social network data
  - Profiles (Facebook, Instagram, …)
  - Dynamic data: posts on blogs, FB, tweets
- Maps and georeferenced data
  - Localization, interesting locations for users

Example: profiling

- User/service profiling
  - Recommendation systems, advertisements
- Market basket analysis
  - Correlated objects for cross selling
    - User registration, fidelity cards
- Context-aware data analysis
  - Integration of different dimensions
    - E.g., location, time of the day, user interest
- Text mining
  - Brand reputation, sentiment analysis, topic trends

Example: biological data



- Microarray
  - expression level of genes in a cellular tissue
  - various types (mRNA, DNA)

CLID	PATIENT ID	shx013: 49A34	shv060: 45A9	shq077: 52A28	shx009: 4A34	shx014: 61A31	shq082: 99A6	shq083: 46A15	shx008: 41A31
IMAGE:74	ISG20 || in	-1.02	-2.34	1.44	0.57	-0.13	0.12	0.34	-0.51
IMAGE:76	TNFSF13	-0.52	-4.06	-0.29	0.71	1.03	-0.67	0.22	-0.09
IMAGE:36	LOC93343	-0.25	-4.08	0.06	0.13	0.08	0.06	-0.08	-0.05
IMAGE:23	ITGA4 || in	-1.375	-1.605	0.155	-0.015	0.035	-0.035	0.505	-0.865

- Patient clinical records
  - personal and demographic data
  - exam results

- Textual data in public collections
  - heterogeneous formats, different objectives
  - scientific literature (PUBMed)
  - ontologies (Gene Ontology)

