

# **Lecture 1. Word embeddings**

Nikolay Karpachev

5.02.2024

# Organizational

- Offline classes: Mon 17:05 - 20:00
- Approximate syllabus
  - NLP: classic nlp pipeline -> neural task-specific models -> transfer learning -> generative pretraining
  - RL: intro -> classic rl machinery (value-based, policy-based) -> common techniques for applied rl (PPO, TRPO)
- Course credits
  - Semester participation (hw)
  - Oral exam
- Communication
  - Telegram chat & alerts channel

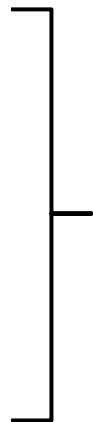


- NLP: introduction
- Text Preprocessing
- Feature Extraction: classical approach
  - Bag-of-Words
  - Bag-of-Ngramms
  - TF-IDF
- Word Embeddings: Word2Vec, GloVe

# Natural Language Processing: Introduction

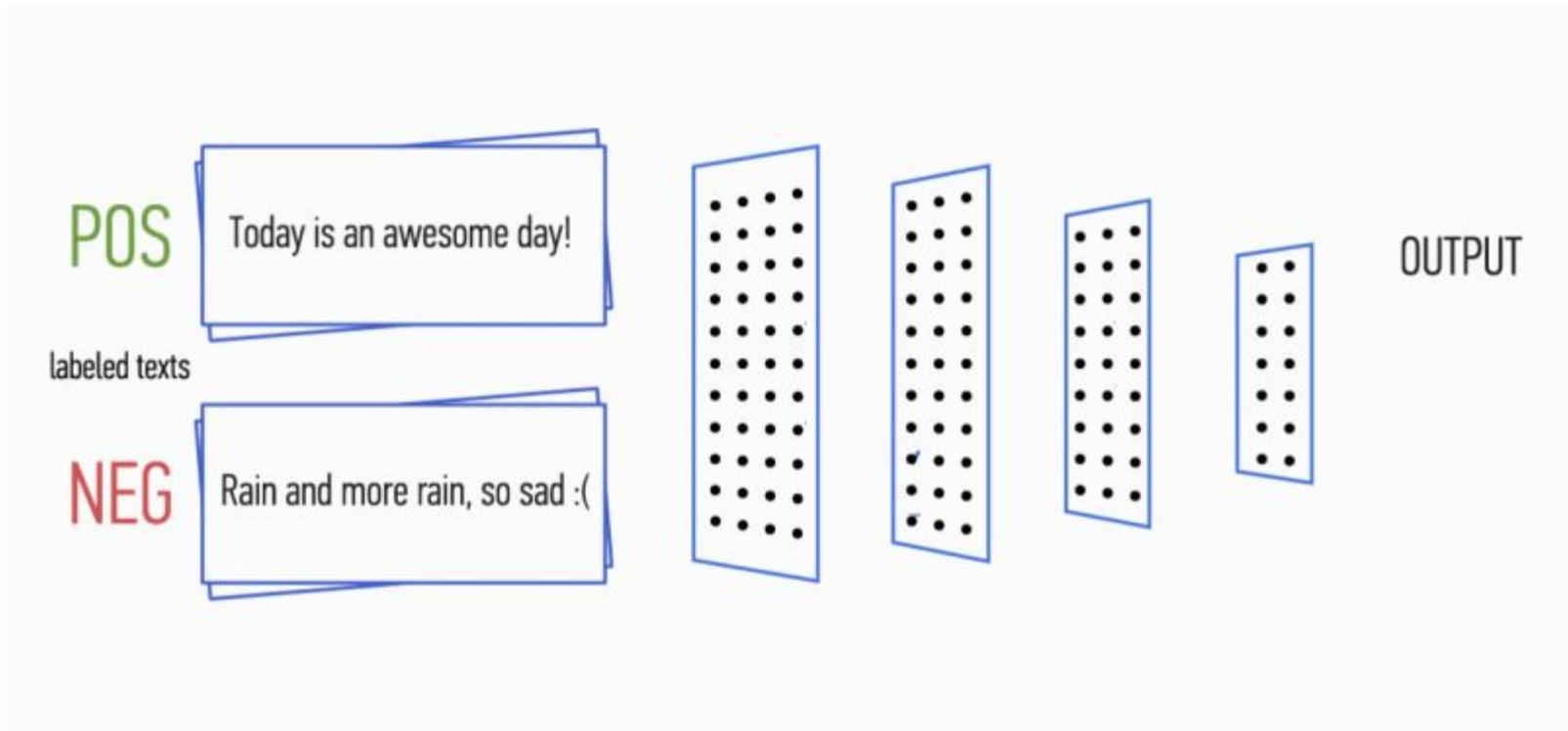
# Popular NLP tasks

- Sentiment analysis
- Spam filtering
- Fake news detection
- Topic prediction
- #hashtag prediction



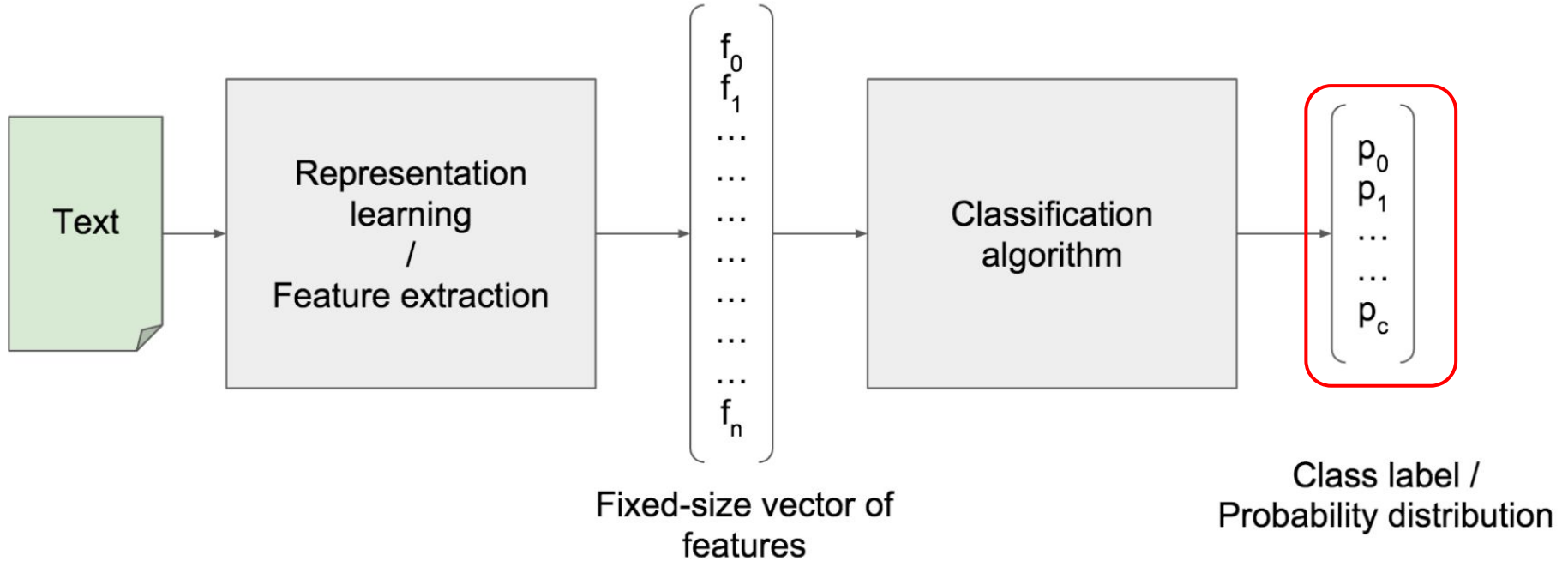
Text classification tasks

# Example: sentiment analysis



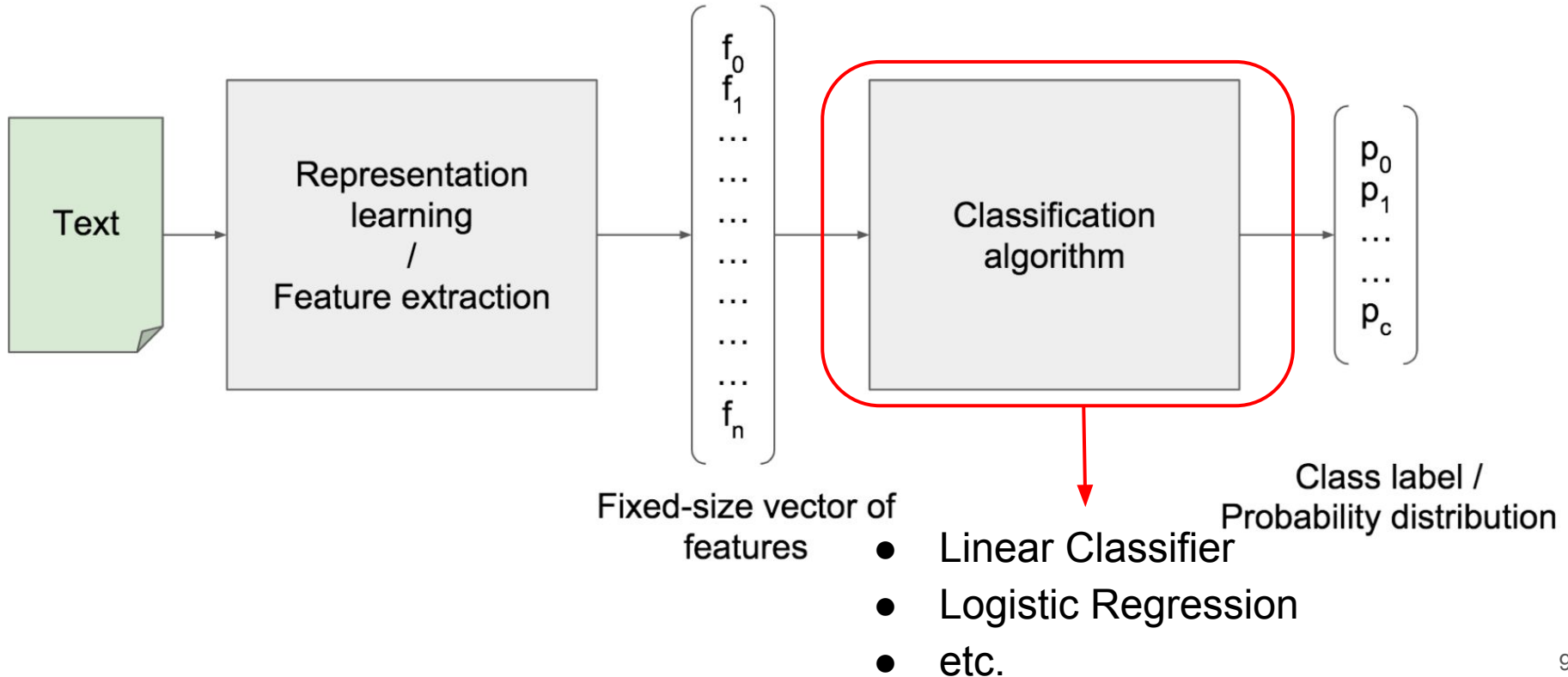
- Discrete labels:
  - Binary
    - spam filtering, sentiment analysis
  - Multi-class
    - categorization of items by its description
  - Multi-label
    - #hashtag prediction
- Continuous labels:
  - Predict product price by its description

