DATA MINING
LECTURE 2

What is data?

The data mining pipeline

What is Data Mining?

- Data mining is the use of efficient techniques for the analysis of very large collections of data and the extraction of useful and possibly unexpected patterns in data.

- “Data mining is the analysis of (often large) observational data sets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data analyst” (Hand, Mannila, Smyth)

- “Data mining is the discovery of models for data” (Rajaraman, Ullman)
  - We can have the following types of models
    - Models that explain the data (e.g., a single function)
    - Models that predict the future data instances.
    - Models that summarize the data
    - Models the extract the most prominent features of the data.

Why do we need data mining?

- Really huge amounts of complex data generated from multiple sources and interconnected in different ways
  - Scientific data from different disciplines
    - Weather, astronomy, physics, biological microarrays, genomics
  - Huge text collections
    - The Web, scientific articles, news, tweets, facebook postings.
  - Transaction data
    - Retail store records, credit card records
  - Behavioral data
    - Mobile phone data, query logs, browsing behavior, ad clicks
  - Networked data
    - The Web, Social Networks, IM networks, email network, biological networks.
  - All these types of data can be combined in many ways
    - Facebook has a network, text, images, user behavior, ad transactions.
- We need to analyze this data to extract knowledge
  - Knowledge can be used for commercial or scientific purposes.
  - Our solutions should scale to the size of the data

What is Data?

- Collection of data objects and their attributes
- An attribute is a property or characteristic of an object
  - Examples: name, date of birth, height, occupation.
  - Attribute is also known as variable, field, characteristic, or feature
- For each object the attributes take some values.
- The collection of attribute-value pairs describes a specific object
  - Object is also known as record, point, case, sample, entity, or instance

Attributes

Objects

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	**No**
2	No	Married	100K	**No**
3	No	Single	70K	**No**
4	Yes	Married	120K	**No**
5	No	Divorced	95K	**Yes**
6	No	Married	60K	**No**
7	Yes	Divorced	220K	**No**
8	No	Single	85K	**Yes**
9	No	Married	75K	**No**
10	No	Single	90K	**Yes**

Size (n): Number of objects
Dimensionality (d): Number of attributes
Sparsity: Number of populated object-attribute pairs

Types of Attributes

- There are different types of attributes
  - Numeric
    - Examples: dates, temperature, time, length, value, count.
    - Discrete (counts) vs Continuous (temperature)
    - Special case: Binary/Boolean attributes (yes/no, exists/not exists)
  - Categorical
    - Examples: eye color, zip codes, strings, rankings (e.g, good, fair, bad), height in {tall, medium, short}
    - Nominal (no order or comparison) vs Ordinal (order but not comparable)

Numeric Relational Data

- If data objects have the same fixed set of numeric attributes, then the data objects can be thought of as points/vectors in a multi-dimensional space, where each dimension represents a distinct attribute

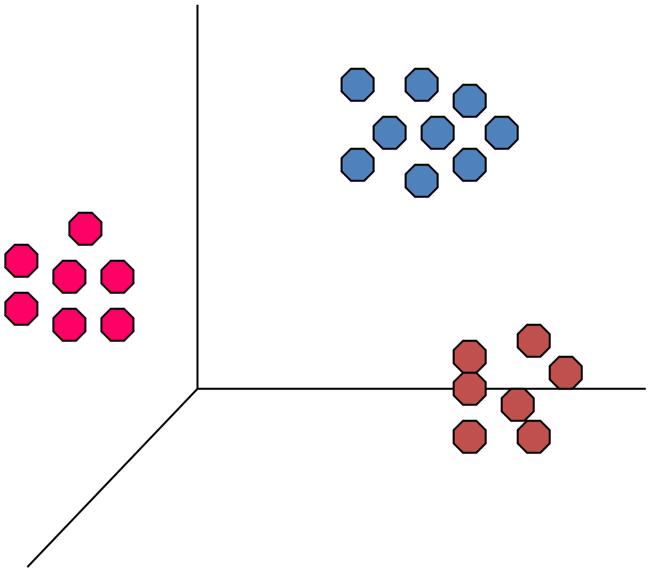
- Such data set can be represented by an n-by-d data matrix, where there are n rows, one for each object, and d columns, one for each attribute

Temperature	Humidity	Pressure
30	0.8	90
32	0.5	80
24	0.3	95

Numeric data

- Thinking of numeric data as points or vectors is very convenient

- For small dimensions we can plot the data
- We can use geometric analogues to define concepts like distance or similarity
- We can use linear algebra to process the data matrix



Categorical Relational Data

- Data that consists of a collection of records, each of which consists of a fixed set of categorical attributes

ID Number	Zip Code	Marital Status	Income Bracket
1129842	45221	Single	High
2342345	45223	Married	Low
1234542	45221	Divorced	High
1243535	45224	Single	Medium

Mixed Relational Data

- Data that consists of a collection of records, each of which consists of a fixed set of both numeric and categorical attributes

ID Number	Zip Code	Age	Marital Status	Income	Income Bracket
1129842	45221	55	Single	250000	High
2342345	45223	25	Married	30000	Low
1234542	45221	45	Divorced	200000	High
1243535	45224	43	Single	150000	Medium

Mixed Relational Data

- Data that consists of a collection of records, each of which consists of a fixed set of both numeric and categorical attributes

ID Number	Zip Code	Age	Marital Status	Income	Income Bracket	Refund
1129842	45221	55	Single	250000	High	No
2342345	45223	25	Married	30000	Low	Yes
1234542	45221	45	Divorced	200000	High	No
1243535	45224	43	Single	150000	Medium	No

Mixed Relational Data

- Data that consists of a collection of records, each of which consists of a fixed set of both numeric and categorical attributes

ID Number	Zip Code	Age	Marital Status	Income	Income Bracket	Refund
1129842	45221	55	Single	250000	High	0
2342345	45223	25	Married	30000	Low	1
1234542	45221	45	Divorced	200000	High	0
1243535	45224	43	Single	150000	Medium	0

Boolean attributes can be thought as both numeric and categorical
When appearing together with other attributes they make more sense as categorical
They are often represented as numeric though

Mixed Relational Data

- Some times it is convenient to represent categorical attributes as boolean.

ID	Zip 45221	Zip 45223	Zip 45224	Age	Single	Married	Divorced	Income	Refund
1129842	1	0	0	55	0	0	0	250000	0
2342345	0	1	0	25	0	1	0	30000	1
1234542	1	0	0	45	0	0	1	200000	0
1243535	0	0	1	43	0	0	0	150000	0

We can now view the whole vector as numeric

Physical data storage

- Stored in a Relational Database
  - Assumes a strict schema and relatively dense data (few missing/Null values)
- Tab or Comma separated files (TSV/CSV), Excel sheets, relational tables
  - Assumes a strict schema and relatively dense data (few missing/Null values)
- Flat file with triplets (record id, attribute, attribute value)
  - A very flexible data format, allows multiple values for the same attribute (e.g., phone number)
- JSON, XML format
  - Standards for data description that are more flexible than relational tables
  - There exist parsers for reading such data.

Examples

Comma Separated File

```
id,Name,Surname,Age,Zip
1,John,Smith,25,10021
2,Mary,Jones,50,96107
3,Joe ,Doe,80,80235
```

- Can be processed with simple parsers, or loaded to excel or a database

Triple-store

```
1, Name, John
1, Surname, Smith
1, Age, 25
1, Zip, 10021
2, Name, Mary
2, Surname, Jones
2, Age, 50
2, Zip, 96107
3, Name, Joe
3, Surname, Doe
3, Age, 80
3, Zip, 80235
```

- Easy to deal with missing values

Examples

JSON EXAMPLE – Record of a person


```json
{
  "firstName": "John",
  "lastName": "Smith",
  "isAlive": true,
  "age": 25,
  "address": {
    "streetAddress": "21 2nd Street",
    "city": "New York",
    "state": "NY",
    "postalCode": "10021-3100"
  },
  "phoneNumbers": [
    {
      "type": "home",
      "number": "212 555-1234"
    },
    {
      "type": "office",
      "number": "646 555-4567"
    }
  ],
  "children": [],
  "spouse": null
}
```


XML EXAMPLE – Record of a person


```xml
<person>
  <firstName>John</firstName>
  <lastName>Smith</lastName>
  <age>25</age>
  <address>
    <streetAddress>21 2nd
Street</streetAddress>
    <city>New York</city>
    <state>NY</state>
    <postalCode>10021</postalCode>
  </address>
  <phoneNumbers>
    <phoneNumber>
      <type>home</type>
      <number>212 555-1234</number>
    </phoneNumber>
    <phoneNumber>
      <type>fax</type>
      <number>646 555-4567</number>
    </phoneNumber>
  </phoneNumbers>
  <gender>
    <type>male</type>
  </gender>
</person>
```

Set data

- Each record is a set of items from a space of possible items
- Example: Transaction data
  - Also called market-basket data

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

Set data

- Each record is a set of items from a space of possible items
- Example: Document data
  - Also called bag-of-words representation

Doc Id	Words
1	the, dog, followed, the, cat
2	the, cat, chased, the, cat
3	the, man, walked, the, dog

Vector representation of market-basket data

- Market-basket data can be represented, or thought of, as numeric vector data
  - The vector is defined over the set of all possible items
  - The values are binary (the item appears or not in the set)

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

TID	Bread	Coke	Milk	Beer	Diaper
1	1	1	1	0	0
2	1	0	0	1	0
3	0	1	1	1	1
4	1	0	1	1	1
5	0	1	1	0	1

Sparsity: Most entries are zero. Most baskets contain few items

Vector representation of document data

- Document data can be represented, or thought of, as numeric vector data
  - The vector is defined over the set of all possible words
  - The values are the counts (number of times a word appears in the document)

Doc Id	Words
1	the, dog, follows, the, cat
2	the, cat, chases, the, cat
3	the, man, walks, the, dog

Doc Id	the	dog	follows	cat	chases	man	walks
1	2	1	1	1	0	0	0
2	2	0	0	2	1	0	0
3	1	1	0	0	0	1	1

Sparsity: Most entries are zero. Most documents contain few of the words

Physical data storage

- Usually set data is stored in flat files
  - One line per set

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 31 32
33 34 35
36 37 38 39 40 41 42 43 44 45 46
38 39 47 48
38 39 48 49 50 51 52 53 54 55 56 57 58
32 41 59 60 61 62
3 39 48
```

- I heard so many good things about this place so I was pretty juiced to try it. I'm from Cali and I heard Shake Shack is comparable to IN-N-OUT and I gotta say, Shake Shake wins hands down. Surprisingly, the line was short and we waited about 10 MIN. to order. I ordered a regular cheeseburger, fries and a black/white shake. So yummerz. I love the location too! It's in the middle of the city and the view is breathtaking. Definitely one of my favorite places to eat in NYC.
- I'm from California and I must say, Shake Shack is better than IN-N-OUT, all day, err'day.

Ordered Data

- Genomic sequence data