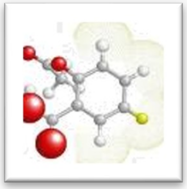
PubMed

GO the Gene Ontology

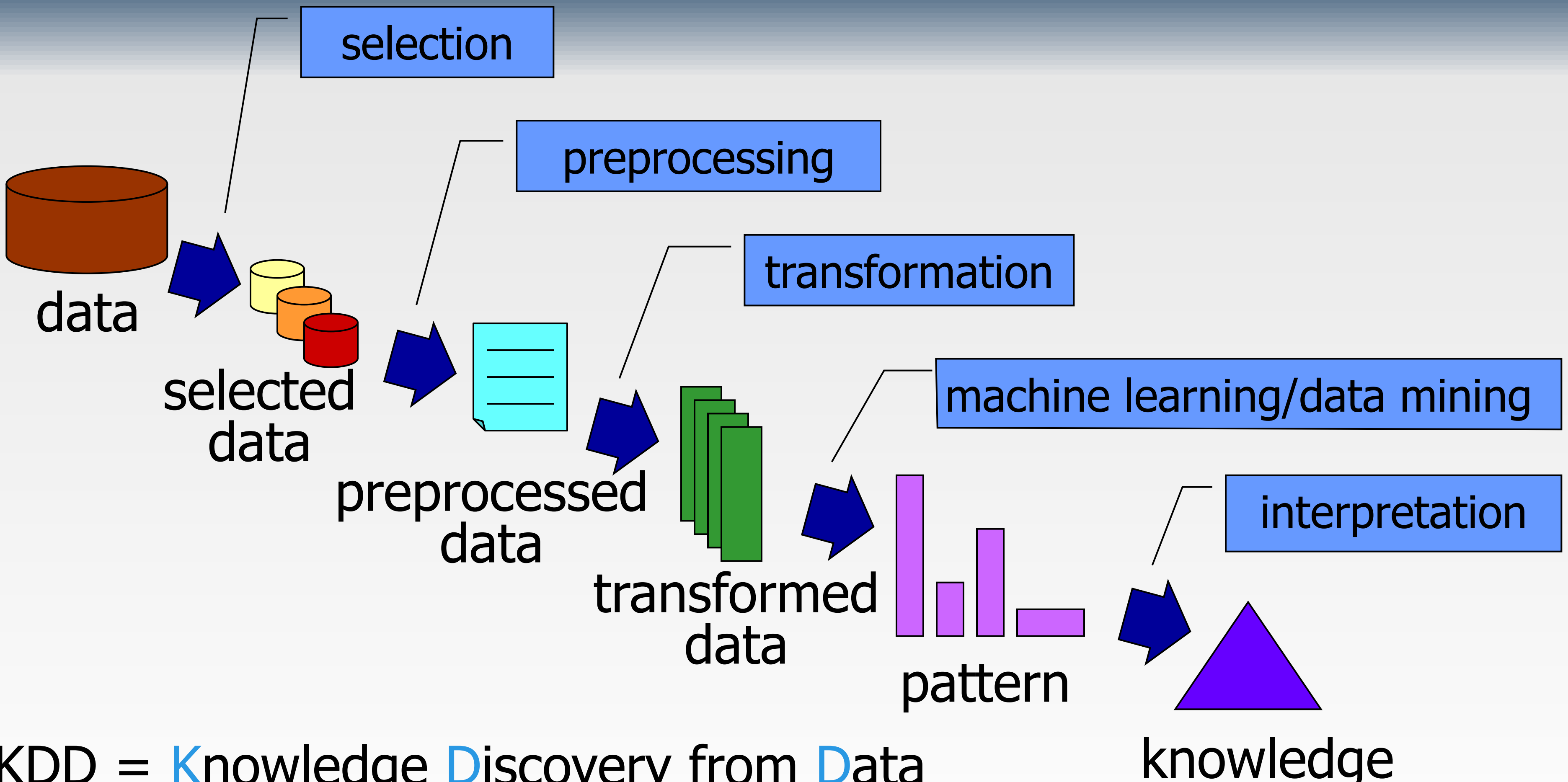
Biological analysis objectives

- Clinical analysis
  - detecting the causes of a pathology
  - monitoring the effect of a therapy
  - ⇒ diagnosis improvement and definition of new specific therapies

- Bio-discovery
  - gene network discovery
  - analysis of multifactorial genetic pathologies
- Pharmacogenesis
  - lab design of new drugs for genic therapies

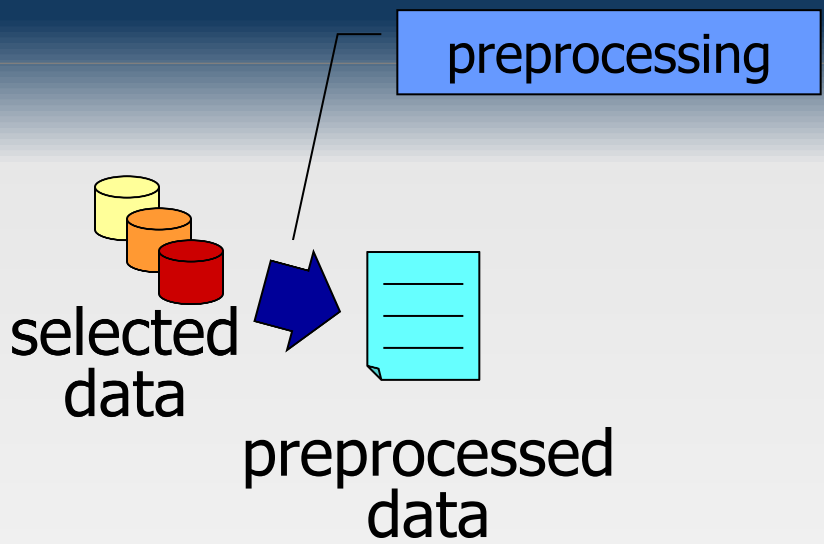


Knowledge Discovery Process



KDD = Knowledge Discovery from Data

Preprocessing



data cleaning

- reduces the effect of noise
- identifies or removes outliers
- solves inconsistencies

data integration

- reconciles data extracted from different sources
- integrates metadata
- identifies and solves data value conflicts
- manages redundancy

Real world data is "dirty"

Without good quality data, no good quality pattern

A word from practitioners

- At least 80-90% of their work involves not machine learning, but
  - Working with experts to understand the domain, assumptions, questions
  - Trying to catalog and make sense of the data sources
  - Wrangling, extracting, and integrating the data
  - Cleaning the wrangled data

Association rules

- Objective
  - extraction of frequent correlations or pattern from a transactional database

