



Feature Engineering

Getting the most out of data for predictive models

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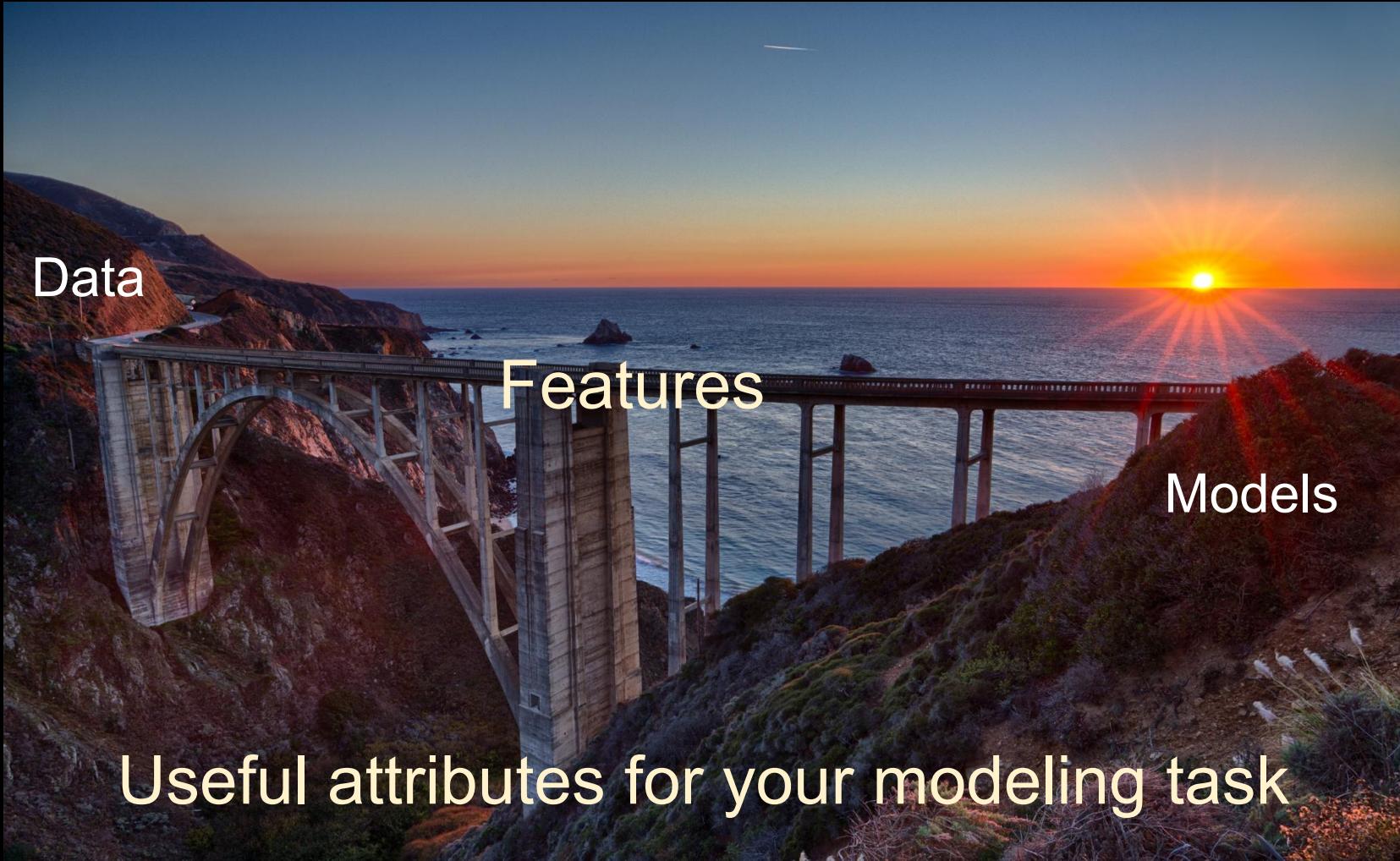
Big Data Borat

@BigDataBorat



Follow

In Data Science, 80% of time spent prepare
data, 20% of time spent complain about need
for prepare data.



Data

Features

Models

Useful attributes for your modeling task

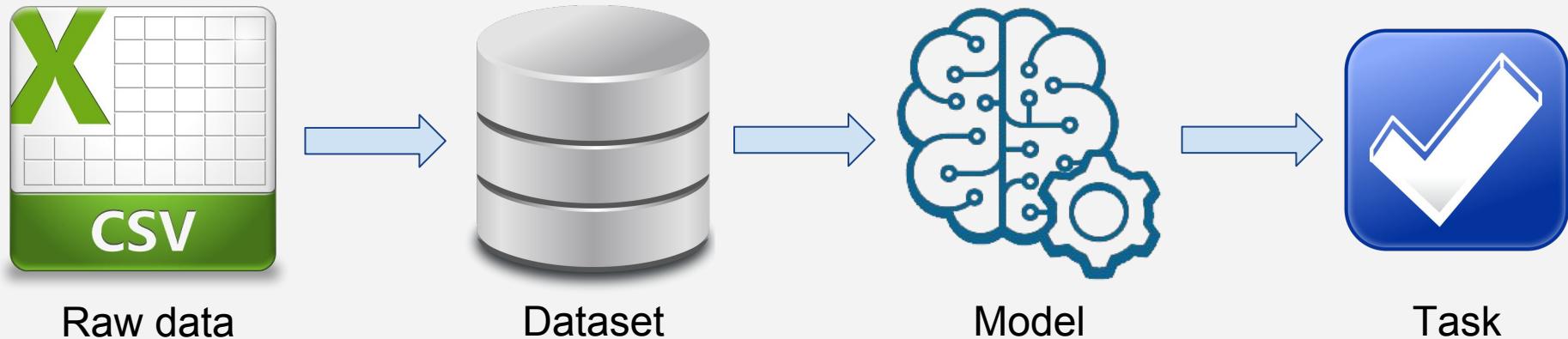
"Feature engineering is the process of transforming raw data into features that better represent the underlying problem to the predictive models, resulting in improved model accuracy on unseen data."

— *Jason Brownlee*

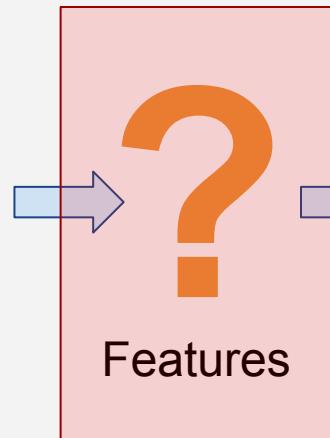
“Coming up with features is difficult,
time-consuming,
requires expert knowledge.
'Applied machine learning' is basically
feature engineering.”

– Andrew Ng

The Dream...



... The Reality



ML Ready
dataset



Model



Task

Raw data

Case Study

Outbrain Click Prediction - Kaggle competition

Can you predict which recommended content each user will click?

The screenshot shows a web browser window. At the top, there's a header with 'Source' and 'Edition: edition.cnn.com'. Below it is a navigation bar with 'CNN' and the text 'Regions » Battle looming: Iraqi troops, militia inch towards ISIS-held Mosul'. A green oval highlights the URL 'edition.cnn.com'. A red arrow points from the text 'Promoted Content Set' to the same URL. Another red arrow points from the text 'Promoted Content Item' to the sidebar.

Promoted Content Set: "I am so happy for them," the man said. "But I am heartbroken myself. My parents were not able to come with me. I don't know how I am going to get them out."