# Text classification in general

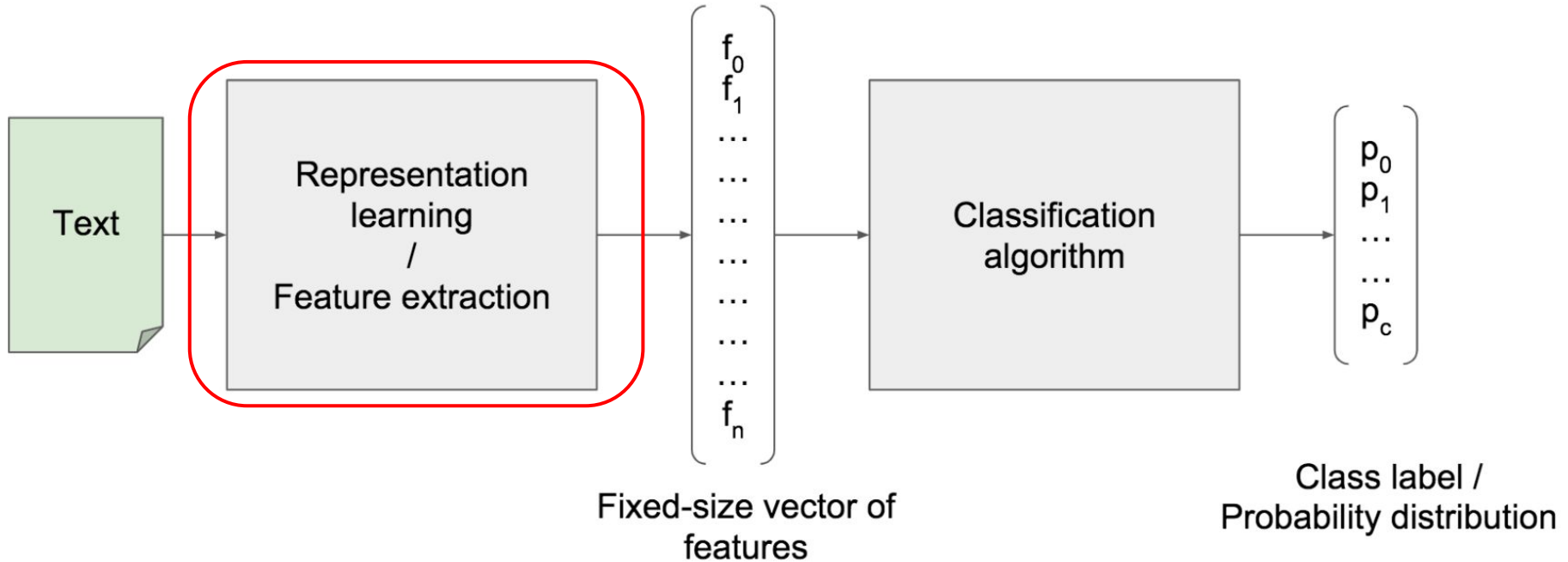




# Text classification in general

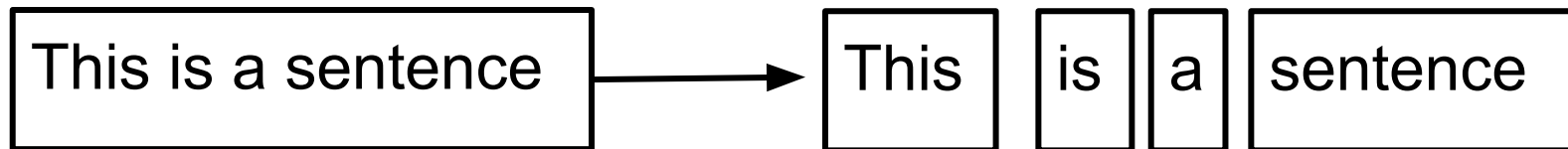


# Text classification in general



# Feature extraction

- Tokenization: split the input into tokens



the dog is on the table

0	0	1	1	0	1	1	2
are	cat	dog	is	now	on	table	the

- Problems:
  - No information about words order
  - Word vectors are huge and very sparse
  - Word vectors are not normalized
  - Same words can take different forms

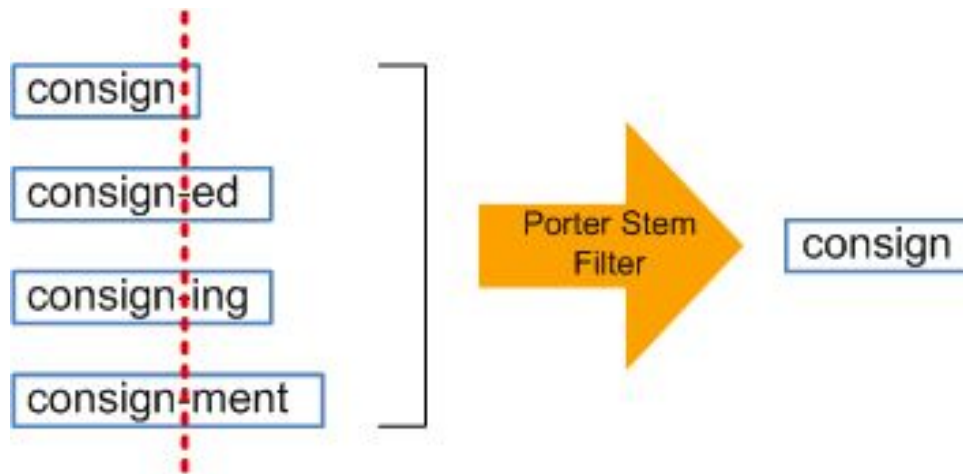
# Text Preprocessing

- Token normalization

Dog, dogs → dog

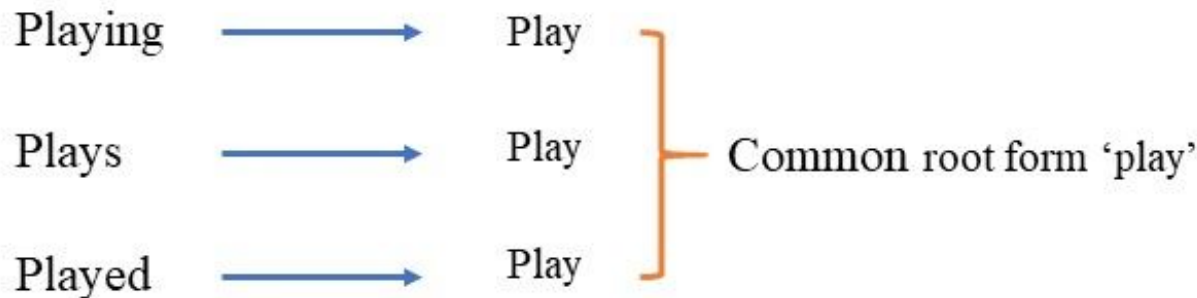
Bark, barks → bark

- Token normalization:
  - **Stemming**: removing and replacing suffixes to get to the root of the word (**stem**)





- Token normalization:
  - **Stemming**: removing and replacing suffixes to get to the root of the word (**stem**)
  - **Lemmatization**: to get base or dictionary form of a word (**lemma**)



# Stemming: Porter vs Lancaster

## Porter stemmer

- Published in 1979
- Base starting option

## Snowball stemmer (Porter 2)

- Based on Porter
- More aggressive
- Most popular option now

## Lancaster stemmer

- Published in 1990
- The most aggressive
- Easy adding of your own rules

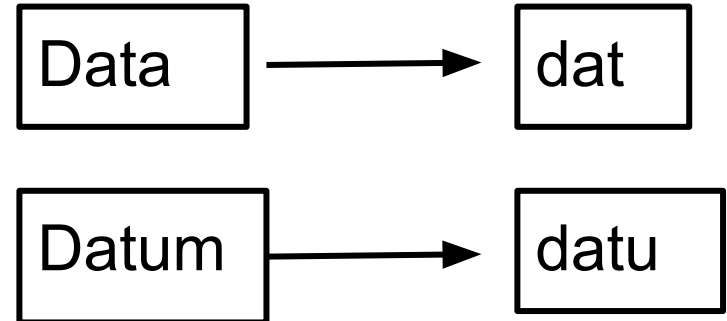
- Porter's stemmer:
  - **Heuristics, applied one-by-one:**
    - SSES - SS (dresses - dress)
    - IES - I (ponies - poni)
    - S - <empty> (dogs - dog)
  - **What's wrong?**
    - **Overstemming and understemming**