```
GGTTCCGCCTTCAGCCCCGCGCC
CGCAGGGCCCGCCCCGCGCCGTC
GAGAAGGGCCCGCCTGGCGGGCG
GGGGGAGGCGGGGCCGCCCGAGC
CCAACCGAGTCCGACCAGGTGCC
CCCTCTGCTCGGCCTAGACCTGA
GCTCATTAGGCGGCAGCGGACAG
GCCAAGTAGAACACGCGAAGCGC
TGGGCTGCCTGCTGCGACCAGGG
```

- Data is a long ordered string

Ordered Data

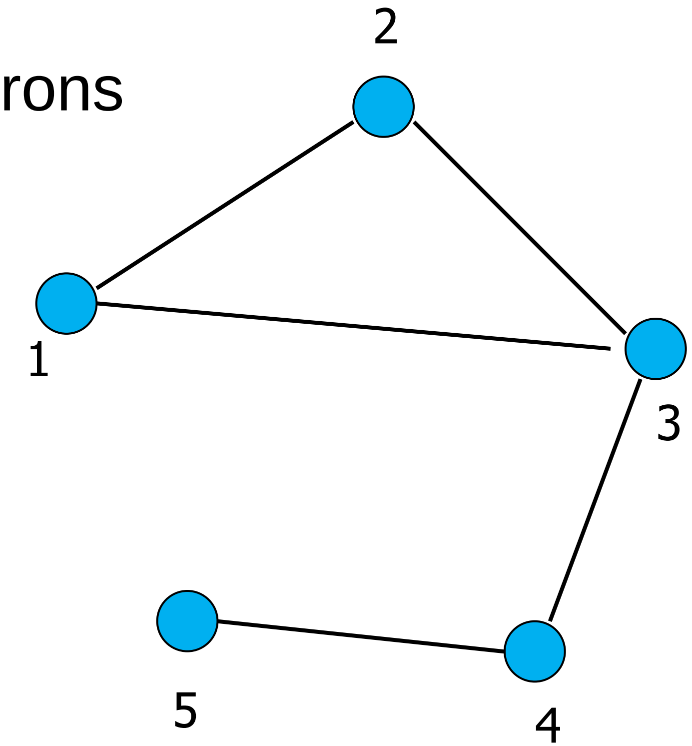
- Time series
  - Sequence of ordered (over "time") numeric values.

Graph Data

- Graph data: a collection of entities and their pairwise relationships. Examples:
  - Web pages and hyperlinks
  - Facebook users and friendships
  - The connections between brain neurons

In this case the data consists of pairs:

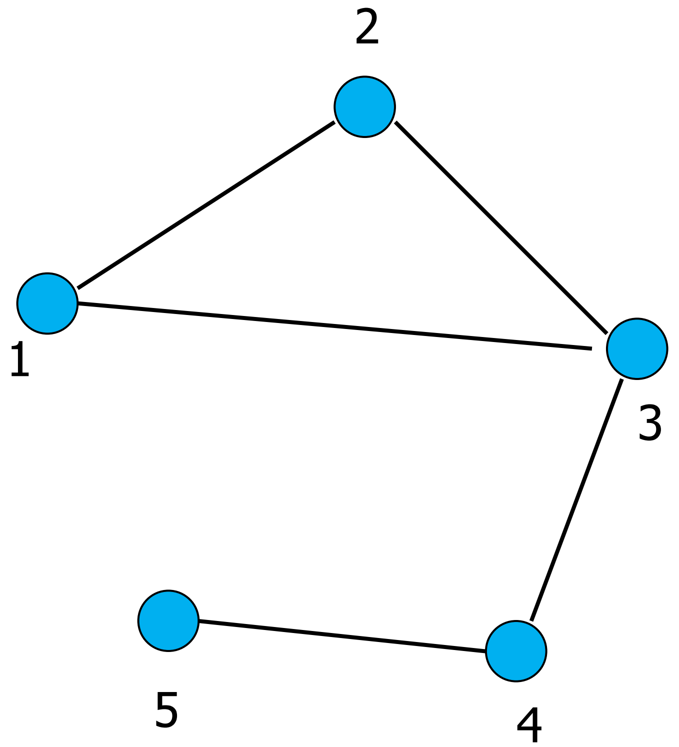
Who links to whom



Representation

- Adjacency matrix
  - Very sparse, very wasteful, but useful conceptually

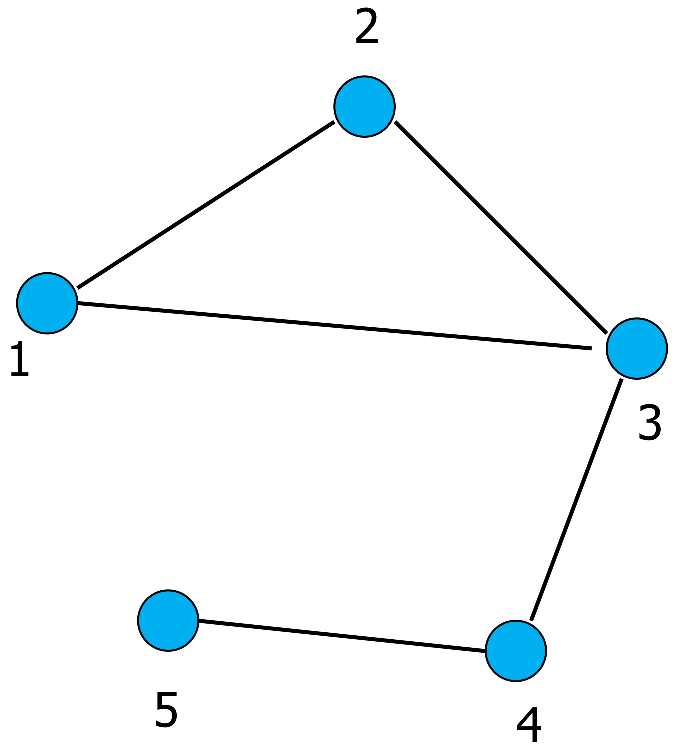
$$A = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



Representation

- Adjacency list
  - Not so easy to maintain

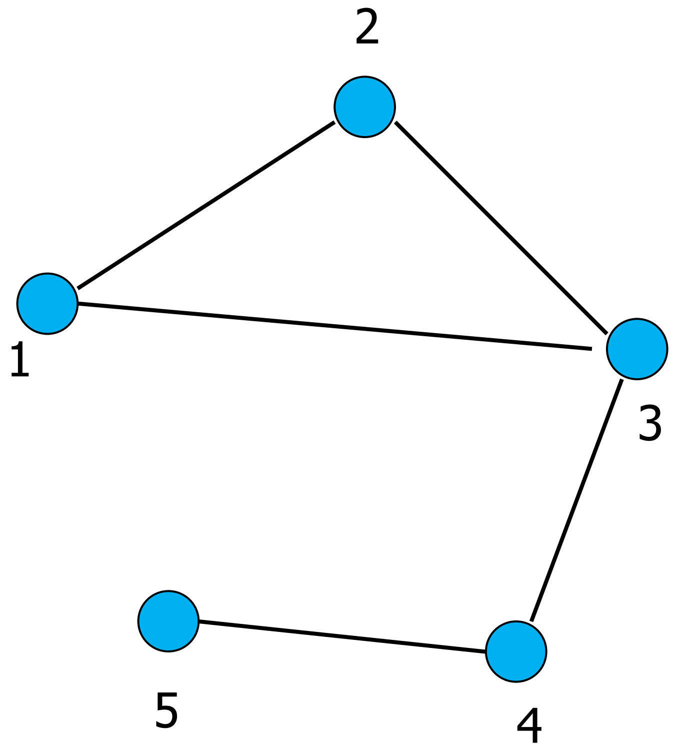
1: [2, 3]
2: [1, 3]
3: [1, 2, 4]
4: [3, 5]
5: [4]



Representation

- List of pairs
  - The simplest and most efficient representation

(1,2)
(2,3)
(1,3)
(3,4)
(4,5)

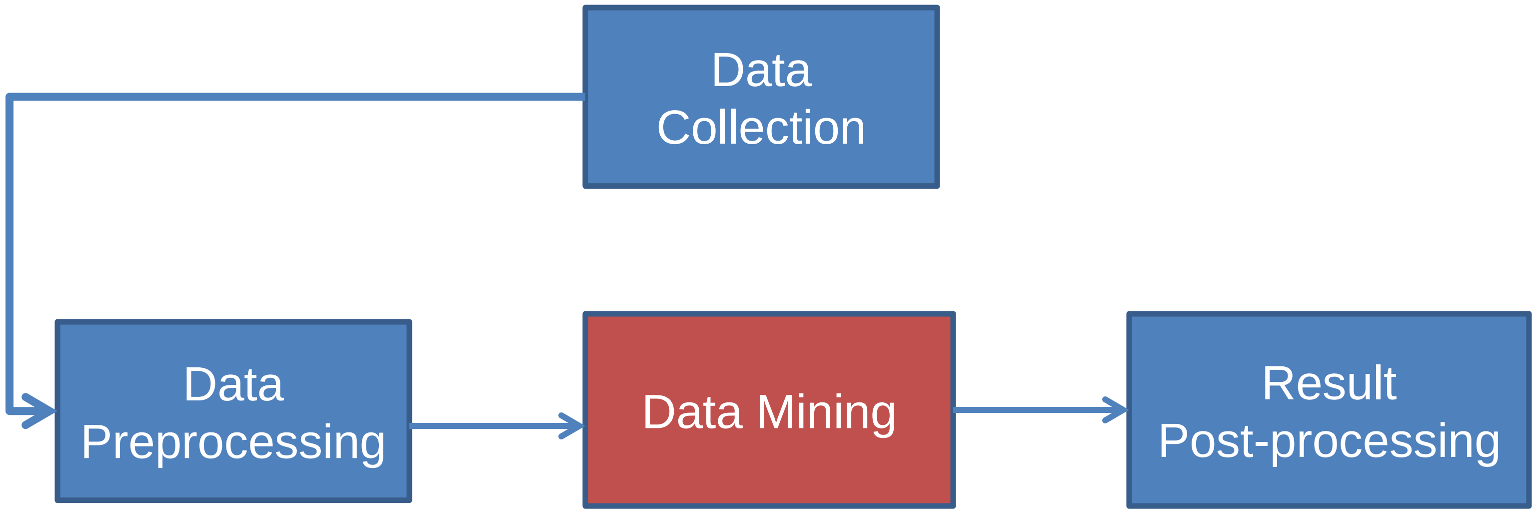


Types of data: summary

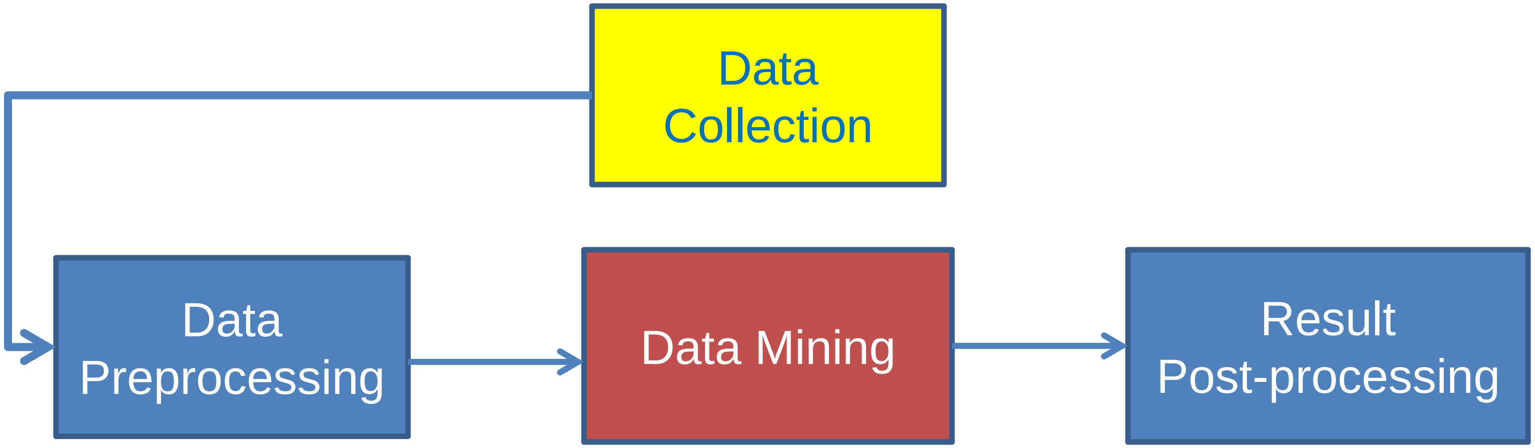
- Numeric data: Each object is a point in a multidimensional space
- Categorical data: Each object is a vector of categorical values
- Set data: Each object is a set of values (with or without counts)
  - Sets can also be represented as binary vectors, or vectors of counts
- Ordered sequences: Each object is an ordered sequence of values.
- Graph data: A collection of pairwise relationships

The data analysis pipeline

Mining is not the only step in the analysis process

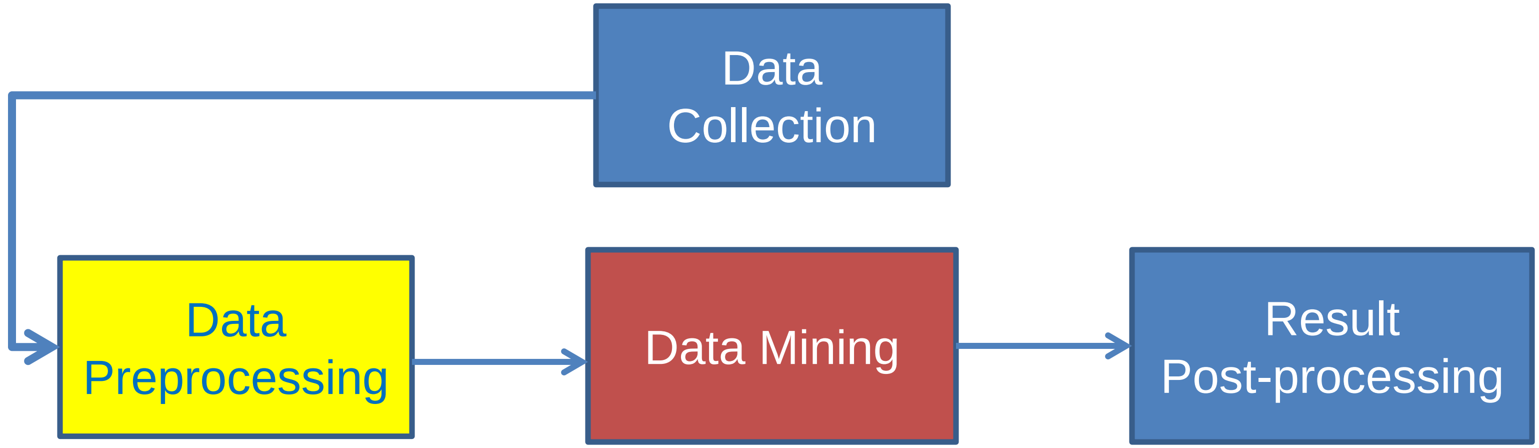


The data analysis pipeline



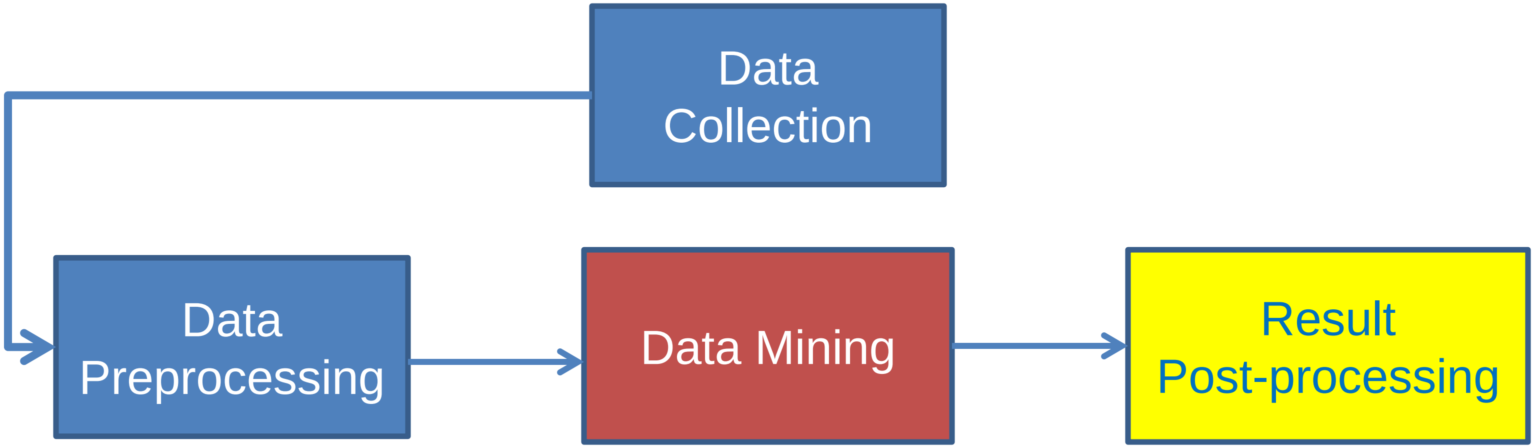
- Today there is an abundance of data online
  - Facebook, Twitter, Wikipedia, Web, City data, Open data initiatives, etc
- Collecting the data is a separate task
  - Customized crawlers, use of public APIs
  - Respect of crawling etiquette
- How should we store them?
- In many cases when collecting data we also need to label them
  - E.g., how do we identify fraudulent transactions?
  - E.g., how do we elicit user preferences?

The data analysis pipeline



- Preprocessing: Real data is large, noisy, incomplete and inconsistent. Data cleaning is required to make sense of the data
  - Techniques: Sampling, Dimensionality Reduction, Feature selection.
- The preprocessing step determines the input to the data mining algorithm
  - A dirty work, but someone has to do it.
  - It is often the most important step for the analysis

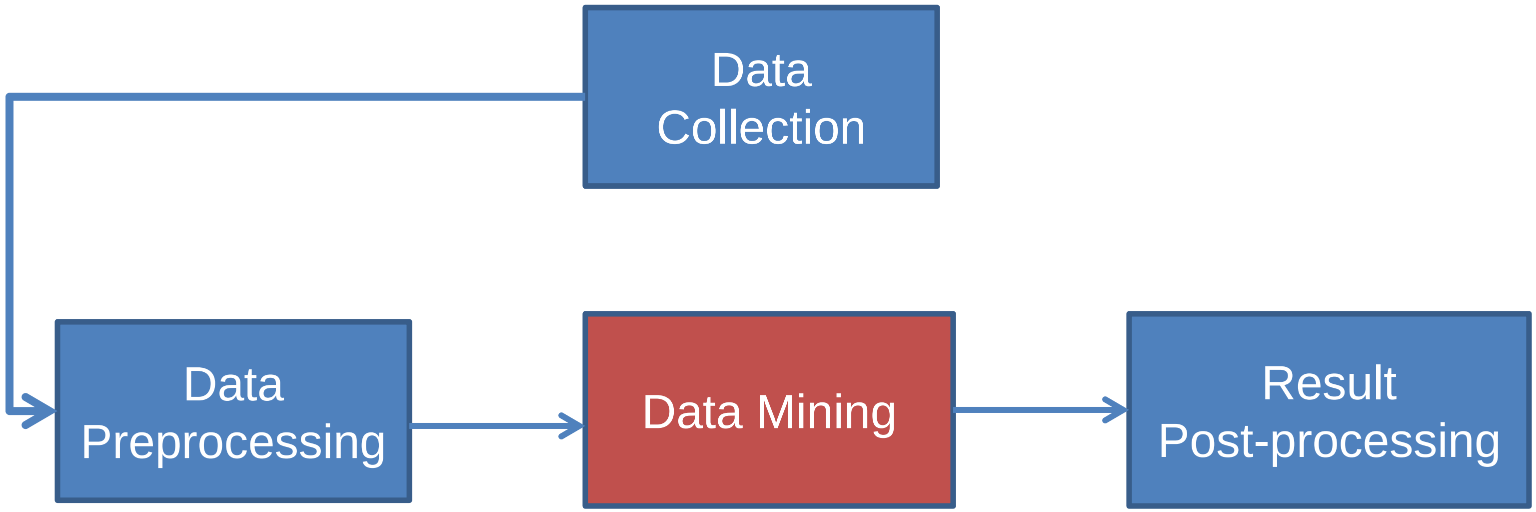
The data analysis pipeline



- Post-Processing: Make the data actionable and useful to the user
  - Statistical analysis of importance of results
  - Visualization

The data analysis pipeline

Mining is not the only step in the analysis process



- Pre- and Post-processing are often data mining tasks as well

Data Quality

- Examples of data quality problems:
  - Noise and outliers
  - Missing values
  - Duplicate data

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	10000K	Yes
6	No	NULL	60K	No
7	Yes	Divorced	220K	NULL
8	No	Single	85K	Yes
9	No	Married	90K	No
9	No	Single	90K	No

A mistake or a millionaire?

Missing values

Inconsistent duplicate entries

Sampling

- Sampling is the main technique employed for data selection.
  - It is often used for both the preliminary investigation of the data and the final data analysis.

- Statisticians sample because obtaining the entire set of data of interest is too expensive or time consuming.
  - Example: What is the average height of a person in Greece?
    - We cannot measure the height of everybody

- Sampling is used in data mining because processing the entire set of data of interest is too expensive or time consuming.
  - Example: We have 1M documents. What fraction of pairs has at least 100 words in common?
    - Computing number of common words for all pairs requires 10^{12} comparisons
  - Example: What fraction of tweets in a year contain the word “Greece”?
    - 500M tweets per day, if 100 characters on average, 86.5TB to store all tweets

Sampling …

