
Deep Learning and Applications

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Today's Outline

- Introduction to Natural Language Processing
- Models with Simple Representations
- Word Embeddings and Word2Vec

Introduction to Natural Language Processing

Natural Language Processing (NLP)

- Concerns will all aspects of (written) natural/human languages
- *We will only sample a very narrow set of topics in this area*
- Text is a sequence of symbols. We need numbers.
 - Naïve way: represent them as one-hot encoded vectors
 - We will see some better approaches

Motivation: Machine Translation



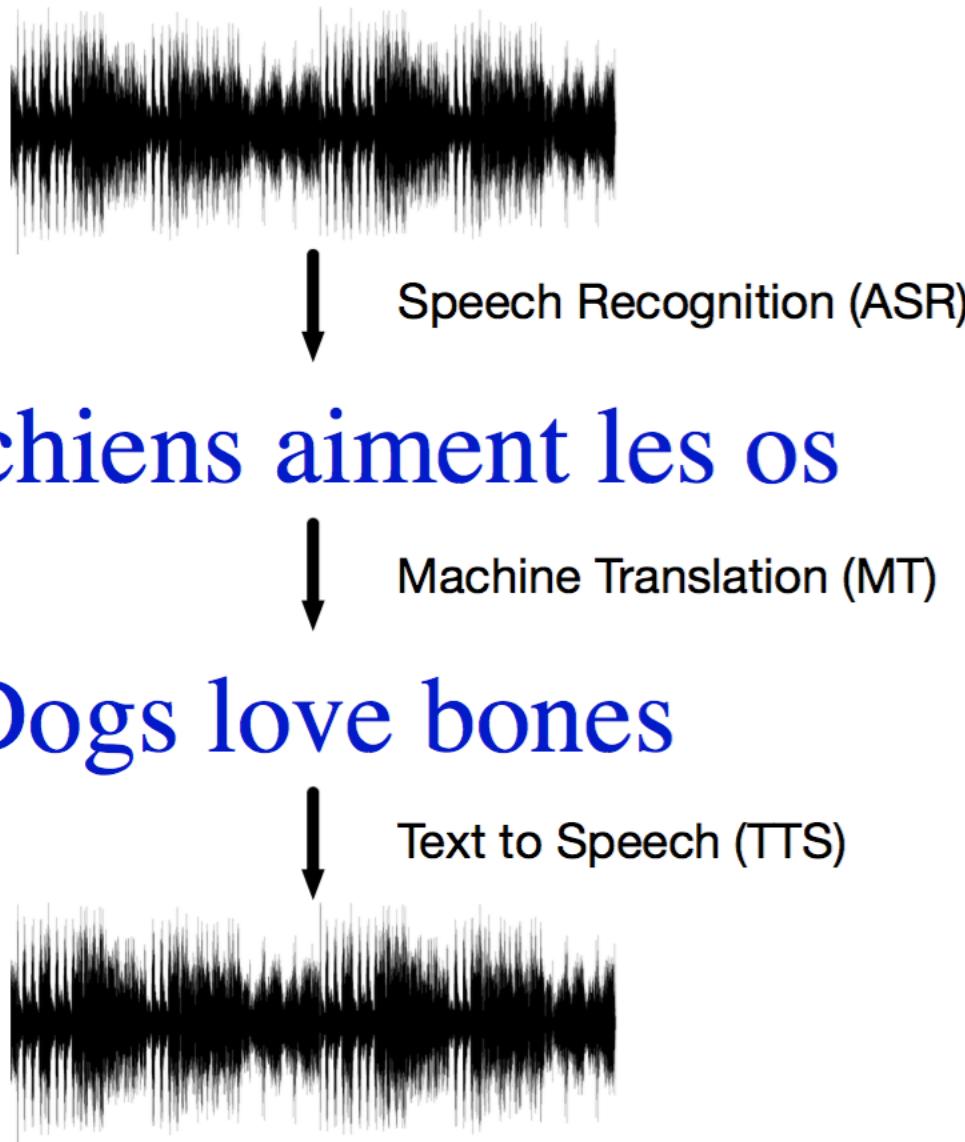
Motivation: Query Answering

Document The BBC producer allegedly struck by Jeremy Clarkson will not press charges against the “Top Gear” host, his lawyer said Friday. Clarkson, who hosted one of the most-watched television shows in the world, was dropped by the BBC Wednesday after an internal investigation by the British broadcaster found he had subjected producer Oisin Tymon “to an unprovoked physical and verbal attack.” . . .

Query Who does the article say will not press charges against Jeremy Clarkson?

Answer Oisin Tymon

Motivation: Speech to Speech



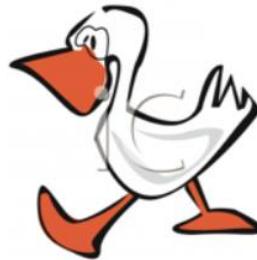
Motivation: Visual Query Answering



What is the man holding?
Does it appear to be raining?
Does this man have 20/20 vision?

Motivation: Harder Text Problems

Sense



I saw her duck



Idioms

He kicked a goal
He kicked the ball
He caught the ball
He kicked the bucket

Reference

The ball did not fit in the box because it was too [big/small].

⁹
¹Figure: <https://github.com/oxford-cs-deepnlp-2017/lectures>

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Models with Simple Representations

Side-stepping Word-word Relationships

- We will look at a few models that
 - Don't explicitly account for word-word relationships
- These are:
 - Naïve Bayes Spam Filter
 - Markov Language Model
 - Latent Dirichlet Allocation

Naïve Bayes Spam Filter

- **Key assumption**

Words occur independently of each other
given the label of the document

$$p(w_1, \dots, w_n | \text{spam}) = \prod_{i=1}^n p(w_i | \text{spam})$$

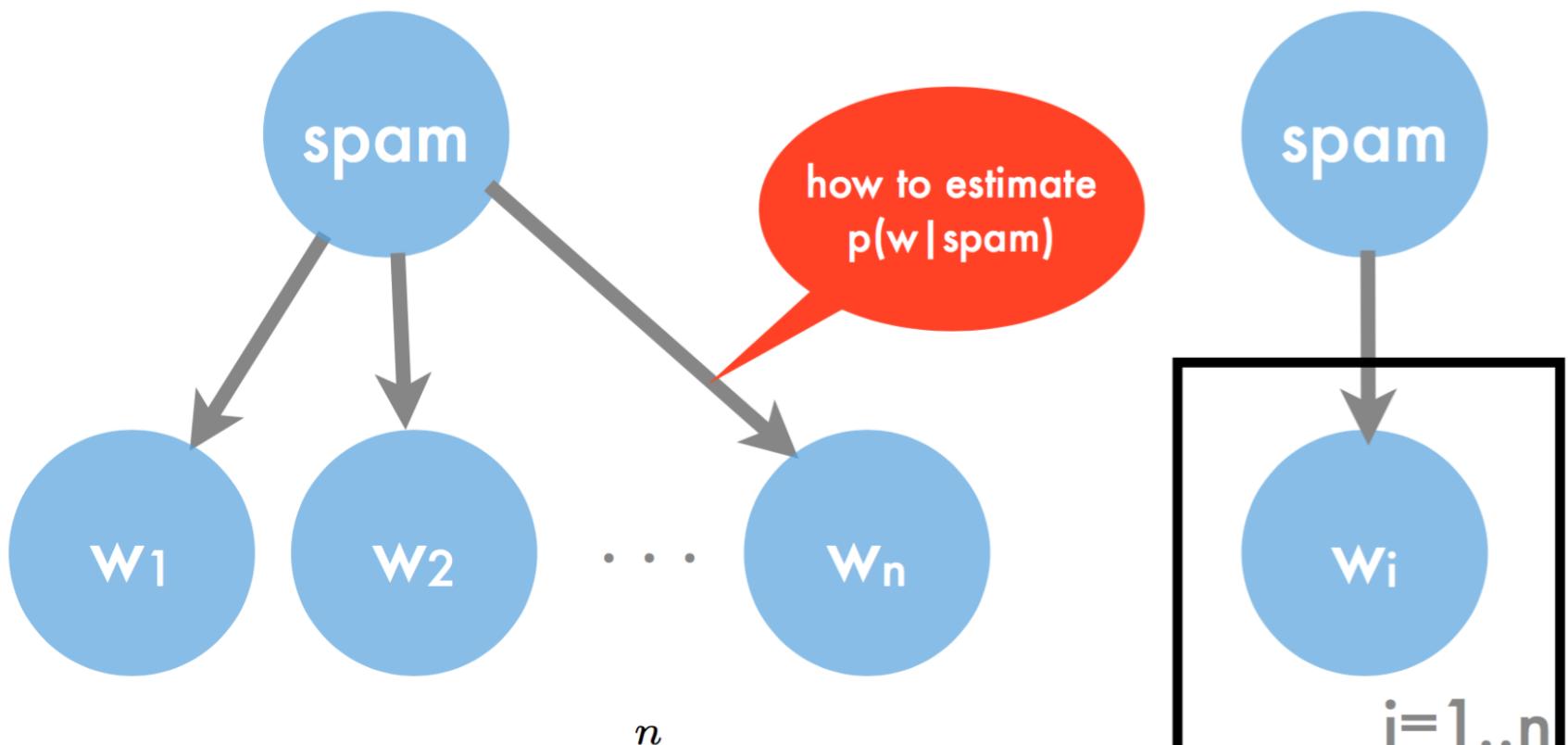
- **Spam classification via Bayes Rule**

$$p(\text{spam} | w_1, \dots, w_n) \propto p(\text{spam}) \prod_{i=1}^n p(w_i | \text{spam})$$

- **Parameter estimation**

Compute spam probability and word
distributions for spam and ham

Naïve Bayes Spam Filter



Naïve Bayes Spam Filter

- Two classes (spam/ham)
- Binary features (e.g. presence of \$\$\$, viagra)
- Simplistic Algorithm
 - Count occurrences of feature for spam/ham
 - Count number of spam/ham mails

feature probability

$$p(x_i = \text{TRUE}|y) = \frac{n(i, y)}{n(y)} \text{ and } p(y) = \frac{n(y)}{n}$$