Paid Content

Recommended by Outbrain

Promoted Content Item:

- Mapping the Startup Nation: The 12 most popular Tech Hubs in... Viola Notes
- First time in Israel: Business degrees in Ramat Gan and New... Israel News
- The most addictive game of the year! Play with 15 million Players... Forge Of Empires

- How to Avoid Everyday Pain Landmines Womens Health
- How One Brand is Disrupting the \$63 Billion Makeup Industry The Huffington Post
- Find out what special ingredient makes this omelette so tasty HomeMadebyYou

Dataset

- Sample of users page views and clicks during 14 days on June, 2016
- 2 Billion page views
- 17 million click records
- 700 Million unique users
- 560 sites



Completed • \$25,000 • 991 teams

Outbrain Click Prediction

Wed 5 Oct 2016 – Wed 18 Jan 2017 (1 hour ago)

Dashboard

Private Leaderboard - Outbrain Click Prediction

This competition has completed. This leaderboard reflects the preliminary final standings.
The results will become final after the competition organizers verify the results.

#	Rank	Team Name	+ in the money	Score	Entries	Last Submission UTC (Best - Last Submission)
1	—	code monkey	★	0.70145	48	Wed, 18 Jan 2017 23:33:17 (-1.7h)
2	—	brain-afk	★ *	0.70144	79	Wed, 18 Jan 2017 23:58:08 (-1.7h)
3	—	Three Data Points	★ *	0.69956	130	Wed, 18 Jan 2017 16:03:08
4	—	Andrii Cherednychenko		0.69782	36	Wed, 18 Jan 2017 20:02:39 (-3.9h)
5	—	FG Knight	★	0.69736	52	Wed, 18 Jan 2017 19:11:20
6	—	Neuron		0.69644	15	Sat, 07 Jan 2017 16:03:16 (-10.6d)
7	—	rokh		0.69481	37	Tue, 17 Jan 2017 05:12:13
8	—	CV	★	0.69412	43	Fri, 23 Dec 2016 01:56:31 (-41.8h)
9	• 1	Igor Pasechnik		0.69394	16	Wed, 18 Jan 2017 19:16:18
10	• 1	Sangxia		0.69393	9	Tue, 17 Jan 2017 12:55:50
11	—	Brain's Out!	★	0.69378	68	Wed, 18 Jan 2017 23:58:56 (-0.9h)
12	—	Medrr		0.69291	29	Wed, 18 Jan 2017 14:55:38
13	—	diaman & ololo	★	0.69285	33	Wed, 18 Jan 2017 19:34:55
14	—	insulator		0.69018	5	Fri, 23 Dec 2016 00:50:34
15	—	Frederik		0.68999	8	Wed, 18 Jan 2017 22:48:39
16	—	mfzszs		0.68890	19	Wed, 18 Jan 2017 22:32:43 (-8.6d)
17	—	clustifier		0.68851	64	Wed, 18 Jan 2017 17:30:29
18	—	Sameh & Marko	★	0.68841	61	Wed, 18 Jan 2017 20:31:43
19	—	gspmoreira		0.68716	20	Wed, 18 Jan 2017 01:19:14

I placed **19th** from about 1000 competitors (top 2%), mostly due to Feature Engineering techniques.

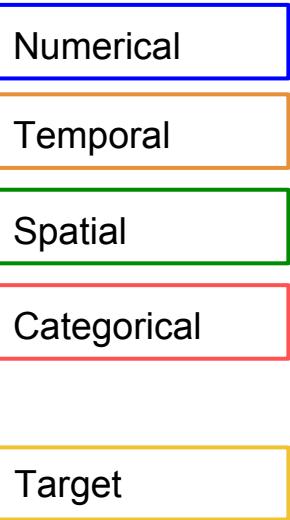
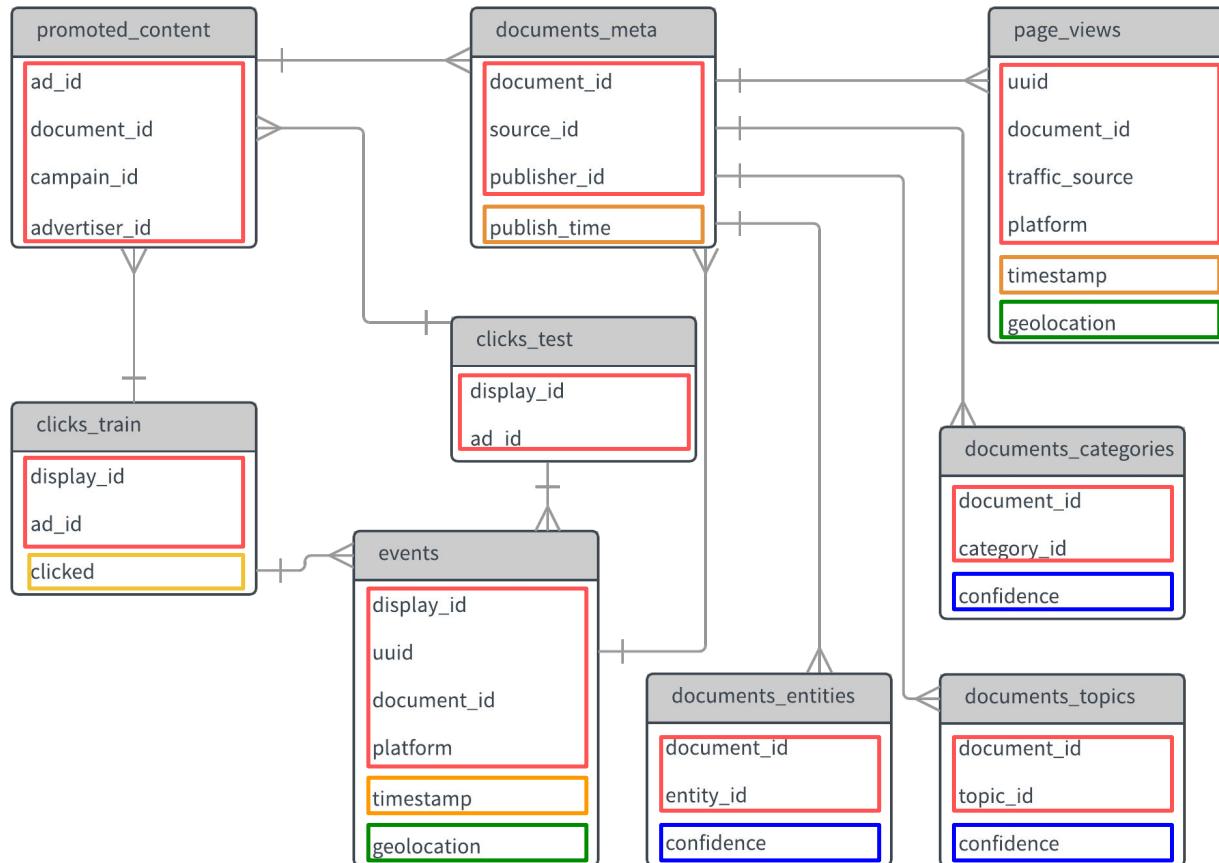
More details of my solution in this [post series](#)

First at all ... a closer look at your data

- What does the data model look like?
- What is the features distribution?
- What are the features with missing or inconsistent values?
- What are the most predictive features?
- Conduct an Exploratory Data Analysis (EDA)