Tickets at a supermarket counter

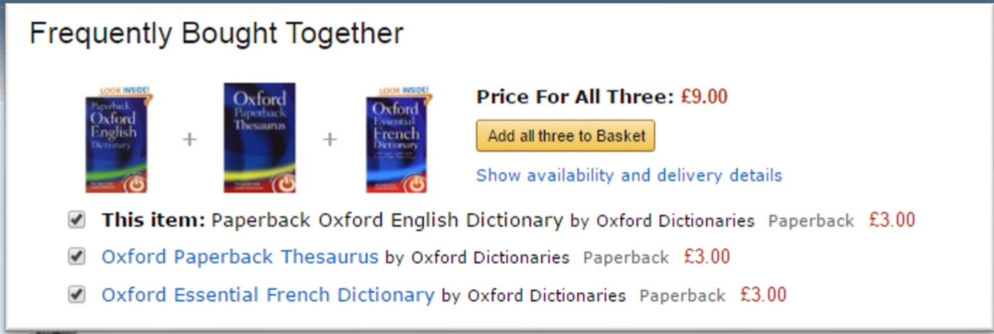
TID	Items
1	Bread, Coke, Milk
2	Beer, Bread
3	Beer, Coke, Diapers, Milk
4	Beer, Bread, Diapers, Milk
5	Coke, Diapers, Milk
…	…

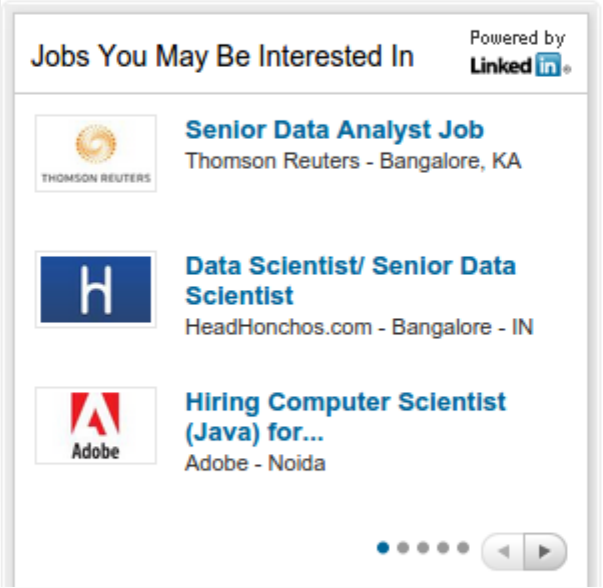
- Association rule

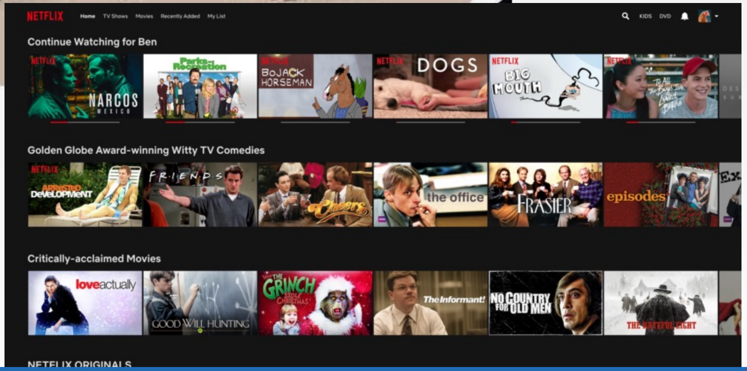
  diapers $\Rightarrow$ beer

  - 2% of transactions contains both items
  - 30% of transactions containing diapers also contain beer