- The key principle for effective sampling is the following:
  - using a sample will work almost as well as using the entire data sets, if the sample is representative
  - A sample is representative if it has approximately the same property (of interest) as the original set of data
  - Otherwise we say that the sample introduces some bias
  - What happens if we take a sample from the university campus to compute the average height of a person at Ioannina?

Types of Sampling

- Simple Random Sampling
  - There is an equal probability of selecting any particular item

- Sampling without replacement
  - As each item is selected, it is removed from the population

- Sampling with replacement
  - Objects are not removed from the population as they are selected for the sample.
    - In sampling with replacement, the same object can be picked up more than once. This makes analytical computation of probabilities easier
    - E.g., we have 100 people, 51 are women $P(W) = 0.51$, 49 men $P(M) = 0.49$. If I pick two persons what is the probability $P(W,W)$ that both are women?
      - Sampling with replacement: $P(W,W) = 0.51^2$
      - Sampling without replacement: $P(W,W) = 51/100 * 50/99$

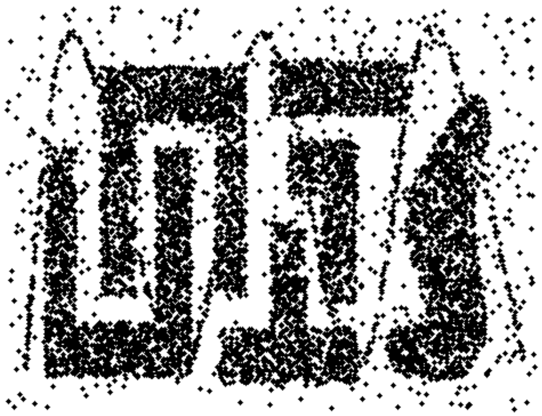
Types of Sampling

- Stratified sampling
  - Split the data into several groups; then draw random samples from each group.
    - Ensures that all groups are represented.
  - Example 1. I want to understand the differences between legitimate and fraudulent credit card transactions. 0.1% of transactions are fraudulent. What happens if I select 1000 transactions at random?
    - I get 1 fraudulent transaction (in expectation). Not enough to draw any conclusions. Solution: sample 1000 legitimate and 1000 fraudulent transactions

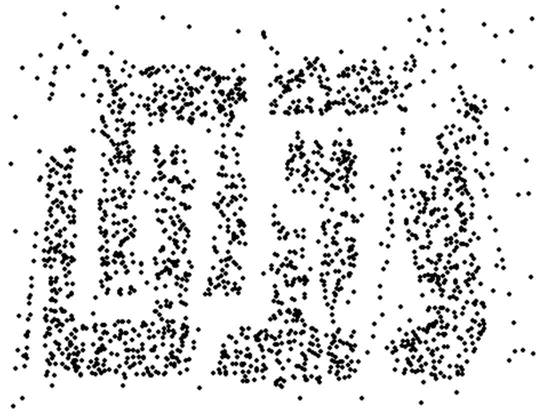
Probability Reminder: If an event has probability p of happening and I do N trials, the expected number of times the event occurs is pN

  - Example 2. I want to answer the question: Do web pages that are linked have on average more words in common than those that are not? I have 1M pages, and 1M links, what happens if I select 10K pairs of pages at random?
    - Most likely I will not get any links. Solution: sample 10K random pairs, and 10K links

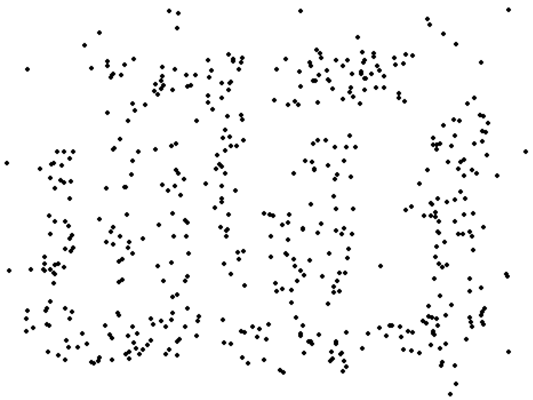
Sample Size



8000 points



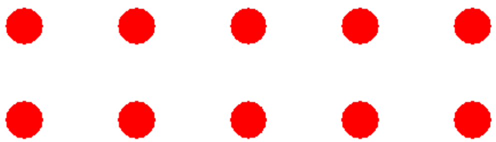
2000 Points

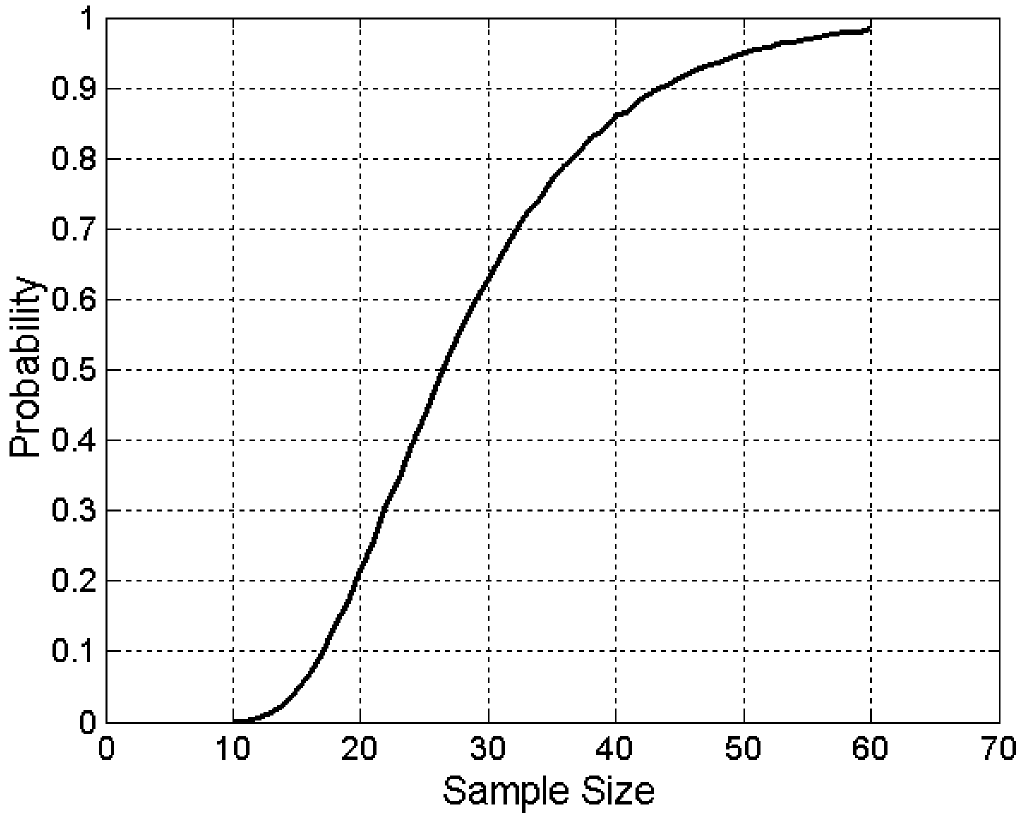


500 Points

Sample Size

- **What sample size is necessary to get at least one object from each of 10 groups.**





A data mining challenge

- You have N items and you want to sample one item uniformly at random. How do you do that?

- The items are coming in a stream: you do not know the size of the stream in advance, and there is not enough memory to store the stream in memory. You can only keep a constant amount of items in memory
- How do you sample?
  - Hint: if the stream ends after reading k items the last item in the stream should have probability 1/k to be selected.

- Reservoir Sampling:
  - Standard interview question for many companies

Reservoir sampling

- Algorithm: With probability 1/k select the k-th item of the stream and replace the previous choice.
- Claim: Every item has probability 1/N to be selected after N items have been read.
- Proof
  - What is the probability of the k-th item to be selected?
    - $\frac{1}{k}$
  - What is the probability of the n-th item to survive for N-n rounds?
    - $\left(1-\frac{1}{n+1}\right)\left(1-\frac{1}{n+2}\right)\cdots\left(1-\frac{1}{N}\right)=\frac{1}{\mathrm{N}}$

Proof by Induction

- We want to show that the probability the k-th item is selected after $n \geq k$ items have been seen is $\frac{1}{n}$
- Induction on the number of steps
  - Base of the induction: For $n = k$, the probability that the k-th item is selected is $\frac{1}{k}$
  - Inductive Hypothesis: Assume that it is true for N
  - Inductive Step: The probability that the item is still selected after $N+1$ items is

$$\frac{1}{N}\left(1 - \frac{1}{N+1}\right) = \frac{1}{N+1}$$

A data preprocessing example

- Suppose we want to mine the comments/reviews of people on Yelp or Foursquare.

Mining Task

- Collect all reviews for the top-10 most reviewed restaurants in NY in Yelp