# Overstemming

- University
- Universal
- Universities
- Universe

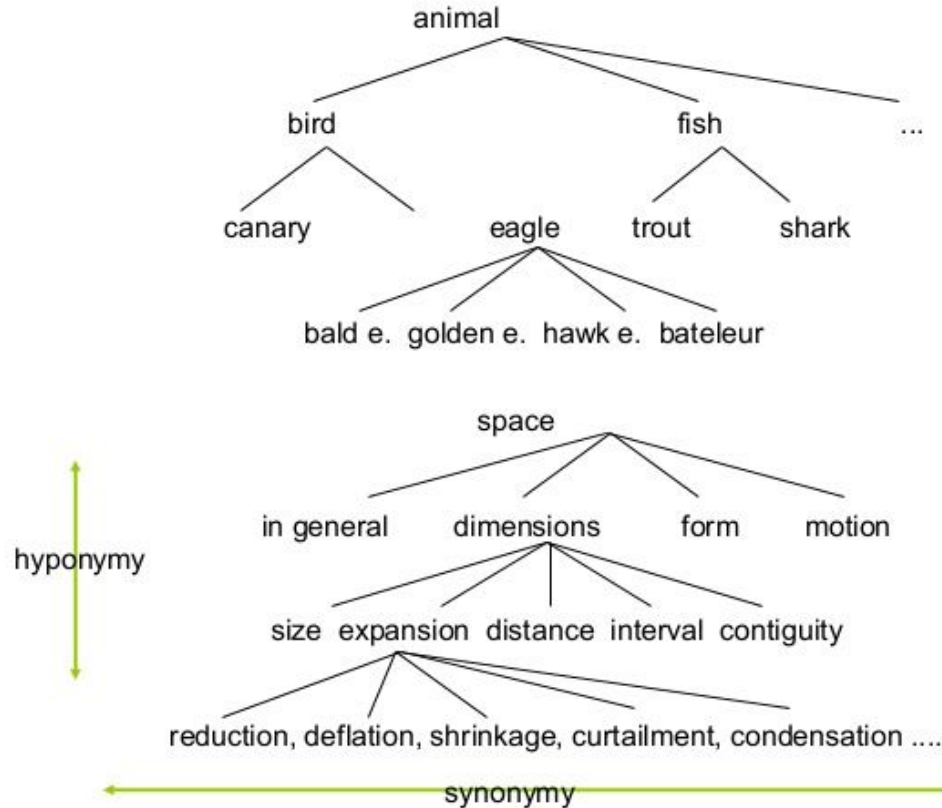
} Univers

# Understemming

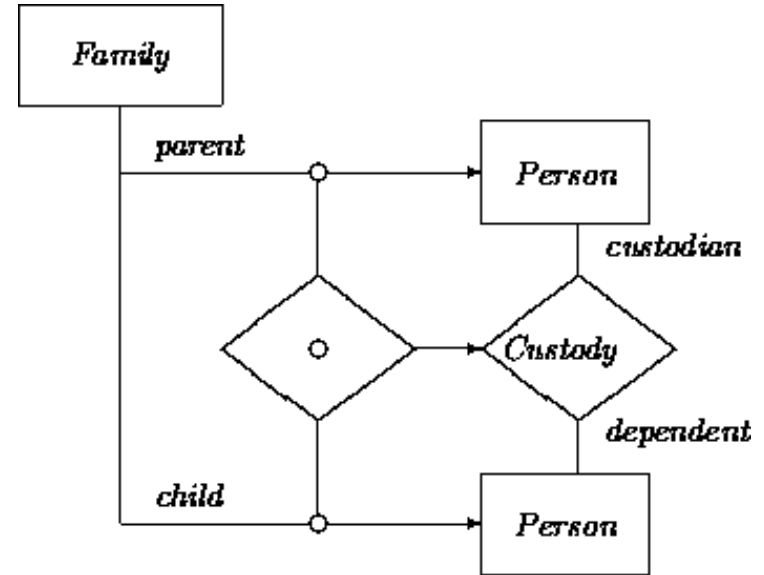


- Lemmatizer from NLTK:
  - Tries to resolve word to its dictionary form
  - Based on **WordNet** database
  - For the best results feed part-of-speech tagger

# BTW, what is WordNet?



3/27



# Handful tools for preprocessing

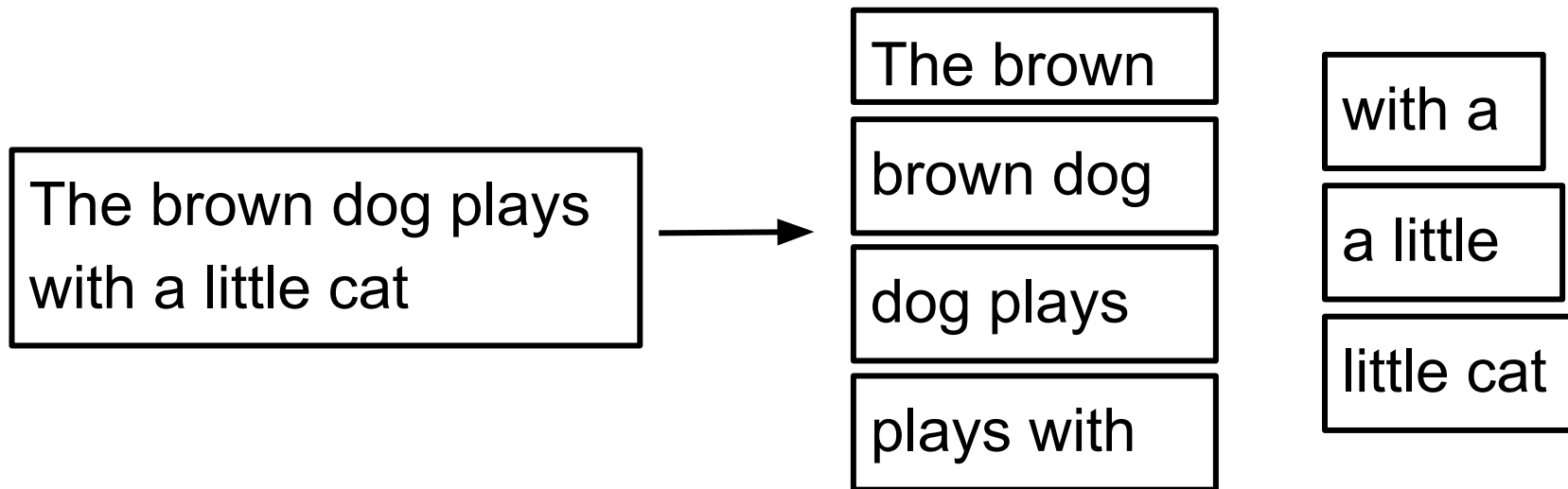
- [NLTK](#)
  - `nltk.stem.SnowballStemmer`
  - `nltk.stem.PorterStemmer`
  - `nltk.stem.WordNetLemmatizer`
  - `nltk.corpus.stopwords`
- [BeautifulSoup](#) (for parsing HTML)
- Regular Expressions (`import re`)
- [Pymorphy2](#)

# What's left?

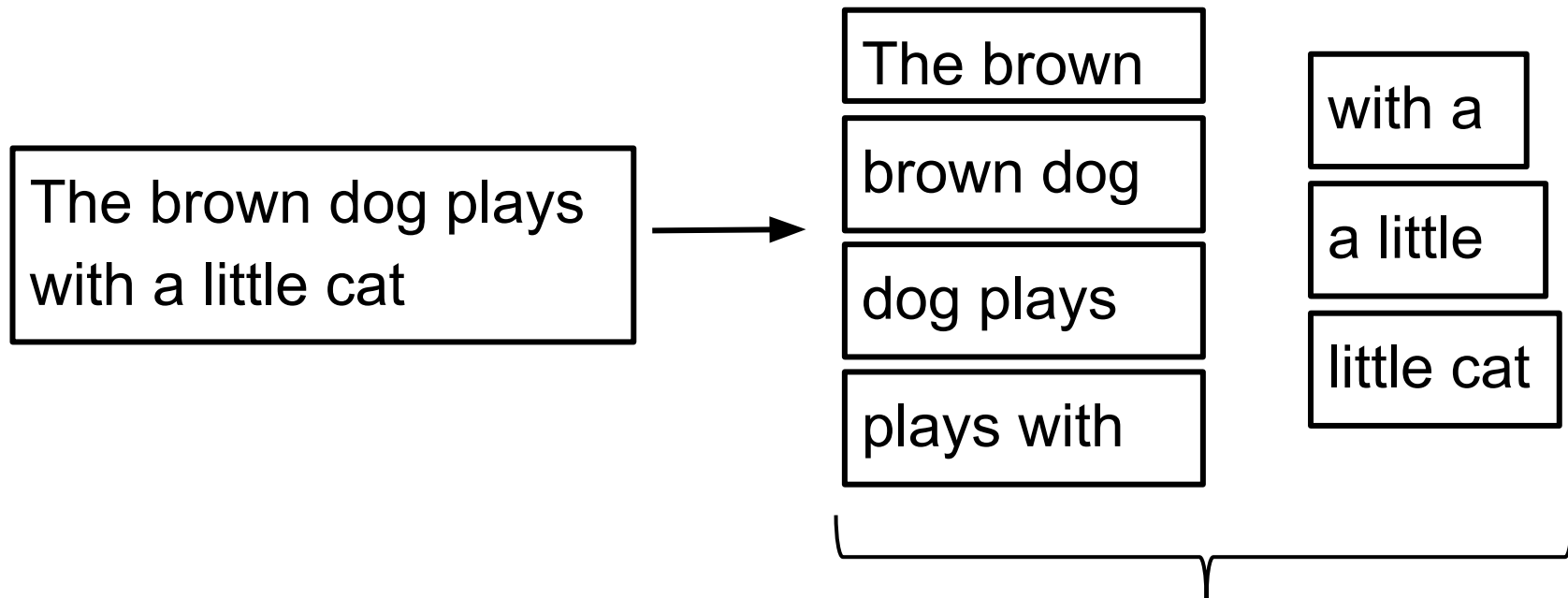
- Capital Letters
- Punctuation
- Contractions (e.g, etc.)
- Numbers (dates, ids, page numbers)
- Stop-words (“the”, “is”, etc.)
- Tags