Association rules

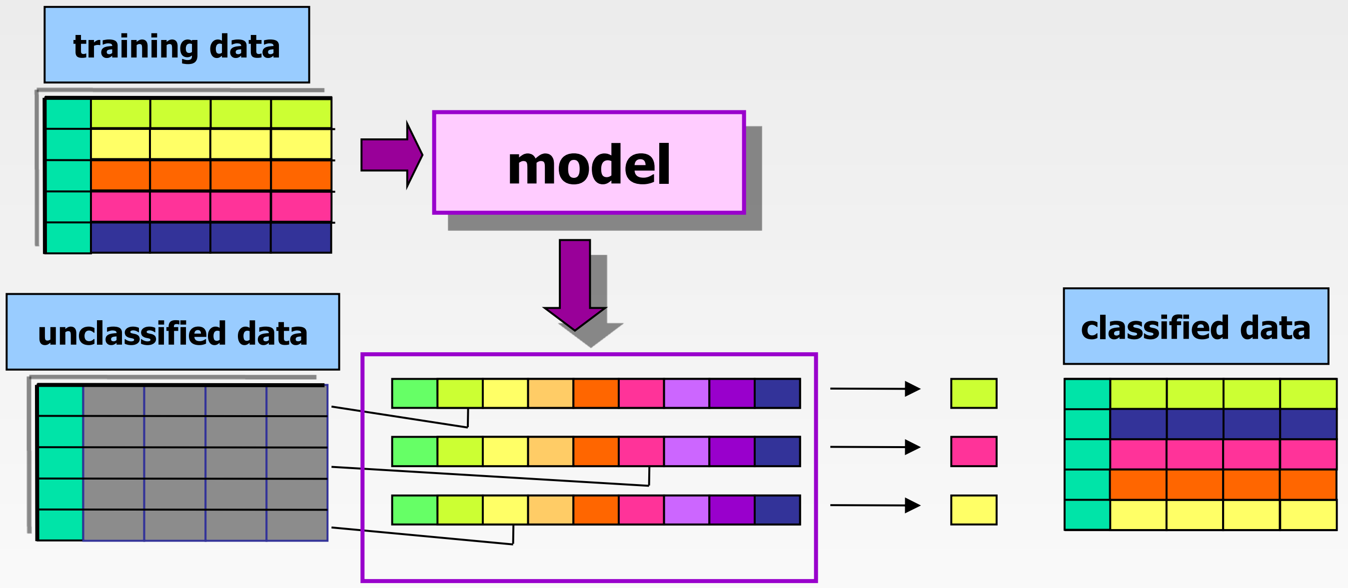






Classification

- Objectives
  - prediction of a class label
  - definition of an interpretable model of a given phenomenon