```
{"votes": {"funny": 0, "useful": 2, "cool": 1},
 "user_id": "Xqd0DzHaiyRqVH3WRG7hzg",
 "review_id": "15SdjuK7DmYqUAj6rjGowg",
 "stars": 5, "date": "2007-05-17",
 "text": "I heard so many good things about this place so I was pretty juiced to
try it.  I'm from Cali and I heard Shake Shack is comparable to IN-N-OUT and I
gotta say,  Shake Shake wins hands down.    Surprisingly, the line was short and
we waited about 10 MIN. to order.  I ordered a regular cheeseburger, fries and a
black/white shake.  So yummerz.   I love the location too!  It's in the middle of
the city and the view is breathtaking.   Definitely one of my favorite places to
eat in NYC.",
 "type": "review",
 "business_id": "vcNAWiLM4dR7D2nwwJ7nCA"}
```


- Find few terms that best describe the restaurants.
- Algorithm?

Example data

- I heard so many good things about this place so I was pretty juiced to try it. I'm from Cali and I heard Shake Shack is comparable to IN-N-OUT and I gotta say, Shake Shake wins hands down. Surprisingly, the line was short and we waited about 10 MIN. to order. I ordered a regular cheeseburger, fries and a black/white shake. So yummerz. I love the location too! It's in the middle of the city and the view is breathtaking. Definitely one of my favorite places to eat in NYC.

- I'm from California and I must say, Shake Shack is better than IN-N-OUT, all day, err'day.

- Would I pay $15+ for a burger here? No. But for the price point they are asking for, this is a definite bang for your buck (though for some, the opportunity cost of waiting in line might outweigh the cost savings) Thankfully, I came in before the lunch swarm descended and I ordered a shake shack (the special burger with the patty + fried cheese & portabella topping) and a coffee milk shake. The beef patty was very juicy and snugly packed within a soft potato roll. On the downside, I could do without the fried portabella-thingy, as the crispy taste conflicted with the juicy, tender burger. How does shake shack compare with in-and-out or 5-guys? I say a very close tie, and I think it comes down to personal affliations. On the shake side, true to its name, the shake was well churned and very thick and luscious. The coffee flavor added a tangy taste and complemented the vanilla shake well. Situated in an open space in NYC, the open air sitting allows you to munch on your burger while watching people zoom by around the city. It's an oddly calming experience, or perhaps it was the food coma I was slowly falling into. Great place with food at a great price.

First cut

- Do simple processing to "normalize" the data (remove punctuation, make into lower case, clear white spaces, other?)
- Break into words, keep the most popular words

the 27514	the 16710	the 16010	the 14241
and 14508	and 9139	and 9504	and 8237
i 13088	a 8583	i 7966	a 8182
a 12152	i 8415	to 6524	i 7001
to 10672	to 7003	a 6370	to 6727
of 8702	in 5363	it 5169	of 4874
ramen 8518	it 4606	of 5159	you 4515
was 8274	of 4365	is 4519	it 4308
is 6835	is 4340	sauce 4020	is 4016
it 6802	burger 432	in 3951	was 3791
in 6402	was 4070	this 3519	pastrami 3748
for 6145	for 3441	was 3453	in 3508
but 5254	but 3284	for 3327	for 3424
that 4540	shack 3278	you 3220	sandwich 2928
you 4366	shake 3172	that 2769	that 2728
with 4181	that 3005	but 2590	but 2715
pork 4115	you 2985	food 2497	on 2247
my 3841	my 2514	on 2350	this 2099
this 3487	line 2389	my 2311	my 2064
wait 3184	this 2242	cart 2236	with 2040
not 3016	fries 2240	chicken 2220	not 1655
we 2984	on 2204	with 2195	your 1622
at 2980	are 2142	rice 2049	so 1610
on 2922	with 2095	so 1825	have 1585

First cut

- Do simple processing to “normalize” the data (remove punctuation, make into lower case, clear white spaces, other?)
- Break into words, keep the most popular words

the 27514	the 16710	the 16010	the 14241
and 14508	and 9139	and 9504	and 8237
i 13088	a 8583	i 7966	a 8182
a 12152	i 8415	to 6524	i 7001
to 10672	to 7003	a 6370	to 6727
of 8702	in 5363	it 5169	of 4874
ramen 8518	it 4606	of 5159	you 4515
was 8274	of 4365	is 4519	it 4308
is 6835	is 4340	**sauce 4020**	is 4016
it 6802	**burger 432**	in 3951	was 3791
in 6402	was 4070	this 3519	**pastrami 3748**
for 6145	for 3441	was 3453	in 3508
but 5254	but 3284	for 3327	for 3424
that 4540	**shack 3278**	you 3220	**sandwich 2928**
you 4366	**shake 3172**	that 2769	that 2728
with 4181	that 3005	but 2590	but 2715
pork 4115	you 2985	food 2497	on 2247
my 3841	my 2514		
this 3487	line 2389		
wait 3184	this 2242	**cart 2236**	
not 3016	**fries 2240**	**chicken 2220**	not 1655
we 2984	on 2204	with 2195	your 1622
at 2980	are 2142	rice 2049	so 1610
on 2922	with 2095	so 1825	have 1585

Most frequent words are stop words

Second cut

- Remove stop words
  - Stop-word lists can be found online.