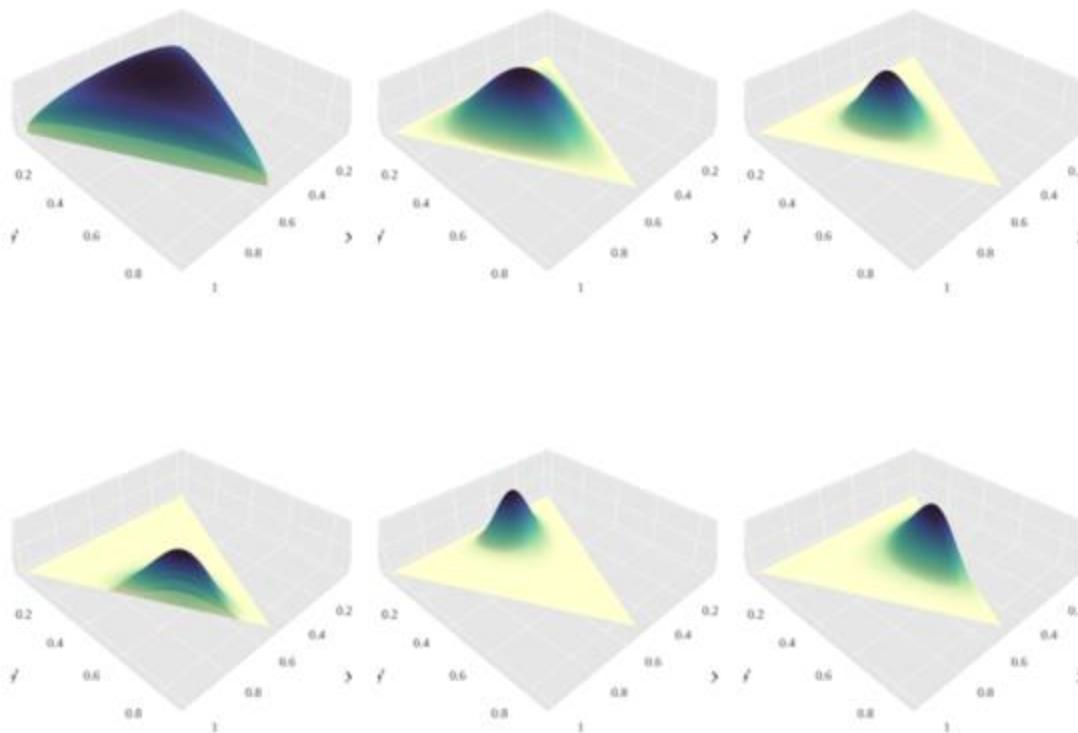
spam probability

$$p(y|x) \propto \frac{n(y)}{n} \prod_{i:x_i=\text{TRUE}} \frac{n(i, y)}{n(y)} \prod_{i:x_i=\text{FALSE}} \frac{n(y) - n(i, y)}{n(y)}$$

A Character-level Language Markov Model

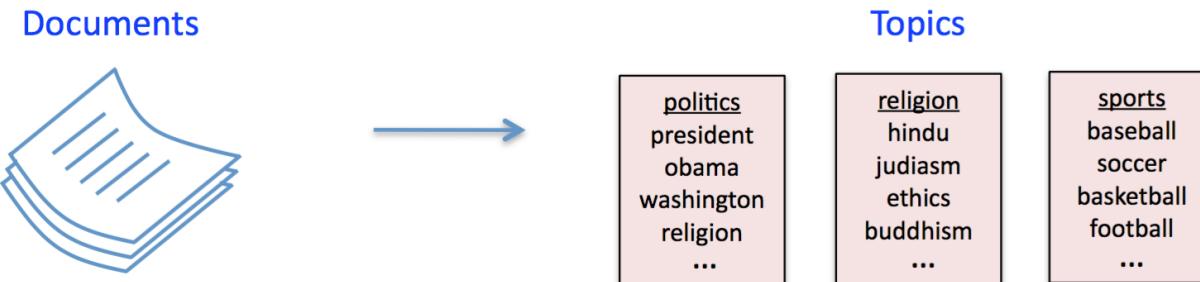
- Character-level language model allows you to generate new text
- It can be modeled using a maximum likelihood based method
- Pick a fixed order = 2
- For a training sequence, e.g., {h,e,l,l,o}
 - Compute $P(\{l\}|\{h, e\}) = \frac{\#\{l,h,e\}}{\#\{h,e\}}$
 - Do this for every three characters in the vocabulary
- Generate new text by sampling!

Aside: Dirichlet Distribution

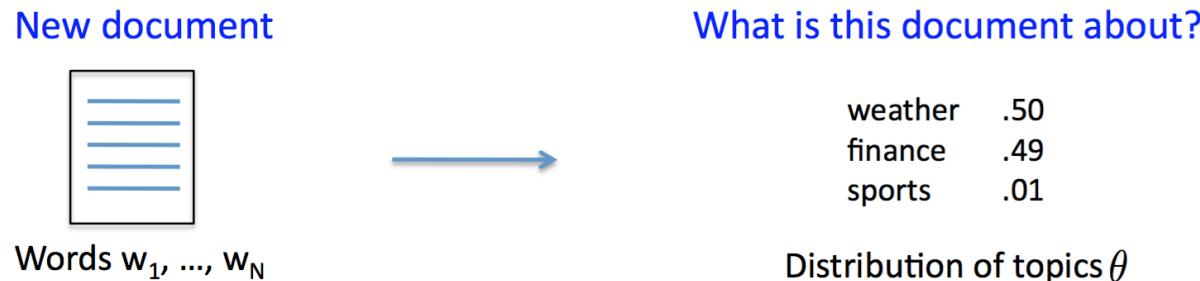


Latent Dirichlet Allocation

- **Topic models** are powerful tools for exploring large data sets and for making inferences about the content of documents



- Many applications in information retrieval, document summarization, and classification



- LDA is one of the simplest and most widely used topic models

Latent Dirichlet Allocation

- ① Sample the document's **topic distribution** θ (aka topic vector)

$$\theta \sim \text{Dirichlet}(\alpha_{1:T})$$

where the $\{\alpha_t\}_{t=1}^T$ are fixed hyperparameters. Thus θ is a distribution over T topics with mean $\theta_t = \alpha_t / \sum_{t'} \alpha_{t'}$

- ② For $i = 1$ to N , sample the **topic** z_i of the i 'th word

$$z_i | \theta \sim \theta$$

- ③ ... and then sample the actual **word** w_i from the z_i 'th topic

$$w_i | z_i \sim \beta_{z_i}$$

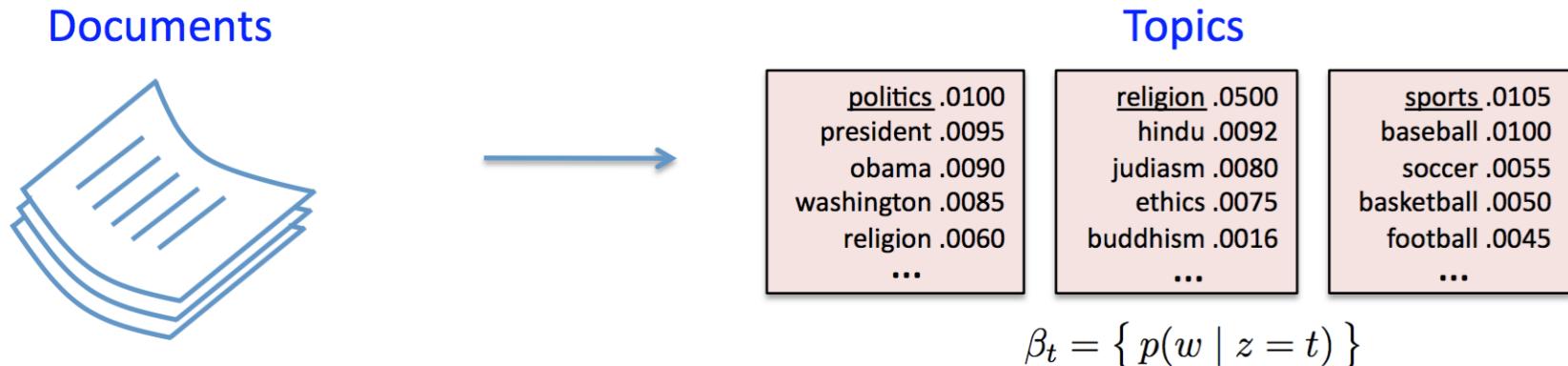
where $\{\beta_t\}_{t=1}^T$ are the *topics* (a fixed collection of distributions on words)

Latent Dirichlet Allocation

... and then sample the actual **word** w_i from the z_i 'th topic

$$w_i | z_i \sim \beta_{z_i}$$

where $\{\beta_t\}_{t=1}^T$ are the *topics* (a fixed collection of distributions on words)



Latent Dirichlet Allocation

Topics

β_1	gene 0.04
	dna 0.02
	genetic 0.01
	...

life 0.02
evolve 0.01
organism 0.01
...

brain 0.04
neuron 0.02
nerve 0.01
...

β_T

data 0.02
number 0.02
computer 0.01
...

Documents

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,⁸ 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 today's organisms 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

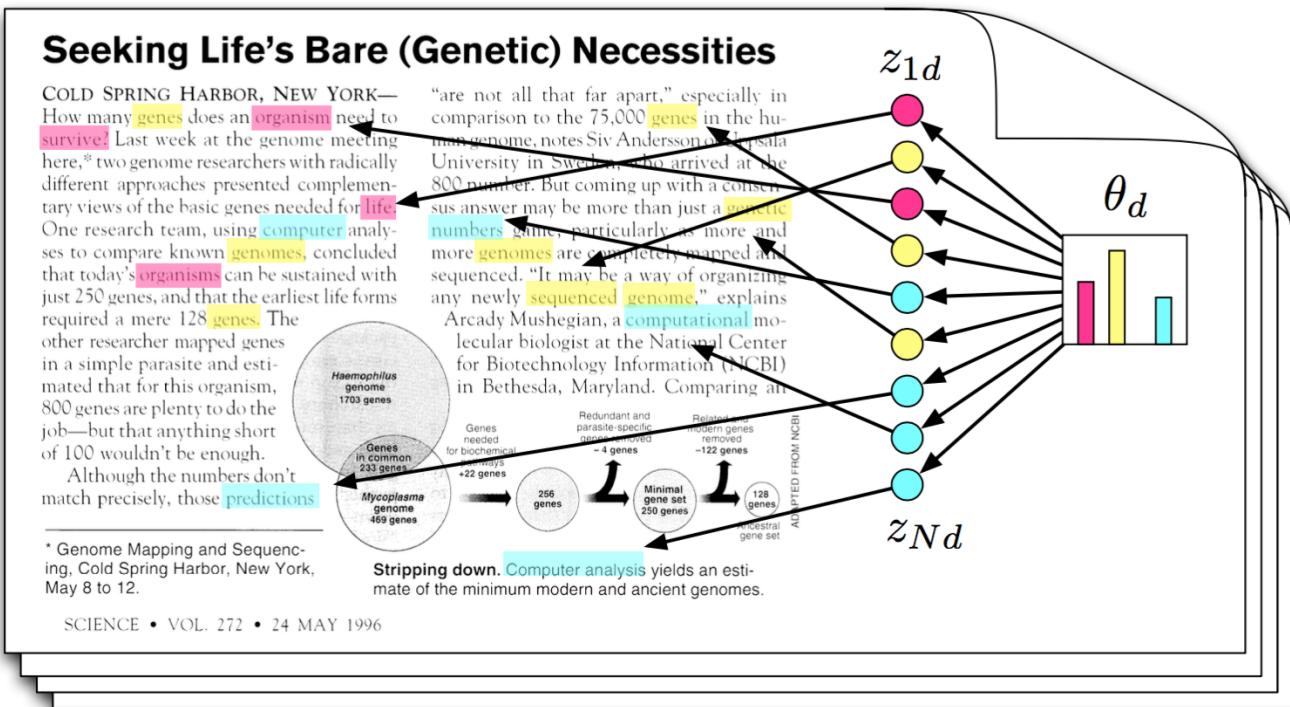
"are not all that far apart," especially in comparison to the 75,000 genes in the human genome, notes Siv Andersson of Uppsala University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a numbers game, particularly as more and more genomes are completely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

* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

SCIENCE • VOL. 272 • 24 MAY 1996

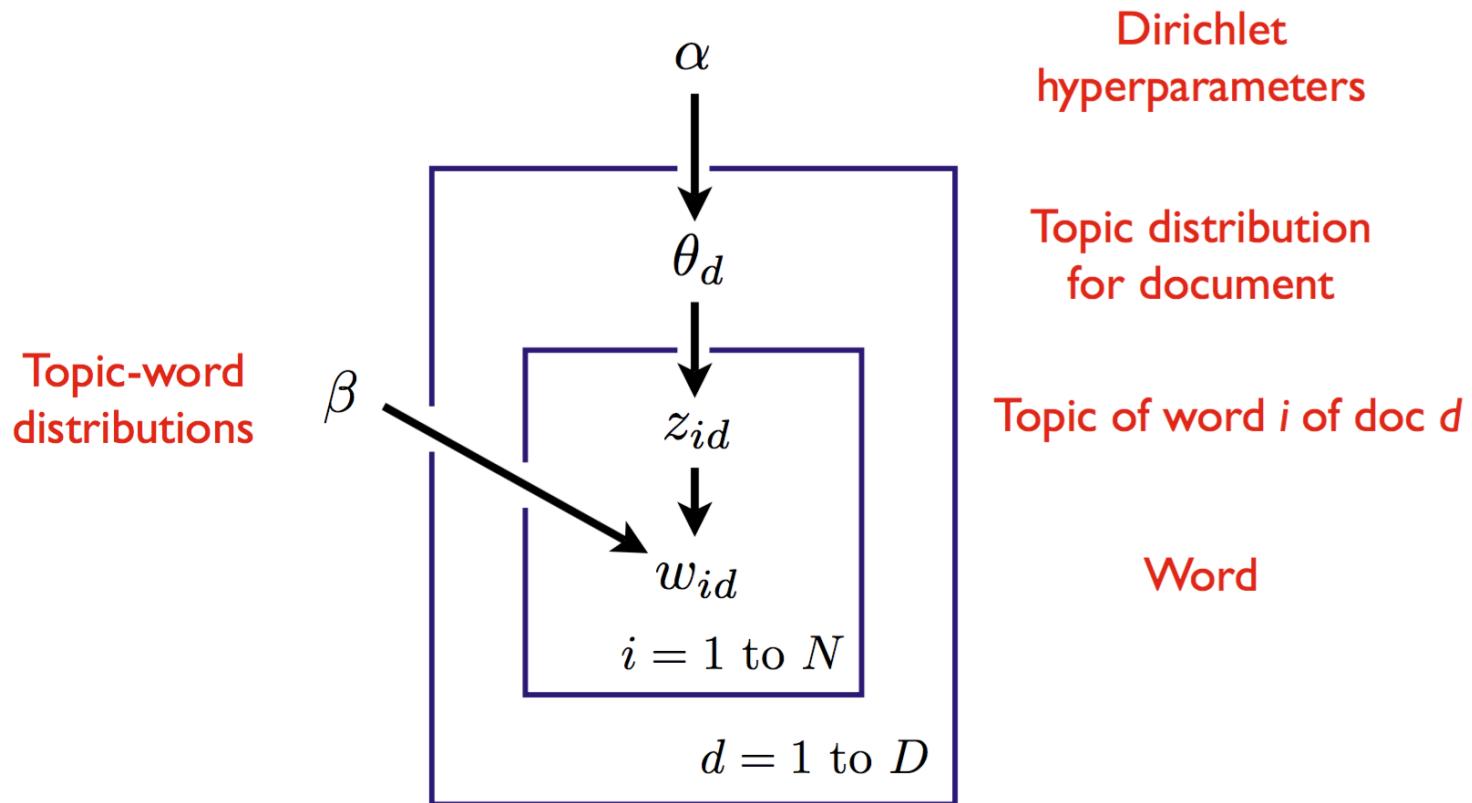
Stripping down. Computer analysis yields an estimate of the minimum modern and ancient genomes.

Topic proportions and assignments



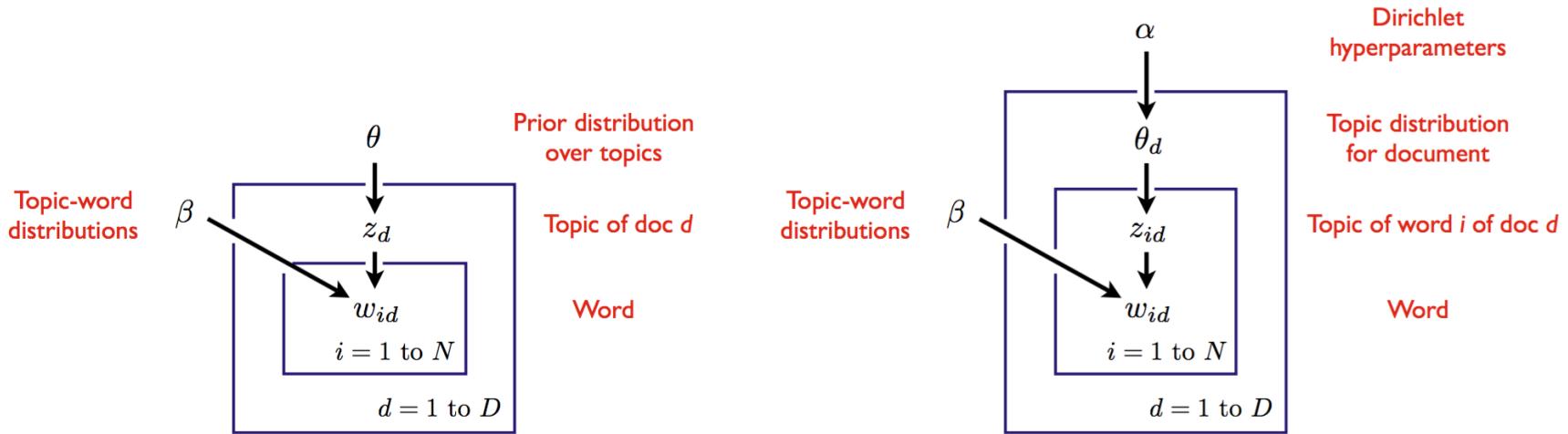
(Blei, *Introduction to Probabilistic Topic Models*, 2011)

Latent Dirichlet Allocation



Variables within a plate are replicated in a conditionally independent manner

Latent Dirichlet Allocation



- Model on left is a **mixture model**
 - Called *multinomial* naive Bayes (a word can appear multiple times)
 - Document is generated from a single topic
- Model on right (LDA) is an **admixture model**
 - Document is generated from a distribution over topics

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Embeddings

A Different Way of Dealing with Words

- Want semantically similar words to be represented similarly
 - This is the idea behind Vector Space Models in NLP
- Distributional Hypothesis (Firth 1957)
 - Words that appear in the same contexts share semantic meaning
- Two types of approaches:
 - Count based (PCA based)
 - Prediction based (creating auxiliary task etc)

Dealing with Words

- A word embedding W : words $\rightarrow \mathbb{R}^n$ is a function
 - Parametric
- Dimension n can be high: e.g., 300
- Example:
 - $W(\text{'university'}) = (0.3, -0.1, 2.0, 1.1, -1.5, \dots)$
 - $W(\text{'class'}) = (0.5, 1.1, -0.7, 2.5, 0.2, \dots)$

Learning an Embedding

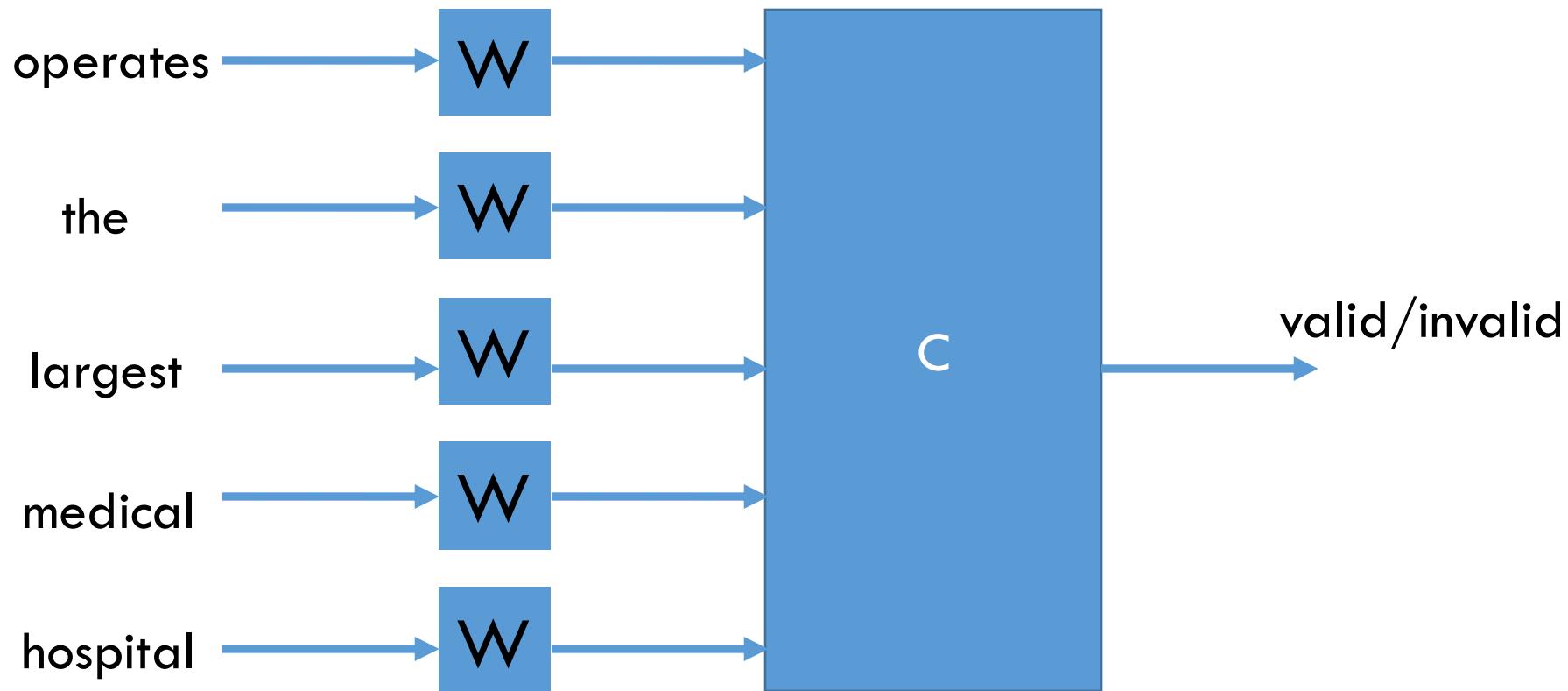
- How do we learn a good W ?
- Start with the same intuitive idea as before
 - Initialize such that W outputs random vectors for each word
 - Change the parameters such that the embedding vectors are meaningful for a task

Which Task? (I)

- Train a network to classify whether an input sequence of 5 words is valid or not
 - The input sequence is called an N-gram (5-gram)
- We get data, say from Wikipedia
 - Example: “operates the largest medical school”
- Break ‘half’ of them by replacing a word in each sequence with a random word
 - Example: “operates the **consistently** medical school”

Which Task? (II)

- Pass each word through W to get the vectors
- Pass the vectors through C (a classifier)



Which Task? (III)

- In order to do the classification correctly, parameters for W and C should be good
- The task itself is **uninteresting** and **inconsequential**
 - We could have defined a different task
- Our objective is to learn a good W

An Attempt at Intuition (I)

- Is it natural for words with similar meanings to have similar vectors (hence nearest neighbors)?
- Example:
 - Change “operates the **largest** medical school” to “operates the **biggest** medical school”
 - If W maps **biggest** and **largest** close by
 - Then classifier C should still be able to work

An Attempt at Intuition (II)