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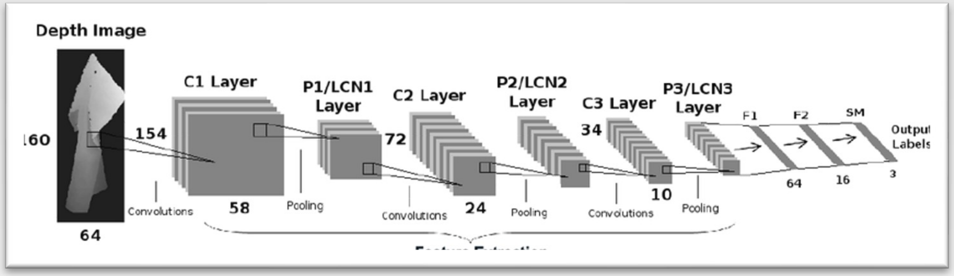
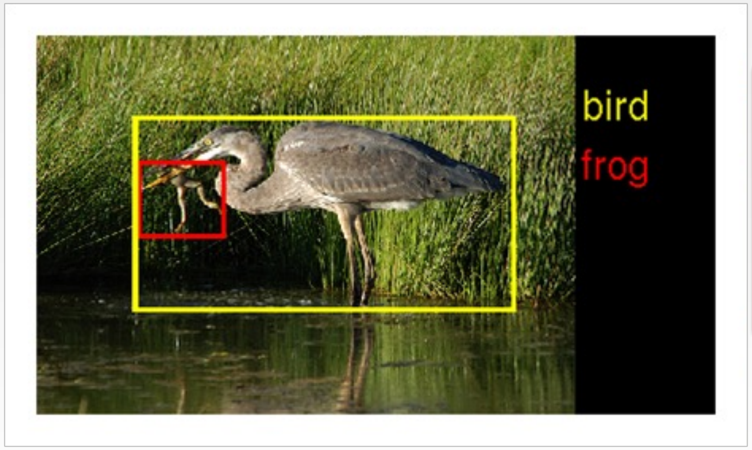
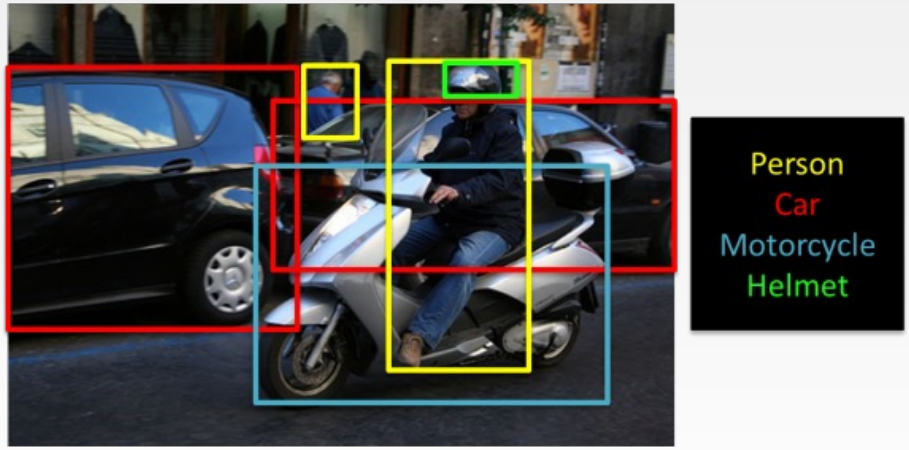
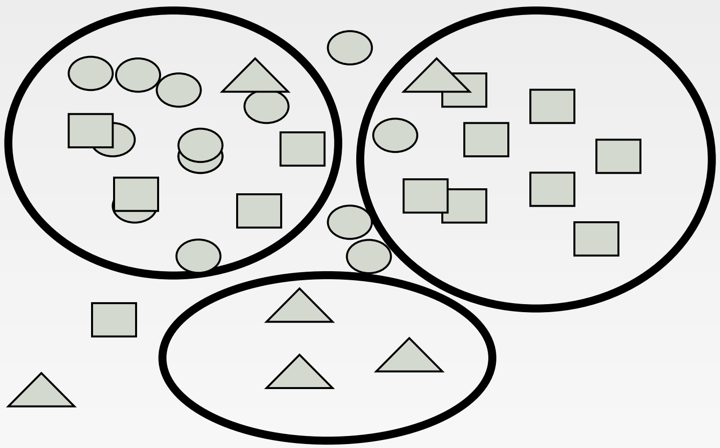






Clustering

- Objectives
  - detecting groups of similar data objects
  - identifying exceptions and outliers