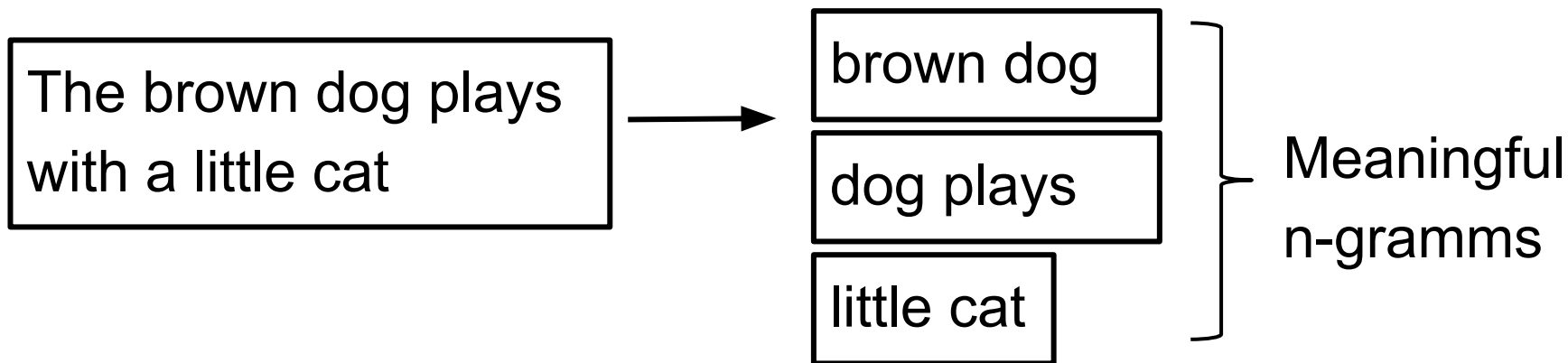


- How to improve BOW?
  - Use n-gramms instead of words!



# Bag-of-Words





Meaningful n-grams are often called **collocations**

How to detect meaningful n-grams?

- Delete:
  - High-frequency n-gramms
    - Articles, prepositions
    - Auxiliary verbs (to be, to have, etc.)
    - General vocabulary
  - Low-frequency n-gramms
    - Typos
    - Combinations that occur 1-2 times in a text

- **Term Frequency (tf):** gives us the frequency of the word in each document in the corpus.

$$\text{tf}(t,d) = f_{t,d}$$

- **Inverse Document Frequency (idf):** used to calculate the weight of rare words across all documents in the corpus. The words that occur rarely in the corpus have a high IDF score.

$$\text{idf}(t, D) = \log \frac{N}{|\{d \in D : t \in d\}|}$$

$N$ : total number of documents in the corpus  $N = |D|$

$|\{d \in D : t \in d\}|$  : number of documents where the term  $t$  appears

# TF-IDF example

- *Sentence A:* The car is driven on the road.
- *Sentence B:* The truck is driven on the highway.

(each sentence is a separate document)

# TF-IDF example

Word	TF		IDF	TF * IDF	
	A	B		A	B
The	1/7	1/7			
Car	1/7	0			
Truck	0	1/7			
Is	1/7	1/7			
Driven	1/7	1/7			
On	1/7	1/7			
The	1/7	1/7			
Road	1/7	0			
Highway	0	1/7			

# TF-IDF example

Word	TF		IDF	TF * IDF	
	A	B		A	B
The	1/7	1/7	$\log(2/2)=0$		
Car	1/7	0	$\log(2/1)=0.3$		
Truck	0	1/7	$\log(2/1)=0.3$		
Is	1/7	1/7	$\log(2/2)=0$		
Driven	1/7	1/7	$\log(2/2)=0$		
On	1/7	1/7	$\log(2/2)=0$		
The	1/7	1/7	$\log(2/2)=0$		
Road	1/7	0	$\log(2/1)=0.3$		
Highway	0	1/7	$\log(2/1)=0.3$		



# TF-IDF example

Word	TF		IDF	TF * IDF	
	A	B		A	B
The	1/7	1/7	$\log(2/2)=0$	0	0
Car	1/7	0	$\log(2/1)=0.3$	0.043	0
Truck	0	1/7	$\log(2/1)=0.3$	0	0.043
Is	1/7	1/7	$\log(2/2)=0$	0	0
Driven	1/7	1/7	$\log(2/2)=0$	0	0
On	1/7	1/7	$\log(2/2)=0$	0	0
The	1/7	1/7	$\log(2/2)=0$	0	0
Road	1/7	0	$\log(2/1)=0.3$	0.043	0
Highway	0	1/7	$\log(2/1)=0.3$	0	0.043

# TF-IDF example

```
from sklearn.feature_extraction.text  
import TfidfVectorizer
```



# Word Embeddings

- **One-hot vectors:**

Rome =  $[1, 0, 0, 0, 0, 0, \dots, 0]$

Paris =  $[0, 1, 0, 0, 0, 0, \dots, 0]$

Italy =  $[0, 0, 1, 0, 0, 0, \dots, 0]$

France =  $[0, 0, 0, 1, 0, 0, \dots, 0]$

word V

## Problems:

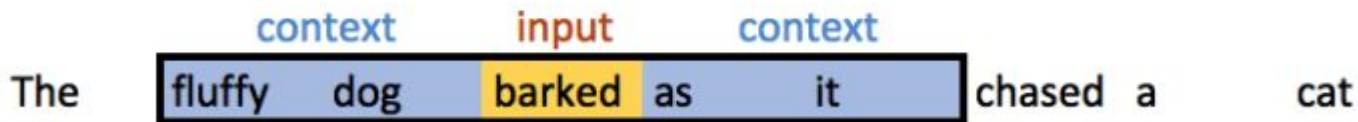
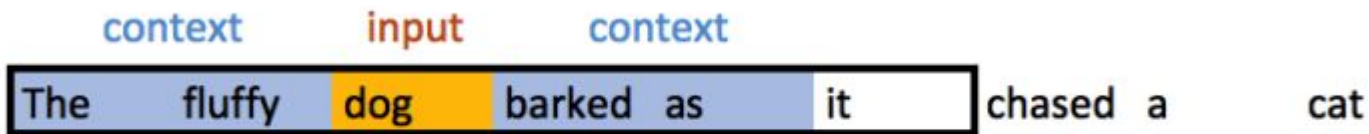
- Huge vectors
- VERY sparse
- No semantics or word similarity information included

# Distributional semantics

Does vector similarity imply semantic similarity?

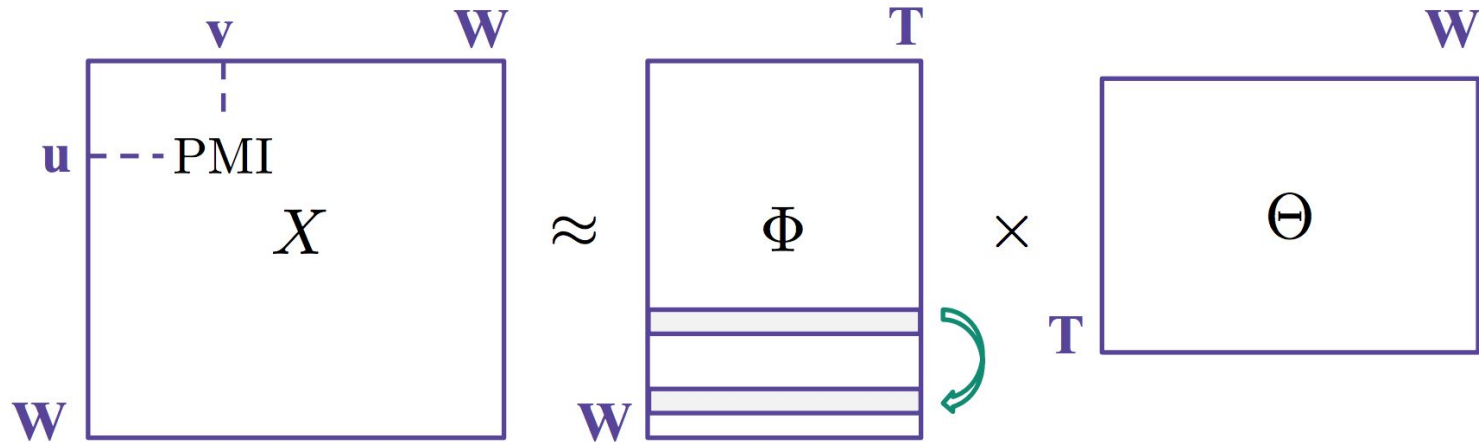
*“You shall know a word by the company it keeps”*

Firth, 1957



# Word representations via matrix factorization

- **Input: PMI, word cooccurrences, etc.**
- **Method: dimensionality reduction (SVD)**
- **Output: word similarities**



- Delete:
  - High-frequency n-gramms
    - Articles, prepositions
    - Auxiliary verbs (to be, to have, etc.)
    - General vocabulary
  - Low-frequency n-gramms
    - Typos
    - Combinations that occur 1-2 times in a text