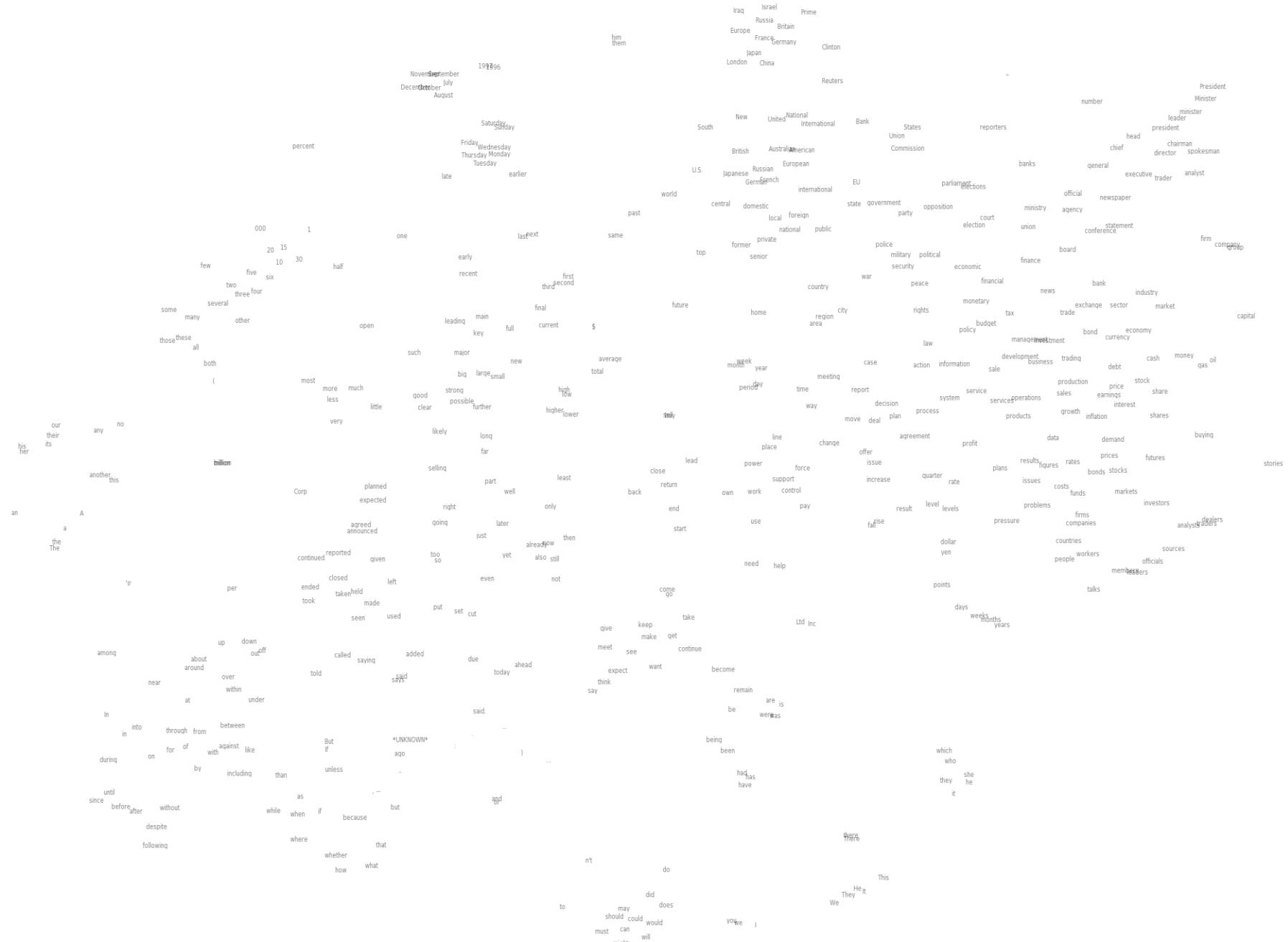
- Similar words getting mapped to close by vectors is great!
- We are not just limited to synonyms
- Example 1: “the inside wall is blue” to “the inside wall is red”
- Example 2: “the inside wall is blue” to “the inside ceiling is red”

How Much Data?

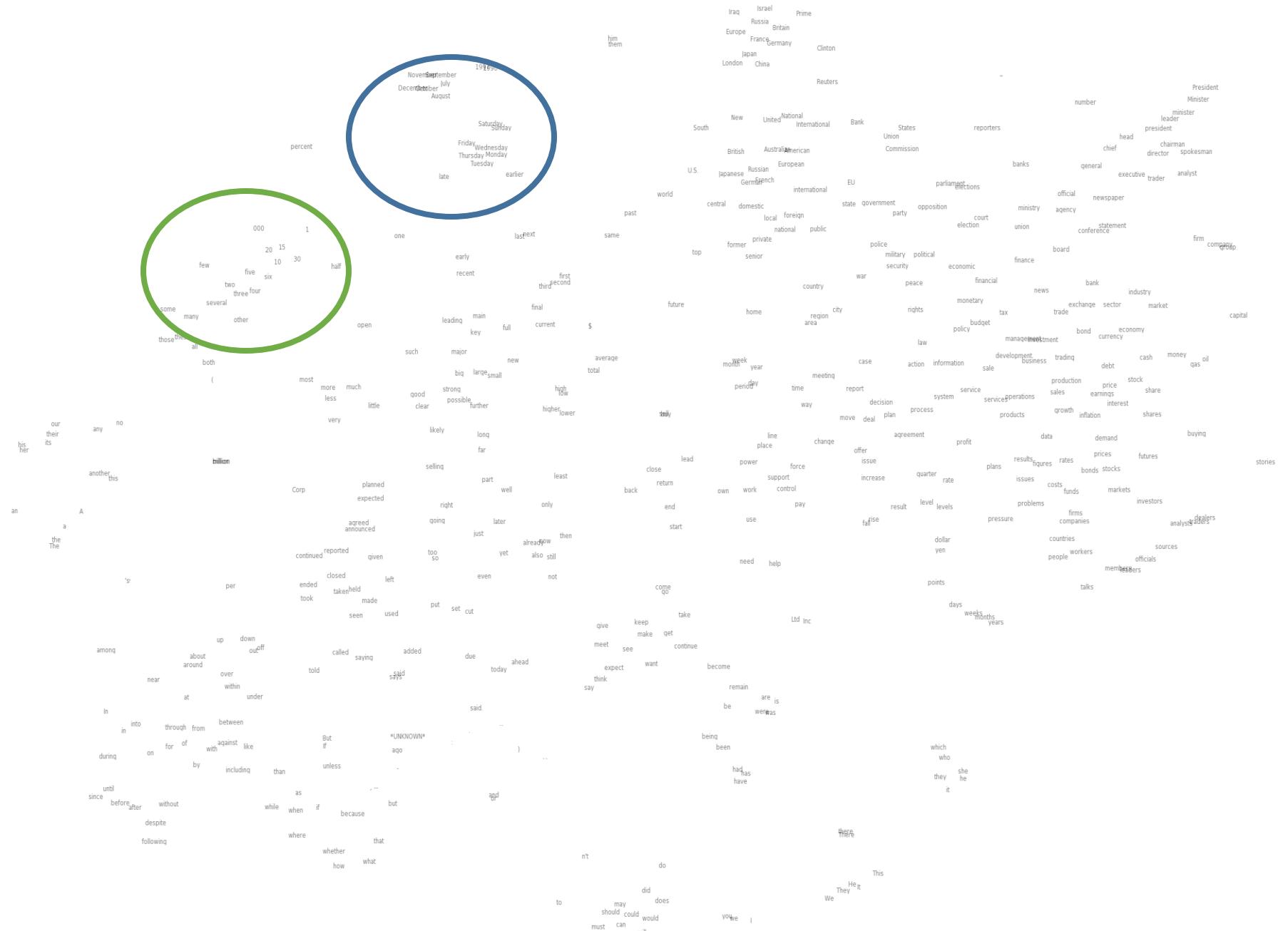
- Clearly, we must see words for whom we need embeddings
- But we need not see all their combinations
- Analogies allow us to generalize to new combination of words
- This is like how humans learn: each of us have seen several words but have not seen all possible sentences with those words

Quality of Embedding (I)

- Say, we learned a good W
 - See Word2Vec or GloVe (for pretrained embeddings)
- How to visualize? Use t-SNE



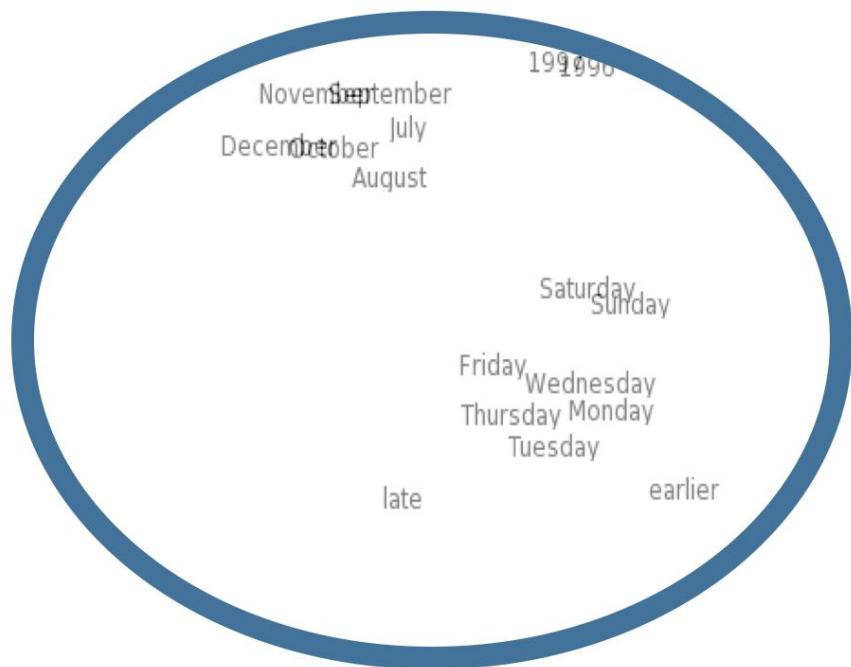
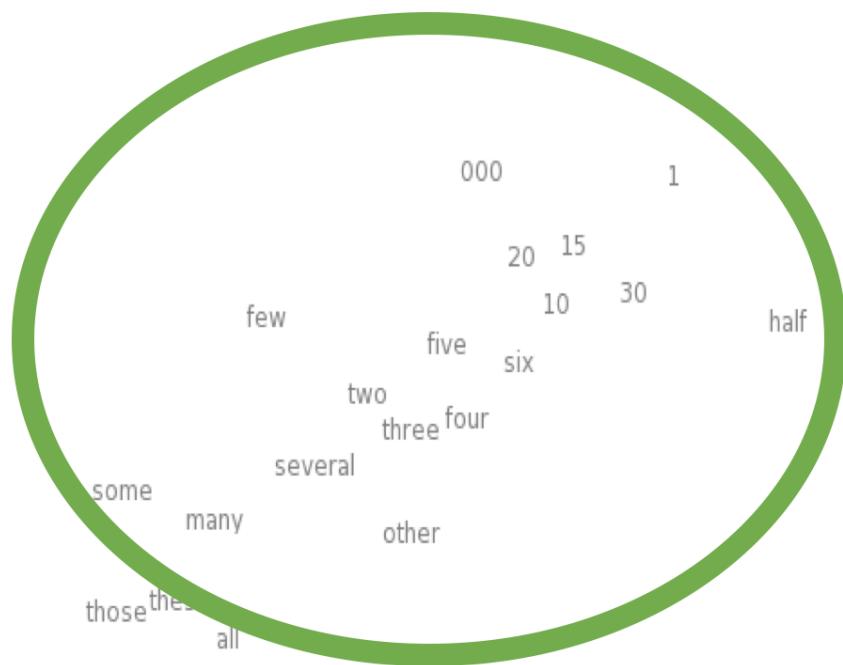
¹Figure: http://metaoptimize.s3.amazonaws.com/cw-embeddings-ACL2010/embeddings-mostcommon.EMBEDDING_SIZE=50.png