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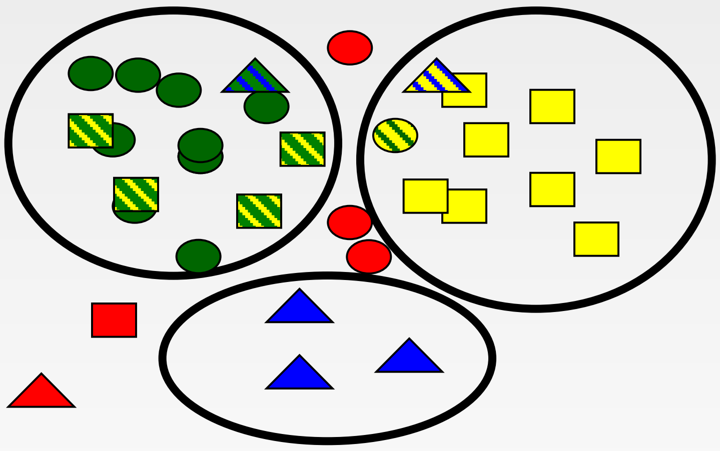
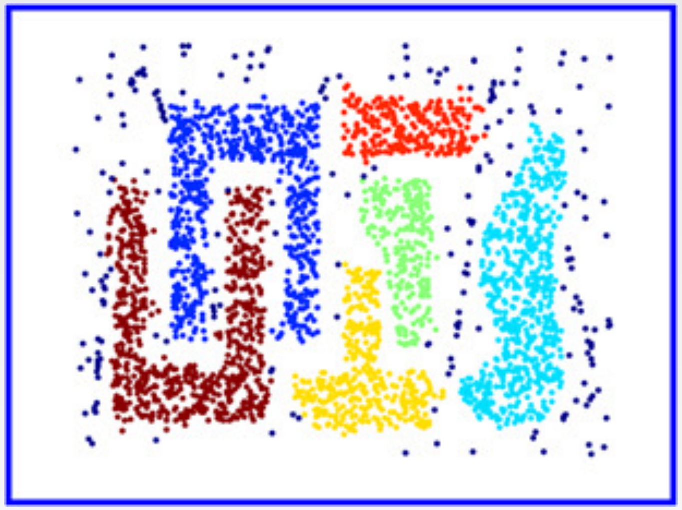
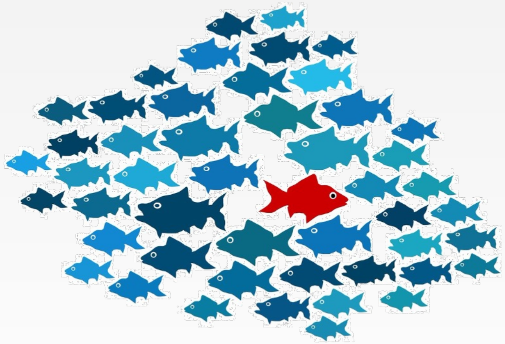
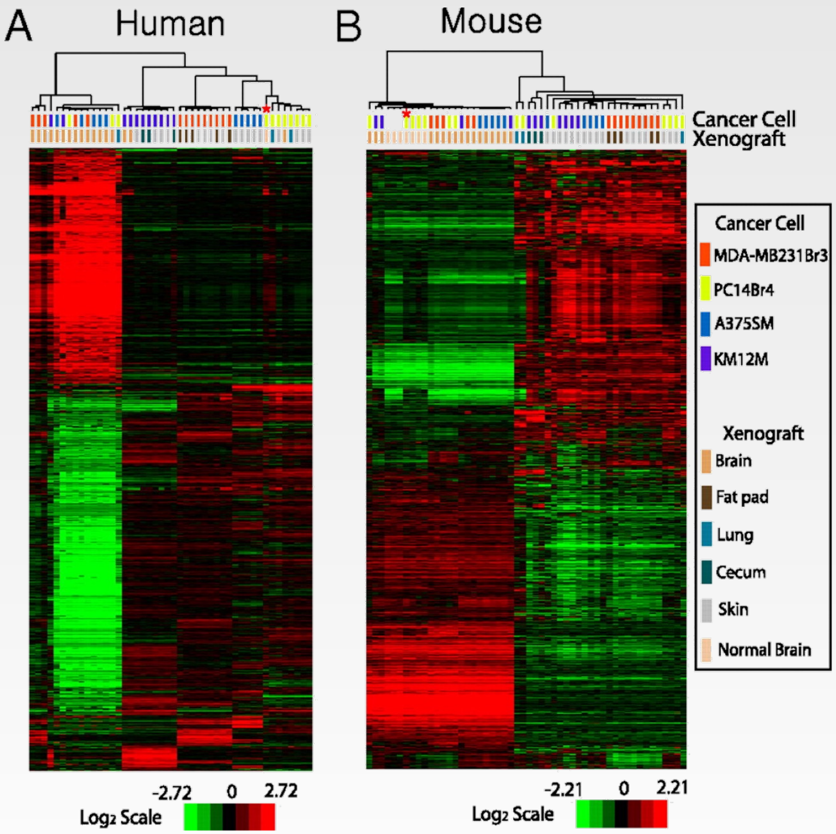




Clustering

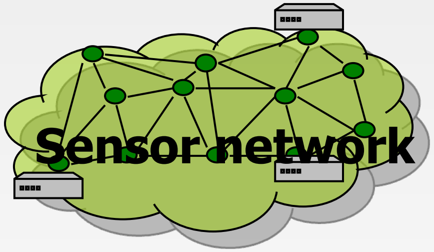



A
Human
B
Mouse
Cancer Cell
Xenograft
Cancer Cell
MDA-MB231Br3
PC14Br4
A375SM
KM12M
Xenograft
Brain
Fat pad
Lung
Cecum
Skin
Normal Brain
-2.72
0
2.72
Log2 Scale
-2.21
0
2.21
Log2 Scale