# Collocations: context is all you need

- Cooccurrence counters in a window of fixed size
  - $n_{uv}$  states for the number of times we've seen word  $u$  and word  $v$  together in the window
- Better solution: Pointwise Mutual Information (PMI)

$$PMI = \log \frac{p(u, v)}{p(u)p(v)} = \log \frac{n_{uv}n}{n_u n_v}$$

- Much better solution: **Positive PMI (pPMI)**

$$pPMI = \max(0, PMI)$$

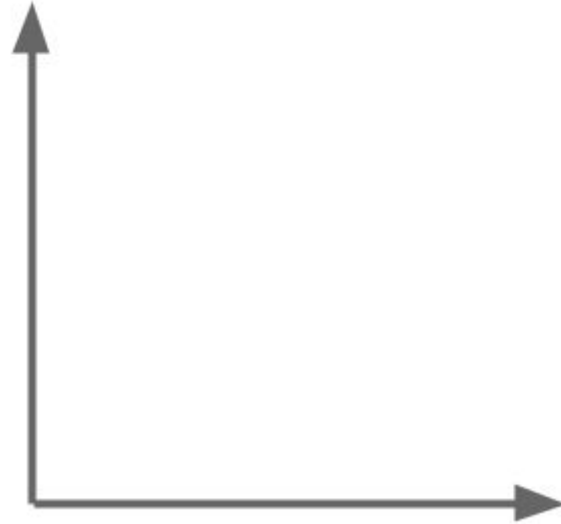


Frequency With Filter		PMI	T-test With Filter	Chi-Sq Test
(front, desk)	(universal, studios)		(front, desk)	(wi, fi)
(great, location)	(howard, johnson)		(great, location)	(cracker, barrel)
(friendly, staff)	(cracker, barrel)		(friendly, staff)	(howard, johnson)
(hot, tub)	(santa, barbara)		(hot, tub)	(la, quinta)
(clean, room)	(sub, par)	(continental, breakfast)		(front, desk)
(hotel, staff)	(santana, row)	(free, breakfast)		(universal, studios)
(continental, breakfast)	(e, g)	(great, place)		(santa, barbara)
(nice, hotel)	(elk, springs)	(parking, lot)		(santana, row)
(free, breakfast)	(times, square)	(customer, service)		( , more)
(great, place)	(ear, plug)	(desk, staff)		(flat, screen)
(desk, staff)	(la, quinta)	(walk, distance)		(french, quarter)
(parking, lot)	(fire, pit)	(comfortable, bed)		(elk, springs)
(customer, service)	(san, clemente)	(nice, hotel)		(walking, distance)

Why not to learn word vectors?

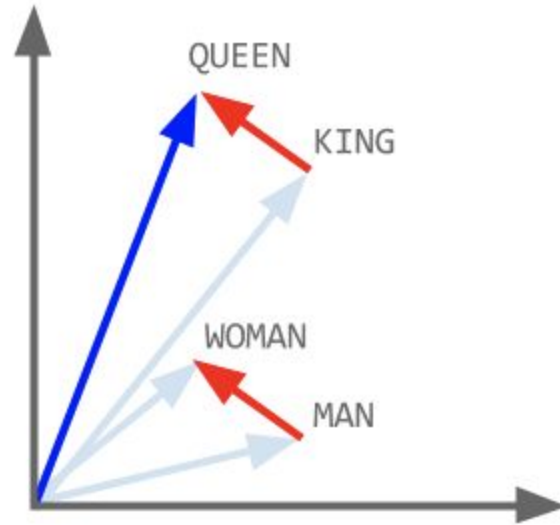
# Embeddings: intuition

What is  $\text{king} - \text{man} + \text{woman}$ ?

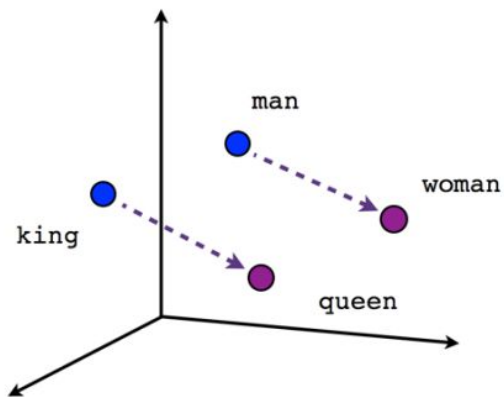


# Embeddings: intuition

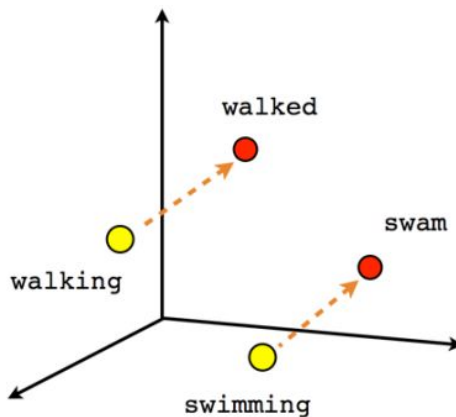
So  $\text{king} - \text{man} + \text{woman} = \text{queen!}$



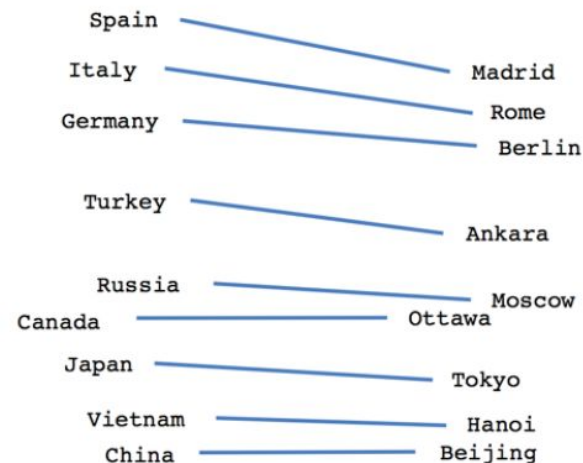
- **Word2vec** (Mikolov et al. 2013) - a framework for learning word embeddings



Male-Female



Verb tense

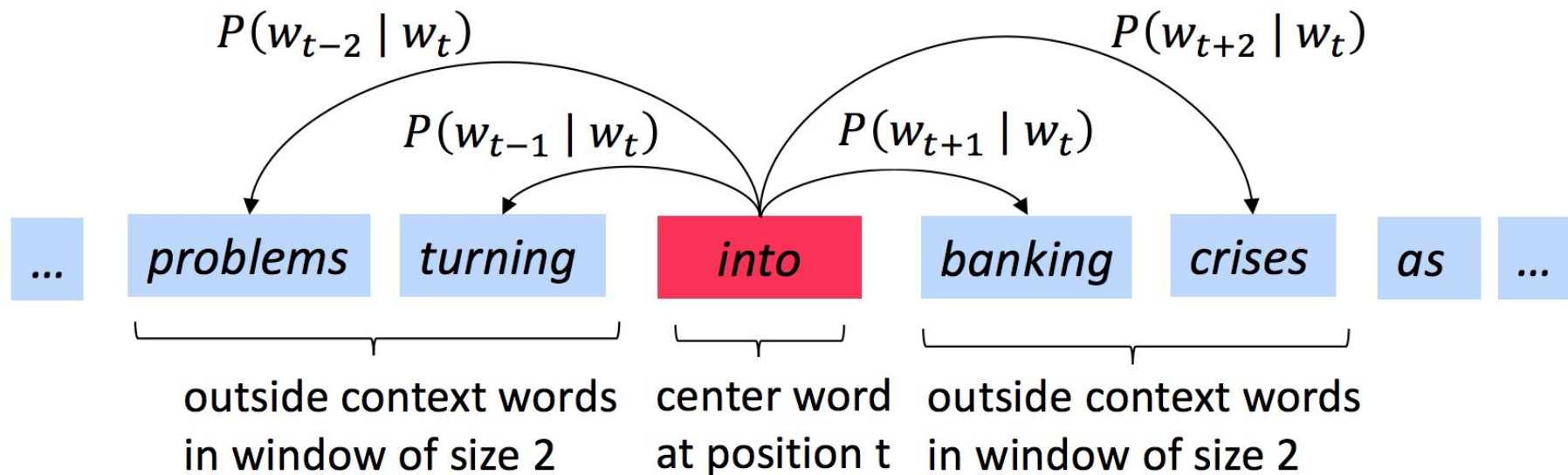


Country-Capital

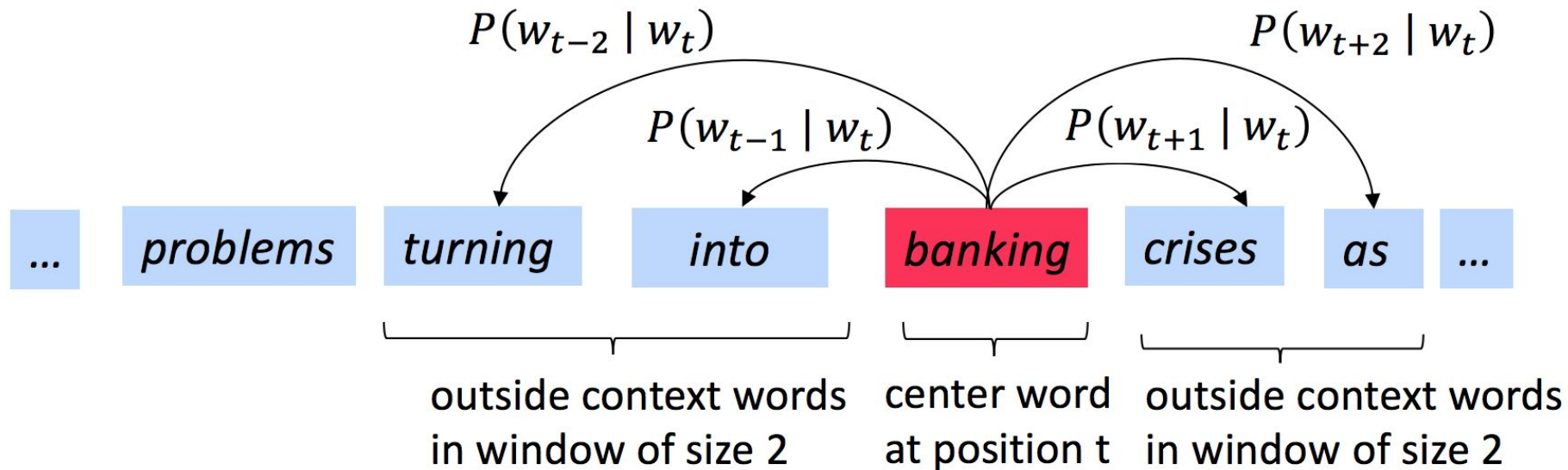
# Embeddings: word2vec

Source Text	Training Samples					
<table><tr><td>The</td><td>quick</td><td>brown</td></tr></table> fox jumps over the lazy dog. ➡	The	quick	brown	(the, quick) (the, brown)		
The	quick	brown				
The <table><tr><td>quick</td><td>brown</td><td>fox</td></tr></table> jumps over the lazy dog. ➡	quick	brown	fox	(quick, the) (quick, brown) (quick, fox)		
quick	brown	fox				
The quick <table><tr><td>brown</td><td>fox</td><td>jumps</td></tr></table> over the lazy dog. ➡	brown	fox	jumps	(brown, the) (brown, quick) (brown, fox) (brown, jumps)		
brown	fox	jumps				
The <table><tr><td>quick</td><td>brown</td><td>fox</td><td>jumps</td><td>over</td></tr></table> the lazy dog. ➡	quick	brown	fox	jumps	over	(fox, quick) (fox, brown) (fox, jumps) (fox, over)
quick	brown	fox	jumps	over		