¹Figure: http://metaoptimize.s3.amazonaws.com/cw-embeddings-ACL2010/embeddings-mostcommon.EMBEDDING_SIZE=50.png

Quality of Embedding (II)

- We see similar words are close together



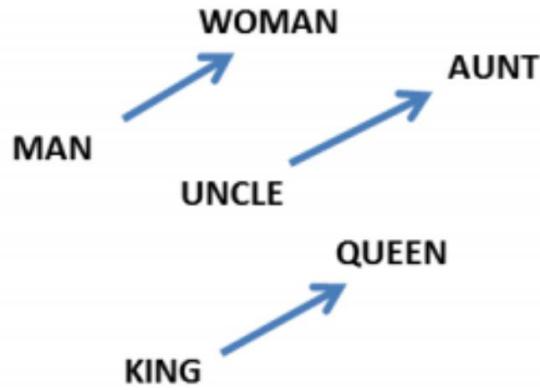
Quality of Embedding (III)

- Look at words closest in the embedding to a given word
- 10 nearest neighbors are listed here

FRANCE 454	JESUS 1973	XBOX 6909	REDDISH 11724	SCRATCHED 29869	MEGABITS 87025
AUSTRIA	GOD	AMIGA	GREENISH	NAILED	OCTETS
BELGIUM	SATI	PLAYSTATION	BLUISH	SMASHED	MB/S
GERMANY	CHRIST	MSX	PINKISH	PUNCHED	BIT/S
ITALY	SATAN	IPOD	PURPLISH	POPPED	BAUD
GREECE	KALI	SEGA	BROWNISH	CRIMPED	CARATS
SWEDEN	INDRA	PSNUMBER	GREYISH	SCRAPED	KBIT/S
NORWAY	VISHNU	HD	GRAYISH	SCREWED	MEGAHERTZ
EUROPE	ANANDA	DREAMCAST	WHITISH	SECTIONED	MEGAPIXELS
HUNGARY	PARVATI	GEFORCE	SILVERY	SLASHED	GBIT/S
SWITZERLAND	GRACE	CAPCOM	YELLOWISH	RIPPED	AMPERES

Difference of Vectors Property (I)

- Many word embeddings exhibit the following property as a **side-effect**:
 - Analogies are encoded in **difference vectors**



$$W(\text{"woman"}) - W(\text{"man"}) \approx W(\text{"aunt"}) - W(\text{"uncle"})$$

$$W(\text{"woman"}) - W(\text{"man"}) \approx W(\text{"queen"}) - W(\text{"king"})$$

Difference of Vectors Property (II)

- For a pair of words, subtract their difference and add to another word. For example,
 - $W(\text{"France"}) - W(\text{"Paris"}) + W(\text{"Rome"}) \approx W(\text{"Italy"})$

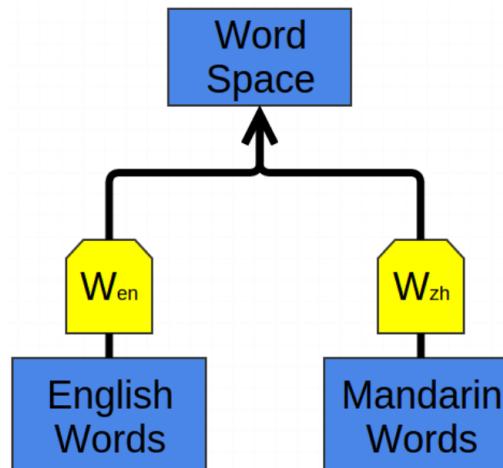
Relationship	Example 1	Example 2	Example 3
France - Paris	Italy: Rome	Japan: Tokyo	Florida: Tallahassee
big - bigger	small: larger	cold: colder	quick: quicker
Miami - Florida	Baltimore: Maryland	Dallas: Texas	Kona: Hawaii
Einstein - scientist	Messi: midfielder	Mozart: violinist	Picasso: painter
Sarkozy - France	Berlusconi: Italy	Merkel: Germany	Koizumi: Japan
copper - Cu	zinc: Zn	gold: Au	uranium: plutonium
Berlusconi - Silvio	Sarkozy: Nicolas	Putin: Medvedev	Obama: Barack
Microsoft - Windows	Google: Android	IBM: Linux	Apple: iPhone
Microsoft - Ballmer	Google: Yahoo	IBM: McNealy	Apple: Jobs
Japan - sushi	Germany: bratwurst	France: tapas	USA: pizza

Bilingual Word Embedding (I)

- Train W_{en} and W_{zh} simultaneously
 - Impose the following: words that we know are close translations should be **close** together
 - Example:

$$W_{en}(\text{'university'}) = (0.3, -0.1, 2.0, 1.1, -1.5, \dots)$$

$$W_{zh}(\text{' 大学 '}) = (0.2, -0.1, 2.2, 1.0, -1.4, \dots)$$



¹Pronunciation of 大学: Dàxué

²Figure: <http://colah.github.io/posts/2014-07-NLP-RNNs-Representations/>

Bilingual Word Embedding (II)

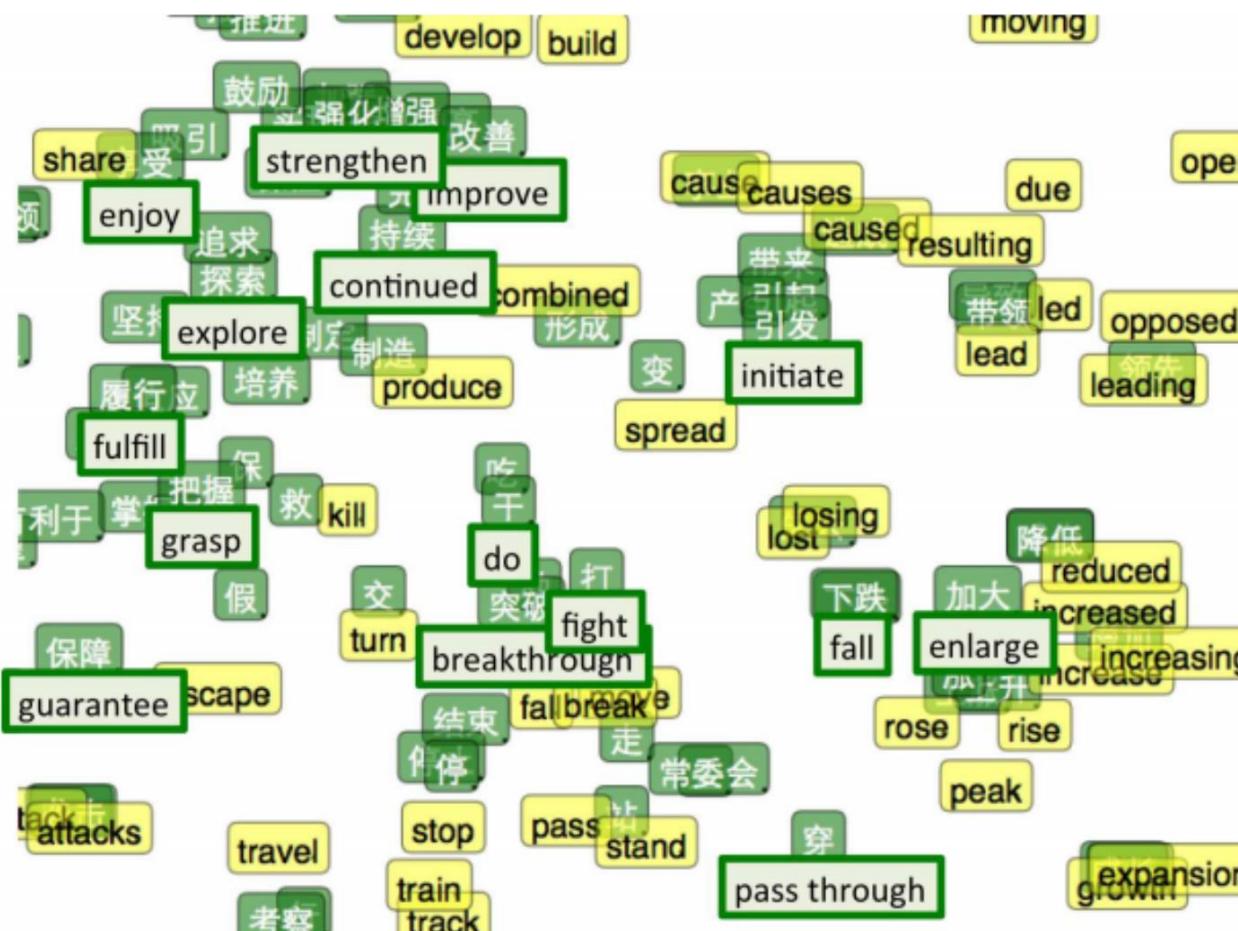
- After training W_{en} and W_{zh} we observe:
 - Words that we didn't know were translations end up close together
 - Example:
 - We did not know 商业 and business are translations. Still we get:

$$W_{en}(\text{'business'}) = (0.7, -0.4, 1.0, 1.8, -0.8, \dots)$$

$$W_{zh}(\text{' 商业'}) = (0.8, -0.3, 0.9, 2.0, -0.9, \dots)$$

¹Pronunciation of 商业: Shāngyè

Bilingual Word Embedding (III)



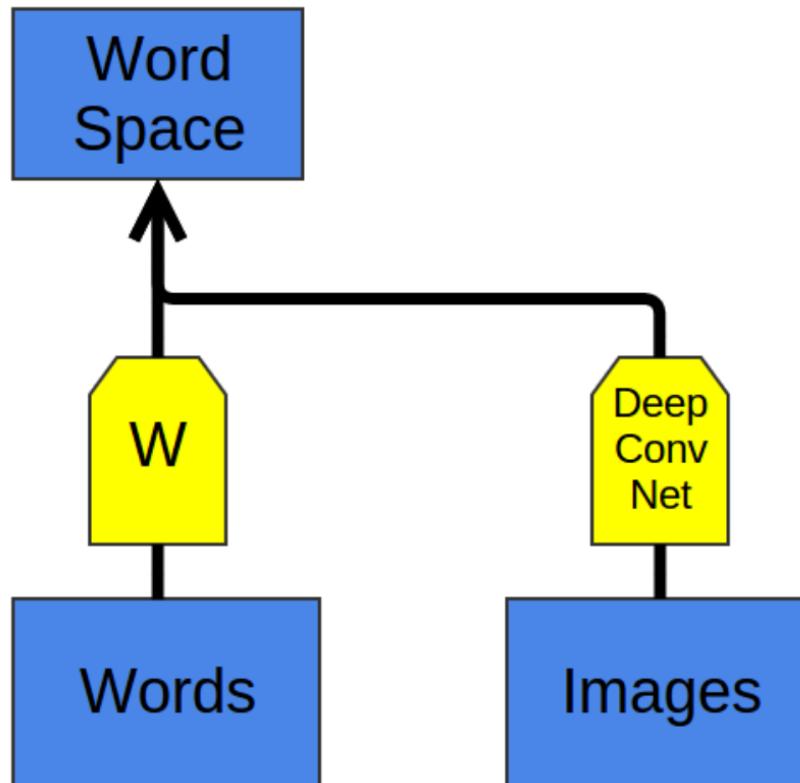
t-SNE visualization of the bilingual word embedding. Green is Chinese, Yellow is English.