```
a,about,above,after,again,against,all,am,an,and,any,are,aren't,as,at,be,be
cause,been,before,being,below,between,both,but,by,can't,cannot,could,could
n't,did,didn't,do,does,doesn't,doing,don't,down,during,each,few,for,from,f
urther,had,hadn't,has,hasn't,have,haven't,having,he,he'd,he'll,he's,her,he
re,here's,hers,herself,him,himself,his,how,how's,i,i'd,i'll,i'm,i've,if,in
,into,is,isn't,it,it's,its,itself,let's,me,more,most,mustn't,my,myself,no,
nor,not,of,off,on,once,only,or,other,ought,our,ours,ourselves,out,over,own
,same,shan't,she,she'd,she'll,she's,should,shouldn't,so,some,such,than,tha
t,that's,the,their,theirs,them,themselves,then,there,there's,these,they,th
ey'd,they'll,they're,they've,this,those,through,to,too,under,until,up,very
,was,wasn't,we,we'd,we'll,we're,we've,were,weren't,what,what's,when,when's
,where,where's,which,while,who,who's,whom,why,why's,with,won't,would,would
n't,you,you'd,you'll,you're,you've,your,yours,yourself,yourselves,
```

Second cut

- Remove stop words
  - Stop-word lists can be found online.

ramen 8572	burger 4340	sauce 4023	pastrami 3782
pork 4152	shack 3291	food 2507	sandwich 2934
wait 3195	shake 3221	cart 2239	place 1480
good 2867	line 2397	chicken 2238	good 1341
place 2361	fries 2260	rice 2052	get 1251
noodles 2279	good 1920	hot 1835	katz's 1223
ippudo 2261	burgers 1643	white 1782	just 1214
buns 2251	wait 1508	line 1755	like 1207
broth 2041	just 1412	good 1629	meat 1168
like 1902	cheese 1307	lamb 1422	one 1071
just 1896	like 1204	halal 1343	deli 984
get 1641	food 1175	just 1338	best 965
time 1613	get 1162	get 1332	go 961
one 1460	place 1159	one 1222	ticket 955
really 1437	one 1118	like 1096	food 896
go 1366	long 1013	place 1052	sandwiches 813
food 1296	go 995	go 965	can 812
bowl 1272	time 951	can 878	beef 768
can 1256	park 887	night 832	order 720
great 1172	can 860	time 794	pickles 699
best 1167	best 849	long 792	time 662
		people 790	

Second cut

- Remove stop words
  - Stop-word lists can be found online.

ramen 8572
pork 4152
wait 3195
good 2867
place 2361
noodles 2279
ippudo 2261
buns 2251
broth 2041
like 1902
just 1896
get 1641
time 1613
one 1460
really 1437
go 1366
food 1296
bowl 1272
can 1256
great 1172
best 1167

burger 4340
shack 3291
shake 3221
line 2397
fries 2260
good 1920
burgers 1643
wait 1508
just 1412
cheese 1307
like 1204
food 1175
get 1162
place 1159
one 1118
park 887
can 860
best 849

sauce 4023
food 2507
cart 2239
chicken 2238
rice 2052
hot 1835
white 1782
line 1755
good 1629
lamb 1422
halal 1343
just 1338
get 1332
one 1222
like 1096
night 832
time 794
long 792
people 790

pastrami 3782
sandwich 2934
place 1480
good 1341
get 1251
katz's 1223
just 1214
like 1207
meat 1168
one 1071
deli 984
best 965
go 961
ticket 955
food 896
order 720
pickles 699
time 662

Commonly used words in reviews, not so interesting

IDF

- Important words are the ones that are unique to the document (differentiating) compared to the rest of the collection
  - All reviews use the word “like”. This is not interesting
  - We want the words that characterize the specific restaurant

- Document Frequency $DF(w)$: fraction of documents that contain word w.

$$DF(w) = \frac{D(w)}{D}$$

$D(w)$: num of docs that contain word w

D: total number of documents

- Inverse Document Frequency $IDF(w)$:

$$IDF(w) = \log\left(\frac{1}{DF(w)}\right)$$

- Maximum when unique to one document : $IDF(w) = \log(D)$
- Minimum when the word is common to all documents: $IDF(w) = 0$

TF-IDF

- The words that are best for describing a document are the ones that are important for the document, but also unique to the document.

- TF(w,d): term frequency of word w in document d
  - Number of times that the word appears in the document
  - Natural measure of importance of the word for the document

- IDF(w): inverse document frequency
  - Natural measure of the uniqueness of the word w

- TF-IDF(w,d) = TF(w,d) $\times$ IDF(w)

Third cut

- Ordered by TF-IDF

ramen 3057.4176194	fries 806.08537330	lamb 985.655290756243	pastrami 1931.94250908298 6
akamaru 2353.24196	custard 729.607519	halal 686.038812717726	katz's 1120.62356508209 4
noodles 1579.68242	shakes 628.4738038	53rd 375.685771863491	rye 1004.28925735888 2
broth 1414.7133955	shroom 515.7790608	gyro 305.809092298788	corned 906.113544700399 2
miso 1252.60629058	burger 457.2646379	pita 304.984759446376	pickles 640.487221580035 4
hirata 709.1962086	crinkle 398.347221	cart 235.902194557873	reuben 515.779060830666 1
hakata 591.7643688	burgers 366.624854	platter 139.45990308004	matzo 430.583412389887 1
shiromaru 587.1591	madison 350.939350	chicken/lamb 135.852520	sally 428.110484707471 2
noodle 581.8446147	shackburger 292.42	carts 120.274374158359	harry 226.323810772916 4
tonkotsu 529.59457	'shroom 287.823136	hilton 84.2987473324223	mustard 216.079238853014 6
ippudo 504.5275695	portobello 239.806	lamb/chicken 82.8930633	cutter 209.535243462458 1
buns 502.296134008	custards 211.83782	yogurt 70.0078652365545	carnegie 198.655512713779 3
ippudo's 453.60926	concrete 195.16992	52nd 67.5963923222322	katz 194.387844446609 7
modern 394.8391629	bun 186.9621782983	6th 60.7930175345658 9	knish 184.206807439524 1
egg 367.3680056967	milkshakes 174.996	4am 55.4517744447956 5	sandwiches 181.415707218 8
shoyu 352.29551922	concretes 165.7861	yellow 54.4470265206673	brisket 131.945865389878 4
chashu 347.6903490	portabello 163.483	tzatziki 52.9594571388	fries 131.613054313392 7
karaka 336.1774235	shack's 159.334353	lettuce 51.323016802268	salami 127.621117258549 3
kakuni 276.3102111	patty 152.22603588	sammy's 50.656872045869	knishes 124.339595021678 1
ramens 262.4947006	ss 149.66803104461	sw 50.5668577816893 3	delicatessen 117.488967607 2
bun 236.5122638036	patties 148.068287	platters 49.90659700031	deli's 117.431839742696 1
wasabi 232.3667512	cam 105.9496067806	falafel 49.479699521204	carver 115.129254649702 1
dama 221.048168927	milkshake 103.9720	sober 49.2211422635451	brown's 109.441778045519 2
brulee 201.1797390	lamps 99.011158998	moma 48.1589121730374	matzoh 108.22149937072 1

Third cut

- TF-IDF takes care of stop words as well
- We do not need to remove the stopwords since they will get IDF(w) = 0

Decisions, decisions…

- When mining real data you often need to make some decisions
  - What data should we collect? How much? For how long?
  - Should we throw out some data that does not seem to be useful?

An actual review