Other data mining techniques

- Sequence mining
  - ordering criteria on analyzed data are taken into account
  - example: motif detection in proteins

- Time series and geospatial data
  - temporal and spatial information are considered
  - example: sensor network data



- Regression
  - prediction of a continuous value
  - example: prediction of stock quotes

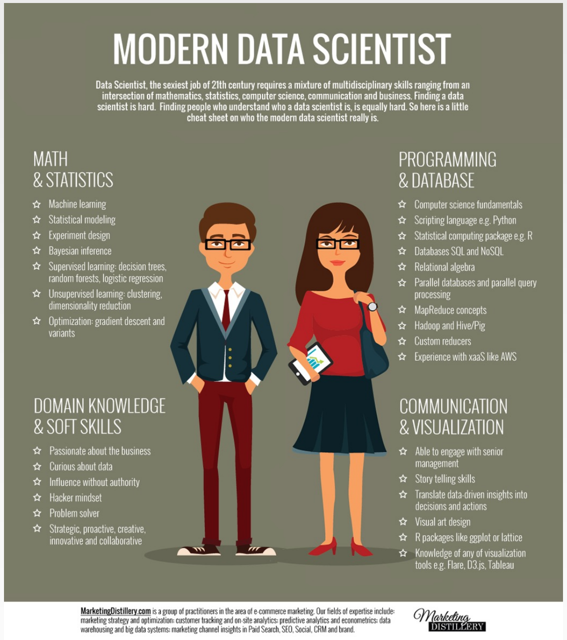
- Outlier detection
  - example: intrusion detection in network traffic analysis

The data science process

- What *question* are you answering?
- What is the right *scope* of the project?
- What *data* will you use?
- What *techniques* are you going to try?
- How will you *evaluate* your result?
- What *maintenance* will be required?

The data science recipe

- Different ingredients needed
  - Data expert
    - Data processing, data structures
  - Data analyst
    - Data mining, statistics, machine learning
  - Visualization expert
    - Visual art design, storytelling skills
  - Domain expert
    - Provide understanding of the application domain
  - Business expert
    - Data driven decisions, new business models

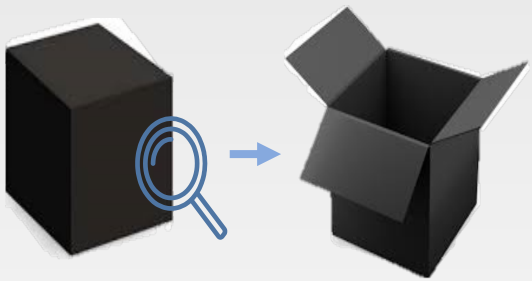


Open issues

- Social impact of analysis is very important
  - Interpretability and transparency of the analysis process
  - Bias in algorithms and data
  - Privacy preservation

Interpretability in machine learning

“The ability to explain or to present in understandable terms to a human”



Open the black box

Trade-off Accuracy-Interpretability

- **Model explanation:** global understanding of how a model works
- **Prediction explanation:** local understanding of why a prediction is made
- **Interpretable feature selection:** incorporating interpretability-based criteria into the model design

Interpretability

- Learned decision rule in pneumonia patients dataset from USA hospital

history of asthma → lower chance of dying from pneumonia

- MD consider asthma as a serious risk factor for people who get pneumonia
- Analysis
  - asthmatics probably notice earlier the symptoms of pneumonia
  - a healthcare professional is going to provide earlier pneumonia diagnosis
  - as high-risk patients, they're going to get high-quality treatment sooner than other people