Outbrain Click Prediction - Data Model



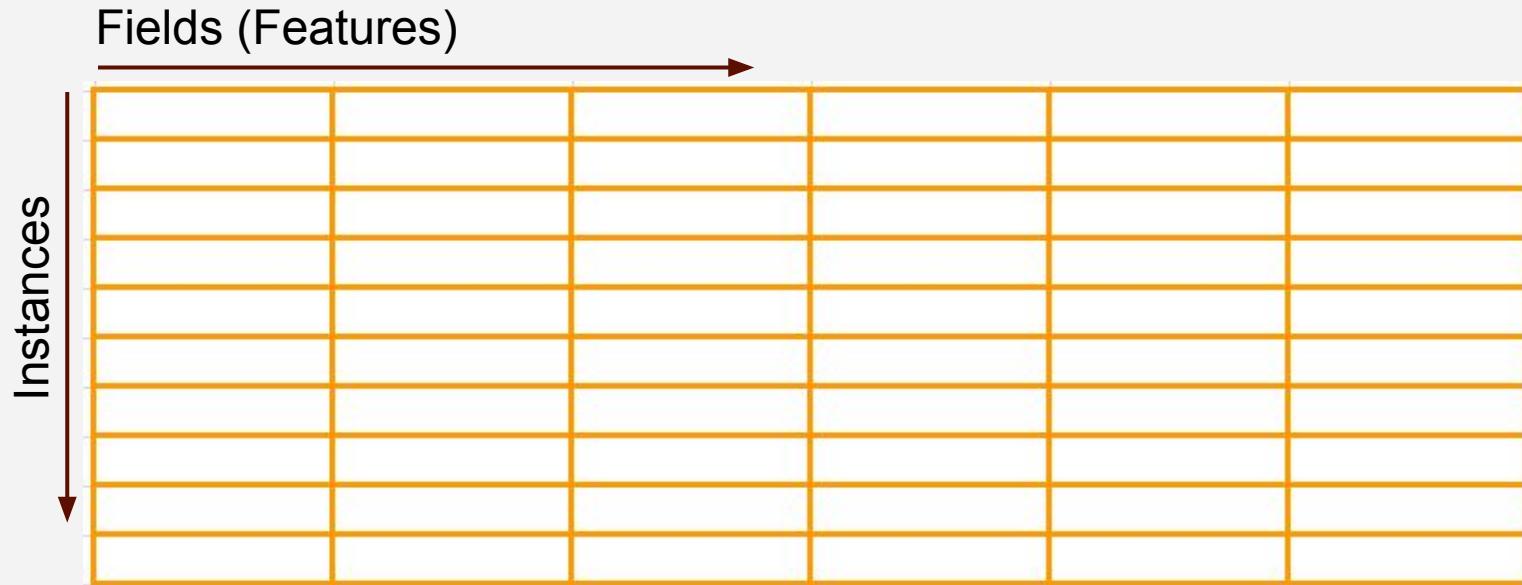
Here are some Feature Engineering techniques
for your Data Science toolbox...



Data Munging



ML-Ready Dataset



Tabular data (rows and columns)

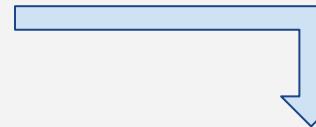
- Usually denormalized in a single file/dataset
- Each row contains information about one instance
- Each column is a feature that describes a property of the instance

Data Cleansing

Homogenize missing values and different types of in the same feature, fix input errors, types, etc.

Name	Date	Duration (s)	Genre	Plays
Highway star	1984-05-24	-	Rock	139
Blues alive	1990/03/01	281	Blues	239
Lonely planet	2002-11-19	5:32s	Techno	42
Dance, dance	02/23/1983	312	Disco	N/A
The wall	1943-01-20	218	Reagge	83
Offside down	1965-02-19	4 minutes	Techno	895
The alchemist	2001-11-21	418	Bluesss	178
Bring me down	18-10-98	328	Classic	21
The scarecrow	1994-10-12	269	Rock	734

Original data



Cleaned data

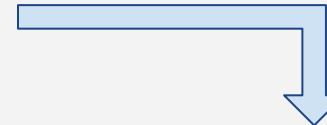
Name	Date	Duration (s)	Genre	Plays
Highway star	1984-05-24		Rock	139
Blues alive	1990-03-01	281	Blues	239
Lonely planet	2002-11-19	332	Techno	42
Dance, dance	1983-02-23	312	Disco	
The wall	1943-01-20	218	Reagge	83
Offside down	1965-02-19	240	Techno	895
The alchemist	2001-11-21	418	Blues	178
Bring me down	1998-10-18	328	Classic	21
The scarecrow	1994-10-12	269	Rock	734

Aggregating

Necessary when the entity to model is an aggregation from the provided data.

Original data (list of playbacks)

Content	Genre	Duration	Play Time	User	Device
Highway star	Rock	190	2015-05-12 16:29:33	User001	TV
Blues alive	Blues	281	2015-05-13 12:31:21	User005	Tablet
Lonely planet	Techno	332	2015-05-13 14:26:04	User003	TV
Dance, dance	Disco	312	2015-05-13 18:12:45	User001	Tablet
The wall	Reagge	218	2015-05-14 09:02:55	User002	Smartphone
Offside down	Techno	240	2015-05-14 11:26:32	User005	Tablet
The alchemist	Blues	418	2015-05-14 21:44:15	User003	TV
Bring me down	Classic	328	2015-05-15 06:59:56	User001	Tablet
The scarecrow	Rock	269	2015-05-15 12:37:05	User003	Smartphone



Aggregated data (list of users)

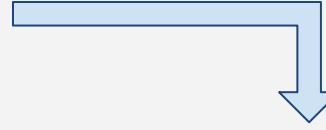
User	Num.Playbacks	Total Time	Pref.Device
User001	3	830	Tablet
User002	1	218	Smartphone
User003	3	1019	TV
User005	2	521	Tablet

Pivoting

Necessary when the entity to model is an aggregation from the provided data.

Original data

Content	Genre	Duration	Play Time	User	Device
Highway star	Rock	190	2015-05-12 16:29:33	User001	TV
Blues alive	Blues	281	2015-05-13 12:31:21	User005	Tablet
Lonely planet	Techno	332	2015-05-13 14:26:04	User003	TV
Dance, dance	Disco	312	2015-05-13 18:12:45	User001	Tablet
The wall	Reagge	218	2015-05-14 09:02:55	User002	Smartphone
Offside down	Techno	240	2015-05-14 11:26:32	User005	Tablet
The alchemist	Blues	418	2015-05-14 21:44:15	User003	TV
Bring me down	Classic	328	2015-05-15 06:59:56	User001	Tablet
The scarecrow	Rock	269	2015-05-15 12:37:05	User003	Smartphone



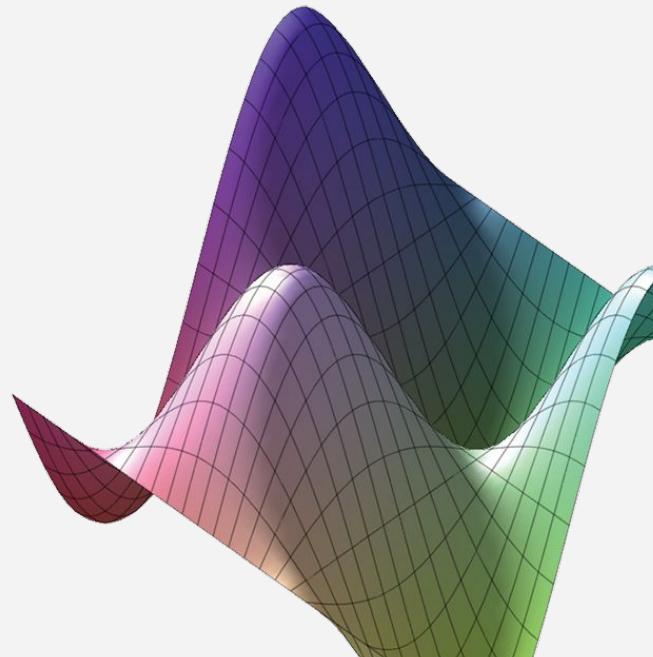
Aggregated data with pivoted columns

playbacks by device

Play duration by device

User	Num.Playback	Total Time	Pref.Device	NP_TV	NP_Tablet	NP_Smartphone	TT_TV	TT_Tablet	TT_Smartphone
User001	3	830	Tablet	1	2	0	190	640	0
User002	1	218	Smartphone	0	0	1	0	0	218
User003	3	1019	TV	2	0	1	750	0	269
User005	2	521	Tablet	0	2	0	0	521	0