```
AAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAA AAAAAAAAAAAAAAAAAAAAAAAAA AAA
```

  - Too frequent data (stop words), too infrequent (errors?), erroneous data, missing data, outliers
  - How should we weight the different pieces of data?

- Most decisions are application dependent. Some information may be lost but we can usually live with it (most of the times)

- We should make our decisions clear since they affect our findings.

- Dealing with real data is hard…

Normalization

- In many cases it is important to normalize the data rather than use the raw values
- In this data, different attributes take very different range of values. For distance/similarity the small values will disappear
- We need to make them comparable

Temperature	Humidity	Pressure
30	0.8	90
32	0.5	80
24	0.3	95

Normalization

- Divide (the values of a column) by the maximum value for each attribute
  - Brings everything in the [0,1] range

Temperature	Humidity	Pressure
0.9375	1	0.9473
1	0.625	0.8421
0.75	0.375	1

new value = old value / max value in the column

Temperature	Humidity	Pressure
30	0.8	90
32	0.5	80
24	0.3	95

Normalization

- Subtract the minimum value and divide by the difference of the maximum value and minimum value for each attribute
  - Brings everything in the [0,1] range, minimum is zero

Temperature	Humidity	Pressure
0.75	1	0.33
1	0.6	0
0	0	1

new value = (old value – min column value) / (max col. value –min col. value)

Temperature	Humidity	Pressure
30	0.8	90
32	0.5	80
24	0.3	95

Normalization

- Are these documents similar?

	Word 1	Word 2	Word 3
Doc 1	28	50	22
Doc 2	12	25	13

Normalization

- Are these documents similar?
- Divide by the sum of values for each document (row in the matrix)
  - Transform a vector into a distribution

	Word 1	Word 2	Word 3
Doc 1	0.28	0.5	0.22
Doc 2	0.24	0.5	0.26

new value = old value / Σ old values in the row

	Word 1	Word 2	Word 3
Doc 1	28	50	22
Doc 2	12	25	13

Normalization

- Do these two users rate movies in a similar way?

	Movie 1	Movie 2	Movie 3
User 1	1	2	3
User 2	2	3	4

Normalization

- Do these two users rate movies in a similar way?
- Subtract the mean value for each user (row)
  - Captures the deviation from the average behavior

	Movie 1	Movie 2	Movie 3
User 1	-1	0	+1
User 2	-1	0	+1

new value = (old value – mean row value) [/ (max row value –min row value)]

	Movie 1	Movie 2	Movie 3
User 1	1	2	3
User 2	2	3	4

Exploratory analysis of data

- Summary statistics: numbers that summarize properties of the data

  - Summarized properties include frequency, location and spread
    - Examples: location - mean
      spread - standard deviation

  - Most summary statistics can be calculated in a single pass through the data

Frequency and Mode

- The frequency of an attribute value is the percentage of time the value occurs in the data set
  - For example, given the attribute ‘gender’ and a representative population of people, the gender ‘female’ occurs about 50% of the time.
- The mode of a an attribute is the most frequent attribute value
- The notions of frequency and mode are typically used with categorical data

Example

Tid	**Refund**	**Marital Status**	**Taxable Income**	**Cheat**
1	Yes	Single	125K	**No**
2	No	Married	100K	**No**
3	No	Single	70K	**No**
4	Yes	Married	120K	**No**
5	No	Divorced	10000K	**Yes**
6	No	NULL	60K	**No**
7	Yes	Divorced	220K	**NULL**
8	No	Single	85K	**Yes**
9	No	Married	90K	**No**
10	No	Single	90K	**No**

Marital Status

Single	**Married**	**Divorced**	**NULL**
4	3	2	1

Mode: Single

Example

Tid	**Refund**	**Marital Status**	**Taxable Income**	**Cheat**
1	Yes	Single	125K	**No**
2	No	Married	100K	**No**
3	No	Single	70K	**No**
4	Yes	Married	120K	**No**
5	No	Divorced	10000K	**Yes**
6	No	NULL	60K	**No**
7	Yes	Divorced	220K	**NULL**
8	No	Single	85K	**Yes**
9	No	Married	90K	**No**
10	No	Single	90K	**No**

Marital Status

Single	**Married**	**Divorced**	**NULL**
40%	30%	20%	10%

Example

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	10000K	Yes
6	No	NULL	60K	No