General Shared Embeddings

- We can also embed **very** different kinds of data into the same space
- Example:
 - Images and words
 - Map the image of an **object** near the **object** word vector
 - Map the image of a **dog** near the **dog** word vector

General Shared Embeddings

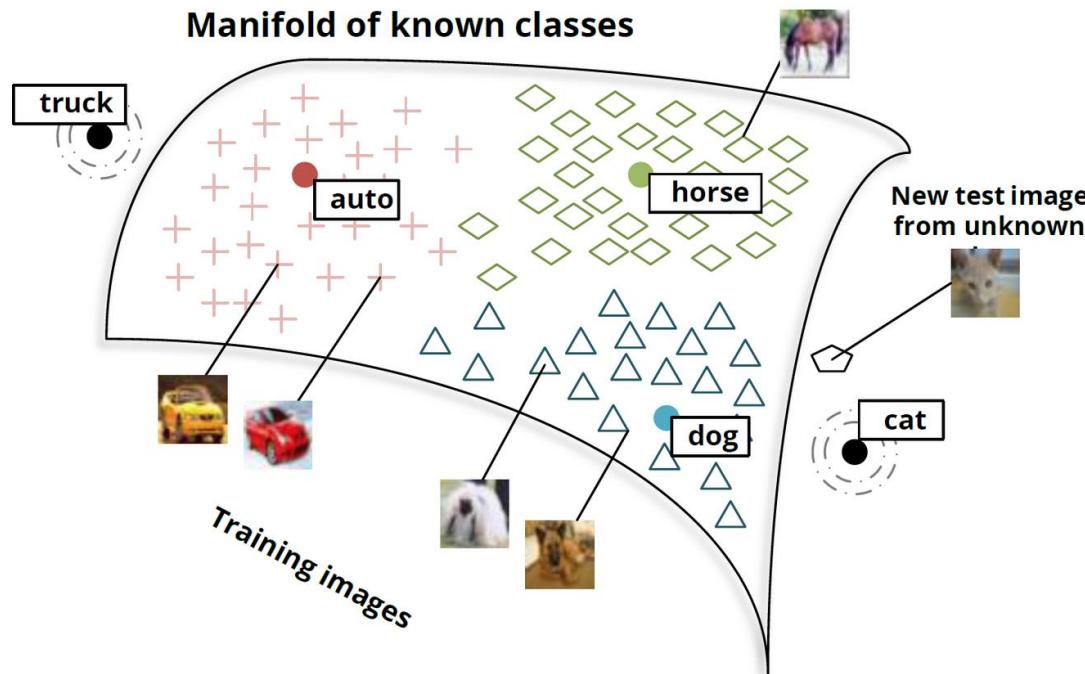
- Essentially the output of the image classifier is not a score vector but a vector in the range(W)



¹Figure: <http://colah.github.io/posts/2014-07-NLP-RNNs-Representations/>

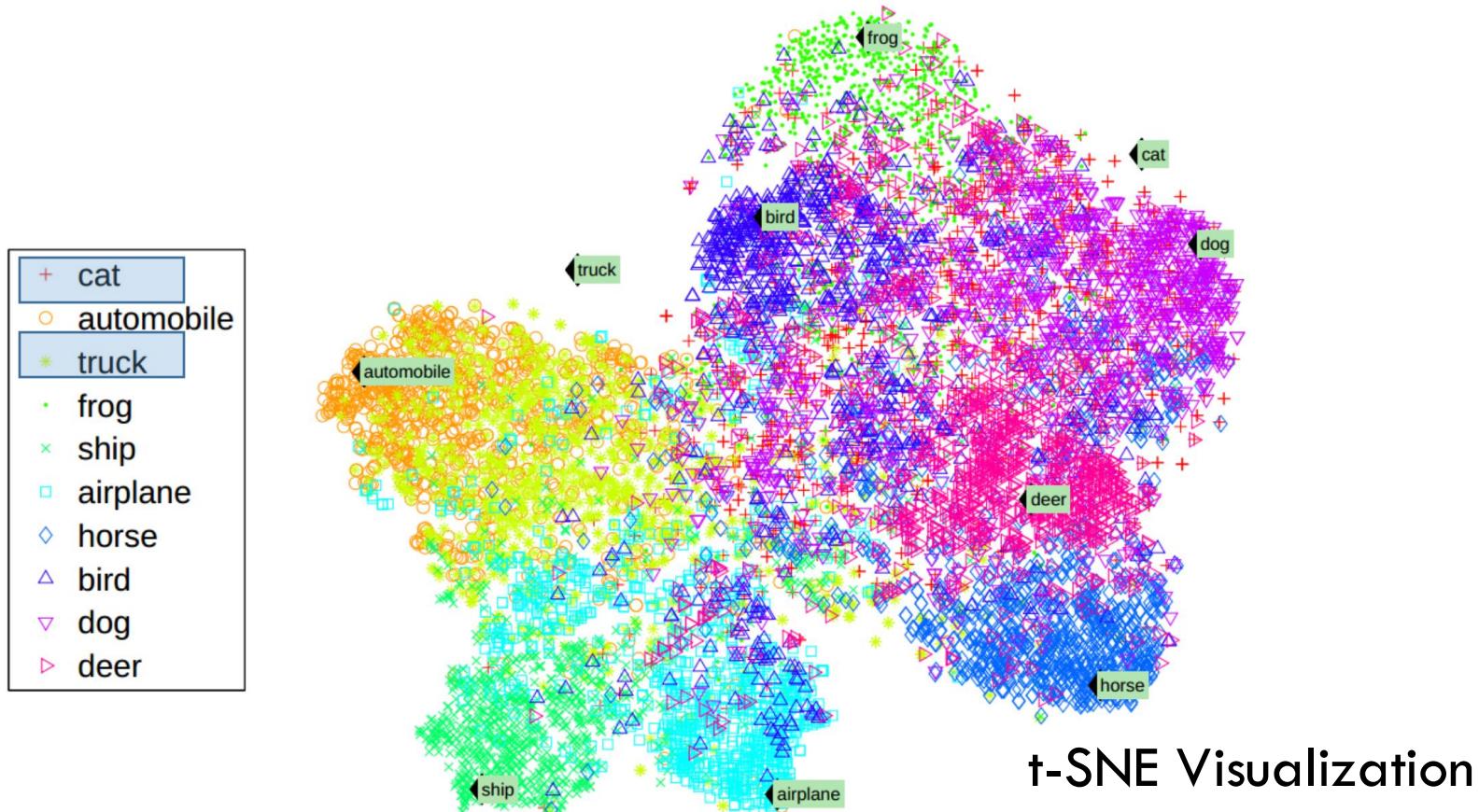
General Shared Embeddings

- When we test the model on **new** classes of images
 - Note: new means *not seen in training*
- For example, we didn't have images of cats



General Shared Embeddings

- *Images of cats are mapped to regions where dog vectors are!*



¹Figure: http://nlp.stanford.edu/~socherr/SocherGanjooManningNg_NIPS2013.pdf

Use of Embeddings (I)

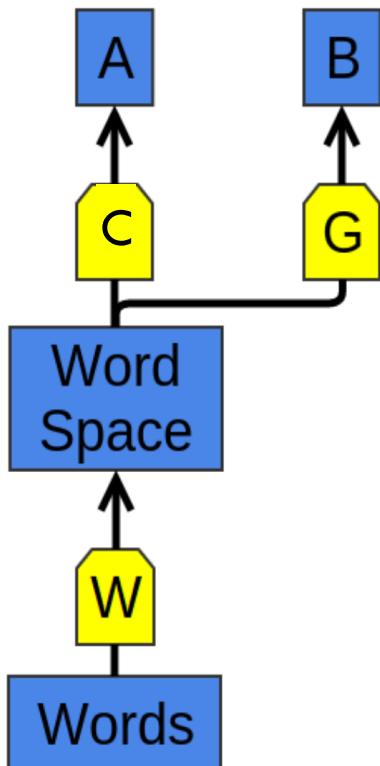
- Embeddings represent **unstructured data** automatically in such a way that a subsequent task's performance is good
 - We have already seen **image embeddings**
 - Here, we are seeing **word embeddings**

Use of Embeddings (I)

- Embeddings represent **unstructured data** automatically in such a way that a subsequent task's performance is good
 - We have already seen **image embeddings**
 - Here, we are seeing **word embeddings**
- Once a word embedding W is learned, we can use it for many other NLP (Natural Language Processing) tasks
 - **Transfer learning** (just like for images!)

Use of Embeddings (II)

- Learn a good representation (i.e., W) on some task and use it for other tasks



W and F learn to perform task A. Later, G can learn to perform B based on W .

“The use of word representations... has become a key “secret sauce” for the success of many NLP systems in recent years, across tasks including named entity recognition, part-of-speech tagging, parsing, and semantic role labeling. (Luong et al. (2013))

Use of Embeddings (III)

- Key benefit of W
 - Can train using more than one kind of data
- Thus, we can learn a way to map multiple kinds of data into a single representation!
- Example: Bilingual word embedding¹
 - English words
 - Mandarin words
 - Embed both words in the same space

CNN based Sentence Classification

- Input is a sequence of words (variable)
 - Output is a class label (fixed)
-
- Baseline 1:
 - Ignore sequence
 - Ignore semantic information
 - Treat input as a fixed length bag of words
 - This is a fixed size input and output classifier

CNN based Sentence Classification

- Baseline 2:
 - Weighted average of the word vectors as a vector for the sentence
 - Still loses word order
 - Retains some semantic information
 - Again, a fixed size input and output classifier

CNN based Sentence Classification

- Can also use Convolutional Neural Network!
 - For NLP, they became popular 2014
 - Less prominent currently due to other techniques
- Recall

1 <small>x1</small>	1 <small>x0</small>	1 <small>x1</small>	0	0
0 <small>x0</small>	1 <small>x1</small>	1 <small>x0</small>	1	0
0 <small>x1</small>	0 <small>x0</small>	1 <small>x1</small>	1	1
0	0	1	1	0
0	1	1	0	0