Numerical Features



Numerical features

- Usually easy to ingest by mathematical models.
- Can be prices, measurements, counts, ...
- Distribution and scale matters to many models
- Easier to impute missing data



Imputation for missing values

- Datasets contain missing values, often encoded as blanks, NaNs or other placeholders
- Ignoring rows and/or columns with missing values is possible, but at the price of loosing data which might be valuable
- Better strategy is to infer them from the known part of data
- Strategies
 - **Mean:** Basic approach
 - **Median:** More robust to outliers
 - **Mode:** Most frequent value
 - **Using a model:** Can expose algorithmic bias



Binarization

- Transform discrete or continuous numeric features into binary features
- Example: Number of user views of the same document

document_id	uuid	views_count
25792	6d82e412aa0f0d	8
25792	571016386ffee7	6
25792	6a91157d820e37	6
25792	ad45fc764587b0	6
25792	a743b03f2b8ddc	3



document_id	uuid	viewed
25792	6d82e412aa0f0d	1
25792	571016386ffee7	1
25792	6a91157d820e37	1
25792	ad45fc764587b0	1
25792	8d87becfb35857	1
25792	abcdefg1234567	0

```
>>> from sklearn import preprocessing  
>>> X = [[ 1., -1.,  2.],  
...       [ 2.,  0.,  0.],  
...       [ 0.,  1., -1.]]  
  
>>> binarizer =  
preprocessing.Binarizer(threshold=1.0)  
>>> binarizer.transform(X)  
array([[ 1.,  0.,  1.],  
      [ 1.,  0.,  0.],  
      [ 0.,  1.,  0.]])
```

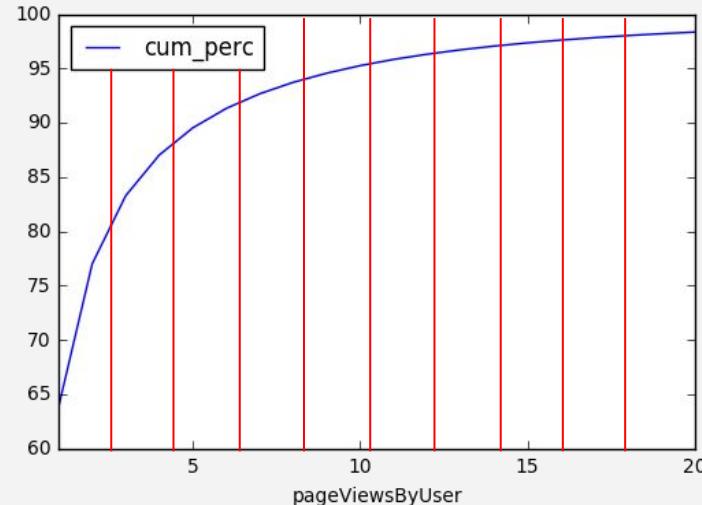
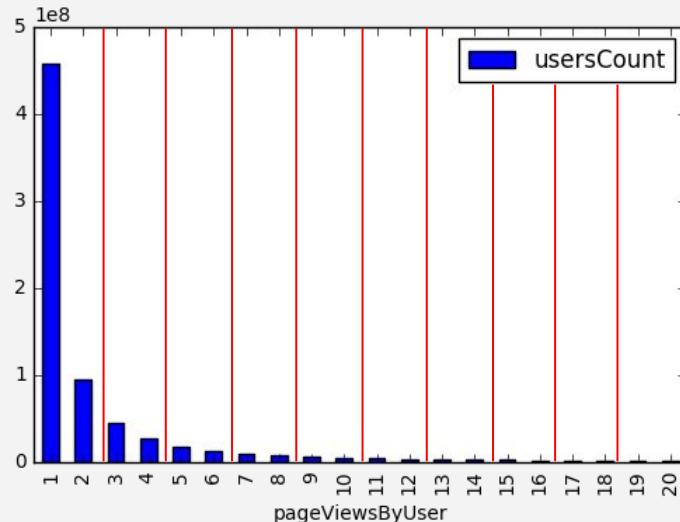
Binarization with scikit-learn



Binning

- Split numerical values into bins and encode with a bin ID
- Can be set arbitrarily or based on distribution
- **Fixed-width binning**

Does fixed-width binning make sense for this long-tailed distribution?



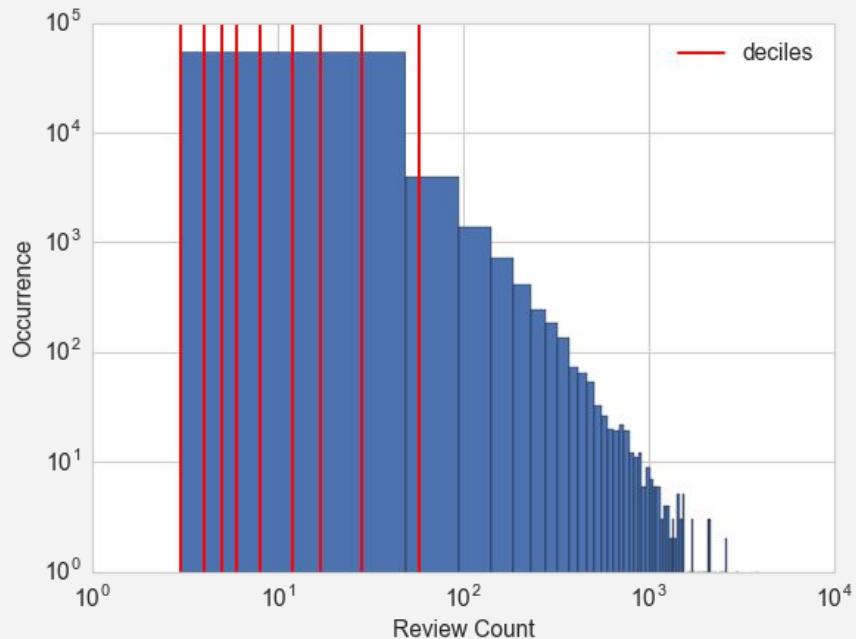
Most users (458M $\sim 5 \times 10^8$) had only 1 pageview during the period.



Binning

- **Adaptative or Quantile binning**

Divides data into equal portions (eg. by median, quartiles, deciles)



```
>>> deciles = dataframe['review_count'].quantile([.1, .2, .3, .4, .5, .6, .7, .8, .9])  
>>> deciles  
0.1    3.0  
0.2    4.0  
0.3    5.0  
0.4    6.0  
0.5    8.0  
0.6   12.0  
0.7   17.0  
0.8   28.0  
0.9   58.0
```

Quantile binning with Pandas



Log transformation

Compresses the range of large numbers and expand the range of small numbers.