# Embeddings: word2vec

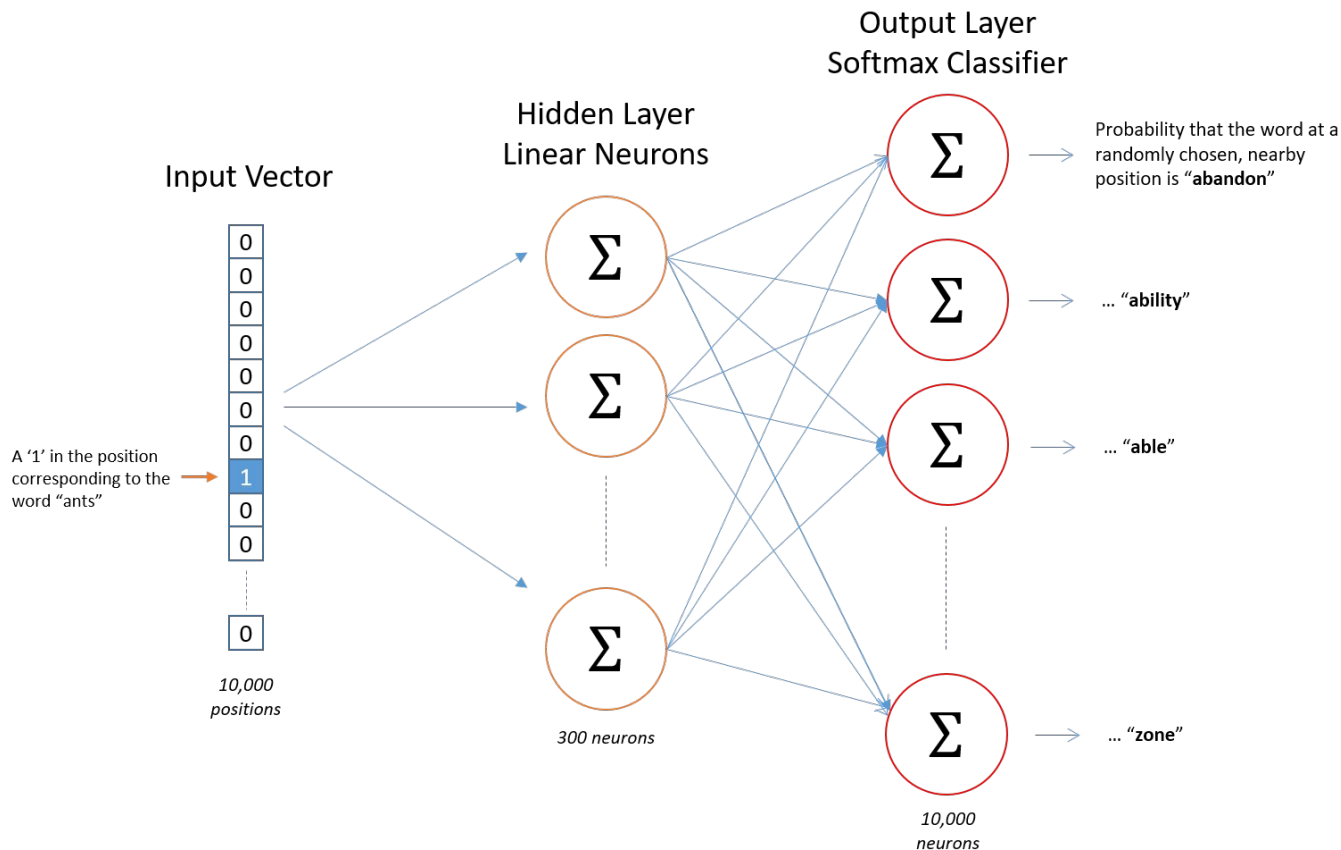


# Embeddings: word2vec

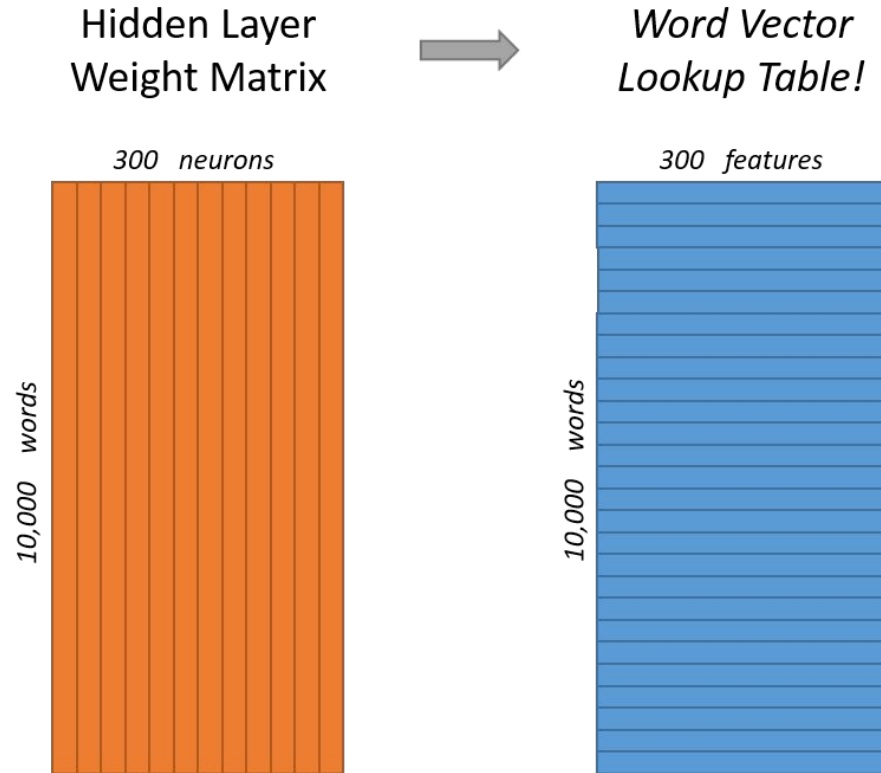




# Embeddings: word2vec



# Embeddings: word2vec



# Embeddings: word2vec

- Word vectors with 300 components
- Vocabulary of 10,000 words.
- Weight matrix with  $300 \times 10,000 = 3$  million weights each!

Training is too long and computationally expensive

## How to fix this?

## Basic approaches:

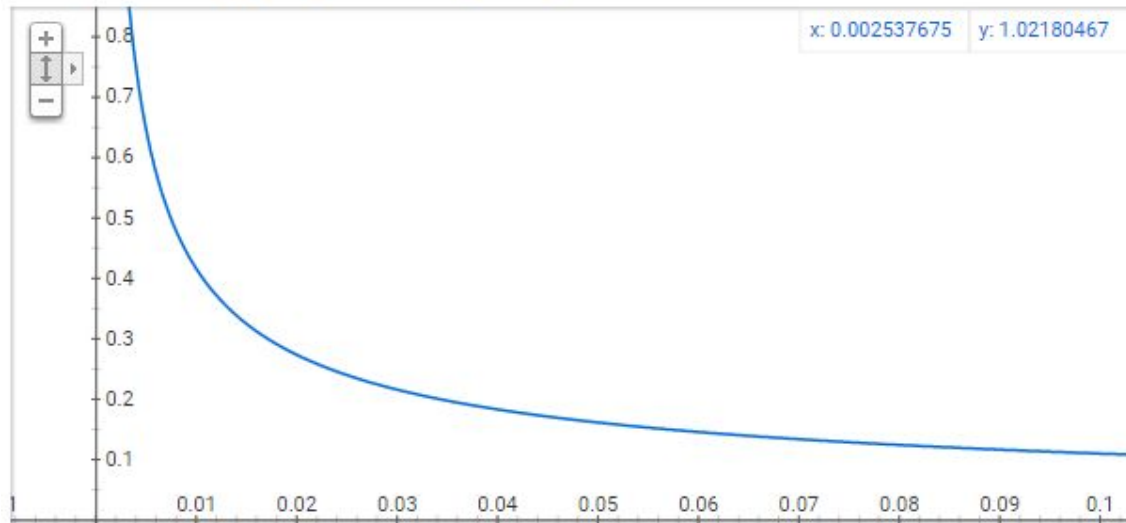
1. Treating common word pairs or phrases as single “words” in their model.
2. Subsampling frequent words to decrease the number of training examples.
3. Modifying the optimization objective with a technique they called “Negative Sampling”, which causes each training sample to update only a small percentage of the model’s weights.

# Embeddings: word2vec

Subsampling frequent words.

$w_i$  is the word,  $z(w_i)$  is the fraction of this word in the text

Graph for  $(\sqrt{x/0.001}+1)*0.001/x$



$P(w_i)$  is the probability of *keeping* the word:

$$P(w_i) = \left( \sqrt{\frac{z(w_i)}{0.001}} + 1 \right) \cdot \frac{0.001}{z(w_i)}$$

# Embeddings: negative sampling

Negative Sampling idea: only few words error is computed. All other words have zero error, so no updates by the backprop mechanism.