7	Yes	Divorced	220K	NULL
8	No	Single	85K	Yes
9	No	Married	90K	No
10	No	Single	90K	No

Marital Status

Single	Married	Divorced
44%	33%	22%

Percentiles

- For continuous data, the notion of a percentile is more useful.

Given an ordinal or continuous attribute x and a number p between 0 and 100, the p^{th} percentile is a value x_p of x such that p% of the observed values of x are less or equal than x_p.

- For instance, the 80th percentile is the value $x_{80\%}$ that is greater or equal than 80% of all the values of x we have in our data.

Example

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	10000K	Yes
6	No	NULL	60K	No
7	Yes	Divorced	220K	NULL
8	No	Single	85K	Yes
9	No	Married	90K	No
10	No	Single	90K	No

Taxable Income
10000K
220K
125K
120K
100K
90K
90K
85K
70K
60K

$x_{80\%}$ = 125K

Measures of Location: Mean and Median

- The mean is the most common measure of the location of a set of points.
- However, the mean is very sensitive to outliers.

$$\mathrm{mean}(x) = \overline{x} = \frac{1}{m}\sum_{i=1}^{m} x_i$$

$$\mathrm{median}(x) = \begin{cases} x_{(r+1)} & \text{if } m \text{ is odd, i.e., } m = 2r+1 \\ \frac{1}{2}(x_{(r)} + x_{(r+1)}) & \text{if } m \text{ is even, i.e., } m = 2r \end{cases}$$

- Thus, the median or a trimmed mean is also commonly used.

Example

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	**No**
2	No	Married	100K	**No**
3	No	Single	70K	**No**
4	Yes	Married	120K	**No**
5	No	Divorced	10000K	**Yes**
6	No	NULL	60K	**No**
7	Yes	Divorced	220K	**NULL**
8	No	Single	85K	**Yes**
9	No	Married	90K	**No**
10	No	Single	90K	**No**

Mean: 1090K

Trimmed mean (remove min, max): 105K

Median: (90+100)/2 = 95K

Measures of Spread: Range and Variance

- Range is the difference between the max and min

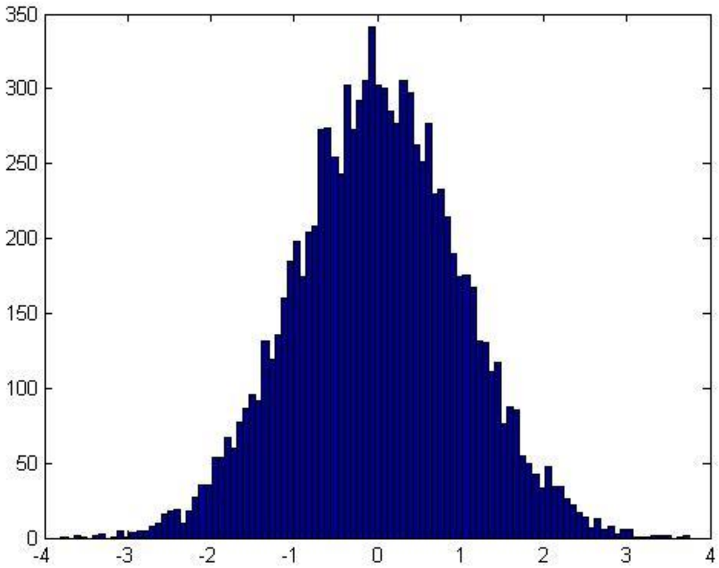
- The variance or standard deviation is the most common measure of the spread of a set of points.

$$var(x) = \frac{1}{m}\sum_{i=1}^{m}(x - \bar{x})^2$$

$$\sigma(x) = \sqrt{var(x)}$$

Normal Distribution

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

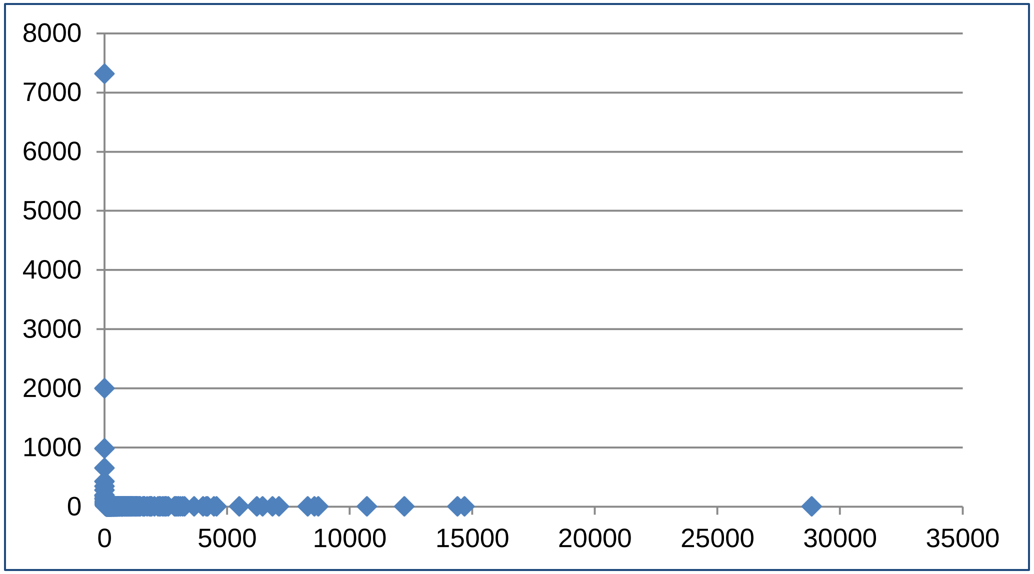


This is a value histogram

- An important distribution that characterizes many quantities and has a central role in probabilities and statistics.
  - Appears also in the central limit theorem
- Fully characterized by the mean μ and standard deviation σ

Not everything is normally distributed

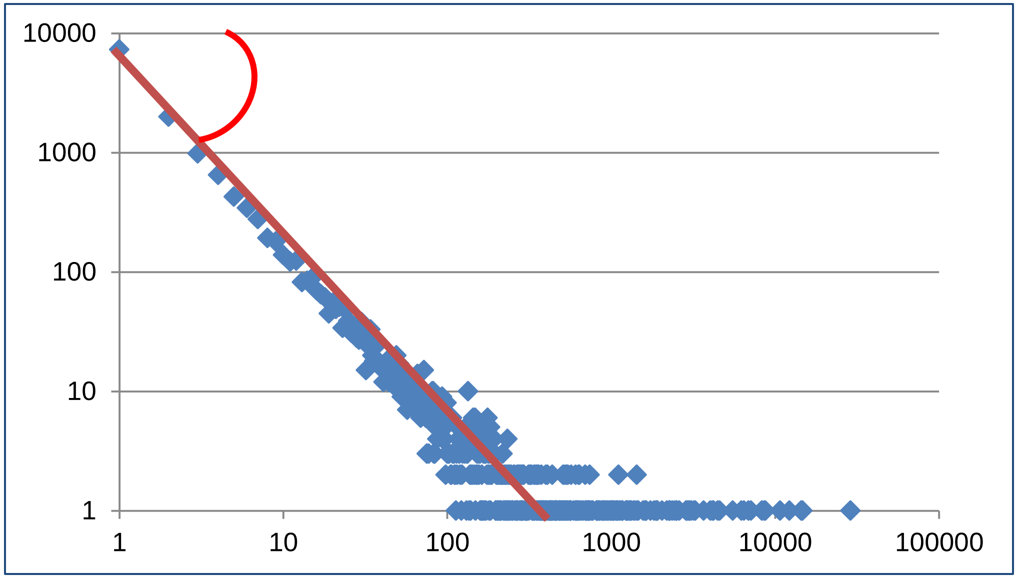
- Plot of number of words with x number of occurrences



- If this was a normal distribution we would not have a frequency as large as 28K

Power-law distribution

- We can understand the distribution of words if we take the log-log plot



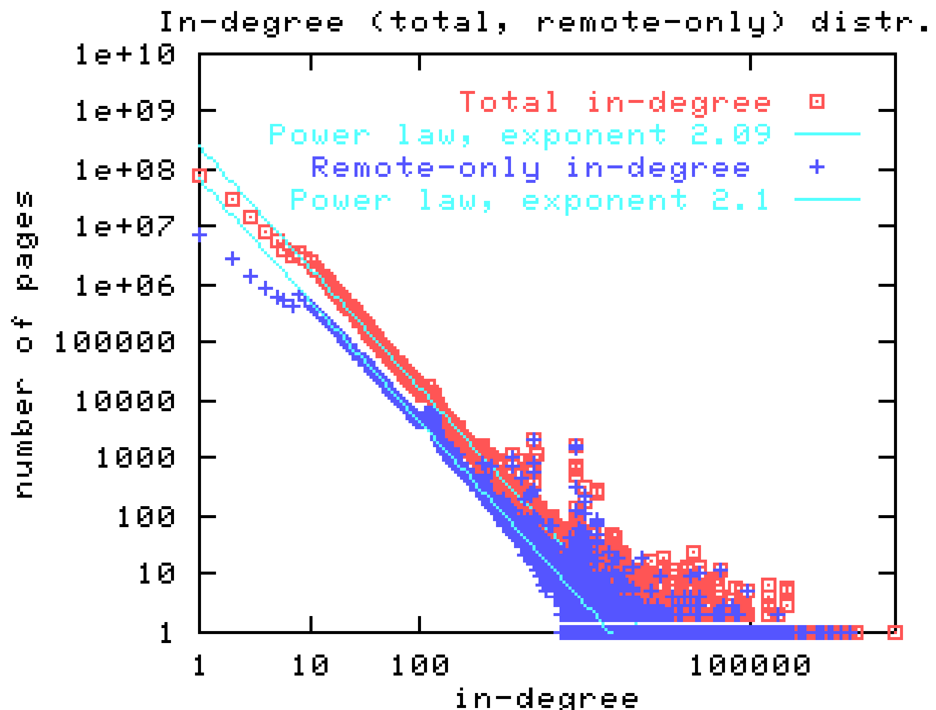
The slope of the line gives us the exponent α

- Linear relationship in the log-log space

$$\log p(x = k) = -a \log k$$
$$p(x = k) = k^{-a}$$

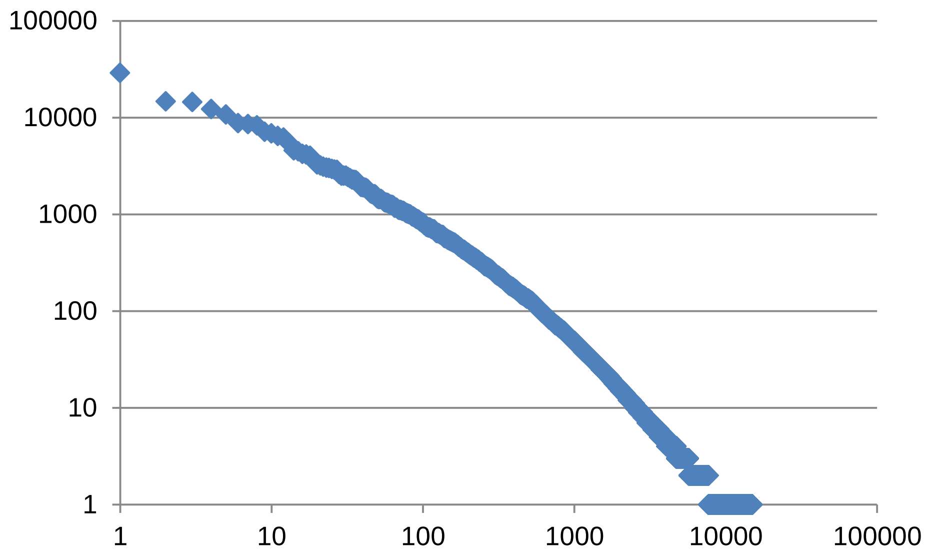
Power-laws are everywhere

- Incoming and outgoing links of web pages, number of friends in social networks, number of occurrences of words, file sizes, city sizes, income distribution, popularity of products and movies
  - Signature of human activity?
  - A mechanism that explains everything?
  - Rich get richer process



Zipf's law

- Power laws can be detected also by a linear relationship in the log-log space for the rank-frequency plot



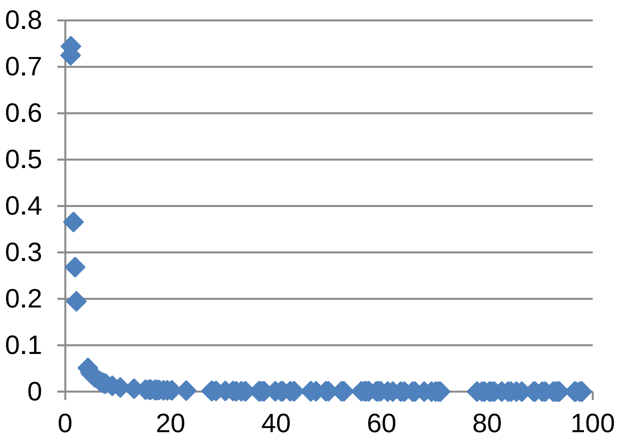
- $f(r)$: Frequency of the r-th most frequent word

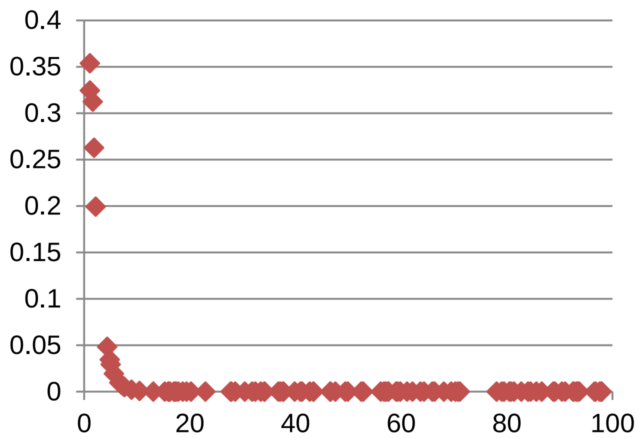
$$\log f(r) = -\beta \log r$$

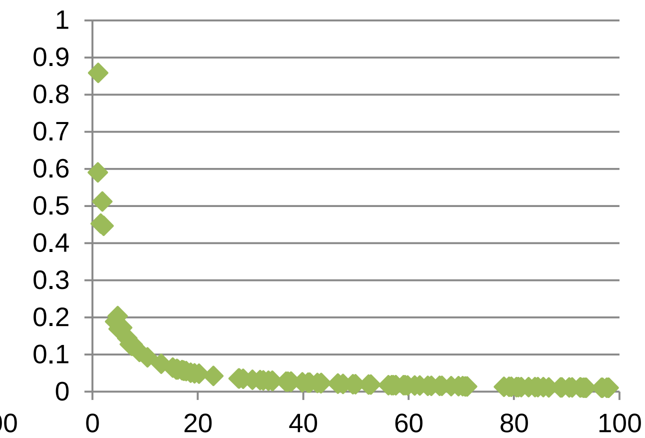
$$f(r) = r^{-\beta}$$

The importance of correct representation

- Consider the following three plots which are histograms of values. What do you observe? What can you tell of the underlying function?

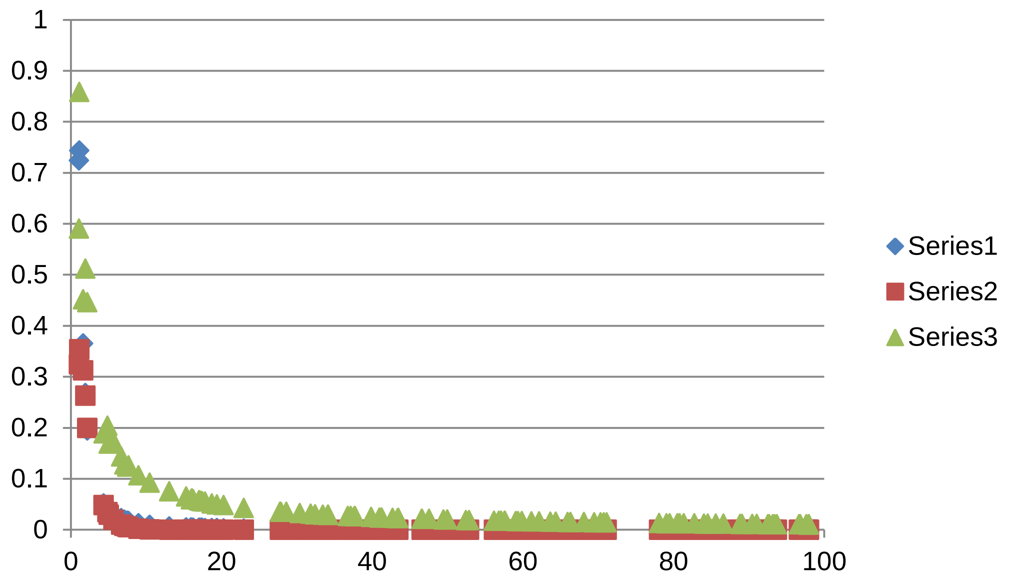






The importance of correct representation

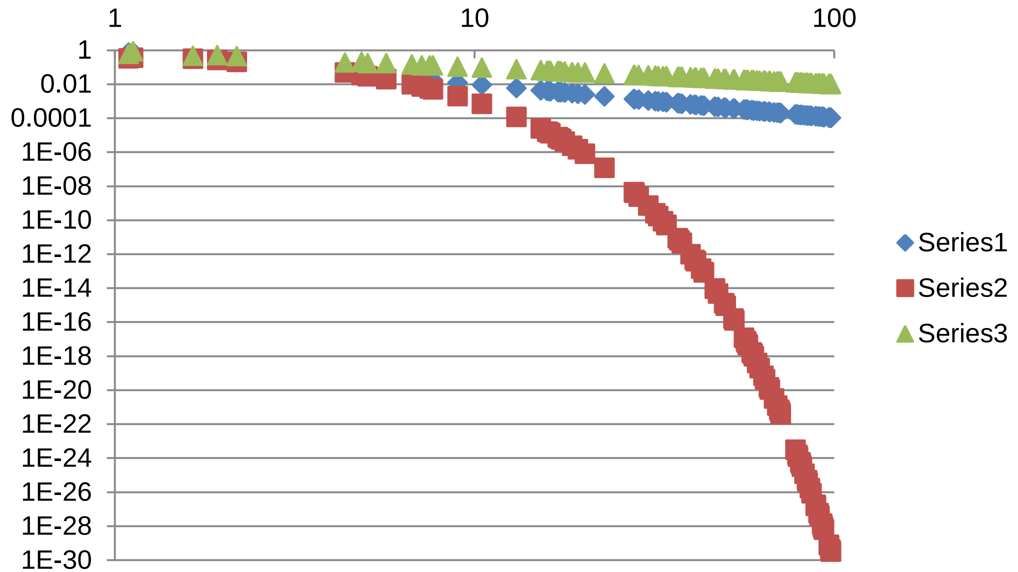
- Putting all three plots together makes it more clear to see the differences



- Green falls more slowly. Blue and Red seem more or less the same