Eg. The larger x is, the slower $\log(x)$ increments.

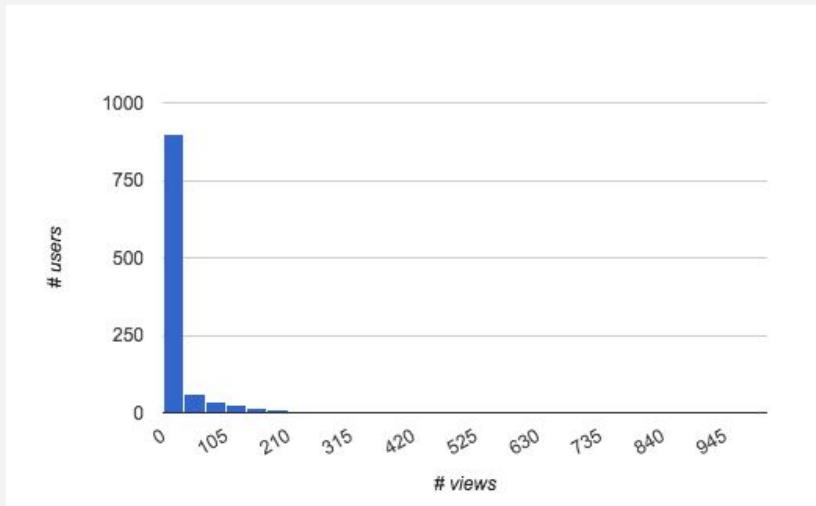


user_id	views_count	$\log(1+views_count)$
a	1000	6.91
b	500	6.22
c	300	5.71
d	200	5.30
e	150	5.02
f	100	4.62
g	70	4.26
h	50	3.93
i	30	3.43
j	20	3.04
k	10	2.40
l	5	1.79
m	1	0.69

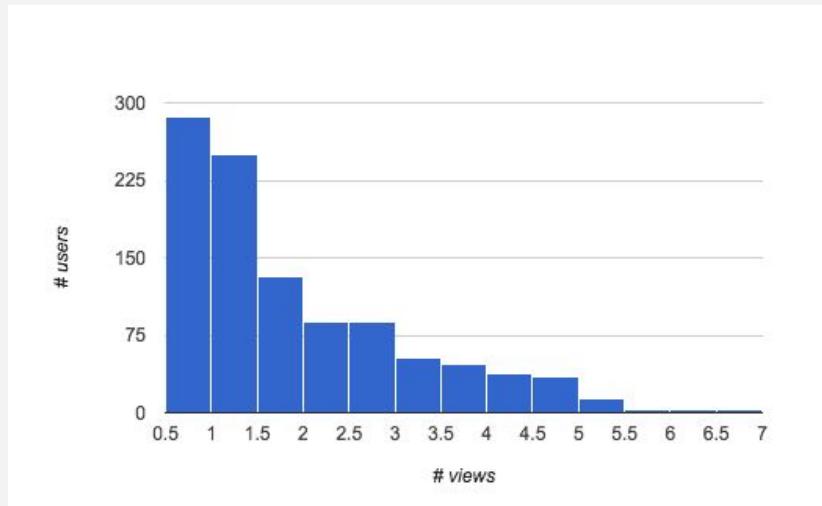


Log transformation

Smoothing long-tailed data with log



Histogram of # views by user



Histogram of # views by user
smoothed by $\log(1+x)$

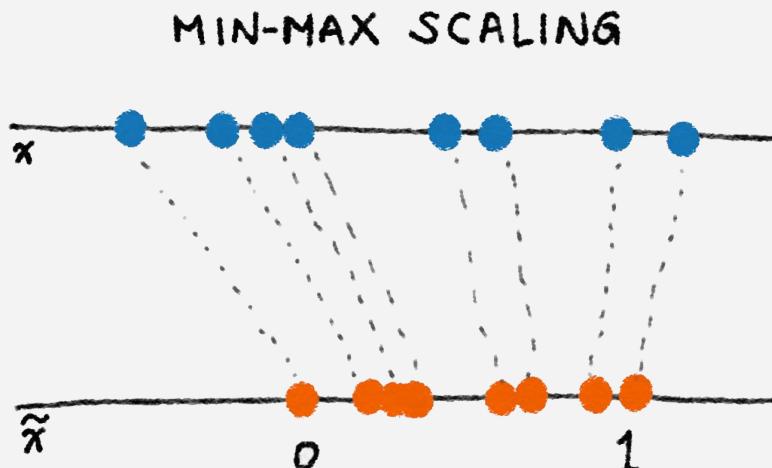
Scaling

- Models that are smooth functions of input features are sensitive to the scale of the input (eg. Linear Regression)
- Scale numerical variables into a certain range, dividing values by a normalization constant (no changes in single-feature distribution)
- Popular techniques
 - MinMax Scaling
 - Standard (Z) Scaling



Min-max scaling

- Squeezes (or stretches) all values within the range of [0, 1] to add robustness to very small standard deviations and preserving zeros for sparse data.



$$\tilde{x} = \frac{x - \min(x)}{\max(x) - \min(x)}$$

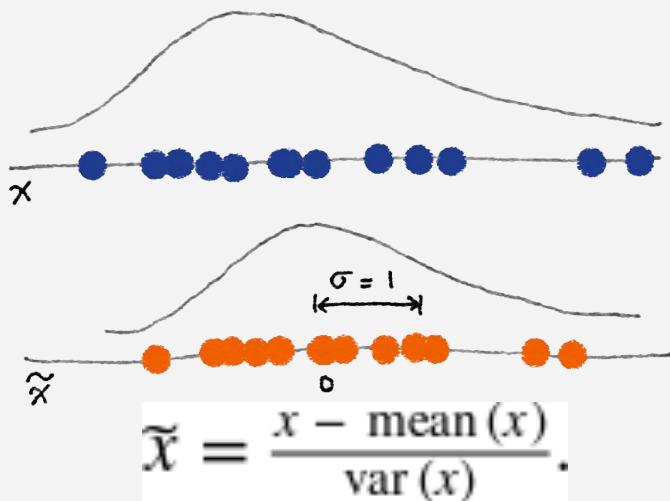
```
>>> from sklearn import preprocessing  
>>> X_train = np.array([[ 1., -1.,  2.,  
...                   [ 2.,  0.,  0.],  
...                   [ 0.,  1., -1.]])  
  
...  
>>> min_max_scaler =  
preprocessing.MinMaxScaler()  
>>> X_train_minmax =  
min_max_scaler.fit_transform(X_train)  
>>> X_train_minmax  
array([[ 0.5      ,  0.       ,  1.       ],  
       [ 1.       ,  0.5     ,  0.33333333],  
       [ 0.       ,  1.       ,  0.       ]])
```



Standard (Z) Scaling

After Standardization, a feature has mean of 0 and variance of 1 (assumption of many learning algorithms)

STANDARDIZATION



```
>>> from sklearn import preprocessing
>>> import numpy as np
>>> X = np.array([[ 1., -1.,  2.],
...                 [ 2.,  0.,  0.],
...                 [ 0.,  1., -1.]])
>>> X_scaled = preprocessing.scale(X)
>>> X_scaled
array([[ 0. ..., -1.22...,  1.33...],
       [ 1.22...,  0. ..., -0.26...],
       [-1.22...,  1.22..., -1.06...]])
>> X_scaled.mean(axis=0)
array([ 0.,  0.,  0.])
>>> X_scaled.std(axis=0)
array([ 1.,  1.,  1.])
```

Standardization with scikit-learn



Interaction Features

- Simple linear models use a linear combination of the individual input features, x_1, x_2, \dots, x_n to predict the outcome y .

$$y = w_1 x_1 + w_2 x_2 + \dots + w_n x_n$$

- An easy way to increase the complexity of the linear model is to create feature combinations (nonlinear features).