➡ asthmatics actually have almost half the chance of dying of non-asthmatics

- Using a neural network, this model issue would *never* have been uncovered

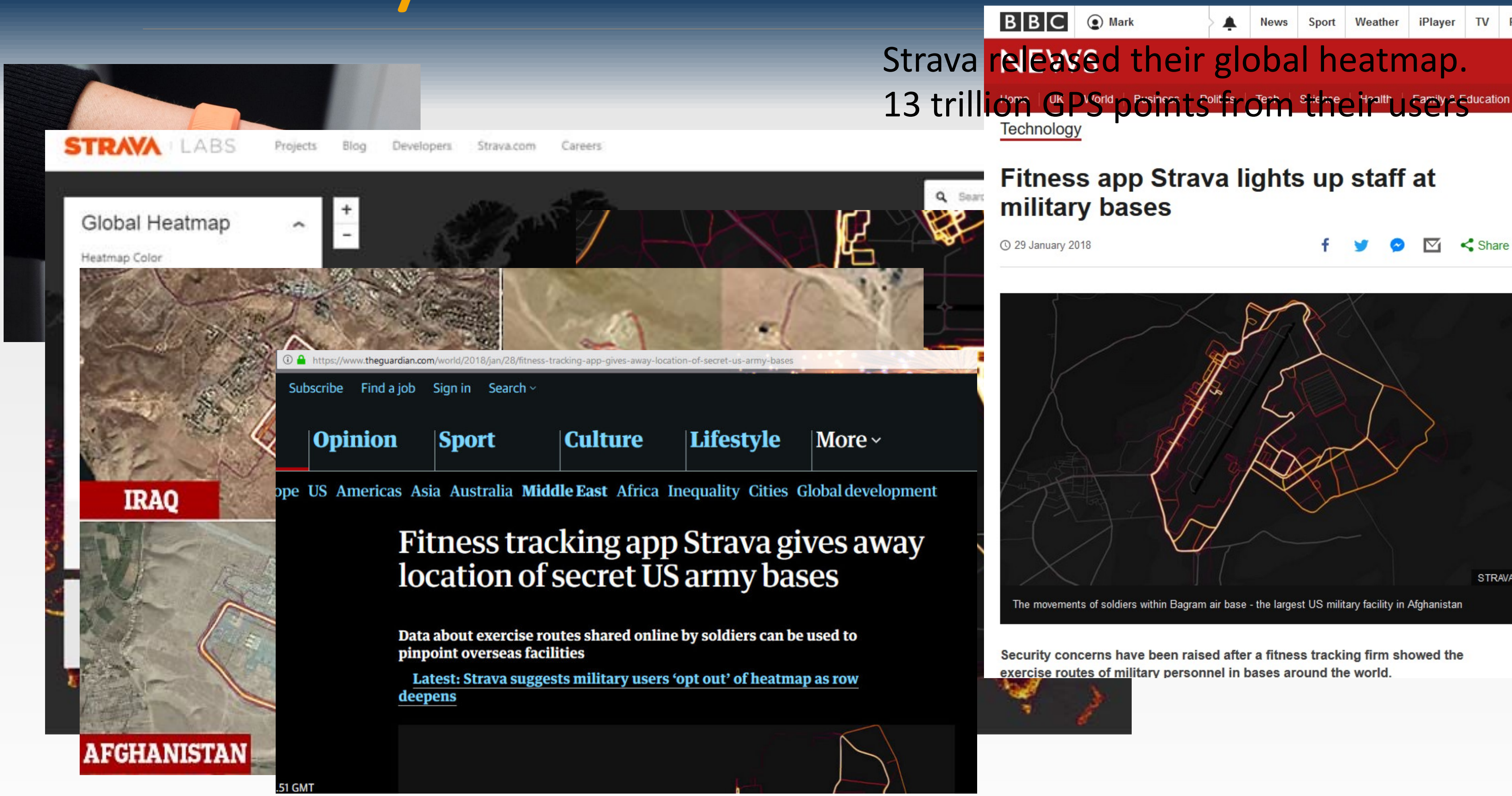
Algorithmic and data bias

- Task: predict likelihood of an individual committing a future crime
  - Risk scores used by US criminal justice system
- Scores computed from
  - Questions answered by the defendants
  - Information pulled by criminal records
- Race was not among the questions
  - … however other items may be correlated (e.g., poverty, joblessness)
- Software product flagged black defendants as future criminals more frequently than white defendants

➡ Training data was biased by a larger black defendant population

Privacy

Strava released their global heatmap.
13 trillion GPS points from their users



Open issues

- Social impact of analysis is very important
  - Interpretability and transparency of the analysis process
  - Privacy preservation
- Many technical issues are not solved
  - Scalability to ***huge*** data volumes
  - Data dimensionality
  - Complex data structures, heterogeneous data formats
  - Data quality
  - Streaming data