Image

4		

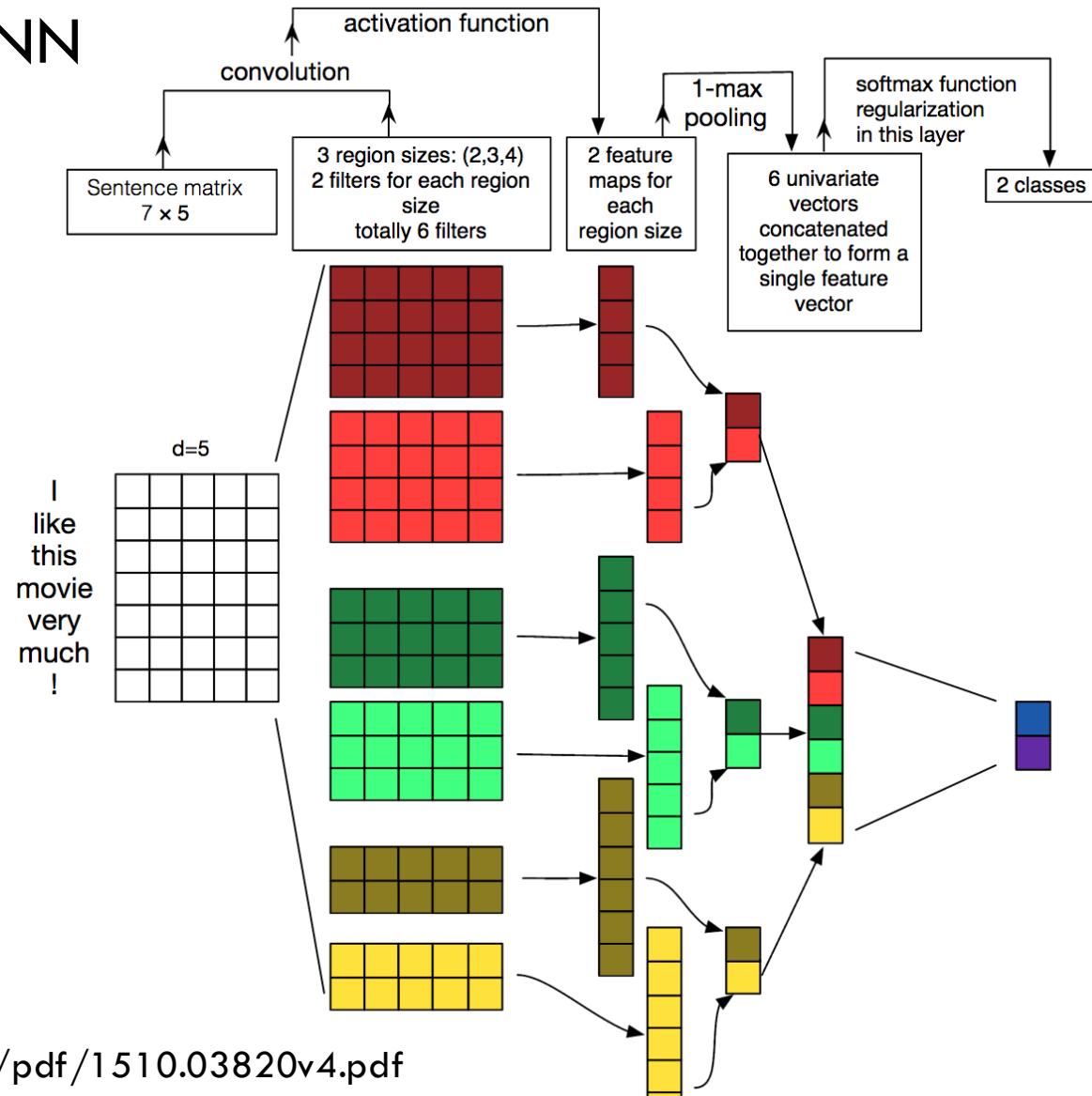
Convolved Feature

CNN based Sentence Classification

- As you already know, CNNs capture
 - Location invariance
 - Example: In images, don't care where the 'cat' is in the input
 - Compositionality
 - Example: In images, lower level features to higher level patterns
- We will represent the sentence as a matrix
 - Each row for one word

CNN based Sentence Classification

- Example CNN



¹Reference: <https://arxiv.org/pdf/1510.03820v4.pdf>

Questions?

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Word2Vec In Detail

Word2Vector

- A technique proposed by Google in 2013
- Is a predictive method rather than a count based method
- Objective: Vector representations of words that capture their co-occurrence statistics

Word2Vector: Two Versions

- Continuous Bag of Words and Skip-Gram
- Lets go through the skip-gram model in some detail now

W2V: The Skip-Gram Version

- This is a very simple neural network model to learn W
- We will train a single hidden layer NN to perform an auxiliary task
- The goal will be to just learn the weights of the network
 - This will give us W

W2V: The Auxiliary Task

- Task:
 - Pick a word in the middle of a sentence
 - Pick one of the **nearby** words at random
 - Make network learn probability of every word in our vocab of being this nearby word
- Input: a word pair (one hot encoded)
- Output: normalized scores (of length: vocab size)
- Meaning of ‘nearby’:
 - Essentially defined using a window size
 - Example: Window size 2 means 2 words to left and 2 to right of the input word are nearby

W2V: The Auxiliary Task

- Feed word pairs
- Example: “The quick brown fox jumps over the lazy dog”

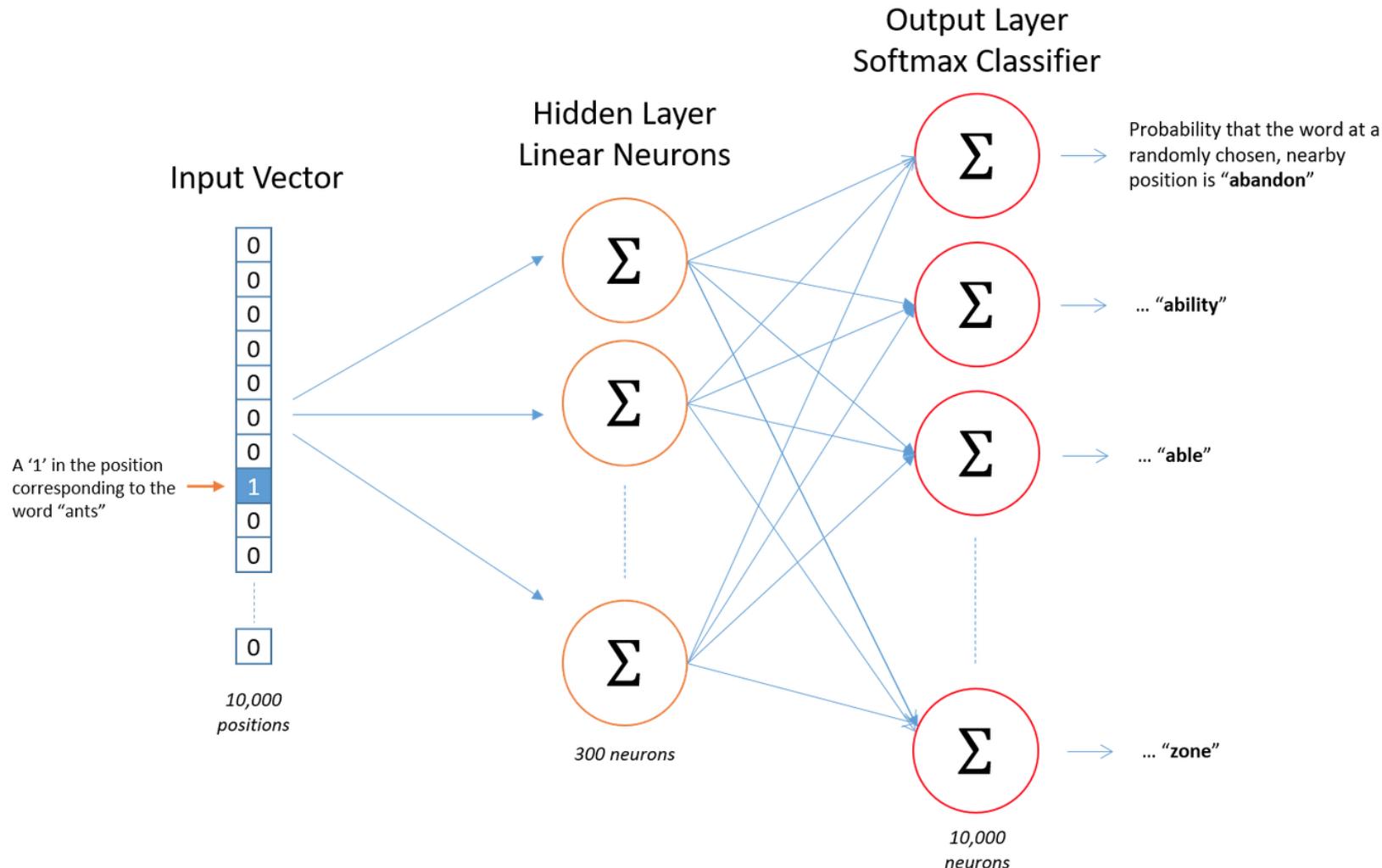
Source Text	Training Samples
The quick brown fox jumps over the lazy dog. →	(the, quick) (the, brown)
The quick brown fox jumps over the lazy dog. →	(quick, the) (quick, brown) (quick, fox)
The quick brown fox jumps over the lazy dog. →	(brown, the) (brown, quick) (brown, fox) (brown, jumps)
The quick brown fox jumps over the lazy dog. →	(fox, quick) (fox, brown) (fox, jumps) (fox, over)

W2V: The Network

- Say we have 10000 words in our vocab
- Then the input word is 10000 dimensional vector
 - Example: Cat word will have 'Cat' coordinate 1, everything else 0
- The true label (word) is also 10000 dimensional vector
- Network outputs 10000 scores which pass through softmax
 - Each coordinate is the probability that a particular word is the randomly selected nearby word

W2V: The Network

- Notice: No nonlinearity in the hidden layer!



W2V: The Objective

- The objective is to maximize the normalized score (recall normalization by softmax operation) of the correct context word
- Say our training data is made with T words, each having a context window size 2
 - That is, each word is associated with 4 other words
 - Total training data is $4T$
- The objective is $\frac{1}{T} \sum_{t=1}^T \sum_{j \in \{-2, -1, 1, 2\}} \log p(w_{t+j} | w_t)$

W2V: The Hidden Layer

- Is represented by a weight matrix W_0
 - Lets represent it by its transpose (just for convenience)
 - $h^T = x^T W_0^T = x^T W$ for each example
 - Number of rows of W is 10000
 - Number of columns of W is 300
- Then the rows of W are our word vectors!

W2V: The Hidden Layer

- Our real goal was just to learn the hidden layer

weights

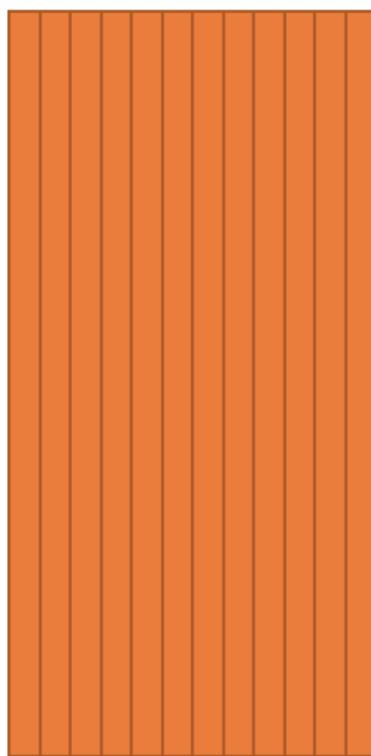
Hidden Layer
Weight Matrix



Word Vector
Lookup Table!

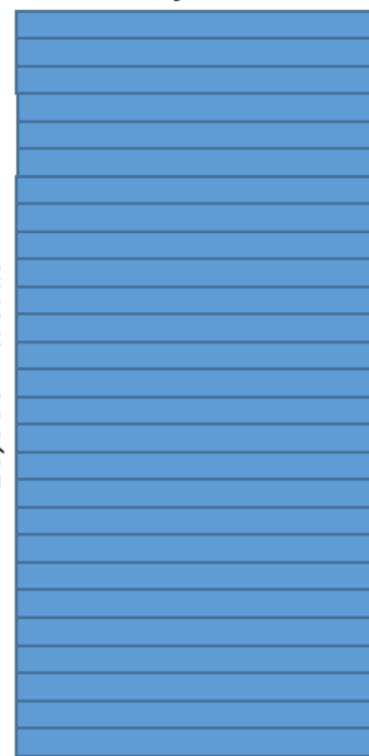
300 neurons

10,000 words



300 features

10,000 words



W2V: The Lookup

- Say word ‘Cat’ has coordinate c for some $c \in \{1, \dots, 10,000\}$
- If we multiply the 1×10000 dim one hot vector for the word ‘Cat’ with W
- It will just select the c^{th} row of W
 - The output of the hidden layer is the word vector!