Example (House Pricing Prediction) Area (m²) # Rooms

Degree 2 interaction features for vector $X = (x_1, x_2)$

Price

$$y = w_1 x_1 + w_2 x_2 + w_3 x_1 x_2 + w_4 x_1^2 + w_5 x_2^2$$



Interaction Features

$$(X_1, X_2) \longrightarrow (1, X_1, X_2, X_1^2, X_1X_2, X_2^2)$$

```
>>> import numpy as np
>>> from sklearn.preprocessing import PolynomialFeatures
>>> X = np.arange(6).reshape(3, 2)
>>> X
array([[0, 1],
       [2, 3],
       [4, 5]])
>>> poly = poly = PolynomialFeatures(degree=2, interaction_only=False,
include_bias=True)
>>> poly.fit_transform(X)
array([[ 1.,  0.,  1.,  0.,  0.,  1.],
       [ 1.,  2.,  3.,  4.,  6.,  9.],
       [ 1.,  4.,  5., 16., 20., 25.]])
```

Categorical Features



Categorical Features

- Nearly always need some treatment to be suitable for models
- Examples:
 - Platform: [“desktop”, “tablet”, “mobile”]
 - Document_ID or User_ID: [121545, 64845, 121545]
- High cardinality can create very sparse data
- Difficult to impute missing



One-Hot Encoding (OHE)

- Transform a categorical feature with m possible values into m binary features.
- If the variable cannot be multiple categories at once, then only one bit in the group can be on.

platform	platform=desktop	platform=mobile	platform=tablet
desktop	1	0	0
mobile	0	1	0
tablet	0	0	1

- Sparse format is memory-friendly
- Example: “platform=tablet” can be sparsely encoded as “2:1”

Large Categorical Variables

- Common in applications like targeted advertising and fraud detection
- Example:

categorical_feature	unique_values
landing_page_document_id	636482
ad_id	418295
ad_document_id	143856
content_entities	52439
advertiser	2052
publisher	830
country_state	1892

Some large categorical features from Outbrain Click Prediction competition



Feature hashing

- Hashes categorical values into vectors with fixed-length.
- Lower sparsity and higher compression compared to OHE
- Deals with new and rare categorical values (eg: new user-agents)
- May introduce collisions

100 hashed columns

The diagram illustrates the process of feature hashing. On the left, there is a vertical table with a single column labeled "country". It contains five rows with the values "brazil", "chile", "venezuela", "colombia", and "... 222 countries". A blue arrow points from the bottom of this table to the left side of a larger table on the right. This larger table has a header row with columns "country_hashed_1", "country_hashed_2", "country_hashed_3", "country_hashed_4", and "...". Below the header, there are five rows corresponding to the country names in the first table. Each row contains four binary values (0 or 1) representing the presence of the country in 100 different hash buckets. The values are: brazil (1, 0, 0, 0), chile (0, 0, 0, 1), venezuela (0, 0, 1, 0), colombia (0, 0, 1, 0), and the last row (...), which also has (...).

country	country_hashed_1	country_hashed_2	country_hashed_3	country_hashed_4	...
brazil	1	0	0	0	...
chile	0	0	0	1	...
venezuela	0	0	1	0	...
colombia	0	0	1	0	...
... 222 countries



Bin-counting

- Instead of using the actual categorical value, use a global statistic of this category on historical data.
- Useful for both linear and non-linear algorithms
- May give collisions (same encoding for different categories)
- Be careful about leakage



Bin-counting

ad_id
423654
123646
68655
54345



ad_views
18339
335
1244
35387

or

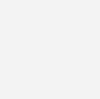
ad_clicks
1355
12
132
1244

or

ad_CTR
0.074
0.036
0.106
0.035



Counts



Click-Through Rate

$$P(\text{click} \mid \text{ad}) = \text{ad_clicks} / \text{ad_views}$$

Temporal Features

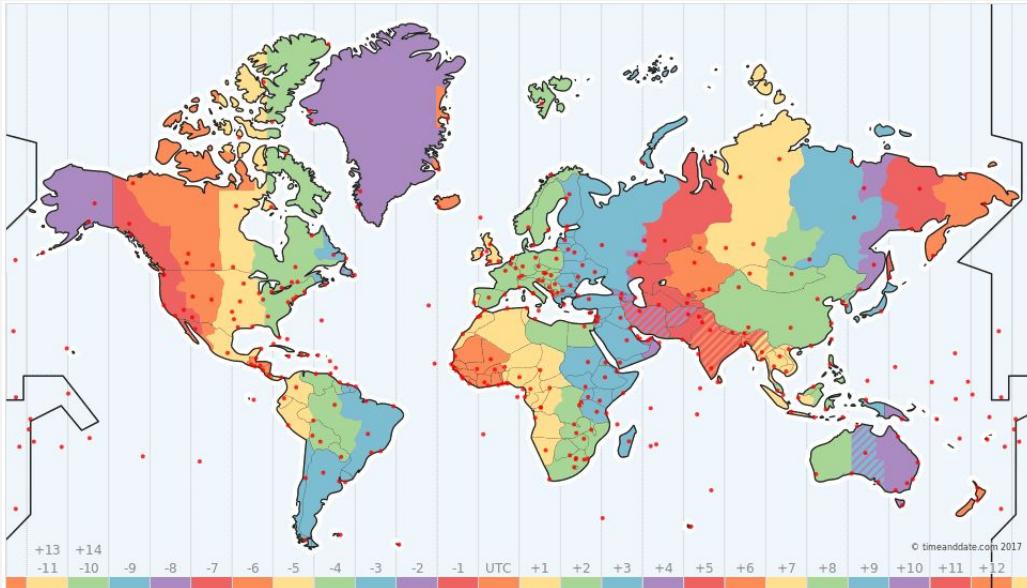




Time Zone conversion

Factors to consider:

- Multiple time zones in some countries
- Daylight Saving Time (DST)
 - Start and end DST dates



	country_name	utc_time_offset	dst_time_offset
0	Afghanistan	+04:30	-
1	Aaland Islands	+02:00	+03:00
2	Albania	+01:00	+02:00
3	Algeria	+01:00	-
4	Samoa (American)	-11:00	-
5	Andorra	+01:00	+02:00
6	Angola	+01:00	-
7	Anguilla (UK)	-04:00	-
8	Antigua & Barbuda	-04:00	-
9	Argentina	-03:00	-



Time binning

- Apply binning on time data to make it categorial and more general.
- Binning a time in hours or periods of day, like below.

Hour range	Bin ID	Bin Description
[5, 8)	1	Early Morning
[8, 11)	2	Morning
[11, 14)	3	Midday
[14, 19)	4	Afternoon
[19, 22)	5	Evening
[22-24) and (00-05]	6	Night

- Extraction: weekday/weekend, weeks, months, quarters, years...



Trendlines

- Instead of encoding: total spend, encode things like:
Spend in last week, spend in last month, spend in last year.
- Gives a trend to the algorithm: two customers with equal spend, can have wildly different behavior — one customer may be starting to spend more, while the other is starting to decline spending.