The importance of correct representation

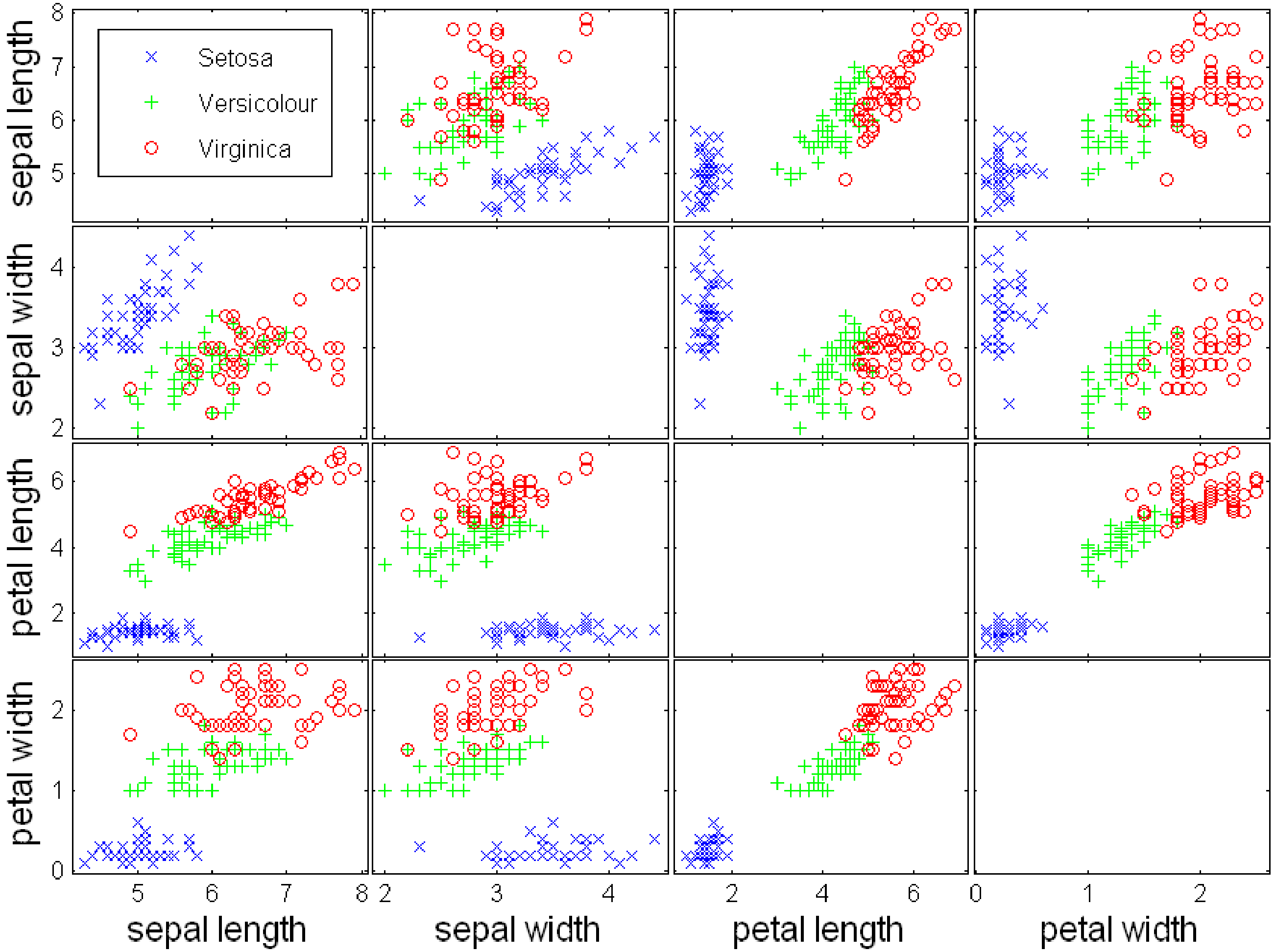
- Making the plot in log-log space makes the differences more clear



- Green and Blue form straight lines. Red drops exponentially.
  - $y = \frac{1}{2x+\epsilon}$ $\log y \approx -\log x + c$
  - $y = \frac{1}{x^2+\epsilon}$ $\log y \approx -2\log x + c$
  - $y = 2^{-x} + \epsilon$ $\log y \approx -x + c = -10^{\log x} + c$

Linear relationship in log-log means polynomial in linear-linear
The slope in the log-log is the exponent of the polynomial

Scatter Plot Array of Iris Attributes



What do you see in these plots?

Correlations

Class Separation

Post-processing

- Visualization
  - The human eye is a powerful analytical tool
  - If we visualize the data properly, we can discover patterns and demonstrate trends
  - Visualization is the way to present the data so that patterns can be seen
    - E.g., histograms and plots are a form of visualization
    - There are multiple techniques (a field on its own)

Visualization on a map

- John Snow, London 1854

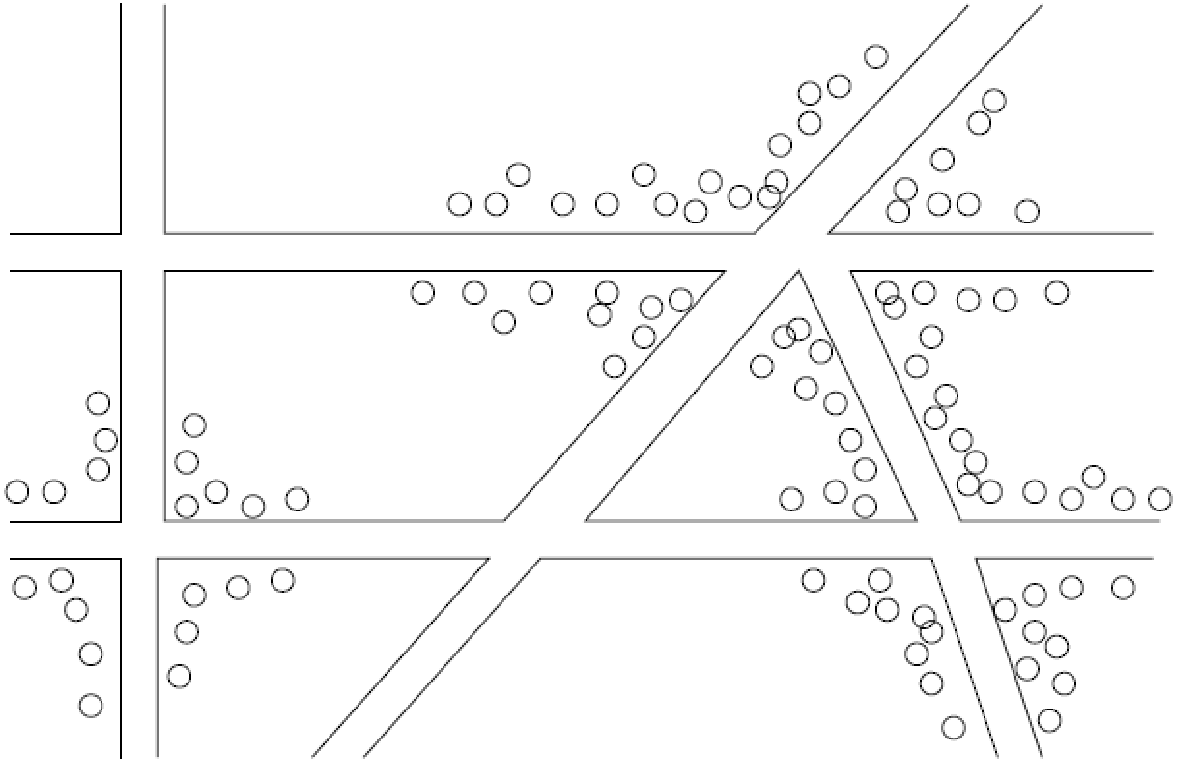
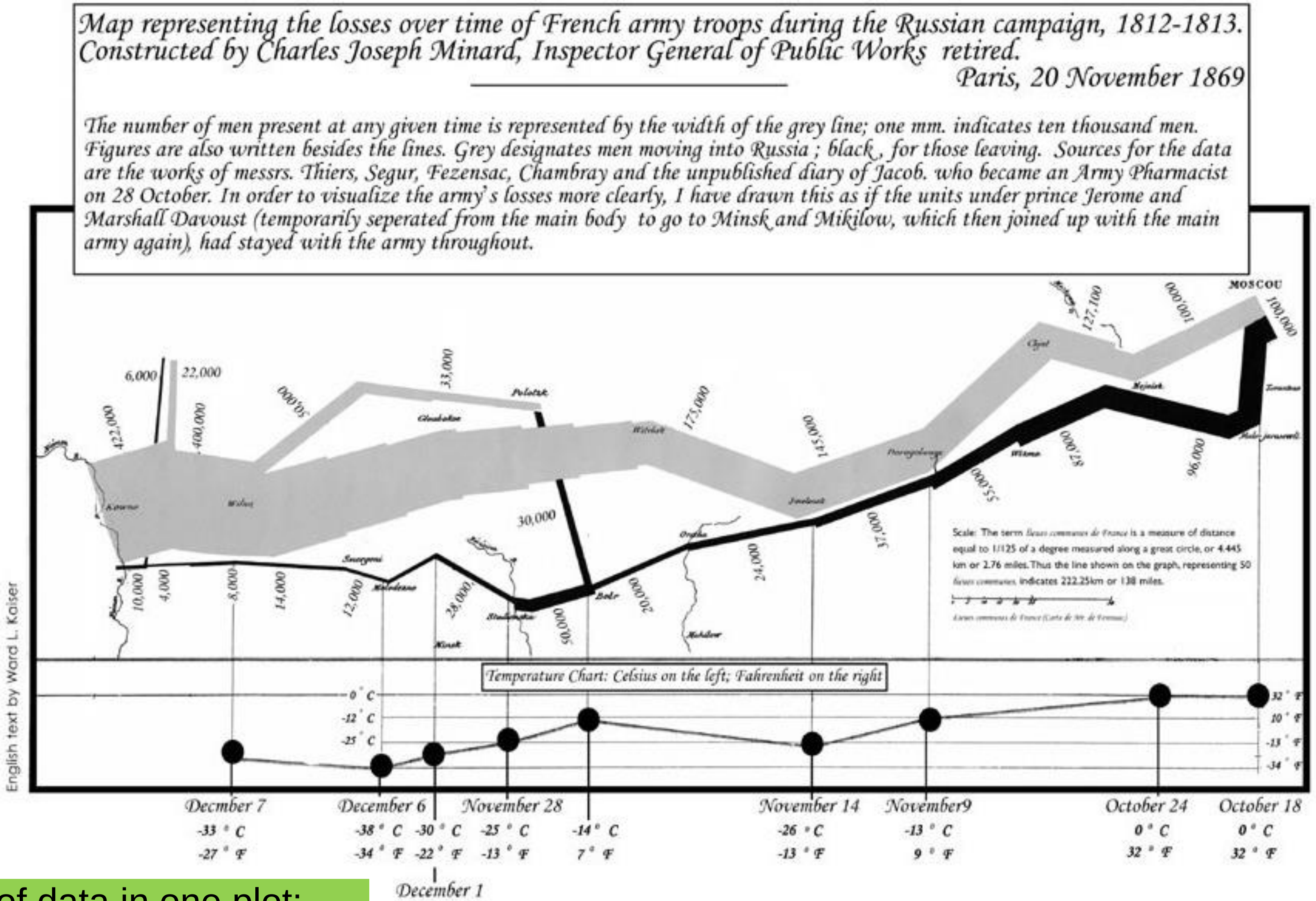


Figure 1.1: Plotting cholera cases on a map of London

Dimensionality Reduction

- The human eye is limited to processing visualizations in two (at most three) dimensions
- One of the great challenges in visualization is to visualize high-dimensional data into a two-dimensional space
  - Dimensionality reduction
  - Distance preserving embeddings

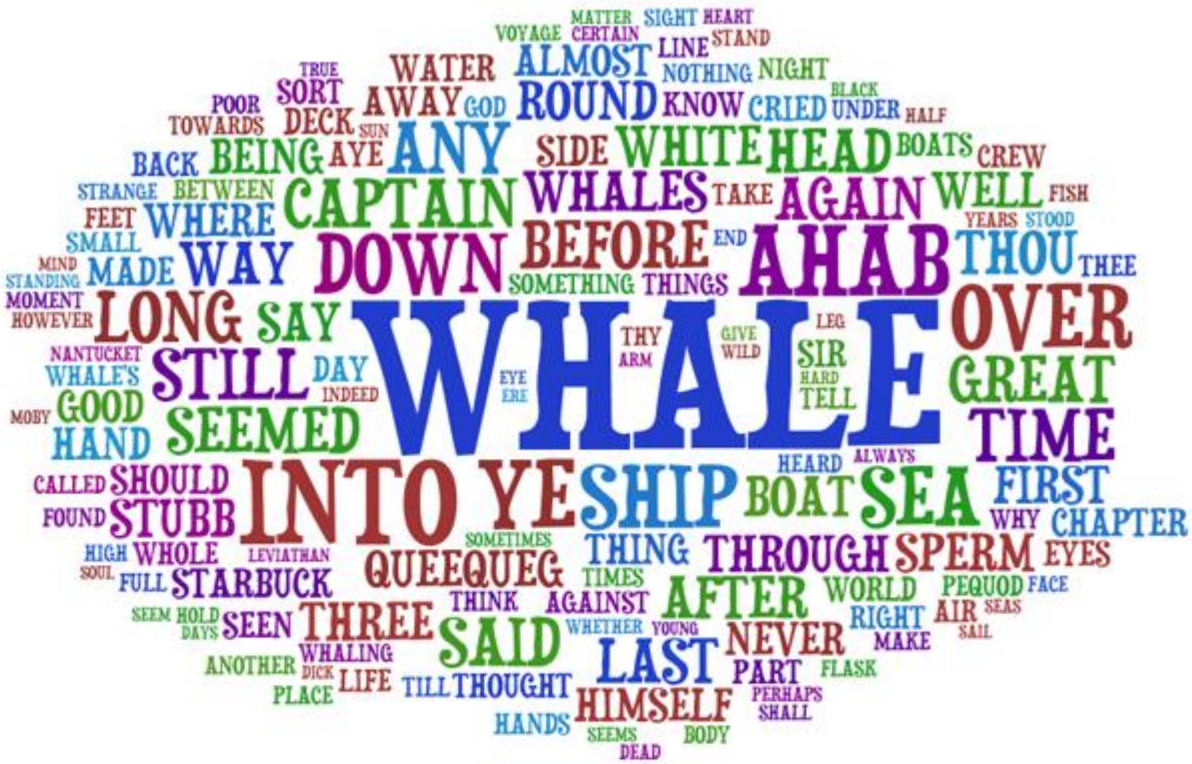
Charles Minard map



Six types of data in one plot:
size of army, temperature,
direction, location, dates etc

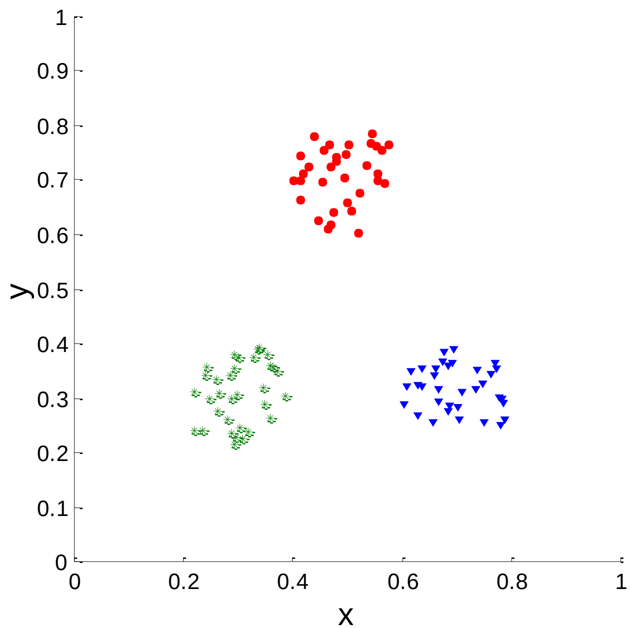
Word Clouds

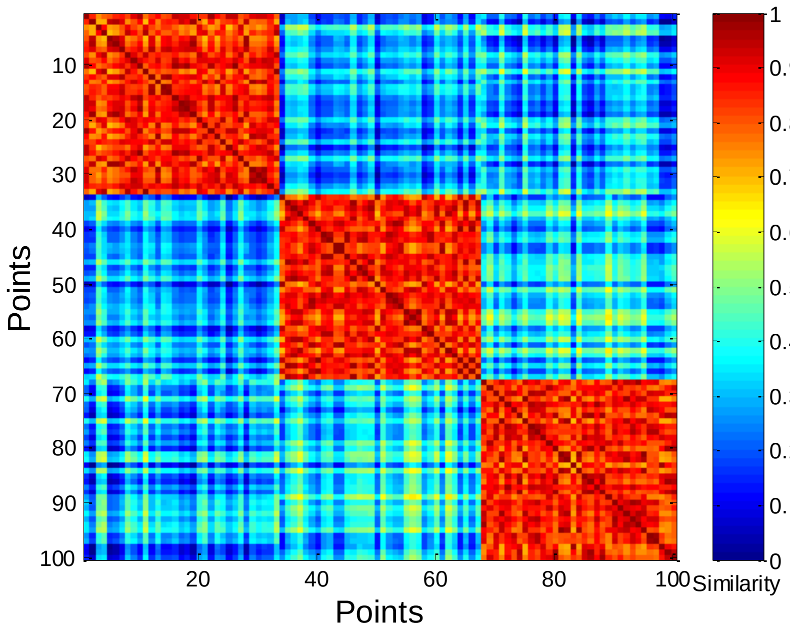
- A fancy way to visualize a document or collection of documents.



Heatmaps

- Plot a point-to-point similarity matrix using a heatmap:
  - Deep red = high values (hot)
  - Dark blue = low values (cold)

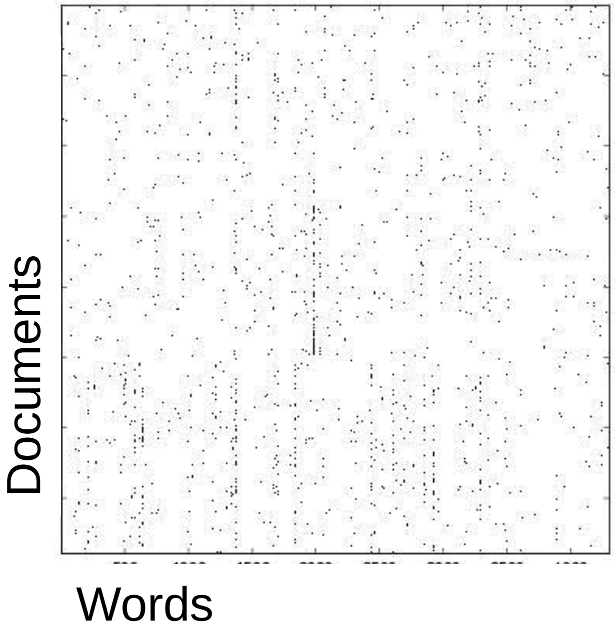




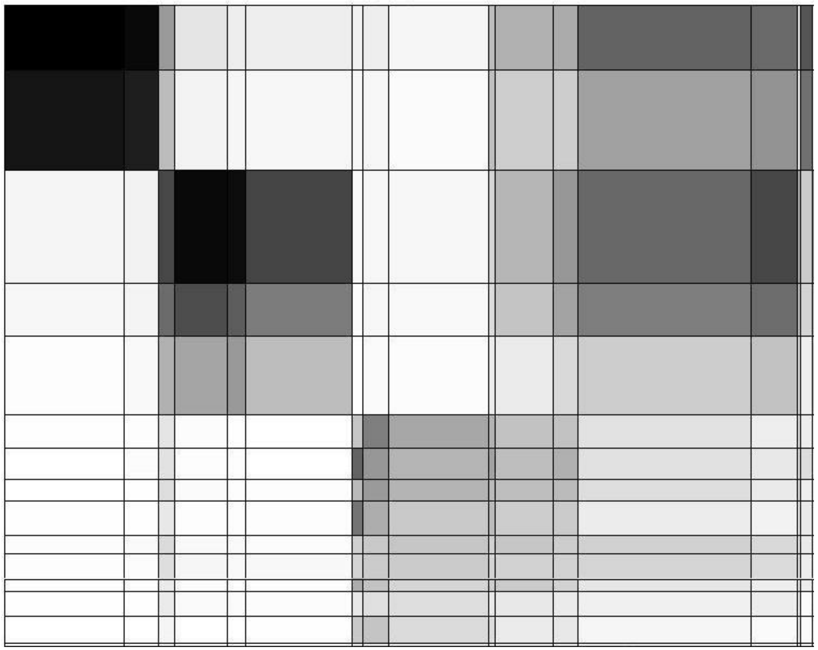
The clustering structure becomes clear in the heatmap

Heatmaps

- Heatmap (grey scale) of the data matrix
  - Document-word frequencies



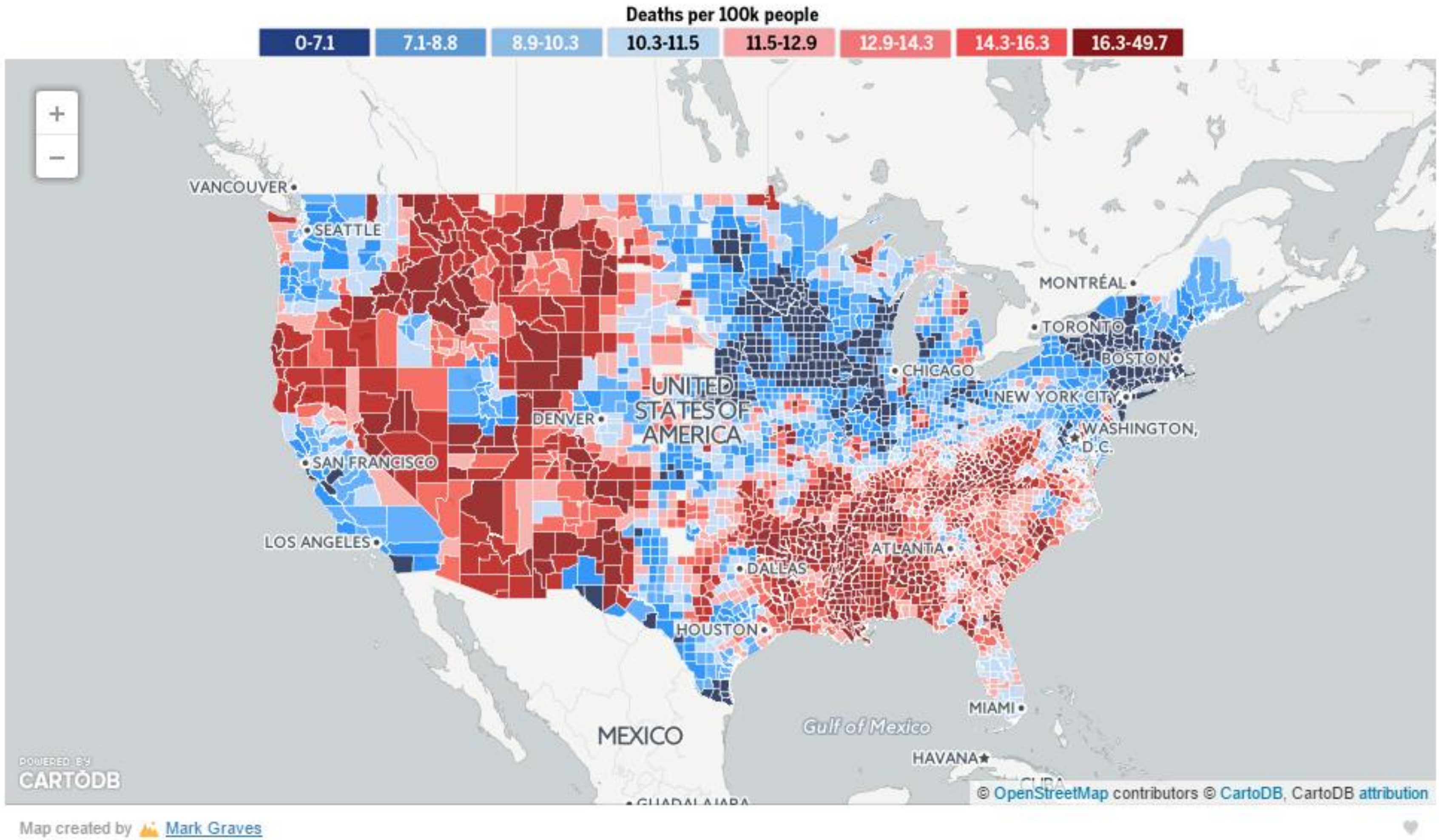
Before clustering



After clustering

Heatmaps

A very popular way to visualize data



http://projects.oregonlive.com/ucc-shooting/gun-deaths.php

Statistical Significance

- When we extract knowledge from a large dataset we need to make sure that what we found is not an artifact of randomness
  - E.g., we find that many people buy milk and toilet paper together.
  - But many (more) people buy milk and toilet paper independently
- Statistical tests compare the results of an experiment with those generated by a null hypothesis
  - E.g., a null hypothesis is that people select items independently.
- A result is interesting if it cannot be produced by randomness.
  - An important problem is to define the null hypothesis correctly: What is random?

Meaningfulness of Answers

- A big data-mining risk is that you will "discover" patterns that are meaningless.
- Statisticians call it Bonferroni's principle: (roughly) if you look in more places for interesting patterns than your amount of data will support, you are bound to find crap.
- The Rhine Paradox: a great example of how not to conduct scientific research.

Rhine Paradox – (1)

- Joseph Rhine was a parapsychologist in the 1950's who hypothesized that some people had Extra-Sensory Perception.
- He devised (something like) an experiment where subjects were asked to guess 10 hidden cards – red or blue.
- He discovered that almost 1 in 1000 had ESP – they were able to get all 10 right!

Rhine Paradox – (2)

- He told these people they had ESP and called them in for another test of the same type.
- Alas, he discovered that almost all of them had lost their ESP.
  - Why?
- What did he conclude?
  - Answer on next slide.

Rhine Paradox – (3)

- He concluded that you shouldn’t tell people they have ESP; it causes them to lose it.