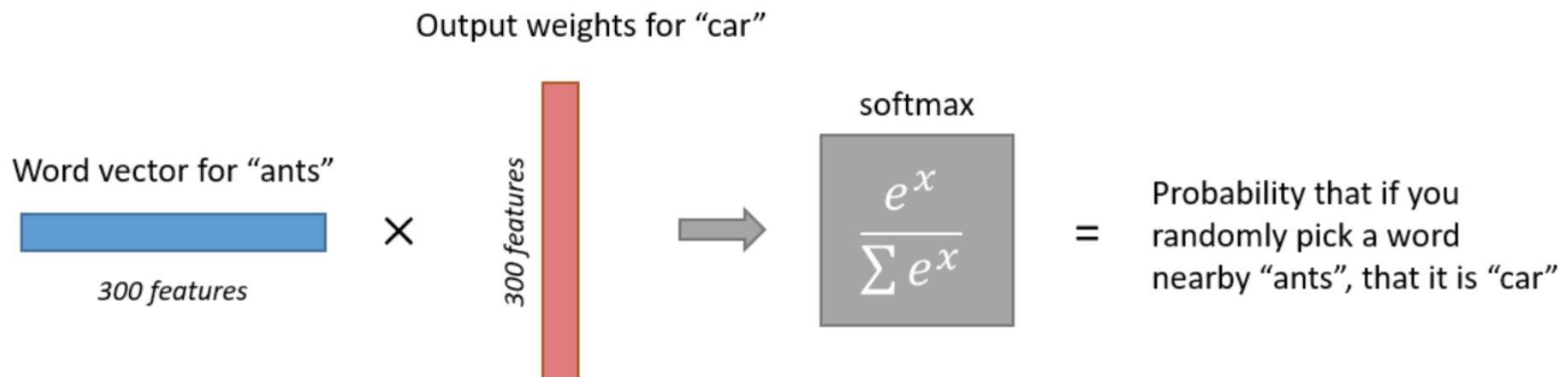
W2V: The Lookup

- Say word ‘Cat’ has coordinate c for some $c \in \{1, \dots, 10,000\}$
- If we multiply the 1×10000 dim one hot vector for the word ‘Cat’ with W
- It will just select the c^{th} row of W
 - The output of the hidden layer is the word vector!
- Example visualization

$$[0 \ 0 \ 0 \ 1 \ 0] \times \begin{bmatrix} 17 & 24 & 1 \\ 23 & 5 & 7 \\ 4 & 6 & 13 \\ 10 & 12 & 19 \\ 11 & 18 & 25 \end{bmatrix} = [10 \ 12 \ 19]$$

W2V: Auxiliary Task Again

- Output of the network is a bunch of normalized scores (i.e., probabilities)
 - Denote the probability that this word is a nearby word
- Example:
 - Pick the word vector for ‘ants’
 - Pick the output neuron for word ‘car’



W2V: Intuition for Vectors

- If two different words have similar “contexts”
 - Words that are likely to appear around them
 - Then the output probability vector should be similar
- For output vector to be similar
 - The word vector (weights of hidden layer) should be similar
 - Since the inputs are 1-hamming distance apart always

W2V: Intuition for Vectors

- Word2Vec is capturing nothing but the co-occurrence statistics!
- Example:
 - Words like ‘university’ and ‘masters’ would have similar contexts, hence similar word vectors
- This will also handle stemming!
 - Example: words like ‘car’ and ‘cars’ will have similar vectors because contexts would be similar

W2V: Practice

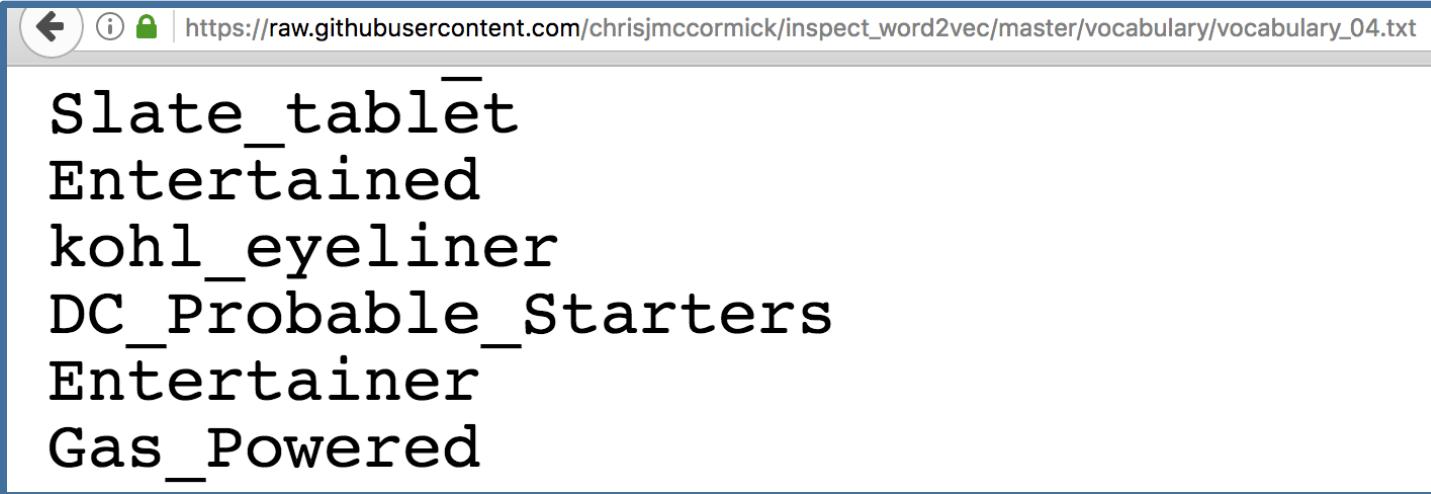
- The network is relatively large
 - Two weight matrices
 - 300*10000 parameters each
- Need a lot of data to train
- And engineering tricks are needed to deal with data

W2V: Engineering Tricks

- Subsample frequent words
 - Example: Too many pairs like ('the',...). So delete them proportional to how frequent they are
- Treat common phrases as single ‘words’
- Optimization trick: negative sampling
 - Only update the weights of neurons corresponding to a few (5-20) non-nearby words
 - These few are sampled inversely proportional to their frequency

W2V: From Google

- 100 Billion words from the Google News Dataset
- Vocab size totals about 3 million!



A screenshot of a web browser window displaying a list of words from a vocabulary file. The URL in the address bar is https://raw.githubusercontent.com/chrisjmccormick/inspect_word2vec/master/vocabulary/vocabulary_04.txt. The words listed are:

```
Slate_tablet
Entertained
kohl_eyeliner
DC_Probable_Starters
Entertainer
Gas_Powered
```

¹Reference: https://github.com/chrisjmccormick/inspect_word2vec/tree/master/vocabulary

²word2Vec file: <https://drive.google.com/file/d/0B7XkCwpI5KDYNINUTTISS21pQmM/edit>

W2V: From Google

- 100 Billion words from the Google News Dataset
- Vocab size totals about 3 million!

```
In [1]: import gensim
```

```
In [3]: model = gensim.models.Word2Vec.load_word2vec_format('./GoogleNews-vectors-negative300.bin.gz', binary=True)
```

```
In [7]: model.most_similar('good')
```

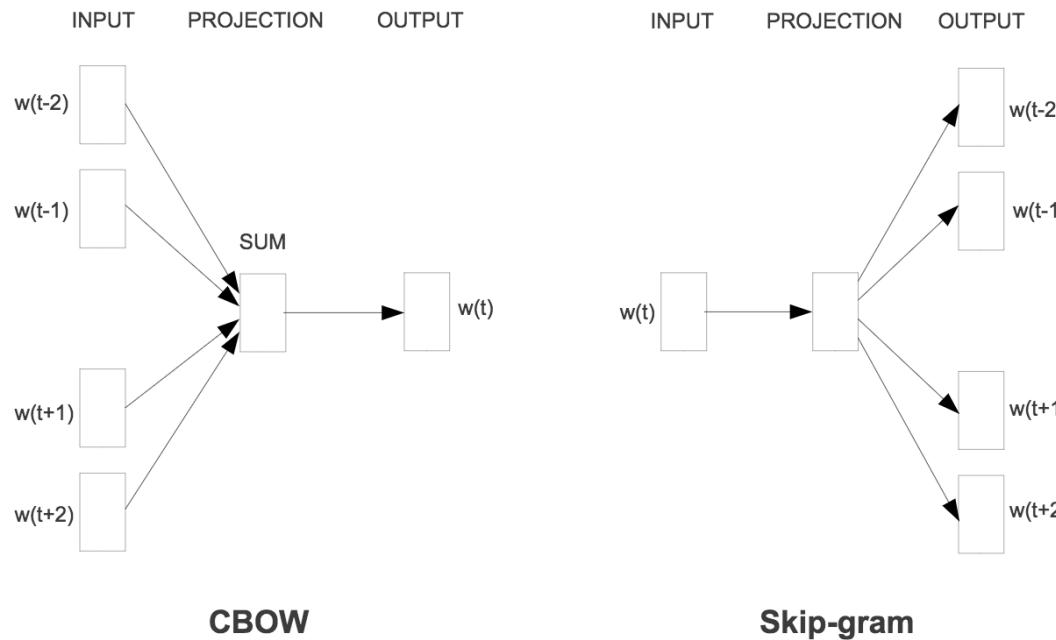
```
Out[7]: [(u'great', 0.7291509509086609),  
 (u'bad', 0.7190051078796387),  
 (u'terrific', 0.6889115571975708),  
 (u'decent', 0.6837348341941833),  
 (u'nice', 0.6836091876029968),  
 (u'excellent', 0.6442928910255432),  
 (u'fantastic', 0.6407778859138489),  
 (u'better', 0.6120729446411133),  
 (u'solid', 0.5806034803390503),  
 (u'lousy', 0.5764203071594238)]
```

¹Reference: https://github.com/chrisjmccormick/inspect_word2vec/tree/master/vocabulary

²word2Vec file: <https://drive.google.com/file/d/0B7XkCwpI5KDYNlNUlSS21pQmM/edit>

W2V: The CBOW Version

- Continuous Bag of Words (CBOW) version of Word2Vec
 - Essentially, a slightly different prediction task



- There is another popular embedding called GLoVe

¹Figure: <https://arxiv.org/pdf/1301.3781.pdf>

²Reference for GLoVe: <http://nlp.stanford.edu/projects/glove/>

Questions?

Summary

- Text processing is very useful in multiple applications
- We saw some models that did not need to understand word meanings
 - Naïve bayes, Markov assumption based, LDA
- The notion of embedding words (or characters or phrases ...) is useful and such embeddings can be learned
- We saw how Word2Vec embeddings were created

Appendix

A Variety of NLP Tasks

- There are many traditional NLP tasks and techniques that may be helpful to know about:
 - Tokenizing
 - Handling stop words
 - Stemming
 - Parts-of-speech tagging
 - Chunking and chinking
 - Named Entity Recognition
 - Lemmatizing
 - ...

LDA: More Intuition (different notation)

Question: given a text document, what topics is it about?



Probabilistic program: latent Dirichlet allocation

Generate a distribution over topics $\alpha \in \mathbb{R}^K$

For each position $i = 1, \dots, L$:

Generate a topic $Z_i \sim p(Z_i | \alpha)$

Generate a word $W_i \sim p(W_i | Z_i)$