Spatial Features



Spatial Variables

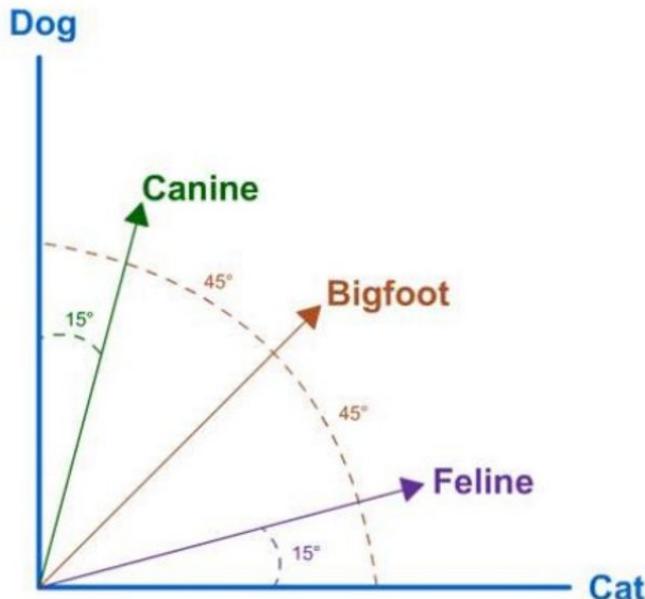
- Spatial variables encode a location in space, like:
 - GPS-coordinates (lat. / long.) - sometimes require projection to a different coordinate system
 - Street Addresses - require geocoding
 - ZipCodes, Cities, States, Countries - usually enriched with the centroid coordinate of the polygon (from external GIS data)
- Derived features
 - Distance between a user location and searched hotels (Expedia competition)
 - Impossible travel speed (fraud detection)

Textual data



Cosine Similarity

Similarity metric between two vectors is cosine among the angle between them



$$\vec{a} \cdot \vec{b} = \|\vec{a}\| \|\vec{b}\| \cos \theta$$

$$\cos \theta = \frac{\vec{a} \cdot \vec{b}}{\|\vec{a}\| \|\vec{b}\|}$$

```
from sklearn.metrics.pairwise import cosine_similarity  
cosine_similarity(tfidf_matrix[0:1], tfidf_matrix)
```

Cosine Similarity with scikit-learn





Topic Modeling

Topics

gene 0.84
dna 0.82
genetic 0.81
...

life 0.82
evolve 0.81
organism 0.81
...

brain 0.84
neuron 0.82
nerve 0.81
...

data 0.82
number 0.82
computer 0.81
...

Documents

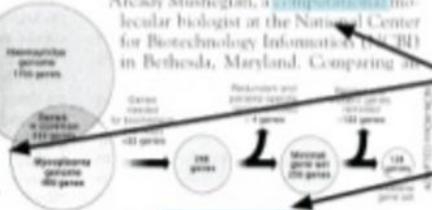
Topic proportions and assignments

Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many genes does an organism need to survive? Last week at the genome meeting here, two genome researchers with radically different approaches presented complementary views of the basic genes needed for life. One research team, using computer analyses to compare known genomes, concluded that only 12 genes can be sustained with just 250 genes, and that the earliest life forms required a mere 128 genes. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those predictions

"are not all that far apart," especially in comparison to the 75,000 genes in the human genome, notes Siv Andersson of Uppsala University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a numbers game. As particularly more and more genomes are sequenced, "there's been a sequencing explosion," explains Arcady Mushegian, a computational molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing all



Stripping down. Computer analysis yields an estimate of the minimum modern and ancient genomes.

