annotated version

Machine Learning Course - CS-433

Text Representation Learning

Nov 23, 2017

Last updated: November 23, 2017

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Motivation

Finding numerical representations for words is fundamental for all machine learning methods dealing with text data.

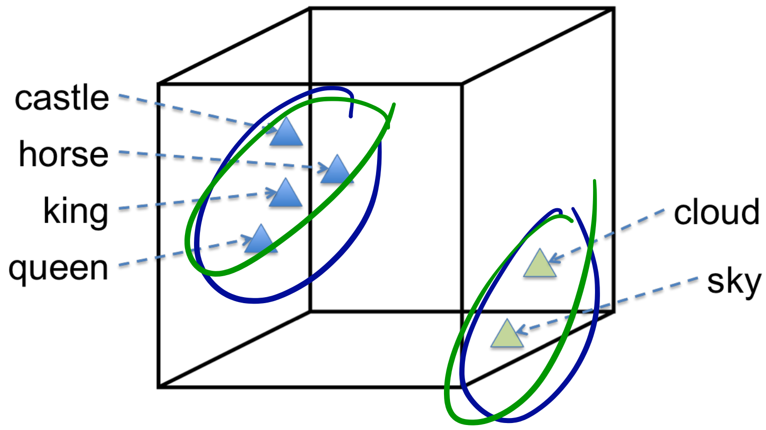
Goal: For each word, find mapping (embedding)

$$w_i \mapsto \underline{\mathbf{w}_i} \in \mathbb{R}^K$$

Representation should capture semantics of the word.

Bag-of-words

$$w_i \rightarrow \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{pmatrix} \leftarrow i$$



Constructing good feature representations (= representation learning) benefits all ML applications.

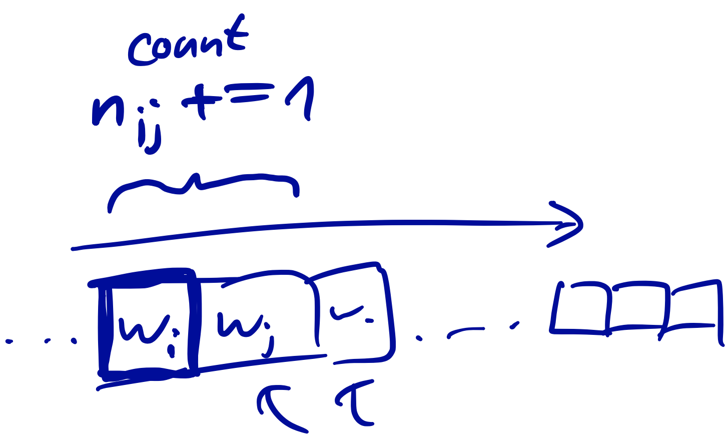
The Co-Occurence Matrix

A big corpus of un-labeled text can be represented as the co-occurrence counts

n_{ij} := #contexts where word w_i occurs together with word w_j.

w_j (context words)

	0	1	1	0	0
	0	0	3	0	0
		1			
		2		1	
w_i	1				1
			1		
		1		1	1



Needs definition of

- Context e.g. document, paragraph, sentence, window

typical: window size = 5

- Vocabulary
  $\mathcal{V} := \{w_1, \ldots, w_D\}$

For words $w_d = 1, 2, \ldots, D$ and context words $w_n = 1, 2, \ldots, N$, the co-occurence counts n_{ij} form a very sparse $D \times N$ matrix.

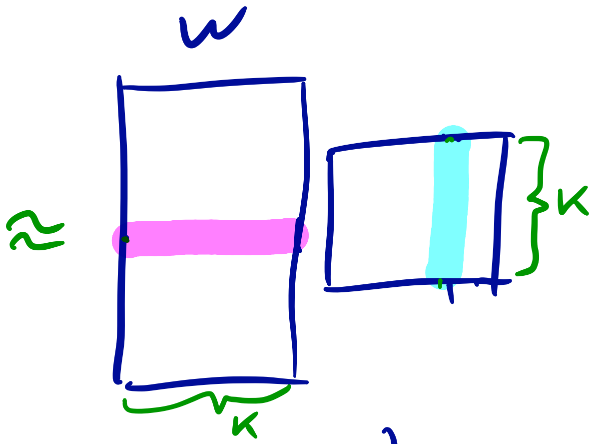
$N = D = |V|$

Learning Word-Representations (Using Matrix Factorization)

Find a factorization of the co-occurence matrix!
Typically uses log of the actual counts, i.e. $x_{dn} := \log(n_{dn})$.