More frequent words are selected to be negative samples more often. The probability for selecting a word is just its weight divided by the sum of weights for all words.

$$P(w_i) = \frac{f(w_i)^{3/4}}{\sum_{j=0}^n (f(w_j)^{3/4})}$$

## Continuous BOW (CBOW)

$$p(w_i | w_{i-h}, \dots, w_{i+h})$$

Predict center word from  
(bag of) context words

- Predicting one word each time
- Relatively fast

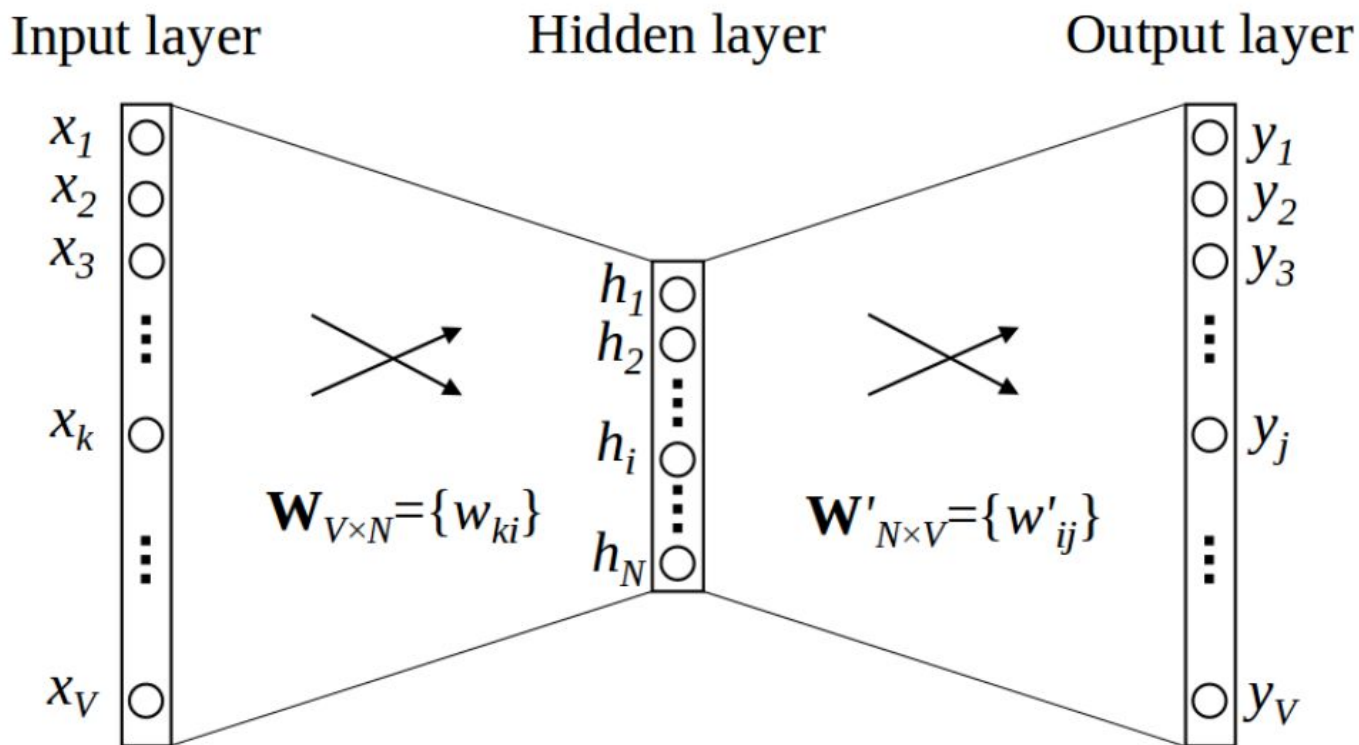
## Skip-gram

$$p(w_{i-h}, \dots, w_{i+h} | w_i)$$

Predict context ("outside")  
words (position independent)  
given center word

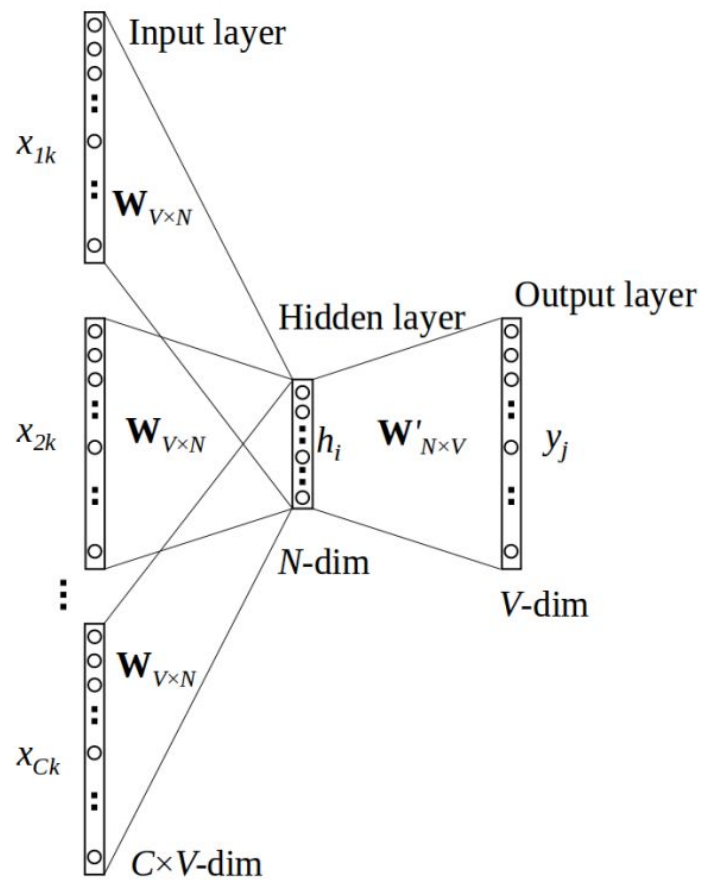
- Predicting context by one word
- Much slower
- Better with infrequent words

# Skip-gram





# CBOW



## GloVe (Global Vectors for word representations)

- **PMI / Frequency factorization** - use count-based corpus statistics

## GloVe (Global Vectors for word representations)

- **PMI / Frequency factorization** - use count-based corpus statistics
- **Word2Vec** - predict *proximity* with neural embeddings
- **GloVe** - predict *count-based statistics* with neural embeddings

$$J = \sum_{i,j=1}^V f(X_{ij}) (w_i^T \tilde{w}_j + b_i + \tilde{b}_j - \log X_{ij})$$

## GloVe (Global Vectors for word representations)

- **PMI / Frequency factorization** - use count-based corpus statistics
- **Word2Vec** - predict *proximity* with neural embeddings
- **GloVe** - predict *count-based statistics* with neural embeddings

$$J = \sum_{i,j=1}^V f(X_{ij}) (w_i^T \tilde{w}_j + b_i + \tilde{b}_j - \log X_{ij})$$

Trainable embeddings

Trainable bias vectors

## GloVe (Global Vectors for word representations)

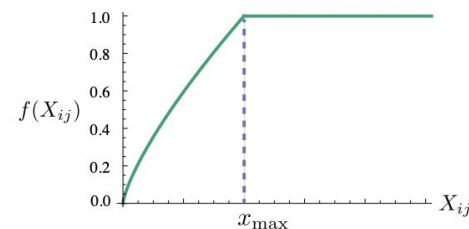
- **PMI / Frequency factorization** - use count-based corpus statistics
- **Word2Vec** - predict *proximity* with neural embeddings
- **GloVe** - predict *count-based statistics* with neural embeddings

$$J = \sum_{i,j=1}^V f(X_{ij}) (w_i^T \tilde{w}_j + b_i + \tilde{b}_j - \log X_{ij})$$

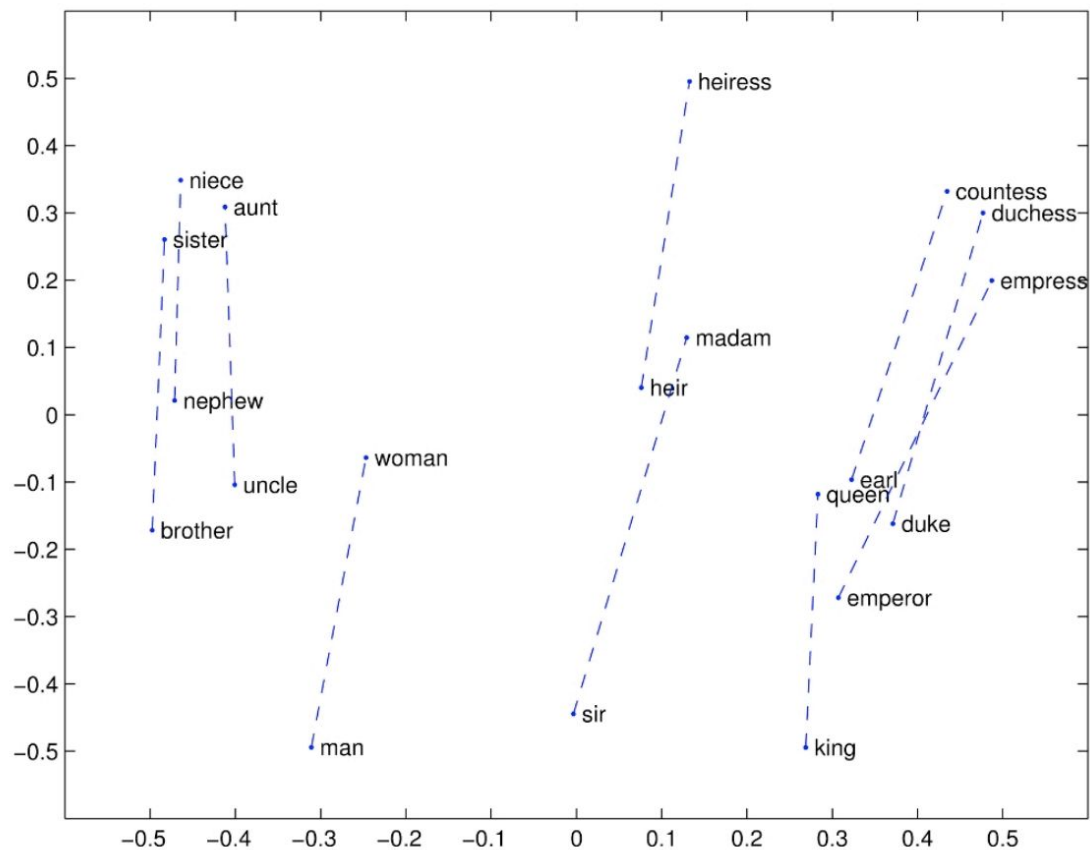
Weighting function  
(penalize rare  
cooccurrences, regularize  
frequent ones)