SCIENCE • VOL. 272 • 24 MAY 1996



Feature Selection

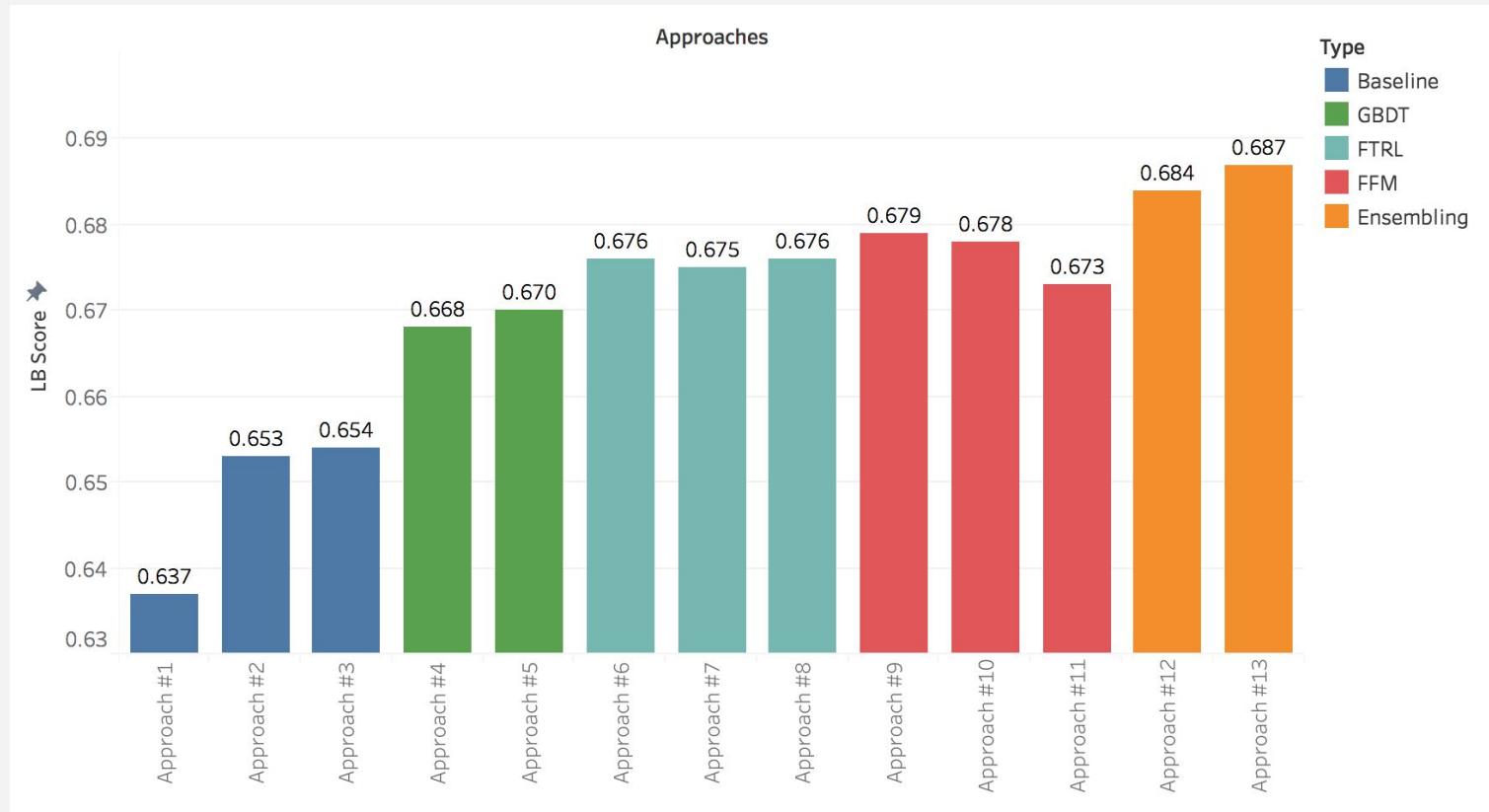


Feature Selection

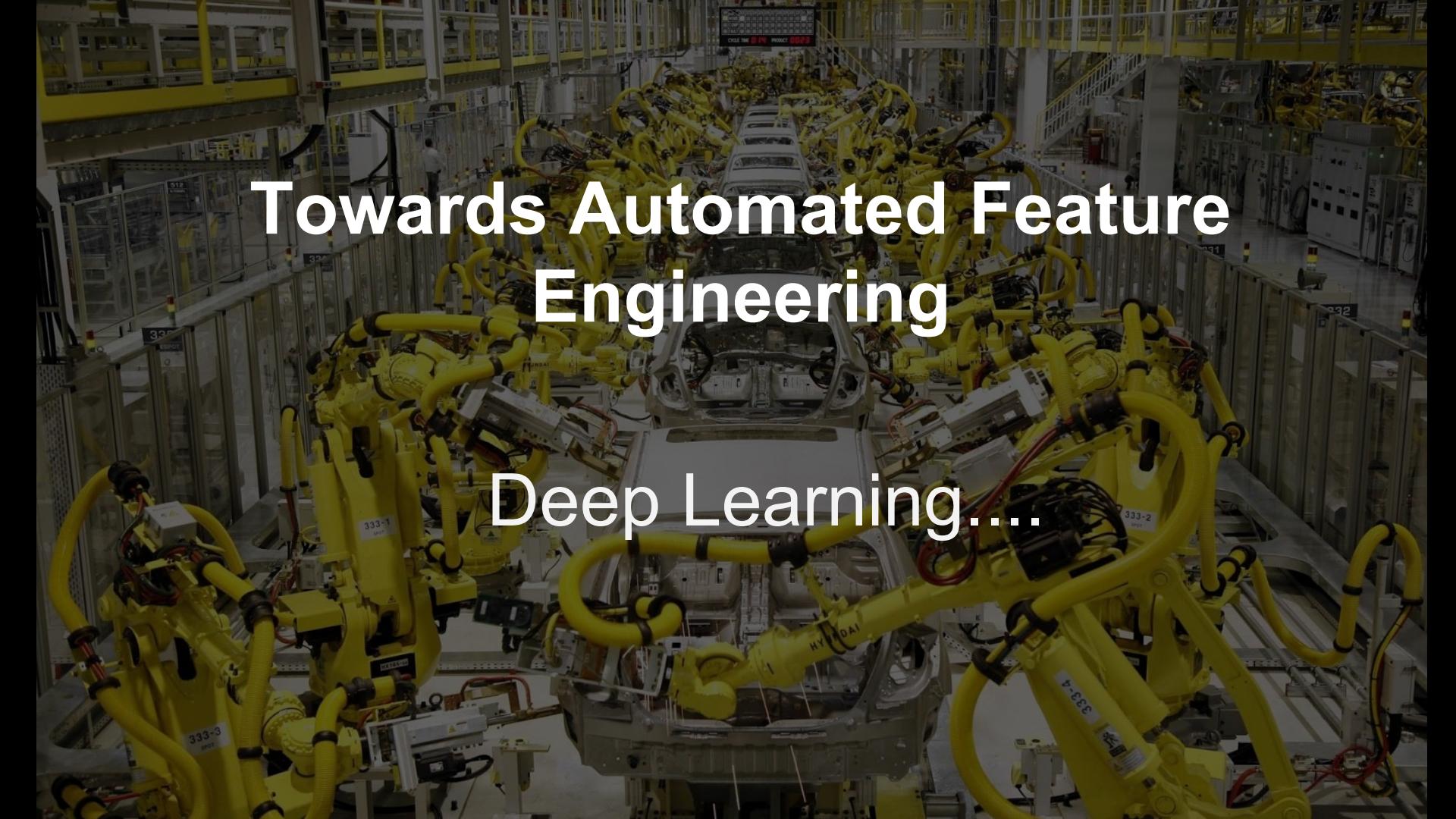
Reduces model complexity and training time

- **Filtering** - Eg. Correlation or Mutual Information between each feature and the response variable
- **Wrapper methods** - Expensive, trying to optimize the best subset of features (eg. Stepwise Regression)
- **Embedded methods** - Feature selection as part of model training process (eg. Feature Importances of Decision Trees or Trees Ensembles)

Diverse set of Features and Models leads to different results!



Outbrain Click Prediction - Leaderboard score evolution of my approaches

A photograph of a modern automobile assembly line. Numerous yellow industrial robots are positioned around a white car chassis, performing tasks like welding and painting. The factory is a large, clean space with white walls and a polished floor. In the background, there are control panels, ladders, and other industrial equipment.

Towards Automated Feature Engineering

Deep Learning....

“More data beats clever algorithms,
but **better data** beats more data.”

– Peter Norvig

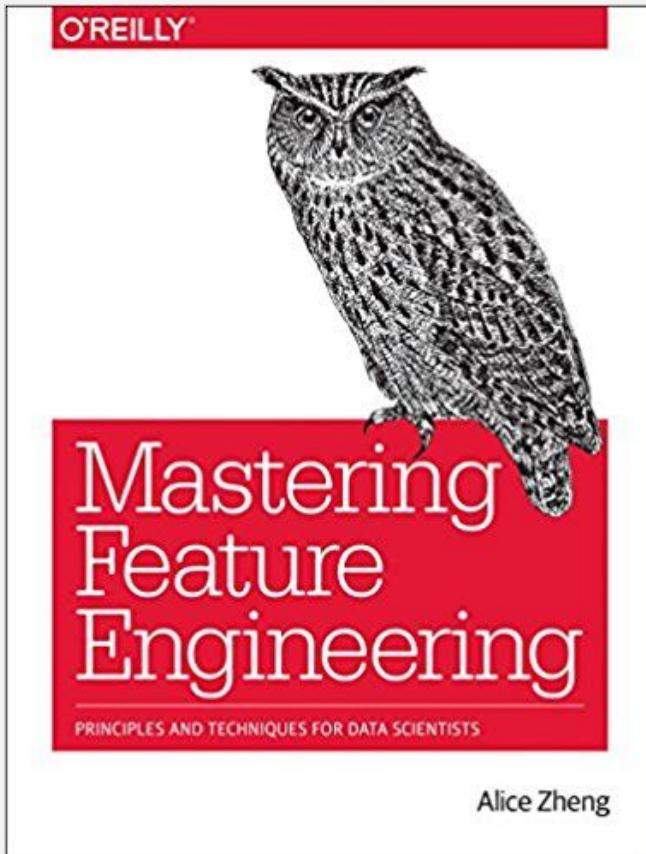
“...some machine learning projects succeed and some fail.

Where is the difference?

Easily the most important factor is the features used.”

– *Pedro Domingos*

References



FEATURE ENGINEERING

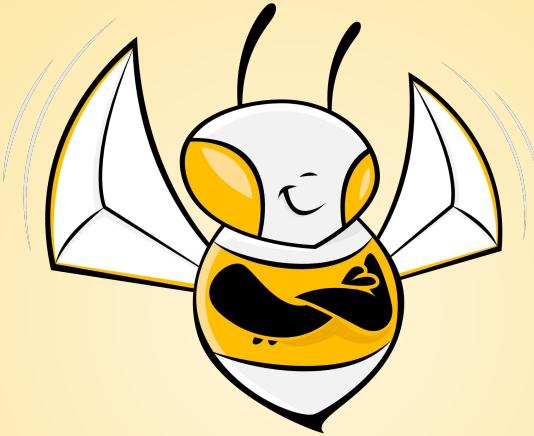
HJ van Veen - Data Science - Nubank Brasil

[Scikit-learn - Preprocessing data](#)

[Spark ML - Feature extraction](#)

[Discover Feature Engineering...](#)

Questions?



MACHINE
LEARNING



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