We will aim to find $\mathbf{W}, \mathbf{Z}$ s.t.

$$\boxed{\mathbf{X} \approx \mathbf{W}\mathbf{Z}^\top .}$$



So for each pair of words (w_d, w_n), we try to 'explain' their co-occurence count by a numerical representation of the two words
- in fact by the inner product of the two feature vectors $\mathbf{W}_{d:}, \mathbf{Z}_{n:}$. log(count = #$(w_d, w_n)$)

$$\min_{\mathbf{W},\mathbf{Z}} \mathcal{L}(\mathbf{W}, \mathbf{Z}) := \frac{1}{2} \sum_{(d,n)\in\Omega} f_{dn} \left[x_{dn} - (\mathbf{W}\mathbf{Z}^\top)_{dn} \right]^2$$

non-zero

where $\mathbf{W} \in \mathbb{R}^{D\times K}$ and $\mathbf{Z} \in \mathbb{R}^{N\times K}$ are tall matrices, having only $K \ll D, N$ columns.
The set $\Omega \subseteq [D] \times [N]$ collects the indices of non-zeros of the count matrix $\mathbf{X}$.
Each row of those matrices forms a representation of a word ($\mathbf{W}$) or a context word ($\mathbf{Z}$) respectively.

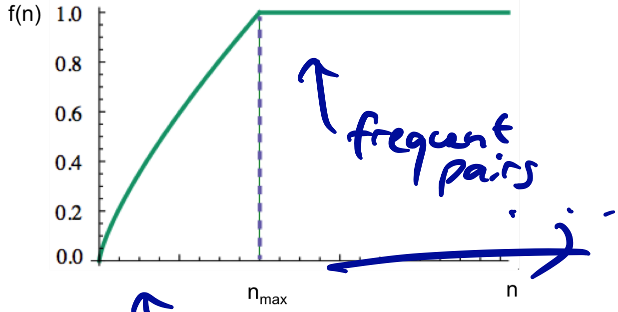
GloVe

This model is called GloVe, and is a variant of word2vec.

Weights f_{dn}: Give "importance" of each entry. Choosing $f_{dn} := 1$ is ok. GloVe weight function:

$$f_{dn} := \min\left\{1, (n_{dn}/n_{\max})^{\alpha}\right\}, \quad \alpha \in [0;1] \quad \text{e.g. } \alpha = \tfrac{3}{4}$$

count
$\#(w_d, w_n)$

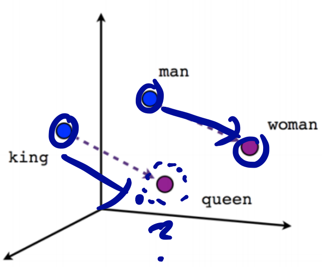


rare pair
(w_d, w_n)