Trainable embeddings

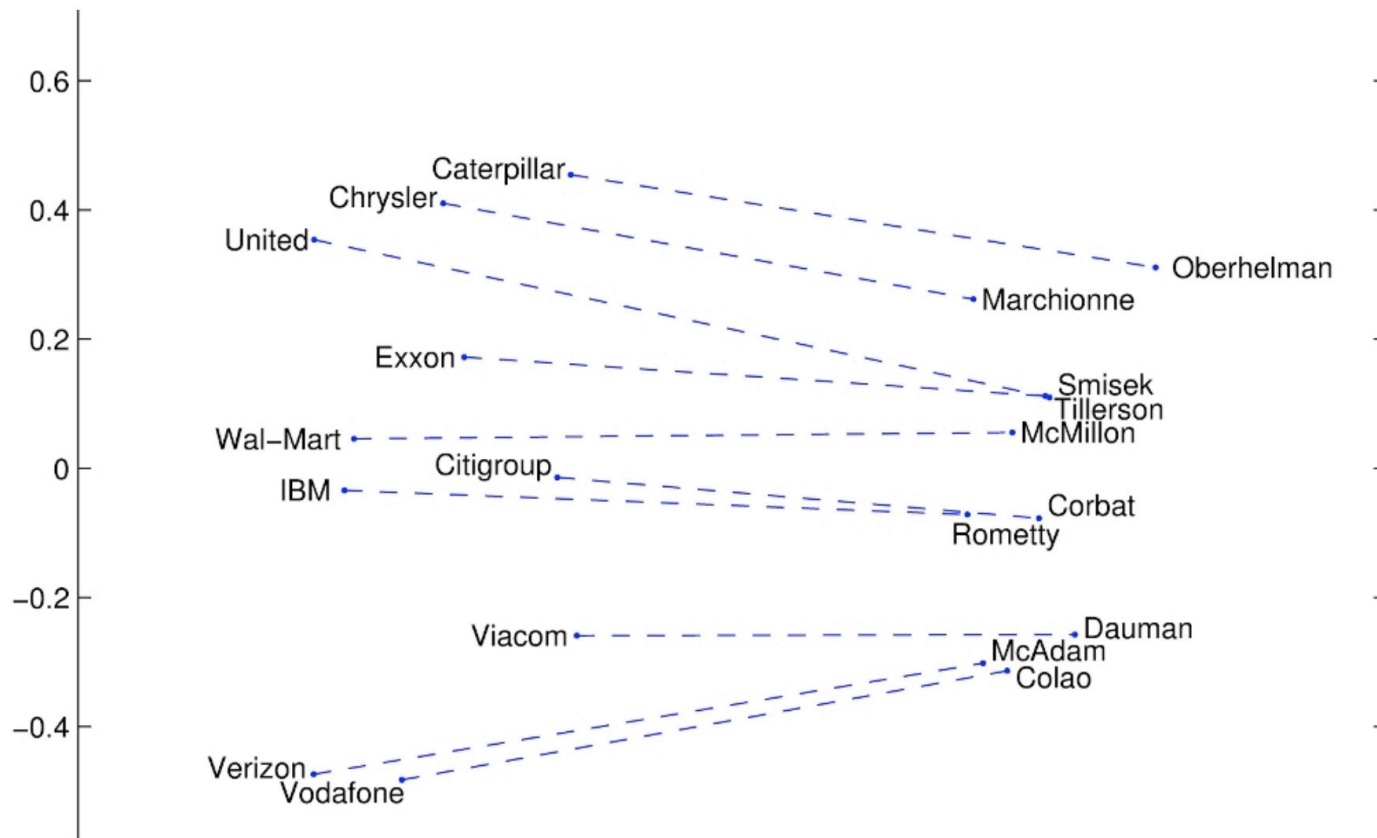
Trainable bias vectors



# GloVe Visualizations



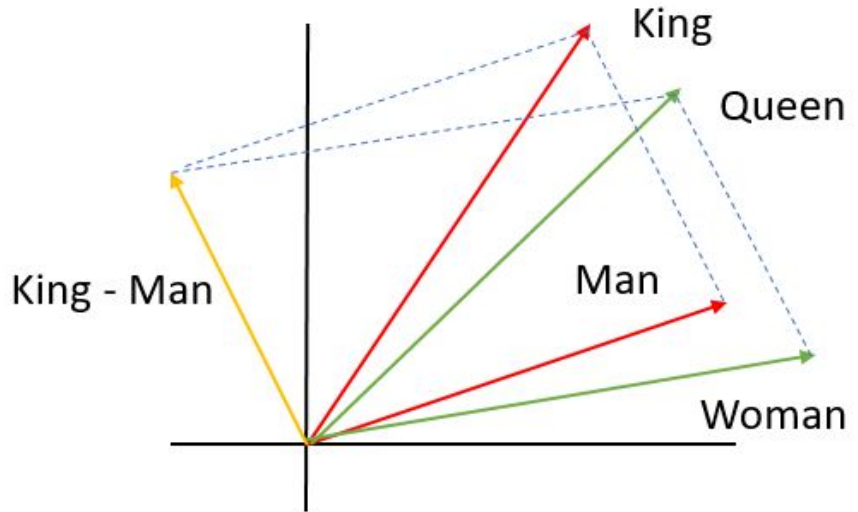
# GloVe Visualizations: Company - CEO



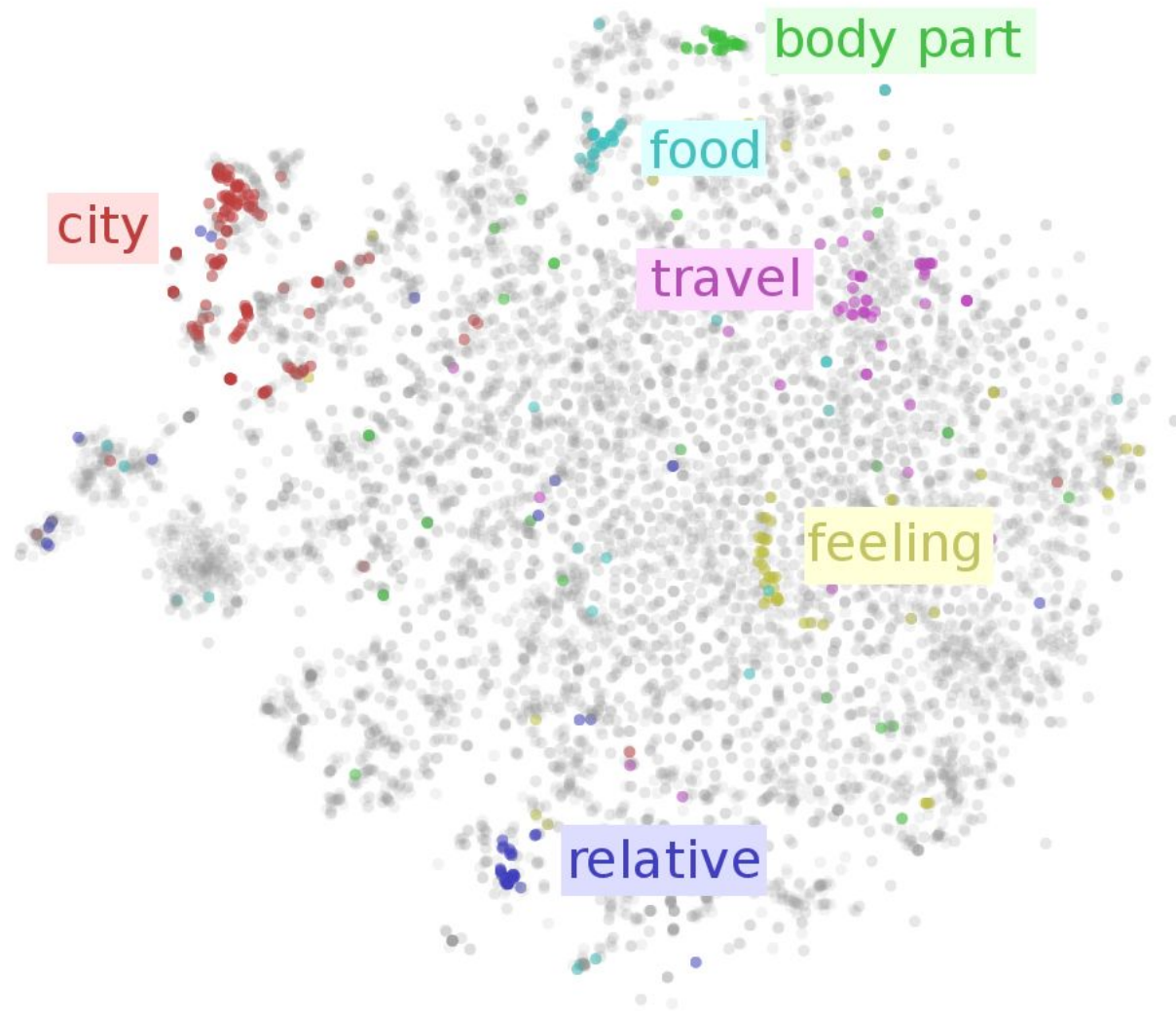
# Word2vec: word analogies

King - man + woman = queen  
↓        ↓        ↓        ↓  
 $x$          $y$          $y'$          $target$

$\cos(x - y + y', target) \rightarrow \max_{target}$







Word vectors are vectors of numbers that represent the meaning of a word

Approaches:

- One-hot encoding
- Bag-of-words models
- Counts of word / context co-occurrences
- TF-IDF
- Neural models for prediction of co-occurrence events (word2vec) or counts (glove)