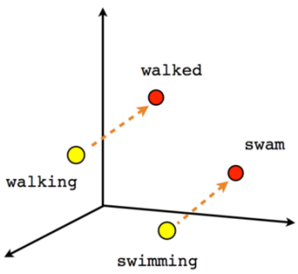
Choosing K

K e.g. 50, 100, 200

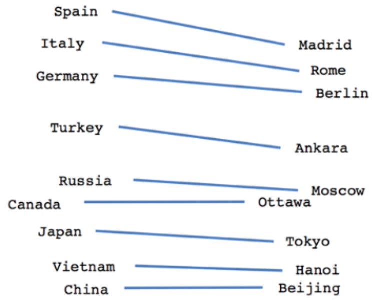
Word Analogies



Male-Female



Verb tense



Country-Capital

Newspapers			
New York	New York Times	Baltimore	Baltimore Sun
San Jose	San Jose Mercury News	Cincinnati	Cincinnati Enquirer
NHL Teams			
Boston	Boston Bruins	Montreal	Montreal Canadiens
Phoenix	Phoenix Coyotes	Nashville	Nashville Predators
NBA Teams			
Detroit	Detroit Pistons	Toronto	Toronto Raptors
Oakland	Golden State Warriors	Memphis	Memphis Grizzlies
Airlines			
Austria	Austrian Airlines	Spain	Spanair
Belgium	Brussels Airlines	Greece	Aegean Airlines
Company executives			
Steve Ballmer	Microsoft	Larry Page	Google
Samuel J. Palmisano	IBM	Werner Vogels	Amazon

Germany

Lufthansa

France

?

Training

- Stochastic Gradient Descent (SGD)
- Alternating Least-Squares (ALS)

same as for Recommender System

Open questions:

- Parallel and distributed training
- Does regularization help?

Alternative: Skip-Gram Model

(Original word2vec) (CBOW)

Uses binary classification (logistic regression objective), to separate real word pairs (w_d, w_n) from fake word pairs. Same inner product score = matrix factorization.

, w_a, w_b, w_c, w_d, . . .

Given w_d, a context word w_n is

- real = appearing together in a context window of size 5
- fake = any word $w_{n'}$ sampled randomly: Negative sampling (also: Noise Contrastive Estimation)

real

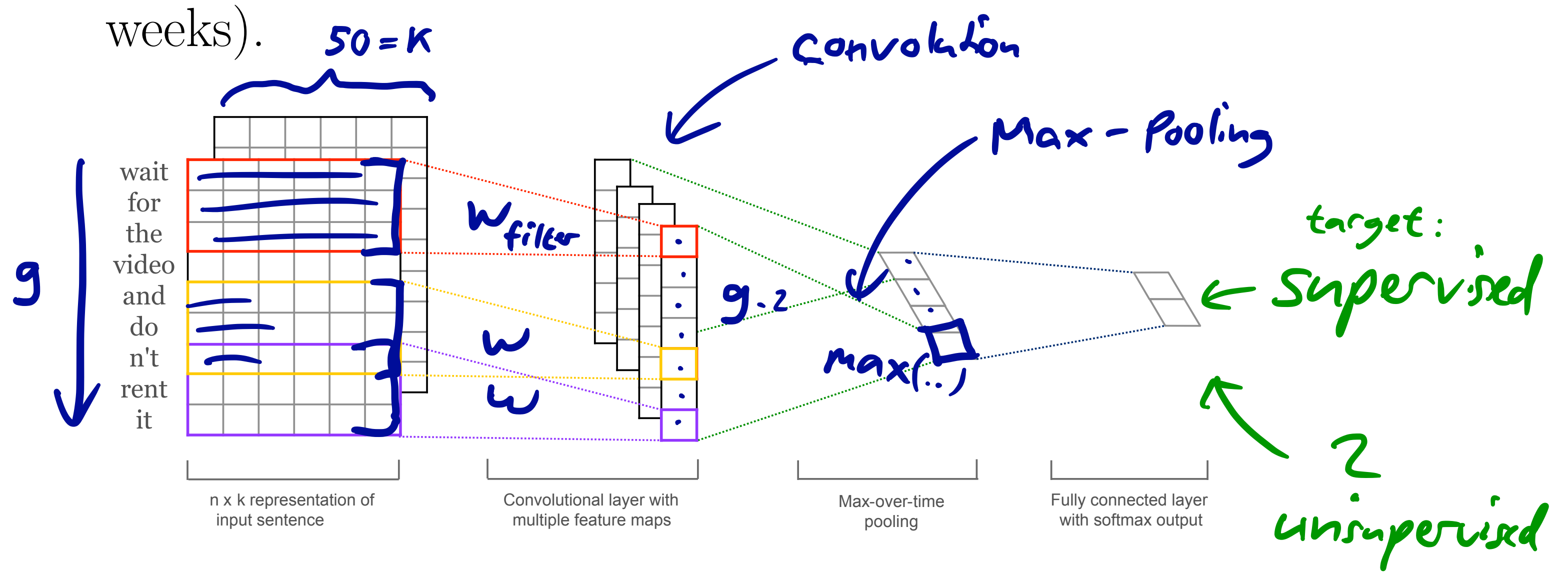
$w_d^T w_n$

$w_d^T w_{fake}$

Learning Representations of Documents

Supervised: For a supervised task (e.g. predicting the emotion of a tweet), we can use matrix-factorization (below) or convolutional neural networks (see next weeks).

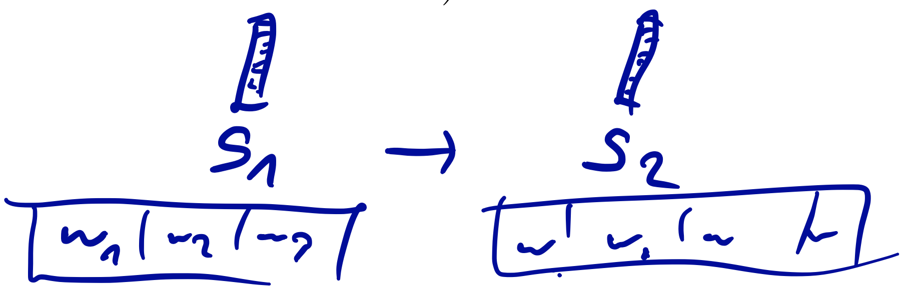
CNN



→ SemEval competition for tweet classification.

Unsupervised:

- Adding (fixed, given) word vectors over sentence or document
- Training word vectors such that adding works well
- Direct unsupervised training for sentences (appearing together with context sentences) instead of words



supervised (document classification)

FastText

Matrix factorization to learn document/sentence representations (supervised).

Given a sentence $s_n = (w_1, w_2, \ldots, w_m)$, let $\mathbf{x}_n \in \mathbb{R}^{|\mathcal{V}|}$ be the bag-of-words representation of the sentence.

$\begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 1 \\ 1 \\ 0 \end{pmatrix}$ „Bag of words" $= x_n \in \mathbb{R}^{|V|}$

target $+1$ / -1

$$\min_{\mathbf{W},\mathbf{Z}} \mathcal{L}(\mathbf{W},\mathbf{Z}) := \sum_{s_n \text{ a sentence}} f(y_n \mathbf{W} \boxed{\mathbf{Z}^\top \mathbf{x}_n})$$

$Z^T = [\ \ldots\ ]$ „Dictionary" = word vectors $\mathbb{R}^{50}$

where $\mathbf{W} \in \mathbb{R}^{1 \times K}$, $\mathbf{Z} \in \mathbb{R}^{|\mathcal{V}| \times K}$ are the variables, and the vector $\mathbf{x}_n \in \mathbb{R}^{|\mathcal{V}|}$ represents our n-th training sentence.

$W = \underbrace{[\ \ldots\ ]}_{50}$ „classifier"

SGD

Here f is a linear classifier loss function, and $y_n \in \{\pm 1\}$ is the classification label for sentence $\mathbf{x}_n$.

like in Logistic regression

Multi-Class

$H = 7$:

50

7 W

$y_n = \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$

Further Pointers

1. word2vec:
   code: code.google.com/p/word2vec/
   paper:
   "Distributed representations of words and phrases and their compositionality" - T Mikolov, I Sutskever, K Chen, GS Corrado, J Dean. NIPS 2013

2. GloVe:
   code and vectors: nlp.stanford.edu/projects/glove/
   paper:
   "GloVe: Global Vectors for Word Representation" - Pennington, J., Socher, R., Manning, C. D.. EMNLP 2014

3. FastText
   code: github.com/facebookresearch/fastText
   papers:
   "Bag of Tricks for Efficient Text Classification" - Joulin, A., Grave, E., Bojanowski, P., Mikolov, T. - EC-ACL, 2017.
   "Enriching Word Vectors with Subword Information" - Bojanowski, P., Grave, E., Joulin, A., Mikolov, T. - TACL, 2017.
   "Unsupervised Learning of Sentence Embeddings using Compositional n-Gram Features" - Pagliardini, M., Gupta, P., Jaggi, M. arXiv 2017.